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EVALUATION OF INDUSTRIAL LIQUID WASTE TREATMENT PLANT DESIGN AT HOLSTON ARMY AMMUNITION PLANT PHASE I, PART I

ROBERT P. CARNAHAN, Ph.D., P.E.
PATRICIA MARSACK
W. DICKINSON BURROWS, Ph.D., P.E.

PREPARED FOR
US ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MD 21010

U S ARMY MEDICAL BIOENGINEERING RESEARCH & DEVELOPMENT LABORATORY

Fort Detrick

Frederick, Maryland 21701

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Design of the Industrial Liquid Waste Treatment Plant (ILWTP) at Holston Army Ammunition Plant has been assessed with respect to removal of conventional pollutants and inorganic nitrogen. Computer simulation of the ILWTP, supported by some very preliminary operating data, indicates that the Facility will meet NPDES criteria for BOD and nitrogen, and that it is capable of sustaining any expected upsets without exceeding permit criteria.

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TABLE OF CONTENTS

APPENDIXES

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The purpose of this study is to evaluate the design of the industrial liquid waste treatment plant presently under prove out at Holston Army Ammunition Plant. The initial design work was completed in 1974 by Clark, Dietz & Associates Engineers.[2,3] Based upon their preliminary design and additional pilot plant studies conducted by Holston Defense Corporation in 1977, a final concept design was developed in 1977.

The major concern (in this study) was to validate the present design and to establish guidelines for development of design criteria for future plants requiring the same types of processes. This was to be accomplished by evaluating data collected during previous studies, and then performing computer simulation studies of these processes. The computer simulations were to provide information on the transient response of the processes due to variations in the mass and hydraulic loading.

LITERATURE REVIEW

GENERAL

The industrial liquid waste treatment plant, which is shown in Figure 1, consists of anaerobic denitrification filters (anoxic filters), aerobic fixed film reactors (trickling filters), and aerobic suspended growth reactors (activated sludge). Only the wastewater from Area B is to be treated in the anoxic filters, with Area A wastewater to enter the system just ahead of aerobic fixed film reactors (trickling filters). The wastewater from the activated sludge processes is clarified and filtered through dual media filters, with this effluent receiving reaeration prior to discharge into the Holston River. The piping for this plant is such that the activated sludge system may be operated ahead of the trickling filters or in the normal sequence with the trickling filters preceding the activated sludge process. Sludge wasted from the activated sludge process is thickened before being aerobically digested and mechanically dewatered. The dried sludge is disposed of in landfill.

The characteristics of the wastewater being treated are shown in Table 1. One of the major concerns was the ability of this plant to ensure that the effluent complied with NPDES waste load allocation. The area of particular concern was the total nitrate-as-nitrogen loading. The 1980 NPDES permit is summarized in Appendix D.

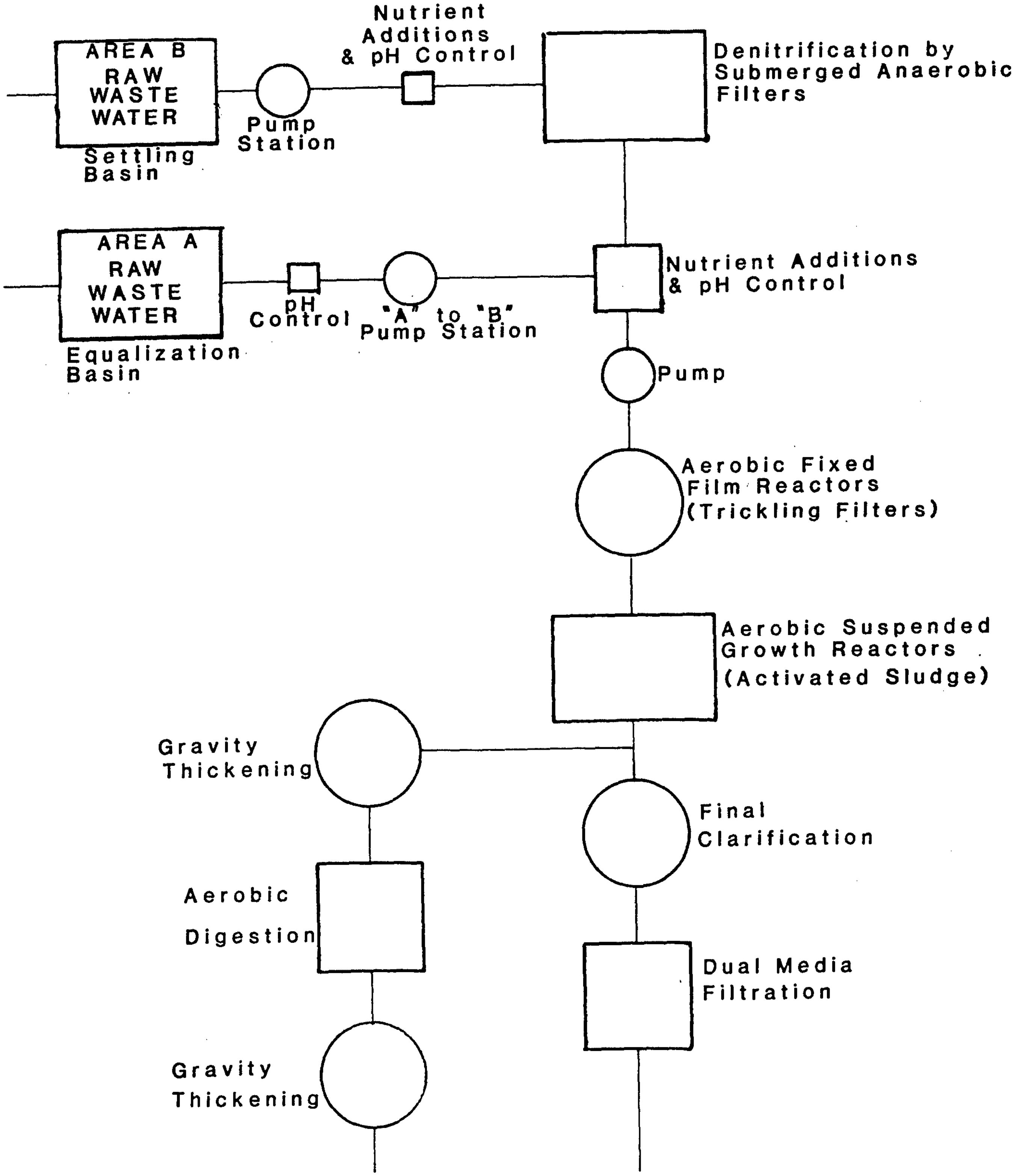


Figure 1. Process flow sheet.

TABLE 1. SUMMARY OF DESIGN WASTEWATER CHARACTERISTICS HOLSTON ARMY AMMUNITION PLANT

Parameter	Design Value (Full Mobilization)[a]
Average Flow	12.6 MGD
Maximum Flow	16.3 MGD
COD	61,535 pounds/day
BOD_5	43,000 pounds/day
NH_3-N	510 pounds/day
Total P	70 pounds/day
Total N	3,375 pounds/day
Total SS	4,092 pounds/day

a. Constructed for 50% of mobilization rates (assume straight line).

Review of Denitrification

Denitrification is coupled with the aerobic oxidation of organic material; the nitrate which acts as electron acceptor must be the limiting substrate present in the system. In other words, the carbonaceous organic concentration or the concentration of methanol, which may be used as an organic carbon source, must exceed the nitrate concentration in order to effectively denitrify the wastewater. Although the literature implies that denitrification systems may be designed such that the two substrates will be rate limiting, it is difficult in practice to accomplish this. If the Monod[19] kinetics were to be used, there would be a specific growth function for each of the substrates as shown below.

$$\mu = \frac{\hat{\mu}\, S_n\, S_c}{(K_n + S_n)\,(K_c + S_c)} \tag{1}$$

where $\hat{\mu}$, S_n, S_c are the maximum rate constant, nitrate substrate concentration, and carbonaceous substrate concentration, respectively. The K_n and K_c are the half rate constants, i.e., the half rate constant is the substrate concentration at half the maximum growth rate, expressed in units of mass/volume.

In practice however, the organic substrate would be in such concentration ($S_c >> K_c$) that the nitrate would in fact be the rate limiting substrate, and the rate-of-growth equation reverts to a saturation function involving only nitrate, as shown:

$$\mu = \frac{\hat{\mu}\, S_n}{(K_n + S_n)} \tag{2}$$

While the suspended growth system for denitrification represents a more efficient process, Grady[4] found that, due to the filamentous nature of the biomass, the suspended growth system could not be used. Therefore, it was recommended that the submerged anaerobic filters be used. Grady[4] proposed that the system followed a first-order kinetics expression and the design could be based upon

$$N = N_o e^{\frac{-\lambda Z}{(V)^n}} \qquad (3)$$

where N is the effluent nitrate concentration in milligrams per liter, N_o is the influent nitrate concentration in milligrams per liter, Z is the filter depth in feet and V is the hydraulic application rate in cubic feet per second per square foot. The coefficient lambda was found to be equal to 1.45 while the power of the hydraulic application rate n was found to be equal to 0.5. This expression implies that the removal of nitrate is essentially a logarithmic function of the height of the column. Hash, Evans, and Simerly[5] showed in their work, however, that there were two distinct rates of reactions occurring within the column. Through the first 4 feet of the column, the reaction was fast; it then proceeded at a much slower rate through the next (upper) 10 feet of the column. These data are shown in Figure 2. Their report[5] indicates that performance of the anoxic towers (submerged anaerobic filters) was purely a function of application rate and that the kinetics for the system could not be clearly described. Harremose[20] found that fixed-film reactors did not follow classical first-order kinetics but rather followed a series of first-order, half-order, and zero-order reactions which overall appeared similar to Monod kinetics. He found that there were two distinct break points within the kinetic relationships in which the substrate transport as well as a reaction resistance became limiting, as shown in Figure 3.

Kornegay and Andrews[21] found that the reaction rate was a function of the degree of penetration of the substrate into the film and that the shear effect of the fluid had a significant effect upon the rate of overall reaction. It is clear from all the information presently available that there was a discrepancy between the data collected by Grady[4] versus that of Hash et al.[5] These discrepancies in data may well have been due to the aging of the samples forwarded to Grady and the formulation of the wastewater used in his experimental work. Hash et al.[5] used water directly from the production process, which was representative of the wastewater that will be treated at Holston.

REVIEW OF TRICKLING FILTER DESIGN

The pilot plant work conducted by Grady[4] and Clark and Dietz[3] shows the activated sludge process to be unstable due to development of filamentous growth. Grady[4] recommended that a trickling filter or attached growth system be used for treating the carbonaceous portion of the wastewater. Again, Grady[4] was able to describe the removal of carbonaceous BOD with first-order kinetics, relating the rate of removal with depth of the column and hydraulic application rate. The expression developed was

$$S_c = S_{co}\, e^{\frac{-\lambda Z}{(V)^n}} \qquad (4)$$

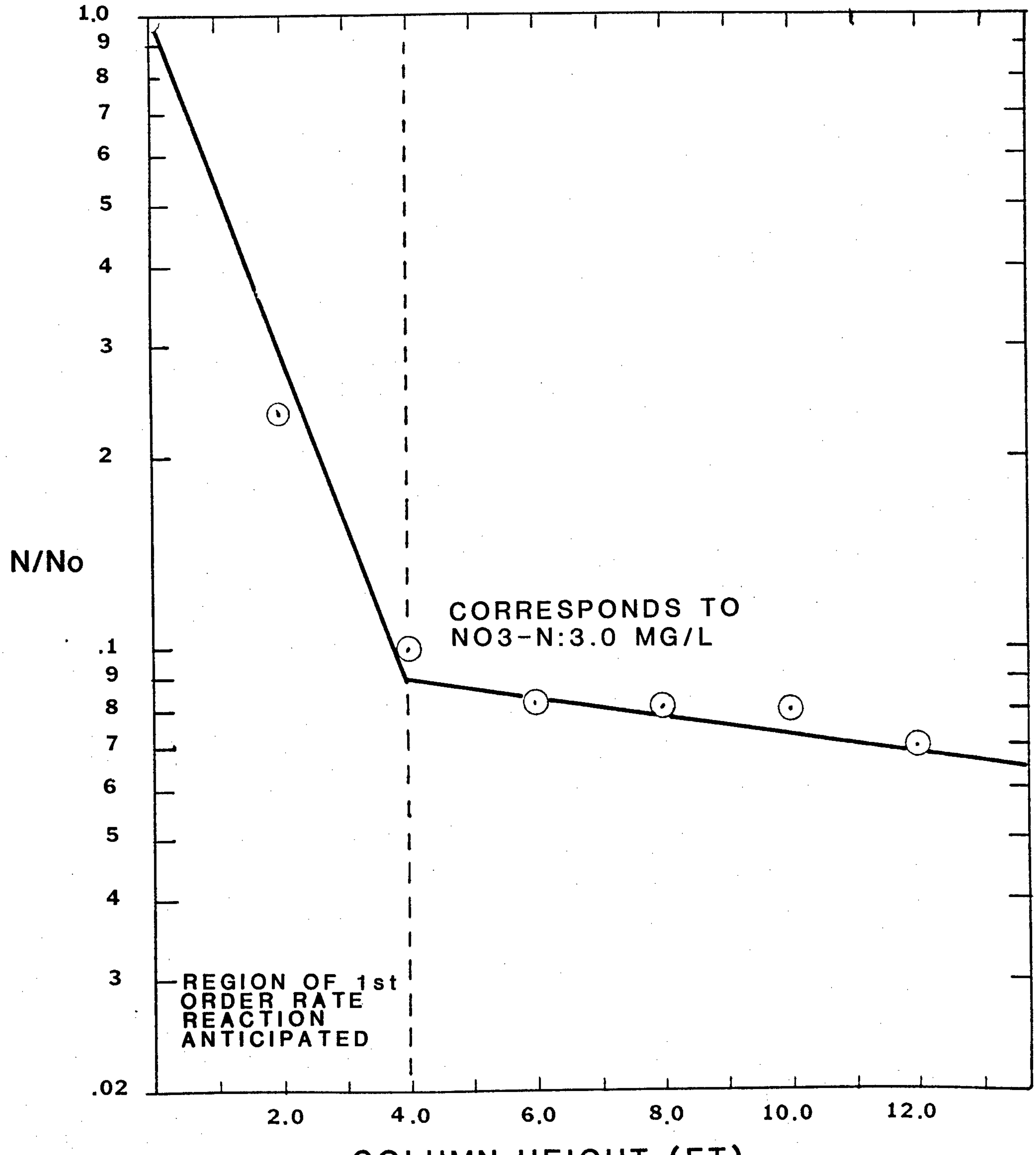
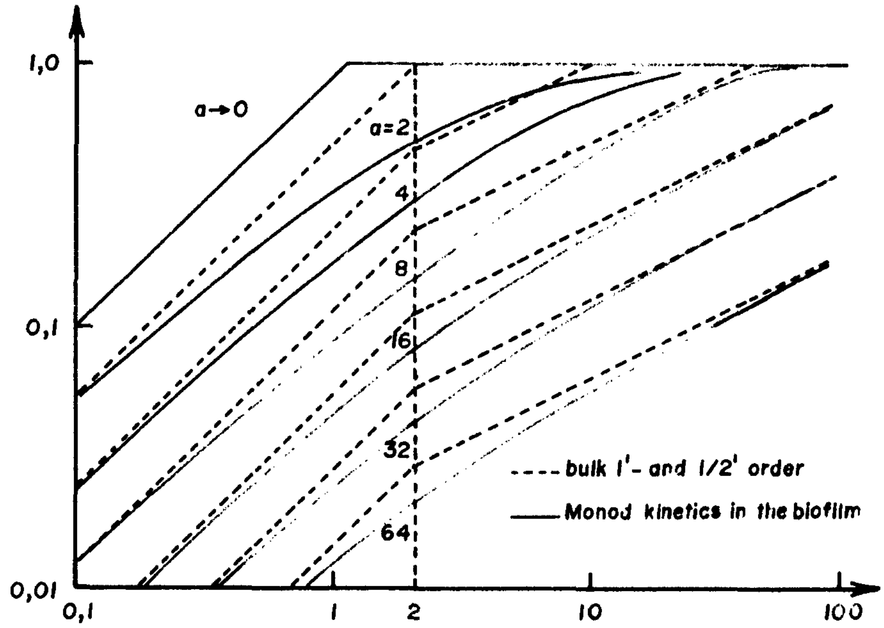


Figure 2. Rate of nitrate reduction versus tower height.

$\frac{r_a}{k_{oa}}$



C*/K_s

r_a = reaction rate per unit surface area
k_{oa} = zero-order reaction constant per unit surface area
C* = bulk liquid concentration
K_s = saturation constant
α = $(K_f L^2/D)^{1/2}$
K_f = biofilm constant (mass transfer coefficient)
L = depth of biofilm
D = diffusion coefficient

Figure 3. Trickling filter kinetics, according to Harremose (20).

where Z is the depth of the filter and S_c and S_{co} are the effluent and influent total biochemical oxygen demand in milligrams per liter. Lambda was found to be 0.1 and n was found to be 0.5 for application rate (V) in cubic feet per second per square foot. Based upon this study it was recommended that four biological filters 57 feet in diameter with a media depth of 26 feet, be constructed. It was further recommended that the hydraulic application rate be 0.8 gallons per minute per square foot.

Hash et al.[5] again found some deviation from results presented by Grady; they found that lambda actually had an average value of 0.05 as compared to the 0.1 recommended by Grady. They agreed that the hydraulic application rate exponent was essentially equivalent to one-half. This is consistent with Rich[22] where n is actually an effectiveness factor for the hydraulic application rate.

At similar application rates, Hash et al.[5] observed a 30 percent reduction in COD as compared with the 90 percent reduction reported by Grady.[4] It is difficult to explain why such a wide deviation would exist except that the characteristics of the feed streams must have been different.

REVIEW OF ACTIVATED SLUDGE DESIGN

Hash et al.[5] further investigated the possibility of using activated sludge as a treatment process. Applied to raw, high strength wastewater, the activated sludge system gave good organic removal, but poor sludge settling characteristics. However, activated sludge operating at a solids retention time (SRT) of 8 days provided an excellent second stage treatment of the trickling filter effluent. The results (Table 2) show that the process removed 76 percent of the COD, 85 percent of the BOD and 90 percent of the NH_3-N using a 6-hour aeration cycle. The sludge volume index was 110 mL/gm, which indicates good settling characteristics of the sludge. An aeration period of 4 hours gave slightly inferior performance overall, and reducing sludge age to 3 days gave serious bulking problems. It was recommended that the activated sludge plant be designed for an aeration time of 6 hours, a SRT of 8 days, and a flow of 12.5 million gallons per day.

TABLE 2. PERFORMING OF ACTIVATED SLUDGE SYSTEM (From Hash et al.[5])

Item	6 Hours Aeration 8 Day Sludge Age (Trickling Filter Effluent)	12 Hours Aeration 8 Day Sludge Age	4 Hours Aeration 8 Day Sludge Age (Trickling Filter Effluent)	9 Hours Aeration 8 Day Sludge Age
Influent BOD_5, mg/L	130	410	130	419
Effluent BOD_5, mg/L	19	20	13	32
DO, mg/L	6.7	5.5	5.3	3.6
pH	7.6	7.6	7.8	7.8
Temperature, ^{o}C	20	21	20	20
Sludge Volume Index, mL/g	110	319	117	305
Mixed Liquor Suspended Solids, mg/L	1,527	1,140	1,816	1,478
Average Daily Removal, Percent				
BOD_5	85	96	90	91
COD	76	85	70	80
NH_3-N	90	60	70	43

DEVELOPMENT OF DYNAMIC MODEL

GENERAL

The approach used in developing these models was to use equations which could be related to actual design variables. It was also necessary to represent these design variables in the form of differential equations or integral equations so that the dynamics of the processes could be evaluated.

DENITRIFICATION ANOXIC TOWERS

A block diagram for the development of the unsteady state model for the anoxic towers is shown in Figure 4. This block diagram shows the input and output functions as they relate to the differential equations contained within the block diagram. These differential equations were developed from the literature and reports by Hash et al.[5] and Grady.[4] Analysis of the data of Hash et al.[5] shows that increasing the hydraulic loading rate did not lower the percent removal of nitrate. These results imply that their[5] system may have been substrate-limited, since the towers did not show a breakthrough characteristic. Based upon the information available, a rate equation was developed using the lambda that Grady reported, but dependence on the depth of the column was considered a fractional order function. This is consistent with observations that Eckenfelder[23] made in trickling filter operation. The fractional order for the operational loading rate was obtained as shown in Figure 2. The data of Hash et al.[5] were replotted and found to be essentially the same as reported by Grady[4] and by Eckenfelder.[23] While the rate did change and was significantly different in the first 4 feet on the column, the next (upper) 6 feet had essentially the same rate of removal. For this reason an attempt was made to fit the data to zero-order reaction rate as well as half-order reaction rate. This analysis has not been completed at this time. The primary concern was to obtain a rate contour for the total depth of the tower by analyzing the data of Hash et al.[5] A mean value of 1.20 for the power term (R in equation 9 below) of depth was determined. Using this term, the Continuous Simulation Modeling Program (CSMP) equations for the model were written. Modeling of the denitrification system was done on a macro basis and did not in any way consider characteristics of transport within the biofilm. Transport in the biofilm is being looked at as another element of the study, but has not been thoroughly documented at this point. The output observed from this model is shown in Appendix A. The general structure of the model is as follows:

$$\begin{array}{c}\text{rate of}\\ \text{mass N}\\ \text{in}\end{array} - \begin{array}{c}\text{rate of}\\ \text{mass N}\\ \text{out}\end{array} + \begin{array}{c}\text{rate of}\\ \text{mass N}\\ \text{reacting}\end{array} = \begin{array}{c}\text{rate of}\\ \text{mass N}\\ \text{accumulating}\end{array} \qquad (5)$$

$$\left[F_N \big|_{Z} - F_N \big|_{Z+\Delta Z} \right] \Delta X \Delta Y + [r_N] \, \Delta X \Delta Y \Delta Z = \frac{\partial N}{\partial t} \, \Delta X \Delta Y \Delta Z \qquad (6)$$

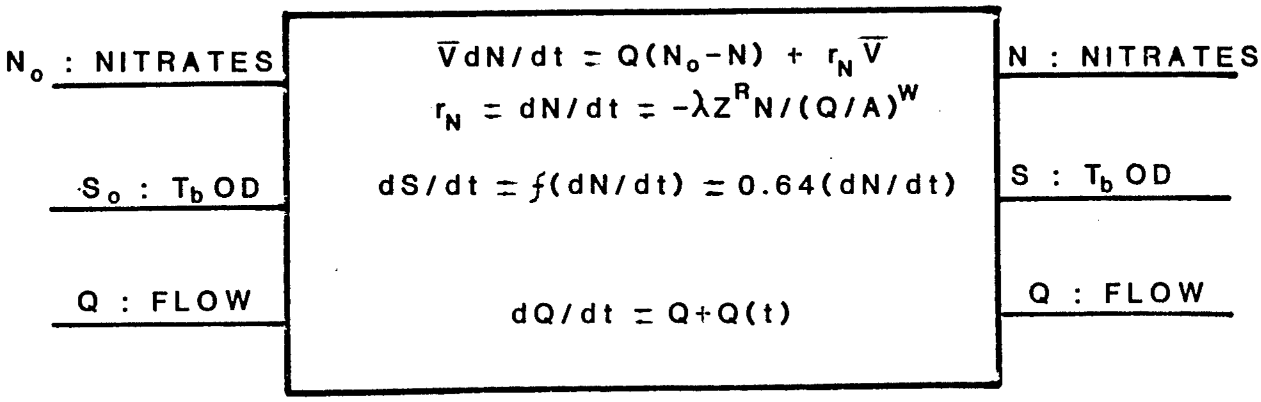


Figure 4. Anoxic tower model.

Dividing Equation 6 by (ΔX, ΔY, ΔZ), the differential sections, and taking the limit as $\Delta Z \to 0$, the following equation is obtained

$$\frac{\partial F_N}{\partial Z} + r_N = \frac{\partial N}{\partial t} \tag{7}$$

or

$$\frac{dF_N}{dZ} + r_N = \frac{dN}{dt} \tag{8}$$

where F_N is the flux term, N is the nitrate concentration, and r_N is the reaction term.

The reaction term is expressed empirically in terms of Z

$$r_N = \frac{dN}{dt} = - \left(\frac{\lambda Z^R}{(Q/A)^w} \right) N \tag{9}$$

where λ is a rate coefficient, R is an effectiveness factor, and w is a function of the packing used in the column.

The function Z represents the column depth, while Q represents flow rate in cubic feet per second, and A is the cross sectional area of the column, which gives the velocity through the column.

The change in flux may be expressed as

$$\text{(10)} \qquad \Delta F_N = \frac{\text{mass}}{\text{length}^2 \times \text{time}} = \frac{Q}{A} (N_o - N)$$

Therefore, the unsteady state equation (Equation 8) may be expressed as

$$\frac{\bar{V}dN}{dt} = Q\,(N_o - N) + r_N\,\bar{V} \tag{11}$$

Then, eliminating the volume term $(\bar{V})$ where $t = (\bar{V}/Q)$, the equation becomes

$$\frac{dN}{dt} = \frac{1}{t}\,(N_o - N) + r_N \tag{12}$$

This differential equation describes the function of the denitrification columns. In order to evaluate the dynamic response of the system, the program was written so that the influent flow and nitrate concentration could be varied independently with time. This was done by using either a step or impulse function. Figure 5 shows how these functions were defined within the program.

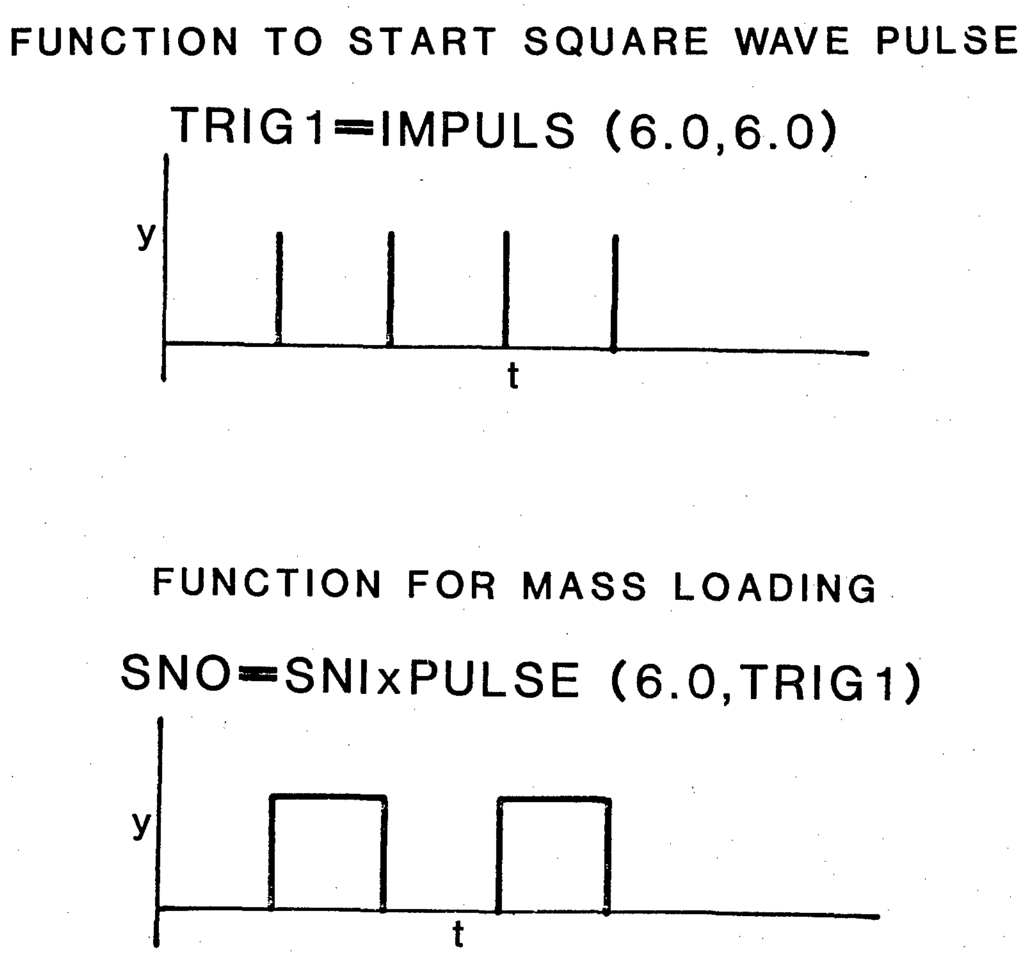


Figure 5. Transient function for computer simulations.

TRICKLING FILTER SYSTEM

The trickling filter model was developed in exactly the same manner as the anoxic towers model. Replacing N, the nitrate concentration with S, the carbonaceous substrate concentration, an equation for the trickling filter was expressed as follows:

$$\frac{dS}{dt} = \frac{1}{t}(S_o - S) + r_S \tag{13}$$

$$\text{where } r_S = \frac{dS}{dt} = -\left(\frac{\lambda Z^B}{(Q/A)^u}\right) S \tag{14}$$

The parameters Q, A, and Z represent flow, cross-sectional area, and column height, just as in the anoxic tower. The terms B and u represent an effectiveness factor and a media packing factor. As in the case of anoxic towers the Q/A term represents a velocity and the u represents a holdup adjustment for the media. Lambda (λ) represents a rate term.

ACTIVATED SLUDGE SYSTEM

The activated sludge model was based upon Monod kinetics. Substrate and organism material balances were written over the entire system, as follows:

(SUBSTRATE BALANCE)

$$\frac{dS}{dt} = \frac{Q}{V}(S_o - S) - \frac{\mu_m X S}{Y(S + K_m)} \tag{15}$$

(ORGANISM BALANCE)

$$\frac{dX}{dt} = \frac{Q}{V}(X_o - X) + \frac{\mu_m X S}{S + K_m} - K_D X \tag{16}$$

where S_o and S are influent and effluent substrate concentrations, respectively, X_o and X are influent and effluent organism concentrations, respectively, Y is the mass ratio of cells formed to substrate consumed, and μ_m, K_m, and K_D are constants.

The constants used in the model were those recommended for design in ASCE Manual of Practice Number 36.[24] Solid retention time of 8 days was used in order to tune the model with the data collected at Holston. It is expected that once the model is tuned, the SRT will be varied in order to assess the system's ability to respond to transient loadings.

GENERAL ASSESSMENT OF MODEL

The Continuous Simulation Modeling Program (CSMP) is capable of predicting the effluent discharge from the Holston AAP industrial waste treatment plant. The model is based upon the rational design equations used in current practice and is consistent with equations used to design the wastewater treatment plant. All expressions used in this model have physical significance; no empirical mathematical expressions were used.

The model is also written in BASIC language for use on the Apple^{R}* computer. The program in BASIC appears to be better suited to the process than CSMP. CSMP did not adapt well in modeling the trickling filter, due to the nature of the equation describing the trickling filter. The CSMP program also has the disadvantage of requiring a special compiler, while the BASIC program can be run on the Apple^{R} or other microcomputers.

In the verification phase of the study, the mass transfer rates for the anoxic tower and the trickling filter will be studied.

DISCUSSION OF RESULTS

GENERAL DESIGN COMMENTS

Review of the proposed design indicates that the modifications recommended by Hash et al.[5] were justified. These modifications to the original design certainly provide greater flexibility in the operation of the wastewater treatment plant and a greater degree of assurance in meeting the NPDES criteria. The development of the simulation models, which are discussed below, shows that all processes in the system are compatible and that the plant should function well under wide variation in loadings.

In the verification phase the mass transfer rates for both the anoxic tower and trickling filter need to be further refined. An attempt will be made to correlate the operational data with the height and number of theoretical units or a j_D function. If this correlation can be developed it will permit the sizing of a column for a specific efficiency and capacity very quickly and easily. The simulation studies which are discussed below were based upon the most extreme conditions that might be encountered. Results indicate that the industrial waste plant has the capacity to respond both to extreme organic and hydraulic surges. While the simulations do not show that the system complies with all the NPDES criteria, there is a trend which implies compliance. When data are available to tune the models, more accurate predictions may be made.

CONTINUOUS SIMULATION MODELING PROGRAM

The initial modeling of the wastewater treatment plant was done using a Continuous Simulation Modeling Program (CSMP). This provided an easy means of developing the differential equation in a computer format. This model is shown in Appendix A. The dynamic section of the program contains the anoxic towers followed by the trickling filters and activated sludge processes.

The CSMP graphically displays the inputs and output of each process. For example, the anoxic towers with inputs ranging between 25 and 75 mg/L of nitrate nitrogen showed effluent concentrations of 3 mg/L to 15 mg/L. The transients in the tower effluent lag the input transient by approximately 30

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minutes. Sensitivity analysis of the parameters needs to be performed; when actual operational data are available this will be accomplished.

Simulation of the trickling filter showed that effluent from the trickling filters varied from 16 mg/L to 35 mg/L. The influent pulse ranged from 250 to 350 mg/L with the effluent response lagging by 1 hour. These simulations indicated an efficiency of the filters ranging between 90 and 94 percent. These results were slightly different than those given by the BASIC Simulation Program, but are in agreement with the findings of Hash et al.[5]

The simulated effluent concentrations from the activated sludge process showed a concentration of carbonaceous material which ranged from 5 mg/L to 50 mg/L. The organism concentration was approximately 100 mg/L, which implied that the system was dispersed and substrate limited. Until actual data are available, it will be difficult to determine if this is a representative case of actual operating conditions.

BASIC SIMULATION MODELING PROGRAM

A simulation of 48 hours of operation was made using the Basic program, shown in Appendix B. The initial nitrate concentration of 25 mg/L was periodically pulsed to 50 mg/L. Flow rates were also pulsed from 15.0 million gallons per day (mgd) to 19.5 mgd to simulate hydraulic disturbances. The output from the simulation (Appendix B) showed that the program was responsive to the changes in the input parameters, with effluent nitrate concentrations ranging from 3 to 12 mg/L. It is expected that with proper tuning of the model, greater sensitivity may be obtained. Verification of the model with actual plant data is essential to the development of an accurate effectiveness ratio and rate constant.

The same simulation study was used to evaluate the trickling filter portion of the model. A carbonaceous organic concentration of 250 mg/L was used in the simulations. Using the rate constants and effectiveness factor previously described for the trickling filter, the simulations predicted between 87 and 91 percent reduction in the carbonaceous concentration. Based upon the limited data available, these results seem appropriate. Again, verification of the systems using actual plant data will provide a better assessment of the rate constants and effectiveness coefficients.

The activated sludge process, which follows the trickling filter, was simulated using substrate concentrations which ranged between 50 mg/L and 150 mg/L. Hydraulic transients were also used in this process analysis. Results of the simulation showed that effluent would range between 5 mg/L and 77 mg/L using the rate constants selected.

As indicated throughout the discussion of the modeling phase of this study, the future use of actual operational data to refine the rate constants will make the models more predictive. These models have, however, proven that the processes selected in the design are interactive and should prove to be an effective treatment system. Certainly these processes warrant consideration in treatment of any wastewater containing these contaminants.

CONCLUSIONS

The following conclusions may be made:

1. Design of the Holston Industrial Waste Treatment Plant is consistent with good engineering practice.

2. Simulation studies using the model previously described indicates that this plant would meet the NPDES permit criteria.

3. Transient analysis of the treatment plant shows that the processes are capable of sustaining any expected upsets without exceeding permit criteria.

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APPENDIX A

CSMP MODEL

```
****DIFFERENTIAL ANALOG DIGITAL SYSTEM****

***PROBLEM INPUT STATEMENTS***
************************* HOLSTON AAP ******************************

***************** INDUSTRIAL WASTE TREATMENT PLANT *****************

**************CARNAHAN, MARCH 1983************************

INITIAL

*        ANOXIC TOWERS

       CONSTANT     A=6655.0, ZLAM=1.45, U=0.5, R=0.33,...
                         Z=10.0, VOL=66550.0

       CONSTANT     QIN2=7.5, QIN3=2.25, SNINF=25.0,...
                         SN1=50.0, SNI=25.0

*        TRICKLING FILTER

       CONSTANT     CA=10000.0, CLAM=0.71, ZT=26.0, W=0.5,...
                         B=.33, CVOL=260000.0

       CONSTANT     QIC2=1.1, QIC3=0.25, SCINF=250.0,...
                         SC1=100.0, SCI=250.0

*        ACTIVATED SLUDGE

       CONSTANT     K=5.0, KS=60.0, KD=0.06, YG=0.60,...
                         AVOL=2870000.0, QR=0.25

*************** ASSUMED XC SHOULD BE 0.0 ****************
       INCON        XI=100.0, SC=50.0, XC=100.0

DYNAMIC

      K1=K/24
      K2=KD/24
      V1=VOL
      V2=CVOL
      V3=AVOL

*        ANOXIC TOWER

        TRIG1=IMPULS(2.0,6.0)
        TRIG2=IMPULS(2.0,4.0)
        TRIG3=IMPULS(2.0,6.0)
        TRIG4=IMPULS(2.0,3.0)

        QIN1=(QIN3/(24.0*60))*10**6
        QINF=(QIN2/(24.0*60))*10**6
        QIC1=(QIC3/(24.0*60))*10**6
        QICF = (QIC2/(24.0*60))*10**6

        SNO=SN1*PULSE(2.0,TRIG1)+SNINF
        QO=QIN1*PULSE(3.0,TRIG2)+QINF
        SCO=SC1*PULSE(2.0,TRIG3)+SCINF
        QTO=QIC1*PULSE(2.0,TRIG4)+QICF+QO
        QTOA=QTO+(QR*QTO)
        XO=((XI*QTO)+(X*QR*QTO))/QTOA
        SAF=((QTO/CA)**W)
```

```
***************SECOND SECTION**********************

        SNF=INTGRL(SN1,DOTSN)
        DOTSN=((QO*8.021)/V1)*(SNO-SNF)+((-ZLAM*(Z**R))/((QO/A)**U))*SN

        SCF=INTGRL(SCI,DOTSC)
        DOTSC=((QTO*8.021)/V2)*(SCO-SCF)+((-CLAM*(ZT**B))/SAF)*SCF

        DSDT=(((QTOA*8.021)/V3)*(SCF-S))-(K1*(S/(S+KS))*X)
        DXDT=(((QTOA*8.021)/V3)*(XO-X))+((K1*YG)*(S/(S+KS))*X)-(K2*X)
        S=INTGRL(SC,DSDT)
        X=INTGRL(XC,DXDT)

    NOSORT

        IF(X.GT.10000.0) X=10000.0
        IF(SCF.LT.10.0) SCF=10.0
        IF(S.LT.5.0) S=5.0


TERMINAL

        METHOD    MILNE
        TIMER     PRDEL=0.5, OUTDEL=0.5, FINTIM=48.0,...
                    DELT=0.1
        PRINT     QO, QTOA, QTO
        LABEL     INFLUENT NITRATE CONCENTRATION
        PRTPLT    SNO
        LABEL     EFFLUENT NITRATE CONCENTRATION
        PRTPLT    SNF
        LABEL     T.F.  INFLUENT CONCENTRATION
        PRTPLT    SCO
        LABEL     T.F.  EFFLUENT CONCENTRATION
        PRTPLT    SCF
        LABEL     A.S.  EFFLUENT CONCENTRATION
        PRTPLT    S
        LABEL     ORGANISM CONCENTRATION
        PRTPLT    X

END
STOP

OUTPUT VARIABLE SEQUENCE
TRIG1  SNO    V1     QINF   TRIG2  QIN1   QO     DOTSN  SNF    QICF
TRIG4  QIC1   QTO    SAF    TRIG3  SCO    V2     DOTSC  SCF    K1
V3     QTOA   DSDT   S      K2     XO     DXDT   X      X      SCF
S

 OUTPUTS    INPUTS    PARAMS   INTEGS + MEM BLKS   FORTRAN   DATA CDS
 35(500)   66(1400)   35(400)    4+   0=   4(300)   32(600)      28
```

```
        CONSTANT    A=6655 0, ZLAM=1.45, U=0.5, R=0.33,...
                          Z=10.0, VOL=66550.0
        CONSTANT    QIN2=7.5, QIN3=2.25, SNINF=25.0,...
                          SN1=50.0, SNI=25.0
        CONSTANT    CA=10000.0, CLAM=0.71, ZT=26.0, W=0.5,...
                          B=.33, CVOL=260000.0
        CONSTANT    QIC2=1.1, QIC3=0.25, SCINF=250.0,...
                          SC1=100.0, SCI=250.0
        CONSTANT    K=5.0, KS=60.0, KD=0.06, YG=0.60,...
                          AVOL=2870000.0, QR=0.25
        INCON       XI=100.0, SC=50.0, XC=100.0
        METHOD    MILNE
        TIMER     PRDEL=0.5, OUTDEL=0.5, FINTIM=48.0,...
                    DELT=0.1
        PRINT     QO, QTOA, QTO
        LABEL     INFLUENT NITRATE CONCENTRATION
        PRTPLT    SNO
        LABEL     EFFLUENT NITRATE CONCENTRATION
        PRTPLT    SNF
        LABEL     T.F. INFLUENT CONCENTRATION
        PRTPLT    SCO
        LABEL     T.F. EFFLUENT CONCENTRATION
        PRTPLT    SCF
        LABEL     A.S. EFFLUENT CONCENTRATION
        PRTPLT    S
        LABEL     ORGANISM CONCENTRATION
        PRTPLT    X
END
TIMER VARIABLES
 DELT   = 1.2500E-01
 DELMIN= 4.8000E-06
 FINTIM= 4.8000E 01
 PRDEL = 5.0000E-01
 OUTDEL= 5.0000E-01
```

TIME	QO	QTOA	QTO
0.0000E-01	5.2083E 03	7.4653E 03	5.9722E 03
5.0000E-01	5.2083E 03	7.4653E 03	5.9722E 03
1.0000E 00	5.2083E 03	7.4653E 03	5.9722E 03
1.5000E 00	5.2083E 03	7.4653E 03	5.9722E 03
2.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
2.5000E 00	6.7708E 03	9.6354E 03	7.7083E 03
3.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
3.5000E 00	6.7708E 03	9.6354E 03	7.7083E 03
4.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
4.5000E 00	6.7708E 03	9.4184E 03	7.5347E 03
5.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
5.5000E 00	5.2083E 03	7.6823E 03	6.1458E 03
6.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
6.5000E 00	6.7708E 03	9.6354E 03	7.7083E 03
7.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
7.5000E 00	6.7708E 03	9.4184E 03	7.5347E 03
8.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
8.5000E 00	6.7708E 03	9.6354E 03	7.7083E 03
9.0000E 00	6.7708E 03	9.6354E 03	7.7083E 03
9.5000E 00	5.2083E 03	7.6823E 03	6.1458E 03
1.0000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.0500E 01	6.7708E 03	9.4184E 03	7.5347E 03
1.1000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.1500E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.2000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.2500E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.3000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.3500E 01	5.2083E 03	7.4653E 03	5.9722E 03
1.4000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.4500E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.5000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.5500E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.6000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.6500E 01	6.7708E 03	9.4184E 03	7.5347E 03
1.7000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.7500E 01	5.2083E 03	7.6823E 03	6.1458E 03
1.8000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.8500E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.9000E 01	6.7708E 03	9.6354E 03	7.7083E 03
1.9500E 01	6.7708E 03	9.4184E 03	7.5347E 03
2.0000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.0500E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.1000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.1500E 01	5.2083E 03	7.6823E 03	6.1458E 03
2.2000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.2500E 01	6.7708E 03	9.4184E 03	7.5347E 03
2.3000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.3500E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.4000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.4500E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.5000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.5500E 01	5.2083E 03	7.4653E 03	5.9722E 03
2.6000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.6500E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.7000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.7500E 01	6.7708E 03	9.6354E 03	7.7083E 03

TIME	QO	QTOA	QTO
2.8000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.8500E 01	6.7708E 03	9.4184E 03	7.5347E 03
2.9000E 01	6.7708E 03	9.6354E 03	7.7083E 03
2.9500E 01	5.2083E 03	7.6823E 03	6.1458E 03
3.0000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.0500E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.1000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.1500E 01	6.7708E 03	9.4184E 03	7.5347E 03
3.2000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.2500E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.3000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.3500E 01	5.2083E 03	7.6823E 03	6.1458E 03
3.4000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.4500E 01	6.7708E 03	9.4184E 03	7.5347E 03
3.5000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.5500E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.6000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.6500E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.7000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.7500E 01	5.2083E 03	7.4653E 03	5.9722E 03
3.8000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.8500E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.9000E 01	6.7708E 03	9.6354E 03	7.7083E 03
3.9500E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.0000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.0500E 01	6.7708E 03	9.4184E 03	7.5347E 03
4.1000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.1500E 01	5.2083E 03	7.6823E 03	6.1458E 03
4.2000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.2500E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.3000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.3500E 01	6.7708E 03	9.4184E 03	7.5347E 03
4.4000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.4500E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.5000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.5500E 01	5.2083E 03	7.6823E 03	6.1458E 03
4.6000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.6500E 01	6.7708E 03	9.4184E 03	7.5347E 03
4.7000E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.7500E 01	6.7708E 03	9.6354E 03	7.7083E 03
4.8000E 01	6.7708E 03	9.6354E 03	7.7083E 03

VARIABLE	MINIMUM	TIME	MAXIMUM	TIME
SNO	2.5000E 01	0.0000E-01	7.5000E 01	2.0000E 00
SNF	3.8100E 00	1.9995E 00	5.0000E 01	0.0000E-01
SCO	2.5000E 02	0.0000E-01	3.5000E 02	2.0000E 00
SCF	1.6398E 01	1.4000E 01	2.5000E 02	0.0000E-01
S	5.0000E 00	8.1562E 00	5.0000E 01	0.0000E-01
X	1.0000E 02	0.0000E-01	1.2369E 02	1.0000E 01

INFLUENT NITRATE CONCENTRATION

```
                              MINIMUM              SNO     VERSUS TIME                 MAXIMUM
                             2. 5000E 01                                             7. 5000E 0
  TIME           SNO            I                                                        I
0. 0000E-01    2. 5000E 01      +
5. 0000E-01    2. 5000E 01      +
1. 0000E 00    2. 5000E 01      +
1. 5000E 00    2. 5000E 01      +
2. 0000E 00    7. 5000E 01      --------------------------------------------------+
2. 5000E 00    7. 5000E 01      --------------------------------------------------+
3. 0000E 00    7. 5000E 01      --------------------------------------------------+
3. 5000E 00    7. 5000E 01      --------------------------------------------------+
4. 0000E 00    7. 5000E 01      --------------------------------------------------+
4. 5000E 00    2. 5000E 01      +
5. 0000E 00    2. 5000E 01      +
5. 5000E 00    2. 5000E 01      +
6. 0000E 00    2. 5000E 01      +
6. 5000E 00    2. 5000E 01      +
7. 0000E 00    2. 5000E 01      +
7. 5000E 00    2. 5000E 01      +
8. 0000E 00    7. 5000E 01      --------------------------------------------------+
8. 5000E 00    7. 5000E 01      --------------------------------------------------+
9. 0000E 00    7. 5000E 01      --------------------------------------------------+
9. 5000E 00    7. 5000E 01      --------------------------------------------------+
1. 0000E 01    7. 5000E 01      --------------------------------------------------+
1. 0500E 01    2. 5000E 01      +
1. 1000E 01    2. 5000E 01      +
1. 1500E 01    2. 5000E 01      +
1. 2000E 01    2. 5000E 01      +
1. 2500E 01    2. 5000E 01      +
1. 3000E 01    2. 5000E 01      +
1. 3500E 01    2. 5000E 01      +
1. 4000E 01    7. 5000E 01      --------------------------------------------------+
1. 4500E 01    7. 5000E 01      --------------------------------------------------+
1. 5000E 01    7. 5000E 01      --------------------------------------------------+
1. 5500E 01    7. 5000E 01      --------------------------------------------------+
1. 6000E 01    7. 5000E 01      --------------------------------------------------+
1. 6500E 01    2. 5000E 01      +
1. 7000E 01    2. 5000E 01      +
1. 7500E 01    2. 5000E 01      +
1. 8000E 01    2. 5000E 01      +
1. 8500E 01    2. 5000E 01      +
1. 9000E 01    2. 5000E 01      +
1. 9500E 01    2. 5000E 01      +
2. 0000E 01    7. 5000E 01      --------------------------------------------------+
2. 0500E 01    7. 5000E 01      --------------------------------------------------+
2. 1000E 01    7. 5000E 01      --------------------------------------------------+
2. 1500E 01    7. 5000E 01      --------------------------------------------------+
2. 2000E 01    7. 5000E 01      --------------------------------------------------+
2. 2500E 01    2. 5000E 01      +
2. 3000E 01    2. 5000E 01      +
2. 3500E 01    2. 5000E 01      +
2. 4000E 01    2. 5000E 01      +
2. 4500E 01    2. 5000E 01      +
2. 5000E 01    2. 5000E 01      +
```

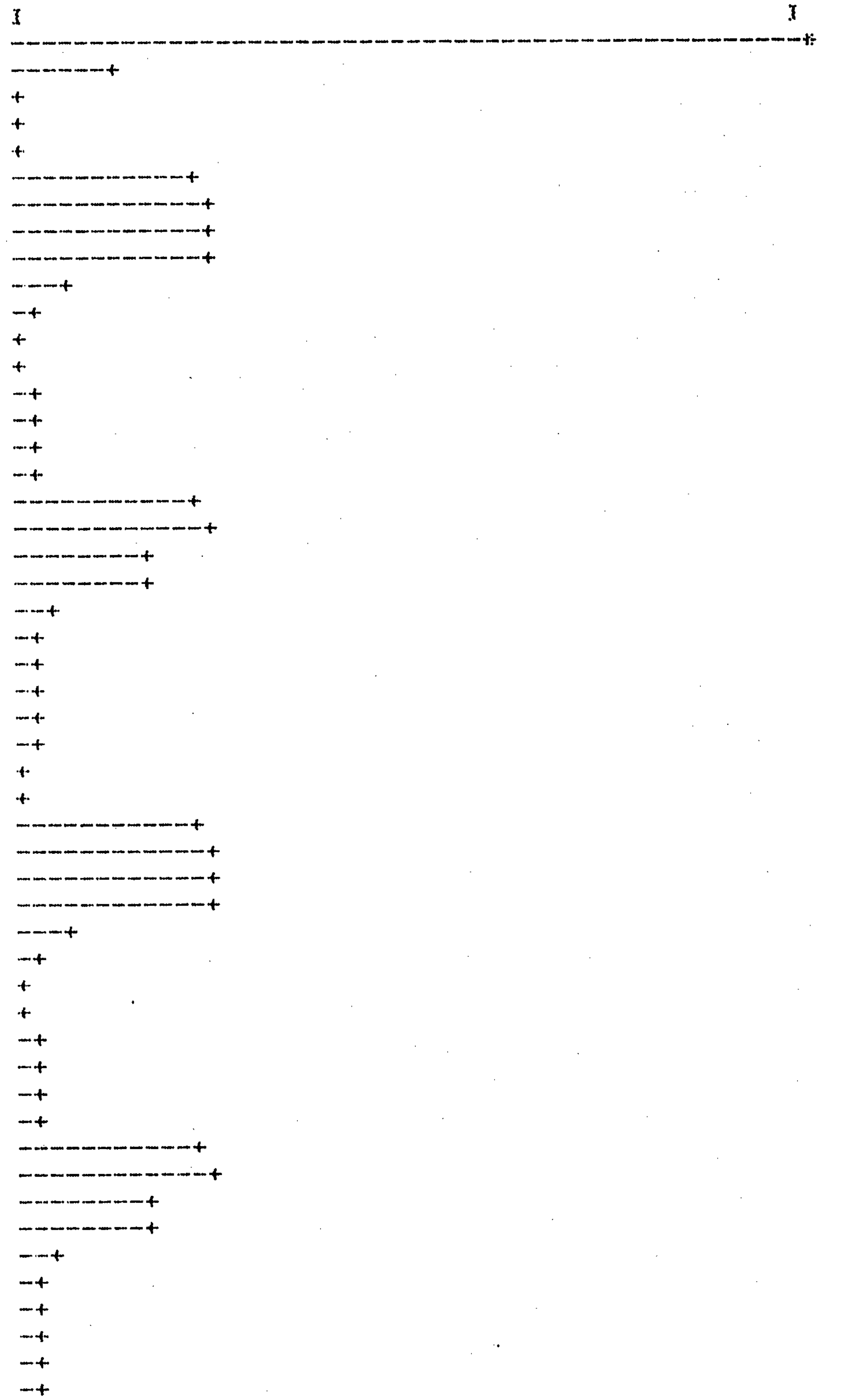
INFLUENT NITRATE CONCENTRATION

```
                                  MINIMUM                 SNO     VERSUS TIME                 MAXIMUM
                                 2.5000E 01                                                 7.5000E 01
  TIME            SNO              I                                                            I
2.5500E 01     2.5000E 01        +
2.6000E 01     7.5000E 01         ---------------------------------------------------------------+
2.6500E 01     7.5000E 01         ---------------------------------------------------------------+
2.7000E 01     7.5000E 01         ---------------------------------------------------------------+
2.7500E 01     7.5000E 01         ---------------------------------------------------------------+
2.8000E 01     7.5000E 01         ---------------------------------------------------------------+
2.8500E 01     2.5000E 01         +
2.9000E 01     2.5000E 01         +
2.9500E 01     2.5000E 01         +
3.0000E 01     2.5000E 01         +
3.0500E 01     2.5000E 01         +
3.1000E 01     2.5000E 01         +
3.1500E 01     2.5000E 01         +
3.2000E 01     7.5000E 01         ---------------------------------------------------------------+
3.2500E 01     7.5000E 01         ---------------------------------------------------------------+
3.3000E 01     7.5000E 01         ---------------------------------------------------------------+
3.3500E 01     7.5000E 01         ---------------------------------------------------------------+
3.4000E 01     7.5000E 01         ---------------------------------------------------------------+
3.4500E 01     2.5000E 01         +
3.5000E 01     2.5000E 01         +
3.5500E 01     2.5000E 01         +
3.6000E 01     2.5000E 01         +
3.6500E 01     2.5000E 01         +
3.7000E 01     2.5000E 01         +
3.7500E 01     2.5000E 01         +
3.8000E 01     7.5000E 01         ---------------------------------------------------------------+
3.8500E 01     7.5000E 01         ---------------------------------------------------------------+
3.9000E 01     7.5000E 01         ---------------------------------------------------------------+
3.9500E 01     7.5000E 01         ---------------------------------------------------------------+
4.0000E 01     7.5000E 01         ---------------------------------------------------------------+
4.0500E 01     2.5000E 01         +
4.1000E 01     2.5000E 01         +
4.1500E 01     2.5000E 01         +
4.2000E 01     2.5000E 01         +
4.2500E 01     2.5000E 01         +
4.3000E 01     2.5000E 01         +
4.3500E 01     2.5000E 01         +
4.4000E 01     7.5000E 01         ---------------------------------------------------------------+
4.4500E 01     7.5000E 01         ---------------------------------------------------------------+
4.5000E 01     7.5000E 01         ---------------------------------------------------------------+
4.5500E 01     7.5000E 01         ---------------------------------------------------------------+
4.6000E 01     7.5000E 01         ---------------------------------------------------------------+
4.6500E 01     2.5000E 01         +
4.7000E 01     2.5000E 01         +
4.7500E 01     2.5000E 01         +
4.8000E 01     2.5000E 01         +
```

EFFLUENT NITRATE CONCENTRATION

MINIMUM 3.8100E 00 — SNF VERSUS TIME — MAXIMUM 5.0000E 01

TIME	SNF
0.0000E-01	5.0000E 01
5.0000E-01	9.6515E 00
1.0000E 00	4.5396E 00
1.5000E 00	3.8920E 00
2.0000E 00	3.8173E 00
2.5000E 00	1.4031E 01
3.0000E 00	1.5492E 01
3.5000E 00	1.5701E 01
4.0000E 00	1.5731E 01
4.5000E 00	6.7526E 00
5.0000E 00	5.4609E 00
5.5000E 00	4.0107E 00
6.0000E 00	3.8322E 00
6.5000E 00	5.0432E 00
7.0000E 00	5.2164E 00
7.5000E 00	5.2412E 00
8.0000E 00	5.2512E 00
8.5000E 00	1.4236E 01
9.0000E 00	1.5522E 01
9.5000E 00	1.1923E 01
1.0000E 01	1.1483E 01
1.0500E 01	6.1413E 00
1.1000E 01	5.3734E 00
1.1500E 01	5.2636E 00
1.2000E 01	5.2479E 00
1.2500E 01	5.2457E 00
1.3000E 01	5.2454E 00
1.3500E 01	3.9834E 00
1.4000E 01	3.8289E 00
1.4500E 01	1.4033E 01
1.5000E 01	1.5492E 01
1.5500E 01	1.5701E 01
1.6000E 01	1.5731E 01
1.6500E 01	6.7526E 00
1.7000E 01	5.4609E 00
1.7500E 01	4.0107E 00
1.8000E 01	3.8322E 00
1.8500E 01	5.0432E 00
1.9000E 01	5.2164E 00
1.9500E 01	5.2412E 00
2.0000E 01	5.2512E 00
2.0500E 01	1.4236E 01
2.1000E 01	1.5522E 01
2.1500E 01	1.1923E 01
2.2000E 01	1.1483E 01
2.2500E 01	6.1413E 00
2.3000E 01	5.3734E 00
2.3500E 01	5.2636E 00
2.4000E 01	5.2479E 00
2.4500E 01	5.2457E 00
2.5000E 01	5.2454E 00



EFFLUENT NITRATE CONCENTRATION

MINIMUM 3.8100E 00 — SNF VERSUS TIME — MAXIMUM 5.0000E 01

TIME	SNF	I ... I
2.5500E 01	3.9834E 00	+
2.6000E 01	3.8289E 00	+
2.6500E 01	1.4033E 01	-----------+
2.7000E 01	1.5492E 01	------------+
2.7500E 01	1.5701E 01	------------+
2.8000E 01	1.5731E 01	------------+
2.8500E 01	6.7526E 00	---+
2.9000E 01	5.4609E 00	-+
2.9500E 01	4.0107E 00	+
3.0000E 01	3.8322E 00	+
3.0500E 01	5.0432E 00	-+
3.1000E 01	5.2164E 00	-+
3.1500E 01	5.2412E 00	-+
3.2000E 01	5.2512E 00	-+
3.2500E 01	1.4236E 01	-----------+
3.3000E 01	1.5522E 01	------------+
3.3500E 01	1.1923E 01	--------+
3.4000E 01	1.1483E 01	--------+
3.4500E 01	6.1413E 00	--+
3.5000E 01	5.3734E 00	-+
3.5500E 01	5.2636E 00	-+
3.6000E 01	5.2479E 00	-+
3.6500E 01	5.2457E 00	-+
3.7000E 01	5.2454E 00	-+
3.7500E 01	3.9834E 00	+
3.8000E 01	3.8289E 00	+
3.8500E 01	1.4033E 01	-----------+
3.9000E 01	1.5492E 01	------------+
3.9500E 01	1.5701E 01	------------+
4.0000E 01	1.5731E 01	------------+
4.0500E 01	6.7526E 00	---+
4.1000E 01	5.4609E 00	-+
4.1500E 01	4.0107E 00	+
4.2000E 01	3.8322E 00	+
4.2500E 01	5.0432E 00	-+
4.3000E 01	5.2164E 00	-+
4.3500E 01	5.2412E 00	-+
4.4000E 01	5.2512E 00	-+
4.4500E 01	1.4236E 01	-----------+
4.5000E 01	1.5522E 01	------------+
4.5500E 01	1.1923E 01	--------+
4.6000E 01	1.1483E 01	--------+
4.6500E 01	6.1413E 00	--+
4.7000E 01	5.3734E 00	-+
4.7500E 01	5.2636E 00	-+
4.8000E 01	5.2479E 00	-+

T. F. INFLUENT CONCENTRATION

```
                                    MINIMUM                SCO    VERSUS TIME               MAXIMUM
                                  2.5000E 02                                              3.5000E 02
   TIME           SCO                I                                                        I
0.0000E-01    2.5000E 02             +
5.0000E-01    2.5000E 02             +
1.0000E 00    2.5000E 02             +
1.5000E 00    2.5000E 02             +
2.0000E 00    3.5000E 02             ---------------------------------------------------------+
2.5000E 00    3.5000E 02             ---------------------------------------------------------+
3.0000E 00    3.5000E 02             ---------------------------------------------------------+
3.5000E 00    3.5000E 02             ---------------------------------------------------------+
4.0000E 00    3.5000E 02             ---------------------------------------------------------+
4.5000E 00    2.5000E 02             +
5.0000E 00    2.5000E 02             +
5.5000E 00    2.5000E 02             +
6.0000E 00    2.5000E 02             +
6.5000E 00    2.5000E 02             +
7.0000E 00    2.5000E 02             +
7.5000E 00    2.5000E 02             +
8.0000E 00    3.5000E 02             ---------------------------------------------------------+
8.5000E 00    3.5000E 02             ---------------------------------------------------------+
9.0000E 00    3.5000E 02             ---------------------------------------------------------+
9.5000E 00    3.5000E 02             ---------------------------------------------------------+
1.0000E 01    3.5000E 02             ---------------------------------------------------------+
1.0500E 01    2.5000E 02             +
1.1000E 01    2.5000E 02             +
1.1500E 01    2.5000E 02             +
1.2000E 01    2.5000E 02             +
1.2500E 01    2.5000E 02             +
1.3000E 01    2.5000E 02             +
1.3500E 01    2.5000E 02             +
1.4000E 01    3.5000E 02             ---------------------------------------------------------+
1.4500E 01    3.5000E 02             ---------------------------------------------------------+
1.5000E 01    3.5000E 02             ---------------------------------------------------------+
1.5500E 01    3.5000E 02             ---------------------------------------------------------+
1.6000E 01    3.5000E 02             ---------------------------------------------------------+
1.6500E 01    2.5000E 02             +
1.7000E 01    2.5000E 02             +
1.7500E 01    2.5000E 02             +
1.8000E 01    2.5000E 02             +
1.8500E 01    2.5000E 02             +
1.9000E 01    2.5000E 02             +
1.9500E 01    2.5000E 02             +
2.0000E 01    3.5000E 02             ---------------------------------------------------------+
2.0500E 01    3.5000E 02             ---------------------------------------------------------+
2.1000E 01    3.5000E 02             ---------------------------------------------------------+
2.1500E 01    3.5000E 02             ---------------------------------------------------------+
2.2000E 01    3.5000E 02             ---------------------------------------------------------+
2.2500E 01    2.5000E 02             +
2.3000E 01    2.5000E 02             +
2.3500E 01    2.5000E 02             +
2.4000E 01    2.5000E 02             +
2.4500E 01    2.5000E 02             +
2.5000E 01    2.5000E 02             +
```

T. F. INFLUENT CONCENTRATION

```
                                     MINIMUM                 SCO     VERSUS TIME                 MAXIMUM
                                    2. 5000E 02                                                3. 5000E 02
 TIME            SCO                 I                                                             I
2. 5500E 01    2. 5000E 02           +
2. 6000E 01    3. 5000E 02           -----------------------------------------------------------+
2. 6500E 01    3. 5000E 02           -----------------------------------------------------------+
2. 7000E 01    3. 5000E 02           -----------------------------------------------------------+
2. 7500E 01    3. 5000E 02           -----------------------------------------------------------+
2. 8000E 01    3. 5000E 02           -----------------------------------------------------------+
2. 8500E 01    2. 5000E 02           +
2. 9000E 01    2. 5000E 02           +
2. 9500E 01    2. 5000E 02           +
3. 0000E 01    2. 5000E 02           +
3. 0500E 01    2. 5000E 02           +
3. 1000E 01    2. 5000E 02           +
3. 1500E 01    2. 5000E 02           +
3. 2000E 01    3. 5000E 02           -----------------------------------------------------------+
3. 2500E 01    3. 5000E 02           -----------------------------------------------------------+
3. 3000E 01    3. 5000E 02           -----------------------------------------------------------+
3. 3500E 01    3. 5000E 02           -----------------------------------------------------------+
3. 4000E 01    3. 5000E 02           -----------------------------------------------------------+
3. 4500E 01    2. 5000E 02           +
3. 5000E 01    2. 5000E 02           +
3. 5500E 01    2. 5000E 02           +
3. 6000E 01    2. 5000E 02           +
3. 6500E 01    2. 5000E 02           +
3. 7000E 01    2. 5000E 02           +
3. 7500E 01    2. 5000E 02           +
3. 8000E 01    3. 5000E 02           -----------------------------------------------------------+
3. 8500E 01    3. 5000E 02           -----------------------------------------------------------+
3. 9000E 01    3. 5000E 02           -----------------------------------------------------------+
3. 9500E 01    3. 5000E 02           -----------------------------------------------------------+
4. 0000E 01    3. 5000E 02           -----------------------------------------------------------+
4. 0500E 01    2. 5000E 02           +
4. 1000E 01    2. 5000E 02           +
4. 1500E 01    2. 5000E 02           +
4. 2000E 01    2. 5000E 02           +
4. 2500E 01    2. 5000E 02           +
4. 3000E 01    2. 5000E 02           +
4. 3500E 01    2. 5000E 02           +
4. 4000E 01    3. 5000E 02           -----------------------------------------------------------+
4. 4500E 01    3. 5000E 02           -----------------------------------------------------------+
4. 5000E 01    3. 5000E 02           -----------------------------------------------------------+
4. 5500E 01    3. 5000E 02           -----------------------------------------------------------+
4. 6000E 01    3. 5000E 02           -----------------------------------------------------------+
4. 6500E 01    2. 5000E 02           +
4. 7000E 01    2. 5000E 02           +
4. 7500E 01    2. 5000E 02           +
4. 8000E 01    2. 5000E 02           +
```

T. F. EFFLUENT CONCENTRATION

```
                                     MINIMUM                SCF    VERSUS TIME             MAXIMUM
                                   1. 6398E 01                                          2. 5000E 02
   TIME              SCF              I                                                      I
 0. 0000E-01     2. 5000E 02      -----------------------------------------------------------*
 5. 0000E-01     7. 1545E 01      -------------+
 1. 0000E 00     2. 9192E 01      ---+
 1. 5000E 00     1. 9140E 01      +
 2. 0000E 00     1. 6761E 01      +
 2. 5000E 00     2. 7803E 01      ---+
 3. 0000E 00     3. 0801E 01      ----+
 3. 5000E 00     3. 1615E 01      ----+
 4. 0000E 00     3. 1836E 01      ----+
 4. 5000E 00     2. 4724E 01      --+
 5. 0000E 00     2. 2842E 01      --+
 5. 5000E 00     1. 8169E 01      +
 6. 0000E 00     1. 7051E 01      +
 6. 5000E 00     2. 1238E 01      --+
 7. 0000E 00     2. 2375E 01      --+
 7. 5000E 00     2. 2196E 01      --+
 8. 0000E 00     2. 2130E 01      --+
 8. 5000E 00     2. 9261E 01      ---+
 9. 0000E 00     3. 1197E 01      ----+
 9. 5000E 00     2. 5248E 01      --+
 1. 0000E 01     2. 3826E 01      --+
 1. 0500E 01     2. 2569E 01      --+
 1. 1000E 01     2. 2263E 01      --+
 1. 1500E 01     2. 2653E 01      --+
 1. 2000E 01     2. 2759E 01      --+
 1. 2500E 01     2. 2788E 01      --+
 1. 3000E 01     2. 2796E 01      --+
 1. 3500E 01     1. 7634E 01      +
 1. 4000E 01     1. 6404E 01      +
 1. 4500E 01     2. 7706E 01      ---+
 1. 5000E 01     3. 0774E 01      ----+
 1. 5500E 01     3. 1608E 01      ----+
 1. 6000E 01     3. 1834E 01      ----+
 1. 6500E 01     2. 4723E 01      --+
 1. 7000E 01     2. 2842E 01      --+
 1. 7500E 01     1. 8169E 01      +
 1. 8000E 01     1. 7051E 01      +
 1. 8500E 01     2. 1238E 01      --+
 1. 9000E 01     2. 2375E 01      --+
 1. 9500E 01     2. 2196E 01      --+
 2. 0000E 01     2. 2130E 01      --+
 2. 0500E 01     2. 9261E 01      ---+
 2. 1000E 01     3. 1197E 01      ----+
 2. 1500E 01     2. 5248E 01      --+
 2. 2000E 01     2. 3826E 01      --+
 2. 2500E 01     2. 2569E 01      --+
 2. 3000E 01     2. 2263E 01      --+
 2. 3500E 01     2. 2653E 01      --+
 2. 4000E 01     2. 2759E 01      --+
 2. 4500E 01     2. 2788E 01      --+
 2. 5000E 01     2. 2796E 01      --+
```

T. F. EFFLUENT CONCENTRATION

TIME	SCF	MINIMUM 1. 6398E 01 I	SCF VERSUS TIME	MAXIMUM 2. 5000E 02 I
2. 5500E 01	1. 7634E 01	+		
2. 6000E 01	1. 6404E 01	+		
2. 6500E 01	2. 7706E 01	--+		
2. 7000E 01	3. 0774E 01	---+		
2. 7500E 01	3. 1608E 01	---+		
2. 8000E 01	3. 1834E 01	---+		
2. 8500E 01	2. 4723E 01	-+		
2. 9000E 01	2. 2842E 01	-+		
2. 9500E 01	1. 8169E 01	+		
3. 0000E 01	1. 7051E 01	+		
3. 0500E 01	2. 1238E 01	-+		
3. 1000E 01	2. 2375E 01	-+		
3. 1500E 01	2. 2196E 01	-+		
3. 2000E 01	2. 2130E 01	-+		
3. 2500E 01	2. 9261E 01	--+		
3. 3000E 01	3. 1197E 01	---+		
3. 3500E 01	2. 5248E 01	-+		
3. 4000E 01	2. 3826E 01	-+		
3. 4500E 01	2. 2569E 01	-+		
3. 5000E 01	2. 2263E 01	-+		
3. 5500E 01	2. 2653E 01	-+		
3. 6000E 01	2. 2759E 01	-+		
3. 6500E 01	2. 2788E 01	-+		
3. 7000E 01	2. 2796E 01	-+		
3. 7500E 01	1. 7634E 01	+		
3. 8000E 01	1. 6404E 01	+		
3. 8500E 01	2. 7706E 01	--+		
3. 9000E 01	3. 0774E 01	---+		
3. 9500E 01	3. 1608E 01	---+		
4. 0000E 01	3. 1834E 01	---+		
4. 0500E 01	2. 4723E 01	-+		
4. 1000E 01	2. 2842E 01	-+		
4. 1500E 01	1. 8169E 01	+		
4. 2000E 01	1. 7051E 01	+		
4. 2500E 01	2. 1238E 01	-+		
4. 3000E 01	2. 2375E 01	-+		
4. 3500E 01	2. 2196E 01	-+		
4. 4000E 01	2. 2130E 01	-+		
4. 4500E 01	2. 9261E 01	--+		
4. 5000E 01	3. 1197E 01	---+		
4. 5500E 01	2. 5248E 01	-+		
4. 6000E 01	2. 3826E 01	-+		
4. 6500E 01	2. 2569E 01	-+		
4. 7000E 01	2. 2263E 01	-+		
4. 7500E 01	2. 2653E 01	-+		
4. 8000E 01	2. 2759E 01	-+		

A. S. EFFLUENT CONCENTRATION

```
                                        MINIMUM               S       VERSUS TIME             MAXINUM
                                       5. 0000E 00                                           5. 0000E 01
   TIME             S                   I                                                         I
 0. 0000E-01     5. 0000E 01            ---------------------------------------------------------+
 5. 0000E-01     4. 6252E 01            ----------------------------------------------------+
 1. 0000E 00     4. 1687E 01            ----------------------------------------------+
 1. 5000E 00     3. 7121E 01            -----------------------------------------+
 2. 0000E 00     3. 2770E 01            -----------------------------------+
 2. 5000E 00     2. 8755E 01            ------------------------------+
 3. 0000E 00     2. 5145E 01            --------------------------+
 3. 5000E 00     2. 1885E 01            ---------------------+
 4. 0000E 00     1. 8961E 01            ------------------+
 4. 5000E 00     1. 6305E 01            --------------+
 5. 0000E 00     1. 3923E 01            -----------+
 5. 5000E 00     1. 1793E 01            --------+
 6. 0000E 00     9. 9341E 00            ------+
 6. 5000E 00     8. 3971E 00            ----+
 7. 0000E 00     7. 1307E 00            --+
 7. 5000E 00     6. 0725E 00            -+
 8. 0000E 00     5. 1919E 00            +
 8. 5000E 00     5. 0000E 00            +
 9. 0000E 00     5. 0000E 00            +
 9. 5000E 00     5. 0000E 00            +
 1. 0000E 01     5. 0000E 00            +
 1. 0500E 01     5. 0000E 00            +
 1. 1000E 01     5. 0000E 00            +
 1. 1500E 01     5. 0000E 00            +
 1. 2000E 01     5. 0000E 00            +
 1. 2500E 01     5. 0000E 00            +
 1. 3000E 01     5. 0000E 00            +
 1. 3500E 01     5. 0000E 00            +
 1. 4000E 01     5. 0000E 00            +
 1. 4500E 01     5. 0000E 00            +
 1. 5000E 01     5. 0000E 00            +
 1. 5500E 01     5. 0000E 00            +
 1. 6000E 01     5. 0000E 00            +
 1. 6500E 01     5. 0000E 00            +
 1. 7000E 01     5. 0000E 00            +
 1. 7500E 01     5. 0000E 00            +
 1. 8000E 01     5. 0000E 00            +
 1. 8500E 01     5. 0000E 00            +
 1. 9000E 01     5. 0000E 00            +
 1. 9500E 01     5. 0000E 00            +
 2. 0000E 01     5. 0000E 00            +
 2. 0500E 01     5. 0000E 00            +
 2. 1000E 01     5. 0000E 00            +
 2. 1500E 01     5. 0000E 00            +
 2. 2000E 01     5. 0000E 00            +
 2. 2500E 01     5. 0000E 00            +
 2. 3000E 01     5. 0000E 00            +
 2. 3500E 01     5. 0000E 00            +
 2. 4000E 01     5. 0000E 00            +
 2. 4500E 01     5. 0000E 00            +
 2. 5000E 01     5. 0000E 00            +
```

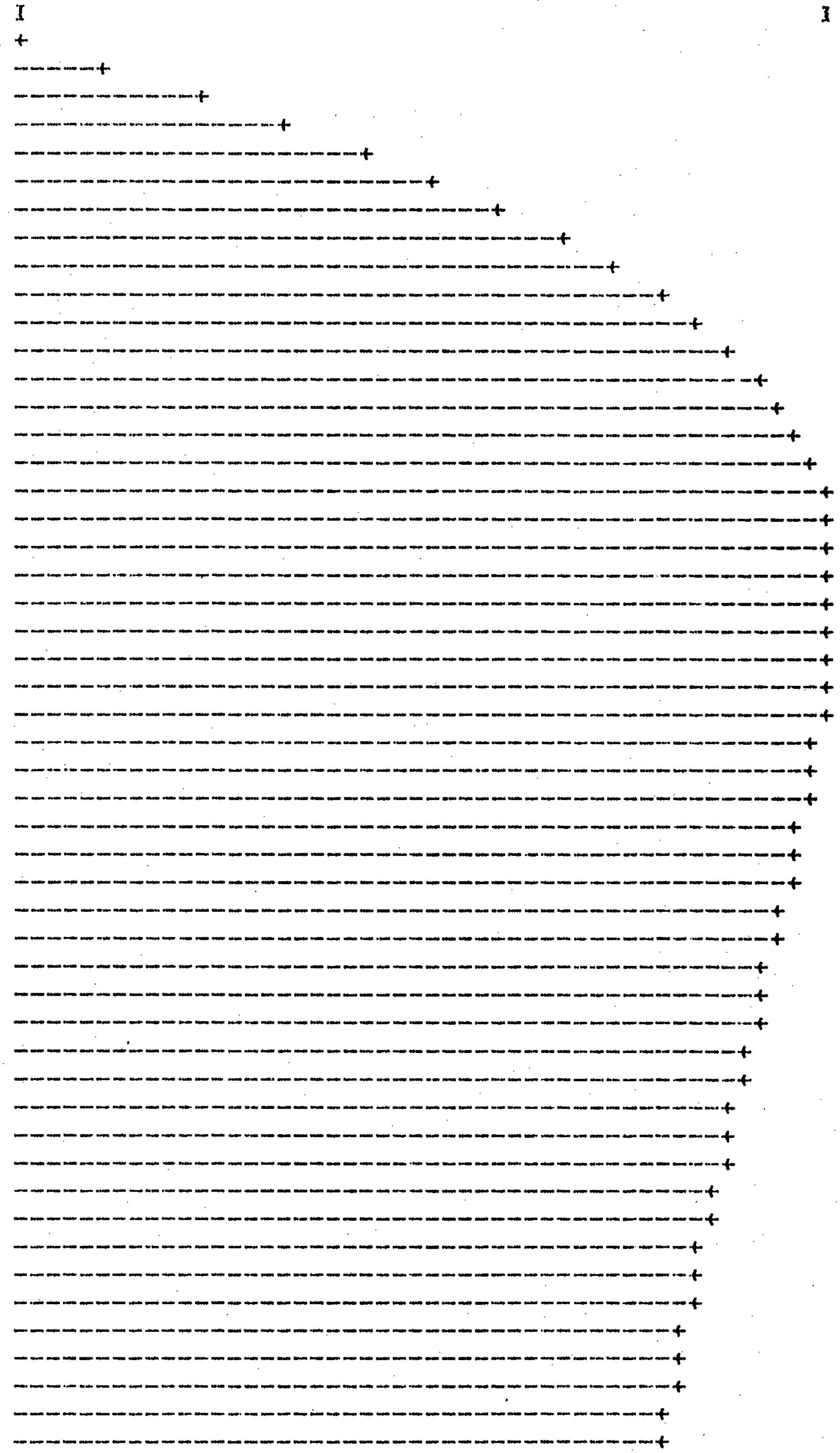
A.5. EFFLUENT CONCENTRATION

		MINIMUM 5.0000E 00	S VERSUS TIME	MAXIMUM 5.0000E 01
TIME	S	I		I
2.5500E 01	5.0000E 00	+		
2.6000E 01	5.0000E 00	+		
2.6500E 01	5.0000E 00	+		
2.7000E 01	5.0000E 00	+		
2.7500E 01	5.0000E 00	+		
2.8000E 01	5.0000E 00	+		
2.8500E 01	5.0000E 00	+		
2.9000E 01	5.0000E 00	+		
2.9500E 01	5.0000E 00	+		
3.0000E 01	5.0000E 00	+		
3.0500E 01	5.0000E 00	+		
3.1000E 01	5.0000E 00	+		
3.1500E 01	5.0000E 00	+		
3.2000E 01	5.0000E 00	+		
3.2500E 01	5.0000E 00	+		
3.3000E 01	5.0000E 00	+		
3.3500E 01	5.0000E 00	+		
3.4000E 01	5.0000E 00	+		
3.4500E 01	5.0000E 00	+		
3.5000E 01	5.0000E 00	+		
3.5500E 01	5.0000E 00	+		
3.6000E 01	5.0000E 00	+		
3.6500E 01	5.0000E 00	+		
3.7000E 01	5.0000E 00	+		
3.7500E 01	5.0000E 00	+		
3.8000E 01	5.0000E 00	+		
3.8500E 01	5.0000E 00	+		
3.9000E 01	5.0000E 00	+		
3.9500E 01	5.0000E 00	+		
4.0000E 01	5.0000E 00	+		
4.0500E 01	5.0000E 00	+		
4.1000E 01	5.0000E 00	+		
4.1500E 01	5.0000E 00	+		
4.2000E 01	5.0000E 00	+		
4.2500E 01	5.0000E 00	+		
4.3000E 01	5.0000E 00	+		
4.3500E 01	5.0000E 00	+		
4.4000E 01	5.0000E 00	+		
4.4500E 01	5.0000E 00	+		
4.5000E 01	5.0000E 00	+		
4.5500E 01	5.0000E 00	+		
4.6000E 01	5.0000E 00	+		
4.6500E 01	5.0000E 00	+		
4.7000E 01	5.0000E 00	+		
4.7500E 01	5.0000E 00	+		
4.8000E 01	5.0000E 00	+		

ORGANISM CONCENTRATION

MINIMUM 1.0000E 02 — X VERSUS TIME — MAXIMUM 1.2369E 02

TIME	X
0.0000E-01	1.0000E 02
5.0000E-01	1.0268E 02
1.0000E 00	1.0527E 02
1.5000E 00	1.0772E 02
2.0000E 00	1.1001E 02
2.5000E 00	1.1210E 02
3.0000E 00	1.1401E 02
3.5000E 00	1.1572E 02
4.0000E 00	1.1725E 02
4.5000E 00	1.1858E 02
5.0000E 00	1.1973E 02
5.5000E 00	1.2073E 02
6.0000E 00	1.2155E 02
6.5000E 00	1.2217E 02
7.0000E 00	1.2265E 02
7.5000E 00	1.2301E 02
8.0000E 00	1.2327E 02
8.5000E 00	1.2344E 02
9.0000E 00	1.2355E 02
9.5000E 00	1.2365E 02
1.0000E 01	1.2369E 02
1.0500E 01	1.2364E 02
1.1000E 01	1.2356E 02
1.1500E 01	1.2344E 02
1.2000E 01	1.2331E 02
1.2500E 01	1.2315E 02
1.3000E 01	1.2298E 02
1.3500E 01	1.2286E 02
1.4000E 01	1.2271E 02
1.4500E 01	1.2250E 02
1.5000E 01	1.2229E 02
1.5500E 01	1.2209E 02
1.6000E 01	1.2191E 02
1.6500E 01	1.2173E 02
1.7000E 01	1.2156E 02
1.7500E 01	1.2141E 02
1.8000E 01	1.2125E 02
1.8500E 01	1.2104E 02
1.9000E 01	1.2083E 02
1.9500E 01	1.2063E 02
2.0000E 01	1.2043E 02
2.0500E 01	1.2022E 02
2.1000E 01	1.2003E 02
2.1500E 01	1.1989E 02
2.2000E 01	1.1975E 02
2.2500E 01	1.1957E 02
2.3000E 01	1.1938E 02
2.3500E 01	1.1920E 02
2.4000E 01	1.1901E 02
2.4500E 01	1.1883E 02
2.5000E 01	1.1865E 02



ORGANISM CONCENTRATION

MINIMUM 1.0000E 02 — X VERSUS TIME — MAXIMUM 1.2369E 02

TIME	X
2.5500E 01	1.1852E 02
2.6000E 01	1.1837E 02
2.6500E 01	1.1817E 02
2.7000E 01	1.1799E 02
2.7500E 01	1.1782E 02
2.8000E 01	1.1767E 02
2.8500E 01	1.1753E 02
2.9000E 01	1.1739E 02
2.9500E 01	1.1728E 02
3.0000E 01	1.1716E 02
3.0500E 01	1.1699E 02
3.1000E 01	1.1682E 02
3.1500E 01	1.1666E 02
3.2000E 01	1.1650E 02
3.2500E 01	1.1634E 02
3.3000E 01	1.1620E 02
3.3500E 01	1.1609E 02
3.4000E 01	1.1598E 02
3.4500E 01	1.1584E 02
3.5000E 01	1.1570E 02
3.5500E 01	1.1556E 02
3.6000E 01	1.1542E 02
3.6500E 01	1.1528E 02
3.7000E 01	1.1514E 02
3.7500E 01	1.1504E 02
3.8000E 01	1.1492E 02
3.8500E 01	1.1477E 02
3.9000E 01	1.1463E 02
3.9500E 01	1.1450E 02
4.0000E 01	1.1439E 02
4.0500E 01	1.1429E 02
4.1000E 01	1.1418E 02
4.1500E 01	1.1410E 02
4.2000E 01	1.1401E 02
4.2500E 01	1.1388E 02
4.3000E 01	1.1375E 02
4.3500E 01	1.1362E 02
4.4000E 01	1.1350E 02
4.4500E 01	1.1338E 02
4.5000E 01	1.1327E 02
4.5500E 01	1.1319E 02
4.6000E 01	1.1311E 02
4.6500E 01	1.1300E 02
4.7000E 01	1.1290E 02
4.7500E 01	1.1279E 02
4.8000E 01	1.1268E 02

APPENDIX B

VARIABLE LIST

The program written in BASIC uses the same model as the CSMP program. The programs use Runge-Kutta as a method of integration.

The variables used in the two programs are described in the following pages; the BASIC program is arranged as follows:

Line #	Function
100 - 900	constants, initial conditions, pulses set
1000 - 1999	anoxic tower with lines 1500-1599 as subroutine
2000 - 2999	trickling filter with lines 2500-2999 as subroutine
3000 - 3999	activated sludge with lines 3500-3999 as subroutine

VARIABLE LIST

ANOXIC TOWER

CSMP		BASIC
A	Cross sectional area (ft)	A
ZLAM	Rate constant (gal/min-ft^3)	ZLAM
U	Packing coefficient	U
R	Effectiveness factor	R
Z	Column depth (ft)	Z
VOL	Volume (ft^3)	VOL
QINZ	Steady-state flow (mgd)	QZ
QIN1	Steady-state flow (gpm)	QA
QIN3	Additional peak flow (mgd)	Q3
QINF	Additional peak flow (gpm)	QB
QO	Flow thru anoxic tower (gpm)	QO
QZ	Conversion of QO to ft^3/hr	
SNI	Initial condition - nitrates (mg/L)	SNI
SNINF	Influent nitrates (mg/L)	SN
SNO	Influent nitrates (pulse)	NS
SN1	Peak flow - nitrates (mg/L)	S1
SNF	Effluent - nitrate (mg/L)	FS

TRICKLING FILTER

CA	Cross sectional area (ft)	CA
CLAM	Rate constant (gal/min - ft^3)	CLAM
ZT	Depth (ft)	ZT
W	Packing coefficient	W
B	Effectiveness factor	B
CVOL	Volume (ft^3)	CVOL
QIC2	Constant flow rate (mgd)	Q4
QIC1	Constant flow (gpm)	QC
QIC3	Pulse flow (mgd)	Q5
QICF	Pulse flow (gpm)	QD
QTO	Flow thru trickling filter (gpm)	QT
Q1	Conversion of QTO to ft^3/hr	
SCI	Initial condition - carbon (mg/L)	CI
SC1	Pulse conc. - carbon (mg/L)	C1
SCINF	Carbonaceous substrate influent (mg/L)	CF
SCO	Pulse-carbonaceous substrate influent	SO

VARIABLE LIST

ACTIVATED SLUDGE

CSMP		BASIC
K	Rate constant (1/day)	K
K1	K (1/hr)	
KS	Half-velocity constant (mg/L)	KS
KD	Endogenous decay coefficient (1/day)	KD
K2	KD (1/hr)	
YG	Yield coefficient	YG
AVOL1	Volume (ft^3)	AVOL
QR	Set recirculation	QR
XI	Initial condition on organism (mg/L)	XI
SC	Initial condition on substrate (mg/L)	SC
XC	Startup condition on organism (mg/L)	XC
XO	Organism concentration with recycle (mg/L)	XO
X	Organism concentration (mg/L)	X
S	Substrate concentration (mg/L)	S
QTOA	Influent flow to activated sludge (gpm)	QE

ADDITIONAL VARIABLES - BASIC:

M8 = Counter (outputs every 5th valve)
T, T2, T3 = Time for anoxic tower, trickling filter, activated sludge, respectively
K1, K2, K3, K4
K5, K6, K7, K8 Valves for Runge-Kutta
S8, X8
T4, T5, T6 = Counter for time array

EQUATIONS DESCRIBING PROCESS:

ANOXIC TOWER:

DN = U1 - [EXP(U2)] * FS
where
U1 = (QO/VOL) * (NS-FS)
UZ = [-ZLAM * (Z^R)]/[(QO/A)^U]

TRICKLING FILTER:

DC = U3 - [EXP(U4)] * SF
where
U3 = (QT/CVOL) * (SO - SF)
U4 = [-CLAM * [ZT^B)]/[(QT/CA)^W]

ACTIVATED SLUDGE:

X(I) = (US - U6) * H
where
U5 = (QE/AVOL) * (XØ - X) * 1440
U6 = [((K * YG) * (S/CS + KS)) - KD * X)]
H = Increment for Runge-Kutta

S(I) - H * [((QE/AVOL) * (SF (T3) - S)) * 1440 - (K * (S/CS + KS)) * X)]

ADDITIONAL VARIABLES NEEDED FOR BASIC PROGRAM:

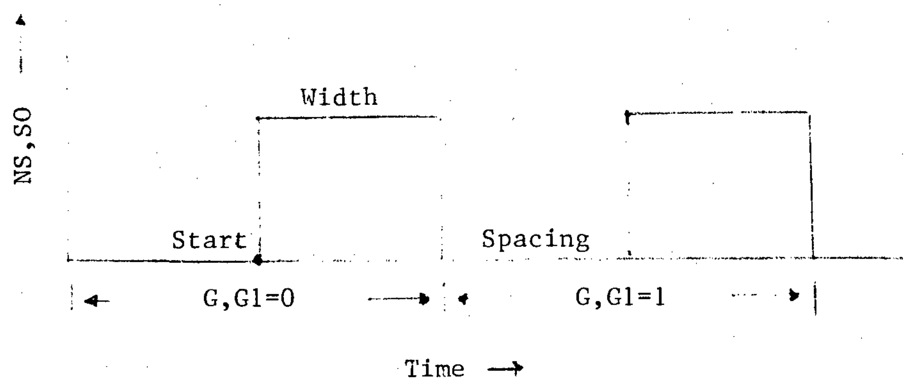
P1: Time where pulse begins (for TRIG1 in CSMP)
P2: Time spacing between pulses (for TRIG1)
P3: Length of pulse (for TRIG1)

P4: Time where pulse beings (for TRIG2)
P5: Time spacing between pulses
P6: Length of pulse

P7: Begin pulse (TRIG 3)
P8: Spacing
P9: Length

PØ: Begin pulse (TRIG4)
PI: Spacing
PJ: Length

G,G1: To keep pulses moving with time:



APPENDIX C

BASIC MODEL

```
20 LPRINT:LPRINT:LPRINT
30 LPRINT CHR$(14)" INDUSTRIAL WASTE TREATMENT PLANT"
40 LPRINT:LPRINT
50 LPRINT CHR$(14)"              HOLSTON AAP"
60 LPRINT:LPRINT:LPRINT
65 LPRINT:LPRINT:LPRINT
70 LPRINT TAB(15);"HOW MANY HOURS WOULD YOU LIKE TO SEE ?"
72 PRINT"HOW MANY HOURS WOULD YOU LIKE TO SEE?"
75 INPUT "CHOOSE UP TO 48";LP
77 LPRINT TAB(15);LP
80 LPRINT:LPRINT:LPRINT
82 INPUT "INPUT FLOW FROM AREA B (MGD)   ";QB
83 LPRINT:LPRINT
84 LPRINT TAB(15);"FLOW FROM AREA B (MGD) IS
"QB:LPRINT:LPRINT
85 INPUT "INPUT FLOW FROM AREA A (MGD)   ";QD
86 LPRINT TAB(15);"FLOW FROM AREA A (MGD) IS
"QD:LPRINT:LPRINT
87 LPRINT TAB(15);"ENTER VALUE FOR COD (mg/L) IN TRICKLING
FILTER INFLUENT":INPUT CF:LPRINT TAB(15);CF
88 LPRINT TAB(15);"DO YOU WANT THE TRICKLING FILTER EFFLUENT
TO BE THE":LPRINT TAB(15);"ACTIVATED SLUDGE INFLUENT ? (Y or
N)":INPUT X$
89 LPRINT TAB(15);X$:LPRINT:LPRINT
90 DIM QO(500),QT(500),S(500),X(500),SF(500)
98 DIM T(500)
100 REM ...CONSTANTS
110 REM ...ANOXIC TOWERS
120 A = 6655!:REM ...AREA (C.S.)
130 ZLAM = 1.45:REM ... RATE CONSTANT (CF/CF-HR)
135 U = .5: REM ...PACKING COEFF.
140 R = .6: REM ...EFFECTIVENESS FACTOR FOR TOWER
150 Z = 10!: REM ...DEPTH OF COLUMN MEDIA
160 VOL = 66550!: REM ...VOLUME
170 Q2 = 15!: REM ...CONSTANT FLOW RATE
171 REM ...FLOW RATES ARE MGD.
180 Q3 = 4.5 :REM  ...PEAK NITRATES
190 SN = 25!:REM ...PEAK NITRATES
200 S1 = 10!:REM ...INFLUENT NITRATES
210 SNI = 25!:REM ...INIT. COND.-NITRATES
220 REM ...TRICKLING FILTER
230 CA = 10000:REM ...AREA (C.S.)
240 CLAM = .33: REM ...RATE CONSTANT FOR TRICKLING FILTER
250 ZT = 26!:REM ...DEPTH
260 W = .5: REM ...PACKING COEFF.
270 B = .67:REM ...EFFECTIVENESS FACTOR
280 CVOL = 260000!
290 Q4 = 1.1: REM ...CONS. FLOW (MGD)
300 Q5 = .25: REM ...ADDITIONAL PEAK FLOW
310 REM ... CF ... SUBSTRATE C INFL."
320 C1 = 100
330 CI = 50 :REM ...INIT. COND. (MG/L)
340 REM ...ACTIVATED SLUDGE
350 K = 5:REM ...RATE CONSTANT (1/DAY)
351 K = K/24: REM ...CONVERT TO (1/HR.)
```

```
360 KS = 60:REM ...HALF REACTION CONSTANT
370 KD = .06 :REM ...ENDOGENOUS DECAY COEFF. (1/DAY)
371 KD = KD / 24: REM     ...(1/HR.)
380 YG = .6: REM ...YEILD COEFF.
390 AVOL = 2870000!
410 QR = .25: REM ...SET RECIRCULATION
420 XI = 100 : REM  ...INIT. COND. ORG. CONC.
430 SC = 50 :REM ... INITIAL SUBSTRATE (MG/L)
440 XC = 0: REM  ...INIT.COND.
450 REM ...FLOWS, (GPM)
460 QA = (Q3 / 1440) * 1000000!
470 QB = (QB / 1440)* 1000000!
480 QC = (Q5 / 1440) * 1000000!
490 QD = (QD / 1440) * 1000000!
525 REM ...P2,P5,P8,PIARE THE SPACING BETWEEN PULSES.
P1,P4,P7,PO ARE WHERE
526 REM ...THE PULSES BEGIN.   P3,P6,P9,AND PJ ARE THE
LENGTH OF THE PULSE.
527 REM ...ANOXIC TOWER:
530 P1 = 2
540 P2 = .5
550 P3 = 2.4
560 P4 = 2!
570 P5 = 2.5
580 P6 = 3
585 REM TRICKLING FILTER
590 P7 = 2
600 P8 = .5
610 P9 = 2.4
620 PO = 2
630 PI = .5
640 PJ = 2.4
645 H = .1
650 GOSUB 1000: REM ...ANOXIC TOWER
660 GOSUB 2000: REM ...TRICK. FILTER
665 IF X$ = "Y" THEN 680
670 GOSUB 3000: REM ...ACT. SLUDGE
671 GOTO 790
680 GOSUB 4000
790 LPRINT:LPRINT
810 LPRINT:LPRINT:LPRINT
820 LPRINT TAB(15);"TO CHANGE ANY CONSTANTS OR INITIAL "
821 LPRINT
825 LPRINT TAB(15);"CONDITIONS, LIST LINES 100 - 500"
826 LPRINT
830 LPRINT TAB(15);"TO CHANGE PULSES LIST LINES 525 - 640"
900 END
1000 REM ...ANOXIC TOWER
1005 G = 0
1007 G1 = 0
1010 T = 0
1011 T6 = 0
1020 QO = QB
1022 QO = INT(QO * 100 + .5)/100
1023 QO(0) = QO
```

```
1025 NS = SN
1030 FS = SNI
1032 LPRINT
1033 LPRINT TAB(15);"                    ANOXIC TOWER"
1034 LPRINT
1035 LPRINT TAB(15);"TIME     N-INFL.      N-EFFL.      FLOW"
1037 LPRINT TAB(15);"(HRS.)     (mg/L)        (mg/L)       (GPM)"
1038 LPRINT TAB(15);"-----------------------------------------------------"
1039 LPRINT
1040 LPRINT TAB(17);T;TAB(28);NS;TAB(37);FS;TAB(46);QO
1047 M8 = 1
1050 FOR I = 1 TO 481
1052 T = T + H
1053 T6 = T6 + 1
1054 IF T > LP THEN 1450
1055 GOSUB 1500
1060 K1 = H * DN
1070 FS = FS + .5 * K1
1080 GOSUB 1500
1090 K2 = H * DN
1100 FS = FS + .5 *K2 - .5 *K1
1110 GOSUB 1500
1130 K3 = H*DN
1140 FS = FS + K3 - .5 * K2
1150 GOSUB 1500
1160 K4 = H * DN
1165 FS = FS - K3
1170 FS = FS + (1 / 6 ) * ( K1 + 2 * (K2 + K3) + K4)
1206 IF M8 = 5 THEN 1208
1207 GOTO 1230
1208 M8 = 0
1209 NS = INT(NS * 100 + .5) / 100:FS = INT( FS * 100 + .5 )
/ 100
1210 QO = INT(     QO * 100 + .5) / 100
1211 T = INT ( T * 100 + .5 ) / 100
1215 QO(T6) = QO
1217 GOTO 1225
1219 LPRINT:LPRINT:LPRINT
1220 LPRINT "TIME";TAB(10);"N-INFL.";TAB(20);"N-
EFFL.";TAB(31);"FLOW"
1225 LPRINT TAB(17);T;TAB(28);NS;TAB(37);FS;TAB(46);QO
1227 IF T > LP THEN 1450
1230 M8 = M8 + 1
1250 NEXT I
1450 RETURN
1500 REM
1520 IF T >= (P1 + G * P2 + G * P3) THEN 1540
1530 GOTO 1560
1540 IF T <= (P1 + G * P2 + (G + 1) * P3) THEN 1580
1560 NS = SN
B1570 GOTO 1590
1580 NS = SN + S1
1590 IF T >= (P4 + G1 * P5 + G1  * P6) THEN 1640
1630 GOTO 1660
1640 IF T <= (P4 + G1 * P5 + (G1 + 1) * P6) THEN 1680
```

```
1660 QO = QB
1665 QO(T6) = QO
1670 GOTO 1700
1680 QO = QA + QB
1685 QO(T6) = QO
1700 IF T >= (P4 + (G1 + 1) * P6 + (G1 + 1) * P5) THEN GOTO
1720
1710 GOTO 1730
1720 G1 = G1 + 1
1730 U1 = (QO / VOL) * (NS - FS)
1731 U1 = U1 * 8.021: REM ...CONVERSION
1732 U2 = ( - ZLAM * ( Z ^ R)) / ((QO / A) ^ U)
1740 DN = U1 + ( U2 * FS)
1800 RETURN
2000 REM TRICKLING FILTER
2001 LPRINT:LPRINT:LPRINT
2002 T2 =0
2005 G = 0
2006 G1 = 0
2010 SF = CI
2015 M8 = 1
2016 T4 = 0
2020 SO = CF
2030 QT = QD + QO(T4)
2035 QT(0) = QT
2036 QT = . 'T(QT * 100 + .5) / 100
2037 LP.. 'T TAB(28);"TRICKLING FILTER"
2038 LPRINT:LPRINT:LPRINT
2039 LPRINT TAB(17);"TIME     C-INFL.";TAB(35);"C-EFFL.
FLOW"
2045 LPRINT TAB(15);"(HRS.)      (mg/L)";TAB(34);"(mg/L)
(GPM)"
2047 LPRINT
TAB(15);"---------------------------------------------------"
2054 LPRINT TAB(17);T2;TAB(27);SO;TAB(36);SF;TAB(46);QT
2060 FOR J = 1 TO 481
2065 T2 = T2 + H
2066 T4 = T4 + 1
2067 IF T2 > LP THEN 2300
2070 GOSUB 2500
2080 K5 = H * DC
2100 SF = SF + .5 * K5
2110 GOSUB 2500
2120 K6 = H * DC
2130 SF = SF + .5 * K6 - .5 * K5
2140 GOSUB 2500
2150 K7 = H * DC
2160 SF = SF = K7 - .5 * K6
2180 GOSUB 2500
2190 K8 = H * DC
2195 FS = FS - K7
2199 WHY = 2 * (K6 + K7)
2200 SF = SF + .166667 * (K5 + WHY + K8)
2202 SF(T4) = SF
2205 IF M8 = 5 THEN 2215
```

```
2210 GOTO 2260
2215 M8 = 0
2220 IF SF > 10 THEN 2235
2230 SF = 10
2235 SF = INT( SF * 100 + .5) / 100:QT = INT( QT * 100 + .5
)/100
2237 SF(T4) = SF
2240 T2 = INT( T2 * 100 + .5) / 100
2250 LPRINT TAB(17);T2;TAB(27);SO;TAB(36);SF;TAB(46);QT
2260 M8 = M8 + 1
2270 NEXT J
2300 RETURN
2500 REM
2520 IF T2 >= (P7 + G * P8 + G * P9) THEN 2540
2530 GOTO 2560
2540 IF T2 <= (P7 + G * P8 + (G + 1) * P9) THEN 2580
2560 SO = CF
2570 GOTO 2590
2580 SO = CF + C1
2590 IF T2 >=  (P7 + ( G + 1) * P9 + ( G+1) * P8) THEN 2599
2595 GOTO 2600
2599 G = G + 1
2600 IF T2 >= (PO + G1 * PI + G1 * PJ) THEN 2640
2630 GOTO 2660
2640 IF T2 <= (PO + G1 * PI + (G1 + 1) * PJ) THEN 2680
2655 QT(T4) = QT
2660 QT = QD + QO(T4)
2680 QT = QD +  QC + QO(T4)
2685 QT(T4) = QT
2700 IF T2 >= (PO + (G1 + 1) * PJ + ( G1 + 1) * PI) THEN
2720
2710 GOTO 2730
2720 G1 = G1 + 1
2730 U3 = ( QT / CVOL) * (SO - SF) * 8.021
2740 U4 = (- CLAM * (ZT ^ B)) / ((QT / CA ) ^ W)
2750 DC = U3 + (U4 * SF)
2800 RETURN
3000 REM ...ACTIVATED SLUDGE
3010 T3 = 0
3015 M8 = 1
3016 QE = QT(0) + (QR * QT(0))
3017 QE = INT( QE * 100.5)/100
3020 S = SC
3021 LPRINT
3022 LPRINT
3025 X = XC
3026 LPRINT TAB(15);"                    ACTIVATED SLUDGE"
3027 LPRINT
3028 LPRINT TAB(15);"TIME     ORG.CONC.     EFFL.CONC.
FLOW"
3029 LPRINT TAB(15);"(HRS.)     (mg/L)         (mg/L)
(GPM)"
3030 LPRINT
TAB(15);"---------------------------------------------------"
3031 LPRINT TAB(17);T3;TAB(26);X;TAB(37);S;TAB(46);QE
```

```
3050 FOR V = 1 TO 481
3052 T3 = T3  + H
3053 T5 = T5 + 1
3054 IF T3 > LP THEN 3400
3055 S8 = S
3060 X8 = X
3065 I = 1
3070 GOSUB 3500
3075 S8 = S + S(I) / 2
3080 X8 = X + X(I) / 2
3085 I = 2
3090 GOSUB 3500
3095 S8 = S + S(I) / 2
3100 X8 = X + X(I) / 2
3110 1 = 3
3120 GOSUB 3500
3130 S8 = S + S(I) / 2
3140 X8 = X + X(I) / 2
3150 I = 4
3160 GOSUB 3500
3170 S = S + (1 /6) * (S(1) + S(4) + 2 * (S(3) = S(2)))
3180 X = X + (1 /6) * (X(1) + X(4) + 2 * (X(2) + X(3)))
3190 IF M8 = 5 THEN 3210
3200 GOTU 3290
3210 M8 = 0
3212 IF S > 5 THEN 3240
3215 S = 5
3240 S = INT(S * 100 + .5 )/100: X = INT( X * 100 + .5) /
100
3250 T3 = INT (T3 * 100 + .5) / 100: QE = INT(QE * 100 +
3270 LPRINT TAB(17);T3;TAB(26);X;TAB(37);S;TAB(46);QE
3290 M8 = M8 + 1
3310 NEXT V
3400 RETURN
3500 REM
3506 IF X < 10000 THEN 3510
3507 X = 10000
3510 QE = QT(T5) + (QR * QT(T5))
3520 XO = ((XI * QT(T5)) + (X * QR * QT(T5))) / QE
3521 IF S > 5 THEN 3530
3522 S = 5
3530 S(I) = H * (((QE / AVOL) * (SF(T5) -S )) * 8.021 -(K *
(S / (S + KS)) * X))
3538 U5 = (QE/ AVOL) * (XO - X      ) * 8.021
3539 U6 = ((K * YG) * (S / (S + KS)) * X) - (KD * X)
3540 X(I) = H * (U5 + U6)
3550 RETURN
4000 REM ...ACTIVATED SLUDGE FROM TRICKLING FILTER
4100 T4 = 0
4110 M8 = 1
4120 QE = QT(0) + (QR * QT(0))
4130 QE = INT(QE * 100 + .5)/100
4150 LPRINT
4160 LPRINT
4170 X = XC
```

```
4180 LPRINT TAB(15);"                    ACTIVATED SLUDGE"
4190 LPRINT
4200 LPRINT TAB(15);"TIME     ORG.CONC.     EFFL.CONC.
FLOW"
4210 LPRINT TAB(15);"(HRS.)     (mg/L)         (mg/L)
(GPM)"
4220 LPRINT
TAB(15);"-------------------------------------------------------------"
4230 LPRINT TAB(17);T4;TAB(26);X;TAB(37);SF;TAB(46);QE
4240 FOR V = 1 TO 481
4250 T4 = T4 + H
4260 T6 = T6 + 1
4270 IF T4 > LP THEN 3400
4280 S8 = SF
4290 X8 = X
4300 I = 1
4310 GOSUB 4600
4320 S8 = SF + SF(I) / 2
4330 X8 = X + X(I) / 2
4340 I = 2
4350 GOSUB 4600
4360 S8 = SF + SF(I) / 2
4370 X8 = X + X(I) / 2
4380 I = 3
4390 GOSUB 4600
4400 S8 = SF + SF(I) /2
4410 X8 = X + X(I) / 2
4420 I = 4
4430 GOSUB 4600
4440 SF = SF + ( 1 / 6) * (SF (1) + SF(4) + 2 * (SF (3) + SF
(2)))
4450 X = X + (1 / 6) * (X(1) + X(4) + 2 * ( X(3) + X(2)))
4460 IF M8 = 5 THEN 4480
4470 GOTO 4540
4480 M8 = 0
4490 IF SF > 5 THEN 4510
4500 SF = 5
4510 SF = INT ( SF * 100 + .5)/100: X = INT( X * 100 +
4520 T4 = INT(T4 * 100 + .5)/100: QE = INT(QE * 100 +
4530 LPRINT TAB(17);T4;TAB(26;X;TAB(37);SF;TAB(46)QE
4540 M8 = M8 + 1
4550 NEXT V
4560 RETURN
4600 REM
4610 IF X< 10000 THEN 4630
4630 QE = QT(T5) + (QR * QT(T5))/QE
4635 XO = (( XI * QT(T5)) + (X * QR *QT(T5))) / QE
4640 IF SF > 5 THEN 4660
4650 SF = 5
4660 SF(I) = H * (((QE / AVOL) * (SF(T6) - SF))* 8.021 -
(K*(SF/ (SF + KS))* X))
4670 U5 = (QE / AVOL) * (XO - X) * 8.021
4680 U6 = (( K * YG) *(SF /(SF + KS)) * X) - (KD * X)
4690 X(I) = H* (U5 + U6)
4700 RETURN
```

INDUSTRIAL WASTE TREATMENT PLANT

HOLSTON AAP

HOW MANY HOURS WOULD YOU LIKE TO SEE ?
8

FLOW FROM AREA B (MGD) IS 4.5

FLOW FROM AREA A (MGD) IS .5

ENTER VALUE FOR COD (mg/L) IN TRICKLING FILTER INFLUENT
300
DO YOU WANT THE TRICKLING FILTER EFFLUENT TO BE THE ACTIVATED SLUDGE INFLUENT ? (Y or N)
Y

ANOXIC TOWER

TIME (HRS.)	N-INFL. (mg/L)	N-EFFL. (mg/L)	FLOW (GPM)
0	25	25	3125
.5	25	1.38	3125
1	25	1.07	3125
1.5	25	1.07	3125
2	35	2.46	6250
2.5	35	3.88	6250
3	35	3.93	6250
3.5	35	3.93	6250
4	35	3.93	6250
4.5	25	3.38	6250
5	25	2.83	6250
5.5	25	1.09	3125
6	25	1.07	3125
6.5	25	1.07	3125
7	25	1.07	3125
7.5	25	1.07	3125
8	25	2.74	6250

TRICKLING FILTER

TIME (HRS.)	C-INFL. (mg/L)	C-EFFL. (mg/L)	FLOW (GPM)
0	300	50	3472.22
.5	300	10	3645.83
1	300	10	3645.83
1.5	300	10	3645.83
2	400	10	6770.83
2.5	400	10	6770.83
3	400	10	6770.83
3.5	400	10	6770.83
4	400	10	6770.83
4.5	300	10	6770.83
5	400	10	6770.83
5.5	400	10	3645.83
6	400	10	3645.83
6.5	400	10	3645.83
7	400	10	3645.83
7.5	300	10	3645.83
8	400	10	6770.83

ACTIVATED SLUDGE

TIME (HRS.)	ORG.CONC. (mg/L)	EFFL.CONC. (mg/L)	FLOW (GPM)
0	0	10	4340.28
.5	.49	9.95	3472.47
1	.98	9.89	3472.47
1.5	1.47	9.82	3472.47
2	1.96	9.75	3472.47
2.5	2.45	9.67	3472.47
3	2.95	9.59	3472.47
3.5	3.45	9.5	3472.47
4	3.95	9.399999	3472.47
4.5	4.45	9.3	3472.47
5	4.95	9.189999	3472.47
5.5	5.45	9.07	3472.47
6	5.95	8.95	3472.47
6.5	6.45	8.82	3472.47
7	6.96	8.689999	3472.47
7.5	7.47	8.55	3472.47
8	7.98	8.41	3472.47

TO CHANGE ANY CONSTANTS OR INITIAL

CONDITIONS, LIST LINES 100 - 500

TO CHANGE PULSES LIST LINES 525 - 640

APPENDIX D

NPDES PERMIT, 1980, SUMMARY

EFFLUENT LIMITATIONS AND MONITORING REQUIREMENTS

Area A and Area B

(Single Consolidated Outfall)

Effluent Characteristic	Discharge Limitations kg/day (lbs/day)		Other Units		Monitoring Requirements		
	Daily Avg	Daily Max	Daily Avg	Daily Max	Measurement Frequency		Sample Type
Flow-m^3/day (mgd)					Continuous		
BOD_5 (May 1 - Oct 31)	367(810)	735(1,620)			Daily	24-hr	Composite
BOD_5 (Nov 1 - Apr 30)	551(1,215)	1,100(2,430)			Daily	24-hr	Composite
T.S.S.	227(500)	454(1,000)			Daily	24-hr	Composite
T.D.S.	272,000(600,000)	272,000(600,000)			Quarterly		Grab
Total Nitrogen (May 1 - Oct 31)	175(385)	354(780)			Daily	24-hr	Composite
Total Nitrogen (Nov 1 - Apr 30)	272(600)	354(780)			Daily	24-hr	Composite
Ammonia (as N) (May 1 - Oct 31)	45(100)	91(200)			Daily	24-hr	Composite
Ammonia (as N) (Nov 1 - Apr 30)	91(200)	136(300)			Daily	24-hr	Composite
Phosphorus, Total	97(213)	97(213)			Daily	24-hr	Composite
Phenols	4.5(10)	9(20)			Daily	24-hr	Composite
Chromium, total			0.05 mg/L	0.05 mg/L	Quarterly		Grab
Copper, total			0.05 mg/L	0.10 mg/L	Quarterly		Grab
Lead, total			0.05 mg/L	0.05 mg/L	Quarterly		Grab
Mercury, total			0.005 mg/L	0.005 mg/L	Quarterly		Grab
Settleable solids			0.05 mg/L	0.05 mg/L	Quarterly		Grab

The pH shall not be less than 6.0 standard units nor greater than 9.0 standard units and shall be monitored by weekly grab sample.

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