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LABORATORY AND PILOT PLANT EVALUATION OF INTERMITTENT LOADING ON SMALL-SCALE EXTENDED AERATION BIOLOGICAL SYSTEMS

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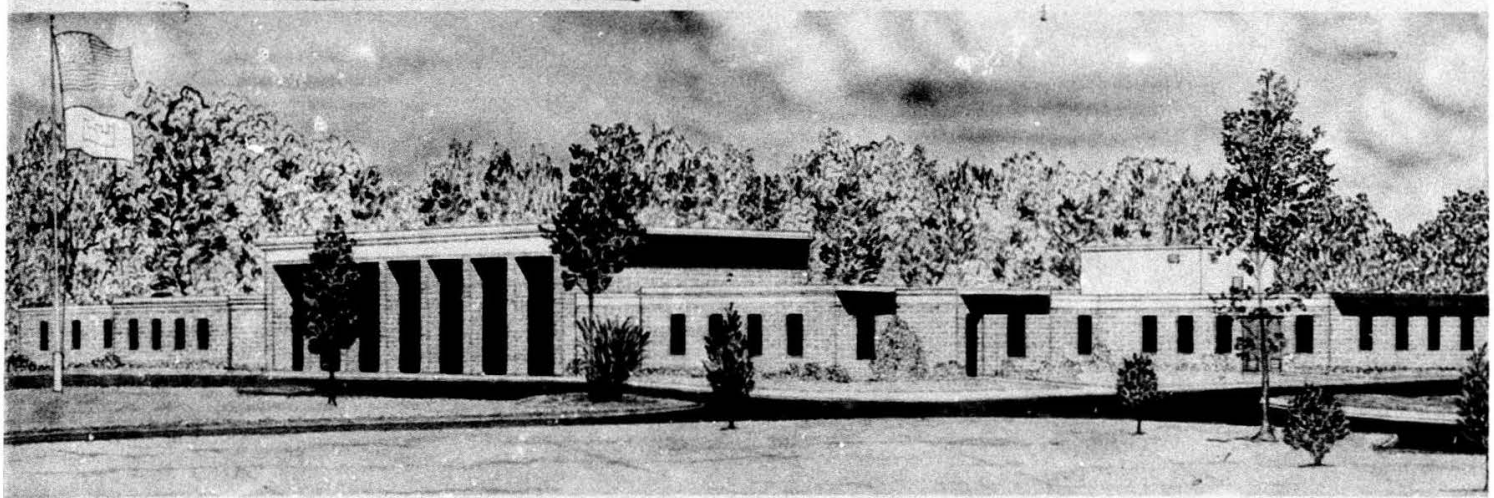
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The U. S. Army Corps of Engineers is responsible for designing, constructing, and operating wastewater treatment systems for its recreational areas. The use of these areas by 391 million visitors in 1976 emphasizes the importance and significance of this responsibility. Reducing or eliminating the discharge of organic matter and suspended solids from recreational areas to receiving streams or lakes is of paramount importance in the protection of the environment and the maintenance of acceptable water quality. The importance attached to the

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production of a stable, high-quality effluent increases the priority to define the performance of a biological treatment system under intermittent loading conditions.

The approach used in this study involved development of a mathematical model to predict the performance of a completely mixed activated sludge system under intermittent loading conditions, defined for this study as time-dependent hydraulic and organic loadings. The model was verified first with laboratory data from a bench-scale extended aeration system and then with field data from a prototype extended aeration package treatment plant. Parameters used in developing the study included effluent quality, dissolved oxygen uptake, and other performance indicators related to biomass response to intermittent loading conditions.

Results of the laboratory phase of this study indicate that an extended aeration activated sludge system will generally perform satisfactorily under intermittent loading conditions. Biological evaluation of the laboratory systems subjected to intermittent loadings indicated that the animal populations within the reactor were chiefly responsible for the fluctuations in the performance of the system. Evaluation of the pilot system demonstrated that intermittent loadings would produce a failure in the solids handling system due to the hydraulic overload.

Appendix A presents the mathematical model developed by this study. Appendix B describes the analytical test procedures, and Appendix C presents the raw data.

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PREFACE

The investigation reported herein was conducted under Department of the Army Project No. 4A161101A91D, Task 02, "In-House Laboratory Independent Research (ILIR) Program," Work Unit 100, "Effects of Intermittent Loading on a Biological Treatment System," sponsored by the Assistant Secretary of the Army (R&D).

This investigation was conducted during the period 1975-1977 by personnel of the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES).

The study was conducted by Dr. Jerome L. Mahloch, Mr. Daniel E. Averett, and Dr. Marcia Headstream, Environmental Engineering Division, EEL, under the direct supervision of Mr. Norman R. Francingues, Chief, Treatment Processes Research Branch, and the general supervision of Mr. Andrew J. Green, Chief, Environmental Engineering Division, and Dr. John Harrison, Chief, EEL. This report was prepared by Dr. Mahloch, Mr. Averett, and Dr. Headstream.

Directors of WES during the investigation and preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to U. S. Customary		
milligrams	0.0000022	pounds (mass)
grams	0.002204	pounds (mass)
millilitres	0.0002642	gallons (U. S. liquid)
litres	0.2642	gallons (U. S. liquid)
litres per minute	0.2642	gallons (U. S. liquid) per minute
milligrams per litre	0.0000083	pounds (mass) per gallon (U. S. liquid)
Celsius degrees or Kelvins	9/5	Fahrenheit degrees*
U. S. Customary to Metric (SI)		
inches	2.54	centimetres
feet	0.3048	metres
square feet	0.09290304	square metres
cubic feet	0.02831685	cubic metres
gallons (U. S. liquid)	0.003785	cubic metres
cubic feet per minute	0.02831685	cubic metres per minute
gallons (U. S. liquid) per minute	0.003785	cubic metres per minute
gallons (U. S. liquid) per day	0.003785	cubic metres per day
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch gage	6.894757	kilopascals

* To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following equation: $F = 9/5(C) + 32$. To obtain Fahrenheit readings from Kelvin (K) readings, use: $F = 9/5(K - 273.15) + 32$.

LABORATORY AND PILOT PLANT EVALUATION OF INTERMITTENT LOADING ON SMALL-SCALE EXTENDED AERATION BIOLOGICAL SYSTEMS

PART I: INTRODUCTION

Background

1. The U. S. Army Corps of Engineers is responsible for designing, constructing, and operating wastewater treatment systems for its recreational areas. The use of these areas by 391 million visitors in 1976 emphasizes the magnitude of this responsibility. Reducing or eliminating the discharge of organic matter and suspended solids from recreational areas to receiving streams or lakes is of paramount importance in the protection of the environment and the maintenance of acceptable water quality.

2. Wastewater treatment is particularly important in recreational areas because of the ultimate utilization of the receiving water for both primary and secondary contact recreation. Waters in these areas should not only be aesthetically pleasing but should also meet health standards. Under present regulations, the major constituents of wastewater that must be removed prior to discharge are materials exerting a biochemical oxygen demand (BOD), and suspended solids (SS). Nitrogen and phosphorus removal is required in some instances depending on their effects on the receiving water, and a minimum level of coliform bacteria in the effluent is required by most state pollution control agencies.

3. Visitation at recreation areas is highly variable both on a seasonal and on a weekly basis. The majority of the activity occurs during the summer vacation months; some facilities, however, are not even used in the winter. During the summer, peak visitation occurs during weekends, with the heaviest use occurring on holiday weekends. Because wastewater production is proportional to recreation area usage, highly variable wastewater flows, which pose operational problems for

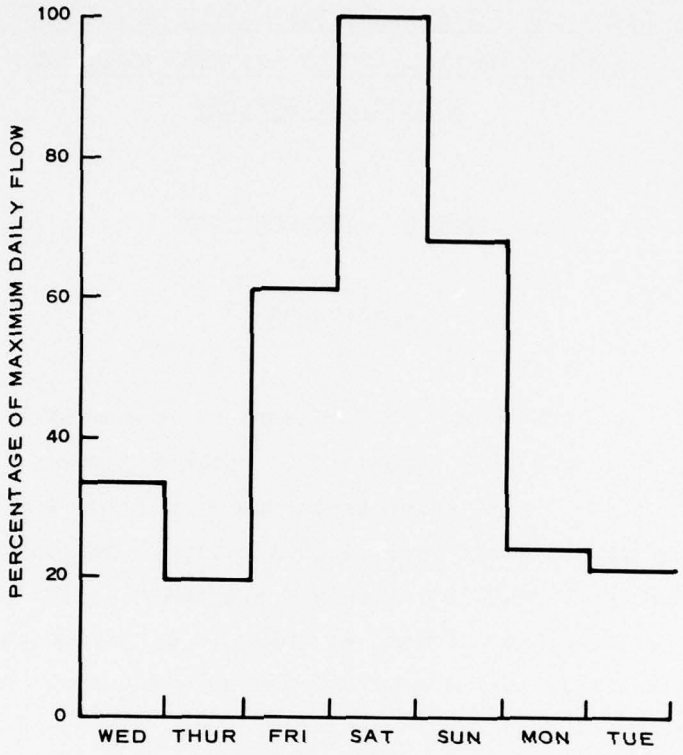


Figure 1. Typical variations in wastewater flow at a recreation area (from Reference 1)

small wastewater treatment systems, are characteristic of most recreational areas. Typical variations in recreational site wastewater flow are shown in Figure 1.

4. Extended aeration, which is a modification of the activated sludge treatment process, is particularly well suited to flows of less than 1 mgd* and therefore may be effectively utilized for the treatment of wastewater generated in recreational areas. Because the volume of wastewater produced at recreation areas does not necessitate the construction of a large treatment facility with high capital costs, the extended aeration system to be used is generally prefabricated and partially assembled when delivered to the site, hence the term "package treatment plant."

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units, and U. S. customary to metric (SI) units is presented on page 4.

5. Extended aeration as a biological treatment process is dependent on living organisms for the removal of organic material, nutrients, and contaminants from wastewater. The microorganisms, primarily bacteria, have difficulty responding to extremes in their environment during periods of low hydraulic and organic loadings, such as those that would occur in recreational areas in the winter or during the week. Many of the beneficial organisms die because of insufficient food and are thus lost from the system. When the loading increases, the organisms grow rapidly, often creating a microbial mass (sludge) that does not settle easily, ultimately increasing the BOD of and SS in the effluent. The BOD and concentrations of SS in the effluent are also increased by hydraulic fluctuations that can wash much of the active microbial mass out of the system. The extent to which intermittent loading affects the performance of recreational area treatment systems has not been sufficiently documented.

Purpose

6. It is the purpose of this research to investigate the response of an extended aeration system to intermittent shock loads similar to those encountered in recreational areas.

Technical Approach

7. A three-phase study was designed to define the performance of a biological treatment system under intermittent loading conditions:

a. Phase I. Develop a mathematical model to predict the performance of a completely mixed activated sludge (CMAS) system under intermittent loading conditions. Intermittent loading conditions are defined as time-dependent hydraulic loadings similar to those encountered in recreation area wastewater treatment.

b. Phase II. Subject bench-scale extended aeration treatment system to intermittent loadings in the laboratory to define the effect of intermittent loading on the extended aeration system performance.

c. Phase III. Evaluate prototype extended aeration package plant in the field to provide data for verification of the laboratory results and to determine what operational procedures are necessary to maintain efficient operation of a biological treatment system under intermittent loading conditions.

PART II: LITERATURE REVIEW

Activated Sludge

8. Activated sludge is one of the most economical and efficient of the wastewater treatment processes available. In an activated sludge system, raw wastewater enters an aeration tank and is mixed with a heterogeneous culture of aerobic/facultative microorganisms. Aeration holds the microorganisms in suspension and provides the oxygen that is necessary for the microbial metabolism of the organic matter. The contents of the aeration tank, termed mixed liquor, flow into a settling tank, or clarifier, for removal of suspended solids prior to discharge. Most of the settled sludge is returned to the aeration tank in order to maintain a suitable concentration of the active microbial mass in the mixed liquor, but a portion of the sludge may be wasted from the system. A schematic diagram of the activated sludge process is given in Figure 2.

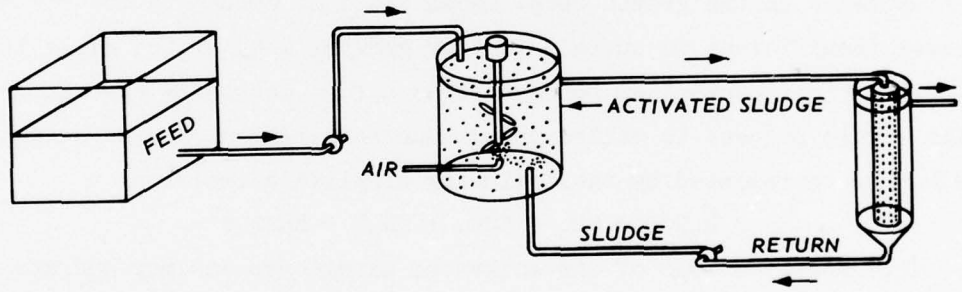


Figure 2. Schematic of activated sludge process

9. Activated sludge systems are designed primarily to remove those organic compounds that would exert a BOD. The organic carbon and other nutrients are used by the microorganisms, primarily bacteria, for energy and for synthesis of new cells. This reaction may be represented by the following expression:

$$\text{Organic carbon} + O_2 + \text{nutrients (N, P)} \xrightarrow{\text{microorganisms}} CO_2 + H_2O + \text{new cells}$$

The cellular mass generated may be represented by the formula $C_5H_7NO_2$.

10. The growth of microorganisms is a function of the amount of available food. Microbial growth can be defined in three phases: log

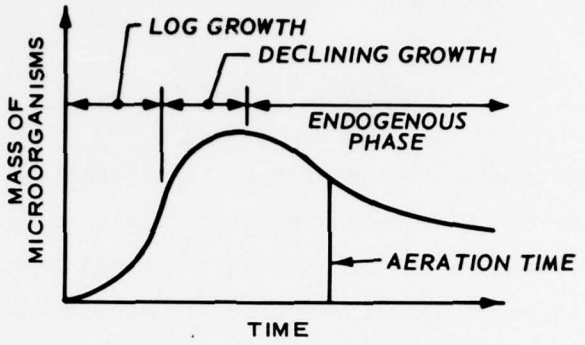


Figure 3. Microbial growth curve

growth, declining growth, and endogenous growth. Figure 3 shows the phases of growth and the relationship between the mass of microorganisms and food available. In the log growth phase, initiated by an excess of food, the growth rate, which is at a maximum, is limited only by the ability of the microorganisms to metabolize the food. In the declining growth phase, the bacteria need more food than is available, resulting in a decrease in the growth rate. When the food concentration reaches a level insufficient to sustain further growth, many of the cells lyse, releasing their protoplasm to be used as a food source by the remaining cells. This process is called endogenous respiration or auto-oxidation and may be represented by the following simplified reaction:

$$C_5H_7NO_2 \rightarrow NH_3 + 5CO_2 + 2H_2O + \text{Energy}$$

11. Modifications of the activated sludge process may operate in any one or more of the growth phases depending on the masses of food and microorganisms present. A major operational and design parameter is the food to microorganism (F/M) ratio, which relates the mass of food in the aeration basin to the microbial mass. The F/M ratio is important because of its effect on the kinetics of BOD removal and sludge settleability.

12. The principle of wastewater stabilization within an activated sludge plant involves the uptake of soluble food (BOD) by bacteria and subsequent stabilization of the bacterial mass through endogenous respiration and predation by the animal population present in the activated sludge. Primary animal populations involved are the protozoa,

predominantly the ciliates, and rotifers.

13. The ultimate success of an activated sludge system is, in fact, dependent on the animal population present. The lack of adequate animal populations generally results in poor BOD removal and the appearance of a turbid effluent. High performance within the activated sludge system as a result of maintaining a proper animal population has been documented.[2-5] The present tendency, however, has generally been not to rely on direct enumeration of animal populations for process control, but rather to depend on the control of such parameters as F/M ratio and amount of solids to provide adequate animal populations and to maintain satisfactory performance.[6] Since these parameters represent indirect measurements, process failure may occur prior to actual detection, even in the presence of presumably normal operating conditions.

14. Generally, the animal populations resident within activated sludge systems are more sensitive to changes in operation than are other microorganisms in the biological community. Introduction of toxic compounds and lack of adequate aeration are two conditions that dramatically affect the animal population. The imposition of a shock load may also affect the animal population.[7] Data relating to the effect of shock loads on animal populations are generally lacking and represent an area of current interest.[8,9]

Extended Aeration

15. Extended aeration is one of several modifications of the activated sludge process. It has proven to be very effective in the treatment of flows of less than 1 mgd and will achieve a high degree of treatment efficency when subjected to relatively consistent and sustained loadings. About 98 percent of the influent BOD is either oxidized or converted to cellular mass in the extended aeration tank, resulting in a consistently low soluble effluent BOD_5. Because it is so well suited to low flows, extended aeration is the primary modification of activated sludge used in recreational areas. It operates in the endogenous growth phase and is characterized by a low F/M ratio, usually

in the range of 0.05-0.15 lb BOD_5 per pound of mixed liquor volatile suspended solids (MLVSS) per day. In order to maintain the desired F/M ratio, the mass of microorganisms, or MLVSS, must be controlled. This is accomplished by recycling a portion of the sludge from the clarifier to the aeration tank and then wasting the excess sludge. Other design parameters for extended aeration systems are given in Table 1.

16. When extended aeration was first developed, it was thought that the long sludge age would make possible complete oxidation of the sludge produced. However, later investigations indicated that 23 percent of the biological solids produced were refractory and could not be further degraded.[10] Because the system cannot handle a continuous build-up of solids, sludge must be wasted or discharged in the effluent, which reduces effluent water quality. Because inert solids are generally denser and settle faster than active biological solids,[11] a major portion of the solids discharged over the clarifier weir are biodegradable organics that may exert a significant BOD on the receiving stream or lake.

17. Efficient solids settling and removal in the clarifier is of primary importance in the design of extended aeration systems. Problems in sludge settling may be caused by sludge bulking, denitrification, and the production of nonflocculant solids. Sludge bulking, caused by filamentous bacteria and usually resulting from an overloaded system and low oxygen levels, will generally not be a problem in a properly designed extended aeration system. Denitrification, which causes nitrogen gas bubbles and rising sludge, is probably the most significant problem in an extended aeration plant at a recreation area. This problem may be minimized by limiting the time that settled solids remain in the clarifier. Nonflocculant solids are produced at low organic loadings and lack the ability to flocculate in the clarifier. Studies by Pfeffer[11] showed that suspended solids removal decreases with loadings less than 15 lb BOD_5 per 1000 cu ft of aeration. The clarifier cannot perform efficiently when subjected to significant increases in hydraulic loadings because of the corresponding increase in the surface overflow rate.

Shock Loading Studies

18. In recent years, considerable research effort has been devoted to improving the design and operation of biological wastewater treatment systems. The effects of shock loading on activated sludge systems have been the subject of much of this research. The effects of shock loads or sustained periods of underloading on extended aeration systems such as might be encountered at recreation areas have not been fully investigated. This section will review selected studies of the effects of shock loading on activated sludge systems. These studies reflect potential problems that may be encountered when an extended aeration biological system is subjected to intermittent loading.

19. One of the more recent studies in the literature is that of Sherrard and Lawrence,[8] who evaluated the response of a laboratory-activated sludge system with recycle to a step increase in loading. Included in this study was a relatively complete literature review of experimental and mathematical studies of the problem. Important conclusions in this field include those of Eckhoff and Jenkins,[12] who found that an activated sludge system with a high concentration of mixed liquor suspended solids (MLSS) was better able to withstand a shock loading, and those of Krishnan and Gaudy,[9] who found that an activated sludge system with a longer solids retention time or sludge age was better able to withstand shock loading. Sherrard and Lawrence[8] found in their laboratory study that sludge age had a greater effect on removal of organics than did aeration tank detention time for a system subjected to a step increase in loading. They also reported that for a short sludge age, the biomass did not settle well when subjected to shock loading.

20. Adams and Eckenfelder[13] compared the response of a laboratory activated sludge system under organic transient loadings with that of a similar system operated at steady-state conditions. The organic transient loads were varied in magnitude and duration. A threefold increase in organic concentration of the influent waste for 12 hours each day did not affect the effluent soluble chemical oxygen demand (COD) for a

period of several days. Eckenfelder's first-order model for substrate removal was found to be valid for transient as well as steady-state conditions, but different removal rate coefficients were observed under transient conditions.

21. Another study of organic shock loadings was reported by O'Brien and Burkhead.[14] Laboratory activated sludge systems with and without recycle were evaluated. The system with sludge return withstood shock loadings considerably better than the system without recycle. Significant concentration increases did not produce a change in effluent soluble COD for the sludge return system.

22. Storer and Gaudy[15] subjected an aeration system without recycle to a threefold increase in organic loading and attempted to fit the response of the system to the Monod model. The system responded qualitatively but not quantitatively in accordance with the Monod model. Varying cell yield during the transient state was responsible for failure of the model to predict the biological solids and substrate concentrations accurately.

23. George and Gaudy[16] evaluated the response of an activated sludge system without recycle to hydraulic shock loads in a laboratory experiment. A reference level of 8 hours' retention time was chosen, and flow rates of 25 to 250 percent of the reference level were evaluated. None of the shocks caused irreparable disruption of the system. In all cases, a new steady state was approached that was predictable in accordance with general kinetic theory of continuous culture. Equalization was recommended for greater than 100 percent increases of the reference level since the new steady-state effluent values were higher than those of preshock. However, for increases less than 100 percent of the reference level, the postshock characteristics were not significantly different from those of the influent value.

24. McLelland and Busch[17] evaluated organic and hydraulic shock loadings of a laboratory activated sludge system. They concluded that microorganisms have a reserve potential to handle shock loadings. The exhibition of this potential can be predicted, but the extent of the effect cannot be predicted because of the resulting physiological changes.

25. Grady[18] reviewed modeling efforts for the transient response of activated sludge systems and modeled the activated sludge shock load response using an analog computer. The model predicted that the response would vary based on the specific growth rate of the microorganisms and the hydraulic retention time in the reactor. A lower growth rate prior to the shock produced a better response; and for a given specific growth rate constant, the response to a shock load was found to be relatively independent of the reactor hydraulic retention time prior to the shock. However, these results were not verified by experimental data. Burkhead and Wood[19] also developed an analog model of activated sludge systems subjected to daily periodic loadings using McKinney's equations.[20] Several activated sludge systems, including extended aeration, were evaluated.

26. Hellier and Cadman[21] conducted one of the few field evaluations of an extended aeration system at a recreation area. Influent and effluent hydraulic and wastewater characteristics data were collected for the plant, and three mathematical models were developed to simulate operation of the plant. A first-order kinetics model that assumes all of the influent BOD to be in solution and the aeration tank to be a completely mixed system proved to be the best representation of the system. Kinetics constants were obtained from experimental data. This situation did not reflect the more severe problems of intermittent loading that are discussed in this report.

27. To summarize the results of previous studies, activated sludge systems can withstand hydraulic and organic shock loads to a certain degree. The ability to withstand shock loads is related to the MLSS, sludge age, hydraulic retention time, and specific growth rate of the system. First-order kinetics models have been used with some success, but the kinetics constants may not be the same as for steady-state conditions. The extended aeration system operates at conditions that optimize these factors, and thus might better withstand shock loadings than other activated sludge modifications. However, most of the studies in the literature are based on laboratory systems, and the effluent characteristics are often described only in terms of soluble

organic concentration. Additionally, the loading fluctuations at recreation areas are much more severe than those reported in these studies. Reports from the field indicate that the extended aeration package plants in use at recreation areas do experience significant operational problems from intermittent loadings and that the major problem is probably the loss of solids in the effluent accompanied by a concurrent rise in the effluent organic concentration.

PART III: MODEL DEVELOPMENT

28. The approach used in this study was to develop a computer model to predict the performance of a CMAS system under intermittent loading conditions. Intermittent loadings for this study are defined as time-dependent hydraulic and organic loadings. Parameters to be considered include effluent quality, dissolved oxygen uptake, and other performance indicators related to biomass response to intermittent loadings.

29. A functional computer model to predict the response of a CMAS system to intermittent loading was developed. The model, called ASMODEL, is written in Fortran language and can be executed on the time-sharing system at the U. S. Army Engineer Waterways Experiment Station. The loading functions selected for inclusion in the model may be discrete or continuous with time. A minimum time interval of 1 hour was selected for the basic time unit of the model. This interval was chosen because smaller time intervals would be more difficult to define precisely in terms of a model that could be verified by laboratory data. For continuous loading functions, an hourly average loading can be computed for input to the CMAS model.

30. A schematic diagram of the model is shown in Figure 4. The functional model includes an aeration basin and clarifier for solids separation. Any activated sludge system that may be described by these two unit operations can be modeled by the approach used in this study. Response of the aeration tank is described by McKinney's equations.[20] Soluble food is the only source of BOD considered, and suspended organics are assumed to be negligible as input to the aeration tank. The key descriptors for the response of the aeration tank using McKinney's equations are the synthesis rate constant, the endogenous respiration rate constant, and the food removal rate constant. Under conditions of intermittent loading these parameters are assumed to be a function of the state of the biomass in the aeration tank as described by the F/M ratio in the aeration tank. The performance of the clarifier is described by the empirical relationships presented by Agnew.[22] The

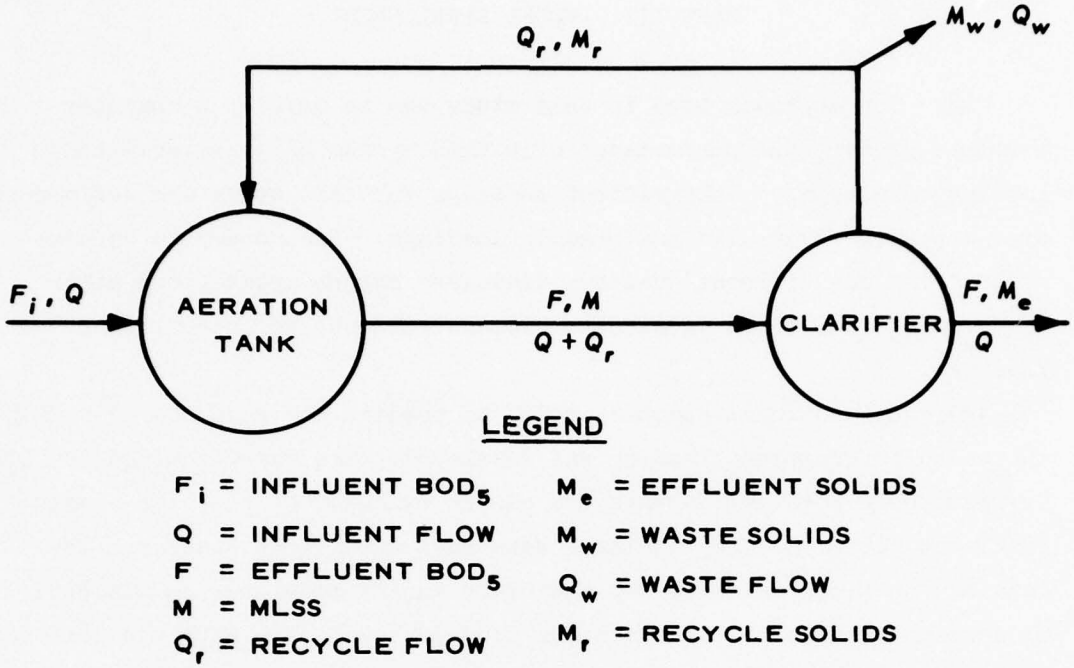


Figure 4. Flow diagram for model CMAS system

equations presented by Agnew, which appear to be theoretically sound, are based on observed clarifier performance, and were incorporated into the model. The model used for clarifier performance is not expected to be improved by using laboratory data because of similitude problems with field scale units.

31. The computer program for the model uses the basic 1-hour time unit as discrete units for describing the CMAS system. In this manner, inputs that are described as functions of time and response parameters are segmented into hourly units. The complete model operates over a calculated detention period for the aeration tank and clarifier. The hourly responses are summed over the detention period and adjusted volumetrically to calculate the response. One detention period is hydraulically the shortest time unit for presentation of data. All output parameters are expressed as the values calculated at the end of an aeration tank hydraulic detention time. A detailed description of the CMAS model and a program listing are presented in Appendix A.

PART IV: EXTENDED AERATION SYSTEMS

Experimental Laboratory Extended Aeration System

Equipment, apparatus, and feed

32. A photograph and schematic diagram of the laboratory extended aeration system are shown in Figures 5 and 6, respectively. Components of the system included a Plexiglass feed tank, settling column,

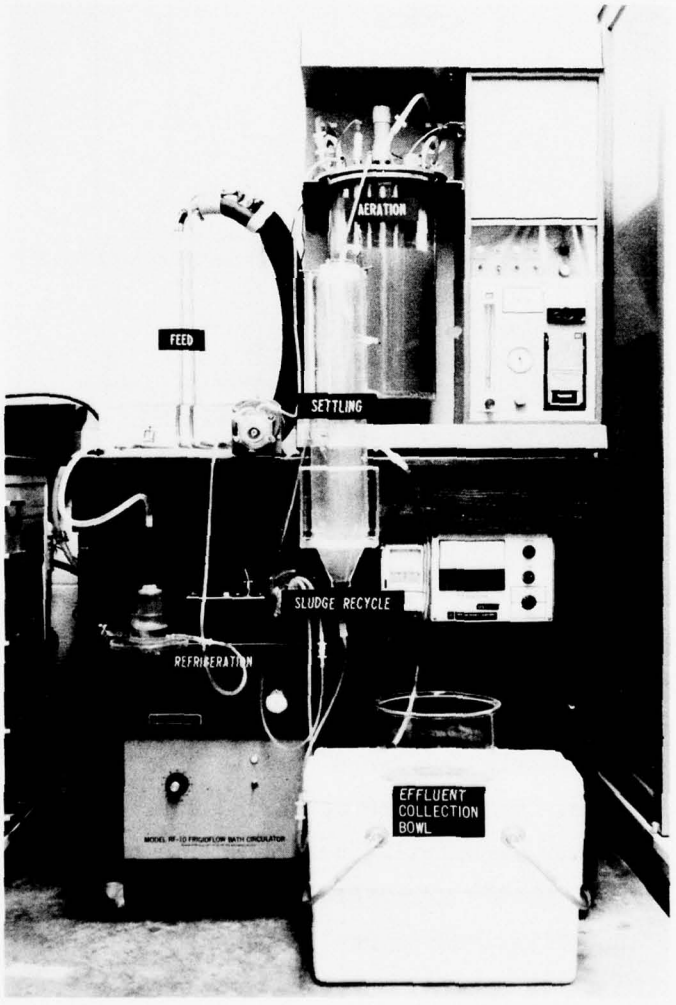


Figure 5. Laboratory extended aeration system

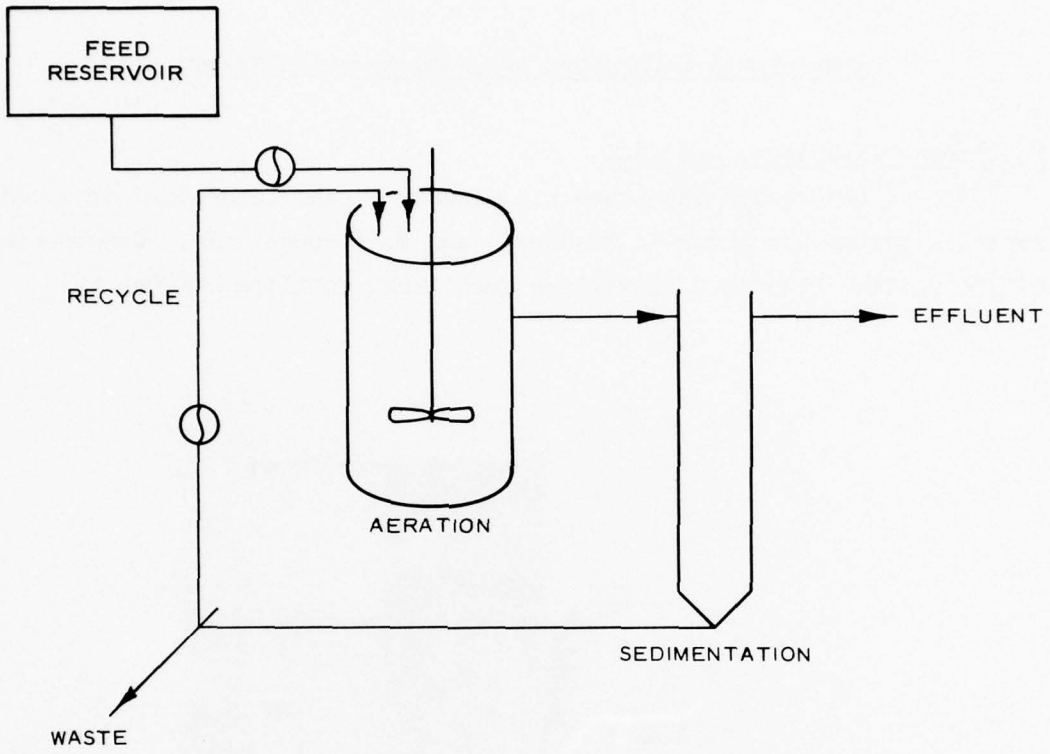


Figure 6. Schematic diagram of laboratory extended aeration system

peristaltic pump for sludge recycle, and effluent collection bowl. The feed solution was kept at 5°C with an immersed cooling coil to prevent microbial decomposition prior to transfer to the aeration basin. Solids in the aeration basin were completely mixed using diffused air and a motor-driven stirrer. The airflow rate was 2 ℓ/min at a pressure of 5 psig, and the stirrer was set at 250 rpm throughout the study. Air leaving the basin passed through a water-cooled condenser to reduce evaporation losses. Temperature of the mixed liquor was maintained at 25°C by continuously circulating heated or cooled water through baffles submerged in the liquid. An oxygen probe was available for continuous monitoring of the dissolved oxygen of the mixed liquor. The aeration system, refrigeration system, and dissolved oxygen monitoring equipment were components of a fermenter manufactured by New Brunswick Scientific

Company. Design data for the laboratory system are given in Table 2.

33. To allow preparation of a food source consistent in concentration and composition, a synthetic feed solution prepared daily from a stock feed concentrate and a stock buffer solution was selected for use for laboratory evaluations in lieu of domestic sewage. The stock feed concentrate was prepared using 8 ℓ of water obtained from a reverse osmosis system. Constituents added to the water and their concentrations are listed in the following tabulation.

Constituent	Concentration mg/ℓ	Weight g
Ferric chloride ($FeCl_3$)	16.8	2.688
Magnesium sulfate ($MgSO_4.7H_2O$)	3000	24.00
Ammonium chloride (NH_4Cl)	4418	35.35
Sucrose ($C_{12}H_{22}O_{11}$)	4800	38.40
Bacto-peptone	5333	42.67

After the stock feed solution was prepared, 250-mℓ aliquots were added to plastic bottles, which were then autoclaved at 250°C for 25 min, cooled, capped, and refrigerated.

34. The stock buffer solution was prepared using 2 ℓ of water obtained from a reverse osmosis system and the chemical constituents listed in the following tabulation. The prepared buffer solution was stored at 4°C.

Constituent	Concentration mg/ℓ	Weight, g
Dipotassium hydrogen phosphate (K_2HPO_4)	7900	26.00
Potassium dihydrogen phosphate (KH_2PO_4)	4000	10.00
Disodium hydrogen phosphate ($Na_2HPO_4.7H_2O$)	4700	41.00

35. The synthetic feed was prepared daily by mixing one of the previously prepared and autoclaved 250-mℓ aliquots of the stock feed and 80 mℓ of the stock buffer concentrate with 12 ℓ of tap water. The solution was well mixed by water jet or stirring. Fresh feed solution was cooled to about 4°C within 2 hours after preparation and maintained at that temperature throughout the 24-hour flow cycle. The synthetic substrate formulation is shown in the following tabulation.

Compound	Concentration, mg/ℓ
Ferric chloride ($FeCl_3$)	0.35
Magnesium sulfate ($MgSO_4.7H_2O$)	62.5
Ammonium chloride (NH_4Cl)	92.0
Sucrose ($C_{12}H_{22}O_{11}$)	100.0
Bacto-peptone	111.1
Dipotassium hydrogen phosphate (K_2HPO_4)	217.0
Disodium hydrogen phosphate ($Na_2HPO_4.7H_2O$)	375.0

Operational procedures

36. The laboratory system required daily operation and maintenance, which was normally performed at the beginning of each workday. Fresh feed solution was prepared each day. Old feed from the previous day was discarded and the feed tank and constant head device were washed. Flow rate for the feed solution and for the sludge return was checked and adjusted if necessary. The sludge return rate was held constant at 20 ℓ per day, or 200 percent of the steady-state flow throughout the experiment. Mixed liquor temperature, airflow rate and pressure, and the mixing rate were checked daily and adjusted if necessary. Clarifier walls were scraped daily to remove any growth clinging to the walls. Growth on the walls of the aeration tank was removed by slightly increasing the mixing rate. Since this was an extended aeration system, the rate of sludge production was low, and sludge was not intentionally wasted except for sampling of the mixed liquor for suspended solids and microscopic observations. Tubing for the peristaltic pumps had to be

replaced every 2 to 3 weeks because of fatigue.

Experimental design

37. The laboratory evaluation was conducted in two parts. The first part of the laboratory study evaluated circumstances that might exist at recreation areas having a high day visitation rate and excluding overnight campers. This initial study also provided insight into the efficiency of the process and microbial population dynamics under steady-state and shock loading conditions similar to those studied by others. Steady-state conditions have previously been defined in Table 2. Prior to imposition of the shock load, the system was operated at steady state for a 20-day period to establish an equilibrium condition. A diagram of a pulse hydraulic and organic load, used to simulate a shock condition, is shown in Figure 7. The shock loading pattern was repeated for a 10-day period to assess any cumulative effects, and operation was subsequently returned to steady state to determine recovery.

38. The second part of the laboratory study sought to simulate a loading pattern more typical of those encountered at recreational areas where the wastewater treatment system is severely underloaded during the week and then experiences peak loadings for one or more days during the

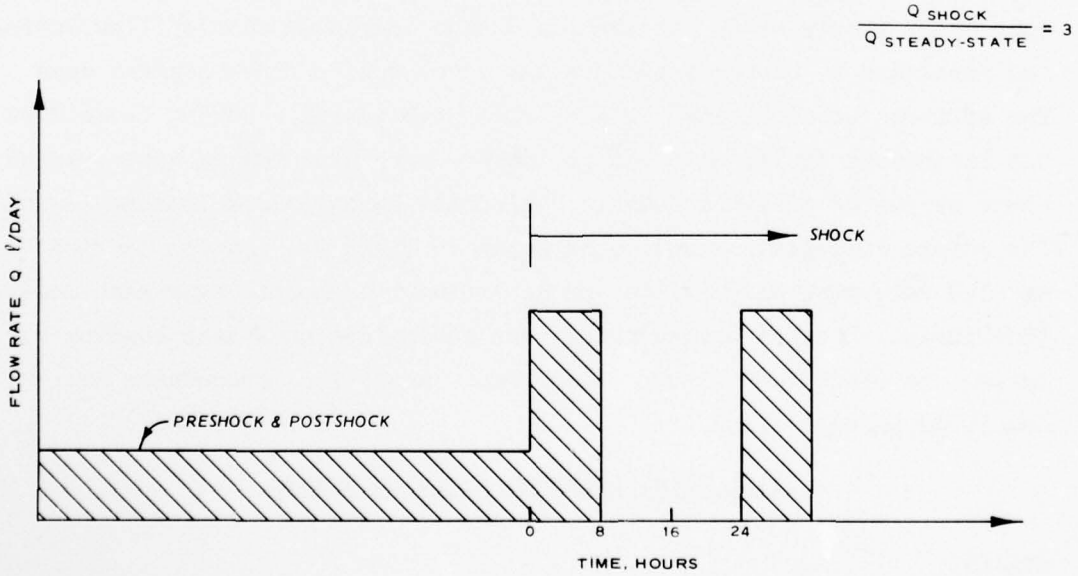


Figure 7. Experimental shock loading

weekend. Five different intermittent loading patterns were evaluated. Each pattern consisted of a period of severe underloading, which was varied to achieve different patterns, and a period of overloading or shock loading, which was always 8 hours. Influent substrate flow was varied to create the desired loading condition. The low-flow rate was set at 10 percent of the design flow or 1 ℓ/day, whereas the shock load was set at 300 percent of the design flow or 30 ℓ/day. Three cycles were evaluated for each intermittent loading with the exception of the 7-day cycle, where six cycles were evaluated; and the system was returned to steady-state operation after the last cycle of each intermittent loading. The loadings with shorter periods of flow were evaluated first.

Sampling and analysis

39. Performance of the bench-scale extended aeration system was determined by monitoring MLSS and MLVSS, effluent suspended solids (ESS) and effluent volatile suspended solids (EVSS), total and total soluble organic carbon (TOC), and the dissolved oxygen uptake rate of the mixed liquor. Additionally, total and soluble effluent COD was monitored during the 5- and 7-day intermittent cycles. Effluent parameters for Phase 1 of the laboratory study were measured on a 24-hour composite sample for steady-state days and an 8-hour composite sample (flow during the remaining 16 hours of the day was zero) during shock loading days. The effluent was collected in a refrigerated vessel. During Phase 2 of the laboratory study, effluent parameters were measured on grab samples taken at 30- or 60-min intervals during the 8-hour shock loading period. The sample collection schedule is shown in Table 3. Low-flow period samples were generally limited to an effluent composite over each low-flow period. Oxygen uptake rates were determined once each loading day during the sixth hour of the 8-hour run. Analytical procedures are described in Appendix B.

Pilot Plant Extended Aeration System

Design

40. A schematic diagram of the pilot plant extended aeration

system is shown in Figure 8. Wastewater was pumped from a wet well of a municipal sewerage system through the comminutor to the surge tank. From the surge tank the wastewater entered the second aeration tank of the treatment unit, where biological degradation occurred. The aerated

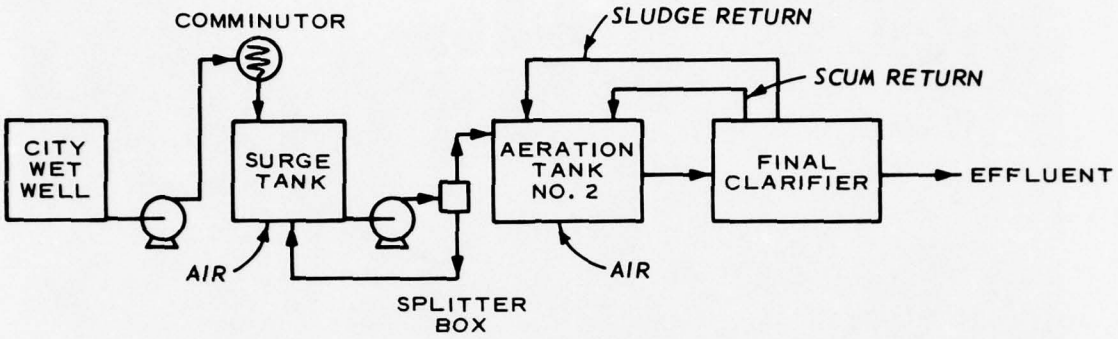


Figure 8. Schematic diagram of extended aeration pilot plant

contents of the aeration tank (mixed liquor) flowed through a slide gate, with an opening approximately 18 in. below the water level, to the clarifier. The suspended solids that settled in the clarifier were returned to the aeration tank using an air-lift pump. Clarified liquid flowed over the weir and was discharged back into the wet well. A photograph of the plant is shown in Figure 9. Figure 10 provides a layout of the pilot plant used in the field study. The operation of individual units of the plant is discussed below.

Surge tank

41. When filled to the splitter box, the aerated surge tank had a capacity of 4150 gal. This volume is approximately equal to 500 gal per foot of tank depth (excluding the bottom 1.5 ft). The surge tank was equipped with a comminutor that was manually activated when influent was pumped from the wet well to fill the tank to the desired depth. Wastewater was aerated and mixed by two blowers that were in operation 15 min per hour during the study. There were two diffusers in the surge tank, each controlled by a gate valve. Air pressure, which was measured by a gage on the header pump for the diffusers, was set at 3-4 psig.

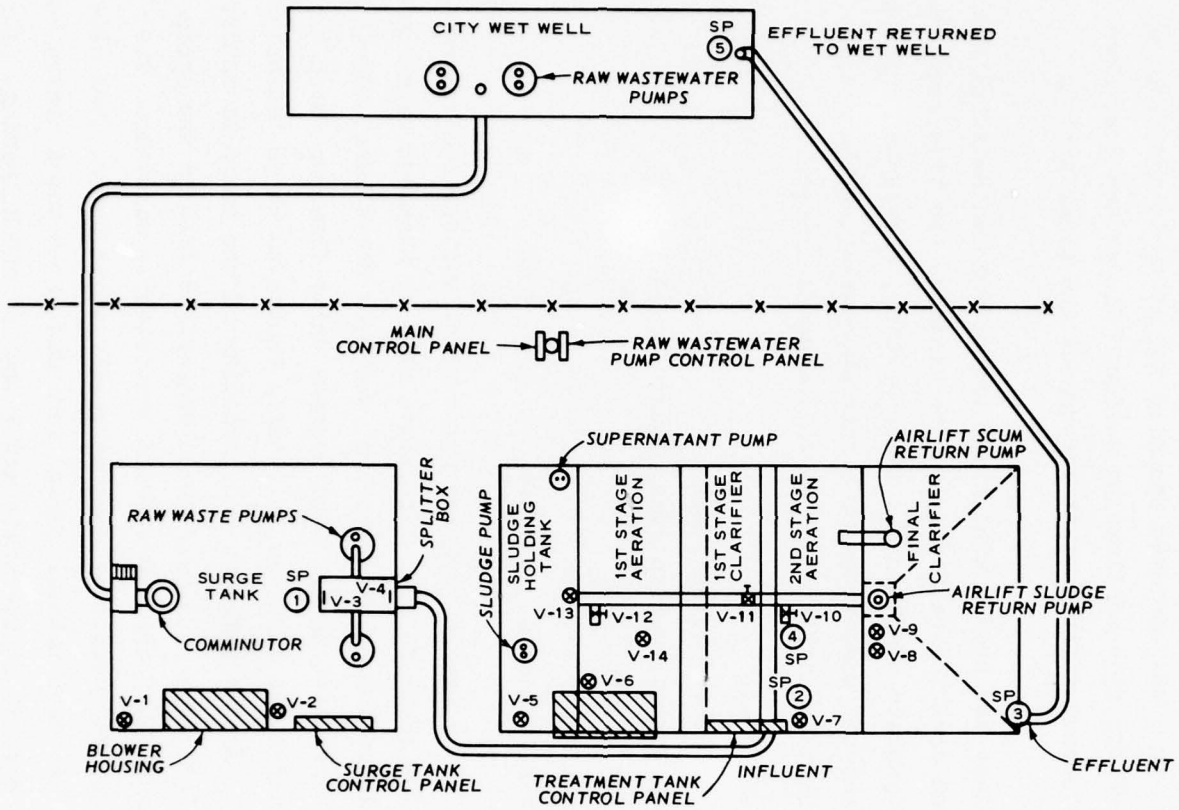


Figure 9. Extended aeration pilot plant

42. Wastewater was pumped from the surge tank to a splitter box using either of two 80-gpm submersible pumps. The splitter box allowed the return of a large portion of the flow to the surge tank. A progressing cavity pump was then used to pump the raw waste from the splitter box to the aeration basin.

Treatment plant

43. The second aeration tank in the treatment plant had a capacity of 2340 gal. Air was pumped through a diffuser in the bottom of the tank by either of two blowers. These blowers were controlled by a timer and were automatically alternated to provide for continuous aeration. The blowers also served the sludge holding tank, the first aeration tank, and the air-lift pumps for mixed liquor removal from the first aeration tank and for return of the sludge from the final clarifier. To prevent violent aeration in the second aeration tank, air was vented through the diffusers in the sludge holding tank and in the first aeration tank. Air was also necessary for the operation of the sludge return pumps and



LEGEND

SP1 SAMPLES TAKEN BETWEEN POINTS WHERE WASTE GOES FROM THE SPLITTER BOX AND THE TANK

SP2 SAMPLES TAKEN FROM THE AERATION TANK ABOVE AIR DIFFUSER

SP3 SAMPLES TAKEN FROM THE TROUGH DOWNSTREAM OF FINAL CLARIFIER WEIR

Figure 10. Pilot plant layout

for scum removal in the final clarifier. Air pressure was regulated at 3.75 psig, and the valve controlling air diffusion into the second aeration tank was not changed during the study.

44. The sludge return pump was operated continuously at 10 gpm. The scum removal pump was operated manually for 15 to 45 min each day to keep the clarifier free of floating solids. Sludge and scum were returned to the second aeration tank throughout the study period.

Plant operation

45. The plant was seeded with mixed liquor from an existing well-operated extended aeration package plant to minimize the time required to achieve steady-state conditions. After seeding, the system was continuously fed domestic wastewater at a rate approximating the design steady-state conditions defined in the following tabulation.

Flow rate, gpd	1728 (1.2 gpm)
Volume of aeration tank, gal	2340
Aeration tank detention time, hours	32.5
Clarifier volume, gal	1650
Sludge return rate, gpm	10
Clarifier surface area, sq ft	3.69

Design flow for the extended aeration pilot plant was set equivalent to average daily flow expected at a recreation site as obtained using data collected at Arkabutla Lake, Mississippi, and Deer Creek Lake, Ohio, two Corps-operated recreation areas. The average daily flow was found to be 1.625 gpm. Steady-state flow was originally chosen to be 50 percent of the design flow. However, due to the inability of the pumps to achieve and maintain a flow of 0.8125 gpm, the steady-state flow in the study was 1.2 gpm, a rate that the pumps could consistently maintain. The system was allowed to operate 11 days at steady state before each experimental period. An experimental period included three shock cycles, each consisting of 5 days at steady state and 2 days of shock loading. During each day of shock loading, the system was shocked for 16 hours and allowed to rest for 8 hours. A loading scheme for steady state and one experimental period is shown in Figure 11.

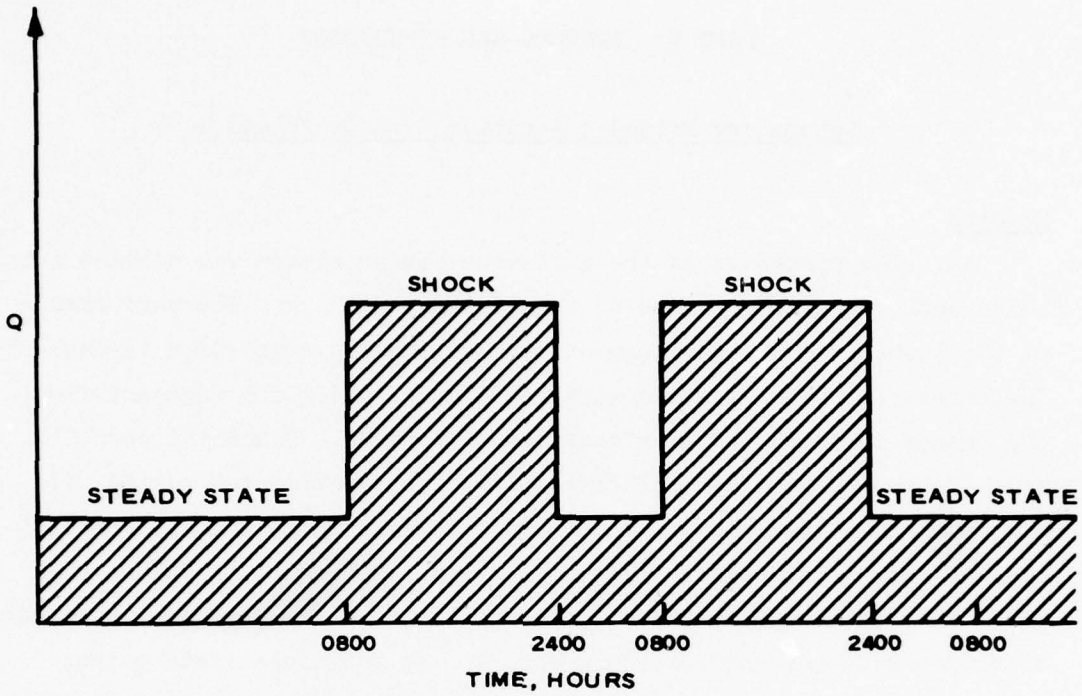


Figure 11. Loading schedule for extended aeration pilot plant

Sampling and analysis

46. Table 4 indicates the sampling schedules for the package plant and the analyses made for the steady-state and shock loading phases.

47. The three primary sampling points were as follows:

a. Influent (Inf). Taken between points where waste goes from the splitter box and the tank.

b. Mixed liquor (MT). Taken from the aeration tank above air diffuser.

c. Effluent. Taken from the trough downstream of final clarifier weir.

48. Analyses of both total and dissolved solids in the influent and effluent were made. Samples were filtered through a Millipore AP-40 glass fiber filter to remove the suspended fraction.

49. All samples other than those requiring immediate analysis were broken down into subsamples, preserved if necessary, and stored at 4°C. All unfiltered samples for TOC, COD, and nutrients were blended prior to preservation. Analytical procedures are described in Appendix B.

PART V: RESULTS AND DISCUSSION

Laboratory Extended Aeration System: Phase 1

Results

50. The operation of the activated sludge system was divided into three basic periods: preshock, shock, and postshock. The performance of the system during these operational periods is summarized in Table 5. The effects of shock loading on mixed liquor solids are apparent from the change in values between operational periods. Since the percent volatile solids remained constant during the experimental period, it may be assumed that changes in active mass were predominately responsible for changes in solids. Figure 12 presents the actual values for MLVSS during the entire experimental period, and the peak for these data coincides with the shock loading period. An additional data point, labelled u, also indicated in Figure 12, reflects the point at which a loss of solids occurred due to operational difficulty with the laboratory activated sludge system.

51. Both quantitative and qualitative changes in mixed liquor solids shock load the activated sludge system with concurrent changes in effluent quality. Changes in effluent quality (Table 5) were manifested primarily in changes in total TOC, ESS, and EVSS. Except for the late shock and postshock periods, the soluble TOC remained relatively constant throughout the experimental period. The TOC data from the experiment are presented in Figure 13 and verify this observation. A relatively constant soluble TOC is expected under the operating conditions of this experiment. A large increase in soluble TOC would not normally occur unless a toxic load or a very short hydraulic detention time were imposed. The increase in ESS and EVSS arose from the unsteady condition in the mixed liquor and the resultant loss of solids. It is interesting to note that the percent EVSS for the shock and postshock periods is approximately 100 compared with 79 for the preshock period, implying a greater loss of active solids during the two later operational periods. The loss of solids was directly responsible for

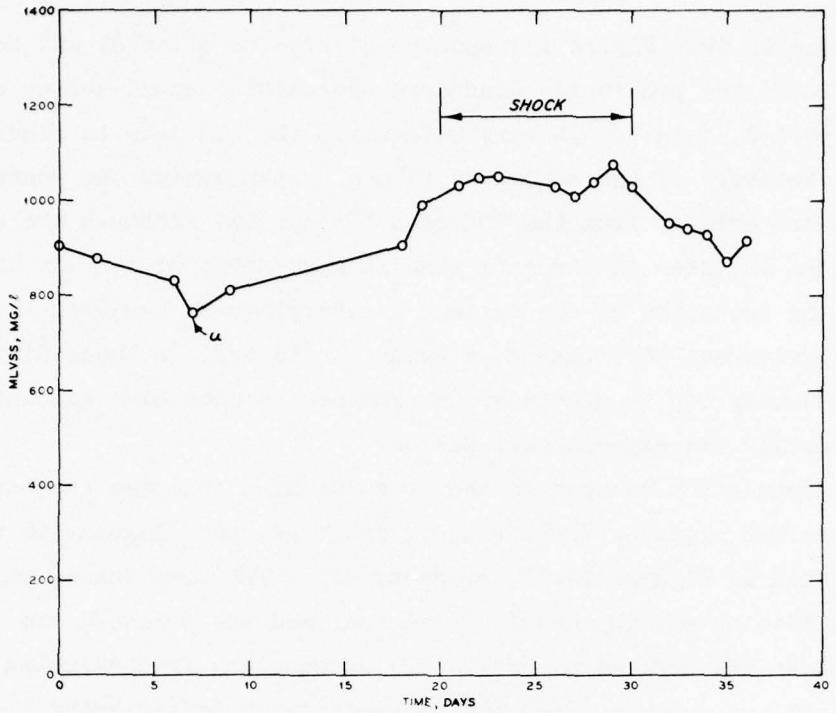


Figure 12. MLVSS versus time

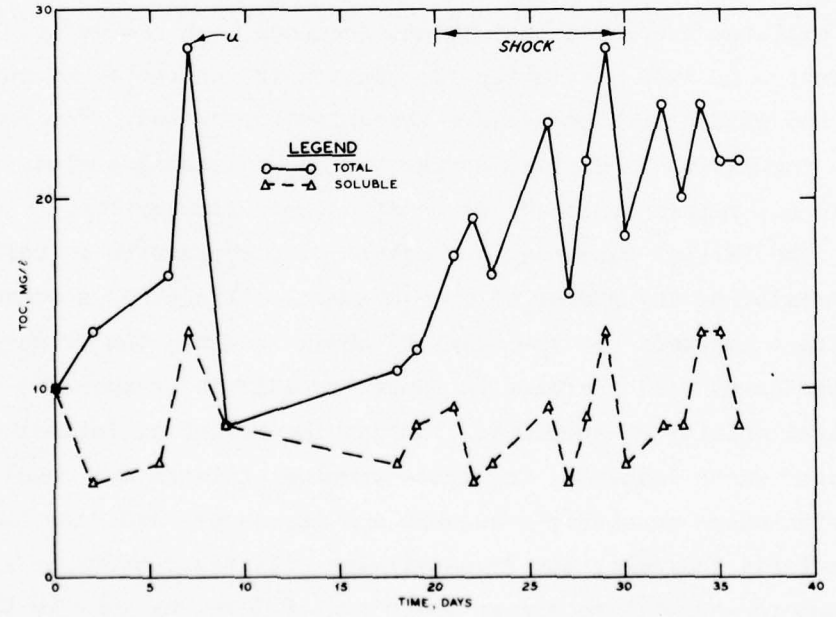


Figure 13. Effluent TOC versus time

the increase in TOC (Figure 13) and the divergence of total and soluble forms of TOC. The previously discussed operational upset during the preshock period, point u, is very evident in the TOC data in Figure 13.

52. Recovery of the activated sludge system during the postshock period is not evident from the TOC data (Figure 13) although the solids data (Figure 12) seem to indicate that it was taking place. At this point in the operation of the system, a divergence in agreement between solids behavior and performance is evident. To explain these differences adequately, it is necessary to examine the microbial population dynamics during the experimental period.

53. Population changes in the free-swimming ciliates (hypotrichida), stalked ciliates (peritricha), rotifers, and oligochaete worms are presented in Figures 14-17, respectively. The time during which the shock loading was imposed is indicated, and the preshock and postshock periods are defined accordingly. Because the free-swimming ciliates are the primary consumers of bacteria in an activated sludge system,[23] their numbers reflect the bacterial population dynamics. With the exception of two time periods, the free-swimming ciliates (Figure 14) were present in low numbers (<200/mℓ). The first exception is the period of operational upset (day 7) at which time the number of free-swimming ciliates increased rapidly and returned to a low value. The short duration of this population fluctuation is indicative of rapid recovery and return to steady-state (baseline) operation. The second change in population is evident during the shock loading period. The system did not return to steady state after this fluctuation.

54. The initial response to shock loading appears to be reflected in a depression of the number of free-swimming ciliates as a consequence of the stress imposed. At the onset of shock loading, the primary consumers (bacteria) will increase in number rapidly in response to increased availability of substrate. During the period of initial increase under shock loadings, the free-swimming ciliates are unable to compete with other secondary consumers and are suppressed. As the number of bacteria increase, the free-swimming ciliates respond by increasing in numbers and will remain at the elevated level as long as they are

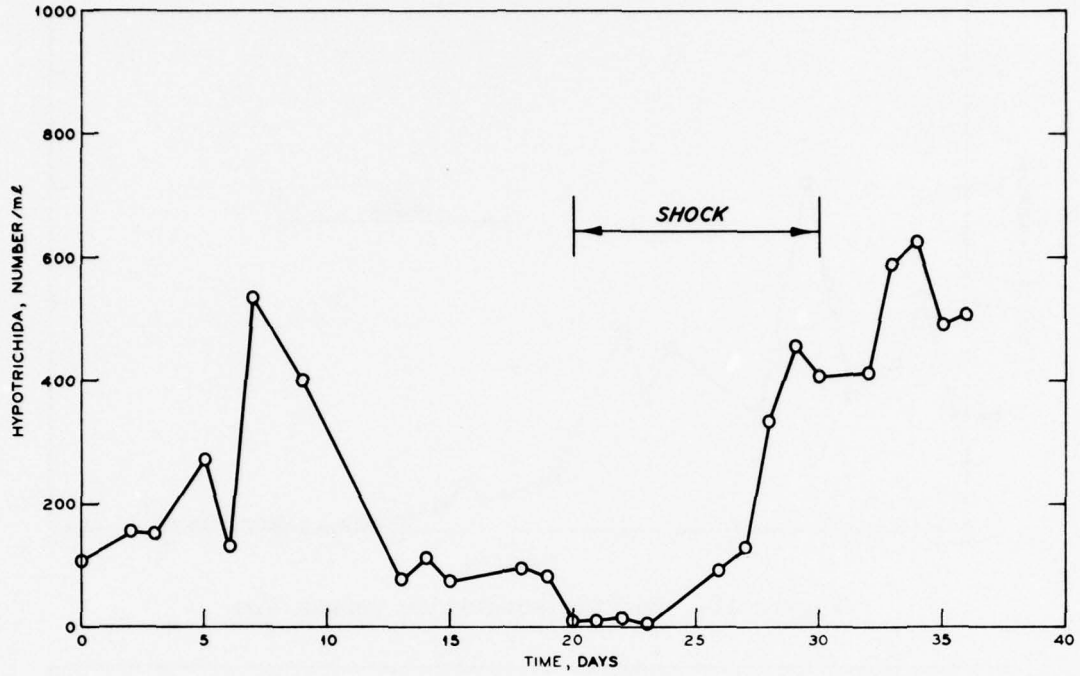


Figure 14. Hypotrichida population versus time

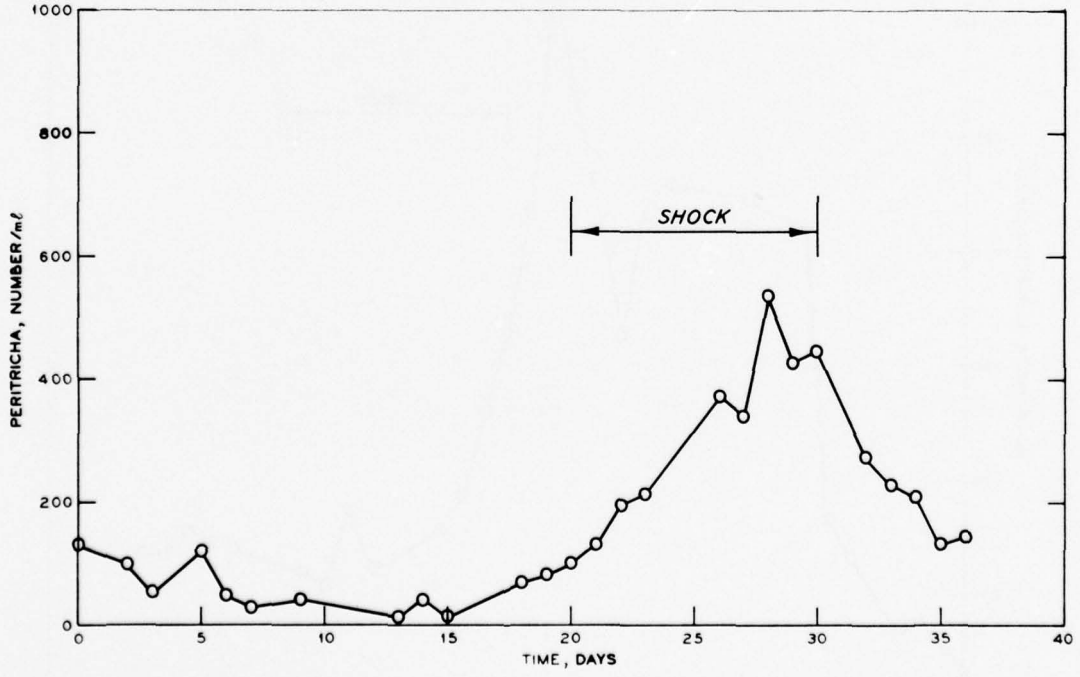


Figure 15. Peritricha population versus time

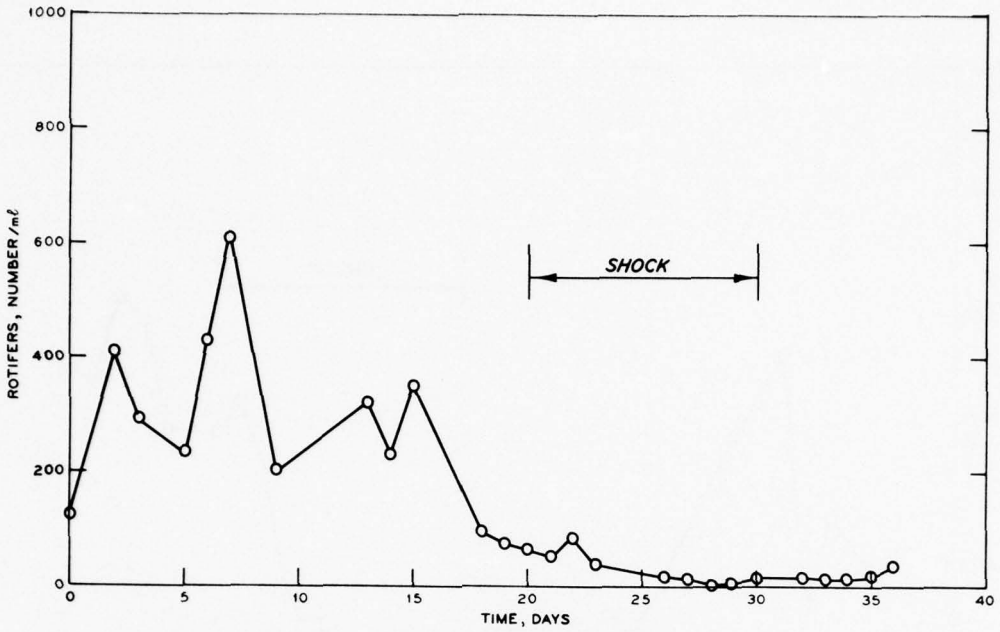


Figure 16. Rotifer population versus time

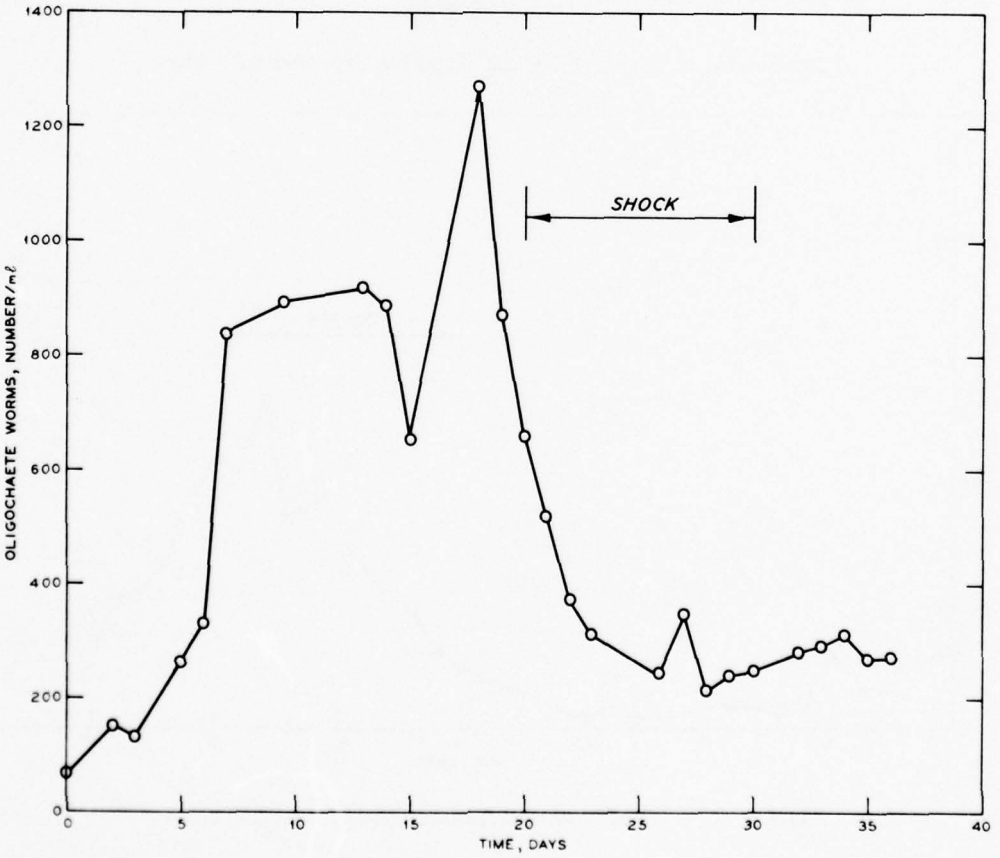


Figure 17. Oligochaete worm population versus time

able to effectively compete for the bacteria.[23] The presence of high numbers of free-swimming ciliates is therefore indicative of a high bacterial population and generally represents a condition of poor process performance (high effluent solids and TOC). The fact that this trend continued into and through the postshock period suggests that recovery from the shock loading requires a substantial time period. This fact is verified by the performance data in Table 5. It is interesting to note that the number of free-swimming ciliates appears to be higher during the postshock period. This increase is a result of overpredation on the bacteria (primary consumers), and may be responsible for poor soluble TOC removal during this period (Figure 13).

55. The stalked ciliates (Figure 15) appeared to respond well to the shock loading condition. Their numbers during the preshock period were low and stable, indicating a low F/M ratio. At the onset of shock loading, the number of stalked ciliates increased and continued to increase until the termination of the shock period. During postshock, their numbers declined and appeared to approach the preshock level. In contrast to the free-swimming ciliates, the stalked ciliates appeared unaffected by the operational upset at day 7 and were not initially depressed during the shock period. The behavior of the stalked ciliates during shock may be explained by considering their primary food source, bacteria. During the initial shock period, as the bacteria increased, the stalked ciliates responded by increasing. This initial situation was favorable for the stalked ciliates because the number of bacteria were probably still low and the stalked ciliates were able to compete effectively with the free-swimming ciliates. This fact also would seem to account for the initial depression in the number of free-swimming ciliates noted earlier. As the number of bacteria increased, the free-swimming ciliates were not competitive but ultimately replaced the stalked ciliates as the predominate secondary consumers (postshock).

56. The rotifer population (Figure 16) demonstrated a response to shock loading opposite that of the ciliates. Rotifers are usually characteristic of a very stable activated sludge system, such as the one operated during this experiment. During the preshock period, the

rotifer population was high and variable. A noticeable increase in rotifers was apparent at the point of operational upset (day 7). This response was very similar to that of the free-swimming ciliates. At the onset of shock loading, the rotifer population declined rapidly, a response also very similar to that of the free-swimming ciliates. This response was due largely to the increase in numbers of bacteria and inability of the rotifers to compete effectively with the ciliates as secondary consumers. During postshock, the numbers of rotifers remained low, representing a lack of recovery similar to that of the free-swimming ciliates.

57. The population response of the oligochaete worms (Figure 17) was very similar to that of the rotifers. The oligochaete worms are also representative of a stable activated sludge system. The response at the period of operational upset was a rapid increase in numbers that was sustained until the initiation of shock loading. During shock loading the number of oligochaete worms decreased rapidly and remained at this level throughout the postshock period.

Discussion

58. The performance of biological wastewater treatment systems is dependent on the maintenance of a proper animal population, both in number and composition. Federal and state regulations require high standards of performance. The operation of biological wastewater treatment plants to meet high performance standards requires constant monitoring of the system. The primary method of monitoring is to employ analytical techniques to determine directly the current level of performance. The use of biological examinations to assess treatment system performance is practical, but seldom used exclusively, since they do not directly relate to performance standards. The principal advantage of biological examination is that it may indicate impending treatment plant upset or failure. Furthermore, it may be used to determine the present operational state of the biological system. Equipped with this information, it is possible in some cases to alleviate the problem or return the system to a normal operating state. The imposition of a shock load on a biological treatment system is an example of a condition

that could cause poor process performance. In this case biological examination could prove to be useful by indicating the presence of a shock condition that may not have been readily apparent. It may also be utilized to indicate the return of the system to normal status.

59. The population dynamics associated with the activated sludge system have been documented previously.[2,4] Basically these observations may be summarized by the following:

a. Predominance of free-swimming ciliates represents a high F/M ratio and generally a poor effluent quality.

b. Predominance of stalked ciliates indicates an intermediate loading and a good effluent quality.

c. Predominance of rotifers or higher animal forms (e.g. oligochaete worms) indicates a very stable system and excellent effluent quality.

60. Responses of these biological communities to changes in process loading are not extensively documented. The capability of the activated sludge system to respond to a shock load is chiefly a function of its existing animal communities. Generally, the more stable the system is, the longer the response to a shock loading becomes because the biological system must repeat the animal population succession cycle every time the loading condition changes. If the loading condition is transient, the response may be adequate with only minor deterioration in effluent quality. If the loading condition continues for a long period of time, a new equilibrium must be established. Any shift from this new loading condition (e.g. return to normal) requires a readjustment of the animal community. Consequently, the duration of the shock loading period becomes critical.

61. The fact that changes in the equilibrium of an activated sludge system can be detected by monitoring the changes in the animal population verifies the usefulness of a biological examination. The period of process upset shown as u in Figures 12 and 13 was representative of a short-duration event; and although performance deteriorated during this time, recovery was rapid. The shock period imposed on the experimental system represented a longer duration event, and response occurred during the initial shock and postshock phases. Both instances

resulted in a poor system performance marked by substantial and long-lasting changes in the animal community. The same result could be expected of a biological system treating waste from a recreation area or highway rest area that would be characterized by long-duration transient shock loading conditions followed by a return to normal operation.[1]

62. To extend the usefulness of the data presented in this discussion, relationships between the animal populations and process performance were developed. Since the measurements represent fundamentally different sets of variables, canonical correlation analysis was employed.[24] This technique is similar to the product-moment correlation analysis commonly used in statistical analysis, except that the aim of the canonical correlation is to explore relationships between sets of variables. The canonical correlation analysis may be interpreted graphically by construction of plots composed of linear combinations of the variables in each set. If the weight of each factor is known, the dominant variables may be extracted and portrayed graphically. The results of this analysis are presented in Figures 18 and 19. The data points representing preshock, shock, and postshock conditions are separated for convenience. It is apparent from the plot and canonical correlations that significant interrelationships exist for both cases. The plots are presented in terms of standard deviations from the mean of the variable set. In all cases noted, the relationship for the dominant variables is direct: a positive deviation represents an increase in the value of the variable.

63. In Figure 18, the dominant biological variable is the number of rotifers, and the dominant performance or operational variables are MLSS and MLVSS. In this case the preshock rotifer population is related to a low level of MLSS and MLVSS. During the shock period, the mixed liquor solids rise sharply and the rotifer population declines because of competitive pressures from the secondary consumers (ciliates). This is shown in Figure 18 by the clustering of points for the shock period. During the postshock period, the system tends to return to the prior state as evidenced by the shift of points toward the preshock data. It appears from Figure 18 that rotifers are sensitive indicators of shock

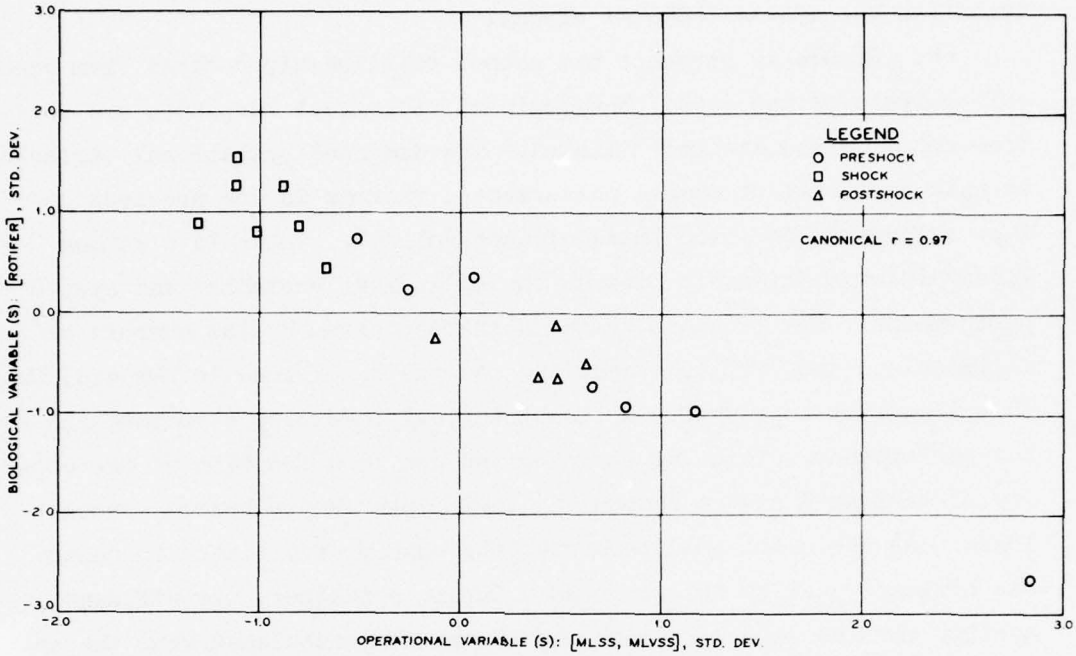


Figure 18. Results of first canonical analysis

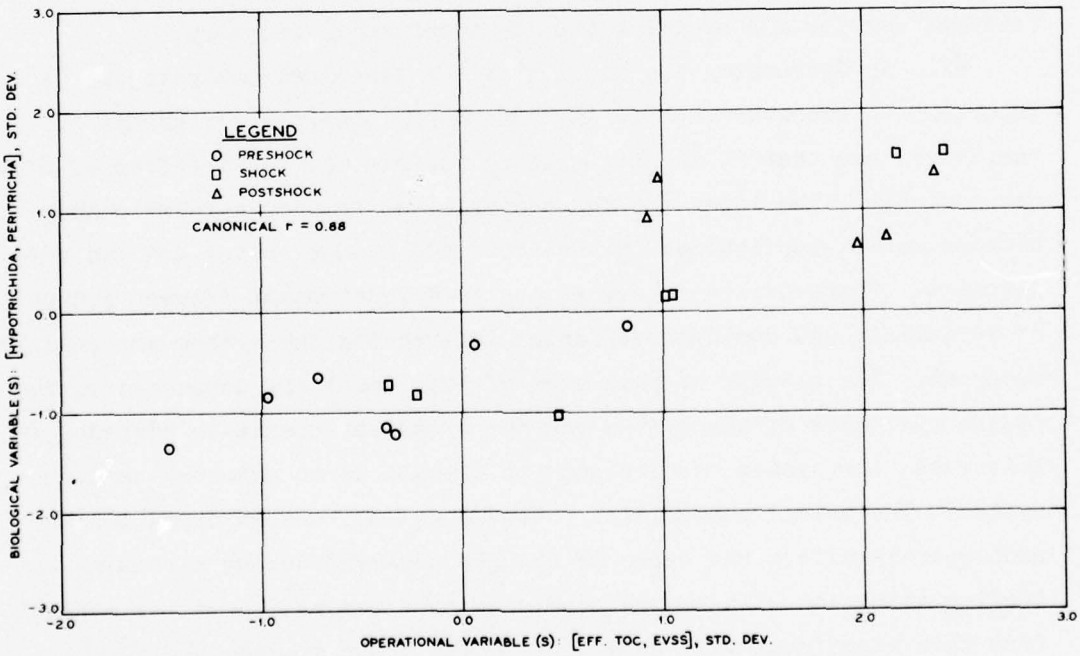


Figure 19. Results of second canonical analysis

loadings. Thus, the number of rotifers may be coupled to operational data from the system (MLSS or MLVSS).

64. Figure 19 presents the second relationship derived from canonical analysis of the data. The dominant biological variables are the free-swimming and stalked ciliates. The dominant operational variables in this case reflect system performance, whereas in the previous case they reflected operation (mixed liquor solids). There is a strong linear interrelationship between the biological variables and system performance. The preshock state is characterized by low numbers of ciliates and good effluent quality. As the shock load is imposed, there is a lag prior to a shift in the biological community structure and system performance. This lag was expected and is a function of the capacity of activated sludge systems to assimilate short-duration shock loads. As the shock load persists, the number of ciliates increases and effluent quality deteriorates. During postshock, the effluent quality remains generally poor due to the lag associated with the shift in the animal community for the activated sludge system. Thus, the number of ciliates is an indicator of the performance expected from the treatment system and explains the lag observed in recovery.

65. In discussing the results of the canonical analysis, it is important to remember that relationships are obtained for groups of variables, and that it is difficult to isolate the total effect of only one variable. The intent of the analysis was to show a relationship between animal populations in the activated sludge system and its performance. There exists a very strong interrelationshp between groups of variables, and dominant variables influencing the system are readily apparent. The results of this type of experiment are dependent on the design operation of the system and the transient condition tested. In this case, the system was designed to operate as an extended aeration system. The animal communities observed reflect design operation and consequently affect the types of changes observed during a transient loading situation. It may be concluded that the relationships derived from this experiment will remain valid for other systems due to the biological principle on which the derived relationships are based.

66. The observations on individual groups of organisms are also critical. The number of free-swimming ciliates, a good indicator of system upsets, may be depressed at the beginning of a shock period. Increases in free-swimming ciliates reflect a new equilibrium point in system operation although the transition has already occurred. The number of stalked ciliates is a good indicator of a shock condition since a sharp fluctuation in their population mirrors the shock period with only a small degree of lag. The rotifers and oligochaete worms are excellent indicators because their numbers decrease rapidly in response to the onset of a shock period.

Laboratory Extended Aeration System: Phase 2

Results

67. Raw data for the second phase of the laboratory evaluation of the bench-scale extended aeration system are presented in Appendix C. The unit was subjected to shock loadings and samples were taken every 30 or 60 min throughout an 8-hour shock loading day. Appendix C includes the results of effluent analyses for both total and soluble TOC and COD, SS, and MLSS, and the percent removals of total and soluble TOC and COD that were achieved by the system.

Discussion

68. In the analysis of the data from the second phase, mean and standard deviations for the raw data for each loading day were calculated and are shown in Tables 6-8. Table 6 describes effluent TOC as a function of cycle time. Total effluent TOC values were considerably higher than soluble effluent TOC values during cycle times of 2 and 3 days, but the total and soluble values were much closer during the longer cycle times of 4, 5, and 7 days. Average TOC's for the three loading days of each cycle are plotted as cycle times in Figure 20. The highest TOC values occurred during the 3-day loading cycle.

69. To explore the statistical relationships among effluent TOC values for different cycle times, loading days, and hourly samples, a three-way factorial analysis of variance (ANOVA) was performed on both

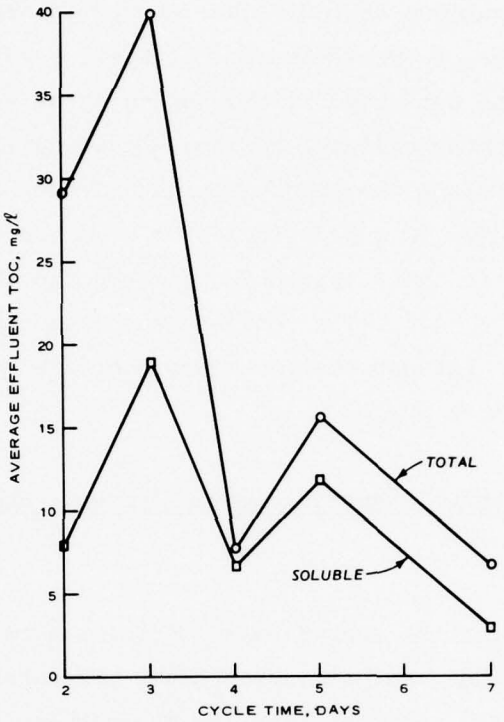


Figure 20. Effluent TOC versus cycle time

total TOC data and on the soluble TOC data. The triple-order interaction, cycle-day-time, was used as an estimate of sample error. The ANOVA results are presented for total TOC and soluble TOC in Tables 9 and 10, respectively.

70. The results shown in Figure 20 should be analyzed carefully for a statistical analysis of the data. Figure 20 shows that the total and soluble effluent TOC values correlated well. This correlation would tend to indicate that the performance of the laboratory unit under stress was not related to clarifier performance, but rather to the performance of the biological system. If this were not the case, there would be a deviation between total TOC, which reflects the contribution of the EVSS, and soluble TOC, which reflects the performance of the activated sludge system. Traditionally, process failures of extended aeration systems have been attributed to a hydraulic overload or a solids overload of the system, which results in a poorer quality effluent.

71. The results of the statistical analysis indicate a definite

relationship between cycle time and performance of the system. This has been shown previously in Figure 20, and the factors relating to this behavior of the system have been discussed. Because total and soluble effluent TOC values correlate well, it is expected that the results from the ANOVA tests on these dates would be similar, as they indeed are. A nonsignificant variation between days for a particular sample would indicate that the system performed consistently under repeated loadings within the experimental errors of the system. A significant variation for the cycle time-day interaction would indicate that performance under repeated cycles is related to the length of the cycle itself. This fact can also be explained by the previous discussion regarding Figure 20. If a particular cycle time produces process failure, in a biological sense, it would be expected that this effect would be amplified under repeated application of that particular cycle time. A nonsignificant variation for time implies that process performance was consistent within any one day of a cycle, again related to the experimental error. The remaining interactions are not significant, which does not contradict the previous discussion.

72. It is obvious from Appendix C that ESS values were relatively high for the laboratory system. The clarifier did not return settled solids to the aeration tank efficiently, resulting in denitrification.

Extended Aeration Pilot Plant

Results

73. Pilot plant operation and data collection were initially started in the summer of 1976. However, due to the operational problems encountered, the collected data were inconclusive and are therefore not included in this report. However, the experience gained in operating the pilot plant and in clarifying sampling and laboratory procedures during that period enabled researchers to initiate a second and more successful series of shock loading studies in the spring and summer of 1977. The study is composed of three experimental periods, each with a

successively higher shock load. Each period includes three shock cycles with identical quantitative shock load and length of shock. The data included in this section are representative of Period I, in which the flow for shock days was 209 percent of the average daily design flow, and two shock cycles of Period II, in which the shock load was 302 percent of the average design flow. At the time of this writing, the pilot plant study has not been completed. A third shock cycle for Period II is in progress, to be followed by Period III, in which the shock flow will be approximately 400 percent of the design flow.

74. The results of the laboratory analyses made during experimental Periods I and II are shown in Table 11. Tables 12-16 present the results of the laboratory analyses conducted every 3 hours on composite samples during shock cycles 1, 2, and 3 of Period I and cycles 1 and 2 of Period II, respectively. The values, except for pH, given in Table 11 for shock days are averages of all the composite samples analyzed during the shock loading period. The values for pH in Table 11 for shock days represent either the value occurring most frequently during the shock, or in the cases where no particular value occurred more frequently, the median value.

75. Influent total COD loadings for each day are shown in Figure 21. Figure 22 represents both the total and soluble COD concentrations found in the effluent, and Figure 23 shows the results obtained from the daily ESS and EVSS analyses.

Discussion

76. It is obvious from Figure 21 that the total COD of the raw waste varied greatly preceding and throughout Period I. The waste was largely composed of domestic sewage from a residential area in Vicksburg, Mississippi, but also included wastes from a large service station and several small businesses. The contributions from the commercial concerns could account for the varying waste composition. As can be seen from Table 11, high influent COD values were accompanied by high influent suspended and volatile suspended solids concentrations, indicating that the increase in COD was due primarily to an increase in organic suspended solids. In an attempt to control the solids loadings

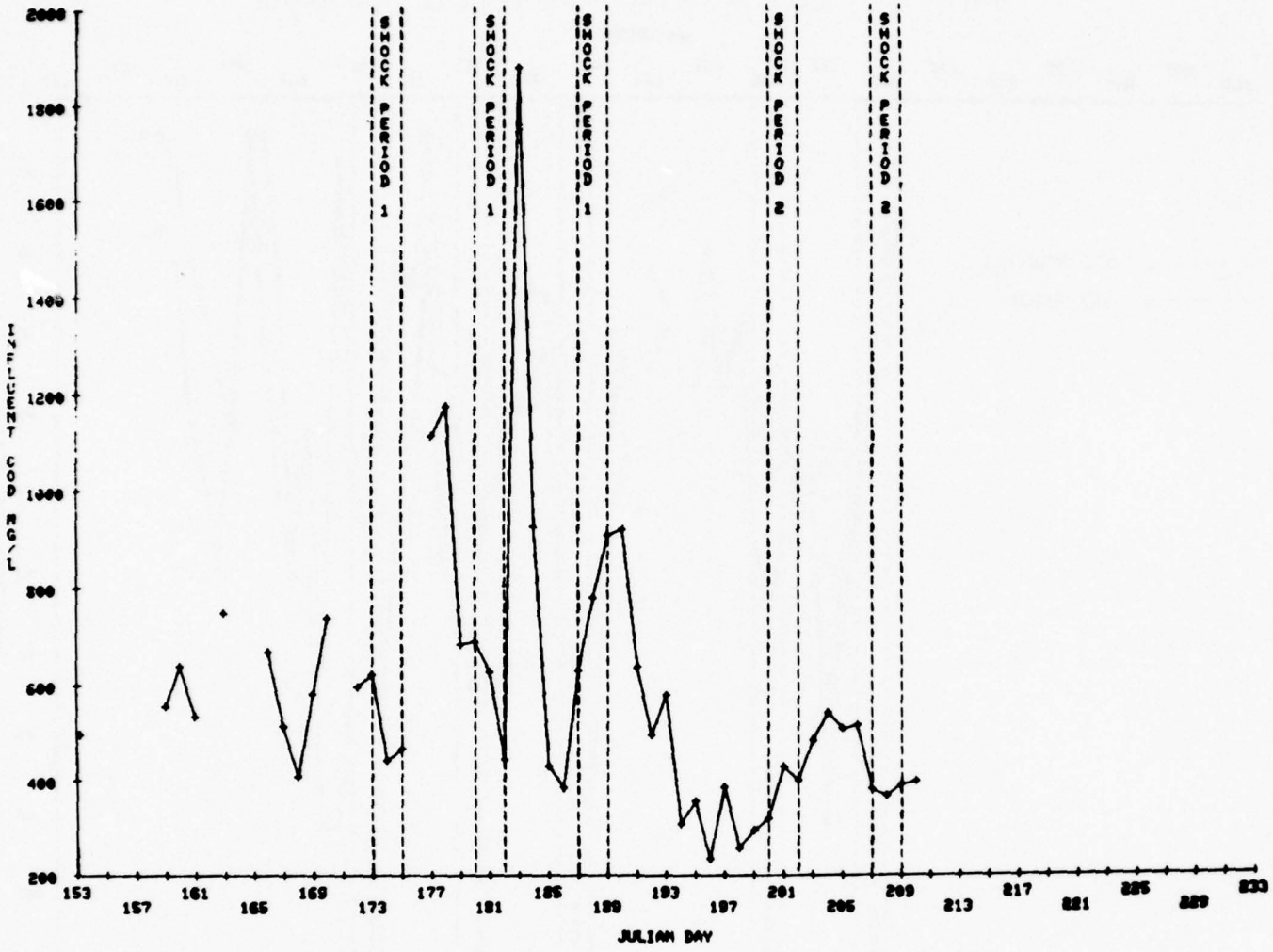


Figure 21. Influent total COD loading to extended aeration plant

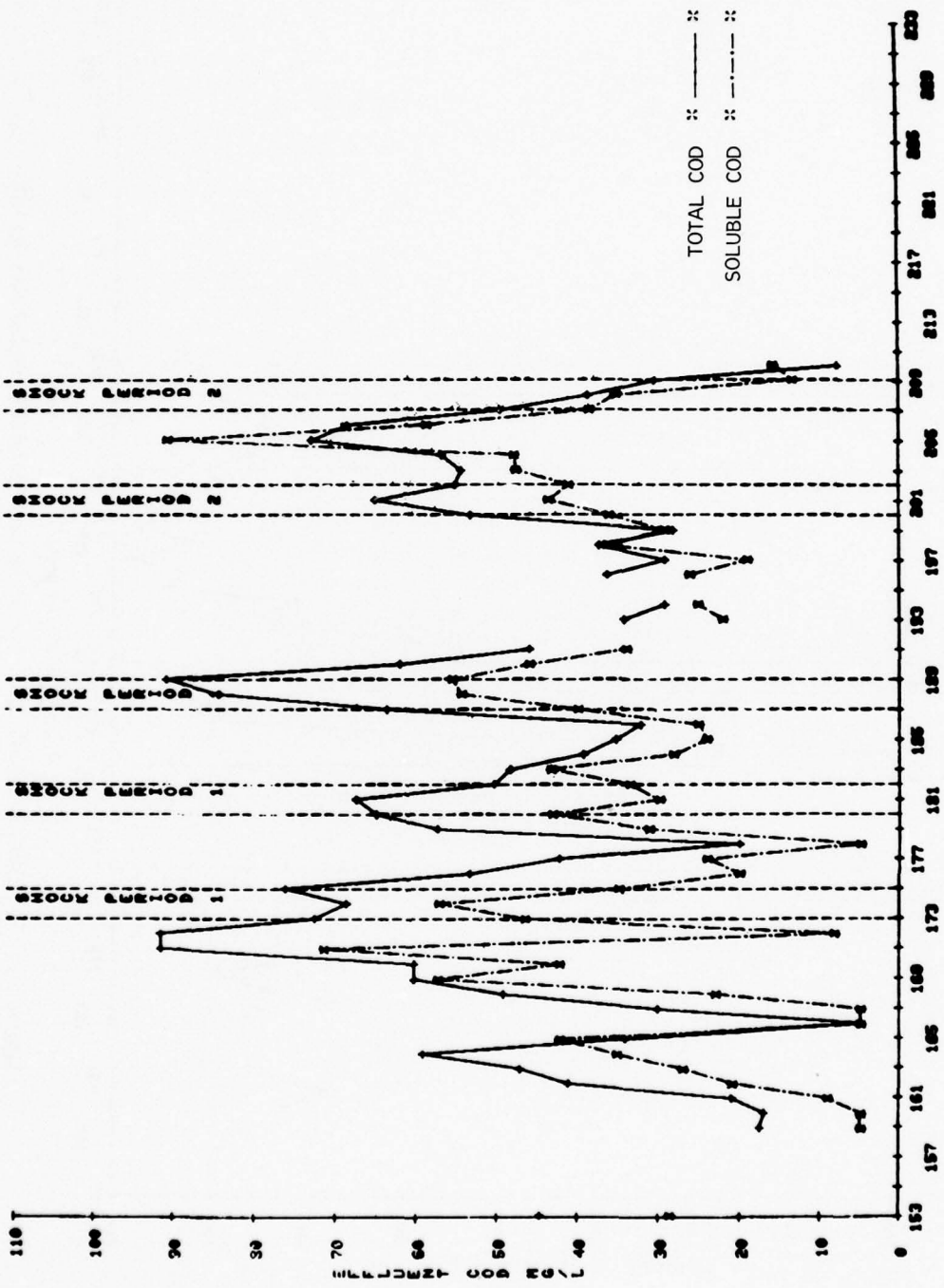


Figure 22. Effluent total and soluble COD versus time

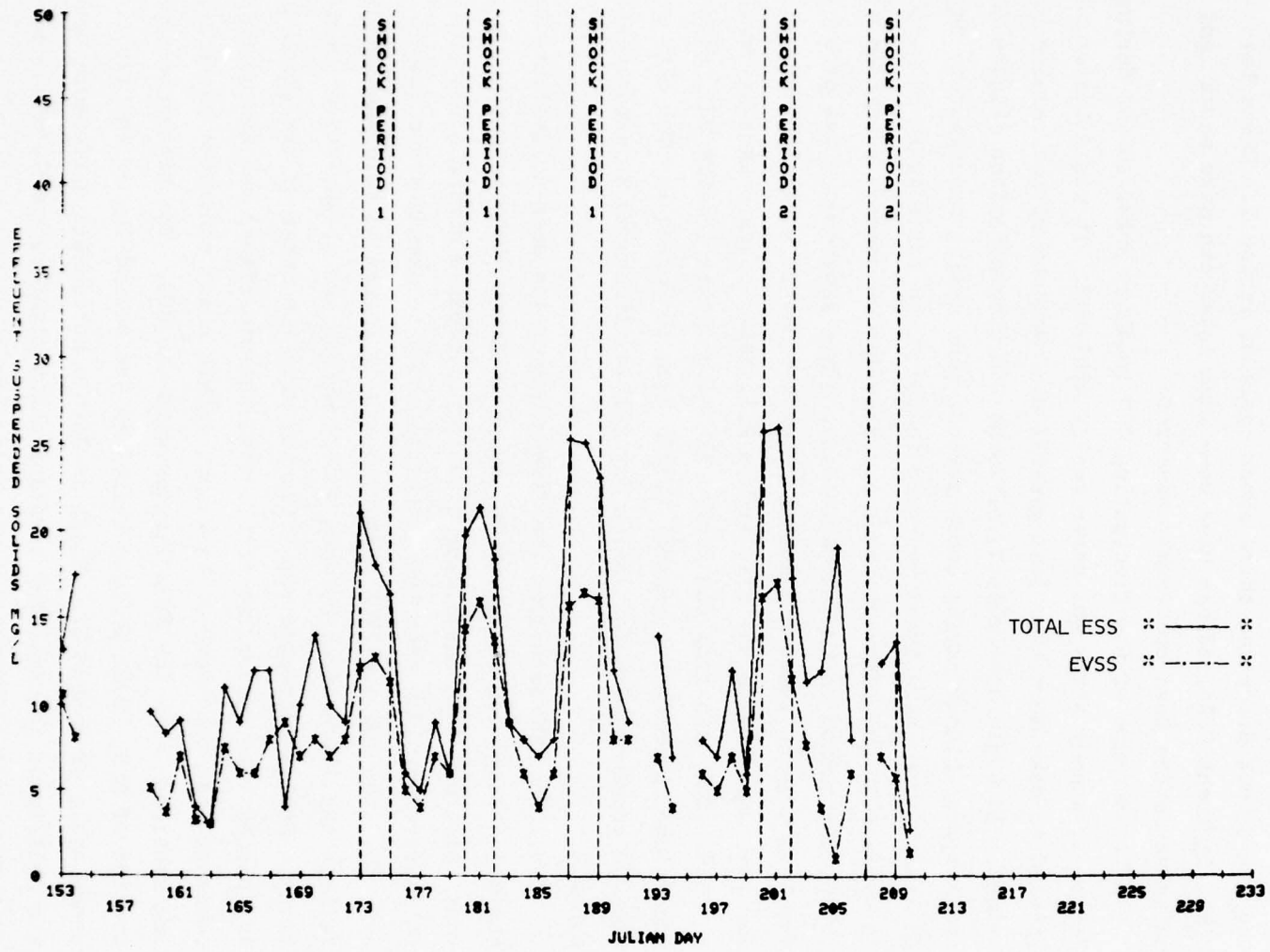


Figure 23. Total ESS and EVSS versus time

and therefore the widely fluctuating COD concentrations, a small screened preliminary sedimentation basin was installed at the head of the surge tank after the third shock cycle of Period I. Since that time, influent COD loadings have been much lower and have shown less daily variation than previously observed.

77. Because of the fluctuating COD loadings prior to and during Period I, steady state was never really achieved. It would therefore be invalid to make more than just general observations of the results obtained. As would be expected, effluent COD concentrations (Figure 22) are somewhat higher during shock periods than during steady-state days. An exception to this trend occurred in the first shock cycle of Period I, in which both the effluent total and soluble COD reached a maximum prior to the initiation of the shock loading. This discrepancy was probably due to a high influent COD loading; but because of a missing data point for that day (Julian day 171, Figure 21), this theory cannot be verified.

78. COD data from the Period II shock cycles (Figure 22), although incomplete, support the general trends seen in Period I. The high soluble COD concentration for Julian day 205 is attributed to experimental error.

79. The COD data from the five shock cycles seem to indicate that the pilot plant can withstand the shock loadings without complete process failure. Although effluent quality decreased during shock periods, it improved rapidly once the system returned to steady-state flow.

80. The ESS and EVSS data as shown in Figure 23 more adequately reflect the differences between shock periods and steady-state conditions. Solids increased significantly with the onset of the shock loading period (i.e. hydraulic overload to the clarifier) and decreased in concentration to steady-state values within a day after the shock loading subsided, with the EVSS varying with the ESS. The highest concentration of ESS, 25.81 mg/ℓ, occurred on the second day of the first shock cycle of Period II. There is little noticeable difference between the ability of the extended aeration pilot plant to handle a 200 percent shock and a 300 percent shock loading.

81. On Julian days 205 and 208 there was an accidental overflow

of the waste sludge holding tank into the aeration basin, which caused a significant increase in MLSS and MLVSS. This is reflected in Tables 11 and 15.

82. Table 11 indicates that there were no significant changes in pH in the effluent, aeration basin, or effluent during shock periods.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

83. A computer model was developed to determine the effects of intermittent loads on an activated sludge system. Because of the basis for the algorithm used for evaluating clarifier performance in the model, the results of the laboratory and pilot studies cannot be used to verify this model on the total system.

84. Results of the laboratory phase of this study indicate that an extended aeration activated sludge system will generally perform satisfactorily under intermittent loading conditions. Intermittent loadings imposed on the system at a high frequency (2 to 3 days) cause the biological system to fail. Repeated loadings at lower frequencies (6 to 7 days) will give satisfactory performance primarily because of the long residence time in the reactor resulting from prolonged rest periods. Traditional failure of the clarifier system due to hydraulic overloads was not observed in the laboratory phase due to extremely low overflow rates for the laboratory clarifier.

85. Biological evaluation of the laboratory systems subjected to intermittent loadings indicated that fluctuations in the animal populations within the reactor were chiefly responsible for the fluctuations in the performance of the system. These fluctuations in animal populations within the reactor were related to the frequency of imposed intermittent loadings.

86. Evaluation of the pilot system demonstrated that intermittent loadings would produce a failure in the solids handling system (clarifier) due to the hydraulic overload. This type of failure was representative of the traditional failures observed for extended aeration in field applications at recreation areas.

Recommendations

87. A pilot scale extended aeration system should be evaluated to establish design relationships for various intermittent loading

conditions, and to determine operational requirements for field application.

88. The differences between the laboratory and pilot plant systems should be minimized in order to make the systems more compatible.

REFERENCES

1. Francingues, N. R., Jr., and Green, A. J., Jr., "Water Usage and Wastewater Characterization at a Corps of Engineers Recreation Area," Miscellaneous Paper No. Y-76-1, Jan 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. McKinney, R. E. and Gram, A., "Protozoa and Activated Sludge," Sewage and Industrial Wastes, Vol 28, 1219, 1956.

3. McKinney, R. E., Microbiology for Sanitary Engineers, McGraw-Hill, New York, 1962.

4. Curds, C. R. and Cockburn, A., "Protozoa in Biological Sewage Treatment Processes-I. A Survey of the Protozoan Fauna of British Percolating Filters and Activated Sludge Plants," Water Research, Vol 4, 225, 1970.

5. Curds, C. R. and Cockburn, A., "Protozoa in Biological Sewage Treatment Processes-II. Protozoa as Indicators in the Activated-Sludge Process," Water Research, Vol 4, 237, 1970.

6. Keyes, T. W. and Asano, T., "Application of Kinetic Models to the Control of Activated Sludge Processes," Journal, Water Pollution Control Federation, Vol 47, 2574, 1975.

7. Liao, C. F. H. and Dawson, R. N., "Microbiology of Two-Stage Kraft Waste Treatment," Journal, Water Pollution Control Federation, Vol 47, 1848, 1975.

8. Sherrard, J. H. and Lawrence, A. W., "Response of Activated Sludge to Step Increase in Loading," Journal, Water Pollution Control Federation, Vol 47, No. 7, Jul 1975, pp 1848-1856.

9. Krishnan, P. and Gaudy, A. F., Jr., "Response of Activated Sludge to Quantitative Shock Loading," Journal, Water Pollution Control Federation, Vol 48, 906, 1976.

10. McCarty, P. L. and Brodergen, C. F., "Theory of Extended Aeration Activated Sludge," Journal, Water Pollution Control Federation, Vol 34, No. 11, Nov 1962, pp 1095-1103.

11. Pfeffer, J. R., "Design Criteria for Extended Aeration," Kansas University Bulletin of Engineering and Architecture, No. 51, 1963, pp 15-22.

12. Eckhoff, D. W. and Jenkins, D., "Activated Sludge Systems: Kinetics of the Transient State," SERL Report No. 67-12, Dec 1967.

13. Adams, C. E., Jr., and Eckenfelder, W. W., "Response of Activated Sludge to Organic Transient Loadings," Journal, Sanitary Engineering Division, American Society of Civil Engineers, SA2, Apr 1970, pp 333-352.

14. O'Brien, Walter J. and Burkhead, Carl E., "Oxygen Consumption in Continuous Biological Culture," Water Pollution Control Series,

No. 17050DJS05/71, May 1971, U. S. Environmental Protection Agency, Raleigh, N. C.

15. Storer, F. F. and Gaudy, A. F., Jr., "Computational Analysis of Transient Response to Quantitative Shock Loadings of Heterogenous Populations in Continuous Culture," Environmental Science and Technology, Vol 3, No. 2, Feb 1969, pp 143-149.

16. George, Thazhethil K., and Gaudy, Anthony F., Jr., "Response of Completely Mixed Systems to Hydraulic Shock Loads," Journal, Environmental Engineering Division, American Society of Civil Engineers, EE5, Oct 1973, pp 593-606.

17. McLelland, J. C. and Busch, A. W., "Hydraulic and Process Aspects of Reactor Design - II - Response to Variations Processes," Proceedings, 24th Purdue Industrial Waste Conference, Purdue University, West Lafayette, Indiana, 1969, pp 493-505.

18. Grady, C. P. L., Jr., "A Theoretical Study of Activated Sludge Transient Response," Proceedings, 26th Industrial Waste Conference, Purdue University, West Lafayette, Indiania, 1971, pp 318-335.

19. Burkhead, C. E. and Wood, D. J., "Analog Simulation of Activated Sludge Systems," Journal, Sanitary Engineering Division, American Society of Civil Engineers, SA3, Jun 1969, pp 593-606.

20. McKinney, R. E., "Mathematics of Complete Mixing Activated Sludge," Journal, Sanitary Engineering Divison, American Society of Civil Engineers, No. 88, SA3, 1962, pp 87-113.

21. Hellier, W. W. Jr., and Cadman, T. W., "Transient Analysis of a State Park Extended Aeration Wastewater," Sep 1973, Water Resources Research Center, University of Maryland, College Park, Md.

22. Agnew, R. W., "A Mathematical Model of a Final Clarifier, " Water Pollution Control Research Services, Project No. 17090 FJW, Feb 1972, U. S. Environmental Protection Agency, Raleigh, N. C.

23. Curds, C. R. and Fry, F. J., "The Effect of Diluted Protozoa on the Fate of Escherichia coli in the Activated Sludge Process," Water Research, Vol 3, 853, 1969.

24. Cooley, W. W. and Lohnes, P. R., Multivariate Data Analysis, Wiley, New York, 1971.

25. American Public Health Association, "Standard Methods for the Examination of Water and Wastewater," 13th ed., 1971, Washington, D. C.

26. American Public Health Association, "Standard Methods for the Examination of Water and Wastewater," 14th ed., 1975, Washington, D. C.

27. Jirka, A. M. and Carter, M. S., "Micro Semi-Automated Analysis of Surface and Wastewater for Oxygen Demand," Analytical Chemistry, Jul 1975, pp 1397-1401.

Table 1

Extended Aeration Design Criteria (from Reference 1)

Aeration Tank	
Detention time, hours	18-36
Sludge age, days	20-30
F/M ratio, lb BOD_5/lb MLVSS/day	0.05-0.15
BOD_5 loading, lb BOD_5/1000 cu ft	10-25
MLSS, mg/ℓ	3000-6000
Sludge return rate, percent of influent flow	50-200
Air required, cfm/lb BOD_5/day	1500-2000
Clarifier	
Overflow rate, gal/day/sq ft	100-300
Detention time, hours	4

Table 2

Laboratory Extended Aeration System Design

Design flow rate, ℓ/day	10
Influent BOD_5, mg/ℓ	180
Aeration tank	
Volume, ℓ	10
Detention time, hours	24
MLSS, mg/ℓ	1000
F/M ratio, mg BOD_5/mg MLSS/day	0.18
Clarifier	
Inside diameter, in.	4
Overflow rate, g/day/sq ft	30
Volume (18-in. depth), mℓ	3050
Detention time (200 percent sludge recycle), hours	3.7

Table 3

Sampling Collection Schedule for Intermittent Loading Study

Sample	Analysis	Time of Day, hours												
		0800	0830	0900	0930	1000	1030	1100	1130	1230	1330	1430	1530	1630
Feed (FI)	TOC/COD		X											
	pH		X											
Mixed liquor (MT)	TSS/VSS		X		X		X		X	X	X	X	X	X
	pH										X			
	Dissolved oxygen uptake										X			
	Micro										X			
Clarifier overflow, unfiltered (COU)	TOC/COD		X	X	X	X	X	X	X	X	X	X	X	X
	TSS/VSS		X		X		X		X	X	X	X	X	X
	pH										X			
Clarifier overflow, filtered (COF)	TOC/COD		X	X	X	X	X	X	X	X	X	X	X	X
Effluent composite low-flow and shock load samples, unfiltered (ECU)	TOC		X											X
	TSS/VSS		X											X
	TOC		X											X
Effluent composite, filtered (ECF)	TOC		X											X

Note: TSS = total suspended solids. VSS = volatile suspended solids.

Table 4

Sampling Schedule Shock Loading Cycle

	Hour	Influent COD	Influent SS & VSS	Influent pH	Influent Temp	Aeration Basin SS & VSS	Aeration Basin pH	Aeration Basin Temp	Effluent COD	Effluent SS & VSS	Effluent pH	Effluent Temp
Shock Loading	0800	X	X	X	X	X	X	X	X	X	X	X
	0900											
	1000											
	1100	X	X	X	X	X	X	X	X	X	X	X
	1200											
	1300											
	1400	X	X	X	X	X	X	X	X	X	X	X
	1500											
	1600											
	1700	X	X	X	X	X	X	X	X	X	X	X
	1800											
	1900											
	2000	X	X	X	X	X	X	X	X	X	X	X
	2100											
	2200											
	2300	X	X	X	X	X	X	X	X	X	X	X
	2400											
Steady State	0100											
	0200	X	X	X	X	X	X	X	X	X	X	X
	0300											
	0400											
	0500	X	X	X	X	X	X	X	X	X	X	X
	0600											
	0700											
	0800	X	X	X	X	X	X	X	X	X	X	X

Note: Steady-state samples were taken at 0800 hours of the influent COD and SS and VSS, the aeration basin SS and VSS, and the effluent COD and SS and VSS. SS = suspended solids; VSS = volatile suspended solids.

Table 5

Laboratory Extended Aeration System: Phase I

Operation Data Summary

Parameter	Period		
	Preshock	Shock	Postshock
Total effluent TOC, mg/ℓ	14	20	23
Soluble effluent TOC, mg/ℓ	8	8	10
ESS, mg/ℓ	24	28	34
EVSS, mg/ℓ	19	27	33
MLSS, mg/ℓ	945	1200	1100
MLVSS, mg/ℓ	870	1040	920
Percent volatile mixed liquor solids	87	87	87

Table 6

Laboratory Extended Aeration System: Phase II

Mean and Standard Deviations of TOC Data

Cycle Time days	Day No.	Unfiltered Effluent TOC, mg/ℓ			Filtered Effluent TOC, mg/ℓ			Total TOC Removed Percent			Soluble TOC Removed Percent		
		Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples
2	352	27	6.1	11	5.6	0.81	11	61	9.6	9	91	1.3	11
	354	33	22	11	9.4	4.9	11	64	23	10	90	5.4	11
	356	27	4.1	10	8.7	3.8	10	66	16	10	87	7.8	10
3	013	25	8.2	12	17	5.2	13	76	7.1	9	84	5.9	9
	016	51	21	11	27	16	12	47	25	9	73	16	10
	019	44	18	11	15	3.1	11	61	16	9	84	3.2	9
4	048	7.2	2.5	12	6.2	2.2	12	90	3.4	12	91	3.1	12
	052	7.7	4.1	12	4.5	1.6	12	92	4.4	12	95	1.6	12
	056	7.7	5.1	12	8.6	3.7	12	91	5.6	12	90	4.1	12
5	160	20	13	13	13	6.6	13	76	16	13	84	7.8	13
	165	14	3.5	12	11	3.6	12	80	5.0	12	84	5.3	12
	170	13	3.1	12	11	6.3	12	84	3.0	9	86	5.5	9
7	086	6.3	3.2	11	3.6	1.4	10	93	3.5	11	96	1.7	10
	093	9.4	11	11	2.9	1.7	12	87	15	11	96	2.1	12
	100	3.4	1.2	12	2.2	2.1	12	95	1.2	12	98	0.67	12
	107	17	27	10	4.8	2.7	10	83	27	10	95	2.7	10
	121	20	5.4	12	8.6	2.4	12	77	6.7	13	90	3.0	12

Table 7

Laboratory Extended Aeration System: Phase II

Mean and Standard Deviations of COD Data

Cycle Time days	Day No.	Unfiltered Effluent COD, mg/ℓ			Filtered Effluent COD, mg/ℓ			Total COD Removed Percent			Soluble COD Removed Percent		
		Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples
5	160	52	17	13	27	14	13	78	8.5	13	89	4.8	13
	165	56	19	11	18	16	12	76	8.1	11	92	7.0	12
	170	44	21	10	16	18	13	82	6.7	7	92	4.6	8
7	100	46	18	12	23	7.5	12	79	8.6	12	89	3.4	12
	107	34	22	10	13	9.5	10	86	9.4	10	94	4.0	10
	121	39	14	12	22	15	12	79	8.1	13	89	8.5	12

Table 8

Laboratory Extended Aeration System: Phase II

Mean and Standard Deviations of ESS, MLSS, and MLVSS Data

Cycle Time Days	Loading Day	ESS, mg/ℓ			MLSS, mg/ℓ			MLVSS, mg/ℓ		
		Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples	Mean	Std Dev	No. Samples
2	1	83.0	0.0	1	704	99.4	3	686	48.5	4
	2	34.0	0.0	1	837	101	5	698	21.1	5
	3				606	223	4	560	178	5
3	1	53.7	29.0	9	744	120	9	688	125	9
	2	85.5	21.9	8	463	50.0	8	475	101	8
	3	158.0	83.8	7	502	53.2	8	396	108	8
4	1	30.0	6.08	5	823	91.6	9	724	82.5	9
	2	42.4	33.7	9	680	79.8	9	589	79.7	9
	3	36.4	18.9	9	662	66.8	8	601	92.7	9
5	1	25.3	10.9	9	892	71.3	10	768	105	10
	2	42.5	6.87	7	776	120	9	662	108	9
	3	36.12	11.7	8	724	58.5	9	649	49.3	9
7	1	61.0	19.3	7	937	85.7	9	847	63.9	8
	2	58.3	15.8	9	538	103	9	474	93.3	9
	3	44.0	6.67	9	703	101	9	631	93.4	9
	4	25.5	3.73	7	613	55.1	7	560	43.7	8
	5	54.6	9.74	10	682	70.2	9	555	42.0	9

Table 9

ANOVA of Total TOC Data

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F Ratio
Cycle (C)	27,269.6152	4	6817.4038	59.59*
Day (D)	665.6394	2	332.8197	2.91
CD	3,357.4667	8	419.6833	3.67*
Time (T)	887.7121	10	88.7712	0.78
CT	6,772.1517	40	169.3038	1.48
DT	1,883.8606	20	94.1930	0.82
Error	9,152.3666	80	114.4046	--

* Significant at 0.05 level.

Table 10

ANOVA of Soluble TOC Data

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F Ratio
Cycle (C)	4830.9338	4	1207.7333	47.49*
Day (D)	49.9758	2	24.9879	0.98
CD	810.6303	8	101.3288	3.98*
Time (T)	53.5273	10	5.3527	0.21
CT	1234.5333	40	30.8633	1.21
DT	576.6909	20	28.8345	1.31
Error	2034.7030	80	25.4338	--

* Significant at 0.05 level.

Table 11

Extended Aeration Pilot Plant Operational Data

		Influent					Aeration Basin			Effluent				
Day	Julian Day	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
6-2-77	153	488	76	745.84	312.25	7.3	1,633.56	583.11	7.2	44	28	12.86	10.29	7.2
6-3-77	154	-	-	-	-	-	2,935.98	1088.39	7.2	-	-	17.41	8.06	7.2
6-4-77	155	-	-	-	-	-	4,600	1645	-	-	-	-	-	-
6-5-77	156	-	-	-	-	-	4,995	1815	-	-	-	-	-	-
6-6-77	157	-	-	-	-	-	5,620	2115	7.2	-	-	-	-	-
6-7-77	158	-	-	-	-	-	6,350	2372	-	-	-	-	-	-
6-8-77	159	556	79.9	604	300	7.4	6,994.59	2437.66	7.3	17.5	<5	9.59	5.12	7.4
6-9-77	160	639	97	230.50	118.4	7.4	6,647.62	2480.95	7.2	17	<5	8.33	3.67	7.4
6-10-77	161	535	89	597.10	315.4	7.3	6,527.32	2480.70	7.2	21	17	9.12	7	7.4
6-11-77	162	2770	152	2696	1368	7.2	4,891	2041	7.2	41	21	4	3.22	-
6-12-77	163	748	148	766	418.66	-	4,586	1830	-	47	27	3	3	7.2
6-13-77	164	3510	234	6204	3028	7.2	3,725	1460	7.1	59	35	11	7.5	7.2
6-14-77	165	6540	128	4453	2300	7.1	7,028	2651	7.2	34	42	9	6	7.3
6-15-77	166	668	61	6020	304	7.2	7,091	2613	7.2	<5	<5	12	6	7.4
6-16-77	167	514	59	411	220	7.1	7,259	2728	7.1	30	<5	12	8	7.2
6-17-77	168	408	77	459	233	-	7,724	2918	-	49	23	4	9	-
6-18-77	169	581	85	1135	409	-	7,353	2800	-	60	57	10	7	-
6-19-77	170	737	133	1002	454	-	7,789	3031	-	60	42	14	8	-
6-20-77	171	-	-	-	-	-	8,471	3357	-	91	71	10	7	-
6-21-77	172	596	96	499	333	-	8,853	3409	-	91	8.3	9	8	-
6-22-77*	173	621.83	108.67	581.17	340.83	7.3	7,539.17	2958.67	7.2	72.71	46.17	21	12.17	7.4
6-23-77*	174	441.88	99.00	307	202.5	7.3	7,243.25	2968.00	7.2	68.25	56.75	18	12.75	7.3
6-24-77*	175	466.67	379.67	349.67	238.0	7.4	8,697.67	3580.39	7.3	75.67	34.67	16.33	11.33	7.4
6-25-77	176	2590	216	1909	1098	7.2	7,995	3234	7.2	53	20	6	5	7.4
6-26-77	177	1110	172	1062	664	7.2	8,762	3652	7.2	42	24	5	4	7.4
6-27-77	178	1170	148	989	622	7.2	9,092	3692	7.2	20	<5	9	7	7.5
6-28-77	179	683	106	707	157	7.4	8,328	3361	7.1	57	31	6	6	7.6
6-29-77*	180	688	207.17	458.33	322.17	7.5	7,164.5	2947.33	7.3	64.50	42.83	19.67	14.33	7.5
6-30-77*	181	626.19	95.63	361.75	263.25	7.5	9,405,88	3926.30	7.2	67	29.75	21.25	15.88	7.5

(Continued)

* Represents an average of composite samples analyzed every 3 hours except for pH, in which case the value presented is either that one occurring most frequently during the loading period or the median value.

Table 11 (Concluded)

		Influent					Aeration Basin			Effluent				
Day	Julian Day	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
7-1-77	182	444	84.67	325.67	239.00	7.3	10,203.33	4367.67	7.1	50	33.33	18.33	13.67	7.2
7-2-77	183	1870	138	958	702	7.2	10,018	4179	7.1	48	43	9	9	7.2
7-33-77	184	922	198	646	518	7.2	9,100	3837	7.2	39	28	8	6	7.3
7-4-77	185	430	100	288	221	-	7,559	3280	-	35	24	7	4	-
7-5-77	186	385	100	276	208	7.4	8,845	3656	7.2	32	25	8	6	7.5
7-6-77*	187	628.33	151.8	409.67	298	7.4	6,847	2955.17	7.2	63.15	39.68	25.17	15.67	7.4
7-7-77*	188	776.88	130.0	523.13	375.63	7.3	4,026	1851	7.2	83.66	53.94	25.00	16.43	7.2
7-8-77*	189	905	102.2	594	389	7.2	5,140	2338.67	7.2	90.03	55.07	23.00	16.00	7.2
7-9-77	190	917	134	598	350	7.3	10,103	4301	7.1	61.5	<15.6	12	8	7.4
7-10-77	191	635	85.5	646	360	7.3	10,762	4687	7.2	45.6	33.7	9	8	7.4
7-11-77	192	496	77	598	335	7.3	9,795	4174	7.0	-	-	-	-	-
7-12-77	193	578	89	520	314	7.2	7,986	3429	7.0	34	22	14	7	7.3
7-13-77	194	308	104	372	149	7.3	7,960	3342	7.1	29	35	7	4	7.4
7-14-77	195	355	104	398	150	7.4	6,595	2756	7.2	-	-	-	-	-
7-15-77	196	234	102	<106	161	7.4	8,852	3689	7.2	36	26	8	6	7.6
7-16-77	197	385	88	494	194	7.4	8,235	3418	7.0	29	19	7	5	7.5
7-17-77	198	256	112	463	198	7.4	7,365	2857	7.1	37	36	12	7	7.5
7-18-77	199	293	113	353	152	7.6	6,564	2646	7.3	28	29	6	5	7.5
7-19-77*	200	319.3	104.66	381	162	7.6	7,049	2935.5	7.4	52.8	35.8	25.66	16.16	7.6
7-20-77*	201	427.73	118.50	443.5	202	7.5	6,911.83	3375.83	7.3	645	43.2	25.87	17	7.5
7-21-77*	202	399.5	123.75	445.13	197.25	7.7	9,231.83	3732.83	7.3	54.71	40.73	17.25	11.50	7.3
7-22-77	203	483.33	162.33	548.33	217.67	7.3	8,857	3555	7.1	53.9	47.2	11.33	7.67	7.5
7-23-77	204	541.5	191	713	177	-	7,088	2593	-	56.3	47.4	12	4	-
7-24-77	205	507.5	186	350		-	13,990	5279	-	72.3	89.7	19	1	-
7-25-77	206	515.5	184	426		-	9,269	3737	-	68	58.2	8	6	-
7-26-77*	207	381.17	132.67	-	-	7.6	-	-	7.3	49.17	38.33	-	-	6.9
7-27-77*	208	366.40	117.88	307.80	120.00	7.7	13,025.20	5348.2	7.3	38.38	34.09	12.40	7	7.5
7-28-77	209	390.4	107.28	382.86	146.13	7.7	9,800	3907.5	7.3	30.27	13.42	13.63	5.75	7.5
7-29-77	210	397	115.33	394.67	141.33	7.7	9,415	3685	7.3	7.73	15.80	2.67	1.33	7.6

Table 12

Results of Laboratory Analyses, Period I, Shock Cycle 1

			Influent					Aeration Basin			Effluent				
Day	Julian Day	Hour	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
6-22-77	173	0800	664	48	708	379	7.3	7,441	2845	7.2	85	44	10	6	7.3
		1100	753	165	687	391	7.3	7,713	2978	7.2	79	13	26	13	7.3
		1400	503	79	502	281	7.4	7,800	3045	7.2	75	52	24	14	7.4
		1700	514	130	589	360	7.5	7,582	2982	7.3	84	76	26	16	7.4
		2000	633	115	464	301	7.4	7,315	2950	7.3	57	57	19	12	7.5
		2300	664	115	537	333	7.3	7,384	2951	7.2	53	35	21	12	7.4
		Avg	621.83	108.67	581.17	340.83	—	7,539.17	2958.67	—	72.17	46.17	21	12.17	—
6-23-77	174	0200	500	70	444	292	7.3	7,690	3081	7.2	92	45	23	14	7.4
		0500	491	107	354	226	7.4	7,546	3025	7.3	56	45	16	8	7.4
		0800	396	61	337	214	7.2	7,262	2930	7.2	37	9	12	6	7.3
		1100	437	106	330	210	7.5	7,555	3110	7.4	62	60	24	14	7.4
		1400	397	127	328	208	7.3	7,452	3076	7.2	81	75	19	14	7.3
		1700	445	108	234	162	7.3	6,751	2784	7.2	90	85	14	21	7.3
		2000	447	129	277	188	7.3	6,624	2764	7.2	81	73	18	13	7.3
		2300	422	84	142	120	7.3	7,066	2965	7.2	47	42	18	12	7.3
		Avg	441.88	99	307	202.5	—	7,243.25	2968	—	68.25	56.75	18	12.75	—
6-24-77	175	0200	381	73	260	188	7.4	7,184	2957	7.2	81	55	20	14	7.3
		0500	398	110	255	190	7.5	11,029	4514	7.3	74	>5	15	10	7.4
		0800	621	56	534	336	7.4	7,880	3270	7.3	72	44	14	10	7.4
		Avg	466.67	379.67	349.67	238.00	—	8,697.67	3580.39	—	75.67	34.67	16.33	11.33	—

Table 13

Results of Laboratory Analyses, Period I, Shock Cycle 2

			Influent					Aeration Basin			Effluent				
Day	Julian Day	Hour	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
6-29-77	180	0800	542	217	612	387	7.3	7,668	3041	7.2	34	19	6	5	7.5
		1100	756	358	543	357	7.3	7,788	3151	7.2	56	26	19	12	7.5
		1400	676	134	533	343	7.6	7,327	2960	7.3	46	35	23	16	7.5
		1700	567	93	486	320	7.5	7,283	3019	7.3	53	46	24	17	7.4
		2000	819	279	329	274	7.5	6,647	2868	7.3	125	77	22	18	7.5
		2300	768	162	346	252	7.5	6,270	2665	7.3	73	54	24	18	7.4
		Avg	688	207.17	485.33	322.17		7,164.5	2947.33		64.50	42.83	19.67	14.33	
	181	0200	800	108	314	222	7.4	5,978	2548	7.2	102	8	24	17	7.3
		0500	929	100	340	259	7.4	9,503	3954	7.2	78	66	27	21	7.3
		0800	946	132	428	310	7.3	10,757	4503	7.2	81	53	20	17	7.2
		1100	799	76	557	389	7.5	9,772	3960	7.3	37	14	21	14	7.5
		1400	372	82	348	245	7.4	9,549	3951	7.2	14	>5	22	16	7.4
		1700	431	80	319	221	7.5	10,074	4217	7.3	53	>5	18	13	7.4
		2000	404	104	282	238	7.5	9,661	4103	7.2	101	53	21	16	7.5
		2300	328	83	306	220	7.5	9,953	4174	7.3	70	34	17	13	7.5
		Avg	626.19	95.63	361.75	263.25		9,405.88	3926.3		67	29.75	21.75	15.88	
7-1-77	182	0200	424	81	302	216	7.3	10,155	4368	7.2	34	22	19	15	7.2
		0500	426	110	329	246	7.3	9,998	4275	7.1	78	68	17	13	7.2
		0800	482	63	346	255	7.4	10,457	4462	7.1	38	10	19	13	7.3
		Avg	444	84.67	325.67	239		10,203.33	4367.67		50	33.33	18.33	13.67	

Table 14

Results of Laboratory Analyses, Period I, Shock Cycle 3

			Influent					Aeration Basin			Effluent				
Day	Julian Day	Hour	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
7-6-77	187	0800	619	86.8	216	184	7.2	6577	2970	6.8	25.3	22.3	12	10	7.2
		1100	504	103	460	329	7.1	7450	3114	7.0	48.8	31.9	36	21	7.3
		1400	696	243	470	348	7.4	6762	2867	6.9	71.4	45.7	31	16	7.1
		1700	646	175	399	263	7.6	6883	2923	7.3	67.6	22.6	21	13	7.5
		2000	642	146	419	302	7.5	6627	2884	7.2	871	55.7	30	19	7.4
		2300	663	157	494	362	7.4	6783	2973	7.2	78.7	59.9	21	15	7.4
		Avg	628.33	151.8	409.67	298		6847	2955.17		63.15	39.68	25.17	15.67	
7-7-77	188	0200	726	165	446	326	7.3	6822	3025	7.2	97.5	59.5	22	15	7.2
		0500	710	125	435	315	7.3	6934	3001	7.1	56.1	9.98	23	15	7.1
		0800	861	131	466	339	7.2	--	--	7.0	84.8	58	--	--	7.2
		1100	774	139	476	361	7.2	5860	2644	7.0	77.4	58.7	23	16	7.2
		1400	909	132	491	354	7.4	6310	2806	7.2	97.2	64.3	38	24	7.4
		1700	718	114	632	460	7.4	5327	2472	7.1	85.3	65.5	25	15	7.3
		2000	734	113	760	535	7.3	5424	2476	7.2	85.5	53.8	22	15	7.2
		2300	783	121	479	315	7.2	4026	1851	7.1	85.5	61.7	22	15	7.2
		Avg	776.88	130	523.13	375.63		5814.7	2610.7		83.66	53.94	25	16.43	
7-8-77	189	0200	--	--	--	--		4609	2116	7.2	89.5	55.8	24	17	7.2
		0500	1060	109	684	476	7.2	4506	2098	7.1	89.5	53.8	21	14	6.9
		0800	750	95.4	504	302	7.4	6306	2802	7.2	91.1	55.6	24	17	7.4
		Avg	905	102.2	594	389		5104.3	2338.67		90.03	55.07	23	16	

Table 15

Results of Laboratory Analyses, Period II, Shock Cycle 1

		Influent						Aeration Basin			Effluent				
Day	Julian Day	Hour	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
7-19-77	200	0800	396	93	420	161	7.7	6220	2589	7.4	43	34	11	9	7.4
		1100	365	72	368	146	7.6	7188	3023	7.3	40	28	25	15	7.4
		1400	330	97	412	148	8.0	6908	2852	7.4	65	30	36	21	7.6
		1700	239	163	261	127	8.0	7385	3044	7.4	51	35	31	19	7.7
		2000	256	114	451	209	7.8	7191	2981	7.3	56	49	26	16	7.7
		2300	330	89	374	181	7.6	7402	3124	7.4	62	39	25	17	7.6
		Avg	319.3	104.66	381	162		7049	2935.50		52.80	35.80	25.66	16.16	
7-20-77	201	0200	373	143	392	186	7.5	-	-	-	74	39	23	18	7.2
		0500	351	101	268	118	7.3	-	-	-	54	43	19	14	7.5
		0800	431	104	545	255	7.6	7327	3041	7.3	54	36	15	11	7.5
		1100	308	117	316	126	7.7	7767	3202	7.4	67	35	28	18	7.5
		1400	372	120	449	204	7.8	6777	2823	7.3	50	41	32	18	7.6
		1700	445	118	444	183	7.5	7043	2927	7.4	68	52	29	19	7.4
		2000	503	122	520	257	7.6	6463	2733	7.3	71	51	27	17	7.4
		2300	639	123	614	287	7.5	6094	2529	7.3	78	49	34	21	7.3
		Avg	427.75	118.5	443.5	202		6911.83	3375.83		64.50	35.80	25.87	17	
7-21-77	202	0200	326	116	476	228	-	-	-	-	85	64	26	19	-
		0500	333	101	333	168	-	-	-	-	79	41	29	20	-
		0800	439	112	496	219	7.4	9400	3830	7.3	76	55	17	12	7.4
		1100	409	116	430	177	7.6	9742	3886	7.2	54.9	45	18	10	7.5
		1400	384	212	540	245	7.7	9561	3884	7.3	35.6	27.6	16	9	7.5
		1700	422	120	359	160	7.7	9131	3682	7.4	39	27.6	13	6	7.3
		2000	487	102	447	181	7.7	8756	3556	7.2	33.65	32.7	9	8	7.3
		2300	396	111	480	200	7.4	8801	3559	7.3	34.5	32.9	10	8	7.3
		Avg	399.5	123.75	445.13	197.25		9231.83	3732.83		54.71	40.73	17.25	11.50	
7-22-77	203	0200	443	127	563	217	-	-	-	-	36	24.6	12	8	-
		0500	433.5	116	502	197	-	-	-	-	59.5	53.4	10	7	-
		0800	573.5	244	580	239	7.3	8857	3555	7.1	53.9	47.2	12	8	7.5
		Avg	483.33	162.33	548.33	217.67		8857	3555		49.8	41.73	11.33	7.67	

Table 16

Results of Laboratory Analyses, Period II, Shock Cycle 2

			Influent					Aeration Basin			Effluent				
Day	Julian Day	Hour	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH	SS mg/ℓ	VSS mg/ℓ	pH	Total COD mg/ℓ	Soluble COD mg/ℓ	SS mg/ℓ	VSS mg/ℓ	pH
7-21-77	207	0800	459	153	-	-	7.4	-	-	7.0	51	32	-	-	6.9
		1100	365	120	-	-	7.2	-	-	7.1	35	26	-	-	6.8
		1400	377	133	-	-	7.6	-	-	7.4	44	34	-	-	6.8
		1700	347	117	-	-	7.8	-	-	7.3	58	44	-	-	6.9
		2000	395	137	-	-	7.6	-	-	7.3	55	44	-	-	7.0
		2300	344	136			7.4	-	-	7.3	52	50	-	-	6.9
		Avg	381.17	132.67				-	-		49.17	38.33	-	-	
7-27-77	208	0200	478	120	-	-	-	-	-	-	60	38	-	-	-
		0500	376	109	-	-	-	-	-	-	52	45	-	-	-
		0800	408	106	-	-	7.7	-	-	7.3	43	44	-	-	7.5
		1100	221	108	214	84	7.8	13,413	5205	7.3	33	25.4	8	5	7.5
		1400	372	120	407	140	7.6	13,932	5897	7.3	32.7	23.7	4	1	7.5
		1700	337	126	262	107	7.7	12,970	5567	7.3	34	37.9	9	5	7.5
		2000	387	102	353	126	7.8	13,092	5391	7.3	37.7	21.6	18	16	7.5
		2300	352.5	152	303	143	7.3	11,719	4681	7.1	14.6	37.1	23	8	7.2
		Avg	366.4	117.88	307	120		13,025.20	5348.2		38.38	34.09	12.40	7.00	
7-28-77	209	0200	480	86.4	499	296	-	-	-	-	71.5	11.7	20	4	-
		0500	314.5	98	211	167	-	-	-	-	28.2	12.2	15	5	-
		0800	468	114	458	236	7.6	10,395	4165	7.2	49.9	22	26	16	7.4
		1100	417	97	432	118	7.6	10,415	4190	7.2	33.1	26.5	22	6	7.5
		1400	396	142	452	152	7.7	9,890	3905	7.3	32	0.949	15	10	7.5
		1700	-	-	-	-	-	10,700	4325	7.1	8.55	18	5	2	7.5
		2000	348	123	320	148	7.8	9,155	3560	7.3	16.1	14.2	4	2	7.5
		2300	309.5	90.6	308	112	7.8	8,250	3300	7.3	2.85	1.89	2	1	7.4
		Avg	390.4	107.28	382.86	146.13		9,800	3907.5		30.27	13.42	13.63	5.75	
7-29-77	210	0200	427.5	95	530	192	-	-	-	-	5.2	14.6	2	1	-
		0500	352.5	132	318	108	-	-	-	-	15.2	5.8	3	2	-
		0800	411	119	336	124	7.7	9,415	3685	7.3	2.8	27	3	1	7.6
		Avg	397	115.33	394.67	141.33		9,415	3685		7.73	15.8	2.67	1.33	

APPENDIX A: ASMODEL DESCRIPTION

Model Tasks

1. The basic tasks performed by the model are described as follows. A program listing is presented in Table A1.

Task 1. INITIALIZE PROGRAM

- a. Read input data
- b. Initialize all constants

Task 2. EVALUATE AERATION TANK PERFORMANCE

- a. Determine hydraulic detention time
- b. Calculate food (BOD) distribution (including recycle if any)
- c. Determine food (BOD) removal
- d. Perform all mass calculations (including recycle, if any)
- e. Assign values to output variables

Task 3. EVALUATE CLARIFIER PERFORMANCE

- a. Determine hydraulic detention time
- b. Calculate performance
- c. Calculate recycle conditions

Task 4. PROGRAM EXECUTION

- a. Iterate Tasks 2 and 3 for specified number of intervals
- b. Output ASMODEL results

Program Input and Execution (Task 1)

2. The first group of variables requested are IP, N, IHR, FLIM, and LIMMA. These variables are defined as follows:

IP = print control variable. Upon output, ASMODEL will print the results of every IP^{th} detention period cycle; thus, IP = 1 will print the results of every cycle.

N = number of loading cycles to be imposed on the system. This term refers to the number of different hydraulic and BOD loading cycles to be processed by ASMODEL. N must be the same for both the BOD and flow parameters.

IHR = number of hours specified by one loading cycle for BOD or flow. The combination of N and IHR will produce N × IHR hourly loading cycles to ASMODEL. (Note: N and IHR must be integers and > 0).

FLIM = limiting food condition for endogenous respiration or system failure, mg/ℓ. This value must be specified (it may be zero), and the user should note that food distribution (see Task 2d) will affect the decision made by querying FLIM.

LIMMA = limiting active mass concentration in mg/ℓ in aeration tank for system failure.

3. The next variable set required is the BOD loading cycles. N are required. Input is in mg/ℓ and must be positive.

4. The next variable set is the flow loading cycles. N are required. Input is in million gallons (MG) and must be positive. The user must specify sufficient flow data in the N cycles so that the N × IHR hourly flows will require one aeration tank detention time to process. Failure to meet this condition will result in unsatisfactory ASMODEL performance. Another requirement is that N × IHR must be less than 200 under present program constraints. ASMODEL will convert flow and BOD loading data into hourly form based on the values specified by N and IHR. At present limits, the hydraulic detention time must be less than 40 hours.

5. The next variable set includes IMAX, AVOL, CVOL, CSA, FI(1), MAI(1), MASS, KM, KE, KS, WMASS, and MLVSS. These variables are defined as follows:

IMAX = maximum number of loading cycle iterations to be performed by ASMODEL. Numerically it is equal to

$$IMAX = \sum_{i=1}^{N \times IHR} Q_i$$

AVOL = Aeration tank volume, MG

CVOL = clarifier volume, MG

CSA = clarifier surface area, sq ft

FI(1) = initial BOD concentration in the aeration tank, mg/ℓ

MAI(1) = initial active mass concentration in the aeration tank, mg/ℓ

MASS = initial mass (MLSS) concentration in the aeration tank, mg/ℓ

KM = metabolism constant, hr^{-1}

KE = endogenous respiration constant, hr^{-1}

KS = synthesis constant, hr^{-1}

WMASS = maximum concentration of mass (MLSS) in the aeration tank before wasting is required, mg/ℓ

MLVSS = initial volatile suspended solids concentration in the aeration tank, mg/ℓ

ASMODEL does not allow a zero start (i.e. FI(1), MAI(1), or MASS = 0). If a zero start is requested, program output may not be reliable.

6. Upon receipt of all required input data, ASMODEL will execute print requested, output data, and ask the user if he wishes additional iterations on the same data base. If the response is positive (integer > 0), the program will continue and query for additional iterations upon completion of output. If the response is zero (0), the program will terminate and query the user if he wishes to start ASMODEL on another data base. A response of one (1) will reinitialize ASMODEL and request all input data. Any other response will terminate the program.

7. The performance and utility of ASMODEL is directly dependent on the validity of user input data. Illogical output will be produced if improper data are input. The sensitivity of ASMODEL has not been determined.

Program Operation

Task 2a

8. The purpose of this section of the program, Task 2a, is to determine the hydraulic detention time of the aeration tank. Detention time is calculated using the following formula:

$$DT = R + (K-J) + \frac{\sum_{i=1}^{k+1} Q_i - AVOL}{Q_{k+1}} \qquad (1)$$

where

DT = hydraulic detention time (hour)

R = residual time from last cycle

K = Q index

J = Q index

Q = sum of influent and recycle flows

K and J are determined by iteration such that the following conditions are met:

$$\sum_{J}^{k+1} Q_i > AVOL \tag{2}$$

Then one of the two following options is exercised:

a. If K > J, calculate DT

b. If K > J, then K - J = N - J + K (N defined previously) and calculate DT.

Task 2b

9. Before the performance of the aeration tank is calculated, the BOD loading received over one detention period must be distributed with respect to time. The philosophy is that for a completely mixed system, retention of food within the system is a function of the system flow regime. A distribution matrix is calculated for each hourly loading and assumes an upper triangular form for input to the performance calculations.

10. The distribution function used by ASMODEL is:

$$C = C_o e^{-t/DT} \tag{3}$$

where

C = concentration in reactor effluent

C_o = initial influent concentration

t = cumulative resident time

It is further assumed that all food is removed (hydraulically) from the system in two detention periods; thus, the distribution function

(D = distribution coefficient) becomes:

$$D = \frac{C}{C_o} = e^{-t/DT} \tag{4}$$

The distribution function is combined with the hydraulic loading in the loading matrix as

$$L_{i,j} = BOD_i \cdot Q_i \cdot D_j/AVOL + BOD_r \tag{5}$$

where

$L_{i,j}$ = BOD concentration in the reactor for the i^{th} period and j^{th} distribution

BOD_i = influent BOD concentration for the i^{th} period

Q_i = flow for the i^{th} period

D_j = j^{th} distribution coefficient

BOD_r = initial or recycle BOD concentration

Task 2c

11. The equation for BOD removal is given by McKinney and Gram[2] as

$$F = \frac{F_i}{KMt + 1} \tag{6}$$

where

F = remaining food concentration

F_i = influent food

t = detention time

For use in ASMODEL, Equation 6 has been modified to accept the loading matrix defined in the previous task. In this case t becomes the effective detention time within the aeration tank and the remaining food is calculated by the following equation:

$$F = \sum_{i=1}^{DT} \sum_{j=1}^{DT-i+1} \frac{L_{i,j}}{KMt + 1} \tag{7}$$

where t = DT - i - j + 2. The amount of food removed is calculated by difference and used later for determining oxygen requirements. The residual food is added to the next aeration tank cycle.

Task 2d

12. After the residual food concentration has been determined, the next step by McKinney's scheme[2] is to calculate the mass relationships for the aeration tank. The approach used is similar to McKinney's but does not include a term for inert organic mass. The program section for this task is composed of the following sections:

a. Calculation of mass relationships

b. Correction for endogenous respiration

c. Correction for recycled mass

These operations are integrated to impart continuity to the mass terms within the program.

13. The mass terms are calculated in a similar format as residual food in that all terms are partitioned into matrix form; thus the following equations:

$$MA_{i,j} = \sum_{i=1}^{DT} \sum_{j=1}^{DT-i+1} \frac{F_{i,j}}{1/t + KE} \tag{8}$$

where

MA = active mass matrix

F = residual food matrix

t = "effective" detention time = DT - i - j + 2

Similarly, for the other mass quantities

$$ME_{i,j} = \sum_{i=1}^{DT} \sum_{j=1}^{DT-i+1} 0.23 \cdot KE \cdot MA_{i,j} \cdot t \tag{9}$$

where ME = endogenous mass matrix and

$$MI_{i,j} = \sum_{i=1}^{DT} \sum_{i=1}^{DT-i+1} 0.10 \, (MA_{i,j} + ME_{i,j}) \tag{10}$$

where MI = inert mass matrix and the total mass =

$$\sum_{i=1}^{DT} \sum_{j=1}^{DT-i+1} MA_{i,j} + ME_{i,j} + MI_{i,j} \tag{11}$$

14. Correction for endogenous respiration is performed either within a loading period (hourly) or for an entire detention period according to the following decision matrix:

$F_{i,j}$ < FLIM	F < FLIM: yes	F < FLIM: no
yes	END1	END2
no	END1	no action

where

F = sum of remaining food (see Equation 7)

$F_{i,1}$ = remaining food for the i^{th} period

FLIM is a user-assigned variable, and condition END1 dominates in all cases. If any conditions are met, the following calculations are performed to correct for endogenous respiration within the system.

$$ME = ME - 0.23 \cdot KE \cdot MA \cdot t \tag{12}$$

$$MASS = Mass - 0.77 \cdot KE \cdot MA \cdot t \tag{13}$$

$$MA = MA - KE \cdot MA \cdot t \tag{14}$$

where

$$t = \begin{cases} 1, & \text{for END2} \\ DT, & \text{for END1} \end{cases}$$

15. Correction for recycled mass is a procedure for accounting for mass residence within the system (sludge age). The controlling variable is WMASS, the limiting mass accumulation in the aeration tank prior to wasting. If the total mass exceeds WMASS, wasting is performed and the mass constituents are reduced proportionally to their current values

within the system. This condition is checked for every iteration and assures equilibrium under steady-state operation.

Task 3a

16. Task 3 of the program evaluates the performance of the clarifier and establishes recycle conditions for the system. The first step within this section of the program is to establish the clarifier detention time (Task 3a). Since the clarifier volume is assumed to be smaller than that of the aeration tank, its hydraulic detention time is smaller. Thus, for any given aeration tank cycle, multiple clarifier cycles will be produced. Furthermore, since the flow is offset by the detention period of the aeration tank, the clarifier performance must be evaluated in terms of $Q(t + DT)$. ASMODEL produces output in terms of aeration tank cycles; therefore, multiple cycles of clarifier output are required. ASMODEL evaluates clarifier performance for sufficient cycles to equal the aeration tank detention time, and produces as output the average clarifier performance.

17. Determination of clarifier hydraulic detention time follows a similar procedure to that outlined in Task 2a. The flow is offset by the hydraulic detention time of the aeration tank.

Task 3b

18. Evaluation of the clarifier performance is made by use of the equations developed by Agnew.[22] These equations are based on analysis of operational clarifiers and involve the use of the following equations:

$$OFR = \frac{CVOL \cdot 24 \cdot 10^6}{CSA \cdot CLDT} \tag{15}$$

where

OFR = clarifier overflow rate

CLDT = clarifier detention time

and

$$SVI = 540 \cdot A^{4.397} \cdot B^{0.213} \tag{16}$$

where

SVI = sludge volume index

A = percent volatile solid

B = F/M ratio

and

$$M_r = \frac{10^6}{SVI} \tag{17}$$

where M_r is the maximum return sludge concentration

and

$$ESS = \frac{382 \cdot OFR^{0.12} \cdot B^{0.27}}{MLSS^{0.35} \cdot CLDT^{0.03}} \tag{18}$$

where

ESS = effluent suspended solids

MLSS = mixed liquor suspended solids

and

$$P = \frac{SVI \cdot MLSS}{10^6} \tag{19}$$

where P is the percent recycle flow

and

$$SA = \frac{MLSS \cdot DT}{ESS \cdot 24} \tag{20}$$

where SA is the sludge age (clays). Additionally, a mass balance is made around the clarifier to check the accuracy of the above calculation for each clarifier cycle.

Task 3c

19. The recycle parameters are calculated for each clarifier cycle and stored in arrays for use in the next aeration tank cycle. These calculations are made for food, active mass, total mass, inert mass, and flow, and in general, assume the following form:

$$R = X \cdot P \cdot Q\ (t_i + DT) \tag{21}$$

where

R = concentration of recycled parameters

X = concentration of parameter X in aeration tank effluent

P = percent recycle

$Q(t_i + DT)$ = offset flow for the i^{th} period in the clarifier cycle

As mentioned previously, all terms are saved for the next iteration of the ASMODEL.

Task 4a

20. This program section allows for iteration of ASMODEL for a user-specified number of loading cycles. During iteration all program parameters are saved for subsequent cycles, and provisions are made for continuity of the model.

Task 4b

21. Task 4b is the program logic that outputs the results of ASMODEL. All output parameters (Table A2) are saved for each model cycle and printed under user control at the end of ASMODEL iteration.

Table A1

Program Listing

```
                    08/17/77          FILE = NLB              11:19      PAGE  1

0010       DIMENSION IFLAG(2),Q(200),QHR(200),FPER(100),FOOD(40,80)
0020       DIMENSION F(40,30),OUT(100,14),CSUM(6)
0030      DIMENSION FI(50),SUM2I(50),RCF(100)
0040       REAL MAI(50),MASI(50),LIMMA
0050     REAL LOAD(500),LOADHR(500),MA(40,30),ME(40,30)
0060     REAL MASS,IFX,KM,KS,KE,MLVSS,MI(40,30)
0066   2000 WRITE (6,1007)
0067C                        READ INPUT DATA
0068C
0069       WRITE (6,1001)
0070        READ, IP,N,IHR,FLIM,LIMMA
0079       WRITE (6,1002)
0080       READ,  (LOAD(I),I=1,N)
0089       WRITE ( 6,1003)
0090      READ, (Q(I),I=1,N)
0091        SUM1 = 0.0
0092        SUM2 = 0.0
0093        DO 5 I = 1,50
0094        FI(I) = 0.0
0095       SUM2I(I) = 0.0
0096       MAI(I) = 0.0
0097   5   MASI(I) = 0.0
0099       WRITE (6,1004)
0100   20 READ, IMAX,AVOL,CVOL,CSA,FI(1),MAI(1),MASS,KM,KE,KS,WMASS,MLVSS
0109       WRITE (6,1005)
0110       XKE = KE
0111C                       INITIALIZE PROGRAM CONSTANTS
0112C
0120      SALAS = 30.0
0121      ILAS = 1
0122       SUM2I(1) = MASS - MLVSS
0124        DO 2001 I = 1,100
0125  2001  RCF(I) = 0.0
0130       DO 21 I = 1,2
0140   21  IFLAG(I) = 0
0150       IF ( IHR .LE. 1 ) GO TO 101
0160        K = 0
0170       DO 100 I = 1,N
0180       DO 100 J = 1, IHR
0190       K = K + 1
0200     LOADHR(K) = LOAD(I)
0210   100  QHR(K) = Q(I)
0220       N = K
0230       GO TO 102
0240   101  DO 103 I = 1,N
0250     LOADHR(I) = LOAD(I)
0260   103  QHR(I) = Q(I)
0270   102  IEND = 0
0280       DT = 0.0
0281       IFLAGM = 0
```

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Table A1 (Continued)

```
                    08/17/77          FILE = NLB              11:19      PAGE  2

0282          ICNT = 0
0290         RLOAD = 0.0
0300         I1 = 0
0310         RESVOL = 0.0
0320  250    IF ( ICNT .GT. IMAX) GO TO 810
0321C                       DETERMINE AERATION TANK DETENTION TIME
0322C
0330       IJ = IEND
0340         I1 = I1 + 1
0350         TOTQ = RESVOL
0360         IC = IEND
0370         ISTART = IC
0380          GO TO 113
0390  111    TOTQ = TOTQ + QHR(IC) + RCF(IJ)
0400  113    IF ( TOTQ .GT. AVOL) GO TO 110
0410          IC = IC + 1
0420          IJ = IJ + 1
0421       IF ( IJ .GT. 100) IJ = 1
0430          IF ( IC .GT. N) GO TO 901
0440          GO TO 111
0450  901     ICNT = ICNT + 1
0460          IC = 1
0470          GO TO 111
0480  110    IEND = IC
0510          IF ( IC .LE. ISTART) GO TO 112
0520          LIM = IC - 1 - ISTART
0530       DT = DT+LIM+(AVOL-(TOTQ-QHR(IC)-RCF(IJ)))/
0540&      (QHR(IC) + RCF(IJ))
0550          GO TO 115
0560  112     LIM = N - ISTART + IC - 1
0570       DT = DT+LIM+(AVOL-(TOTQ-QHR(IC)-RCF(IJ)))/
0580&      (QHR(IC) + RCF(IJ))
0590  115    RESVOL = TOTQ - AVOL
0591C                       CALCULATE FOOD DISTRIBUTION
0592C
0594         LIM = DT
0600           XK = 1.0/DT
0610         ISTOP = 2*LIM
0620         USUM = 0.0
0630         DO 120 J = 1,ISTOP
0640         FPER(J) = EXP(-J*XK)
0650     120  USUM = USUM + FPER(J)
0660         DO 121 J = 1,ISTOP
0670  121    FPER(J) = FPER(J)/USUM
0680         ALOAD = 0.0
0690         IC = ISTART + 1
0700         DO 130 K = 1,LIM
0710         DO 131 J = 1,ISTOP
0720  131    FOOD(K,J) = LOADHR(IC)*FPER(J)*QHR(IC)/AVOL+FI(K)
0730         IC = IC + 1
```

(Continued)

(Sheet 2 of 7)

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Table A1 (Continued)

```
                    08/17/77          FILE = NLB          11:19      PAGE  3

0740  130  IF ( IC .GT. N) IC = 1
0750    FOOD(1,1) = FOOD(1,1) + RLOAD
0760       DO 135 J = 1,ISTOP
0761       IF ( QHR(IC) .LT. 0.0001) GO TO 135
0770       FOOD(K,J) = FOOD(K,J)*(QHR(IC)+RCF(IJ)-RESVOL)/(QHR(IC)
07718     +RCF(IJ))
0772  135  CONTINUE
0773C                        AERATION TANK PERFORMANCE
0774C
0780       DO 139 I = 1,40
0790       DO 139 J = 1,30
0800  139  F(I,J) = -1.0
0810       IDT = DT
0820       FDT = DT - IDT
0830        IF ( IFLAG(1) .EQ. 0) GO TO 2200
0831        IFLAG(1) = IFLAG(1) - 1
0832        KS = KS*EXP(-IFX/10.0)
0841C                         DETERMINE FOOD REMOVAL
0842C
0850  2200  DO 150 I = 1,LIM
0860       KEND = LIM - I + 1
0870       CDT = DT - I + 1
0880       DO 151 J = 1,KEND
0890       CDT = CDT - J + 1
0900        IF ( CDT .LT. 0.001) GO TO 150
0910  151   F(I,J) = FOOD(I,J)/(KM*CDT + 1.0)
0920        F(I,J) = FOOD(I,J)*FDT/(KM*CDT + 1.0)
0930  150   CONTINUE
0940       SUM = 0.0
0941      FREM = 0.0
0950        DO 170 I = 1,LIM
0960       DO 170 J = 1,30
0970        IF ( F(I,J)) 170,171,171
0980  171   ALOAD = ALOAD + FOOD(I,J)
0990        SUM = SUM + F(I,J)
1000        FREM = FREM + FOOD(I,J) - F(I,J)
1010  170   CONTINUE
1030  174   IF ( SUM .GT. FLIM*DT**2/2.0) GO TO 160
1040        IFLAG (1) = IFLAG(1) + 1
1050        IFX = IFX + DT
1060        GO TO 169
1061C                         DO ALL MASS CALCULATIONS
1062C
1070  160   KE = XKE*EXP(-OUT(I1,5))
1080        IFX = IFX - DT
1090        IF ( IFX .LT. 0.0) IFX = 0.0
1110        DO 161 I = 1,LIM
1120       IF ( IFLAGM .EQ. 1) GO TO 177
1130        RATMA = SUM1/MASS
1140        RATMI = SUM2/MASS
```

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Table A1 (Continued)

```
                    08/17/77          FILE = NLB              11:19      PAGE  4

1151   177  SUM1 = SUM1 + MAI(I)
1152        MASS = MASS + MASI(I)
1153        SUM2 = SUM2 + SUM2I(I)
1154        IF ( MASS .LT. WMASS) GO TO 165
1155        MASS = WMASS
1160        SUM1 = MASS*RATMA
1170        SUM2 = MASS*RATMI
1171        IFLAGM = 1
1181   165  IF(F(I,1) .LT. FLIM) GO TO 163
1190      KEND = LIM - I + 1
1200        CDT = DT - I + 1.0
1210        DO 162 J = 1,KEND
1220         CDT = CDT - J + 1.0
1230      IF ( CDT .LT. 0.001) GO TO 161
1240        MA(I,J) = KS*F(I,J)/(1.0/CDT + KE)
1250    SUM1 = SUM1 + MA(I,J)
1260        ME(I,J) = 0.23*KE*MA(I,J)*CDT
1270        MI(I,J) = 0.10*(MA(I,J) + ME(I,J))
1280         SUM2 = SUM2 + MI(I,J)
1300   162  MASS = MASS + MA(I,J) + ME(I,J) + MI(I,J)
1310        GO TO 161
1320   163  SUM2 = SUM2 + SUM1*0.23*KE
1321        MASS = MASS - 0.77*SUM1*KE
1330        SUM1 = SUM1 - SUM1*KE
1333        IF ( RATMI .GE. 1.0) RATMI = 0.99
1334        IFLAGM = 0
1360   161  CONTINUE
1365   175  OSUM = MASS - SUM2
1370        GO TO 185
1380   169  SUM2 = SUM2 + SUM1*0.23*KE*DT
1381        MASS = MASS - 0.77*SUM1*KE*DT
1390        SUM1 = SUM1 - SUM1*KE*DT
1391        IFLAGM = 0
1400   185  O2 = (1.50*FREM - 1.42*OSUM/SALAS)/DT
1401         OUT(I1,13) = O2
1420        RLOAD = 0.0
1430        IN = 1
1440        IF ( LIM .LT. ISTOP) GO TO 140
1450        IN = LIM - ISTOP
1460   140  DO 141 K = IN,LIM
1470        IST = LIM - K + 2
1480        XSUM = 0.0
1490        DO 142 J = IST,ISTOP
1500   142  XSUM = XSUM + FOOD(K,J)
1510   141  RLOAD = RLOAD + XSUM
1520      IF ( SUM1 .GT. LIMMA) GO TO 180
1530        KM = KM*SUM1/LIMMA
1540         GO TO 181
1550   180  IFLAG(2) = 0
1551C                      OUTPUT VARIABLE ASSIGNMENT
```

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Table A1 (Continued)


```
1552C
1553        KM = 15.0
1560   181  OUT(I1,1) = SUM
1561       OUT(I1,5) = ALOAD * 24.0/(DT*MASS)
1570        OUT(I1,2) = SUM1
1580        OUT(I1,3) = MASS
1590        OUT(I1,4) = (MASS - SUM2)/MASS
1600        OUT(I1,6) = DT
1620        DO 220 I = 1,50
1630        FI(I) = 0.0
1640       MAI(I) = 0.0
1650       MASI(I) = 0.0
1660   220  SUM2I(I) = 0.0
1661C                        CLARIFIER PERFORMANCE
1662C
1670       ICN = IEND
1680       ICEND = 1
1690         IC = IEND
1691      IK = IC
1692       ILAS = IK
1700       CRESVO = RESVOL
1710       CFDT = FDT
1720       IJ = 0
1730       LIMCL = AVOL/CVOL + 1
1732      IL = IEND
1734         DO 234 K = 1,6
1735   234  CSUM(K) = 0.0
1740       DO 255 KKK = 1,LIMCL
1741       IK = ICN
1742C                          CLARIFIER DETENTION TIME
1743C
1750       TOTQ = 0.0
1760       TOTQ = TOTQ + CRESVO
1770   201  IF ( TOTQ .GT. CVOL) GO TO 200
1780      IC = IC + 1
1790       IJ = IJ + 1
1791      IK = IK + 1
1792      IF ( IK .GT. 100) IK = 1
1800         IF ( IC .GT. N) IC = 1
1810      TOTQ = TOTQ + QHR(IC) + RCF(IK)
1820       GO TO 201
1830   200  IF ( IC .LE. ICN) GO TO 202
1840     CLDT= IC-ICN-1-CFDT+1+(CVOL-(TOTQ-QHR(IC)
1850&     -RCF(IK)))/(QHR(IC)+RCF(IK))
1860       GO TO 205
1870   202  CLDT = N-ICN-CFDT+1+IC-1+(CVOL-(TOTQ-QHR(IC)-RCF(IK)))
1880&      /(QHR(IC)+RCF(IK))
1890   205  CRESVO = TOTQ -CVOL
1900       ICDT = CLDT
1910       CFDT = CLDT - ICDT
```

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Table A1 (Continued)

```
                    08/17/77          FILE = NLB              11:19      PAGE  6

1930        IF ( CLDT .LT. DT) GO TO 206
1940        CLDT = DT
1941C                           CLARIFIER PERFORMANCE
1942C
1950  206   OUT(I1,7) = CVOL*24.0*10.0**6/(CSA*CLDT)
1960        OUT(I1,9) = 382.0*OUT(I1,7)**0.12*OUT(I1,5)**0.27/
1970&  (OUT(I1,3)**0.35*CLDT**1.05)
1980        OUT(I1,10) = 540.0*OUT(I1,4)**4.397*OUT(I1,5)**0.213
1990        OUT(I1,8) = 10.0**6/OUT(I1,10)
2000        OUT(I1,11) = OUT(I1,10)*OUT(I1,3)/10.0**6
2010        OUT ( I1,12) = OUT(I1,3)*DT/(OUT(I1,9)*24.0)
2020      RMA = OUT(I1,8)*OUT(I1,11)*OUT(I1,2)/(OUT(I1,3)*AVOL)
2040      RMI = OUT(I1,8)*OUT(I1,11)/AVOL
2050      RF = OUT(I1,1)*OUT(I1,11)/AVOL
2060     BAL=OUT(I1,3)*CVOL/(OUT(I1,11)*CVOL*OUT(I1,8) +
2062C                           ITERATE
2063C
2070&    (1.0-OUT(I1,11)*CVOL*OUT(I1,9)))
2071      IK = ILAS
2072         OUT(I1,14) = BAL
2073C                         RECYCLE
2074C
2080         DO 230 K = ICEND,IJ
2081      IK = IK + 1
2082      IF ( IK .GT. 100) IK = 1
2090      FI(K) = RF*QHR(IL)
2100      MAI(K) = RMA*QHR(IL)
2110      MASI(K) = RMI*QHR(IL)
2120      SUM2I(K) = MASI(K)*(1.0-OUT(I1,4))*QHR(IL)
2121       RCF(IK) = OUT(I1,11)*QHR(IL)
2122       IL = IL + 1
2130  230   IF ( IL .GT. N)  IL = 1
2131     ILAS = IK
2140       ICEND = IJ + 1
2141        DO 232 K = 1,6
2142        KK = K + 6
2143  232   CSUM(K) = CSUM(K) + OUT(I1,KK)
2150       ICN = IC
2160  255   CONTINUE
2161     SALAS = OUT(I1,12)
2162       DO 233 K = 1,6
2163       KK = K + 6
2164        CSUM(K) = CSUM(K)/LIMCL
2165  233   OUT(I1,KK) = CSUM(K)
2170  251   DT = 1.0 - FDT
2171     GO TO 250
2190C                           OUTPUT VALUES
2191C
2200  810   DO 801 I = 1,I1,IP
2210  801   WRITE ( 6,4) (OUT(I,J),J=1,14)
```

(Continued)

(Sheet 6 of 7)

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Table A1 (Concluded)

```
                    08/17/77          FILE = NLB          11:19      PAGE  7

2240   4  FORMAT (/10X,5F10.2)
2241        WRITE (6,1008)
2242   1008  FORMAT (/10X,'DO YOU WISH FURTHER ITERATION,
2243& ENTER NUMBER----'/)
2244        READ, IMAX
2245       IF ( IMAX .EQ. 0) GO TO 2002
2246        I1 = 0
2247        ICNT = 0
2248        GO TO 250
2250   1001  FORMAT (10X,'INPUT:PRINT CONTROL,NUMBER OF
2260& DISCRETE LOADINGS'/10X,'LOADING TIME FACTOR,FLIM,LIMMA'/)
2270   1002  FORMAT (10X,'INPUT: BOD LOADING(MG/L)')
2280   1003  FORMAT (10X,'INPUT: Q(MG)')
2290   1004  FORMAT (10X,'INPUT:  MAXIMUM NO. OF D.T. ITERATIONS,
2300& AERATION TANK VOLUME'/2X,'CLARIFIER VOL.,F(0),MA(0),
2310& MASS(0),KM,KE,KS,WASTE MASS LIM.,MLVSS(0)')
2320   1005  FORMAT (/////5X,'OUTPUT FORMAT :'//
2330&  10X,'F, MA, MLSS, PERCENT VOLATILE MLSS, F/M'/10X,'D.T.,
2340&  OVERFLOW RATE, RETURN SLUDGE CONC., ESS, SVI'/10X,
2350&  'PER, RECYCLE, SLUDGE AGE, O2 DEMAND, CLARIFIER MASS BAL,'//)
2360   2002  WRITE (6,1006)
2370   1006 FORMAT (//25X,'PROGRAM TERMINATE'//5X,
2371& 'DO YOU WISH TO CONTINUE: 1=YES,ELSE=NO'/)
2380        READ, ICONTI
2390        IF ( ICONTI .EQ. 1) GO TO 2000
2400   1007  FORMAT (//25X,'ASMODEL START'//)
3000       STOP
3010       END
```

(Sheet 7 of 7)

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Table A2

Output Parameters

1. Effluent food concentration, mg/ℓ
2. Active mass concentration, mg/ℓ
3. Mass concentration, mg/ℓ
4. Percent volatile solids
5. F/M ratio, lb BOD/lb MLVSS
6. Aeration tank hydraulic detention time, hours
7. Clarifier overflow rate, gal/sq ft/day
8. Maximum return sludge concentration, mg/ℓ
9. Effluent suspended solids, mg/ℓ
10. Sludge volume index (dimensionless)
11. Percent recycle
12. Sludge age, hours
13. O_2 demand per pass, mg/ℓ/hour
14. Clarifier mass balance check (dimensionless)

APPENDIX B: ANALYTICAL TEST PROCEDURES

1. The following paragraphs discuss the methods used for analyzing samples taken from laboratory and pilot plant extended aeration studies.

Biochemical Oxygen Demand

Apparatus:

YSI Model 51-A D.O. Meter and BOD probe
Low temperature incubator
300-mℓ BOD bottles
BOD bottle caps (plastic)

Reagents:

See Standard Methods, 13th Edition[25]
Alpha-Trol Commercial standard solution

Procedure:

BOD analyses were run in accordance with Standard Methods. A membrane probe was used to measure the dissolved oxygen content. The BOD probe and D.O. meter were calibrated using the Winkler Method as outlined in Standard Methods. Filtered samples were obtained using Gelman Type A/E filters.

Residue (Solids, Suspended and Volatile)

Apparatus:

Vacuum pump
Oven 102°C
Muffle furnace for use at 550°C
Desiccator
Analytical balance
Gooch crucibles
Fiber filter disk 21 mm (laboratory study only)
Millipore AP 40 Microfiber Glass Filters (47-mm diam) and filter holders for field study only

Procedure:

See Standard Methods, 14th Edition:[26]

a. Laboratory study. Duplicate samples from the mixing tank (M.T.) and effluent were filtered using Gooch crucibles for the determination of suspended and volatile solids. Sample preservation required refrigeration at 4°C for a period of time exceeding no longer than 7 days from the time of sampling until time of analysis.

b. Field study. Duplicate samples from the surge tank,

aeration basin, and effluent were filtered using AP 40 Microfiber Glass Filters.

pH

Apparatus:

Laboratory study
Beckman Zeromatic 55-3 pH meter and 39501 Beckman electrode

Field Study:

Corning Scientific Instruments, Model 610-A

Reagents:

Matheson Coleman and Bell pH 7 and 4 buffers

Procedure:

The meter was calibrated using a pH 4 buffer, then a pH 7 buffer. The meter was calibrated to the temperature of the sample prior to measurement.

Biological Counts, Qualitative Observation

Apparatus:

Microstar Microscope fitted with a Howard grid ocular micrometer
Standard plain glass slide and cover slip
Falcon 1006 plastic petri dish

Procedure:

Qualitative microbiological observations were taken to evaluate the relative abundance of the microfauna in the mixing tank. With a 25-mℓ graduated pipette from which the tip had been removed, a sample was extracted at mid-depth from the mixing tank and drained into a small beaker. The sample was stirred and a drop placed on a slide for microscopic examination. If the microfauna were not relatively characteristic, a 14-mℓ portion of the sample was drained into a Falcon 1006 plastic petri dish and randomly observed at 100× magnification to determine relative abundance.

Biological Counts, Quantitative Observation

Apparatus:

Microstar series 10 Microscope fitted with a Howard grid ocular micrometer
Sedgwick-Rafter counting cell (S-R)
Magnetic stirring apparatus

Reagent:

Neosynephrin

Procedure:

A sample was removed from the most turbulent section of the mixing tank at a depth of 0.5 ft. The sample was well mixed and a 25-mℓ portion was pipetted and diluted with 24-mℓ distilled H_2O to which one drop of Neosynephrin had been added for relaxation of microorganisms. After the mixture had been mixed using a magnetic stirring apparatus, a 1-mℓ portion was pipetted into a Sedgwick-Rafter counting cell. From Julian days 237 to 248 the magnification was increased. An area equivalent to 100× the former area scanned at 40× magnification was examined and the microorganisms counted. Microorganisms enumerated included peritrich ciliates (with differentations of suctorions), hypotrich ciliates, oligochaete worms, nematodes, rotifers, Acavina mites, and Arthospira algae forms.

Chemical Oxygen Demand (COD), Laboratory Study

Apparatus:

Technicon Corporation Auto Analyzer II

Reagents:

Alpha-Trol Standard
Potassium acid phthalate standard stock solution

Procedure:

See procedure in Analytical Chemistry[27]

Field Study:

See Standard Methods, 13th edition.[25]

Dissolved Oxygen Uptake

Apparatus:

YSI Model 51-A D.O. meter and BOD probe
300-mℓ BOD bottle
Stopwatch

Procedure:

See Standard Methods, 14th edition[26] (Method 213 B, "Oxygen Consumption Rate") and following.

a. Laboratory study. A sample from the mixing tank was removed using a peristaltic pump to rapidly obtain 300 mℓ mixed liquor in a BOD bottle. Immediately the YSI BOD probe was inserted into the BOD bottle and activated. After the meter had equilibrated, an initial D.O. reading was taken and additional readings were taken at 1-min intervals for 20 min.

Total Organic Carbon

Apparatus:

Dorhman D.C. 50, Envirotech Organic Carbon Analyzer

Reagents:

Potassium acid phthalate standards stock solution
Alpha-Trol commercial standard concentration HCl

Procedure:

For the laboratory bench-scale testing, TOC analyses of unfiltered feed solution, effluent, and filtered effluent were made. The effluent was filtered using Gelman Type A/E 47-mm filters.

Note: All TOC samples were preserved by the addition of enough concentrated HCl to lower the pH below 2 and refrigerated until the time of analysis.

APPENDIX C: RAW DATA

1. This appendix presents raw data for the second phase of the laboratory evaluation of the bench-scale extended aeration system. Included are the results of effluent analyses for both total and soluble TOC and COD, suspended solids, and MLSS, and the percent removals of total and soluble TOC and COD that were achieved by the system. The following abbreviations are used in Tables C1-C18.

FTOC = Food TOC

COUTOC = Clarifier overflow unfiltered TOC

PTOCRT = (FTOC - COUTOC) × 100/FTOC

COFTOC = Clarifier overflow filtered TOC

PTOCRS = (FTOC - COFTOC) × 100/FTOC

COUTSS = Clarifier overflow suspended solids

SSMT = Suspended solids mixing tank

FCOD = Food COD

COUCOD = Clarifier overflow unfiltered COD

PCODRT = (FCOD - COUCOD) × 100/FCOD

COFCOD = Clarifier overflow filtered COD

PCODRS = (FCOD - COFCOD) × 100/FCOD

DOUP = Dissolved oxygen uptake

DOU/MSS = Dissolved oxygen uptake/mixing tank suspended solids

TABLE C1

LABORATORY DATA FOR INTERMITTENT LOADING

2-DAY CYCLE, LOADING DAY 1

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	69.	23.	66.7	6.	91.3	83.0	0.	0.	0.	0.	0.	0.	0.	0.
0.5	69.	18.	73.9	5.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	69.	42.	39.1	5.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.5	69.	26.	62.3	5.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	69.	25.	63.8	6.	81.3	0.	590.	0.	0.	0.	0.	0.	0.	0.
3.0	69.	25.	63.8	7.	89.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.0	69.	28.	59.4	5.	92.8	0.	753.	0.	0.	0.	0.	0.	0.	0.
5.0	69.	30.	56.5	5.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
6.0	69.	24.	65.2	5.	92.8	0.	770.	0.	0.	0.	0.	0.	13.2	0.0
7.0	69.	30.	56.5	6.	91.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
8.0	69.	24.	65.2	7.	89.9	0.	0.	0.	0.	0.	0.	0.	0.	0.

TABLE C2

LABORATORY DATA FOR INTERMITTENT LOADING

2-DAY CYCLE, LOADING DAY 2

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	97.	14.	85.6	13.	86.6	34.0	1005.	0.	0.	0.	0.	0.	0.	0.
0.5	97.	27.	72.2	21.	78.4	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	97.	26.	73.2	15.	84.5	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.5	97.	26.	73.2	7.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	97.	27.	72.2	10.	89.7	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	97.	20.	79.4	5.	94.8	0.	803.	0.	0.	0.	0.	0.	0.	0.
4.0	97.	29.	70.1	7.	92.8	0.	848.	0.	0.	0.	0.	0.	0.	0.
5.0	97.	23.	76.3	7.	92.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
6.0	97.	73.	24.7	5.	94.8	0.	791.	0.	0.	0.	0.	0.	13.8	0.0
7.0	97.	81.	16.5	6.	93.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
8.0	97.	21.	78.4	8.	91.8	0.	738.	0.	0.	0.	0.	0.	0.	0.

TABLE C3

LABORATORY DATA FOR INTERMITTENT LOADING

2-DAY CYCLE, LOADING DAY 3

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	99.	30.	69.7	7.	92.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.5	99.	28.	71.7	6.	93.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	99.	33.	66.7	5.	94.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.5	99.	29.	70.7	9.	90.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	99.	23.	76.8	18.	81.8	0.	567.	0.	0.	0.	0.	0.	0.	0.
3.0	99.	25.	74.7	11.	88.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.0	99.	22.	77.8	6.	93.9	0.	870.	0.	0.	0.	0.	0.	0.	0.
6.0	99.	30.	69.7	6.	93.9	0.	659.	0.	0.	0.	0.	0.	6.6	0.
7.0	99.	30.	69.7	8.	91.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
8.0	99.	21.	78.8	11.	88.9	0.	330.	0.	0.	0.	0.	0.	0.	0.

TABLE C4

LABORATORY DATA FOR INTERMITTENT LOADING

3-DAY CYCLE, LOADING DAY 1

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	97.	26.	73.2	9.	90.7	32.0	707.	0.	0.	0.	0.	0.	0.	0.
0.5	97.	0.	100.0	22.	77.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	97.	23.	76.3	11.	88.7	124.0	707.	0.	0.	0.	0.	0.	0.	0.
1.5	97.	32.	67.0	22.	77.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	97.	19.	80.4	15.	84.5	29.0	602.	0.	0.	0.	0.	0.	0.	0.
2.5	97.	41.	57.7	19.	80.4	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	97.	28.	71.1	9.	90.7	58.0	707.	0.	0.	0.	0.	0.	0.	0.
3.5	97.	23.	76.3	19.	80.4	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.0	97.	31.	68.0	15.	84.5	53.0	559.	0.	0.	0.	0.	0.	0.	0.
5.0	97.	30.	69.1	17.	82.5	45.(	767.	0.	0.	0.	0.	0.	0.	0.
6.0	97.	11.	88.7	24.	75.3	60.0	817.	0.	0.	0.	0.	0.	13.9	0.0
7.0	97.	14.	85.6	24.	75.3	53.0	924.	0.	0.	0.	0.	0.	0.	0.
8.0	97.	27.	72.2	15.	84.5	20.0	897.	0.	0.	0.	0.	0.	0.	0.

TABLE C5

LABORATORY DATA FOR INTERMITTENT LOADING

3-DAY CYCLE, LOADING DAY 2

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	92.	27.	70.7	15.	83.7	0.	541.	0.	0.	0.	0.	0.	0.	0.
0.5	92.	20.	78.3	20.	78.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	92.	17.	81.5	16.	82.6	99.0	448.	0.	0.	0.	0.	0.	0.	0.
1.5	92.	71.	22.8	19.	79.3	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	92.	60.	34.8	22.	76.1	97.0	520.	0.	0.	0.	0.	0.	0.	0.
2.5	92.	61.	33.7	57.	38.0	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	92.	58.	37.0	64.	30.4	70.0	0.	0.	0.	0.	0.	0.	0.	0.
4.0	92.	58.	37.0	17.	81.5	43.0	455.	0.	0.	0.	0.	0.	0.	0.
5.0	92.	84.	8.7	17.	81.5	75.0	437.	0.	0.	0.	0.	0.	0.	0.
6.0	92.	0.	100.0	32.	65.2	111.0	383.	0.	0.	0.	0.	0.	12.2	0.0
7.0	92.	41.	55.4	21.	77.2	88.0	483.	0.	0.	0.	0.	0.	0.	0.
8.0	92.	67.	27.2	25.	72.8	101.0	443.	0.	0.	0.	0.	0.	0.	0.

TABLE C6

LABORATORY DATA FOR INTERMITTENT LOADING

3-DAY CYCLE, LOADING DAY 3

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	101.	61.	39.6	10.	90.1	123.0	523.	0.	0.	0.	0.	0.	0.	0.
0.5	101.	65.	35.6	12.	88.1	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	101.	47.	53.5	18.	82.2	169.0	0.	0.	0.	0.	0.	0.	0.	0.
1.5	101.	65.	35.6	15.	85.1	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	101.	47.	53.5	14.	86.1	287.0	483.	0.	0.	0.	0.	0.	0.	0.
2.5	101.	20.	80.2	15.	85.1	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	101.	18.	82.2	17.	83.2	0.	547.	0.	0.	0.	0.	0.	0.	0.
4.0	101.	0.	100.0	0.	100.0	0.	520.	0.	0.	0.	0.	0.	0.	0.
5.0	101.	43.	57.4	19.	81.2	246.0	541.	0.	0.	0.	0.	0.	0.	0.
6.0	101.	21.	79.2	19.	81.2	107.0	538.	0.	0.	0.	0.	0.	10.2	0.0
7.0	101.	36.	64.4	19.	81.2	129.0	477.	0.	0.	0.	0.	0.	0.	0.
8.0	101.	59.	41.6	13.	87.1	44.0	387.	0.	0.	0.	0.	0.	0.	0.

TABLE C7

LABORATORY DATA FOR INTERMITTENT LOADING

4-DAY CYCLE, LOADING DAY 1

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	73.	10.	86.3	4.	94.5	0.	976.	0.	0.	0.	0.	0.	0.	0.
0.5	73.	2.	97.3	6.	91.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	73.	4.	94.5	4.	94.5	38.0	970.	0.	0.	0.	0.	0.	0.	0.
1.5	73.	9.	87.7	7.	90.4	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	73.	4.	94.5	5.	93.2	0.	778.	0.	0.	0:	0.	0.	0.	0.

TABLE C8

LABORATORY DATA FOR INTERMITTENT LOADING

4-DAY CYCLE, LOADING DAY 1

(ADDITIONAL SAMPLING)

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	73.	8.	89.0	8.	89.0	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	73.	8.	89.0	6.	91.8	35.0	750.	0.	0.	0.	0.	0.	0.	0.
4.0	73.	10.	86.3	6.	91.8	25.0	707.	0.	0.	0.	0.	0.	0.	0.
5.0	73.	7.	90.4	12.	83.6	27.0	811.	0.	0.	0.	0.	0.	0.	0.
6.0	73.	8.	89.0	7.	90.4	25.0	804.	0.	0.	0.	0.	0.	0.	0.
7.0	73.	8.	89.0	4.	94.5	0.	817.	0.	0.	0.	0.	0.	0.	0.
8.0	73.	8.	89.0	6.	91.8	0.	794.	0.	0.	0.	0.	0.	0.	0.

TABLE C9

LABORATORY DATA FOR INTERMITTENT LOADING

4-DAY CYCLE, LOADING DAY 2

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	96.	13.	86.5	7.	92.7	32.0	684.	0.	0.	0.	0.	0.	0.	0.
0.5	96.	6.	93.8	2.	97.9	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	96.	18.	81.3	3.	96.9	46.0	705.	0.	0.	0.	0.	0.	0.	0.
1.5	96.	4.	95.8	4.	95.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	96.	6.	93.8	6.	93.8	130.0	717.	0.	0.	0.	0.	0.	0.	0.
2.5	96.	7.	92.7	6.	93.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	96.	5.	94.8	7.	92.7	37.0	698.	0.	0.	0.	0.	0.	0.	0.
4.0	96.	6.	93.8	4.	95.8	33.0	666.	0.	0.	0.	0.	0.	0.	0.
5.0	96.	6.	93.8	4.	95.8	33.0	788.	0.	0.	0.	0.	0.	0.	0.
6.0	96.	8.	91.7	4.	95.8	30.0	751.	0.	0.	0.	0.	0.	8.6	0.0
7.0	96.	9.	90.6	4.	95.8	20.0	575.	0.	0.	0.	0.	0.	0.	0.
8.0	96.	4.	95.8	3.	96.9	21.0	536.	0.	0.	0.	0.	0.	0.	0.

TABLE C10

LABORATORY DATA FOR INTERMITTENT LOADING

4-DAY CYCLE, LOADING DAY 3

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	90.	11.	87.8	12.	86.7	86.0	793.	0.	0.	0.	0.	0.	0.	0.
0.5	90.	4.	95.6	4.	95.6	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	90.	4.	95.6	8.	91.1	34.0	689.	0.	0.	0.	0.	0.	0.	0.
1.5	90.	8.	91.1	14.	84.4	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	90.	7.	92.2	6.	93.3	36.0	619.	0.	0.	0.	0.	0.	0.	0.
2.5	90.	7.	92.2	3.	96.7	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	90.	8.	91.1	5.	94.4	29.0	650.	0.	0.	0.	0.	0.	0.	0.
4.0	90.	2.	97.8	10.	88.9	25.0	594.	0.	0.	0.	0.	0.	0.	0.
5.0	90.	19.	78.9	10.	88.9	35.0	615.	0.	0.	0.	0.	0.	0.	0.
6.0	90.	2.	97.8	14.	84.4	29.0	0.	0.	0.	0.	0.	0.	9.3	0.0
7.0	90.	6.	93.3	7.	92.2	27.0	717.	0.	0.	0.	0.	0.	0.	0.
8.0	90.	15.	83.3	11.	87.8	27.0	623.	0.	0.	0.	0.	0.	0.	0.

TABLE C11

LABORATORY DATA FOR INTERMITTENT LOADING

5-DAY CYCLE, LOADING DAY 1

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	84.	15.	82.1	28.	66.7	35.0	942.	267.	54.	79.8	12.	95.5	0.	0.
1.0	84.	14.	83.3	22.	73.8	37.0	925.	267.	50.	81.3	12.	95.5	0.	0.
0.5	84.	25.	70.2	15.	82.1	0.	0.	267.	65.	75.7	12.	95.5	0.	0.
1.5	84.	12.	85.7	20.	76.2	0.	0.	267.	38.	85.8	44.	83.5	0.	0.
2.0	84.	18.	78.6	8.	90.5	34.0	1002.	267.	65.	75.7	19.	92.9	0.	0.
2.5	84.	16.	81.0	7.	91.7	0.	0.	267.	22.	91.8	19.	92.9	0.	0.
3.0	84.	10.	88.1	8.	90.5	0.	812.	267.	38.	85.8	19.	92.9	0.	0.
3.5	84.	16.	81.0	9.	89.3	21.0	794.	267.	38.	85.8	53.	80.1	0.	0.
4.0	84.	14.	83.3	14.	83.3	22.0	927.	267.	38.	85.8	38.	85.8	0.	0.
5.0	84.	18.	78.6	16.	81.0	26.0	873.	267.	71.	73.4	44.	83.5	0.	0.
6.0	84.	22.	73.8	10.	88.1	30.0	941.	267.	87.	67.4	25.	90.6	156.	0.2
7.0	84.	62.	26.2	8.	90.5	22.0	794.	267.	56.	79.0	38.	85.8	0.	0.
8.0	84.	16.	81.0	9.	89.3	1.0	913.	267.	50.	81.3	19.	92.9	0.	0.

TABLE C12

LABORATORY DATA FOR INTERMITTENT LOADING

5-DAY CYCLE, LOADING DAY 2

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	71.	12.	83.1	13.	81.7	42.0	786.	240.	0.	100.0	19.	92.1	0.	0.
0.5	71.	14.	80.3	10.	85.9	0.	0.	240.	65.	72.9	5.	97.9	0.	0.
1.0	71.	17.	76.1	8.	88.7	42.0	880.	240.	71.	70.4	5.	97.9	0.	0.
1.5	71.	13.	81.7	18.	74.6	0.	0.	240.	54.	77.5	5.	97.9	0.	0.
2.0	71.	12.	83.1	10.	85.9	41.0	728.	240.	71.	70.4	22.	90.8	0.	0.
2.5	71.	22.	69.0	16.	77.5	0.	0.	240.	54.	77.5	27.	88.8	0.	0.
3.0	71.	10.	85.9	9.	87.3	40.0	808.	240.	65.	72.9	54.	77.5	0.	0.
4.0	71.	10.	85.9	6.	91.5	56.0	892.	240.	60.	75.0	38.	84.2	0.	0.
5.0	71.	15.	78.9	11.	84.5	0.	823.	240.	74.	69.2	27.	88.8	0.	0.
6.0	71.	10.	85.9	8.	88.7	0.	810.	240.	65.	72.9	5.	97.9	12.3	0.0
7.0	71.	15.	78.9	8.	88.7	33.0	776.	240.	12.	95.0	5.	97.9	0.	0.
8.0	71.	16.	77.5	14.	80.3	44.0	485.	240.	29.	87.9	5.	97.9	0.	0.

TABLE C13

LABORATORY DATA FOR INTERMITTENT LOADING

5-DAY CYCLE, LOADING DAY 3

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	82.	12.	85.4	10.	87.8	36.0	746.	225.	65.	71.1	19.	91.6	0.	0.
0.5	82.	22.	73.2	2.	97.6	0.	0.	225.	0.	100.0	5.	97.8	0.	0.
1.0	82.	13.	84.1	18.	78.0	54.0	745.	225.	44.	80.4	5.	97.8	0.	0.
1.5	82.	14.	82.9	6.	92.7	0.	0.	225.	30.	86.7	5.	97.8	0.	0.
2.0	82.	13.	84.1	10.	87.8	28.0	798.	225.	22.	90.2	5.	97.8	0.	0.
2.5	82.	12.	85.4	24.	70.7	0.	0.	225.	90.	60.0	5.	97.8	0.	0.
3.0	82.	12.	85.4	5.	93.9	54.0	714.	225.	33.	85.3	5.	97.8	0.	0.
4.0	82.	10.	87.8	18.	78.0	32.0	795.	225.	38.	83.1	16.	92.9	0.	0.
5.0	82.	16.	80.5	9.	89.0	0.	698.	225.	27.	88.0	0.	100.0	0.	0.
6.0	82.	11.	86.6	8.	90.2	34.0	651.	225.	0.	100.0	5.	97.8	11.4	0.0
7.0	82.	12.	85.4	13.	84.1	24.0	628.	225.	54.	76.0	22.	90.2	0.	0.
8.0	82.	13.	84.1	8.	90.2	27.0	749.	225.	33.	85.3	10.	95.6	0.	0.

TABLE C14

LABORATORY DATA FOR INTERMITTENT LOADING

7-DAY CYCLE, LOADING DAY 1

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	92.	8.	91.3	4.	95.7	75.0	1133.	0.	0.	0.	0.	0.	3.4	0.0
0.5	92.	8.	91.3	3.	96.7	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	92.	8.	91.3	6.	93.5	86.0	972.	0.	0.	0.	0.	0.	0.	0.
1.5	92.	6.	93.5	4.	95.7	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	92.	6.	93.5	4.	95.7	77.0	966.	0.	0.	0.	0.	0.	0.	0.
3.0	92.	14.	84.8	4.	95.7	62.0	899.	0.	0.	0.	0.	0.	0.	0.
4.0	92.	5.	94.6	4.	95.7	40.0	915.	0.	0.	0.	0.	0.	0.	0.
5.0	92.	4.	95.7	4.	95.7	51.0	831.	0.	0.	0.	0.	0.	0.	0.
6.0	92.	4.	95.7	0.	100.0	36.0	890.	0.	0.	0.	0.	0.	13.9	0.0
7.0	92.	2.	97.8	2.	97.8	0.	948.	0.	0.	0.	0.	0.	0.	0.
8.0	92.	4.	95.7	1.	98.9	0.	893.	0.	0.	0.	0.	0.	0.	0.

TABLE C15

LABORATORY DATA FOR INTERMITTENT LOADING

7-DAY CYCLE, LOADING DAY 2

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	72.	6.	91.7	2.	97.2	74.0	679.	0.	0.	0.	0.	0.	0.	0.
0.5	72.	0.	100.0	2.	97.2	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.0	72.	4.	94.4	1.	98.6	80.0	392.	0.	0.	0.	0.	0.	0.	0.
1.5	72.	1.	98.6	1.	98.6	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0	72.	4.	94.4	4.	94.4	83.0	562.	0.	0.	0.	0.	0.	0.	0.
2.5	72.	1.	98.6	3.	95.8	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.0	72.	14.	80.6	3.	95.8	47.0	666.	0.	0.	0.	0.	0.	0.	0.
4.0	72.	31.	56.9	3.	95.8	53.0	604.	0.	0.	0.	0.	0.	0.	0.
5.0	72.	29.	59.7	2.	97.2	45.0	495.	0.	0.	0.	0.	0.	0.	0.
6.0	72.	5.	93.1	6.	91.7	50.0	454.	0.	0.	0.	0.	0.	11.5	0.
7.0	72.	3.	95.8	2.	97.2	47.0	422.	0.	0.	0.	0.	0.	0.	0.
8.0	72.	6.	91.7	6.	91.7	46.0	569.	0.	0.	0.	0.	0.	0.	0.

TABLE C16

LABORATORY DATA FOR INTERMITTENT LOADING

7-DAY CYCLE, LOADING DAY 3

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	88.	2.	97.7	1.	98.9	57.0	818.	217.	54.	75.1	28.	87.1	0.	0.
0.5	88.	5.	94.3	1.	98.9	0.	0.	217.	43.	80.2	28.	87.1	0.	0.
1.0	88.	2.	97.7	1.	98.9	45.0	650.	217.	82.	62.2	11.	94.9	0.	0.
1.5	88.	4.	95.5	1.	98.9	0.	0.	217.	25.	88.5	21.	90.3	0.	0.
2.0	88.	2.	97.7	1.	98.9	42.0	862.	217.	39.	82.0	25.	88.5	0.	0.
2.5	88.	3.	96.6	1.	98.9	0.	0.	217.	28.	87.1	36.	83.4	0.	0.
3.0	88.	2.	97.7	1.	98.9	44.0	700.	217.	50.	77.0	16.	92.6	0.	0.
4.0	88.	4.	95.5	7.	92.0	35.0	577.	217.	39.	82.0	14.	93.5	0.	0.
5.0	88.	4.	95.5	5.	94.3	50.0	646.	217.	57.	73.7	28.	87.1	0.	0.
6.0	88.	3.	96.6	1.	98.9	39.0	661.	217.	43.	80.2	21.	90.3	0.	0.
7.0	88.	5.	94.3	1.	98.9	46.0	608.	217.	18.	91.7	32.	85.3	0.	0.
8.0	88.	5.	94.3	5.	94.3	38.0	808.	217.	71.	67.3	21.	90.3	0.	0.

TABLE C17

LABORATORY DATA FOR INTERMITTENT LOADING

7-DAY CYCLE, LOADING DAY 4

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	100.	9.	91.0	4.	96.0	27.0	635.	237.	19.	92.0	5.	97.9	0.	0.
0.5	100.	2.	98.0	1.	99.0	0.	0.	237.	22.	90.7	5.	97.9	0.	0.
1.0	100.	4.	96.0	8.	92.0	19.0	679.	237.	25.	89.5	12.	94.9	0.	0.
1.5	100.	14.	86.0	1.	99.0	0.	0.	237.	50.	78.9	34.	85.7	0.	0.
2.0	100.	94.	6.0	4.	96.0	25.0	587.	237.	92.	61.2	5.	97.9	0.	0.
2.5	100.	8.	92.0	9.	91.0	0.	0.	237.	31.	86.9	5.	97.9	0.	0.
5.0	100.	16.	84.0	4.	96.0	26.0	671.	237.	22.	90.7	18.	92.4	0.	0.
6.0	100.	12.	88.0	4.	96.0	30.0	518.	237.	28.	88.2	12.	94.9	7.7	0.0
7.0	100.	5.	95.0	6.	94.0	23.0	631.	237.	23.	90.3	22.	90.7	0.	0.
8.0	100.	8.	92.0	7.	93.0	29.0	601.	237.	28.	88.2	12.	94.9	0.	0.

TABLE C18

LABORATORY DATA FOR INTERMITTENT LOADING

7-DAY CYCLE, LOADING DAY 5

TIME	FTOC	COUTOC	PTOCRT	COFTOC	PTOCRS	COUTSS	SSMT	FCOD	COUCOD	PCODRT	COFCOD	PCODRS	DOUP	DOU/MSS
0.	86.	6.	93.0	6.	93.0	52.0	765.	182.	37.	79.7	7.	96.2	0.	0.
0.5	86.	18.	79.1	8.	90.7	45.0	0.	182.	28.	84.6	20.	89.0	0.	0.
1.0	86.	28.	67.4	15.	82.6	67.0	746.	182.	47.	74.2	11.	94.0	0.	0.
1.5	86.	22.	74.4	8.	90.7	0.	0.	182.	16.	91.2	5.	97.3	0.	0.
2.0	86.	22.	74.4	7.	91.9	59.0	700.	182.	60.	67.0	28.	84.6	0.	0.
2.5	86.	26.	69.8	8.	90.7	0.	0.	182.	47.	74.2	59.	67.6	0.	0.
3.0	86.	22.	74.4	10.	88.4	63.0	754.	182.	51.	72.0	18.	90.1	0.	0.
4.0	86.	20.	76.7	7.	91.9	66.0	687.	182.	60.	67.0	20.	89.0	0.	0.
5.0	86.	19.	77.9	7.	91.9	51.0	670.	182.	38.	79.1	42.	76.9	0.	0.
6.0	86.	22.	74.4	7.	91.9	59.0	661.	182.	30.	83.5	21.	88.5	0.	0.
7.0	86.	22.	74.4	10.	88.4	46.0	583.	182.	24.	86.6	10.	94.5	0.	0.
8.0	86.	18.	79.1	10.	88.4	38.0	570.	182.	31.	83.0	24.	86.8	0.	0.

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Mahloch, Jerome L
Laboratory and pilot plant evaluation of intermittent loading on small-scale extended aeration biological systems / by Jerome L. Mahloch, Daniel E. Averett, Marcia Headstream. Vicksburg, Miss. : U. S. Waterways Experiment Station; Springfield, Va. : available from National Technical Information Service, 1977.
53, [44] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; Y-77-4)
Prepared for Assistant Secretary of the Army (R&D), Department of the Army, Washington, D. C., under Project No. 4A161101A91D, Task 02, Work Unit 100.
References: p. 52-53.

1. Aeration. 2. Biological properties. 3. Mathematical models. 4. Recreational facilities. 5. Wastewater treatment. I. United States. Assistant Secretary of the Army (Research and Development). II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; Y-77-4.
TA7.W34 no.Y-77-4