# DYNAMIC REAL TIME CONTROL OF THE ACTIVATED SLUDGE PROCESS USING STEP FEED

by

Ⓒ LEONARD J. YUST, B.Sc.(Eng.)

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McMaster University
Hamilton, Ontario, Canada

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# REAL TIME CONTROL OF THE STEP FEED ACTIVATED SLUDGE PROCESS

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| AUTHOR: | Leonard John Yust, B.Sc.(Eng.) (University of Guelph) |
| SUPERVISOR: | Dr. K.L. Murphy |
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# ABSTRACT

This study examined at pilot scale the application of dynamic control with a step feed activated sludge process for control of effluent quality. Computer simulation and pilot studies were used to develop a process control strategy involving the Specific Oxygen Utilization Rate (SCOUR). This control was applied using a real-time minicomputer system. Comparisons were made to a single compartment completely-mixed process operated in parallel to the controlled system.

The control strategy attempted to maintain SCOUR at a desired setpoint in the final compartment of a three reactor step feed system. Optimal influent contacting patterns were continuously calculated for the first and third compartments to satisfy the control objective. Unique optimization was not possible if the flow distribution was made to three compartments.

Using a SCOUR setpoint of 15 $mgO_2/g$ MLSS-h, filterable organic carbon effluent data suggested that a reduced effluent variability can be obtained during high loading periods. At low loadings when SCOUR control was limited, no improvement of effluent TOC was obtained.

With SCOUR control, consistently higher effluent solids concentrations were observed. High effluent suspended solids concentrations for the controlled system were probably caused by the inefficient oxygen transfer by the diffuser aeration system in the pilot plant.

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## NOMENCLATURE

A - parallel step feed pilot plant system.

B - parallel single compartment CSTR pilot plant system.

$b_1$, $b_2$, $b_3$, $b_4$, $b_5$, $b_6$ - coefficients used to obtain an analytical solution to controller model (Appendix D).

C - reactor dissolved oxygen concentration.

$C_i$ - dissolved oxygen concentration for compartment i of step feed system.

$C_I$ - integration constants after solution (Appendix D).

$C_s$ - reactor dissolved oxygen concentration at saturation conditions for wastewater.

$C_s'$ - reactor dissolved oxygen concentration at saturation conditions for clean water.

COD - chemical oxygen demand

CSTR - continuous stirred tank reactor.

D.O. - dissolved oxygen concentration.

$D_x$ - endogenous decay coefficient (Clemson Model).

d - days.

d/dt - time derivative.

EFOC - effluent FOC.

ESS - effluent suspended solids.

e - Naperian logarithm base.

FOC - filterable organic carbon.

F/M - Food to microorganism ratio.

$f_s$ - fraction of $S_m$ to $X_v$ (Clemson Model).

$\hat{f}_s$ - maximum value of $f_s$ (Clemson Model).

g - grams.

HRT - hydraulic retention time.

h - hours.

$K_{La}$ - volumetric oxygen transfer rate for wastewater.

$K_{La}'$ - volumetric oxygen transfer rate for clean water.

$K_x$ - active biomass saturation coefficient (Clemson Model).

$K_{xs}$ - adsorption - absorption coefficient (Clemson Model).

k - k reactor number.

L - litres.

Min - minimum for optimization.

MLSS - mixed liquor suspended solids.

MLVSS - mixed liquor volatile suspended solids.

MR - mixing requirement.

mg - milligrams.

min - minutes.

$m^2$ - square meters.

$m^3$ - cubic meters.

N - total number of compartments of step feed system.

$O_2$ - oxygen.

OTE - oxygen transfer efficiency.

OUR - oxygen utilization rate.

$OUR_k$ - oxygen utilization rate for compartment k of step feed system.

$OUR_v$ - volumetric oxygen utilization.

$OUR_{v,k}$ - volumetric oxygen utilization rate for compartment k of step feed system.

PI - proportional - integral linear controller.

PID - proportional - integral - derivative linear controller.

pH - logarithm of hydrogen ion concentration reciprocal.

Q - plant flow.

R - recycle ratio.

RAS - return activated sludge (recycle).

r - regression correlation coefficient.

$r^2$ - ratio of the sum of squares due to regression and the total sum of squares.

$r_m$ - oxygen uptake due to respiration.

$r_s$ - substrate transfer rate coefficient (Clemson Model).

$S_bk$ - substrate concentration for compartment k of the step feed system (Clemson Model).

$S_{m,k}$ - stored biomass concentration for compartment k of the step feed system (Clemson Model).

$S_{m,r}$ - RAS stored biomass concentration (Clemson Model).

SCOUR - specific oxygen utilization rate.

$SCOUR_{setpt}$ - setpoint specific oxygen utilization rate.

Si - influent substrate concentration.

SIN - sine function.

SRT - sludge retention time.

STP - sewage treatment plant.

SVI - sludge volume index.

T - temperature.

TKN - total Kjeldahl nitrogen.

TSS - total suspended solids.

t - time

$V_k$ - volume of reactor k.

WWT - wastewater treatment plant.

$X_k$ - MLSS for reactor k.

$X_r$ - RAS - TSS concentration.

$X_{a,k}$ = active biomass concentration for reactor k (Clemson Model).

$X_{a,r}$ = RAS active biomass concentration (Clemson Model).

$X_{AVE}$ - average MLSS concentration for step feed system.

$X_e$ - effluent TSS concentration.

$X_{des}$ - desired MLSS concentration for final compartment of step feed system.

$X_{I,k}$ - inert (non-viable) biomass concentration for reactor k (Clemson Model).

$X_{I,r}$ - RAS inert biomass concentration.

$X_v$ - MLVSS concentration ($X_v = X_a + X_I + S_m$).

$x_1$ - SCOUR setpoint variable for factorial analysis.

$x_2$ - D.O. setpoint variable for factorial analysis.

$Y_I$ - concentration of $X_I$ generated per unit of $X_a$ decayed (Clemson Model).

$Y_x$ - active biomass yield (Clemson Model).

$y_1$ - ESS output variable for factorial analysis.

$y_2$ - EFOC output variable for factorial analysis.

$\alpha_k$ - percent of influent flow distributed to reactor k.

$\beta_k$ - additive term for $\alpha$.

$u_x$ - maximum specific growth rate for active mass.

$\rho_a$ - density of air.

w - ratio of waste sludge flow to plant flow.

°C - degrees Centigrade.

% - percent.

$\Sigma$ - summation.

$\leq$ - less than or equal to.

# CHAPTER 1

## INTRODUCTION

A recent survey conducted by the US-EPA (Evans, 1979) indicated that problems associated with biological wastewater treatment facilities frequently are the result of inadequate operation. It has been the practice to operate the activated sludge process with a uniform mixed liquor suspended solids concentration. This method has had limited success as the food to microorganism ratio (F/M) is allowed to vary. Long or short term fluctuations of F/M (organic load) could lead to poor treatment efficiency and possibly process failure.

More recently the concept of maintaining a constant solids inventory through the control of the solids retention time (SRT) has been introduced. Control of SRT implies control of the F/M ratio and is relatively easy to maintain by adjustment of the sludge wasting rate. SRT control maintains a constant biomass growth rate which in turn affects process efficiency as measured by substrate removal and sludge activity. Because of the steady state assumptions, SRT control is only applicable to long term load changes caused by community growth and/or seasonal effects.

Additional control strategies are needed to dampen transient inputs imposed on the process by shock loads and the normal diurnal load variation within the constraints imposed by SRT control. With the advent of affordable computer technology and on line sensing equipment, increased efforts have been directed to development of short-term strategies.

The specific oxygen utilization rate (SCOUR) described by Andrews (1977) is a dynamic indicator of sludge activity, the nature of pollutants, and the substrate reactor concentration. The specific oxygen utilization rate is dependent both on the biological oxygen uptake rate and the concentration of activated sludge in the reactor and is defined by:

$$\mathrm{SCOUR} = \mathrm{OUR}_v / X \qquad (1\ )$$

where: SCOUR is the specific oxygen utilization rate ($mgO_2$/g MLSS-h)

$OUR_v$ is the volumetric oxygen uptake rate ($mgO_2$/L-h), and

X is the MLSS concentration ( g/L).

Control of SCOUR at a setpoint would provide a method of control for the activity of the activated sludge process exposed to transient loadings. A constant low value of SCOUR would indicate that the removal of influent organics is complete.

A multi-staged step feed system manipulates feed distribution to different points of the aerator causing the solids in the system to be redistributed between compartments over a short time interval. Since SCOUR is dependent on the MLSS concentration (Equation 1) a setpoint SCOUR in the last compartment can be maintained by changing the influent contacting pattern. A constant SCOUR in the last compartment should control the effluent substrate concentration being discharged to the secondary settler.

The purpose of this research was to examine, apply and verify this form of control at pilot scale. The objectives to fulfill this requirement are:

1) to examine and understand the dynamics imposed by step feed using an off line computer simulation model,
2) to implement SCOUR control on a pilot step feed process using real-time computer hardware and software, and on-line sensor equipment,
3) to optimize short term contacting feed patterns that would satisfy the SCOUR setpoint control approach, and
4) to compare the effluent variability between a controlled step feed pilot plant and a parallel, uncontrolled conventional pilot plant.

# CHAPTER 2

# LITERATURE REVIEW — DYNAMIC CONTROL OF THE ACTIVATED SLUDGE PROCESS

The most common form of control of the activated sludge process has been to regulate the waste sludge flow with the objective of keeping a constant mixed liquor suspended solids (MLSS) in the aerator. However, this strategy allows the steady-state food to microorganism ratio (F/M) to fluctuate causing the specific growth rate of the microorganisms to vary. Microorganism growth was regulated by maintaining a fixed sludge retention time (SRT). Both these control strategies are based on steady state assumptions and are applicable only to long term influent changes. Discussions and applications of sludge wasting control to buffer long term fluctuations include Garrett (1958), Lawrence and McCarty (1970), Roper and Grady (1974), and Jenkins and Garrison (1968). As short term strategies are needed to control normal diurnal disturbances, increased research efforts towards transient control have been undertaken recently.

## 2.1 Feed Forward — Feedback Linear Control

Classical process control techniques may be used to control many operational functions of biological wastewater systems. Basically, these techniques are applied to situations where small disturbances occur and small corrective actions are taken. Examples include control of hydraulic flow and dissolved oxygen where the usual linear PID controllers are sufficient. Large disturbances such as a shock input or an increase in diurnal load could cause significant changes in the system dynamics due to nonlinear effects. Application of PID control would then become increasingly more complex.

A crude form of feedforward control used widely in practice is to keep the recycle flow and influent flow at a constant ratio. Busby and Andrews (1975) investigated this strategy using a dynamic simulation model and reported optimal recycle ratios for a number of plant operating conditions. Nelson and Mishra (1980) reported that this control was of limited use after application at the Metropolitan Denver Sewage Treatment Plant. This method did not take into account influent concentration changes or variations in solids concentrations in the recycle flow. An increase in recycle flow can increase the total aerator mass which would increase the load on the clarification unit. This increase in solids load and the additional turbulence in the clarifier would increase solids overflow.

Klei and Sundstrom (1974) used proportional control based on influent TOC concentration. An on-line TOC analyzer was used on a pilot scale system to adjust recycle and air flow in proportion to influent substrate concentrations. Their results showed that the effluent concentration could be held constant at residence times characteristic of municipal plants. Attir and Denn (1978) applied influent flow ratio control to both the recycle rate and underflow rate. Variations in reactor MLSS variation were reduced by 30% after the control was applied to a simulation model.

A complex feedforward control strategy to control effluent substrate concentration was developed by Westburg (1968) using the recycle flow rate as the manipulated variable. Using a unique non-linear simulation model, a control algorithm was developed that would control effluent substrate concentrations at preselected levels. Brett et al. (1973) and Davis et al. (1973) refined Westburg's control model and concluded that the best control was obtained with proportional control for influent flow and derivative control for influent concentrations. The numerous mathematical and process assumptions made in model development question the applicability of the model in real time situations. As in all feedforward control systems the model must be correct because of the open loop structure of the control.

Kermode et al. (1973) incorporated feedback control in addition to the feedforward strategy described above. Small errors were corrected by the closed loop feedback control. The authors indicated that sludge storage was required to obtain perfect control. Further research was recommended to incorporate control that would account for solids interactions between the aerator and clarification unit.

Lech et al. (1978) investigated the efficacies of the following strategies with computer simulation: single loop feedback control; multiple loop feedback control; single loop feedforward control; feedforward-feedback control; and multiple loop feedforward control. Multiple loop feedforward control gave the best results. Because of physical constraints of the manipulated variables (recycle and waste flow) the degree of control was limited. The type of model used to simulate the final clarifier greatly affected control results.

## 2.2 Instantaneous F/M Control with Sludge Storage

Control of MLSS in the aerator will provide good results if the incoming wastewater characteristics remain constant but, under transient loading conditions, the food to microorganism ratio is not held constant. For dynamic control of F/M sludge, storage facilities would be required.

Smith (1974) through the use of a time dependent computer simulation model attempted to reduce the average BOD effluent concentration using a constant instantaneous F/M control strategy and sludge storage facilities in the settler. Linear PI control was used to keep the MLSS at desired levels. The study concluded that minimal control could be achieved as the clarifier was ineffective in separating dissolved and suspended fractions of BOD.

Cashion _et_ _al_. (1979) investigated instantaneous F/M control with storage facilities both by computer simulation and at pilot scale. The recycle flow was used as the manipulated variable and the first compartment of a step feed system was used for sludge storage. The results showed that dynamic F/M control using the recycle flow rate and sludge storage did not control effluent quality. Additional hydraulic transients imposed on the process degraded the effluent with respect to particulates.

Nogita _et_ _al_. (1981) investigated instantaneous F/M control using the step feed contacting pattern between the first compartment and the remainder of the aerator. Pilot scale experimentation revealed that effluent quality could be improved using this technique. Hruschka and Hegeman (1981) have intestigated dynamic F/M control using a variable tank volume as the manipulated variable.

## 2.3 Dissolved Oxygen Control

Control of the dissolved oxygen (D.O.) level in the aerator can be achieved by digital PI control or by self-tuning regulators. The air flow rate is used to adjust the dissolved oxygen concentration at setpoint levels. Examples have been given by Roesler (1974) and Petersack and Smith (1975). Generally, the objective of D.O. control has been to optimize process economics rather than process treatment efficiency. D.O. levels controlled at levels above 2 mg/l have not had any beneficial result in effluent quality (Metcalf and Eddy, 1979). Genthe et al. (1978) reported substantial savings in energy usage in 9 out of 12 wastewater treatment plants when comparing automatically controlled systems to manually controlled systems. In addition to the economic benefits, SVI improvements were observed.

By keeping the dissolved oxygen level at fixed setpoint levels, a measure of the oxygen uptake due to respiration and synthesis can be made. The oxygen uptake rate (OUR) is measured or estimated by observing the difference in the air flow rate at controlled D.O. conditions. Application of this technique was illustrated by Olsson and Hansson (1976) on a full scale biological wastewater system operated in Sweden.

Sørensen (1980) utilized this measure of OUR to control effluent quality dynamically using a step feed pilot plant process. Empirical contacting patterns were developed to respond to changes of the estimated on line OUR. $K_{La}$ measurements required for OUR calculations were related empirically to the aeration system blower speed.

Andrews and Olsson (1978) stress the importance of the dissolved oxygen profile to locate the D.O. probe and as a tool to develop dynamic control strategies. Applications using the dissolved oxygen profile to aid control are given by Gillblad and Olsson (1978) on a medium sized plant in Sweden. Use of these profiles in determining the D.O. control setpoint and possible practical control applications were described by Olsson and Andrews (1981). Methods used to estimate the OUR due to carbonaceous and nitrifying organisms by the D.O. profile were given. This control approach has the disadvantage of using numerous D.O. probes to describe accurately the D.O. profile.

## 2.4 SCOUR control

One of the major problems confronted by wastewater treatment control engineers is the ability to measure the extent of biological activity in the system. Biochemical Oxygen Demand (BOD) requires 5 or more days to analyze. On-line instrumentation for measurement requires excessive maintenance making real time control impractical (Stephenson et al., 1980). The Specific Oxygen Utilization Rate (SCOUR) is defined as the mass of oxygen utilized per unit of sludge and time. Olsson (1976) states that there is universal agreement that SCOUR can be used to indicate biomass activity. Field measurements of SCOUR have been reported by Wells et al. (1977).

Use of SCOUR as a control parameter was investigated by Andrews et al. (1976). Computer simulation results showed a rapid response to both substrate loading changes and input of toxic materials. Stenstrom (1976) used a SCOUR setpoint strategy for both a single reactor and step feed simulation model. SCOUR control was used in unison with a long term sludge wasting SRT strategy. A feedforward-feedback control algorithm was developed using the recycle flow rate as the manipulated variable. The control objective was to minimize SCOUR variability. This strategy was applied to a dynamic computer simulation model representing both the conventional and step feed process. Using time series to predict influent flow, an 86% reduction in SCOUR variability was observed when using the return sludge rate to keep the aerator at a setpoint.

Similar strategies were then applied to a four compartment step feed system where the influent was switched between the first two compartments. An average compartment SCOUR was used as the control objective. Only a 30% reduction in SCOUR variance was achieved. A 70% reduction was observed when time series was used to predict influent flow rate. Derivative terms were present in the control algorithm with weighting factors. This may have restricted the control.

## 2.5 Modern Control Theory Applications

Because of the multivariable and highly non-linear characteristics of the activated sludge process, modern control theory application can be difficult when large disturbances occur.

The variational approach to optimization developed by Pontryagin (1962) was applied to biological treatment problems by Fan et al. (1973). This optimization, however, was applied to simulated systems without sludge recycle. Angelbeck and Alam (1978) expanded this methodology to include conventional biological wastewater processes. Control strategies were a direct function of the state variables, disturbance variable and time. The control variables were both the recycle and sludge wasting flow rates. The degree of optimal control was dependent on the weighting factors for the variational optimization solution and were system specific.

Stochastic control methods have also been investigated. Bethouex et al. (1978) applied the time series methods of Box and Jenkins (1970) to study influent-effluent identification models. Olsson and Hansson (1978) developed discrete state models for dissolved oxygen transfer using methods developed by Astrom (1970). Minimum variance stochastic control was applied to a dynamic simulation model by Harris (1978). An improvement was observed when compared to a system without control.

Tong et al. (1980) applied fuzzy set theory described by Mamdani (1974) to activated sludge wastewater treatment plants. This "fuzzy control" approach consisted of a combination of automatic and operator control with a list of control rules and linguistic logic statements within the fuzzy controller (Tong, 1977). The control was applied to a simulation model developed by Beck et al. (1980) which consisted of 14 state variables. Improved control results were reported.

Richalet et al. (1978) reported a model predictive heuristic control approach that may be applicable to control biological wastewater processes. The strategy consists of developing an internal process model used for on-line computer prediction. Future inputs to the control model were computed in such a way that, when applied to the fast time predictive model control, outputs were produced that followed a desired response trajectory, and tended towards the control setpoint. This control was applied successfully to several industrial processes and could be applicable to biological processes that have multivariable non-linear characteristics.

# CHAPTER 3

# COMPUTER SIMULATIONS

## 3.1 Introduction

As it is not economically or physically feasible to test all alternative modification or operating changes on full or pilot scale systems due to the long process response times characteristic of biological systems, a dynamic computer simulation model describing the step feed modification of the activated sludge process was used to obtain a general understanding of process dynamics. This information was used to develop a dynamic control policy and an experimental design for the pilot scale system.

Computer simulation of the step feed process was used:

a) to understand the dynamics of system solids distribution after a change was made in the influent substrate contacting pattern,

b) to determine if the last compartment's SCOUR of the step feed process level was directly related to the last compartment's substrate concentration,

c) to determine the effect a change in influent substrate concentration (step input) had on SCOUR and effluent substrate concentration, and

e) to determine if biomass growth and decay kinetics should be considered in the controller design for the system time constants.

## 3.2 Clemson Model

The microbial interactions and dynamics describing the aerator portion of the activated sludge process were proposed at Clemson University by Andrews and his co-workers (Busby and Andrews, 1975, Stenstrom and Andrews, 1979). The model consists of a sequential system of biological reactions as shown in Figure 3-1. Volatile concentrations of biomass in the aerator were subdivided into stored, active and inert (non-viable) fractions. A listing of the biological reactions are given in Appendix A-1. This description of the biological reactor has been validated in the literature (Ekama and Marais, 1979, Clifft and Andrews, 1979).

## 3.3 Step Feed Mass Balances

Mass balances for substrate, stored mass, active mass, inert mass and dissolved oxygen were developed for each reactor of the step feed system shown in figure 3-2. The step feed hydraulic relationships were those described by Olsson (1975). Each subreactor is a completely mixed system with homogeneous concentrations.

The organic input to the model was assumed to be homogenous throughout the system. Substrate was not separated into collodial or liquid phases.

The substrate mass balance is:

$$\frac{d\, S_{b,k}}{dt} = \frac{Q}{V_k} \left( \alpha_k S_i + (\beta_{k-1} + R) S_{b,k-1} - (\beta_k + R) S_{b,k} \right)$$

$$- r_s X_{v,k} \left( \hat{f}_s \left( \frac{S_{b,k}}{K_{xs} + S_{b,k}} \right) - f_s \right) \qquad (3.1)$$

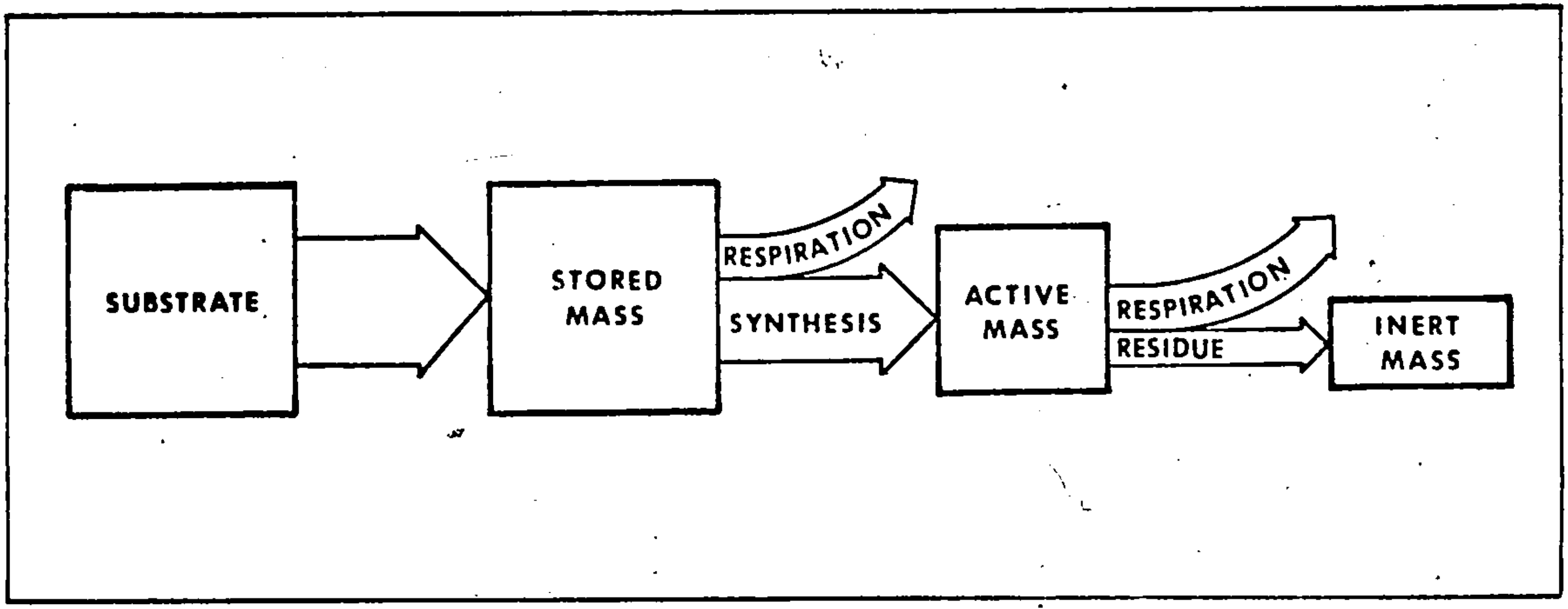


Figure 3.1. Clemson Model Biological Reactions (Andrews, 1975).

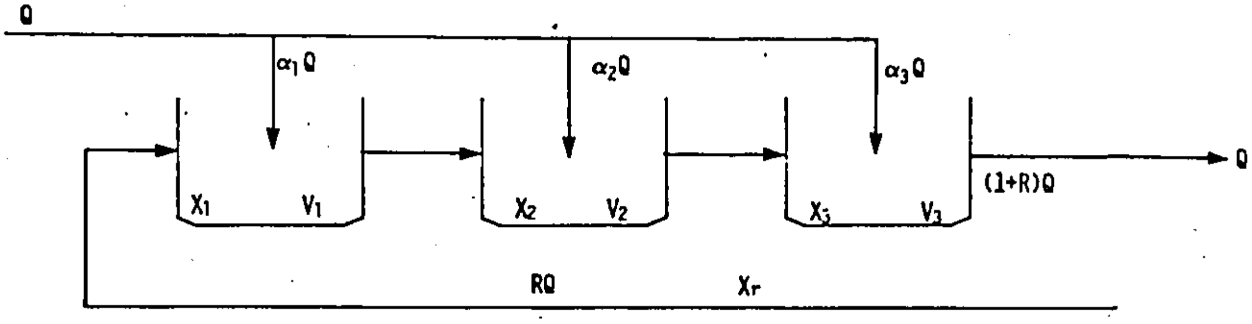


Figure 3.2. Step Feed Schematic.

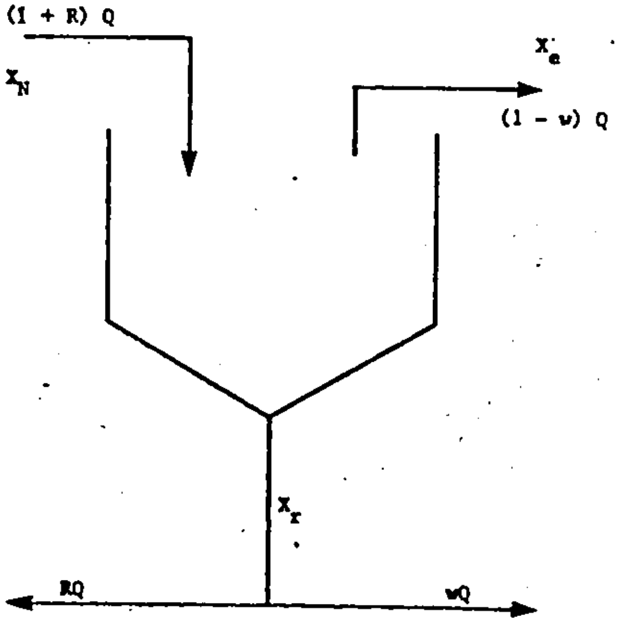


Figure 3.3. Simplified Clarifier Model.

where $S_{b,k}$ is the substrate concentration for reactor k (mg $BOD_5$/L),

$S_i$ is the influent substrate concentration (mg $BOD_5$/L),

$V_k$ is the volume for reactor k (L), and

R is the recycle ratio (%).

The flow proportion to the step feed system was described by:

$$\sum_{k=1}^{N} \alpha_k = 1 \tag{3.2}$$

where $\alpha_k$ is the proportion of plant flow Q for reactor k

$$\beta_k = \sum_{i=1}^{k} \alpha_k \tag{3.3}$$

$$\beta_o = 0 \tag{3.4}$$

where N is the number of tanks in series

$$\beta_N = 1 \tag{3.5}$$

Similarly, mass balances for stored mass ($S_m$), active mass ($X_a$), and inert mass ($X_I$) were as follows:

$$\frac{d\ S_{m,k}}{d_t} = \frac{Q}{V_k} \left( (\beta_{k-1} + R) S_{m,k-1} - (\beta_k + R) S_{m,k} \right) + r_s\ X_{v,k}$$

$$(\hat{f}_s \ \left(\frac{S_{b,k}}{K_{xs} + S_{b,k}}\right) - f_s \ ) - \frac{\mu_x}{Y_x} \left( \frac{f_s}{K_x + f_s} \right) X_{a,k} \tag{3.6}$$

$$\frac{d\,X_{a,k}}{dt} = \frac{Q}{V_k}\left((\beta_{k-1} + R)\,X_{a,k-1} - (\beta_k + R)\,X_{a,k}\right) + \left(\mu_x\left(\frac{f_s}{K_{xs} + f_s}\right) - D_x\right)X_{a,k} \tag{3.7}$$

$$\frac{d\,X_{I,k}}{dt} = \frac{Q}{V_k}\left((\beta_{k-1} + R)\,X_{I,k-1} - (\beta_k + R)\,X_{I,k}\right) + Y_I D_x\,X_{a,k} \tag{3.8}$$

$$\frac{d\,C_k}{dt} = \frac{Q}{V_k}\left((\beta_{k-1} + R)\,C_{k-1} - (\beta_k + R)\,C_k\right) + K_{La}\,(C_s - C) - \left(\left(\left(\frac{1 - Y_x}{Y_x}\right)\left(\frac{f_s}{K_x + f_s}\right)\mu_x\right) - (1 - Y_I)\,D_x\right)X_{a,k} \tag{3.9}$$

for $k = 1$:

$$X_{a,o} = X_{a,r}$$

$$X_{r,o} = X_{I,r}$$

$$S_{m,o} = S_{m,r}$$

$k = r$ represents the recycle concentration.

A summary of the biological kinetic coefficients $r_s$, $\hat{f}_s$ , $K_{xs}$, $f_s$ , $\mu_x$, $Y_x$, $K_x$, $Y_I$ is given in Appendix A. Dissolved oxygen transfer parameters $K_{La}$ and $C_s$ are described in Appendix B. Influent dissolved oxygen concentrations are assumed to be negligible.

## 3.4 Clarifier Model

One of the major shortcomings of modelling the activated sludge process has been inadequate representation of the clarification properties of the secondary settler (Chapman, 1981) which in turn implies difficulty predicting effluent suspended solids concentrations. Because this simulation model was intended only as a screening device, a simplified settler model was used. To estimate return sludge concentrations from the recycle line, a mass balance was completed around the settler after assuming constant effluent solids concentrations.

From figure 3.3 the mass balance for return sludge concentration is:

$$X_r \doteq \frac{(1 + R)\ X_n - (1 + \omega)\ X_e}{R + \omega} \tag{3.10}$$

where $X_r$ is the return sludge total suspended solids concentration,

$\omega$ is the ratio of waste sludge flow to plant flow; and

$X_e$ is the effluent MLSS concentration (mg/L).

The waste sludge flow fraction ($\omega$) was calculated from the definition of SRT as follows:

$$\omega = \frac{V_t\ X_{AVE} - Q\ X_e\ (SRT)}{Q\ X_r\ (SRT) - Q\ X_e\ (SRT)} \tag{3.11}$$

where $V_T$ is the total volume of step feed aerator (L),

$X_{AVE}$ is the average MLSS solids conc. from each reactor (mg/L), and

SRT is the sludge retention time (h).

The time delay in the clarification unit is assumed to be negligible.

## 3.5 Steady State Validation

Algorithms for both the aerator and settler models were prepared and programmed in FORTRAN IV on a Hewlett-Packard HP1000 Mini-Computer at the Wastewater Technology Centre. The simultaneous differential equations (eq. 3.1, 3.6, 3.7, 3.8, 3.9) were solved using a fourth order Runge Kutla numerical integration routine. Results of steady state simulations obtained for a single reactor activated sludge process are compared to those obtained by Stenstrom (1976) in Table 3-1. This agreement indicated that the computer simulation could be used to study the dynamics of the activated sludge process.

## 3.6 Step Feed Simulations

The option of operating N tanks in series with step feed influent distribution was included in the model. The simulated plant operating conditions were those anticipated for pilot plant application (Table 3-2).

After steady state conditions were reached for N compartments connected in series with the influent flow being distributed into the first compartment ($\alpha_1 = 1$), the influent flow was transferred to the last compartment ($\alpha_N = 1$). Figures 3-4, 3-5 and 3-6 show the transient responses of MLSS concentrations, reactor substrate concentrations, and SCOUR levels for a three compartment step feed system. Biological growth effects were included in the model. Tables 3-3 and 3-4 illustrate the steady state condition before and after the change in the contracting pattern was made for k = 1, N compartments.

MLSS response trajectories for each compartment are illustrated in Figure 3.4. All MLSS concentrations in each compartment essentially

TABLE 3.1. STEADY STATE SIMULATION RESULTS (mg/L oxygen equivalents).

| | YUST | STENSTROM (1976) |
|---|---|---|
| $X_a$ | 1010 | 955 |
| $S_m$ | 28.2 | 27.9 |
| $X_I$ | 284 | 270 |
| $S_b$ | 10.0 | 10.4 |
| $X_v$ | 1322 | 1253 |

R = 30%  HRT = 4.3 h  $S_i$ = 130 mg $BOD_5$/L

TABLE 3.2. SIMULATED ACTIVATED SLUDGE OPERATING CONDITIONS FOR STEP FEED SYSTEM.

| | |
|---|---|
| SRT | 3 days |
| Recycle Ratio | 50% |
| Influent Flow (Q) | 7 L/min. |
| Total Aerator volume | 2200 L |
| Effluent Solids Conc | 19 mg TSS/L |
| Influent Substrate | 130 mg $BOD_5$/L |

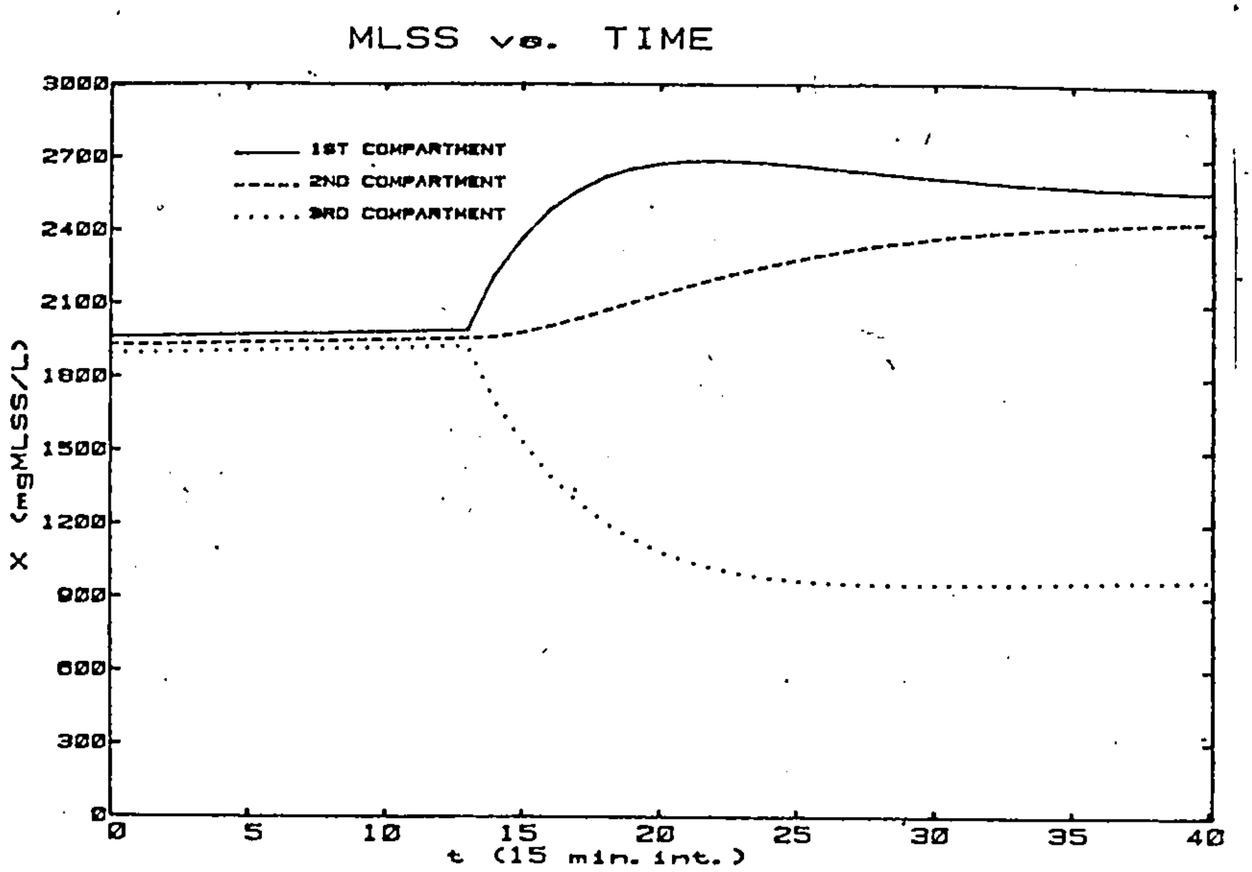


Figure 3.4. Clemson Model MLSS Response.

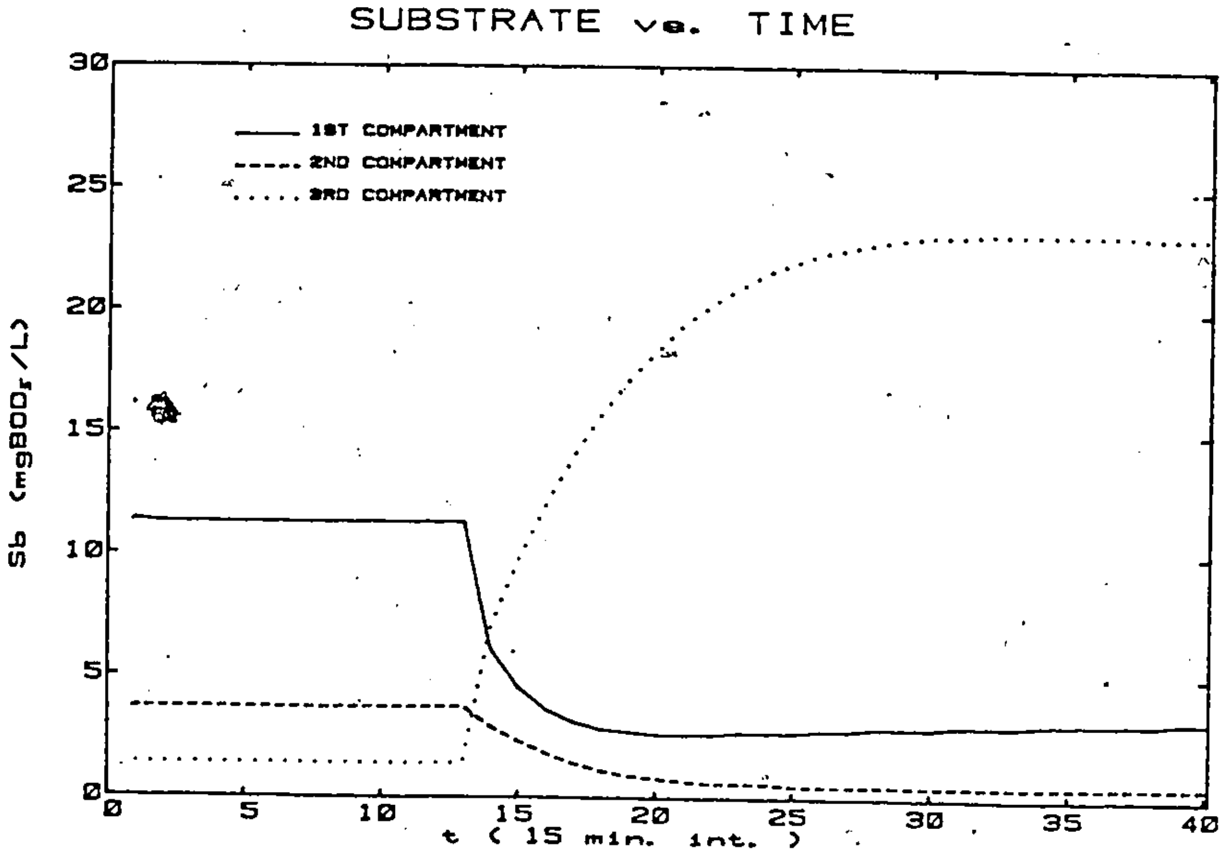


Figure 3.5. Clemson Model Substrate Conc. Response.

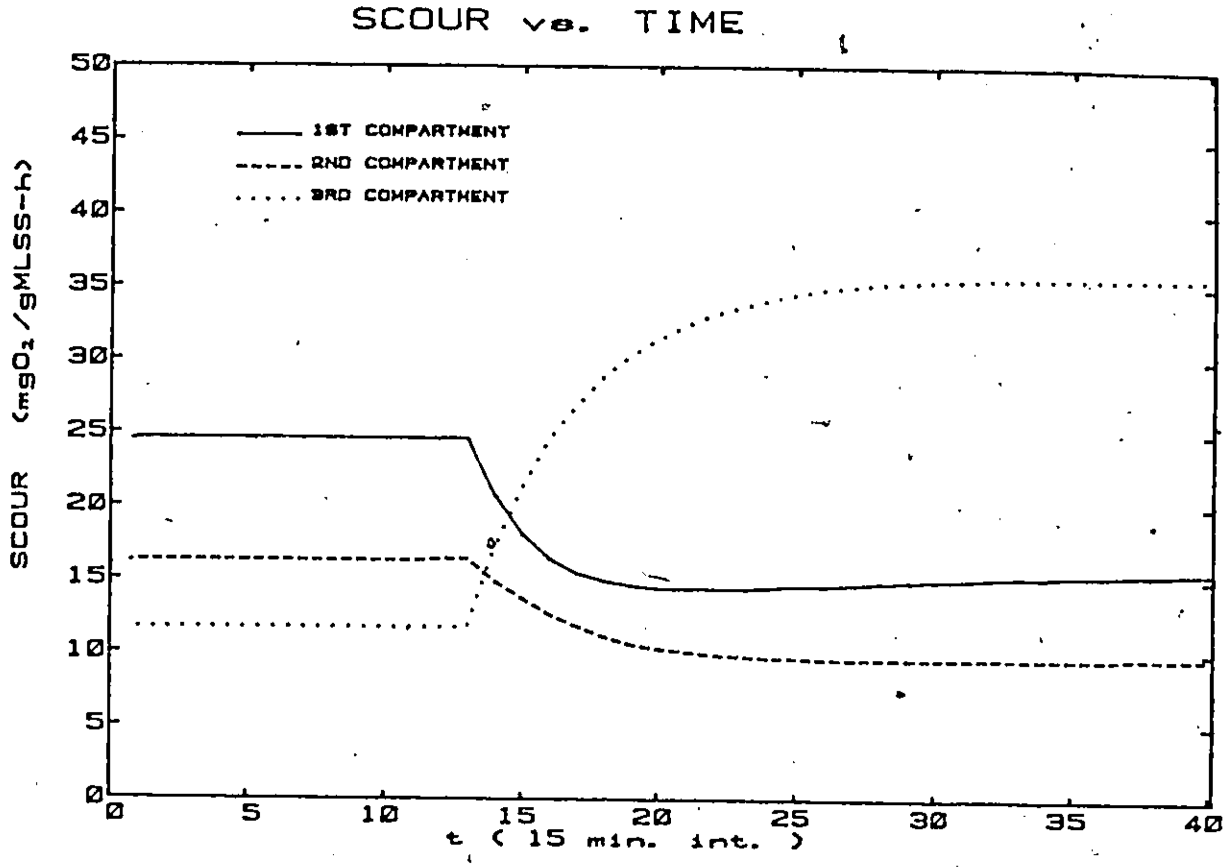


Figure 3.6. Clemson Model Scour Response.

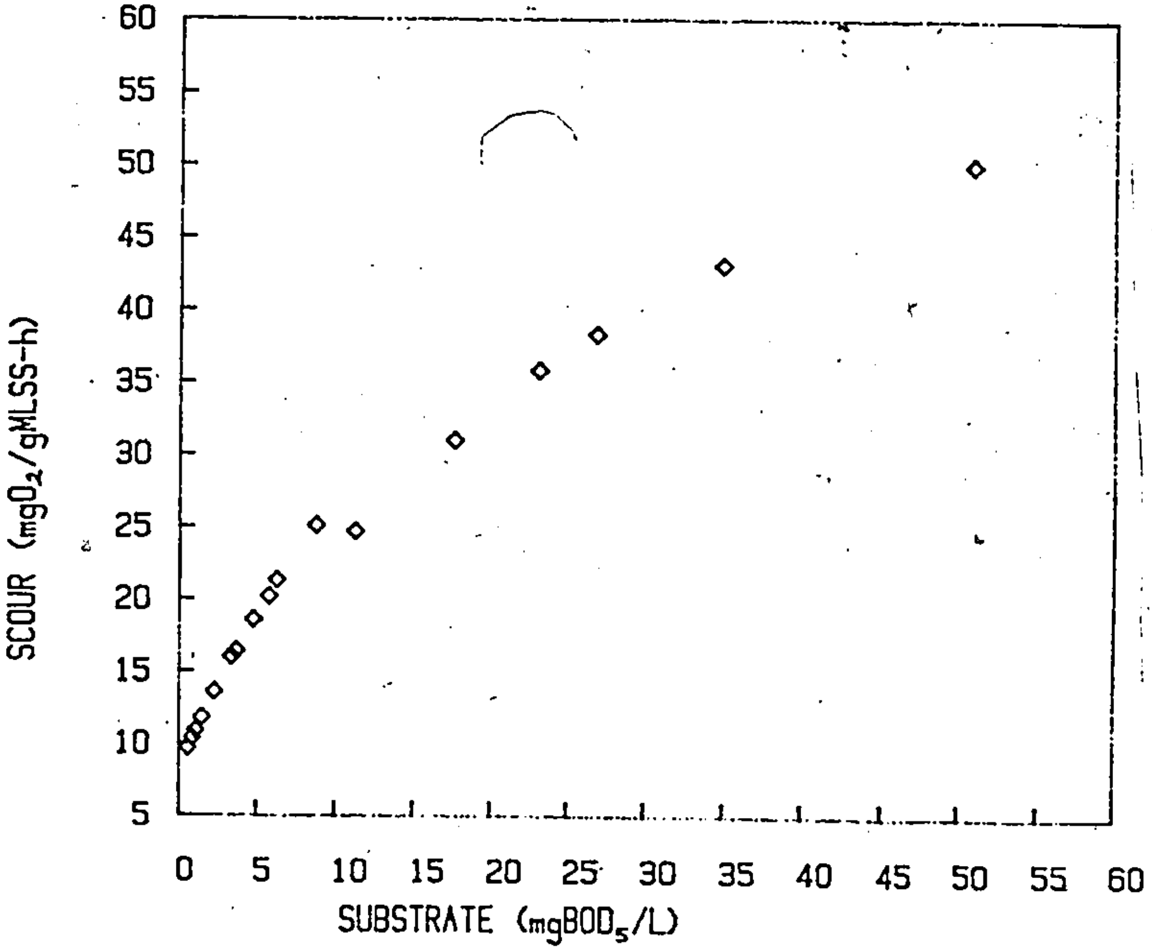


Figure 3.7. Relationship Between SCOUR and 3rd Compartment Substrate Concentration.

TABLE 3.3. COMPUTER SIMULATION STEADY STATE RESULTS ($\alpha_1$ = 1)

| | Xk (mgMLSS/L) | | | | Sb,k (mgBOD$_5$/L) (Total) | | | | SCOUR (mgO$_2$/gMLSS-hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1 | 1950 | — | — | — | 5.0 | — | — | — | 17.3 | — | — | — |
| 2 | 1980 | 1940 | — | — | 8.5 | 2.2 | — | — | 21.8 | 13.3 | — | — |
| 3 | 1990 | 1960 | 1930 | — | 11.3 | 3.7 | 1.5 | — | 24.7 | 16.4 | 11.8 | — |
| 4 | 2000 | 1970 | 1950 | 1920 | 13.7 | 5.2 | 2.4 | 1.1 | 26.6 | 19.2 | 13.9 | 11.0 |

TABLE 3.4. STEADY STATE RESULTS ($\alpha_N$ = 1)

| | Xk (mgMLSS/L) | | | | Sb,k (mgBOD$_5$/L) (Total) | | | | SCOUR (mgO$_2$/g MLSS-hr) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1 | 1950 | — | — | — | 5.0 | — | — | — | 17.3 | — | — | — |
| 2 | 2940 | 1140 | — | — | 1.6 | 15.6 | — | — | 12.2 | 30.1 | — | — |
| 3 | 2580 | 2480 | 990 | — | 3.4 | 0.6 | 23.1 | — | 16.0 | 9.7 | 35.8 | — |
| 4 | 2420 | 2360 | 2300 | 930 | 5.3 | 1.3 | 0.3 | 28.7 | 19.5 | 11.3 | 9.0 | 38.6 |

were equal when operating the system under plug flow conditions. After influent flow was input into the final compartment, increased MLSS concentrations were redistributed into the front end of the aeration system. The response time to achieve steady state was approximately 2 – 2½ hours. A decrease of 1000 mg/L for the final compartment was possible under the hydraulic conditions imposed. This final steady state condition would be beneficial under low influent loadings as only a portion of the biomass is utilized. The remainder is stored in the first and second reactors.

Figure 3-5 illustrates that maximum treatment efficiency in terms of substrate removal is achieved when operating in a plug flow condition ($\alpha_1 = 1$). Conversely, minimum treatment occurs with all influent being directed to the last compartment ($\alpha_3 = 1$). By adjustment of the step feed contacting pattern a given level of substrate removal can be attained. In this way, over-treatment involving excessive energy requirements and possibly impaired solids setting could be avoided.

A comparison of figures 3-5 and 3-6 indicated a direct relationship between SCOUR and compartment substrate concentrations. A plot showing the non-linear relationship is presented in Figure 3.7. This validates the proposal by Andrews (1977) that SCOUR could be used as a measurement of substrate concentration. If SCOUR were controlled in the final compartment of the step feed system, a constant substrate concentration would be discharged to the secondary clarifier.

Maximum and minimum SCOUR control limits for the final compartment are shown in figure 3-6. Steady state SCOUR results from Table 3-3 and 3-4 indicate that the control range can be increased with the addition of reactors connected in series.

All simulations were run under constant influent loading conditions of approximately 900 mg $BOD_5$/min. After achieving steady state conditions for $\alpha_3 = 1$, a step input of substrate concentration from 130 to 300 mg BOD/L was made (t = 6 (1.5 h), figure 3.9). The increase in MLSS concentrations was due to biolobical growth/decay mechanisms and occurred at an approximate rate of 28 mg/L-h. A rapid increase in the third compartment's SCOUR level occurred because of the low MLSS steady state concentration.

To compensate for the increase in organic load, solids were redistributed into the final compartment by directing all influent flow into the first compartment ($\alpha_1 = 1$) (Figure 3-8) at t = 32 (7.7 h ). The change in MLSS concentration after the change was approximately 620 mg/L-h. With such a pronounced response the minor changes due to biological activity can be neglected over the response period. The SCOUR response indicates that effluent substrate transported to the clarifier was reduced by greater than 30 SCOUR units. MLSS response times were consistent with those observed previously when all influent was switched to the last compartment from the first compartment.

In summary, the computer simulations indicated that:

1) SCOUR is directly related to the last compartment's substrate concentration. By fixing SCOUR at a constant value, effluent substrate should be controlled.
2) A change in the step feed influent contacting pattern will affect SCOUR levels in the final compartment. SCOUR can be controlled by continually changing the influent substrate distribution.

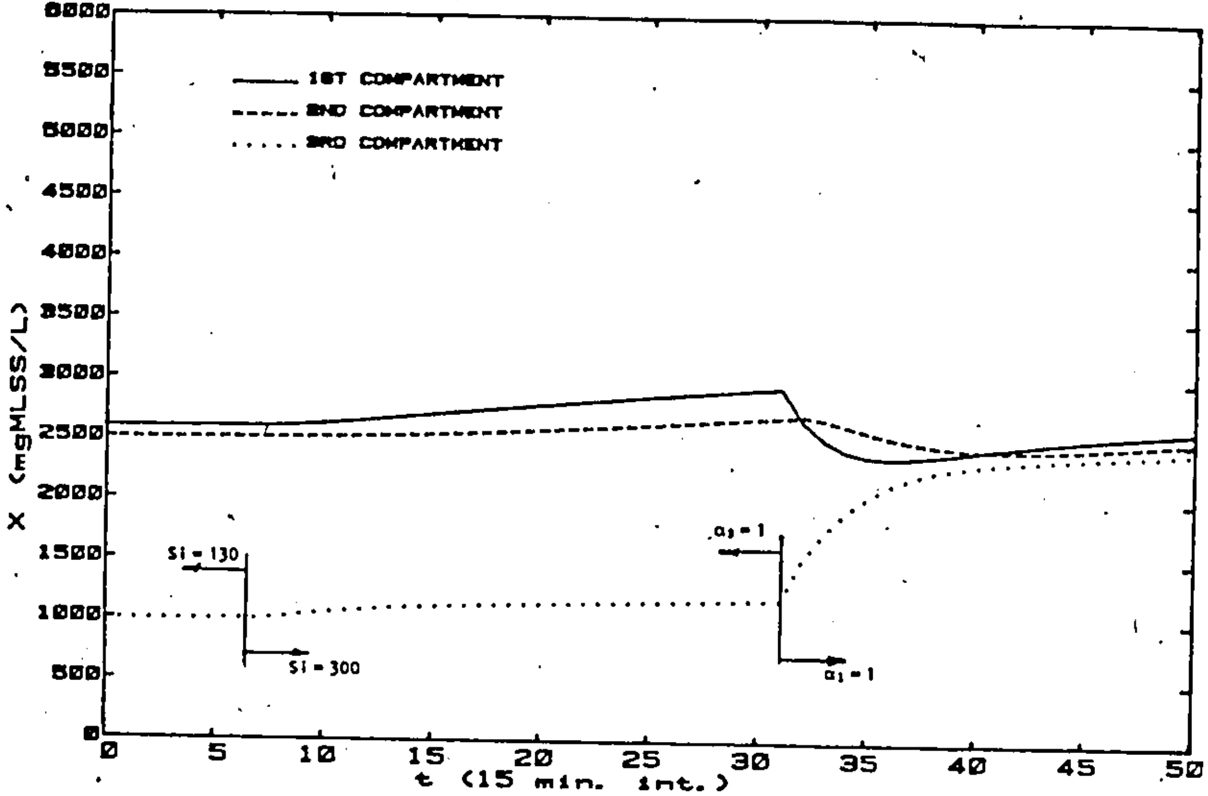


Figure 3.8. Influent Step Test MLSS Response (Clemson Model).

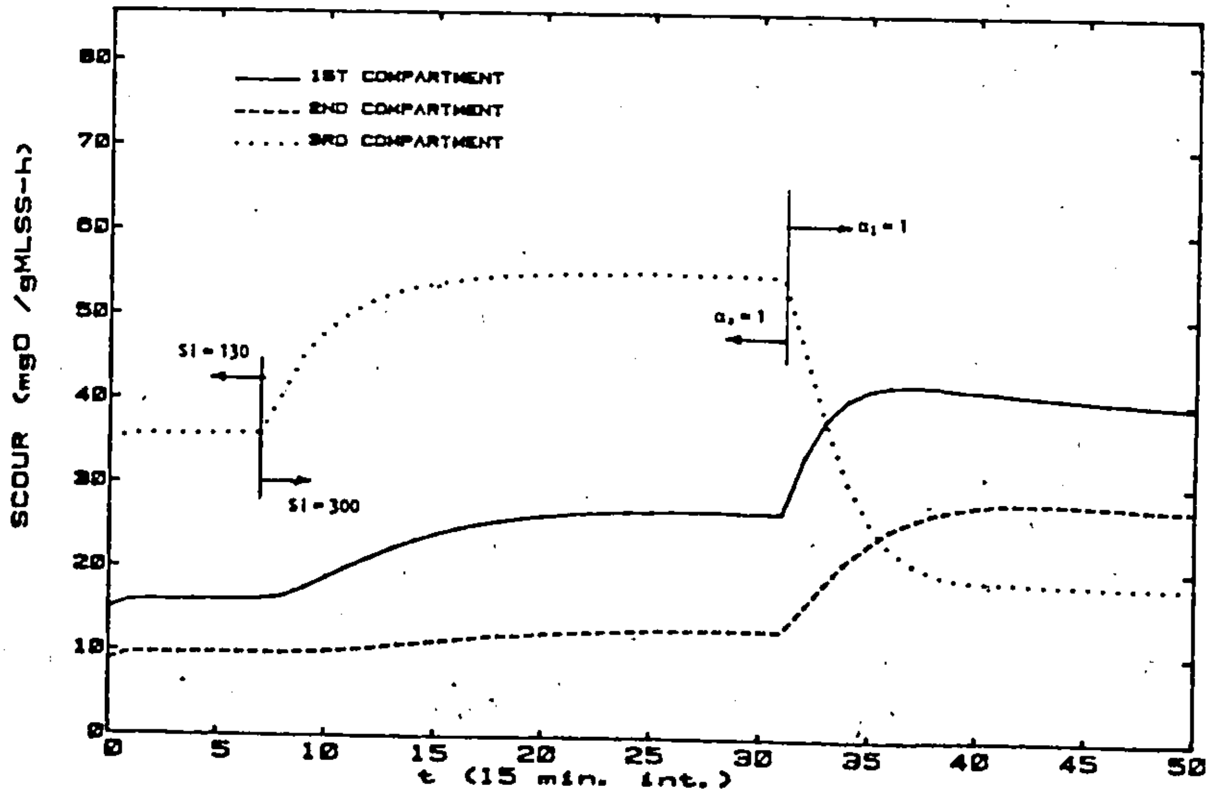


Figure 3.9. Influent Step Test SCOUR Response (Clemson Model).

3) The pseudo-steady state response time to a change in the influent distribution was approximately two hours. Biological growth and decay was insignificant during this period.

4) To maintain a constant SCOUR in the final compartment in response to an increase in influent load, the contacting pattern should be readjusted to distribute more influent to the front end of the aerator. Conversely, the influent should be redistributed to the rear portion of the aerator if a decrease in influent load occurs. The degree of change will be dependent on the SCOUR setpoint selection.

# CHAPTER 4

## PILOT PLANT APPLICATIONS

### 4.1 Control Strategy

Based on the computer simulations described in the previous chapter, a control strategy was selected to maintain a constant sludge activity in the last compartment of the step feed process using a selected SCOUR setpoint. This setpoint would be controlled by monitoring the on-line volumetric oxygen uptake rate ($OUR_V$) and by manipulating the MLSS concentrations between compartments. According to the definition of SCOUR (equation 1 ), a desired last compartment MLSS concentration was calculated as follows:

$$X_{des} = \frac{OUR_{v,N}}{SCOUR_{setp}} \tag{4.1}$$

where $X_{des}$ is the desired MLSS concentration in last compartment ( g/L),

$OUR_{v,N}$ is the volumetric uptake rate for last compartment (N) ($mgO_2$/L-h), and

$SCOUR_{setp}$ is the SCOUR setpoint in the last compartment ($mgO_2$/g MLSS-h).

By fixing SCOUR in the final compartment, a constant substrate concentration in the effluent should be controlled. Choice of the desired SCOUR setpoint is system specific and should be chosen based on an acceptable effluent quality and favourable settling and sludge thickening characteristics (Andrews 1977).

As short term biological growth was demonstrated insignificant compared to the hydraulic transfer of solids between compartments, biomass growth and decay has been neglected. A solids mass balance for a three-compartment step feed reactor illustrated in figure 3-2 can be expressed as follows:

$$\frac{dX_1}{dt} = (RX_r - (1 - \alpha_2 - \alpha_3 + R)\ X_1)\ \frac{Q}{V_1} \tag{4.2}$$

$$\frac{dX_2}{dt} = [(1 - \alpha_2 - \alpha_3 + R)\ X_1 - (1 - \alpha_3 + R)X_2]\ \frac{Q}{V_2} \tag{4.3}$$

$$\frac{dX_3}{dt} = [(1 - \alpha_3 + R)\ X_2 - (1 + R)\ X_3]\ \frac{Q}{V_3} \tag{4.4}$$

$$\alpha_1 = 1 - \alpha_2 - \alpha_3 \tag{4.5}$$

where $X_n$ is the MLSS concentration for compartment n (mg/L),

$V_n$ is the volume of compartment n (L),

$\alpha_n$ is the flow distribution to compartment n (%)

$X_r$ is the return activated sludge concentration (mg/L),

Q is the plant flow (L/h), and

R is the recycle ratio (%).

The above simultaneous differential equations were solved numerically using a fourth order Runge Kutta routine. The integration interval used was equal to the process response time required to achieve MLSS pseudo-steady state conditions after a change was made to the influent contacting pattern. On-line sensors were used to measure the initial conditions required for integration. Alternatively, an analytical solution could have been used to solve the equations (Appendix D). The approach described above, however, was adequate to control the step feed system with the time constants characteristic of the process.

The nonlinear method of Box (1965) was used to search numerically for optimal values of $\alpha_2$ and $\alpha_3$ that would minimize the function:

$$\text{Min} \quad ( X_{des} - X_3)^2 \tag{4.6}$$

This method of optimization (Appendix C) is especially suited to this multivariable application since constraints were imposed on the parameters ($\alpha_2$,$\alpha_3$ ) being searched. Explicit and implicit inequality constraints used for the optimization were;

$$\alpha_2 \leq 1 \tag{4.7}$$

$$\alpha_3 \leq 1 \tag{4.8}$$

$$\alpha_2 + \alpha_3 \leq 1 \tag{4.9}$$

The control was updated every 15 minutes to compensate for changes in flow (Q) and volumetric oxygen uptake ($OUR_v$) in the last compartment. The SCOUR response trajectory resulting from the control tended towards the selected SCOUR setpoint. This control approach was similar to that used by Richalet et al. (1978) in industrial plant applications.

## 4.2 Pilot Plant Description and Operation

Pilot plant verification was carried out using two pilot plants operated in parallel at the Wastewater Technology Centre, Burlington, Ontario, Canada. One system (Plant A) consisted of a three compartment step feed process while the other system (Plant B) was a single compartment completely mixed reactor with recycle. Each process had an aerator volume of approximately 2.2 $m^3$ and secondary clarifiers with surface areas of 0.45 $m^2$. Wastewater from the Burlington Skyway Treatment Plant was pumped to a primary clarifier which supplied the pilot systems with settled influent (figure 4.1). Diffused air was supplied through perforated PVC piping.

On line process instruments were interfaced to a real time minicomputer for data acquisition and process control implementation. Five Moniteck Clam 52-LE photometric sensors were used to measure MLSS and RAS concentrations. Dissolved oxygen and air flow were measured by PHOX 65-B galvanic and Brooks 7000 meters, respectively. Foxboro magnetic flow meters measured wastewater flow. Sensor location on both pilot systems are given in figure 4.2. Further details and evaluations of the instrumentation have been reported by Stephenson _et al_. (1981a). The mini-computer hardware consisted of a Hewlett-Packard (HP) 1000 2MX E-Series system with 160 K words of memory and 120 M-bytes of on-line disc storage. A HP-2240 front end microprocessor was used to interface on-line instrumentation to the minicomputer. On-line software for data acquisition has been reported by Stephenson _et al._ (1981b).

On-line data acquisition consisted of 15 minute average measurements for flow Q, mixed liquor solids for all compartments (MLSS), return activated sludge (RAS), D.O., air flow (AFR), effluent suspended solids (ESS), temperature, pH and volumetric oxygen transfer ($OUR_v$). Off-line sampling programs were used to check SRT control, to calibrate instrumentation, and to assess effluent quality. Composite sampling included 24 h flow proportioned samples for TOC, $BOD_5$, COD, ESS, MLSS, RAS, SVI and TKN. Discrete sampling consisted of hourly TOC and three hour total solids analysis for both the effluent and influent streams. Computer outputs showing the data log of composite and discrete samples are given in Appendix E.

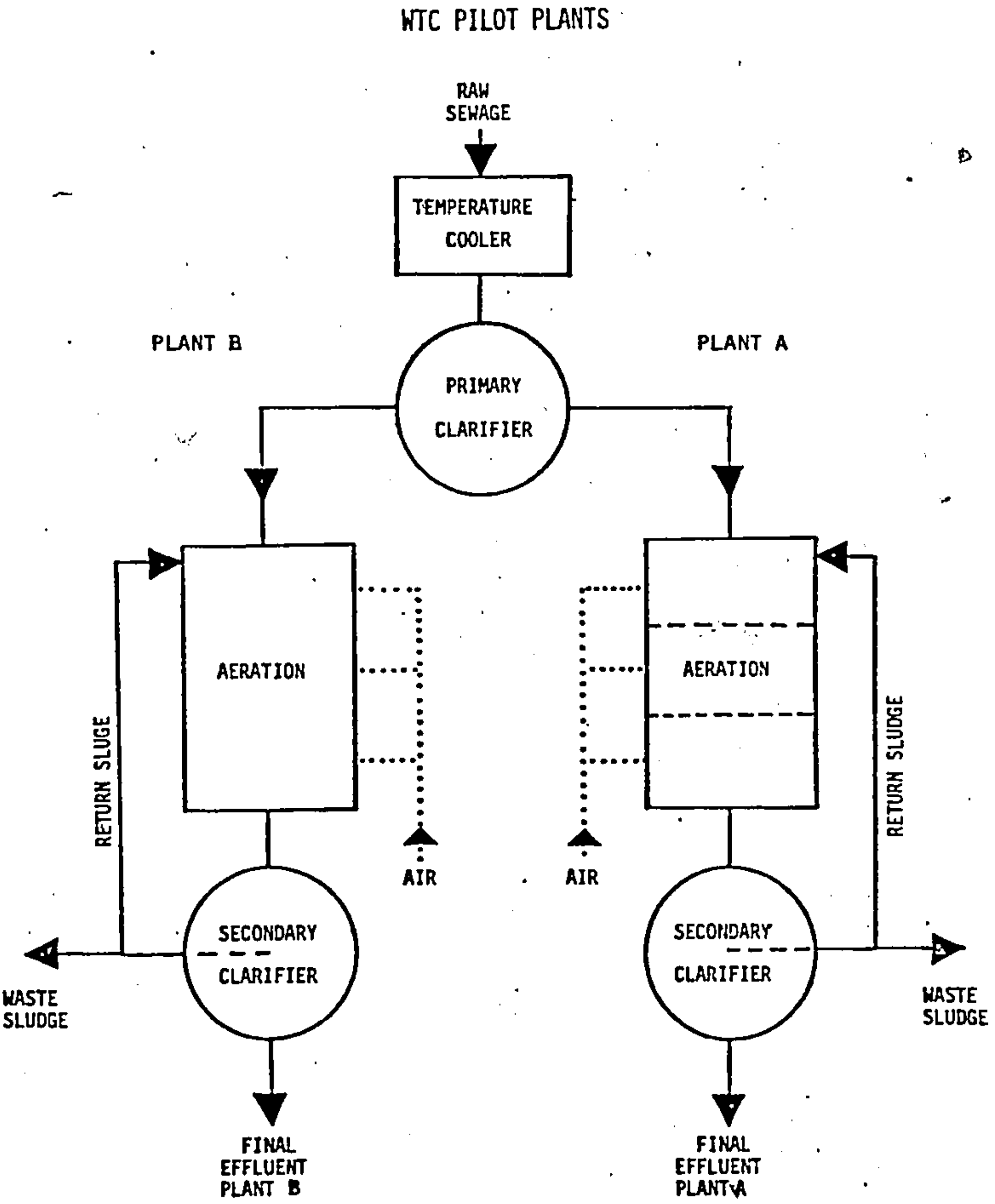


Figure 4.1. Pilot Plant Systems.

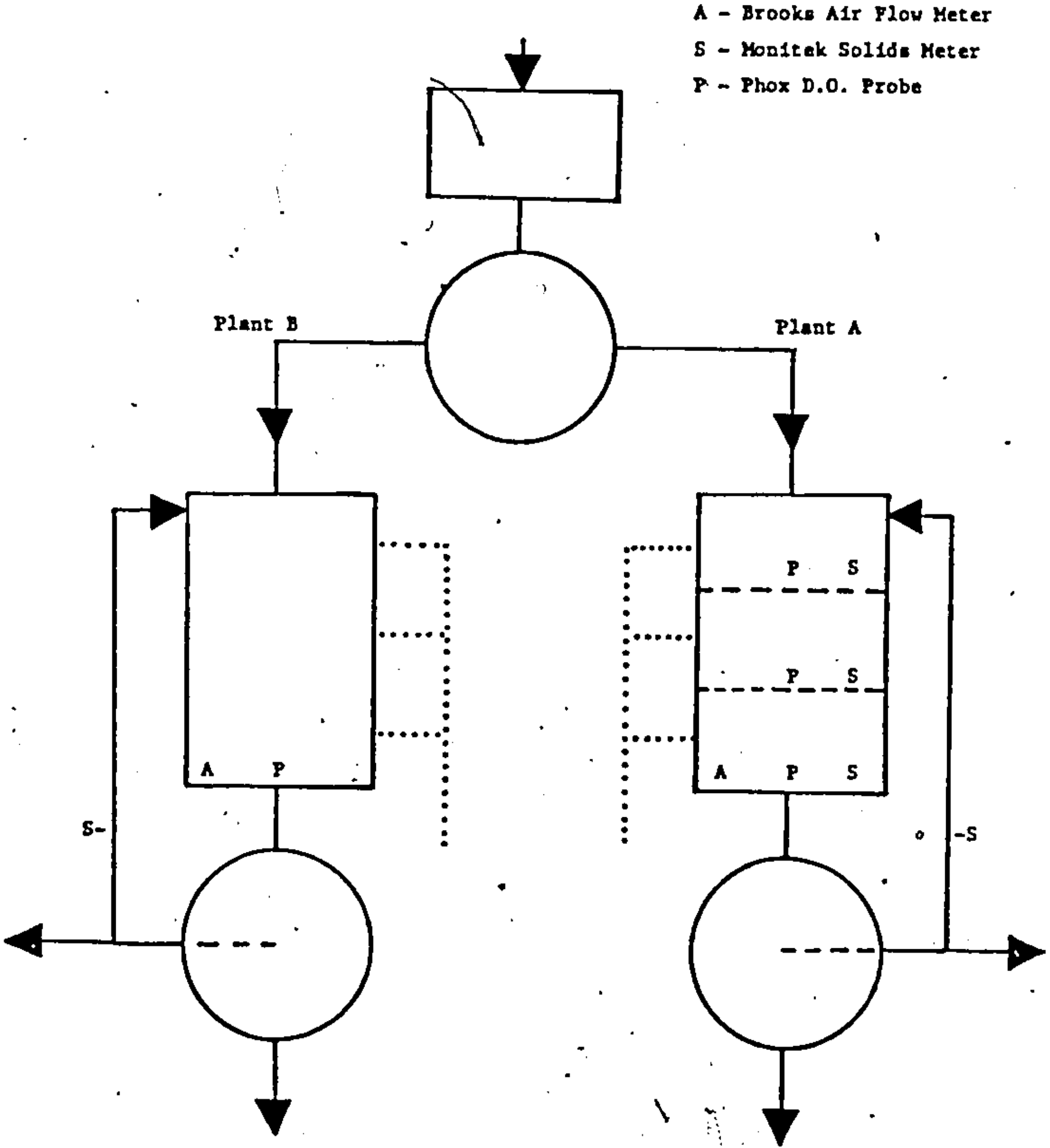


Figure 4.2. On-Line Sensor Location for Process Control.

A summary of the operating conditions used for both systems are given in Table 4.1. To maintain a constant biological growth rate and to minimize nitrification, both plants were automatically controlled at a SRT of 3 days. Wastewater flow to both systems was controlled according to a 24-hour sinusoidal curve with peak flow coinciding with the period having maximum influent organic concentration. Temperature was controlled to approximately 16°C and a 50% recycle ratio was maintained. Air flow meters were installed for the B system aerator and for the last compartment of the A system. Digital PI control algorithms were used to keep the dissolved oxygen levels at 2 mg/L with the exception of the last compartment of the controlled system which was kept at 3 mg/L.

Reaeration tests were performed on both the last compartment of the A system and the B system to estimate volumetric oxygen transfer coefficients ($K_{La}$). Numerical estimates were obtained using non-linear least squares analysis. The air flow rate (AFR) and $K_{La}$ were empirically related as shown in Figure 4.3. The volumetric oxygen uptake was then calculated on-line from a mass balance around the reactor of concern. Details of the reaeration test, non-linear regression, linear regression, and on-line $OUR_V$ calculations are given in Appendix B.

To obtain a time constant for the response trajectory, a step test was used. This provided the response time required to achieve a pseudo-steady state distribution of MLSS between compartments on the step feed system following changes in feed distribution. Under constant hydraulic loading conditions flow was diverted from the first compartment ($\alpha_1 = 1$) to the third compartment ($\alpha_3 = 1$). After reaching steady state the influent was redirected to the first compartment. Response trajectories for three compartments are given in figure 4.4. The time required to reach

TABLE 4.1. PILOT PLANT OPERATING CONDITIONS (Plant A & B)

| | |
|---|---|
| Flow | $480 + 146 \sin \frac{\Pi t}{12}$ L/h |
| HRT | 4.6 h |
| SRT (setpoint) | 3 days |
| F/M Ratio | 0.1 - 0.7 mg $BOD_5$/g MLSS-d |
| Recycle Ratio (setpoint) | 50% |
| Temperature (setpoint) | 16°C |
| D.O. (setpoint) | 2-3 $mgO_2$/L |

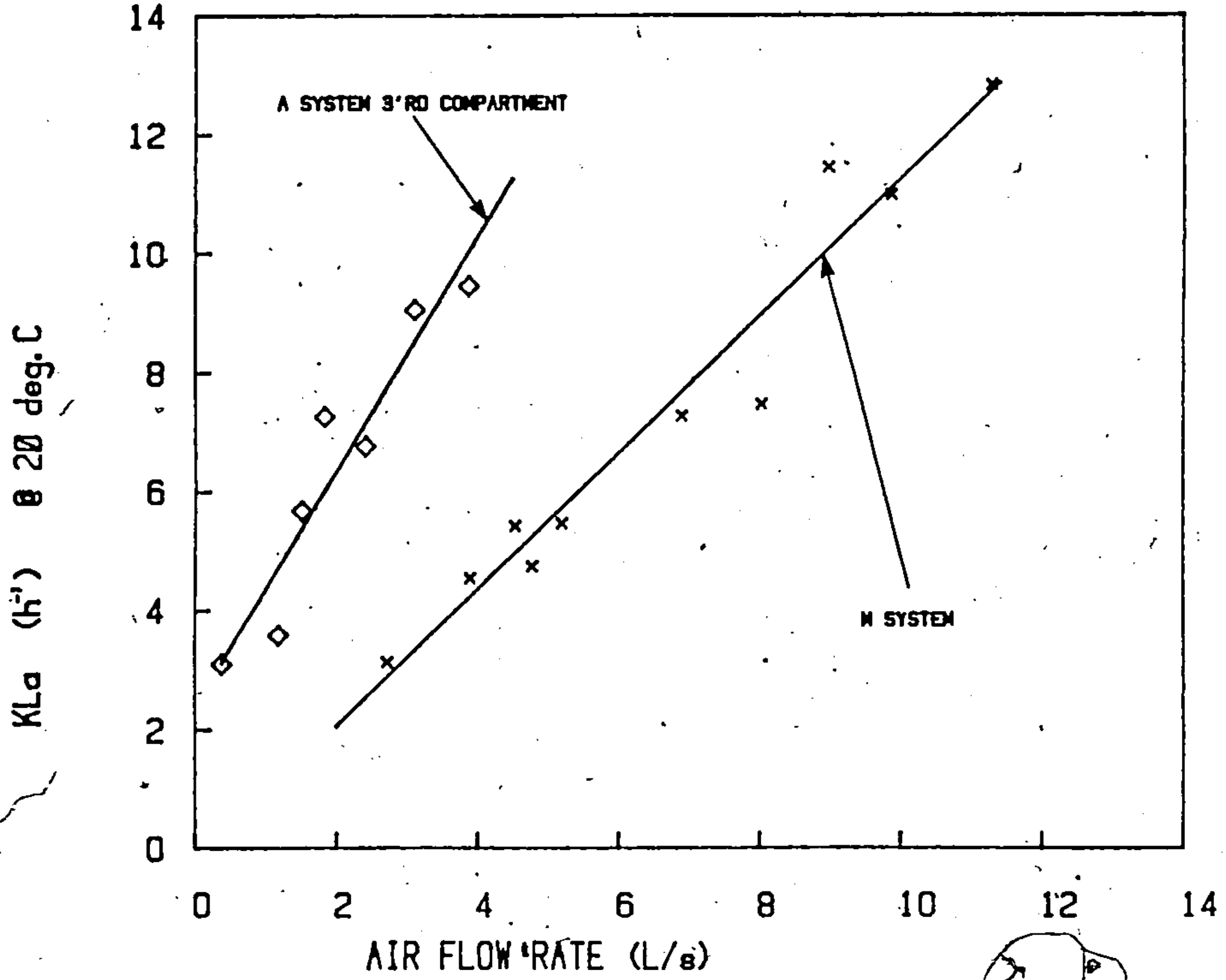


Figure 4.3. Relationship Between $K_{La}$ and Air Flow Rate.

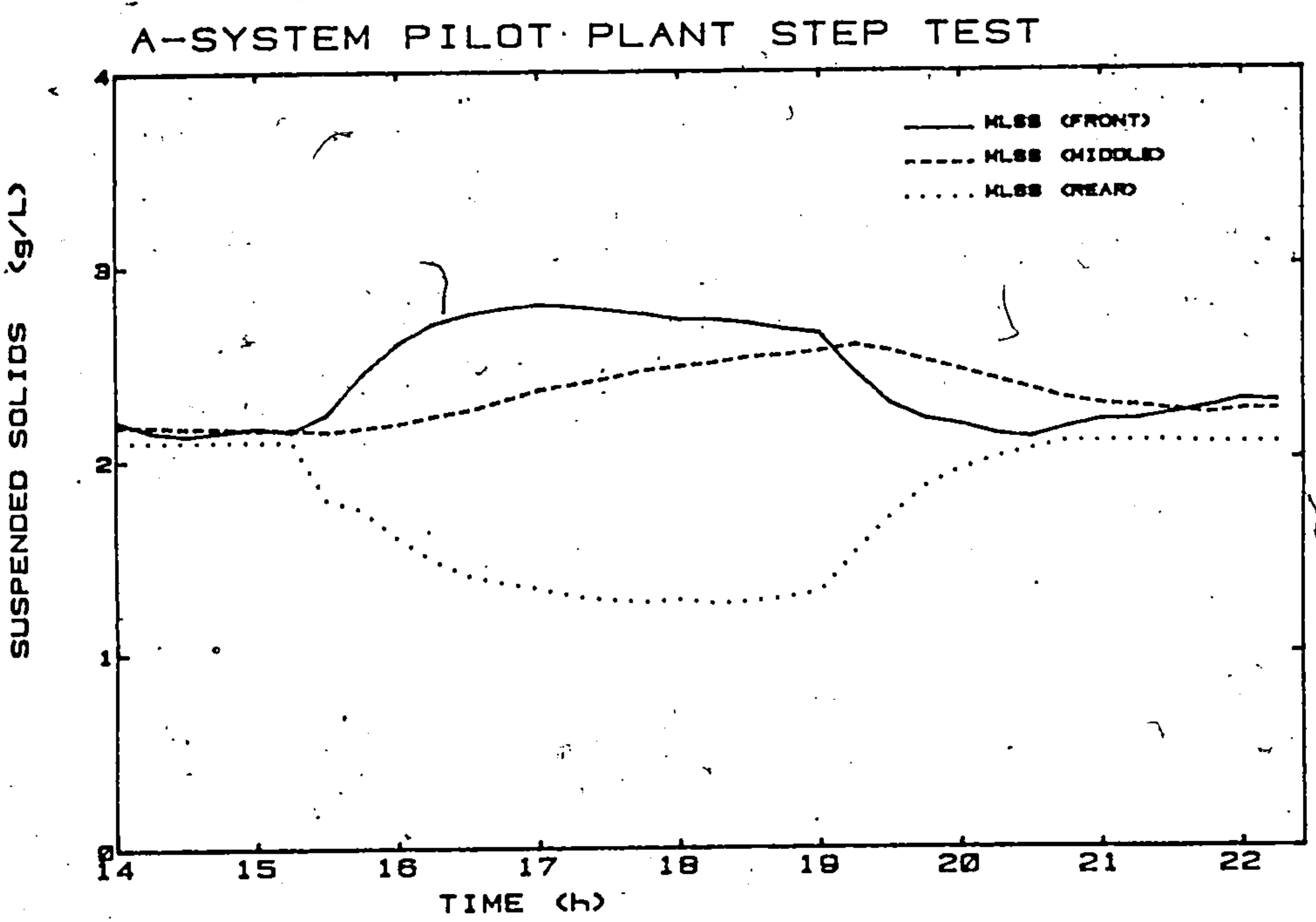


Figure 4.4 On-Line MLSS Response Trajectories.

pseudo-steady state was approximately 100 minutes for a MLSS change of 1000 mg$\cdot$L$^{-1}$ in the third compartment. This response time was approximately 20% less than that obtained from computer simulation. The difference was probably due to the simplified clarifier assumption used for simulation. The steady state response time was used as the integration interval for the solids mass balance (eq. 4.2, 4.3, and 4.4) to obtain the predicted pseudo-equilibrium MLSS values and thus permit calculation of the required $\alpha$ values.

A number of preliminary control runs were performed at different SCOUR setpoints ranging from 11 to 20 mg$O_2$/g MLSS-h. The setpoint chosen was one that would distribute influent flow equally to all compartments during a diurnal control period.

## 4.3 SCOUR Control Optimization

### 4.3.1 Three-compartment optimization

Constant SCOUR control was initially applied to the A system optimizing influent flow to three compartments. The selected SCOUR setpoint was 15 mg$O_2$/g MLSS-h. Before initiating control, the step feed process was operated at steady state with all influent being directed to the first compartment. The parallel B system was operated under identical steady state conditions. Because all flow was distributed to the first compartment, instantaneous SCOUR values for the A system were lower when compared to the B system's SCOUR values.

Actual instantaneous SCOUR values from the B system and the third compartment of the A system are shown in figure 4.5 after control was initiated on the A system. The required contacting patterns ($\alpha_1$, $\alpha_2$, $\alpha_3$,) to achieve this control are expressed as a percentage of

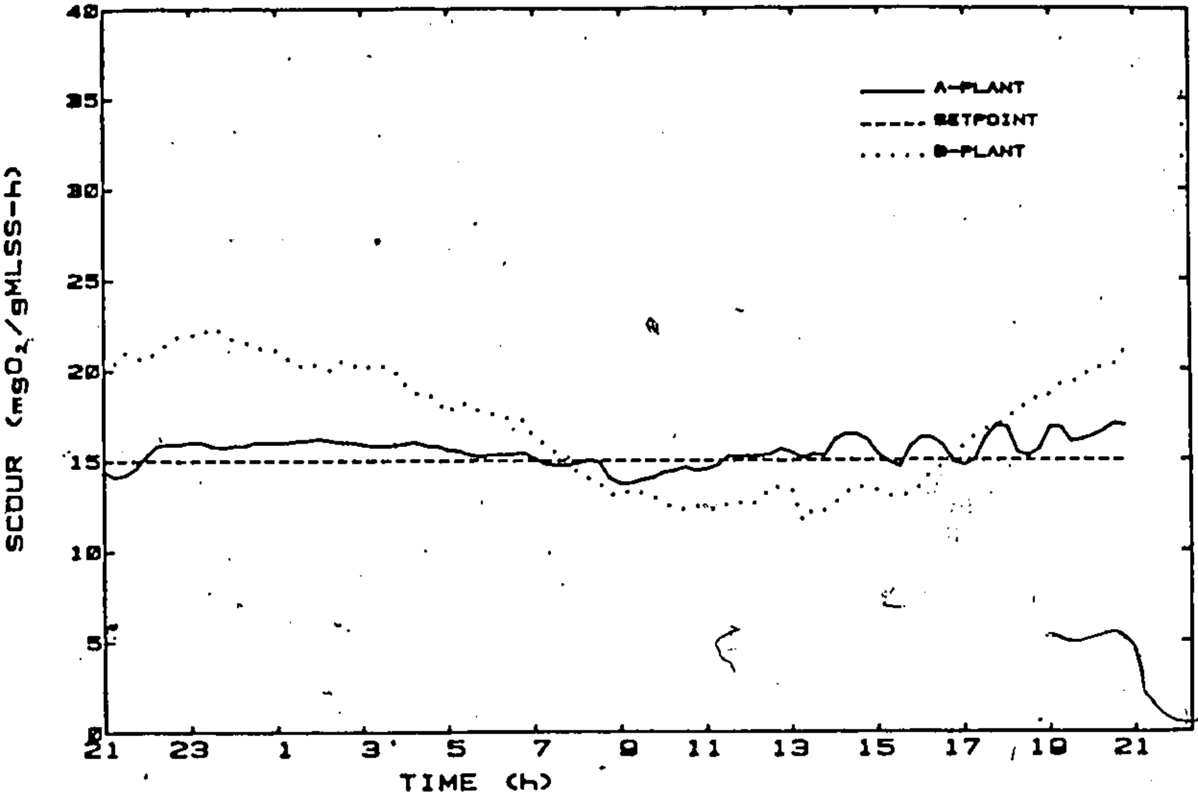


Figure 4.5. Three-Compartment SCOUR Control (Run #1).

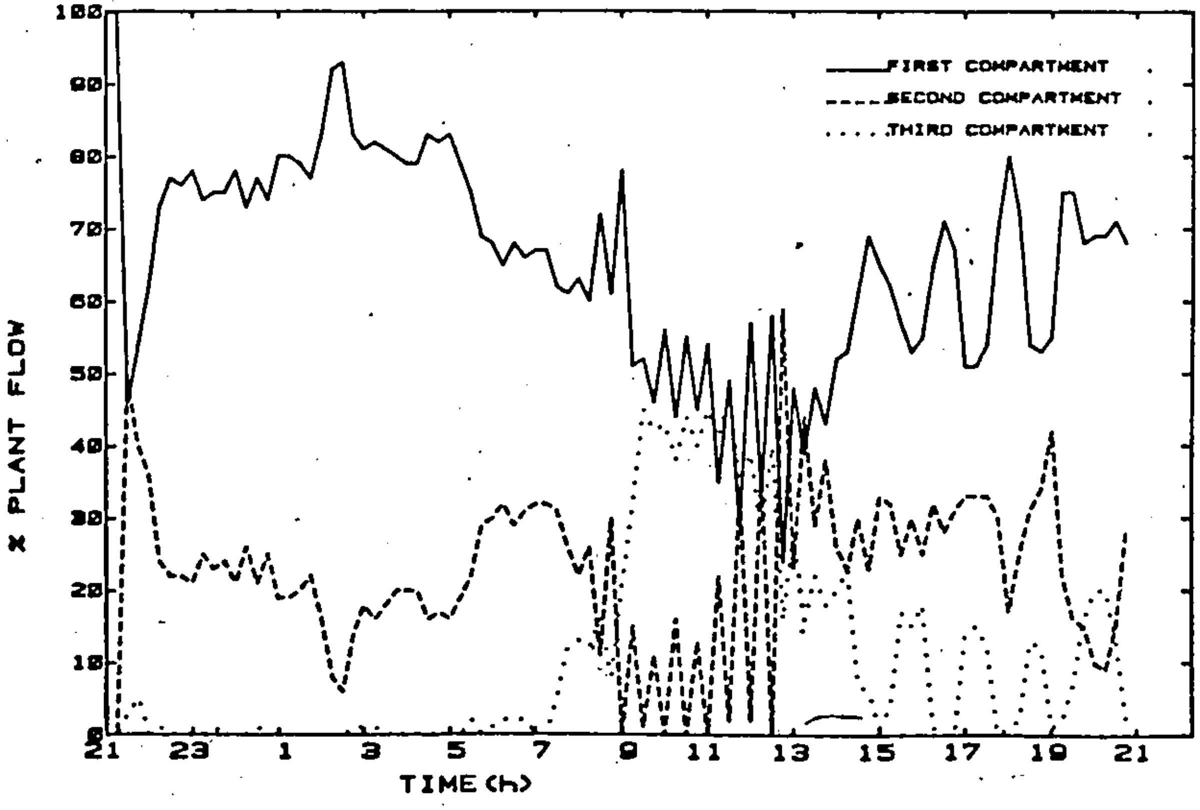


Figure 4.6. Three-Compartment Contacting Pattern (Run #1).

total influent flow and are presented in figure 4.6.

During the initial eight hours of control, stable operation was achieved. After hour 9, extreme oscillation between compartments was observed. Despite this condition, the A system's instantaneous SCOUR approximated the SCOUR setpoint while the B system's instantaneous SCOUR showed considerable variation. The rapid frequency of change in the contacting pattern is unacceptable from a practical standpoint because of the excessive wear on the flow distribution valves.

Discrete off-line sampling from Run #1 is summarized in Table 4.2. Only paired data between the parallel plants were analyzed. The results indicated no significant statistical difference of effluent quality based on EFOC.

To investigate the reason for the rapid switching frequencies observed in figure 4.6, 3-dimensional grids (figure 4.7 and 4.8) were constructed relating $\alpha_2$ and $\alpha_3$ to the objective function ( eq. 4.6). These figures indicate that unique minima do not exist. The optimization could select a number of different $\alpha_2$, $\alpha_3$ combinations giving identical, instantaneous SCOUR values for the third compartment with a wider range being possible at mid-range loading (figure 4.8). Under such conditions, the final contacting pattern is dependent on the initial search values of the complex created in the Box-Complex algorithm (Appendix C). Because there is no unique minimum, contacting patterns varied widely for successive control intervals as different initial search values were selected in the algorithm. Additional control constraints would be required to provide unique optimization for 3-compartment distribution.

TABLE 4.2. DYNAMIC STEP FEED PROCESS CONTROL RESULTS. SCOUR SETPOINT = 15 $mgO_2/g$ MLSS-h

| | | | Mean ± Standard Deviation* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Actual Continuous SCOUR ($mgO_2 \cdot g\ MLSS^{-1} \cdot h^{-1}$) | | EFOC Effluent ($mg \cdot L^{-1}$) | | | ESS† ($mg \cdot L^{-1}$) | | |
| | Duration (h) | Influent Loading ($gBOD_5 \cdot g\ MLSS^{-1} d^{-1}$) | A | B | A | B | N | A | B | N |
| Run 1* | 27 | 0.5 | 15.6 ± .00 | 17.7 ± .56 | 16.5 ± 4.7 | 17.1 ± 5.7 | 16 | 42 ± 11 | 29 ± 11 | 5 |
| Run 2 | 24 | 0.7 | 14.9 ± 1.5 | 18.9 ± 4.2 | 17.4 ± 1.9 | 17.9 ± 4.3 | 25 | 41 ± 9 | 25 ± 5 | 8 |
| Run 3 | 24 | 0.1 | 12.7 ± 2.8 | 14.4 ± 2.1 | 18.1 ± 3.0 | 15.2 ± 2.2 | 25 | 40 ± 12 | 20 ± 5 | 7 |
| Run 4 | 24 | 0.1 | 14.2 ± 2.2 | 15.5 ± 2.5 | 17.0 ± 4.0 | 16.8 ± 2.1 | 25 | 28 ± 8 | 19 ± 5 | 8 |
| Run 5 | 24 | 0.7 | 14.3 ± 2.3 | 21.8 ± 4.3 | 26.4 ± 4.8 | 27.9 ± 6.4 | 25 | 27.6 ± 5 | 23.3 ± 5 | 9 |
| Run 6 | 19 | 0.3 | 15.5 ± 0.5 | 20.9 ± 2.4 | 18.5 ± 2.2 | 18.2 ± 1.3 | 17 | 30.6 ± 18 | 16.3 ± 9 | 7 |
| Run 7 | 24 | 0.4 | 15.8 ± 1.4 | 19.7 ± 1 8 | 19.9 ± 5.3 | 23.4 ± 6.9 | 25 | 21.6 ± 6 | 12.0 ± 3 | 9 |

* Three compartment optimization. All other runs are with two compartments.

† Underlined means and standard deviations indicate differences between A and B were determined to be statistically significant.

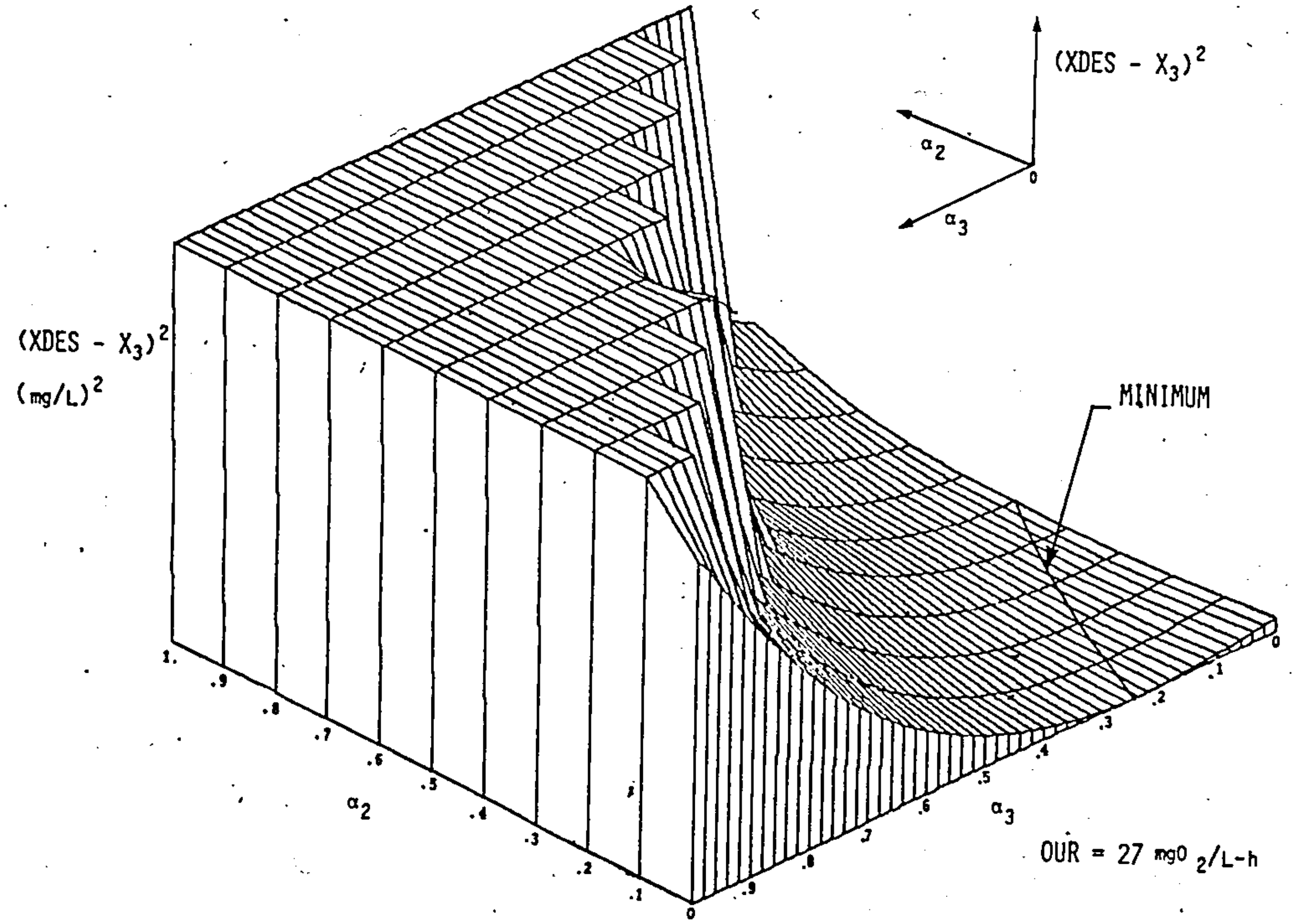


Figure 4.7. Three-dimensional Optimization Grid — High Loading.

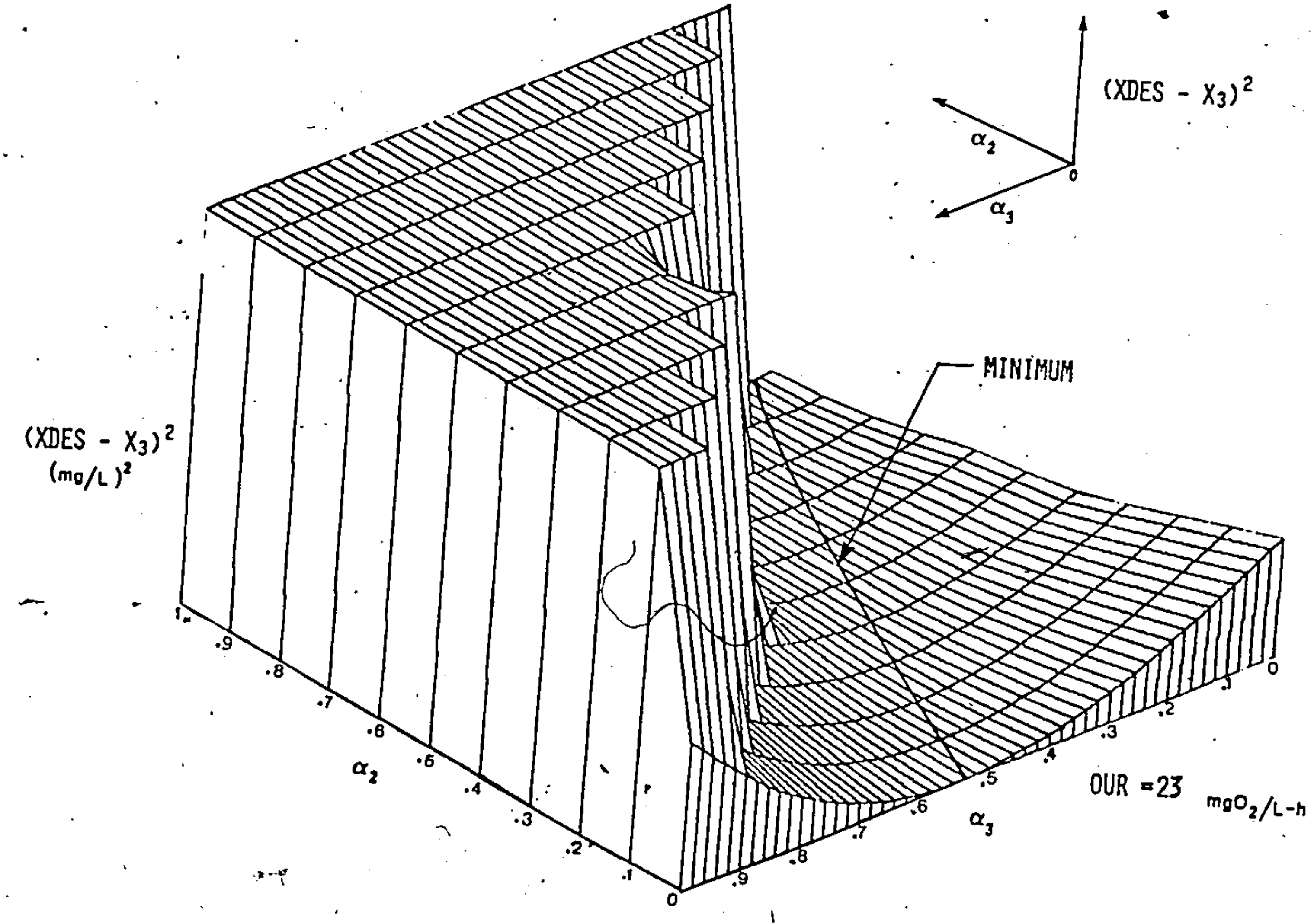


Figure 4.8. Three-dimensional Optimization Grid — Mid Loading.

### 4.3.2 Two-compartment optimization

The control algorithm was modified to split the influent to only two compartments. The first and third compartments were used with the restriction that no influent would be added to the second compartment ($\alpha_2 = 0$). $\alpha_1$ was calculated by difference ($\alpha_1 = 1-\alpha_3$). A 2-dimensional plot showing the relationship between the objective function and percentage of flow to the last compartment is presented in figure 4.9 for three loadings each having different $OUR_V$ rates. Minimization of the objective function produced a unique minimum for each loading.

Six experimental runs were completed at different influent F/M loadings using two-compartment optimization. Table 4.2 summarizes discrete off-line sampling for Runs #2 to #7 using a SCOUR setpoint of 15. Plots for all experimental runs comparing controlled step feed control results to the steady state control on system B are given in Appendix F.

Figures 4.10 and 4.11 present instantaneous results for the A system operating under a high steady F/M loading condition. The A system shows improved SCOUR control compared to the B system. The contacting pattern in figure 4.11 was considered acceptable from a practical viewpoint.

Figures 4.12 and 4.13 present instantaneous control results with a highly variable influent loading. The A system shows improved control during high loading periods when more influent was distributed to the first compartment during this period. Conversely, influent was directed to the last compartment under lower loading conditions at hour 8. During low loadings, the control was restricted as all the

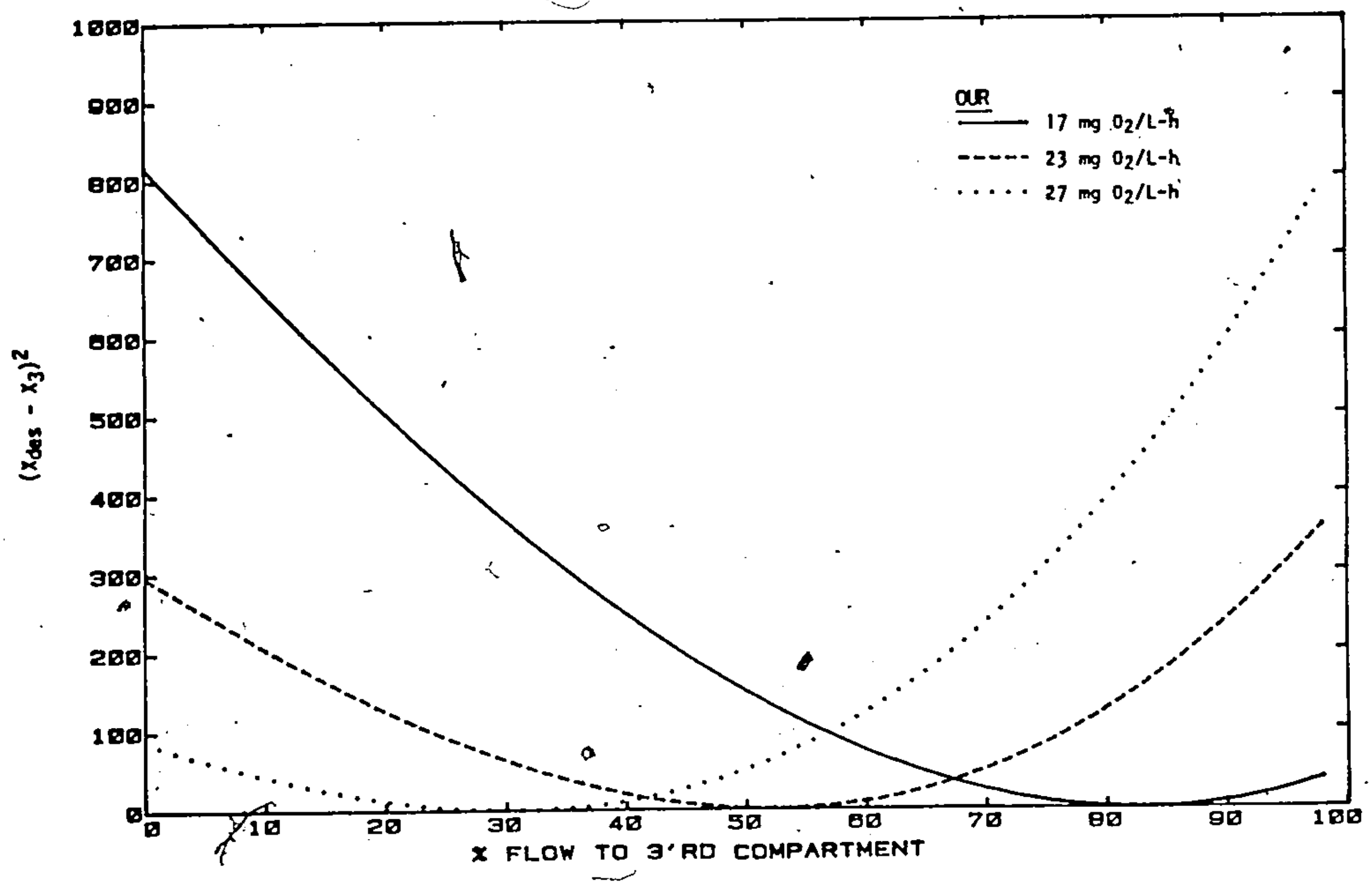


Figure 4.9. Two-Compartment Optimization.

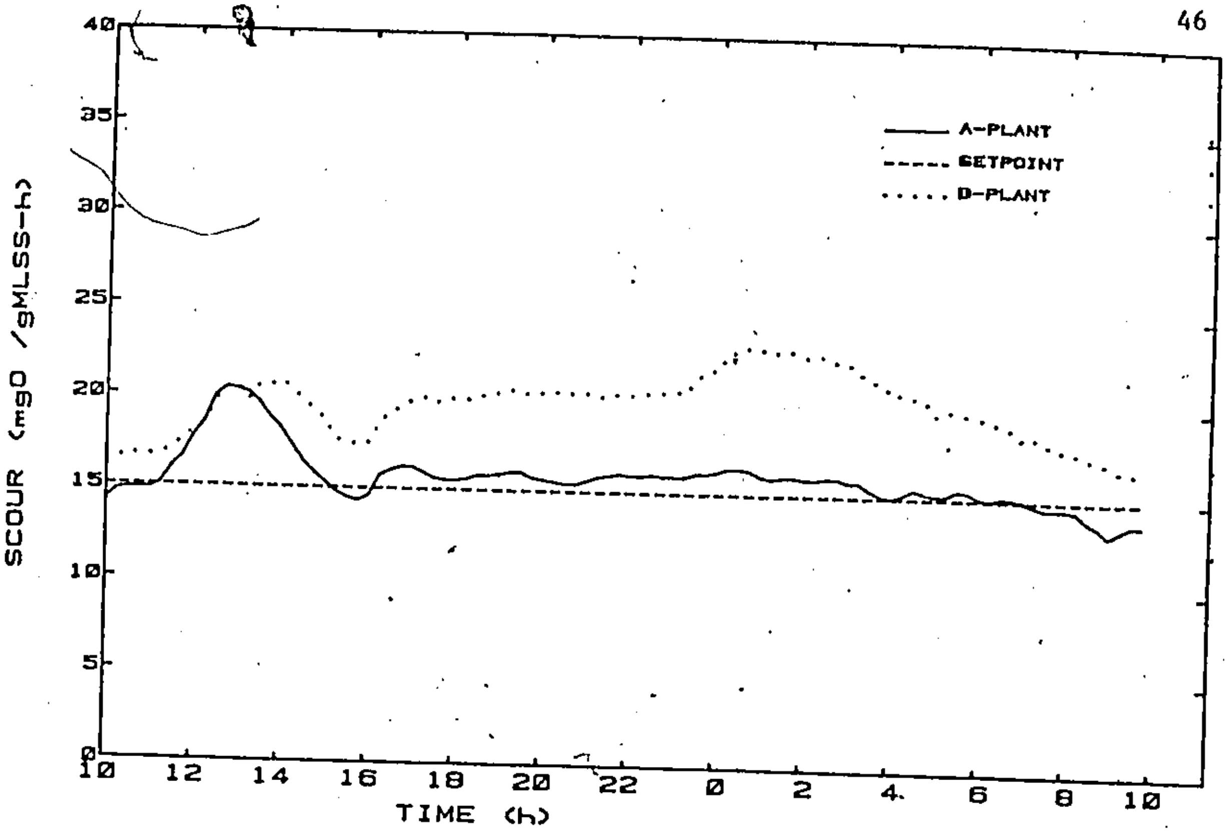


Figure 4.10. Two-Compartment SCOUR Control (High Loading).

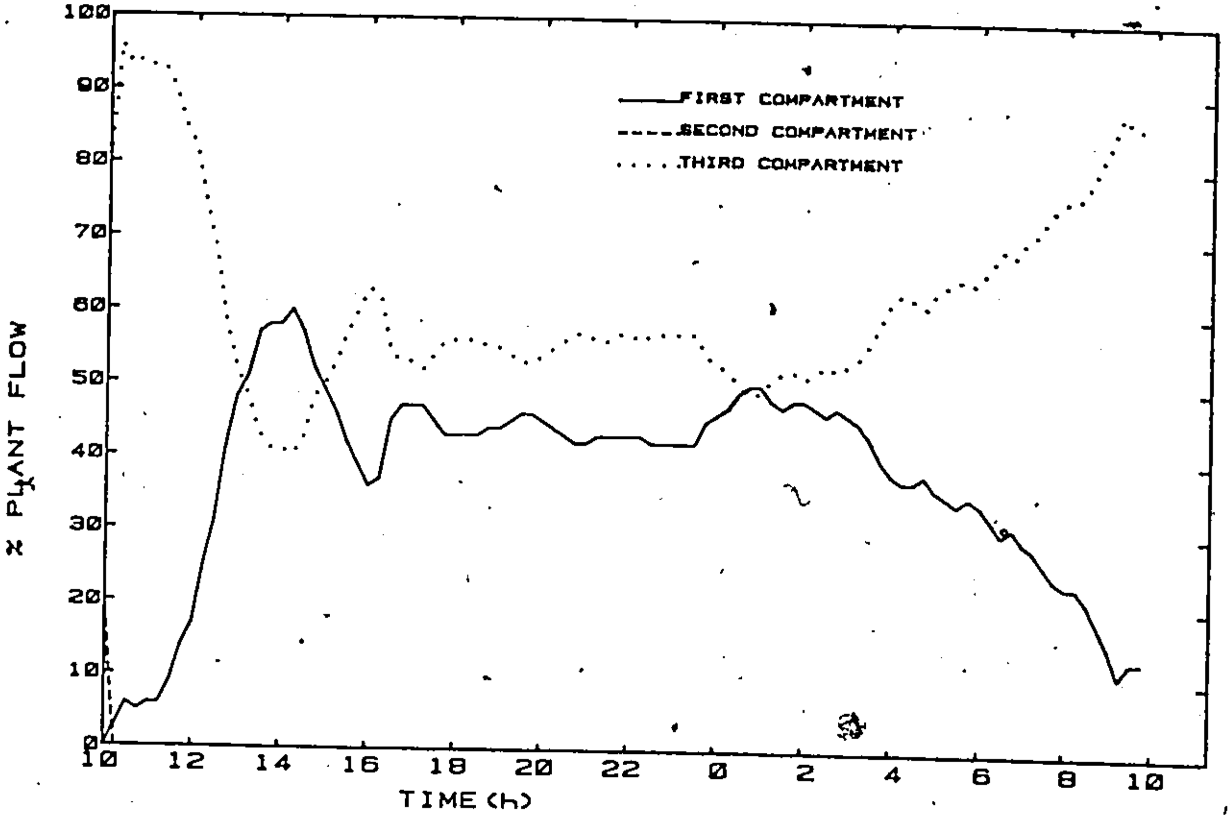


Figure 4.11. Two-Compartment Contacting Pattern (High Loading).

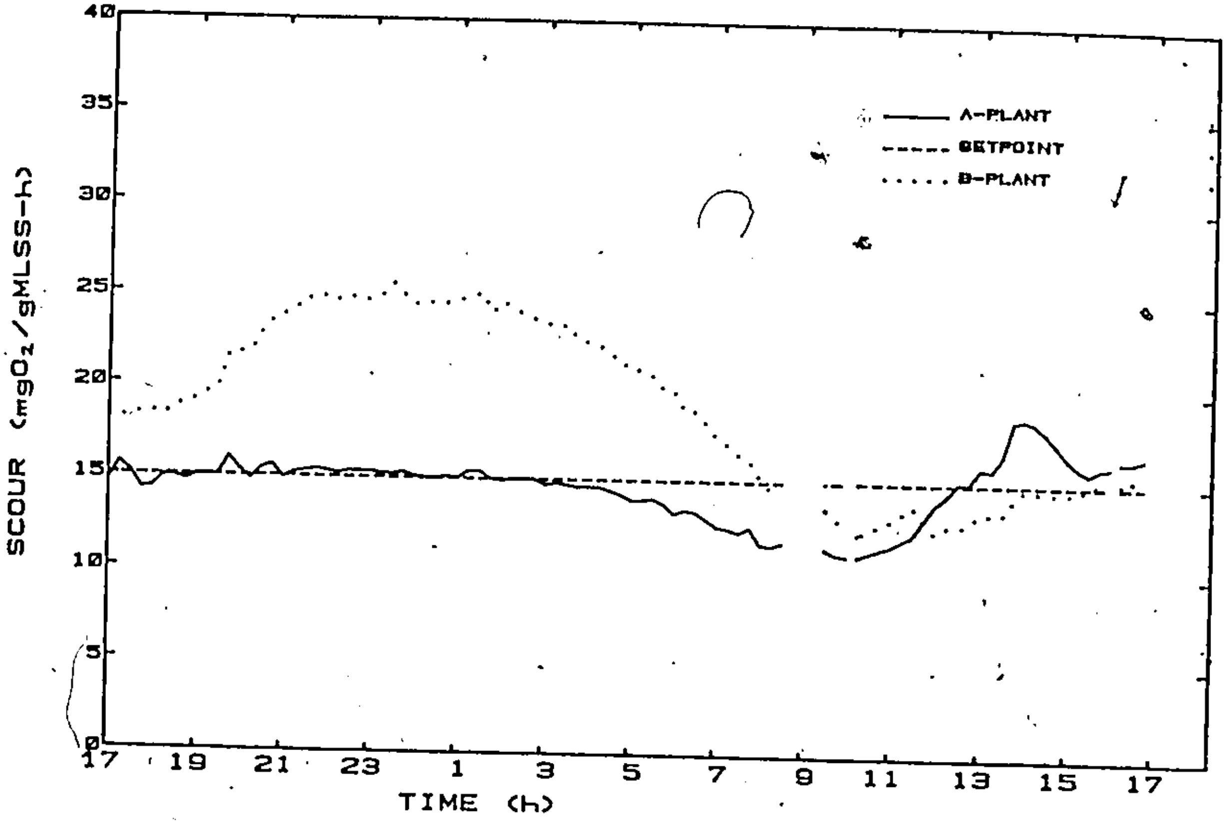


Figure 4.12. Two-Compartment SCOUR Control (Variable Loading).

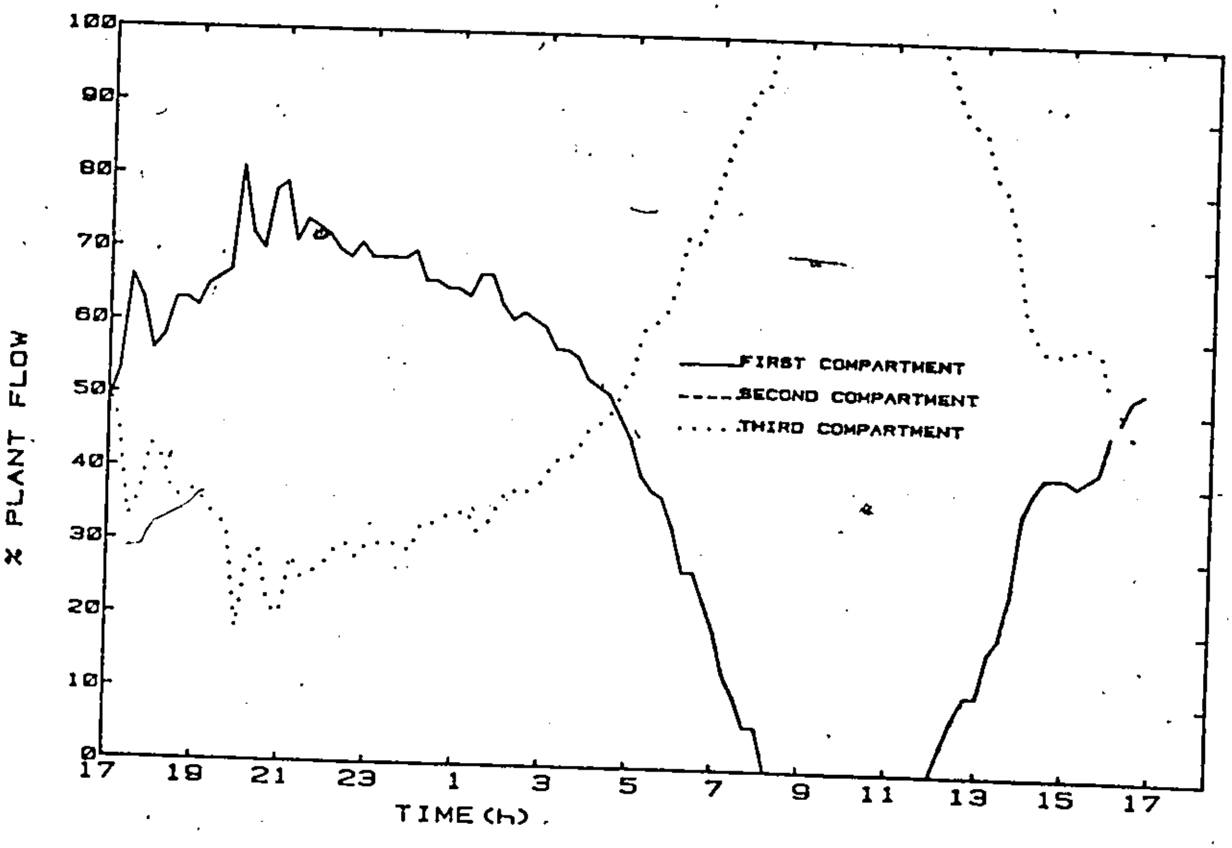


Figure 4.13. Two-Compartment Contacting Pattern (Variable Loading).

influent was being distributed to the final compartment.

Control results under lower average loading conditions are given in figures 4.14 and 4.15. Under the hydraulic restrictions imposed on the control there is no evidence of improved SCOUR control. During a large percentage of the control period, the influent was directed entirely to the final compartment.

Table 4.3 presents pooled results after separating data into runs having high and low loading conditions. Filterable organic carbon effluent data (EFOC) suggest that a reduced effluent variability can be obtained from the SCOUR control proposed during high loading periods. At low loading periods, where SCOUR control is limited, no improvement of instantaneous SCOUR or EFOC variability would be expected in comparison to the B system. Consistently higher effluent suspended solids concentration (ESS) were observed in all experiments with the controlled system.

A number of possible modifications could be undertaken to improve control. During low loading periods, the recycle flow rate could be reduced to decrease the rate of solids transfer to the third compartment and thus raise instantaneous SCOUR values. The simulation results from Chapter 3 suggest that additional compartments would also increase the control range of the step feed systems. Another approach to improve SCOUR control would be to reduce the final reactor's volume during low loading periods using a variable weir. A feed-forward indication of impending plant organic loading could permit more rapid control to minimize overshoot effects.

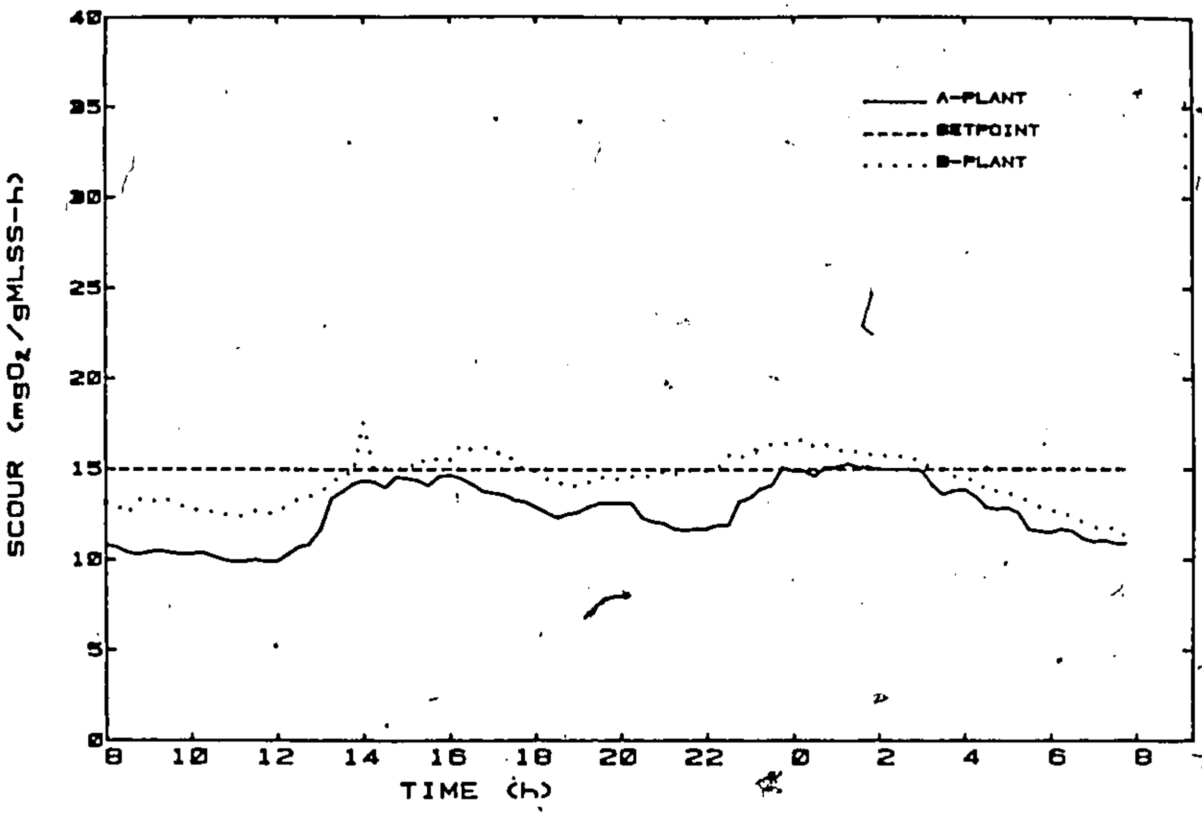


Figure 4.14. Two-Compartment SCOUR Control (Low Loading).

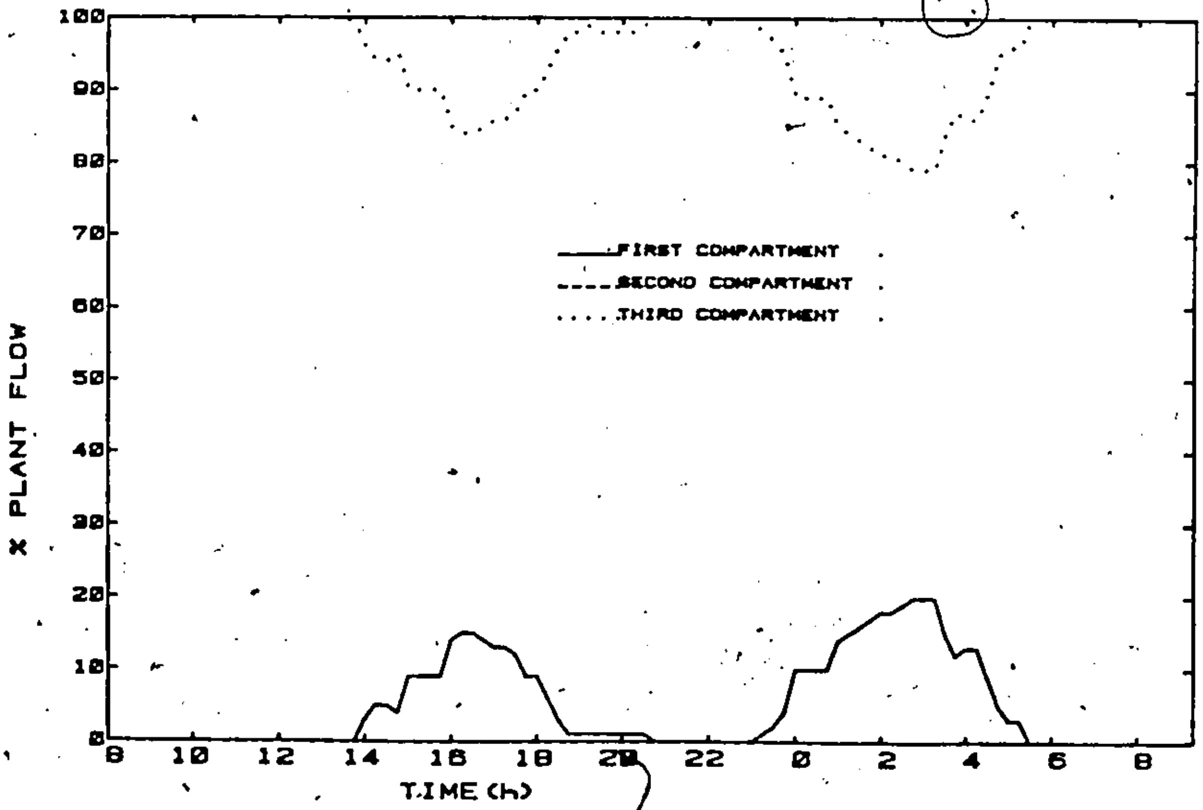


Figure 4.15. Two-Compartment Contacting Pattern (Low Loading).

## TABLE 4.3

PARALLEL PLANT COMPARISONS. (SCOUR Setpoint = 15)

| MEAN LOAD* | CONTINOUS SCOUR (mg$O_2$ /gMLSS – hr ) | | EFOC (mg/L) | | ESS (mg/L) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| .6 | 15.0±1.8 | 20.1±3.9 | 21.2±4.2 | 23.1±6.0 | 30.1±6.9 | 20.1±4.4 |
| .2 | 14.1±2.1 | 16.9±2.3 | 17.8±3.2 | 16.7±1.9 | 32.9±13.3 | 18.4±6.6 |

*(g$BOD_5$ / gMLSS – d )

Before SCOUR control could be evaluated fully, the problem of increased effluent suspended solids concentrations had to be addressed.

## 4.4 Effluent Suspended Solids

Possible causes for the increase in the effluent suspended solids concentrations in the A system could be:

1) the high SCOUR setpoint selection. A high SCOUR selection would increase the system hydraulic transients due to the frequency of change in the influent contacting pattern.
2) the high D.O. setpoint. To keep dissolved oxygen at high setpoints, an average higher air flow rate would be necessary depending on the organic load, Since the system's flocculation performance depends on the level of turbulence in the aerator (Tuntoolavest _et al_., 1980) the D.O. setpoint selection could affect ESS concentrations.
3) Inefficient oxygen transfer caused by the pilot plant's air diffusion system.

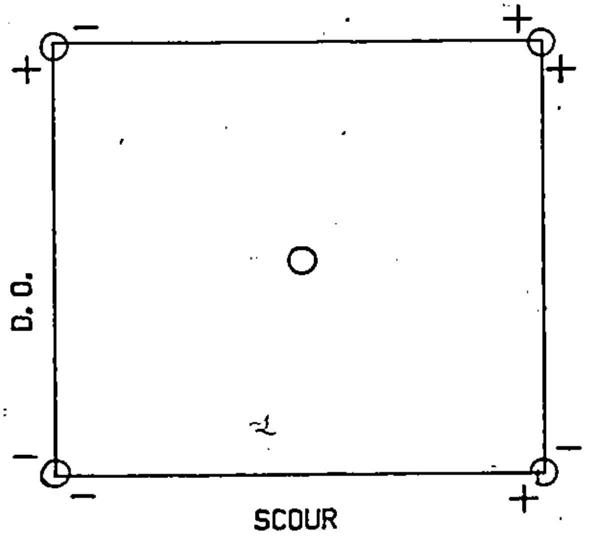
Oxygen transfer efficiencies (US-EPA, 1979) calculated for both pilot systems show that both plants had efficiencies of less than one percent. Typical transfer efficiencies for coarse-bubble aeration systems are reported in the literature as being between 4 and 8 percent (Metcalf and Eddy, 1979). Because of this inefficiency, the excess air required caused an increase in the turbulence levels.

The Ontario Ministry of the Environment (1980) Aeration Mixing Guideline for Activated Sludge Systems recommends a value of $3.3 \times 10^{-3}\ m^3/m^3$-S. The aeration mixing levels for the A system's third compartment while operating at a D.O. setpoint of 3 mg/L exceeded the guideline by a factor of 8 (Appendix B.4). This mixing level would decrease if the D.O. setpoint was operated at a lower setting (Table B.4, Appendix B.4).

To investigate the problem further, a $2^2$ factorial experiment was run to examine both SCOUR and D.O. setpoint settings. Experiment design levels are shown in figure 4.16 with the centre point setting being that used for the previous control experiments. The seven previous control runs were used as replicates for the factorial analysis. Discrete effluent sampling, as described previously, was used for the factorial output. In addition to the regular sampling program, stirred column setting tests (Chapman, 1980) were performed on the A system's third compartment. TSS samples were taken from the supernatant after 30 minute settling during each of the factorial design settings.

Because of constraints at the WTC, the A system was operated with only two MLSS on-line sensors. A predictor model consisting of the model described in section 4.1 was used in unison with the data acquisition software to estimate MLSS concentrations. On-line measured RAS concentrations and flow were used for initial conditions. The MLSS sensor in the A system's third compartment was used to check the predicted values. Figure 4.17 indicates the good agreement between measured on-line sensor third compartment values and the predictor values.

The matrix approach to linear regression described by Draper and Smith (1968) was used to statistically analyze the factorial results. Table 4.4 presents continuous SCOUR and discrete effluent results from the factorial experiment.



| | − | + |
|---|---|---|
| SCOUR | 11 | 19 |
| D. O. | 1 | 5 |

Figure 4.16. Factorial Design Settings.

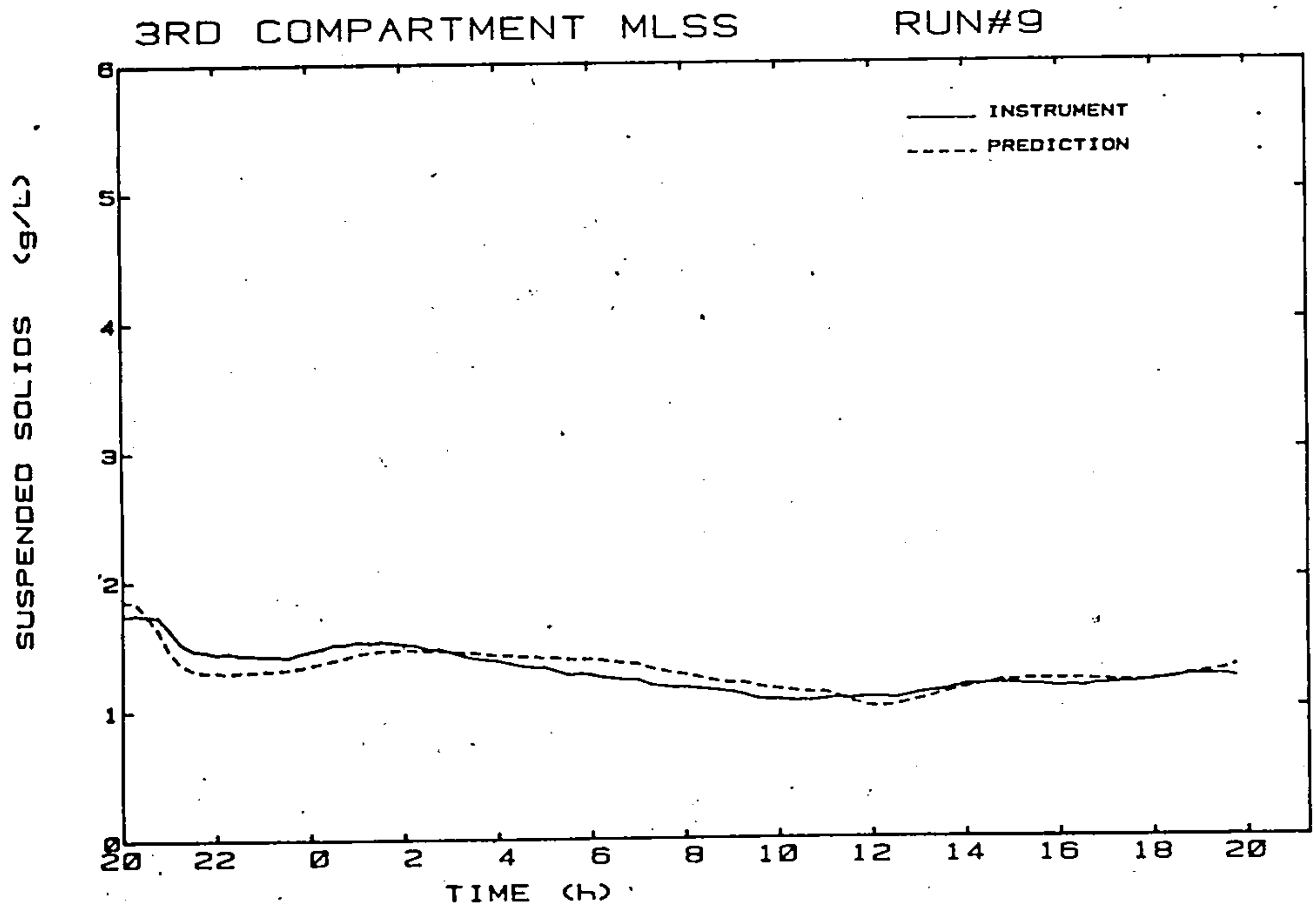


Figure 4.17. On-Line Model Prediction.

The analysis of variance (ANOVA) for ESS, EFOC, and SS (column tests) is shown in Table 4.5.

Linear regressions derived from the analysis are:

$$y_1 = 37.5 + 8.7\,x_1 + 13.7\,x_2 \qquad (4.10)$$

$$y_2 = 22.5 + 11.0\,x_2 \qquad (4.11)$$

where $y_1$ is the ESS concentration,

$y_2$ is the EFOC concentration,

$x_1$ is the SCOUR setpoint setting, and

$x_2$ is the D.O. setpoint setting in the third compartment.

Inferences about the mean square of the model and mean square of the residuals were made at significance levels of 5%. Significant regression was achieved for both ESS and EFOC. A lack of fit was observed for equations 4.10 and 4.11 after testing the mean squares for lack of fit and pure error. The pure error mean square was therefore used to estimate model variances. A lack of fit did not exist for ESS when using a significance level of 1%.

Only parameter estimates statistically significant from zero with a 95% confidence level were included in equations 4.10 and 4.11. The dissolved oxygen setpoint setting ($x_2$) had the largest effect on both the ESS and EFOC concentrations. Column settling supernatant S S concentrations are compared to aeration mixing levels and air flow rate in table 4.6 and figure 4.18, respectively.

TABLE 4.4 FACTORIAL CONTROL RESULTS (TWO COMPARTMENT OPTIMIZATION)

|  | Influent Loading (gBOD₅/g MLSS-d) | A. System Setpoints |  | Mean ± Standard Deviation† |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | D.O. (mg/L) | SCOUR (mgO₂/g MLSS-h) | Actual Continuous SCOUR |  | EFOC (mg/L) |  |  | ESS (mg/L) |  |  |
|  |  |  |  | A | B | A | B | N | A | B | N |
| Run 8 | 0.3 | 5 | 11 | 11.0 ± 0.2 | 11.7 ± 1.8 | 34.9 ± 6.8 | 35.8 ± 4.2 | 24 | 52.9 ± 14 | 19.1 ± 7 | 9 |
| Run 9 | 0.6 | 5 | 19 | 18.7 ± 1.5 | 15.4 ± 2.7 | 43.6 ± 10.8 | 46.7 ± 5.4 | 25 | 69.3 ± 34 | 25.7 ± 6 | 9 |
| Run 10 | 0.4 | 1 | 11 | 12.1 ± 0.9 | 16.8 ± 2.9 | 16.4 ± 1.8 | 17.4 ± 2.1 | 25 | 24.6 ± 7 | 20.3 ± 7 | 8 |
| Run 11 | 0.2 | 1 | 19 | 18.8 ± 1.1 | 13.7 ± 2.5 | 18.0 ± 2.9 | 14.3 ± 1.3 | 25 | 43.0 ± 14 | 14.4 ± 3 | 8 |
| Run 12 | 0.3 | 3 | 15 | 14.8 ± 1.5 | 11.8 ± 2.4 | 17.6 ± 3.4 | 14.4 ± 0.8 | 25 | 33.6 ± 13 | 17.6 ± 4 | 9 |

† Underlined means and standard deviations indicate differences between A and B were determined to be statistically significant.

TABLE 4.5. ANOVA TABLE— FACTORIAL RESULTS

| Variable | Source | Sum of Squares | Degree of Freedcm | Mean Square |
|---|---|---|---|---|
| ESS | Model | 16 495 | 4 | 4124 |
| | Residual | 919 | 7 | 131.3 |
| | LOF | 626 | 1 | 626 |
| | Pure Error | 293 | 6 | 49 |
| | Total | 17 414 | 11 | |
| EFOC | Model | 6 108 | 4 | 1527 |
| | Residual | 268 | 7 | 38 |
| | LOF | 203 | 1 | 203 |
| | Pure Error | 65 | 6 | 11 |
| | Total | 6 376 | 11 | |
| TSS (column settling test) | Model | 27 023 | 4 | 6758 |
| | Residual | 328 | 1 | 328 |
| | Total | 27 351 | 5 | |

TABLE 4-6. FACTORIAL RESULTS FOR STIRRED COLUMN SETTLING TESTS (DAILY AVERAGES).

| Run | D.O. Setpoint (mg/L) | SCOUR Setpoint ($mgO_2$/g MLSS-h) | Supernatant TSS Conc. (mg/L) | Average Air Flow Rate/Volume ($m^3/10^3\ m^3$ - s) |
|---|---|---|---|---|
| 8 | 5 | 11 | 59 | $22.3\ 10^{-4}$ |
| 9 | 5 | 19 | 135 | $25.3\ 10^{-4}$ |
| 10 | 1 | 11 | 29 | $6.0\ 10^{-4}$ |
| 11 | 1 | 19 | 50 | $6.8\ 10^{-4}$ |
| 12 | 3 | 15 | 48 | $8.0\ 10^{-4}$ |

* MOE Guideline for full scale systems = $3.3 \times 10^{-4}$ ($m^3/10^3\ m^3$ - s)

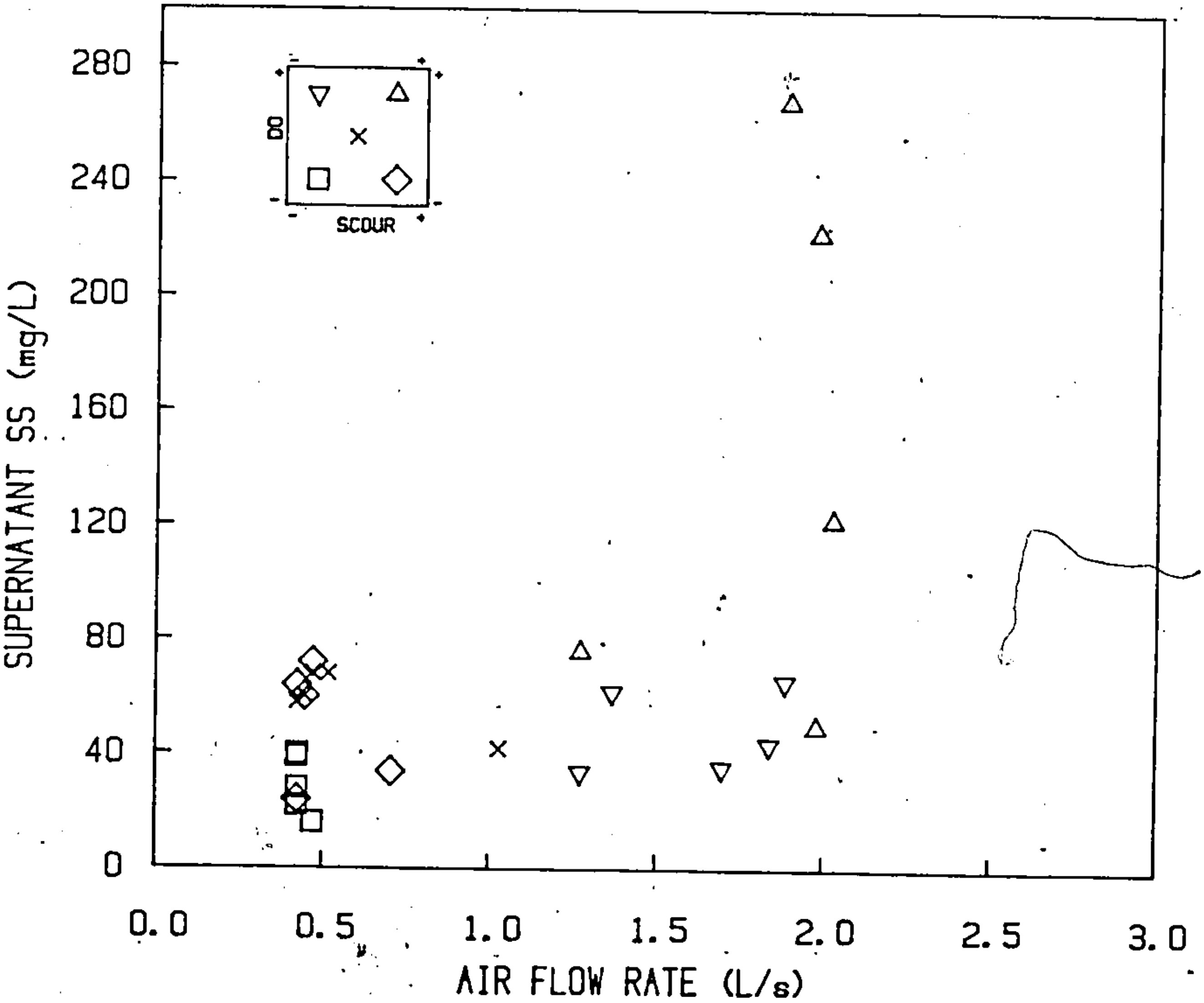


Figure 4.18. Relationship Between Air Flow Rate and Supernatant S.S. Concentrations.

Based on the evidence presented from the factorial experiment and after examining the pilot plant's aeration system, one can conclude that the increase in ESS for the A system was mainly due to high air flow rates levels in the last compartment. The amount of air transfered to the reactor was dependent on the dissolved oxygen setpoint setting. Since the aeration system was inefficient, increased excess air will be transferred with an increase in the dissolved oxygen setpoint. It had been shown by Murphy (1971) that the air flow rate will markedly change mixing conditions and power dissipation within an aerator. The importance of power dissipation in the flocculation process is discussed by Camp (1955). These high air flow rates probably affected the biomass flocculation performance.

# CHAPTER 5

## IMPROVED SCOUR PROCESS CONTROL

Pilot plant results from Chapter 4 indicated that SCOUR control was limited under low influent loading conditions due to the limitations imposed by hydraulic factors ($\alpha_3 = 1$). It was postulated that the recycle ratio and/or final compartment volume could be lowered to increase the instantaneous SCOUR level when all influent is directed to the final compartment. The Clemson simulation model for the step feed system was used to examine thse concepts. Simulated operating conditions are those as listed in Table 3.1. The lower control limit was obtained by directing all influent to the first compartment until steady state was achieved. The upper control limit is reached after redirecting all influent to the finall compartment. Tables 5.1 and 5.2 show steady state control limits after adjustments were made to the recycle ratio and final compartment volume. A substantial increase in SCOUR levels were observed for the final compartment. The simulated results confirm these concepts.

Table 5.3 shows the effect of baffling the aerator into separate sub-reactors on the SCOUR control range. The final compartment's control range will increase with the number of subreactors connected in series.

TABLE 5.1. RECYCLE EFFECTS SCOUR CONTROL LIMITS

| Recycle Ratio (%) | SCOUR RANGE (third compartment) ($mgO_2$/g MLSS-h) |
|---|---|
| 100 | 12.6 - 28.4 |
| 80 | 12.2 - 30.6 |
| 50 | 11.8 - 35.8 |
| 20 | 11.1 - 48.2 |

TABLE 5.2. VARIABLE VOLUME EFFECTS ON SCOUR CONTROL LIMITS

| Volume (L) | SCOUR RANGE (third compartment) ($mgO_2$/g MLSS-h) |
|---|---|
| 733 | 11.8 - 35.8 |
| 700 | 11.9 - 36.2 |
| 650 | 12.0 - 36.9 |
| 600 | 12.4 - 38.4 |
| 400 | 13.1 - 40.3 |

TABLE 5.3. REACTOR EFFECTS ON SCOUR CONTROL LIMITS (TOTAL VOLUME = 2200 L)

| Reactors | SCOUR Range (last compartment) ($mgO_2$/g MLSS-h) |
|---|---|
| 2 | 13.3 - 30.1 |
| 3 | 11.8 - 35.8 |
| 4 | 11.0 - 38.6 |

The process control technique presented in this study required the use of numerical optimization and integration routines that involved a large number of iterative calculations. The software and hardware described in Chapter 4 were adequate to control the step feed system with the time constants characteristic of the process (2 hours). The maximum amount of time to calculate an optimal contacting pattern did not exceed a period of 7 minutes. If the computer computation time required for the control presented in this study is excessive or memory capacity proves limiting, an analytical solution to the sets of simultaneous equations presented in Chapter 4 (equations 4.2, 4.3 and 4.4) could be employed. The solution given in Appendix D would eliminate the use of a Runge Kutta routine and would reduce substantially the amount of computing time and on-line storage requirements.

# CHAPTER 6

## CONCLUSIONS

(1) This study has demonstrated that dynamic control of SCOUR can be achieved using the step feed process leading to considerably less variation than was observed in a parallel single tank completely mixed process.

(2) For the control setpoints chosen (SCOUR = 15, D.O. = 3) filterable organic carbon effluent data suggest that a reduced effluent variability can be obtained from a SCOUR control strategy during high influent loading conditions.

(3) During low influent loading periods SCOUR control was limited due to constraints imposed by hydraulic factors. No improvement in either EFOC or ESS effluent variability could be obtained during these periods.

(4) High effluent suspended solids concentrations observed for the controlled step feed process can be attributed to excess aerator turbulence levels caused by the inefficient oxygen transfer of the pilot scale coarse bubble diffuser and the D.O. setpoint setting.

(5) On-line continuous optimal contacting patterns were calculated and applied to the first and third compartments of a three-compartment step feed system. Additional constraints to the SCOUR control presented would be required to provide unique optimization for influent distribution to three or more compartments.

(6) . Numerical optimization and integration routines normally implemented on large computer system can be utilized for real time process control applications to activated sludge systems using mini-computer hardware and software.

# CHAPTER 7

## RECOMMENDATIONS

Although some interesting research on dynamic control of the activated sludge process using step feed has been undertaken, it also indicates the need for continued work in this area. In view of this consideration, the following recommendations are made:

(1) Application of dynamic SCOUR control to full scale systems.

(2) Investigation of step feed SCOUR process control aimed at:

  (a) improving SCOUR control at low influent loading conditions,

  (b) optimization of the step feed contacting pattern to three or more compartments,

  (c) control of industrial wastewaters having a higher variability in organic loading conditions,

  (d) relating control of the aerator substrate discharge to biomass clarification and flocculation properties and performance, and

  (e) assessing the control based on oxygen consumption and relating this to energy savings.

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# APPENDIX A

# CLEMSON MODEL

## A.1 Biological Reactions

The Clemson Model separates the aerator sludge mass into three components: an adsorbed oxidizable fraction, an active or viable portion, and a biologically inert portion. Dynamic representation of this structured model has been developed by Blackwell (1971) for stored and active mass fractions. Busby and Andrews (1975) and Stenstrom and Andrews (1979) modified the model to include the biologically inert portions. Kinetic coefficients used for simulation were those used by Stenstrom (1976) and are listed on Table A-1. Models were developed for carbonaceous micro-organisms. Nitrification bacteria were not included.

### A.1.1 Substrate adsorption

The rapid uptake of substrate was assumed to be channeled directly into stored mass with an increase in substrate loading. A saturation value was placed on the amount of stored mass ($\hat{f}_s$) and the substrate removal was dependent on the fraction of stored mass to the mixed liquor suspended solids. It was assumed that all substrate was directed through storage before metabolism occurs. Soluble and particulate substrate were assumed homogeneous. Substrate removal was described as:

## TABLE A-1

## CLEMSON MODEL PARAMETER AND COEFFICIENT VALUES

| TERM | VALUE | UNITS |
|---|---|---|
| $f_s$ | 0.45 | $h^{-1}$ |
| $K_{xs}$ | 150 | mg/L |
| $K_x$ | 0.2 | - |
| $\mu_x$ | 0.3 | $h^{-1}$ |
| $D_x$ | .015 | $h^{-1}$ |
| $r_s$ | 5.0 | $h^{-1}$ |
| $Y_x$ | 0.66 | - |
| $Y_I$ | 0.25 | - |

$$\frac{dS_b}{dt} = -r_s X_v \left( \hat{f}_s \left( \frac{S_b}{K_{xs} + S_b} \right) - f_s \right) \qquad \text{(A-1)}$$

$$X_v = S_m + X_a + X_I \qquad \text{(A-2)}$$

where $X_v$ is the MLVSS concentration (mg/L),

$S_m$ is the stored mass conc. (mg/L),

$X_a$ is the active mass conc. (mg/L),

$X_I$ is the inert (non-viable) conc. (mg/L),

$S_b$ is the substrate conc. (mg/L),

$r_s$ is the transfer rate coefficient ($h^{-1}$),

$\hat{f}_s$ is the maximum fraction of $S_m$ to $X_v$,

$f_s$ is the fraction of $S_m$ to $X_v$, and

$K_{xs}$ is the adsorption-absorption coefficient (mg/L).

### A.1.2 Stored mass

Stored mass concentrations are dependent on both the accumulation of stored mass and the synthesis of active mass. Stored mass concentration is described as:

$$\frac{dS_m}{dt} = r_s X_v \left( \hat{f}_s \left( \frac{S_b}{K_{xs} + S_b} \right) - f_s \right) - \frac{\mu_x}{Y_x} \left( \frac{f_s}{K_x + f_s} \right) X_a \qquad \text{(A-3)}$$

where $\mu_x$ is the maximum specific growth rate for active mass ($h^{-1}$),

$Y_x$ is the active mass yield, and

$K_x$ is the active mass saturation coefficient (mg/L).

### A.1.3 Active mass (synthesis and decay)

Monod-type kinetics are used to describe active mass synthesis with the fraction of stored mass used as the limiting substrate factor. Active mass decay is modelled as a first order reaction.

$$\frac{d\,X_a}{dt} = \left(\mu x \left(\frac{f_s}{K_x + f_s}\right) - D_x\right) X_a \tag{A-4}$$

where $D_x$ is the endogenous decay coefficient ($h^{-1}$).

### A.1.4 Inert (non-viable) mass

Inert mass is defined as residual sludge that cannot be degraded further. The first order expression is:

$$\frac{d\,X_I}{d_t} = Y_I\, D_X\, X_a \tag{A-5}$$

where $Y_I$ is the conc. of $X_I$ generated per unit of $X_a$ decayed.

### A.1.5 Dissolved oxygen

During all computer simulations, dissolved oxygen concentrations are assumed sufficiently high to promote adequate biomass growth. The net dissolved oxygen concentration was calculated to permit SCOUR and oxygen uptake estimations. The rate of oxygen consumption is due to both biomass respiration and synthesis.

$$\frac{dC}{dt} = K_{La}\,(C_s - C) - \left(\left(\frac{1 - Y_X}{Y_X}\right)\left(\frac{f_s}{K_X + f_s}\right) u_X - \left(1 - Y_I\right) D_X\right) X_a \tag{A-6}$$

where C is the dissolved oxygen concentration (mg/L),

$C_s$ is the saturation D.O. (mg/L), and

$K_{La}$ is the oxygen transfer rate ($h^{-1}$).

## A.2 SCOUR Calculations from Clemson Model

From Chapter 1, SCOUR was defined as the ratio between the volumetric oxygen utilization rate ($OUR_v$) and the total solids in the aerator (X) expressed as MLSS. In terms of model parameters, the oxygen demand due to cell synthesis and respiration was obtained from equation A6 for reactor k as:

$$OUR_k = \left(\left(\frac{1 - Y_x}{Y_x}\right)\left(\frac{f_s}{K_x + f_s}\right)\mu_x + (1 - Y_I)D_x\right) X_k V_k \qquad \text{(A-7)}$$

where $OUR_k$ is the oxygen utilization rate ($mgO_2/h$).

The volumetric OUR was calculated by division of the reactor volume $V_k$:

$$OUR_v = \frac{OUR}{V_k} \qquad \text{(A-8)}$$

SCOUR is calculated after division by $X_k$ and expressed as:

$$SCOUR = \frac{OUR_{v,k}}{X_k} = \left(\frac{1 - Y_x}{Y_x}\right)\left(\frac{f_s}{K_x + f_s}\right)\mu_x + (1 - Y_I)D_x \qquad \text{(A-9)}$$

where SCOUR is the specific oxygen utilization rate (mg $O_2$/g MLSS-h).

All SCOUR, substrate and solids concentrations reported in Chapter 3 have been converted from oxygen equivalents to their appropriate units. A FORTRAN computer listing of the model is given in Appendix G.

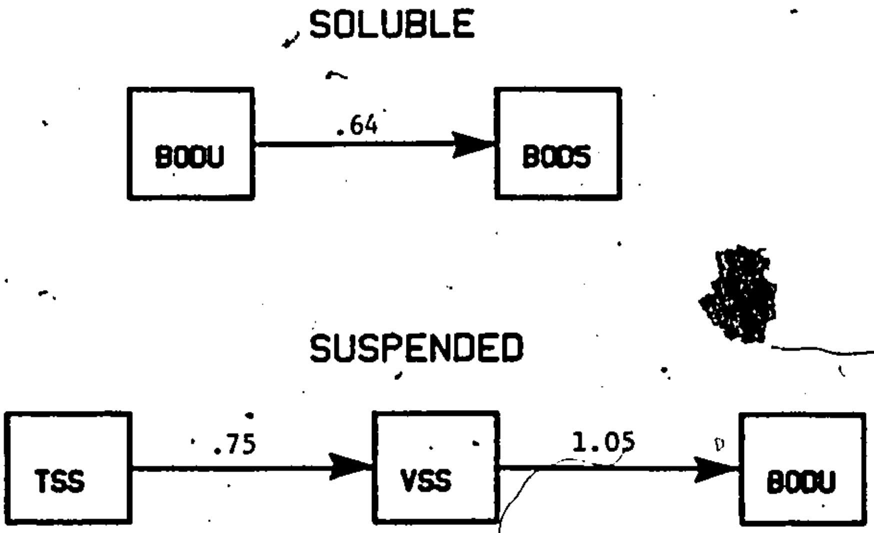

Figure A-1. Oxygen Equivalents.

# APPENDIX B

## ESTIMATION OF VOLUMETRIC OUR

### B.1 Introduction

Stukenberg and McKinney (1977) report the oxygen transfer from gas to the dissolved phase as follows:

$$\frac{dC}{dt} = K_{La}\,(C_s - C) - r_m \qquad \text{(B-1)}$$

$$K_{La} = \alpha_a\, K_{La}'$$

$$C_s = \beta_a\, C_s'$$

where

$\frac{dC}{dt}$ is the volumetric rate of oxygen transferred to wastewater ($mgO_2/L\text{-}h$),

$K_{La}$ is the volumetric mass transfer coefficient ($h^{-1}$),

$K_{La}'$ is the volumetric mass transfer coefficient for pure water ($h^{-1}$),

$C_s$ is the saturation D.O. for wastewater (mg/L),

$C_s'$ is the saturation D.O. for pure water (mg/L),

$\alpha_a$ is the ratio of $K_{La}/K_{La}'$,

$\beta_a$ is the ratio of $Cs/Cs'$,

$C$ is the D.O. Concentration (mg/L), and

$r_m$ is the volumetric oxygen demand by microorganisms ($mgO_2/L\text{-}h$).

The available surface through which oxygen transfer occurs increases with decreasing bubble size in the aerator. Agitation effects and temperature also effect equation (B1). Temperature changes were accounted for using the following (Metcalf and Eddy, 1979)

$$(K_{La})_t = (K_{La})_{20} \text{ x } (1024)^{T-20} \tag{B-2}$$

where

$(K_{La})_t$ is the coefficient at temperature T,

$(K_{La})_{20}$ is the coefficient at 20°C, and

T is the temperature (°C).

Rewriting equation (B1) as

$$\frac{dC}{dt} = (K_{La}C_s - r_m) - K_{La}C \tag{B-3}$$

Solving the differential

$$\int_{C_o}^{C} \frac{dC}{(K_{La}C_s - r_m) - K_{La}C} = \int_{o}^{t} dt \tag{B-4}$$

$$t = \frac{1}{-K_{La}} \ln \left[ (K_{La}C_s - r_m) - K_L aC \right] \Bigg|_{C_o}^{C} \tag{B-5}$$

at initial condition t = o, C = 0

$$K_{La}t = \frac{\ln \left[ (K_{La}Cs - r_m) - K_{La}\, C \right]}{K_{La}\, C_s - r_m} \tag{B-6}$$

after simplification

$$C(t) = \frac{K_{La}\, C_s - r_m}{K_{La}} \left(1 - e^{-K_{L}at}\right) \qquad \text{(B-7)}$$

Estimates of $K_{La}$, $C_s$, and $r_m$ were obtained from reaeration tests as described in the following section.

## B.2 $K_{La}$, $r_m$, and $C_s$ Estimates

### B.2.1 Non-Steady State Batch Reaeration Test

A non-steady state reaeration test illustrated by US-EPA (1978) was used in conjunction with B7 to obtain estimates of $K_{La}$, $r_m$, and $C_s$. The pilot plants described in Chapter 4 were both operated at steady state prior to each test. The last compartment of the step feed system and the aerator of the conventional system were used for the test. All tests were run during extended low loading periods to promote endogenous respiration.

At the start of each test influent and recycle flow to the aeration compartment was discontinued. All aeration was turned off with dissolved oxygen concentrations allowed to reach zero. At this point of time the aeration is restarted with measurements of C and t taken at equal time intervals until a stable value of C is reached. A constant air flow was maintained throughout the test during aeration periods.

The C (t) results of the test were used in conjunction with equation B7 and a non-linear least squares estimation routine (UWHAUS, 1965) to obtain direct numerical values of $K_{La}$, $C_s$, and $r_m$. In all cases when using three parameter estimation the 95% individual confidence limits for $C_s$ and $r_m$ were very large. Also, the results indicated a high corralation between the three parameters. This was due to the mathematical form of equation B7. It was decided that direct multivariable estimation for the three parameters $C_s$, $r_m$ and $K_{La}$ would not be used.

### B.2.2 Measurement of $r_m$ and $C_s$

Alternatively, the oxygen uptake due to endogenous respiration ($r_m$) and D.O. saturation in wastewater ($C_s$) were both determined using the techniques described in Standard Methods (1978). $r_m$ levels were measured from mixed liquor samples using a BOD bottle. The contents were kept in suspension by external mixing. D.O. measurements were taken at 30 second intervals with a YSI - D.O. probe. $C_s$ values were measured directly from settled effluent samples.

D.O. concentrations were plotted against time on rectangular graph paper and linear least squares was used to numerically determine the line of best fit. The oxygen uptake was determined from the slope on a mg/L-h basis. An example of $r_m$ measurement using this method is shown in Figure B-1 for one of the reaeration tests.

### B.2.3 Estimation of $K_{La}$

Measured $C_s$, $r_m$ values and C (t) results from the reaeration tests were used with UWHAUS to obtain a univariate estimate of $K_{La}$. Tables B-1 and B-2 show the estimation results for both the A and B pilot systems. UWHAUS output for one of the $K_{La}$ estimations is given in section B.5.

In some instances where $r_m$ values were not experimentally determined, UWHAUS was used to obtain $r_m$ and $K_{La}$ values numerically (Table B-2)

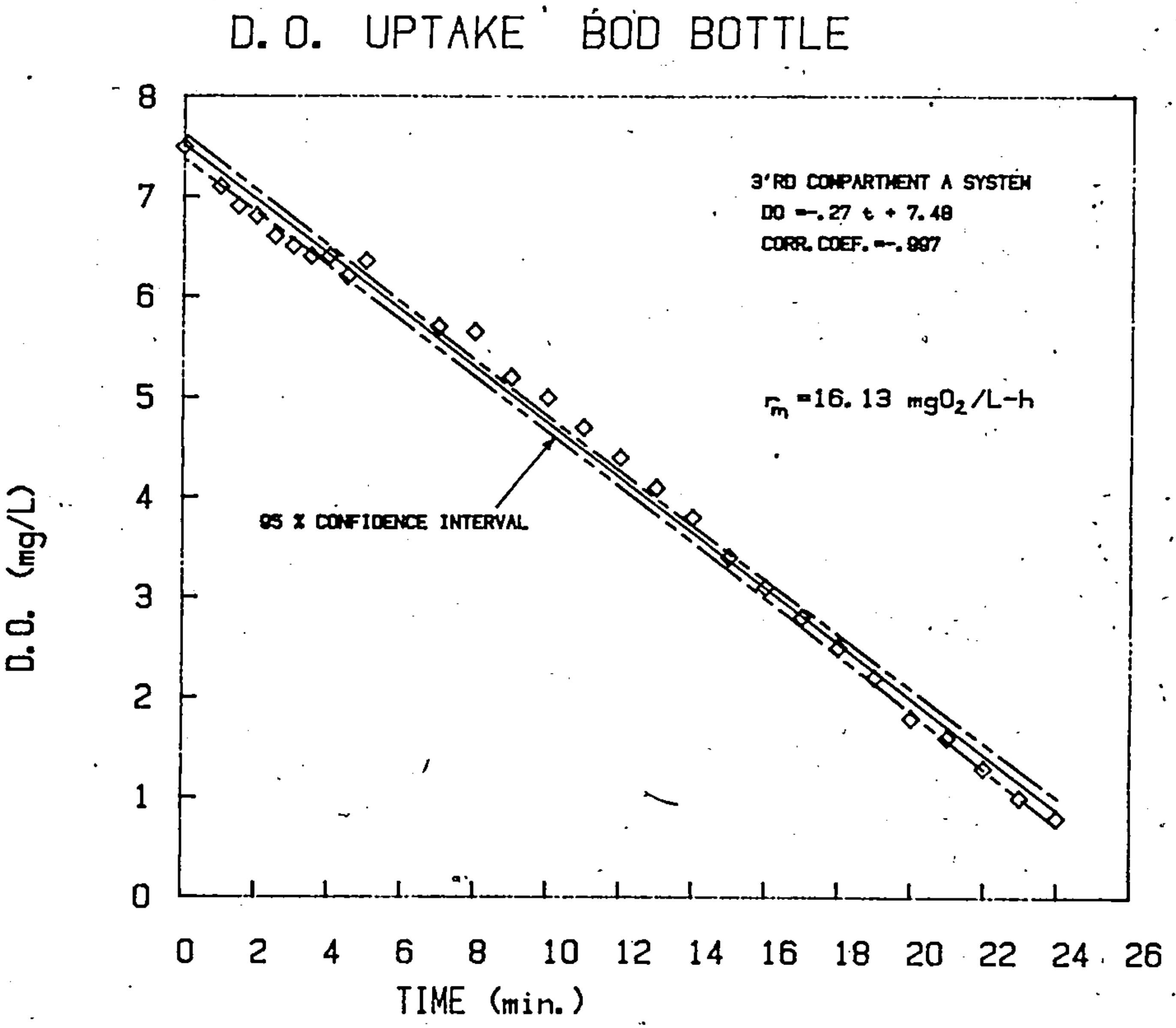

Figure B.1. Graphical Determination of $r_m$.

TABLE B-1. RESULTS OF REAREATION TESTS — A-SYSTEM

| AFR (L/S) | Temperature (°C) | $r_m$ ($mgO_2$/L-h) | $C_s$ (mg/L) | $K_{La}$ ± 95% Confidence Interval ($h^{-1}$) | $K_{La}$ Temp. Corrected ($h^{-1}$) |
|---|---|---|---|---|---|
| 0.38 | 19.2 | 20.80 | 9.2 | 3.39 ± .01 | 3.10 |
| 1.18 | 18.5 | 16.20 | 9.4 | 3.47 ± .07 | 3.58 |
| 1.51 | 17.0 | 24.49 | 9.4 | 5.27 ± .05 | 5.67 |
| 1.83 | 16.5 | 20.59 | 10.2 | 6.68 ± .23 | 7.26 |
| 2.41 | 16.5 | 32.58 | 9.4 | 6.23 ± .06 | 6.77 |
| 3.11 | 17.5 | 26.70 | 9.4 | 8.53 ± .50 | 9.05 |
| 3.87 | 17.8 | 19.72 | 9.4 | 8.96 ± .28 | 9.45 |

TABLE B-2. RESULTS OF REAREATION TESTS — B-SYSTEM

| AFR (L/S) | Temperature (°C) | $r_m$ ($mgO_2$/L-h) | $C_s$ (mg/L) | $K_{La}$ ± 95% Confidence Interval ($h^{-1}$) | $K_{La}$ Temp. Corrected ($h^{-1}$) |
|---|---|---|---|---|---|
| 2.72 | 14.5 | 20.59 | 9.7 | 2.81 .02 | 3.13 |
| 3.89* | 15.0 | 26.51 | 9.9 | 4.02 .50 | 4.53 |
| 4.53 | 13.5 | 24.57 | 9.4 | 4.64 .12 | 5.41 |
| 4.77 | 16.2 | 16.15 | 9.3 | 4.32 .04 | 4.73 |
| 5.19* | 13.8 | 33.66 | 10.6 | 4.71 .24 | 5.46 |
| 6.89* | 14.3 | 29.66 | 9.4 | 6.35 .12 | 7.27 |
| 8.02 | 17 | 17.84 | 9.3 | 6.95 .08 | 7.47 |
| 8.97 | 15.0 | 27.15 | 9.4 | 10.16 .52 | 11.44 |
| 9.86 | 15.0 | 34.36 | 9.3 | 9.76 .13 | 10.98 |
| 11.20 | 15.0 | 23.21 | 9.2 | 11.39 .25 | 12.82 |

* Two parameter estimates for $K_{La}$ and $r_m$.

Although precise estimation for both parameters were obtained, $r_m$ and $K_{La}$ estimates were highly correlated.

## B.3 On-line Estimation of $OUR_v$

By controlling the dissolved oxygen concentration in the aeration tank at a constant value, the oxygen uptake of the microorganisms was indirectly measured by observing the air flow rate. An increase in biomass oxygen consumption due to an increase in load caused an increase in the air flow required to keep the dissolved oxygen level at the setpoint setting.

The air flow rate was empirically related to $K_{La}$ using linear least squares regression. The results of the rearation tests described in the previous section were fitted to the air flow rates as shown in figures B-2 and B-3 for the last reactor of the step feed process and single aeration reactor of the parallel conventional system. On-line calculations for $C_s$ were adjusted for changes in atmospheric pressure changes. $\beta_o$ saturation tests were periodically performed by aeration of settled effluent and distilled water until saturation.

A D.O. mass balance on a single tank CSTR gave the following relationship for $OUR_v$ assuming influent D.O. concentrations are negligible and septic conditions in the recycle line:

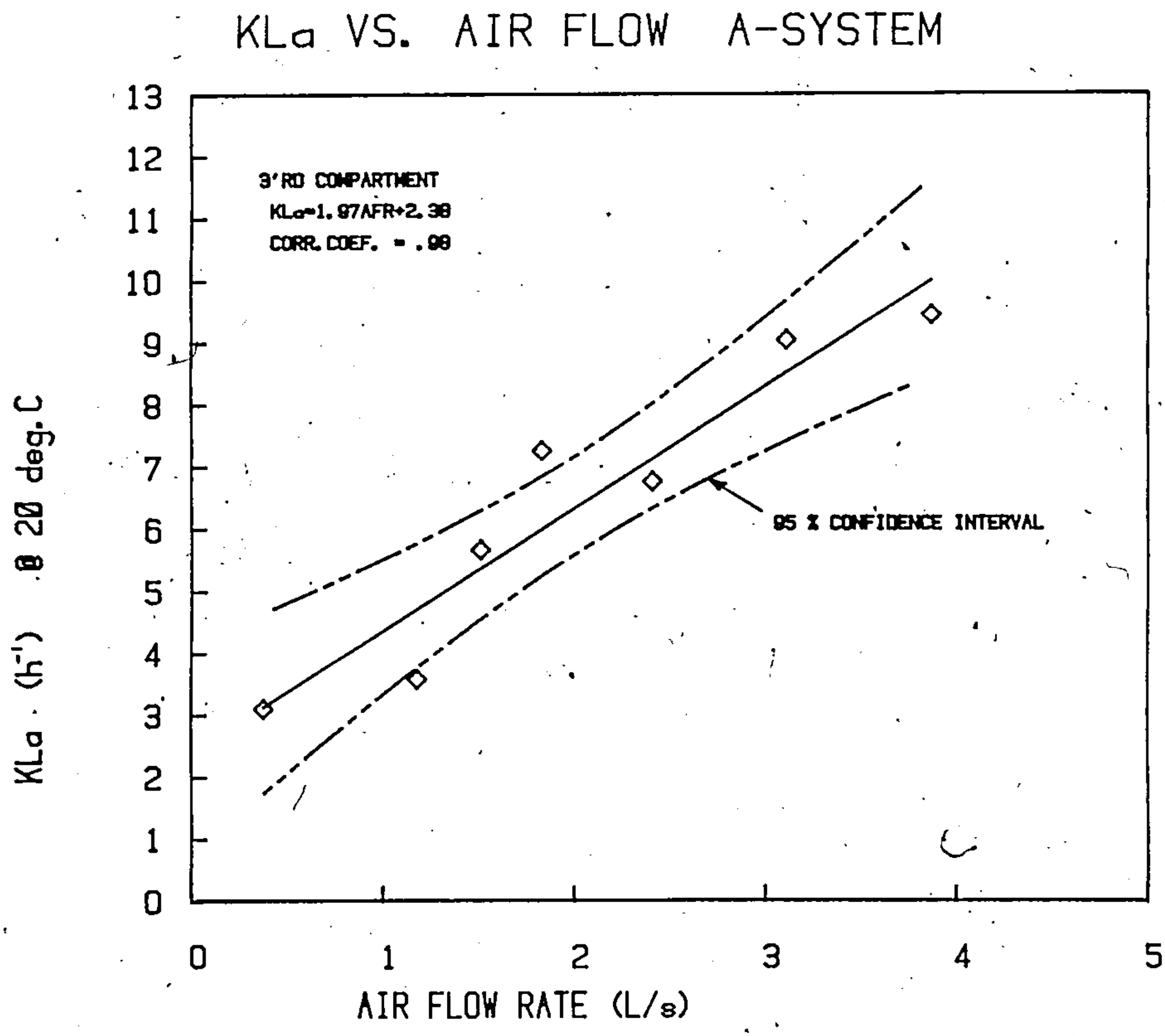

Figure B.2. A-System Linear Regression.

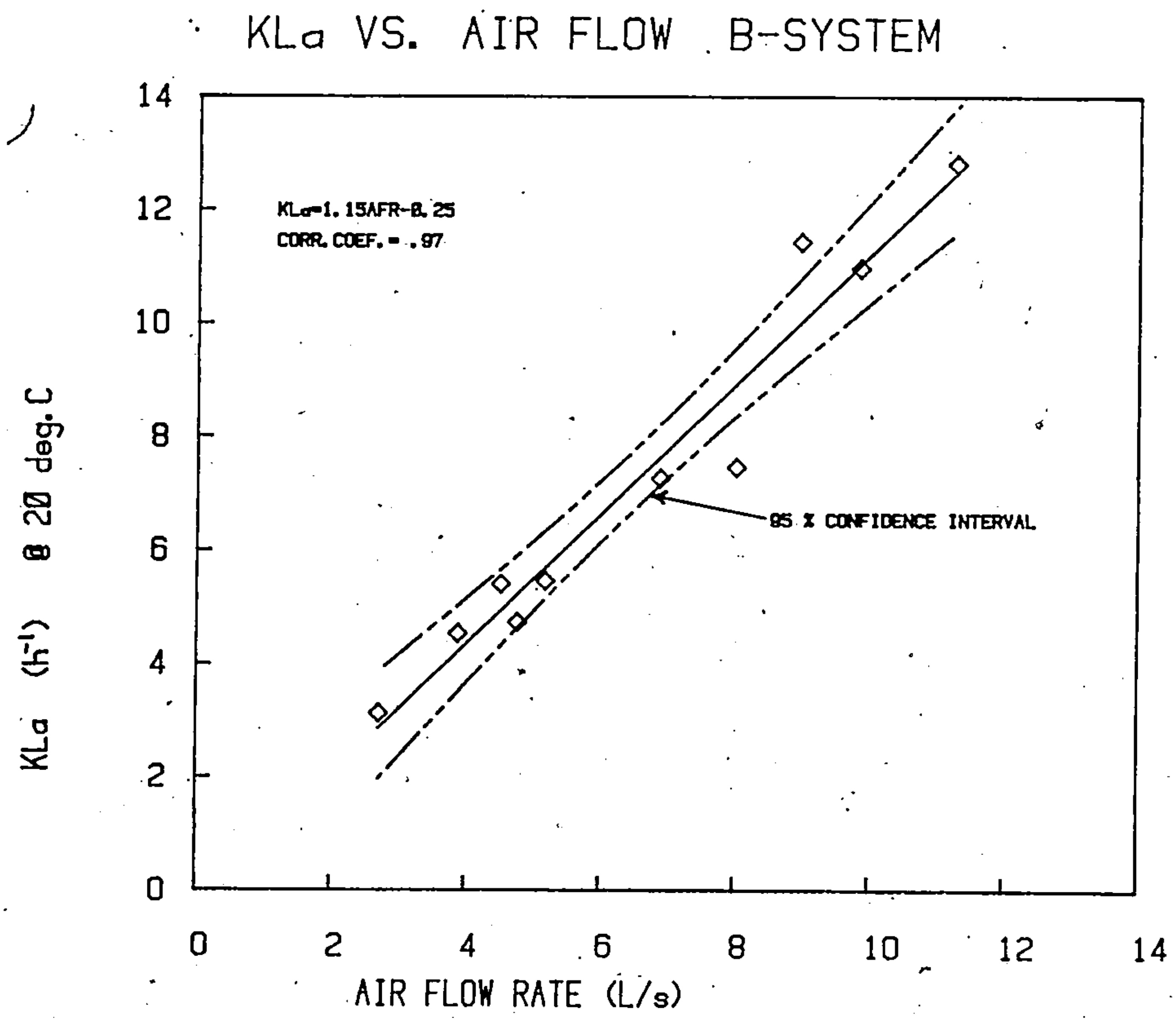

Figure B.3. B-System Linear Regression.

$$OUR_v = K_{La}\,(C_s - C_o) - \frac{(1+R)}{V} Q\, C_o \qquad (B\text{-}8)$$

where;

$C_o$ is the controlled D.O. concentration in the reactor (mg/L).

The above equation was modified to account for the D.O. mass flow from the previous reactor in the step feed system as follows:

$$OUR_{v,k} = K_{La}\,(C_s - C_{o,k}) + (1-\alpha_{k-1}+R)\,C_{o,k-1} - (1+R)\,C_{o,k}\,\frac{Q}{V_k} \qquad (B\text{-}9)$$

where k refers to reactor k of step feed system, and

$\alpha_{k-1}$ is the proportion of Q being input from reactor k-1.

D.O. concentrations input from the previous reactor was negligible (<5%) if the previous reactor's D.O. concentrations were controlled at or below 2 mg/L.

## B.4 Oxygen Transfer Efficiency

The oxygen transfer efficiency is expressed as follows:

$$OTE = \frac{\text{mass rate of oxygen transferred}}{\text{mass rate of oxygen supplied}} \times 100$$

where;

OTE is the Oxygen transfer efficiency (%)

$$= \frac{OUR_{v,k} \times V_k}{\rho_a \times AFR} \times 100 \qquad (B\text{-}10)$$

$\rho_a$ is the density of air at T°C (mg/L)

### B.4.1 Example Calculation

- Calculation example was done for Run #7 during high influent loading conditions (Appendix E.2).
- On-line conditions for A system (3rd compartment) were

$OUR_V = 33.0\ mgO_2/h$

Air Flow = 3.9 cfm $(6.63 \times 10^3\ L/h)$

Volume = 723.7 L

$\rho_a$ @ 16°C = $.076\ \frac{lb}{ft^3}$ $(1.21 \times 10^3\ mg/L)$

$$OTE = \frac{33 * 723.7}{1.2 * 6.63 * 10^6} * 100 = 0.30\%$$

The B system OTE was calculated to be 0.40% at the same instance in time.

### B.4.2 Mixing Requirements

The level of mixing in the reactor will be expressed as

$$MR = \frac{\text{air flow rate}}{\text{volume}}$$

to compensate for volumetric effects.

Using the same example as in the previous section for the A system;

$$MR = \frac{3.9\ cfm}{723.7\ L}$$

$$= \frac{25.42\ m^3}{10^3 m^3 s}$$

The Ontario Ministry of Ontario Guideline (MOE, 1980) for activated sludge treatment plants recommends a mixing requirement of $3.3\ m^3/10^3 m^3\text{-}s$. The mixing level in the final compartment of the step feed system exceeds the guideline by a factor of approximately 8. Using equation B-8 and Figure B-2, mixing levels were calculated at different D.O. setpoints and are shown in

Table B-3. The degree of mixing in the compartment probably had increased when the D.O. setpoint setting was raised.

TABLE B-3. A SYSTEM – THIRD COMPARTMENT AIR FLOW RATES (EXAMPLE FROM SECTION B.4.1)

| D.O. Setpoint (mg/L) | Air Flow Rate/Volume ($m^3 x 10^{-4} / m^3$-s) |
|---|---|
| 0.5 | 8.15 |
| 1.0 | 9.78 |
| 1.5 | 11.62 |
| 2.0 | 13.70 |
| 3.0 | 25.42 |

## B.5 UWHAUS Output

An example output of the univariate non-linear least squares (UWHAUS) $K_{La}$ estimate is given for the following reaeration test results:

| | t (min) | D.O. (mg/L) |
|---|---|---|
| 1 | 0.00 | .10 |
| 2 | .83 | 1.00 |
| 3 | 1.33 | 1.50 |
| 4 | 1.83 | 2.00 |
| 5 | 2.33 | 2.40 |
| 6 | 2.83 | 2.70 |
| 7 | 3.33 | 3.10 |
| 8 | 3.83 | 3.55 |
| 9 | 4.33 | 3.75 |
| 10 | 4.83 | 4.00 |
| 11 | 5.33 | 4.18 |
| 12 | 5.83 | 4.43 |
| 13 | 6.83 | 4.80 |
| 14 | 7.83 | 5.10 |
| 15 | 9.83 | 5.55 |
| 16 | 10.83 | 5.73 |
| 17 | 11.83 | 5.93 |
| 18 | 12.83 | 6.00 |
| 19 | 13.83 | 6.18 |
| 20 | 14.83 | 6.27 |
| 21 | 15.83 | 6.35 |
| 22 | 18.83 | 6.40 |
| 23 | 20.83 | 6.52 |
| 24 | 27.83 | 6.60 |
| 25 | 37.83 | 6.63 |

Laboratory estimates for $C_s$ and $r_m$ were 9.4 mg/L and 0.33 $mgO_2$/L-min, respectively. The air flow rate was 3.97 L/s at a temperature of 17.8°C (Table 3.1).

The resultant $K_{La}$ estimate was 0.149 $min^{-1}$ or 8.96 $hr^{-1}$. A FORTRAN listing of the estimation program is given in Appendix G.

```
NON-LINEAR ESTIMATION, PROBLEM NUMBER  1

  25 OBSERVATIONS,    1 PARAMETERS     81 SCRATCH REQUIRED


INITIAL PARAMETER VALUES

     1
  .7000E+00


PROPORTIONS USED IN CALCULATING DIFFERENCE QUOTIENTS

     1
  .1000E-01


INITIAL SUM OF SQUARES =   .3386E+03




                                        ITERATION NO.   1
DETERMINANT =   .1001E+01      ANGLE IN SCALED COORD. =  .03DEGREES

TEST POINT PARAMETER VALUES
 -.5961E+00

TEST POINT PARAMETER VALUES
  .5193E-01

TEST POINT SUM OF SQUARES =   .3153E+03


PARAMETER VALUES VIA REGRESSION

     1
  .5193E-01


LAMBDA =  .100E-02    SUM OF SQUARES AFTER REGRESSION =   .3153403E+03




                                        ITERATION NO.   2
DETERMINANT =   .1000E+01      ANGLE IN SCALED COORD. = 0.00DEGREES

TEST POINT PARAMETER VALUES
  .1046E+00

TEST POINT SUM OF SQUARES =   .3598E+02


PARAMETER VALUES VIA REGRESSION

     1
  .1046E+00
```

```
                                        ITERATION NO.   3
DETERMINANT =   .1000E+01       ANGLE IN SCALED COORD. = 0.00DEGREES

TEST POINT PARAMETER VALUES
  .1395E+00

TEST POINT SUM OF SQUARES =   .2651E+01


PARAMETER VALUES VIA REGRESSION

    1
  .1395E+00


LAMBDA =  .100E-04     SUM OF SQUARES AFTER REGRESSION =   .2651336E+01




                                        ITERATION NO.   4
DETERMINANT =   .1000E+01       ANGLE IN SCALED COORD. = 0.00DEGREES

TEST POINT PARAMETER VALUES
  .1486E+00

TEST POINT SUM OF SQUARES =   .1455E+01


PARAMETER VALUES VIA REGRESSION

    1
  .1486E+00


LAMBDA =  .100E-05     SUM OF SQUARES AFTER REGRESSION =   .1454907E+01




                                        ITERATION NO.   5
DETERMINANT =   .1000E+01       ANGLE IN SCALED COORD. = 0.00DEGREES

TEST POINT PARAMETER VALUES
  .1493E+00

TEST POINT SUM OF SQUARES =   .1449E+01


PARAMETER VALUES VIA REGRESSION

    1
  .1493E+00


LAMBDA =  .100E-06     SUM OF SQUARES AFTER REGRESSION =   .1449318E+01
```

```
                                      ITERATION NO.   6
DETERMINANT =   .1000E+01       ANGLE IN SCALED COORD. = 0.00DEGREES

TEST POINT PARAMETER VALUES
  .1494E+00

TEST POINT SUM OF SQUARES =   .1449E+01

TEST POINT PARAMETER VALUES
  .1493E+00

TEST POINT SUM OF SQUARES =   .1449E+01

TEST POINT PARAMETER VALUES
  .1493E+00

TEST POINT SUM OF SQUARES =   .1449E+01


PARAMETER VALUES VIA REGRESSION

     1
  .1493E+00

LAMBDA =  .100E-07    SUM OF SQUARES AFTER REGRESSION =   .1449317E+01

ITERATION STOPS - RELATIVE CHANGE IN SUM OF SQUARES LESS THAN   .1000E-05
```

```
FINAL FUNCTION VALUES

  .1000E+00   .9307E+00   .1382E+01   .1800E+01   .2189E+01

  .2549E+01   .2884E+01   .3194E+01   .3482E+01   .3750E+01

  .3998E+01   .4228E+01   .4640E+01   .4995E+01   .5564E+01

  .5791E+01   .5986E+01   .6155E+01   .6300E+01   .6424E+01

  .6532E+01   .6773E+01   .6883E+01   .7088E+01   .7174E+01




RESIDUALS

 -.2831E-06   .6925E-01   .1182E+00   .1997E+00   .2112E+00

  .1508E+00   .2162E+00   .3557E+00   .2676E+00   .2502E+00

  .1770E+00   .1967E+00   .1596E+00   .1046E+00  -.1435E-01

 -.6612E-01  -.6142E-01  -.1546E+00  -.1245E+00  -.1493E+00

 -.1818E+00  -.3727E+00  -.3578E+00  -.4878E+00  -.5490E+00



X PRIME-X MATRIX

     1

  1 11710.9



CORRELATION MATRIX

     1

  1  1.0000



NORMALIZING ELEMENTS

     1
  .9241E-02



VARIANCE OF RESIDUALS =   .6039E-01,  24 DEGREES OF FREEDOM
```

```
      1
 .1539E+00
 .1448E+01
```

```
APPROXIMATE CONFIDENCE LIMITS FOR EACH FUNCTION VALUE

   .1000E+00  .9623E+00  .1429E+01  .1861E+01  .2261E+01
   .1000E+00  .8992E+00  .1334E+01  .1739E+01  .2116E+01

   .2632E+01  .2975E+01  .3293E+01  .3587E+01  .3860E+01
   .2466E+01  .2792E+01  .3096E+01  .3378E+01  .3640E+01

   .4112E+01  .4345E+01  .4762E+01  .5119E+01  .5688E+01
   .3884E+01  .4111E+01  .4519E+01  .4871E+01  .5441E+01

   .5913E+01  .6106E+01  .6272E+01  .6413E+01  .6535E+01
   .5669E+01  .5867E+01  .6038E+01  .6186E+01  .6313E+01

   .6639E+01  .6871E+01  .6976E+01  .7167E+01  .7244E+01
   .6424E+01  .6674E+01  .6790E+01  .7009E+01  .7104E+01


END OF PROBLEM NO.  1
```

# APPENDIX C

## BOX — COMPLEX OPTIMIZATION

### C.1 Summary

This numerical search routine developed by Box (1965) will find the maximum or minimum of a multivariable non-linear problem subjected to linear and/or non-linear inequality constraints. For the problem under study in Chapter 4, optimal $\alpha_2$ and $\alpha_3$ values were calculated after solving equations, 4.2, 4.3 and 4.4. $\alpha_1$ is calculated by difference (eq. 4.5). The objective function consisted of the following:

$$\text{Minimize } (X_3 - X_{des})^2 \tag{C-1}$$

having constraints

$$\alpha_2 \leq 1$$
$$\alpha_3 \leq 1$$
$$\alpha_2 + \alpha_3 \leq 1$$

The optimization method consisted of generating an original "complex" of $\alpha$'s which are greater than or equal to L + 1 points where L equals the number of implicit variables. A feasible starting point was provided by the user while L-1 points satisfying the constraints were generated by a random number generator. When explicit constraints are violated the point was moved a small distance inside the limit. If implicit constraints were violated, the point was moved one half of the distance to the centroid of the complex. The objective function (C-1) was evaluated at each point with a new point created, based on distances to the centroid. Convergence limits are selected by the user. A flow chart describing the procedure is provided in figure C-1.

## C-2 Box - Complex Optimization Output

The following computer example was an output from the Box-Complex optimization routine for system A.

Initial conditions were:

MLSS (front) = 2269 mg/L

MLSS (middle) = 2269 mg/L

MLSS (rear) = 2269 mg/L

Plant flow = 13.0 $m^3/d$

Recycle flow = 6.52 $m^3/d$

RAS = 6659 mg/L

$\alpha_1 = 1.0$

$\alpha_2 = 0.0$

$\alpha_3 = 0.0$

OUR = 18.99 $mgO_2$/L-h.

On Line SCOUR = 8.37 $mgO_2$/g MLSS-h.

A setpoint SCOUR value of 13 was selected. The optimization was restricted to calculating flows to the first and third compartments $\alpha_2 = 0$).

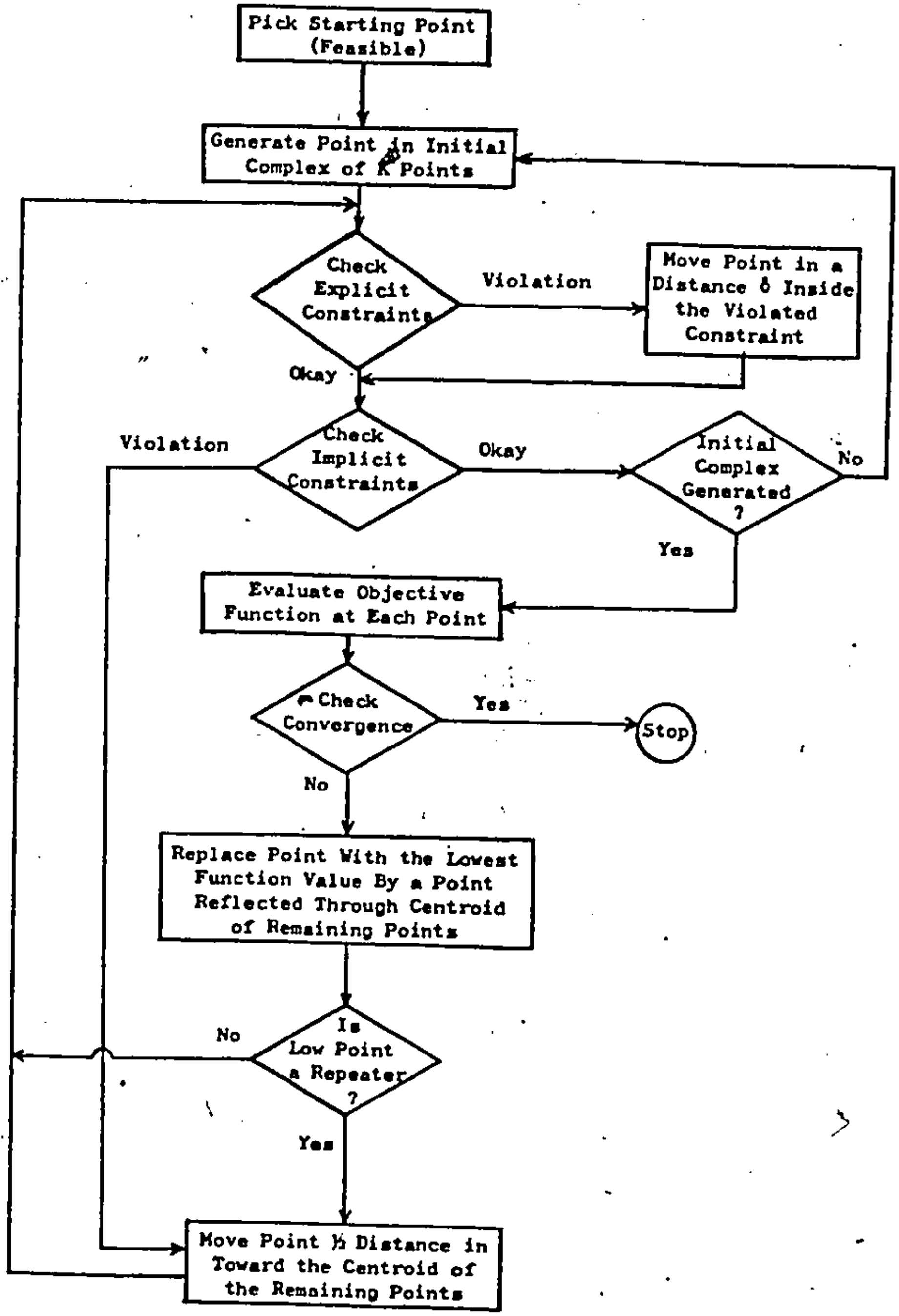

Figure C-1. Box-Complex Optimization (Kuester and Mize, 1973).

The resultant contacting pattern had shifted the influent load towards the rear of the aerator after optimization. A FORTRAN listing of the program is given in Appendix G.

```
     FEED9
   PROGRAM START TIME=   19 HRS.   1 MIN.   0 SEC.
   INITAL TANK DISTRIBUTION= 1.00 0.00 0.00
   CALCULATED  SOLIDS    TANK #1= 2269.00mg/L TANK#2= 2269.00 TANK#3= 2269.00
   PLANT FLOW=  543.68 RECYCLE FLOW=  271.76 R.RATIO=     .50
   VOLUMES=  765.10  734.30  723.70
   RECYCLE SOLIDS=6659.00mg/L
   COMPACTION RATIO=   2.93
   MEASURED SOLIDS= 2269
   OUR= 18.987 mg/L-hr
   ACTUAL SCOUR=  8.368 mgO/gMLSS-hr.
   SETPOINT= 13.000 mgO/mgSS-hr
   DESIRED SOLIDS CONC.= 1460.57 mg/L
   INTEGRATION INT.=   1.80  PROGRAM INT.=   15
   MULTIVARIABLE OPTIMIZATION TECHNIQUE-SUPERBOX
                            CONSTRAINTS
   VARIABLE             LOWER               UPPER
      1                0.00000             1.00000
   NUMBER OF VARIABLES=              1
   NUMBER OF VERTICIES =             3
   MINIMUM ABSOLUTE ERROR=        .1000D+00
   MINIMUM VARIANCE OF ERROR = .1000D-01
   FINISH CRITERIA =                 2
   XIX =                            17
   LLD =                             1
   USER SUPPLIED STARTING POINT
           K1               K2                K3                K4                K5                           COST

        .000000D+00                                                                                           .62351D+03

   RANDOMLY GENERATED POINTS
           K1               K2                K3                K4                K5                           COST

        .679627D-01                                                                                           .54091D+03

        .903107D+00                                                                                           .72194D+02

   SEARCH BEGINING
```

```
                                                                              COMPLEX VARIANCE= .6257D-02
THE OPTIMIZATION HAS TERMINATED NORMALLY
         K1                K2                K3                K4                K5
                                                                                                   COST

      .731697D+00                                                                              .120450D+00

      .733380D+00                                                                              .179250D+00

      .720680D+00                                                                              .226310D-01
ITERATION COUNT=   35
THE VALUE OF INDEX FOR LOWEST COST =  3
OPTIMAL   VALUES ARE
         K1                K2                K3                K4                K5
                                                                                                   COST

      .720680D+00                                                                              .226310D-01
-----------------------------------------------   ---------------------------------------------------------
TANK DISTRIBUTION AFTER OPTIMIZATION=    .28    0.00     .72
```

# APPENDIX D

## ANALYTICAL SOLUTION TO CONTROL MODEL

An alternative analytical solution can be used to solve the sets of differential equations (e.g. 4.2 , 4.3 , and 4.4 ) given in Chapter 4.

The differential equations can be rewritten in the following form.

$$\frac{dX_1}{dt\ Q(t)} = b_1 - b_2 X_1 \qquad \text{(D-1)}$$

$$\frac{dX_2}{dt\ Q(t)} = b_3 X_1 - b_4 X_2 \qquad \text{(D-2)}$$

$$\frac{dX_3}{dt\ Q(t)} = b_5 X_2 - b_6 X_3 \qquad \text{(D-3)}$$

where:

$$b_1 = \frac{RX_r}{V_1}$$

$$b_2 = \frac{(1 - \alpha_2 - \alpha_3 + R)}{V_1}$$

$$b_3 = \frac{(1 - \alpha_2 - \alpha_3 + R)}{V_2}$$

$$b_4 = \frac{(1 - \alpha_3 + R)}{V_2}$$

$$b_5 = \frac{(1 - \alpha_3 + R)}{V_3}$$

$$b_6 = \frac{(1 + R)}{V_3}$$

Solving for $X_2$

$$\frac{dX_2}{dX_1} = \frac{b_3X_1 - b_4X_2}{b_1 - b_2X_1} \tag{D-4}$$

or

$$\frac{dX_2}{dX_1} + \left(\frac{b_4}{b_1 - b_2X_1}\right) X_2 = \frac{b_3X_1}{b_1 - b_2X_1} \tag{D-5}$$

Equation D.5 is a 1st order linear differential equation. The integrating factor is

$$e^{\int (b_4(1 / (b_1 - b_2 X_1)))\, d X_1} \tag{D-6}$$

or

$$(b_1 - b_2 X_1)^{(-b_4/b_2)} \tag{D-7}$$

The general solution of equation D.5 is expressed as:

$$X_2(b_1-b_2X_1)^{(-b_4/b_2)} = \int \frac{b_3 X_1}{b_1-b_2X_1} (b_1-b_2 X_1)^{(-b_4/b_2)} dX_1 + CI \tag{D-8}$$

or $$X_2(b_1-b_2X_1)^{(-b_4/b_2)} = \int b_3 X_1(b_1-b_2X_1)^{((-b_4/b_2)-1)} dX_1 + CI \tag{D-9}$$

solving the integral by parts

$$X_2(b_1-b_2X_1)^{(-b_4/b_2)} = \frac{b_3(b_1-b_2 X_1)^{(1-(b_4/b_2))}}{b_4b_2-b_4^2} - \frac{b_3 X_1}{b_4} (b_1-b_2X_1)^{(-b_4/b_2)} + CI \tag{D-10}$$

or

$$X_2 = \frac{b_3}{b_4 b_2 - b_4{}^2} \quad (b_1 b_2 X_1) \; - \frac{b_3}{b_4} \; X_1 + CI \quad (b_1 - b_2 X_1)^{(b_4/b_2)} \qquad \text{(D-11)}$$

Using similar techniques solutions for $X_1$ and $X_2$ were as follows:

$$X_1 = -\frac{b_1}{b_2} + CI \; (b_5 X_2 - b_6 X_3)^{(-b_2/b_6)} \qquad \text{(D-12)}$$

$$X_3 = \frac{b_5 \; X_2}{b_2 - b_6} \; (b_1 - b_2 X_1) + CI \; (b_1 - b_2 X_1)^{(-b_6/b_2)} \qquad \text{(D-13)}$$

# APPENDIX E

## COMPUTER OUTPUT (RUN #7)

## E.1 SCOUR Control Daily Log

A computer output listing that provides process control results for the A system during experimental run #7. Symbols used on the output are as follows:

DAY - Julian day

HR - hour

$MLSS_i$ - Mixed liquor suspended solids sensor reading (mg/L)

OUR - On line oxygen uptake calculation ($mgO_2$/L-h)

MSLET - Third compartment MLSS setpoint (mg/L)

$ALPHS_j$ - Optimal contacting pattern after calculation for compartment i

ELP TIME - Elasped computing time (sec)

SCOUR SETPT - SCOUR setpoint (mg/$O_2$/g MLSS-h)

ERR - Computer software error code

ACTUAL SCOUR - Actual instantaneous SCOUR

PLANT FLOW - Influent hydraulic flow (L/min)

COMPACTION RATIO - MLSS(3)/RAS

RAS-SS - Return activated sludge TSS (sensor) (Mg/L)

SEED - Random # generator seed.

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**************************************************************************************************

                    STEP FEED PROCESS CONTROL LOG      RUN07

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-------------------------------------------------------------------------------------------------------------
                  MLSS                                          ALPHA           ELP    SCOUR        ACTUAL   PLANT   CDM    RAS
DAY MIN        1       2      3     OUR  MLSET        1      2       3     TIME   SETPT  ERR   SCOUR    FLOW  RATIO    SS   SEED
-------------------------------------------------------------------------------------------------------------
 78 10.1    4362    2502   1170   16.2   1081      .039  0.000   .961      3.33   15.00    0    14.25    5.23   2.62   2979   17.0
 78 10.3    4305    2654   1145   16.9   1128      .062  0.000   .938      3.72   15.00    0    14.78    5.23   2.59   2967   17.0
 78 10.6    4277    2703   1136   16.8   1122      .056  0.000   .744      4.23   15.00    0    14.83    5.29   2.38   2701   17.0
 78 10.8    4213    2747   1133   16.8   1117      .061  0.000   .939      2.28   15.00    0    14.82    5.32   2.32   2625   17.0
 78 11.1    4144    2812   1161   17.2   1149      .062  0.000   .938      2.42   15.00    0    14.86    5.38   2.50   2987   17.0
 78 11.3    4079    2856   1191   18.1   1205      .093  0.000   .907      3.08   15.00    0    15.18    5.43   2.59   3083   17.0
 78 11.6    4036    2894   1189   19.1   1272      .144  0.000   .856      2.57   15.00    0    16.05    5.50   2.45   2918   17.0
 78 11.8    3976    2929   1192   19.9   1326      .176  0.000   .824      3.87   15.00    0    16.69    5.58   2.43   2899   17.0
 78 12.1    3915    2962   1223   21.8   1450      .253  0.000   .747      4.65   15.00    0    17.80    5.65   2.74   3353   17.0
 78 12.3    3858    2997   1264   23.5   1566      .319  0.000   .681      4.40   15.00    0    18.59    5.72   2.79   3526   17.0
 78 12.6    3799    3020   1279   25.5   1698      .413  0.000   .587      4.07   15.00    0    19.92    5.85   2.65   3388   17.0
 78 12.8    3705    3031   1316   27.0   1797      .480  0.000   .520      3.83   15.00    0    20.49    5.92   2.65   3484   17.0
 78 13.1    3621    3043   1379   28.1   1872      .515  0.000   .485      4.30   15.00    0    20.37    6.06   2.88   3967   17.0
 78 13.3    3531    3047   1460   29.5   1965      .570  0.000   .430      3.37   15.00    0    20.19    6.13   2.87   4193   17.0
 78 13.6    3426    3039   1522   29.9   1993      .586  0.000   .414      2.17   15.00    0    19.64    6.28   2.84   4323   17.0
 78 13.8    3324    3018   1594   30.0   2000      .586  0.000   .414      2.25   15.00    0    18.82    6.37   2.74   4375   17.0
 78 14.1    3255    2989   1668   30.5   2030      .600  0.000   .400      2.33   15.00    0    18.26    6.53   2.87   4789   17.0
 78 14.3    3204    2947   1733   30.1   2009      .578  0.000   .422      3.77   15.00    0    17.39    6.63   2.94   5089   17.0
 78 14.6    3136    2915   1764   29.0   1935      .520  0.000   .480      3.13   15.00    0    16.46    6.79   3.00   5290   17.0
 78 14.8    3124    2870   1802   28.5   1898      .493  0.000   .507      2.93   15.00    0    15.81    6.89   2.92   5260   17.0
 78 15.1    3148    2846   1828   28.1   1874      .469  0.000   .531      5.52   15.00    0    15.38    7.07   3.05   5577   17.0
 78 15.3    3196    2821   1845   27.4   1824      .423  0.000   .577      4.48   15.00    0    14.83    7.15   3.13   5769   17.0
 78 15.6    3213    2805   1835   26.6   1776      .393  0.000   .607      4.52   15.00    0    14.52    7.33   3.22   5910   17.0
 78 15.8    3270    2797   1830   26.2   1749      .368  0.000   .632      6.10   15.00    0    14.34    7.44   3.14   5748   17.0
 78 16.1    3347    2803   1815   26.5   1769      .377  0.000   .623      4.77   15.00    0    14.63    7.60   3.20   5805   17.0
 78 16.3    3415    2815   1802   28.4   1891      .455  0.000   .545      5.45   15.00    0    15.74    7.71   3.23   5816   17.0
 78 16.6    3453    2825   1781   28.7   1911      .470  0.000   .530      6.58   15.00    0    16.10    7.85   3.22   5733   17.0
 78 16.8    3501    2843   1767   28.8   1917      .470  0.000   .530      4.60   15.00    0    16.20    7.99   3.09   5459   17.0
 78 17.1    3507    2864   1785   29.0   1935      .476  0.000   .524      4.40   15.00    0    16.27    8.10   3.02   5399   17.0
 78 17.3    3507    2887   1800   28.7   1914      .454  0.000   .546      4.15   15.00    0    15.96    8.24   3.02   5444   17.0
 78 17.6    3473    2895   1807   28.3   1886      .432  0.000   .568      6.13   15.00    0    15.66    8.35   2.99   5397   17.0
 78 17.8    3449    2905   1818   28.3   1884      .432  0.000   .568      3.30   15.00    0    15.55    8.48   2.93   5322   17.0
 78 18.1    3454    2913   1816   28.5   1897      .432  0.000   .568      3.82   15.00    0    15.50    8.58   2.97   5448   17.0
 78 18.3    3466    2913   1832   28.7   1910      .439  0.000   .561      4.10   15.00    0    15.64    8.67   2.99   5481   17.0
 78 18.6    3443    2921   1825   28.9   1924      .447  0.000   .553      4.28   15.00    0    15.82    8.80   3.02   5511   17.0
 78 18.8    3446    2920   1822   28.8   1919      .447  0.000   .553      4.95   15.00    0    15.80    8.85   2.97   5406   17.0
 78 19.1    3472    2927   1821   29.1   1941      .456  0.000   .544      4.12   15.00    0    16.00    8.98   3.02   5507   17.0
 78 19.3    3460    2930   1833   27.3   1956      .463  0.000   .537      4.77   15.00    0    16.01    9.03   3.07   5622   17.0
 78 19.6    3476    2933   1837   29.5   1964      .464  0.000   .536      4.95   15.00    0    16.04    9.12   3.03   5571   17.0
 78 19.8    3505    2936   1861   29.4   1958      .455  0.000   .545      4.50   15.00    0    15.79    9.17   2.95   5492   17.0
 78 20.1    3548    2947   1879   29.4   1961      .445  0.000   .555      4.97   15.00    0    15.66    9.22   3.02   5674   17.0
 78 20.3    3572    2960   1902   29.6   1971      .417  0.000   .563      4.97   15.00    0    15.55    9.26   3.04   5777   17.0
 78 20.6    3564    2973   1902   29.3   1952      .424  0.000   .576      7.15   15.00    0    15.40    9.32   3.09   5870   17.0
 78 20.8    3591    2989   1893   29.3   1953      .424  0.000   .576      7.05   15.00    0    15.48    9.35   3.03   5738   17.0
 78 21.1    3612    3000   1901   29.8   1984      .436  0.000   .564      6.32   15.00    0    15.66    9.35   3.06   5815   17.0
 78 21.3    3647    3017   1888   29.9   1991      .436  0.000   .564      5.05   15.00    0    15.82    9.39   3.10   5860   17.0
 78 21.6    3677    3038   1885   30.0   2001      .430  0.000   .570      4.88   15.00    0    15.93    9.38   3.12   5890   17.0
```

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*************************************************************************************************

                    STEP FEED PROCESS CONTROL LOG      RUN07

*************************************************************************************************

---------------------------------------------------------------------------------------------------------
              MLSS                                    ALPHA          ELP    SCOUR          ACTUAL  PLANT   COM    RAS
DAY MIN      1      2      3     OUR   MLSET      1      2      3    TIME   SETPT ERR     SCOUR   FLOW  RATIO    SS    SEED
---------------------------------------------------------------------------------------------------------
 78 21.8  3702   3061   1882   30.1   2001     .430  0.000   .570    6.9    15.00   0     16.01    9.37   3.11   5850   17.0
 78 22.1  3706   3078   1889   30.2   2011     .432  0.000   .568    6.     15.00   0     16.00    9.35   3.07   5791   17.0
 78 22.3  3718   3095   1896   30.2   2011     .426  0.000   .574    5.     15.00   0     15.91    9.31   3.08   5847   17.0
 78 22.6  3679   3105   1877   30.1   2004     .426  0.000   .574    4.73   15.00   0     16.02    9.29   3.09   5806   17.0
 78 22.8  3650   3110   1880   29.9   1995     .429  0.000   .571    4.35   15.00   0     15.92    9.27   2.99   5622   17.0
 78 23.1  3644   3112   1879   30.0   2002     .429  0.000   .571    4.27   15.00   0     15.99    9.20   3.06   5747   17.0
 78 23.3  3658   3112   1892   30.3   2017     .429  0.000   .571    5.13   15.00   0     15.99    9.15   3.09   5843   17.0
 78 23.6  3649   3117   1912   30.9   2057     .457  0.000   .543    4.95   15.00   0     16.16    9.08   3.07   5866   17.0
 78 23.8  3682   3126   1930   31.1   2076     .461  0.000   .539    4.88   15.00   0     16.14    9.01   3.02   5825   17.0
 79   .1  3712   3132   1953   31.9   [illegible] .478 0.000 .522    5.07   15.00   0     16.21   [illegible] 3.06 6014 17.0
 79   .3  3763   3152   1989   32.1   2125     .495  0.000   .505    5.30   15.00   0     16.41    8.85   3.13   6218   17.0
 79   .6  3769   3167   2008   33.0   2199     .503  0.000   .497    5.87   15.00   0     16.43    8.75   3.14   6311   17.0
 79   .8  3785   3183   2027   33.1   2206     .503  0.000   .497    5.38   15.00   0     16.32    8.66   3.10   6295   17.0
 79  1.1  3798   3203   2053   33.0   2198     .487  0.000   .513    7.40   15.00   0     16.06    8.53   3.16   6479   17.0
 79  1.3  3827   3219   2068   32.9   2194     .474  0.000   .526    6.35   15.00   0     15.91    8.45   3.23   6674   17.0
 79  1.6  3791   3234   2071   33.2   2210     .480  0.000   .520    5.80   15.00   0     16.01    8.29   3.28   6788   17.0
 79  1.8  3808   3249   2079   33.3   2220     .484  0.000   .516    4.97   15.00   0     16.02    8.21   3.23   6723   17.0
 79  2.1  3844   3266   2077   33.2   2211     .471  0.000   .529    6.45   15.00   0     15.97    8.06   3.26   6772   17.0
 79  2.3  3864   3295   2081   33.2   2210     .464  0.000   .536    6.50   15.00   0     15.93    7.94   3.32   6900   17.0
 79  2.6  3856   3298   2068   33.3   2219     .474  0.000   .526    6.23   15.00   0     16.10    7.82   3.34   6905   17.0
 79  2.8  3882   3317   2068   33.1   2208     .465  0.000   .535    3.95   15.00   0     16.02    7.67   3.32   6874   17.0
 79  3.1  3891   3322   2068   32.9   2190     .453  0.000   .547    5.65   15.00   0     15.89    7.55   3.30   6820   17.0
 79  3.3  3913   3339   2066   32.7   2179     .438  0.000   .562    4.83   15.00   0     15.82    7.40   3.32   6853   17.0
 79  3.6  3886   3353   2060   31.7   2115     .403  0.000   .597    4.87   15.00   0     15.40    7.26   3.33   6867   17.0
 79  3.8  3898   3359   2051   31.1   2070     .380  0.000   .620    4.82   15.00   0     15.14    7.14   3.23   6632   17.0
 79  4.1  3907   3368   2050   30.9   2058     .370  0.000   .630    5.03   15.00   0     15.06    6.98   3.26   6681   17.0
 79  4.3  3935   3381   2032   31.1   2070     .375  0.000   .625    3.62   15.00   0     15.28    6.89   3.35   6808   17.0
 79  4.6  3932   3383   2007   31.2   2081     .388  0.000   .612    4.97   15.00   0     15.58    6.71   3.37   6760   17.0
 79  4.8  3948   3374   1986   30.5   2033     .367  0.000   .633    5.18   15.00   0     15.36    6.62   3.21   6377   17.0
 79  5.1  3960   3403   1977   30.2   2010     .351  0.000   .649    4.47   15.00   0     15.25    6.48   3.21   6355   17.0
 79  5.3  3975   3412   1969   30.1   2004     .343  0.000   .657    3.43   15.00   0     15.27    6.35   3.26   6415   17.0
 79  5.6  3950   3416   1944   30.2   2011     .358  0.000   .642    3.68   15.00   0     15.52    6.24   3.43   6667   17.0
 79  5.8  3963   3423   1935   29.8   1989     .348  0.000   .652    4.47   15.00   0     15.42    6.10   3.13   6052   17.0
 79  6.1  3977   3434   1921   29.2   1945     .321  0.000   .679    3.53   15.00   0     15.19    6.01   3.19   6129   17.0
 79  6.3  3979   3440   1918   28.8   1928     .303  0.000   .697    4.03   15.00   0     15.02    5.90   3.23   6192   17.0
 79  6.6  3951   3444   1901   29.0   1935     .318  0.000   .682    3.43   15.00   0     15.28    5.80   3.31   6291   17.0
 79  6.8  3959   3451   1875   28.4   1895     .298  0.000   .702    4.22   15.00   0     15.17    5.71   3.17   5937   17.0
 79  7.1  3964   3454   1867   28.1   1870     .283  0.000   .717    3.12   15.00   0     15.03    5.61   3.28   6131   17.0
 79  7.3  3967   3455   1863   27.6   1841     .266  0.000   .734    2.68   15.00   0     14.82    5.57   3.21   5987   17.0
 79  7.6  3944   3457   1838   26.9   1794     .243  0.000   .757    2.25   15.00   0     14.64    5.46   3.25   5969   17.0
 79  7.8  3945   3461   1828   26.7   1777     .237  0.000   .763    2.42   15.00   0     14.65    5.42   3.03   5586   17.0
 79  8.1  3924   3458   1808   26.4   1768     .231  0.000   .769    2.17   15.00   0     14.61    5.35   3.13   5654   17.0
 79  8.3  3934   3465   1802   26.2   1744     .218  0.000   .782    2.58   15.00   0     14.52    5.31   2.90   5233   17.0
 79  8.6  3945   3460   1805   25.3   1687     .182  0.000   .818    3.20   15.00   0     14.07    5.30   3.05   5498   17.0
 79  8.8  3972   3459   1806   24.8   1653     .152  0.000   .848    2.60   15.00   0     13.73    5.22   3.17   5724   17.0
 79  9.1  3993   3466   1805   23.9   1596     .117  0.000   .883    2.20   15.00   0     13.27    5.24   3.15   5764   17.0
 79  9.3  4045   3474   1791   24.2   1616     .131  0.000   .869    1.10   15.00   0     13.54    5.20   3.23   5782   17.0
```

## E.2 On-Line Data Acquisition Log

The on-line data acquisition computer output is presented for the A and B systems during experimental run #7. The data is averaged over 15 minutes. A Dohrmann-Envirotech TOC analyzer and Lisle-Metric photometric sensor were used to measure filtered organic carbon (FOC) and effluent suspended solids (ESS), respectively. These measurements were used for sensor evaluation purposes (Stephenson et al., 1981a) and were not used for the control applications described in this study.

| | DISSOLVED OXYGEN | | | | AIR FLOW | | TEMP | OXYGEN TR | | FLOW | | RETURN SLUDGE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | A | B | | A | B | A | B | A | B |
| DATE HR MIN | FRONT | MIDDLE | REAR | | | | | | | | | | |
| | mg/L | mg/L | mg/L | mg/L | SCFM | | deg C | mg/L/hr | | cu.m/d | | cu.m/d | |
| 19/03/10: 0 | 2.0 | 2.0 | 2.9 | 2.0 | .8 | 11.3 | 14.7 | 16.2 | 41.7 | 7.5 | 7.5 | 3.8 | 3.7 |
| 19/03/10:15 | 2.0 | 2.0 | 3.0 | 2.0 | .9 | 11.2 | 14.7 | 16.9 | 41.5 | 7.5 | 7.6 | 3.8 | 3.8 |
| 19/03/10:30 | 2.0 | 1.9 | 3.0 | 2.0 | .9 | 11.3 | 14.7 | 16.8 | 42.1 | 7.6 | 7.6 | 3.8 | 3.8 |
| 19/03/10:45 | 2.0 | 2.0 | 3.0 | 2.0 | .9 | 11.4 | 14.7 | 16.8 | 42.1 | 7.7 | 7.7 | 3.8 | 3.8 |
| 19/03/11: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 1.0 | 11.4 | 14.8 | 17.2 | 42.1 | 7.8 | 7.7 | 3.9 | 3.8 |
| 19/03/11:15 | 2.0 | 2.0 | 3.0 | 2.0 | 1.1 | 11.3 | 14.8 | 18.1 | 42.1 | 7.8 | 7.8 | 3.9 | 3.9 |
| 19/03/11:30 | 2.1 | 2.0 | 3.1 | 2.0 | 1.3 | 11.5 | 14.8 | 19.1 | 43.0 | 7.9 | 7.9 | 4.0 | 4.0 |
| 19/03/11:45 | 1.9 | 2.0 | 2.9 | 2.0 | 1.4 | 11.8 | 14.9 | 19.9 | 44.2 | 8.0 | 8.0 | 4.0 | 4.0 |
| 19/03/12: 0 | 1.9 | 2.0 | 3.0 | 2.0 | 1.8 | 12.2 | 15.0 | 21.8 | 45.5 | 8.1 | 8.2 | 4.1 | 4.0 |
| 19/03/12:15 | 1.9 | 2.0 | 3.0 | 2.0 | 2.0 | 12.4 | 15.1 | 23.5 | 46.4 | 8.2 | 8.3 | 4.1 | 4.1 |
| 19/03/12:30 | 2.1 | 2.0 | 3.0 | 2.0 | 2.4 | 13.2 | 15.2 | 25.5 | 49.5 | 8.4 | 8.4 | 4.2 | 4.2 |
| 19/03/12:45 | 1.9 | 2.0 | 3.0 | 2.0 | 2.7 | 13.7 | 15.3 | 27.0 | 51.5 | 8.5 | 8.5 | 4.3 | 4.3 |
| 19/03/13: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 2.9 | 13.9 | 15.5 | 28.1 | 51.7 | 8.7 | 8.7 | 4.4 | 4.3 |
| 19/03/13:15 | 1.9 | 2.0 | 3.0 | 2.0 | 3.1 | 13.9 | 15.7 | 29.5 | 52.2 | 8.8 | 8.8 | 4.4 | 4.4 |
| 19/03/13:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.2 | 14.4 | 15.9 | 29.9 | 54.1 | 9.0 | 9.0 | 4.5 | 4.5 |
| 19/03/13:45 | 2.0 | 1.9 | 3.0 | 2.0 | 3.2 | 14.5 | 16.2 | 30.0 | 54.3 | 9.2 | 9.2 | 4.6 | 4.6 |
| 19/03/14: 0 | 2.0 | 1.9 | 3.0 | 2.0 | 3.3 | 14.7 | 16.4 | 30.5 | 55.1 | 9.4 | 9.4 | 4.7 | 4.7 |
| 19/03/14:15 | 2.1 | 2.0 | 3.0 | 2.0 | 3.3 | 14.4 | 16.6 | 30.1 | 53.8 | 9.5 | 9.6 | 4.8 | 4.8 |
| 19/03/14:30 | 2.1 | 2.0 | 3.0 | 2.0 | 3.1 | 14.0 | 16.7 | 29.0 | 52.2 | 9.8 | 9.7 | 4.9 | 4.9 |
| 19/03/14:45 | 2.1 | 2.0 | 3.0 | 2.0 | 3.1 | 13.6 | 16.8 | 28.5 | 50.7 | 9.9 | 9.9 | 5.0 | 5.0 |
| 19/03/15: 0 | 2.1 | 2.0 | 3.0 | 2.0 | 3.0 | 13.3 | 16.9 | 28.1 | 49.5 | 10.2 | 10.1 | 5.1 | 5.0 |
| 19/03/15:15 | 2.1 | 2.0 | 3.0 | 2.0 | 2.9 | 12.6 | 16.8 | 27.4 | 46.7 | 10.3 | 10.3 | 5.2 | 5.2 |
| 19/03/15:30 | 2.0 | 2.0 | 3.0 | 2.0 | 2.8 | 12.6 | 16.8 | 26.6 | 46.7 | 10.6 | 10.5 | 5.3 | 5.3 |
| 19/03/15:45 | 2.1 | 2.0 | 3.0 | 2.0 | 2.7 | 12.4 | 16.7 | 26.2 | 45.8 | 10.7 | 10.7 | 5.4 | 5.4 |
| 19/03/16: 0 | 1.9 | 2.0 | 3.0 | 1.9 | 2.7 | 12.4 | 16.6 | 26.5 | 46.4 | 10.9 | 10.9 | 5.5 | 5.4 |
| 19/03/16:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.0 | 13.2 | 16.4 | 28.4 | 49.3 | 11.1 | 11.1 | 5.5 | 5.6 |
| 19/03/16:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.1 | 13.6 | 16.3 | 28.7 | 50.8 | 11.3 | 11.3 | 5.7 | 5.7 |
| 19/03/16:45 | 1.9 | 2.0 | 3.0 | 2.0 | 3.1 | 13.7 | 16.2 | 28.8 | 51.2 | 11.5 | 11.4 | 5.7 | 5.7 |
| 19/03/17: 0 | 1.9 | 2.0 | 3.0 | 2.0 | 3.2 | 14.1 | 16.1 | 29.0 | 52.7 | 11.7 | 11.7 | 5.8 | 5.8 |
| 19/03/17:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.1 | 14.2 | 16.1 | 28.7 | 52.8 | 11.9 | 11.8 | 5.9 | 5.9 |
| 19/03/17:30 | 2.1 | 2.0 | 3.0 | 2.0 | 3.1 | 14.0 | 16.0 | 28.3 | 52.2 | 12.0 | 12.0 | 6.0 | 6.0 |
| 19/03/17:45 | 2.1 | 2.0 | 3.0 | 2.0 | 3.0 | 14.1 | 16.0 | 28.3 | 52.7 | 12.2 | 12.2 | 6.1 | 6.1 |
| 19/03/18: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.1 | 14.2 | 15.9 | 28.5 | 52.9 | 12.3 | 12.3 | 6.2 | 6.2 |
| 19/03/18:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.1 | 14.1 | 15.8 | 28.7 | 52.6 | 12.5 | 12.5 | 6.2 | 6.2 |
| 19/03/18:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.2 | 14.4 | 15.7 | 28.9 | 53.5 | 12.7 | 12.7 | 6.3 | 6.3 |
| 19/03/18:45 | 1.9 | 2.0 | 3.0 | 2.0 | 3.2 | 14.2 | 15.6 | 28.8 | 53.2 | 12.7 | 12.7 | 6.4 | 6.4 |
| 19/03/19: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.2 | 14.4 | 15.6 | 29.1 | 53.9 | 12.9 | 12.9 | 6.4 | 6.4 |
| 19/03/19:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.5 | 15.6 | 29.3 | 54.2 | 13.0 | 13.0 | 6.5 | 6.5 |
| 19/03/19:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.5 | 15.5 | 29.5 | 53.9 | 13.1 | 13.0 | 6.6 | 6.6 |
| 19/03/19:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.3 | 15.5 | 29.4 | 53.5 | 13.2 | 13.2 | 6.6 | 6.6 |
| 19/03/20: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.5 | 15.5 | 29.4 | 54.1 | 13.3 | 13.3 | 6.6 | 6.6 |
| 19/03/20:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.4 | 15.4 | 29.6 | 53.9 | 13.3 | 13.4 | 6.7 | 6.7 |
| 19/03/20:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.6 | 15.4 | 29.3 | 54.2 | 13.4 | 13.4 | 6.7 | 6.7 |
| 19/03/20:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.4 | 15.3 | 29.3 | 53.6 | 13.5 | 13.5 | 6.7 | 6.7 |

|  | DISSOLVED OXYGEN |  |  |  | AIR FLOW |  | TEMP | OXYGEN TR |  | FLOW |  | RETURN SLUDGE |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | A | B | A | B |  | A | B | A | B | A | B |
| DATE HR MIN | FRONT | MIDDLE | REAR |  |  |  |  |  |  |  |  |  |  |
|  | mg/L | mg/L | mg/L | mg/L | SCFM |  | deg C | mg/L/hr |  | cu.m/d |  | cu.m/d |  |
| 19/03/21: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.5 | 15.3 | 29.8 | 53.9 | 13.5 | 13.4 | 6.7 | 6.7 |
| 19/03/21:15 | 1.9 | 2.0 | 3.0 | 2.0 | 3.4 | 14.4 | 15.2 | 29.9 | 53.6 | 13.5 | 13.5 | 6.7 | 6.7 |
| 19/03/21:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.3 | 15.1 | 30.0 | 53.6 | 13.5 | 13.5 | 6.8 | 6.7 |
| 19/03/21:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.5 | 15.1 | 30.1 | 53.9 | 13.5 | 13.5 | 6.7 | 6.7 |
| 19/03/22: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.4 | 15.1 | 30.2 | 53.7 | 13.5 | 13.5 | 6.7 | 6.7 |
| 19/03/22:15 | 2.1 | 2.0 | 3.0 | 2.0 | 3.4 | 14.4 | 15.0 | 30.2 | 54.0 | 13.4 | 13.5 | 6.7 | 6.7 |
| 19/03/22:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.6 | 15.0 | 30.1 | 54.3 | 13.4 | 13.4 | 6.7 | 6.7 |
| 19/03/22:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.5 | 15.0 | 29.9 | 54.2 | 13.3 | 13.3 | 6.7 | 6.7 |
| 19/03/23: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.7 | 14.9 | 30.0 | 54.5 | 13.2 | 13.3 | 6.6 | 6.6 |
| 19/03/23:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.5 | 14.9 | 30.3 | 54.3 | 13.2 | 13.1 | 6.6 | 6.6 |
| 19/03/23:30 | 2.0 | 2.0 | 2.9 | 2.0 | 3.4 | 15.0 | 14.9 | 30.9 | 56.5 | 13.1 | 13.1 | 6.5 | 6.5 |
| 19/03/23:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.5 | 15.5 | 14.9 | 31.1 | 57.7 | 13.0 | 13.0 | 6.5 | 6.5 |
| 20/03/ 0: 0 | 2.0 | 2.0 | 2.9 | 1.9 | 3.6 | 15.3 | 14.8 | 31.8 | 57.7 | 12.8 | 12.8 | 6.4 | 6.4 |
| 20/03/ 0:15 | 1.9 | 2.0 | 2.9 | 2.0 | 3.7 | 16.0 | 14.8 | 32.6 | 60.2 | 12.7 | 12.8 | 6.4 | 6.4 |
| 20/03/ 0:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.8 | 16.1 | 14.9 | 33.0 | 60.3 | 12.6 | 12.6 | 6.3 | 6.3 |
| 20/03/ 0:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.8 | 16.3 | 14.9 | 33.1 | 61.4 | 12.5 | 12.5 | 6.2 | 6.2 |
| 20/03/ 1: 0 | 2.0 | 2.0 | 3.0 | 2.1 | 3.9 | 16.3 | 14.9 | 33.0 | 60.7 | 12.3 | 12.3 | 6.1 | 6.1 |
| 20/03/ 1:15 | 2.0 | 2.0 | 3.1 | 2.0 | 3.9 | 16.0 | 14.9 | 32.9 | 60.3 | 12.2 | 12.2 | 6.1 | 6.1 |
| 20/03/ 1:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.9 | 16.3 | 15.0 | 33.2 | 61.0 | 11.9 | 12.0 | 6.0 | 6.0 |
| 20/03/ 1:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.9 | 16.2 | 15.0 | 33.3 | 60.6 | 11.8 | 11.8 | 5.9 | 5.9 |
| 20/03/ 2: 0 | 2.1 | 2.0 | 3.0 | 2.0 | 3.9 | 15.9 | 14.9 | 33.2 | 59.7 | 11.6 | 11.6 | 5.8 | 5.8 |
| 20/03/ 2:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.8 | 15.9 | 15.0 | 33.2 | 60.0 | 11.4 | 11.5 | 5.7 | 5.7 |
| 20/03/ 2:30 | 2.1 | 2.0 | 3.0 | 2.0 | 3.8 | 16.1 | 15.0 | 33.3 | 60.1 | 11.3 | 11.2 | 5.6 | 5.6 |
| 20/03/ 2:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.8 | 15.7 | 14.9 | 33.1 | 59.0 | 11.0 | 11.1 | 5.5 | 5.5 |
| 20/03/ 3: 0 | 2.0 | 2.0 | 3.0 | 2.1 | 3.7 | 15.8 | 14.9 | 32.9 | 59.0 | 10.9 | 10.9 | 5.4 | 5.4 |
| 20/03/ 3:15 | 2.1 | 2.0 | 3.0 | 2.0 | 3.7 | 15.4 | 15.0 | 32.7 | 57.8 | 10.7 | 10.7 | 5.3 | 5.3 |
| 20/03/ 3:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.5 | 15.2 | 15.0 | 31.7 | 56.6 | 10.5 | 10.4 | 5.2 | 5.2 |
| 20/03/ 3:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 15.0 | 15.0 | 31.1 | 56.3 | 10.3 | 10.3 | 5.1 | 5.1 |
| 20/03/ 4: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.6 | 15.0 | 30.9 | 54.6 | 10.1 | 10.1 | 5.0 | 5.0 |
| 20/03/ 4:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.7 | 15.0 | 31.1 | 55.1 | 9.9 | 9.9 | 4.9 | 4.9 |
| 20/03/ 4:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.4 | 14.5 | 15.0 | 31.2 | 54.1 | 9.7 | 9.7 | 4.8 | 4.8 |
| 20/03/ 4:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.3 | 14.4 | 14.9 | 30.5 | 53.9 | 9.5 | 9.5 | 4.8 | 4.8 |
| 20/03/ 5: 0 | 2.1 | 2.0 | 3.0 | 2.0 | 3.3 | 13.9 | 15.0 | 30.2 | 52.0 | 9.3 | 9.3 | 4.7 | 4.6 |
| 20/03/ 5:15 | 1.9 | 2.0 | 3.0 | 2.0 | 3.2 | 14.2 | 15.0 | 30.1 | 52.7 | 9.1 | 9.1 | 4.6 | 4.6 |
| 20/03/ 5:30 | 2.0 | 2.0 | 3.0 | 2.0 | 3.2 | 13.9 | 15.0 | 30.2 | 52.1 | 9.0 | 8.9 | 4.5 | 4.5 |
| 20/03/ 5:45 | 2.0 | 2.0 | 3.0 | 2.0 | 3.2 | 13.9 | 15.0 | 29.8 | 51.8 | 8.8 | 8.8 | 4.4 | 4.4 |
| 20/03/ 6: 0 | 2.0 | 2.0 | 3.0 | 2.0 | 3.0 | 13.8 | 15.0 | 29.2 | 51.5 | 8.7 | 8.7 | 4.3 | 4.3 |
| 20/03/ 6:15 | 2.0 | 2.0 | 3.0 | 2.0 | 3.0 | 13.6 | 15.1 | 28.8 | 50.8 | 8.5 | 8.5 | 4.3 | 4.3 |
| 20/03/ 6:30 | 2.1 | 2.0 | 3.0 | 2.0 | 3.0 | 13.5 | 15.1 | 29.0 | 50.8 | 8.4 | 8.4 | 4.2 | 4.2 |
| 20/03/ 6:45 | 2.0 | 2.0 | 3.0 | 2.0 | 2.9 | 13.4 | 15.1 | 28.4 | 49.8 | 8.2 | 8.2 | 4.1 | 4.1 |
| 20/03/ 7: 0 | 2.1 | 2.0 | 3.0 | 2.0 | 2.8 | 13.0 | 15.0 | 28.1 | 48.5 | 8.1 | 8.1 | 4.0 | 4.0 |
| 20/03/ 7:15 | 2.0 | 2.0 | 3.0 | 2.0 | 2.7 | 13.1 | 15.1 | 27.6 | 48.9 | 8.0 | 8.0 | 4.0 | 4.0 |
| 20/03/ 7:30 | 2.0 | 2.0 | 3.0 | 2.0 | 2.6 | 12.9 | 15.1 | 26.9 | 48.0 | 7.9 | 7.9 | 3.9 | 3.9 |
| 20/03/ 7:45 | 1.9 | 2.0 | 3.0 | 2.0 | 2.6 | 12.9 | 15.1 | 26.7 | 47.9 | 7.8 | 7.8 | 3.9 | 3.9 |
| 20/03/ 8: 0 | 2.1 | 2.0 | 3.0 | 2.0 | 2.5 | 12.5 | 15.1 | 26.4 | 46.6 | 7.7 | 7.7 | 3.9 | 3.8 |

```
                      DISSOLVED OXYGEN       :  AIR FLOW : TEMP:OXYGEN UR   :      FLOW     : RETURN SLUDGE:
                                  A      B   :  A     B  :     : A     B    :    A     B    :  A         B  :
  DATE HR MIN FRONT MIDDLE REAR              :           :     :            :               :              :
               mg/L   mg/L   mg/L   mg/L     :   SCFM    :deg C:  mg/L/hr   :     cu.m/d    :  cu.m/d      :
 20/03/ 8:15   2.0    2.0    3.0    2.0       2.5 12.6   15.2   26.2 46.9       7.6   7.7      3.8       3.8
 20/03/ 8:30   2.0    2.0    3.0    2.0       2.3 12.4   15.2   25.3 46.2       7.6   7.6      3.8       3.8
 20/03/ 8:45   2.1    2.0    3.0    2.0       2.3 12.3   15.2   24.8 45.7       7.5   7.6      3.8       3.8
 20/03/ 9: 0   2.0    2.0    3.0    2.0       2.1 12.2   15.[illegible] 23.9 45.0       7.5   7.5      3.8       3.8
 20/03/ 9:15   2.0    2.0    3.0    2.0       2.2 11.8   15.2   24.2 44.2       7.5   7.5      3.8       3.8
 20/03/ 9:30   2.0    2.0    3.0    2.0       2.1 11.9   15.2   24.2 44.2       7.5   7.5      3.7       3.7
 20/03/ 9:45   2.0    2.0    3.0    2.0       2.1 11.8   15.1   23.5 43.5       7.5   7.5      3.8       3.8
 20/03/10: 0   2.0    2.0    3.0    2.0       1.9 11.7   15.1   22.7 43.2       7.5   7.5      3.8       3.7
```

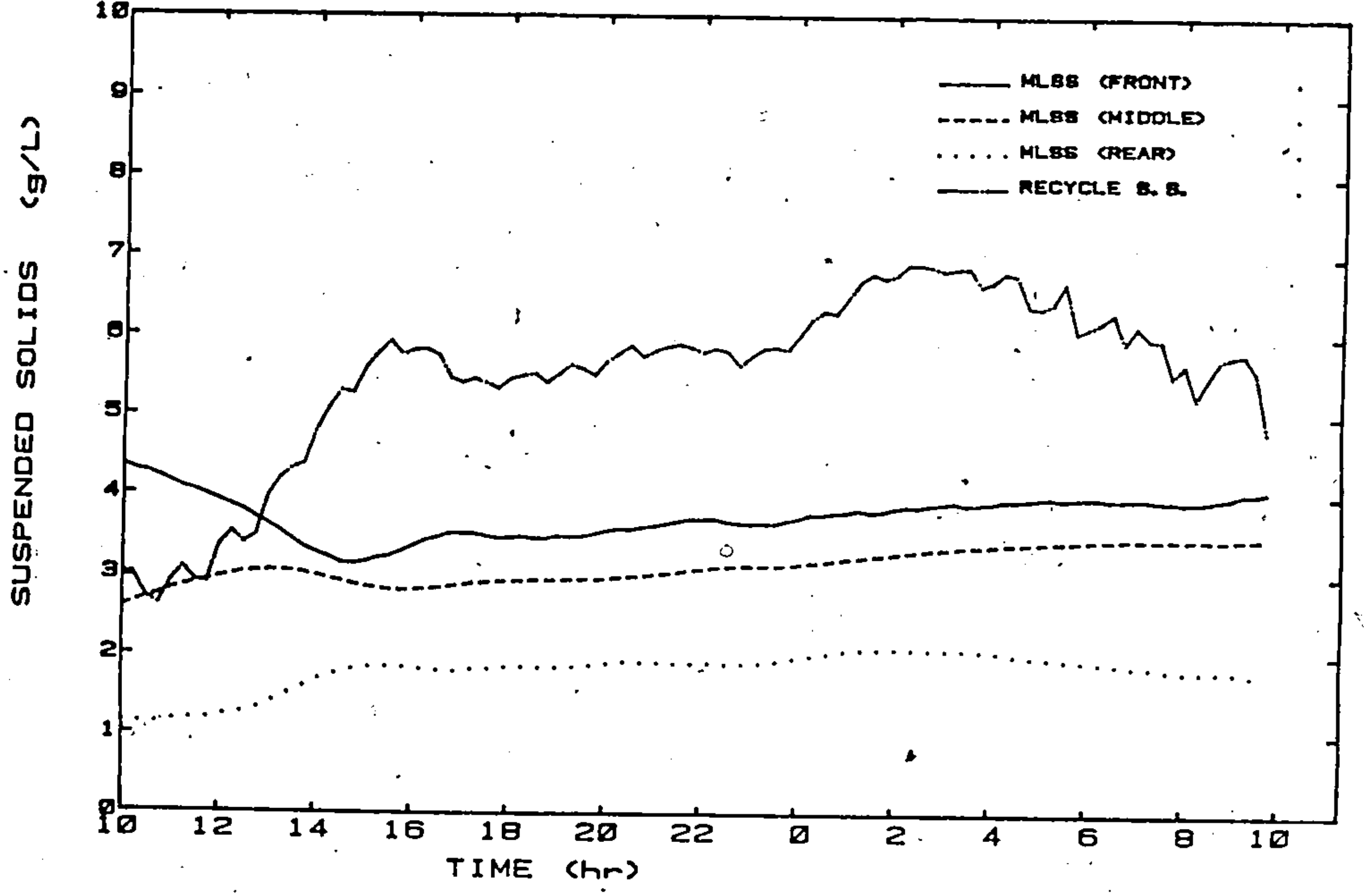
|  | MIXED LIQUOR SUSP SOLIDS |  |  |  | RETURN SLUDGE |  | EFF SS |  | INF SS | EFF FOC |  | INF PH | PH |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | A |  |  | B | A | B | A | B | BOTH | A | B |  | A | B |
|  | FRONT | MIDDLE | REAR |  |  |  |  |  |  |  |  |  |  |  |
|  | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |  |  |  |
| 19/03/10: 0 | 4362 | 2582 | 1138 | 2520 | 2979 | 7700 | 16 | 27 | -1 | -1 | 16 | 9.5 | 7.0 | 7.2 |
| 19/03/10:15 | 4305 | 2654 | 1145 | 2520 | 2967 | 7173 | 14 | 26 | -1 | -1 | -1 | 9.5 | 7.0 | 7.2 |
| 19/03/10:30 | 4277 | 2703 | 1136 | 2520 | 2701 | 7535 | 13 | 26 | -1 | 13 | -1 | 9.4 | 7.0 | 7.2 |
| 19/03/10:45 | 4213 | 2747 | 1133 | 2520 | 2625 | 7796 | 13 | 25 | -1 | -1 | -1 | 9.2 | 7.0 | 7.2 |
| 19/03/11: 0 | 4144 | 2812 | 1161 | 2520 | 2987 | 7820 | 12 | 25 | -1 | -1 | 15 | 9.1 | 7.0 | 7.2 |
| 19/03/11:15 | 4079 | 2856 | 1191 | 2520 | 3083 | 7421 | 13 | 25 | -1 | -1 | -1 | 8.9 | 7.0 | 7.2 |
| 19/03/11:30 | 4036 | 2894 | 1189 | 2520 | 2918 | 7567 | 13 | 25 | -1 | 13 | -1 | 8.8 | 7.0 | 7.2 |
| 19/03/11:45 | 3976 | 2929 | 1192 | 2520 | 2899 | 7667 | 13 | 25 | -1 | -1 | -1 | 8.7 | 7.0 | 7.2 |
| 19/03/12: 0 | 3915 | 2962 | 1223 | 2520 | 3353 | 7642 | 15 | 25 | -1 | -1 | 15 | 8.7 | 7.0 | 7.2 |
| 19/03/12:15 | 3858 | 2997 | 1264 | 2520 | 3526 | 7490 | 16 | 25 | -1 | -1 | -1 | 8.6 | 7.0 | 7.2 |
| 19/03/12:30 | 3799 | 3020 | 1279 | 2520 | 3388 | 7677 | 17 | 25 | -1 | 15 | -1 | 8.5 | 7.0 | 7.2 |
| 19/03/12:45 | 3705 | 3031 | 1316 | 2520 | 3484 | 7684 | 16 | 25 | -1 | -1 | -1 | 8.4 | 7.0 | 7.2 |
| 19/03/13: 0 | 3621 | 3043 | 1379 | 2520 | 3967 | 7546 | 17 | 25 | -1 | -1 | 15 | 8.4 | 7.0 | 7.2 |
| 19/03/13:15 | 3531 | 3047 | 1460 | 2640 | 4193 | 7377 | 19 | 25 | -1 | -1 | -1 | 8.4 | 7.0 | 7.2 |
| 19/03/13:30 | 3426 | 3039 | 1522 | 2640 | 4323 | 7541 | 18 | 25 | -1 | 15 | -1 | 8.4 | 7.0 | 7.2 |
| 19/03/13:45 | 3324 | 3018 | 1594 | 2640 | 4375 | 7632 | 16 | 26 | -1 | -1 | -1 | 8.4 | 7.1 | 7.2 |
| 19/03/14: 0 | 3255 | 2989 | 1668 | 2640 | 4789 | 7511 | 18 | 27 | -1 | -1 | 15 | 8.4 | 7.1 | 7.2 |
| 19/03/14:15 | 3204 | 2747 | 1733 | 2640 | 5089 | 7240 | 21 | 26 | -1 | -1 | -1 | 8.1 | 7.1 | 7.2 |
| 19/03/14:30 | 3136 | 2915 | 1764 | 2640 | 5290 | 7476 | 16 | 26 | -1 | 16 | -1 | 7.7 | 7.1 | 7.2 |
| 19/03/14:45 | 3124 | 2878 | 1802 | 2640 | 5260 | 7633 | 15 | 26 | -1 | -1 | -1 | 7.5 | 7.1 | 7.2 |
| 19/03/15: 0 | 3148 | 2846 | 1828 | 2640 | 5577 | 7579 | 14 | 26 | -1 | -1 | 15 | 7.3 | 7.0 | 7.1 |
| 19/03/15:15 | 3196 | 2821 | 1845 | 2640 | 5769 | 7461 | 16 | 26 | -1 | -1 | -1 | 7.1 | 7.0 | 7.1 |
| 19/03/15:30 | 3213 | 2805 | 1835 | 2640 | 5910 | 7628 | 14 | 26 | -1 | 15 | -1 | 7.1 | 6.9 | 7.1 |
| 19/03/15:45 | 3270 | 2797 | 1830 | 2640 | 5748 | 7649 | 14 | 26 | -1 | -1 | -1 | 7.1 | 6.9 | 7.0 |
| 19/03/16: 0 | 3347 | 2803 | 1815 | 2640 | 5805 | 7737 | 14 | 26 | -1 | -1 | 16 | 7.2 | 6.9 | 7.0 |
| 19/03/16:15 | 3415 | 2815 | 1802 | 2640 | 5816 | 7535 | 17 | 26 | -1 | -1 | -1 | 7.3 | 6.9 | 7.0 |
| 19/03/16:30 | 3453 | 2825 | 1781 | 2640 | 5733 | 7694 | 20 | 27 | -1 | 16 | -1 | 7.4 | 6.9 | 7.0 |
| 19/03/16:45 | 3501 | 2843 | 1767 | 2640 | 5459 | 7730 | 26 | 26 | -1 | -1 | -1 | 7.4 | 6.9 | 7.0 |
| 19/03/17: 0 | 3507 | 2864 | 1785 | 2640 | 5399 | 7648 | 25 | 26 | -1 | -1 | 17 | 7.6 | 6.9 | 7.0 |
| 19/03/17:15 | 3507 | 2887 | 1800 | 2640 | 5444 | 7501 | 27 | 26 | -1 | -1 | -1 | 7.6 | 6.9 | 7.0 |
| 19/03/17:30 | 3473 | 2895 | 1807 | 2640 | 5397 | 7490 | 24 | 26 | -1 | 18 | -1 | 7.7 | 6.9 | 7.1 |
| 19/03/17:45 | 3449 | 2905 | 1818 | 2640 | 5322 | 7588 | 26 | 26 | -1 | -1 | -1 | 7.7 | 6.9 | 7.1 |
| 19/03/18: 0 | 3454 | 2913 | 1836 | 2640 | 5448 | 7578 | 38 | 26 | -1 | -1 | 15 | 7.8 | 6.9 | 7.1 |
| 19/03/18:15 | 3466 | 2913 | 1832 | 2640 | 5481 | 7432 | 31 | 26 | -1 | -1 | -1 | 7.8 | 7.0 | 7.1 |
| 19/03/18:30 | 3443 | 2921 | 1825 | 2640 | 5511 | 7532 | 29 | 26 | -1 | 14 | -1 | 7.8 | 7.0 | 7.1 |
| 19/03/18:45 | 3446 | 2920 | 1822 | 2640 | 5406 | 7565 | 26 | 25 | -1 | -1 | -1 | 7.8 | 7.0 | 7.1 |
| 19/03/19: 0 | 3472 | 2927 | 1821 | 2640 | 5507 | 7526 | 24 | 25 | -1 | -1 | 14 | 7.8 | 7.0 | 7.1 |
| 19/03/19:15 | 3469 | 2930 | 1833 | 2640 | 5622 | 7359 | 25 | 26 | -1 | -1 | -1 | 7.8 | 7.0 | 7.1 |
| 19/03/19:30 | 3475 | 2933 | 1837 | 2640 | 5571 | 7532 | 23 | 26 | -1 | 17 | -1 | 7.8 | 7.0 | 7.2 |
| 19/03/19:45 | 3505 | 2936 | 1861 | 2640 | 5492 | 7597 | 30 | 26 | -1 | -1 | -1 | 7.8 | 7.0 | 7.2 |
| 19/03/20: 0 | 3548 | 2947 | 1879 | 2640 | 5674 | 7635 | 33 | 26 | -1 | -1 | 14 | 7.8 | 7.1 | 7.2 |
| 19/03/20:15 | 3572 | 2960 | 1902 | 2640 | 5777 | 7692 | 42 | 26 | -1 | -1 | -1 | 7.8 | 7.1 | 7.2 |
| 19/03/20:30 | 3564 | 2973 | 1902 | 2640 | 5870 | 7900 | 35 | 26 | -1 | 13 | -1 | 7.8 | 7.1 | 7.2 |
| 19/03/20:45 | 3591 | 2969 | 1893 | 2640 | 5738 | 7880 | 45 | 26 | -1 | -1 | -1 | 7.9 | 7.1 | 7.2 |

| | MIXED LIQUOR SUSP SOLIDS | | | | RETURN SLUDGE | | EFF SS | | INF SS | EFF FOC | | INF PH | PH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | A | B | A | B | BOTH | A | B | | A | B |
| | FRONT | MIDDLE | REAR | | | | | | | | | | | |
| | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | | | |
| 19/03/21: 0 | 3612 | 3000 | 1901 | 2640 | 5815 | 7910 | 43 | 26 | -1 | -1 | 11 | 7.9 | 7.1 | 7.2 |
| 19/03/21:15 | 3647 | 3017 | 1888 | 2640 | 5860 | 7842 | 46 | 27 | -1 | -1 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/21:30 | 3677 | 3038 | 1885 | 2640 | 5890 | 7858 | 45 | 27 | -1 | 10 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/21:45 | 3702 | 3061 | 1882 | 2640 | 5850 | 7893 | 37 | 27 | -1 | -1 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/22: 0 | 3706 | 3078 | 1889 | 2640 | 5791 | 8020 | 40 | 27 | -1 | -1 | 9 | 7.9 | 7.1 | 7.2 |
| 19/03/22:15 | 3718 | 3095 | 1896 | 2640 | 5847 | 7934 | 39 | 27 | -1 | -1 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/22:30 | 3679 | 3105 | 1877 | 2640 | 5806 | 7982 | 33 | 26 | -1 | 8 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/22:45 | 3650 | 3110 | 1880 | 2640 | 5622 | 8011 | 36 | 26 | -1 | -1 | -1 | 7.9 | 7.1 | 7.2 |
| 19/03/23: 0 | 3644 | 3112 | 1879 | 2640 | 5747 | 8104 | 35 | 26 | -1 | -1 | 6 | 7.8 | 7.1 | 7.2 |
| 19/03/23:15 | 3658 | 3112 | 1892 | 2640 | 5843 | 8054 | 34 | 26 | -1 | -1 | -1 | 7.5 | 7.1 | 7.2 |
| 19/03/23:30 | 3649 | 3117 | 1912 | 2640 | 5866 | 8029 | 31 | 26 | -1 | 6 | -1 | 7.1 | 7.1 | 7.2 |
| 19/03/23:45 | 3682 | 3126 | 1930 | 2640 | 5825 | 8124 | 30 | 26 | -1 | -1 | -1 | 7.0 | 7.0 | 7.2 |
| 20/03/ 0: 0 | 3712 | 3132 | 1963 | 2640 | 6014 | 8209 | 29 | 26 | -1 | -1 | 6 | 7.0 | 7.0 | 7.2 |
| 20/03/ 0:15 | 3763 | 3152 | 1989 | 2640 | 6218 | 8207 | 32 | 26 | -1 | -1 | -1 | 7.1 | 7.0 | 7.2 |
| 20/03/ 0:30 | 3769 | 3167 | 2008 | 2640 | 6311 | 8278 | 33 | 26 | -1 | 5 | -1 | 7.1 | 7.0 | 7.2 |
| 20/03/ 0:45 | 3785 | 3183 | 2027 | 2640 | 6285 | 8470 | 34 | 26 | -1 | -1 | -1 | 7.2 | 7.0 | 7.1 |
| 20/03/ 1: 0 | 3798 | 3203 | 2053 | 2640 | 6479 | 8679 | 36 | 26 | -1 | -1 | 5 | 7.3 | 7.0 | 7.1 |
| 20/03/ 1:15 | 3827 | 3219 | 2068 | 2640 | 6674 | 8691 | 36 | 26 | -1 | -1 | -1 | 7.4 | 7.0 | 7.2 |
| 20/03/ 1:30 | 3791 | 3234 | 2071 | 2640 | 6788 | 8804 | 35 | 26 | -1 | 3 | -1 | 7.4 | 7.0 | 7.2 |
| 20/03/ 1:45 | 3808 | 3249 | 2079 | 2640 | 6723 | 8914 | 34 | 26 | -1 | -1 | -1 | 7.5 | 7.0 | 7.2 |
| 20/03/ 2: 0 | 3844 | 3266 | 2077 | 2640 | 6772 | 9076 | 31 | 26 | -1 | -1 | 4 | 7.6 | 7.0 | 7.2 |
| 20/03/ 2:15 | 3864 | 3285 | 2081 | 2640 | 6900 | 9082 | 31 | 26 | -1 | -1 | -1 | 7.6 | 7.0 | 7.2 |
| 20/03/ 2:30 | 3856 | 3298 | 2068 | 2640 | 6905 | 9148 | 29 | 26 | -1 | 3 | -1 | 7.7 | 7.0 | 7.2 |
| 20/03/ 2:45 | 3882 | 3317 | 2068 | 2640 | 6874 | 9248 | 29 | 26 | -1 | -1 | -1 | 7.7 | 7.0 | 7.2 |
| 20/03/ 3: 0 | 3891 | 3322 | 2068 | 2640 | 6820 | 9273 | 29 | 26 | -1 | -1 | 3 | 7.9 | 7.0 | 7.2 |
| 20/03/ 3:15 | 3913 | 3339 | 2066 | 2640 | 6853 | 9261 | 28 | 26 | -1 | -1 | -1 | 8.1 | 7.1 | 7.2 |
| 20/03/ 3:30 | 3886 | 3353 | 2060 | 2640 | 6867 | 9204 | 27 | 26 | -1 | 0 | -1 | 8.5 | 7.1 | 7.2 |
| 20/03/ 3:45 | 3898 | 3359 | 2051 | 2640 | 6632 | 9322 | 26 | 26 | -1 | -1 | -1 | 9.2 | 7.1 | 7.2 |
| 20/03/ 4: 0 | 3907 | 3368 | 2050 | 2640 | 6681 | 9357 | 25 | 26 | -1 | -1 | 2 | 9.7 | 7.2 | 7.3 |
| 20/03/ 4:15 | 3935 | 3381 | 2032 | 2640 | 6808 | 9269 | 24 | 26 | -1 | -1 | -1 | 9.7 | 7.2 | 7.3 |
| 20/03/ 4:30 | 3932 | 3383 | 2007 | 2640 | 6760 | 9277 | 22 | 26 | -1 | 1 | -1 | 9.7 | 7.2 | 7.3 |
| 20/03/ 4:45 | 3948 | 3394 | 1986 | 2640 | 6377 | 9373 | 21 | 26 | -1 | -1 | -1 | 9.6 | 7.2 | 7.3 |
| 20/03/ 5: 0 | 3960 | 3403 | 1977 | 2640 | 6355 | 9453 | 20 | 26 | -1 | -1 | 1 | 9.4 | 7.2 | 7.3 |
| 20/03/ 5:15 | 3975 | 3412 | 1969 | 2640 | 6415 | 9293 | 20 | 26 | -1 | -1 | -1 | 9.4 | 7.2 | 7.3 |
| 20/03/ 5:30 | 3950 | 3416 | 1944 | 2640 | 6667 | 9305 | 19 | 26 | -1 | 0 | -1 | 9.3 | 7.2 | 7.3 |
| 20/03/ 5:45 | 3963 | 3423 | 1935 | 2640 | 6052 | 9360 | 19 | 26 | -1 | -1 | -1 | 9.0 | 7.2 | 7.3 |
| 20/03/ 6: 0 | 3977 | 3434 | 1921 | 2640 | 6129 | 9336 | 19 | 26 | -1 | -1 | 1 | 8.8 | 7.2 | 7.3 |
| 20/03/ 6:15 | 3979 | 3440 | 1918 | 2640 | 6192 | 9211 | 19 | 26 | -1 | -1 | -1 | 8.8 | 7.2 | 7.3 |
| 20/03/ 6:30 | 3951 | 3444 | 1901 | 2640 | 6291 | 9173 | 19 | 26 | -1 | 1 | -1 | 8.7 | 7.1 | 7.3 |
| 20/03/ 6:45 | 3959 | 3451 | 1875 | 2640 | 5937 | 9348 | 18 | 25 | -1 | -1 | -1 | 8.6 | 7.1 | 7.3 |
| 20/03/ 7: 0 | 3964 | 3454 | 1867 | 2640 | 6131 | 9423 | 18 | 25 | -1 | -1 | 0 | 8.5 | 7.1 | 7.2 |
| 20/03/ 7:15 | 3767 | 3455 | 1863 | 2640 | 5987 | 9108 | 17 | 25 | -1 | -1 | -1 | 8.5 | 7.1 | 7.2 |
| 20/03/ 7:30 | 3944 | 3457 | 1833 | 2640 | 5969 | 9138 | 17 | 25 | -1 | 0 | -1 | 8.5 | 7.1 | 7.2 |
| 20/03/ 7:45 | 3945 | 3461 | 1820 | 2640 | 5566 | 9164 | 16 | 25 | -1 | -1 | -1 | 8.5 | 7.1 | 7.2 |
| 20/03/ 8: 0 | 3924 | 3458 | 1808 | 2640 | 5654 | 9253 | 16 | 24 | -1 | -1 | 0 | 8.5 | 7.1 | 7.2 |

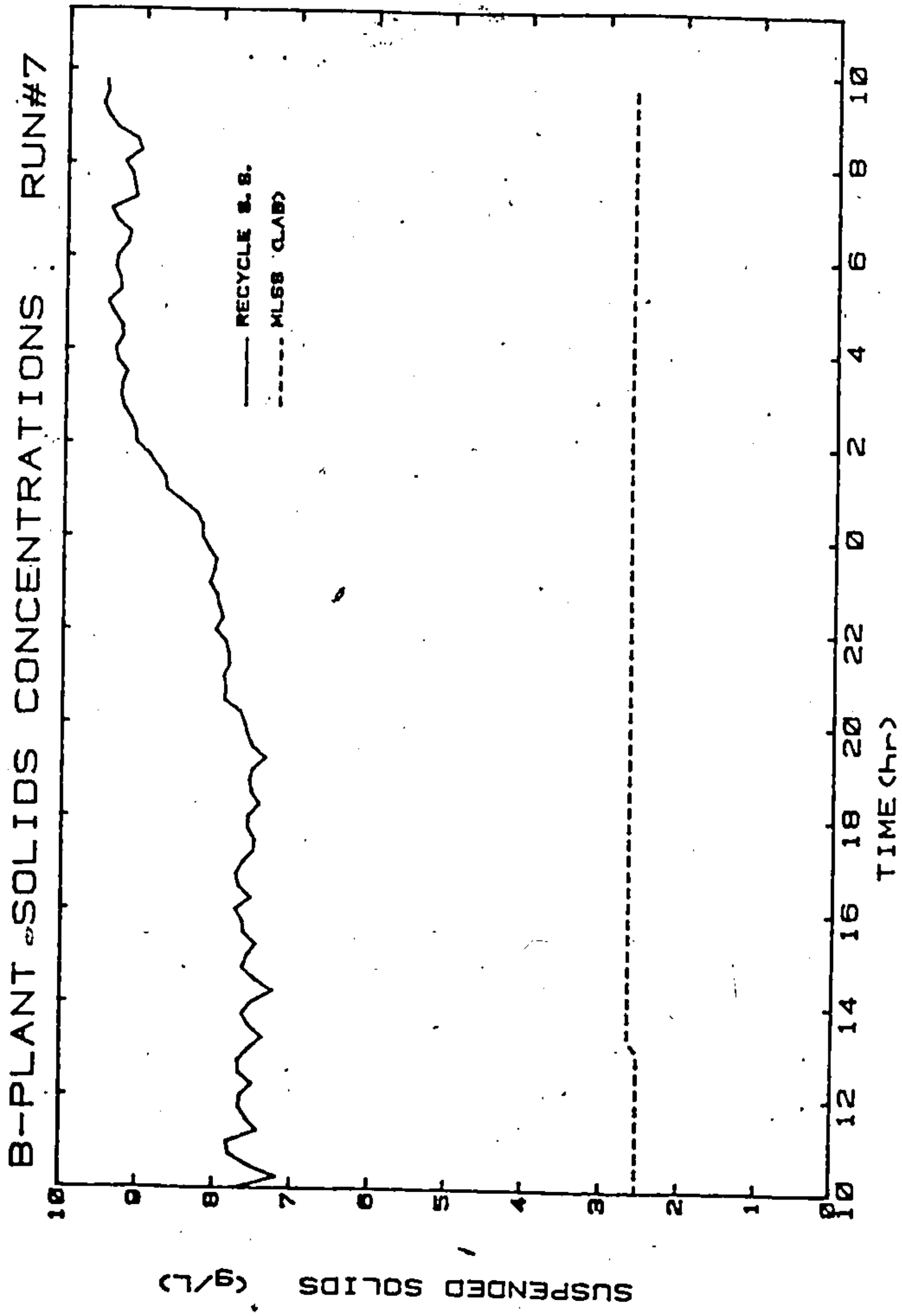
| | MIXED LIQUOR SUSP SOLIDS | | | | RETURN SLUDGE | | EFF SS | | INF SS | EFF FOC | | INF PH | PH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | B | A | B | A | B | BOTH | A | B | | A | B |
| | FRONT | MIDDLE | REAR | | | | | | | | | | | |
| | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | | | |
| 20/03/ 8:15 | 3934 | 3465 | 1802 | 2640 | 5233 | 9056 | 15 | 24 | -1 | -1 | -1 | 8.5 | 7.1 | 7.2 |
| 20/03/ 8:30 | 3945 | 3460 | 1805 | 2640 | 5498 | 9107 | 15 | 24 | -1 | 1 | -1 | 8.4 | 7.1 | 7.2 |
| 20/03/ 8:45 | 3972 | 3459 | 1806 | 2640 | 5724 | 9351 | 15 | 24 | -1 | -1 | -1 | 8.3 | 7.1 | 7.2 |
| 20/03/ 9: 0 | 3993 | 3466 | 1805 | 2640 | 5764 | 9471 | 16 | 24 | -1 | -1 | 22 | 8.3 | 7.1 | 7.2 |
| 20/03/ 9:15 | 4045 | 3474 | 1791 | 2640 | 5782 | 9542 | 16 | 24 | -1 | -1 | -1 | 8.2 | 7.1 | 7.2 |
| 20/03/ 9:30 | 4049 | 3476 | 1750 | 2640 | 5561 | 9481 | 16 | 24 | -1 | 20 | -1 | 8.2 | 7.1 | 7.2 |
| 20/03/ 9:45 | 4070 | 3483 | 1700 | 2640 | 4826 | 9509 | 16 | 24 | -1 | -1 | -1 | 8.2 | 7.1 | 7.2 |
| 20/03/10: 0 | 4083 | 3494 | 1684 | 2640 | 5082 | 10105 | 17 | 24 | -1 | -1 | 22 | 8.2 | 7.1 | 7.2 |

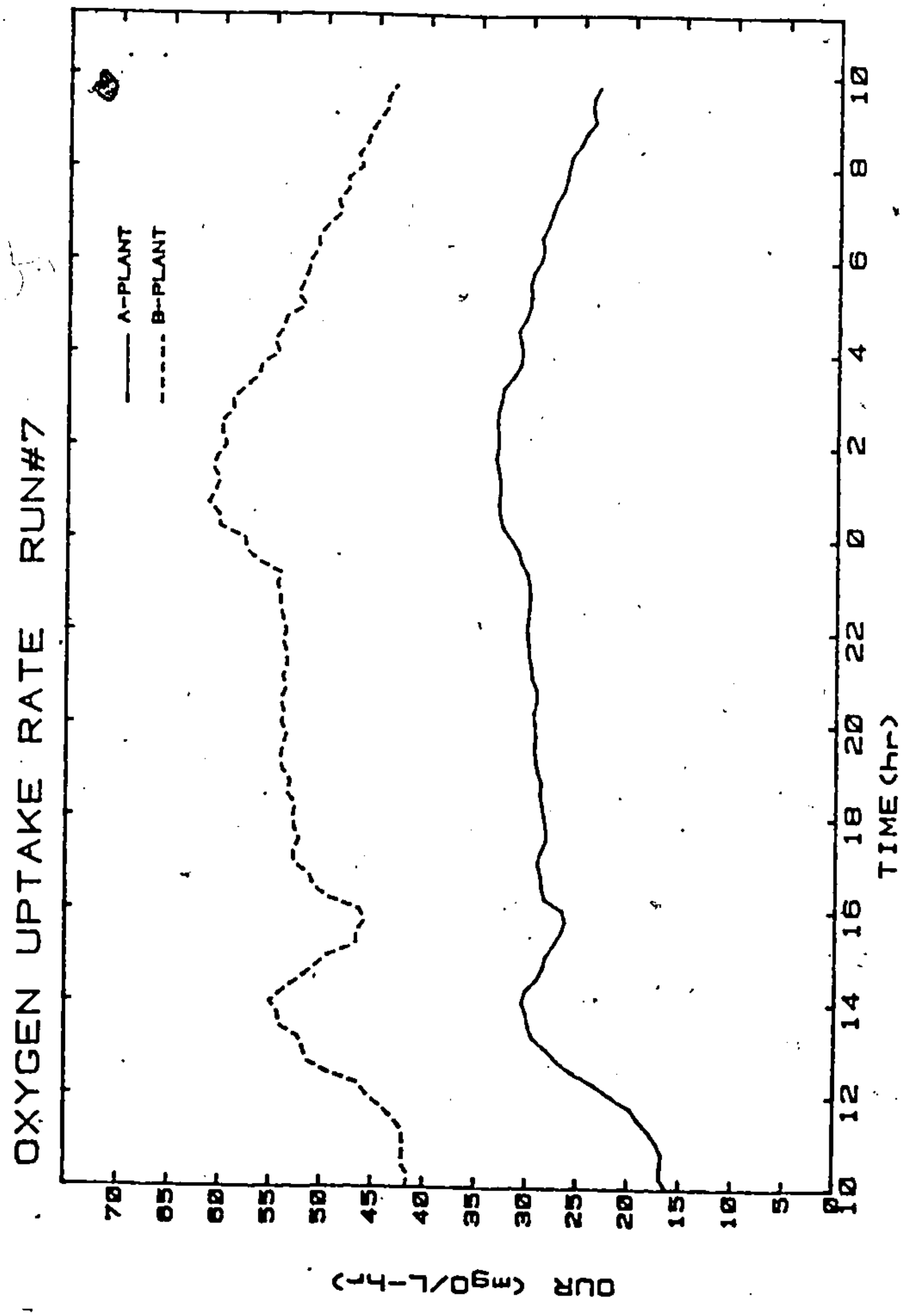
## E.3 On-Line Graphical Results

Graphical plots of on-line data listed in section E.2 are given for MLSS, OUR, D.O., pH, temperature and flow.

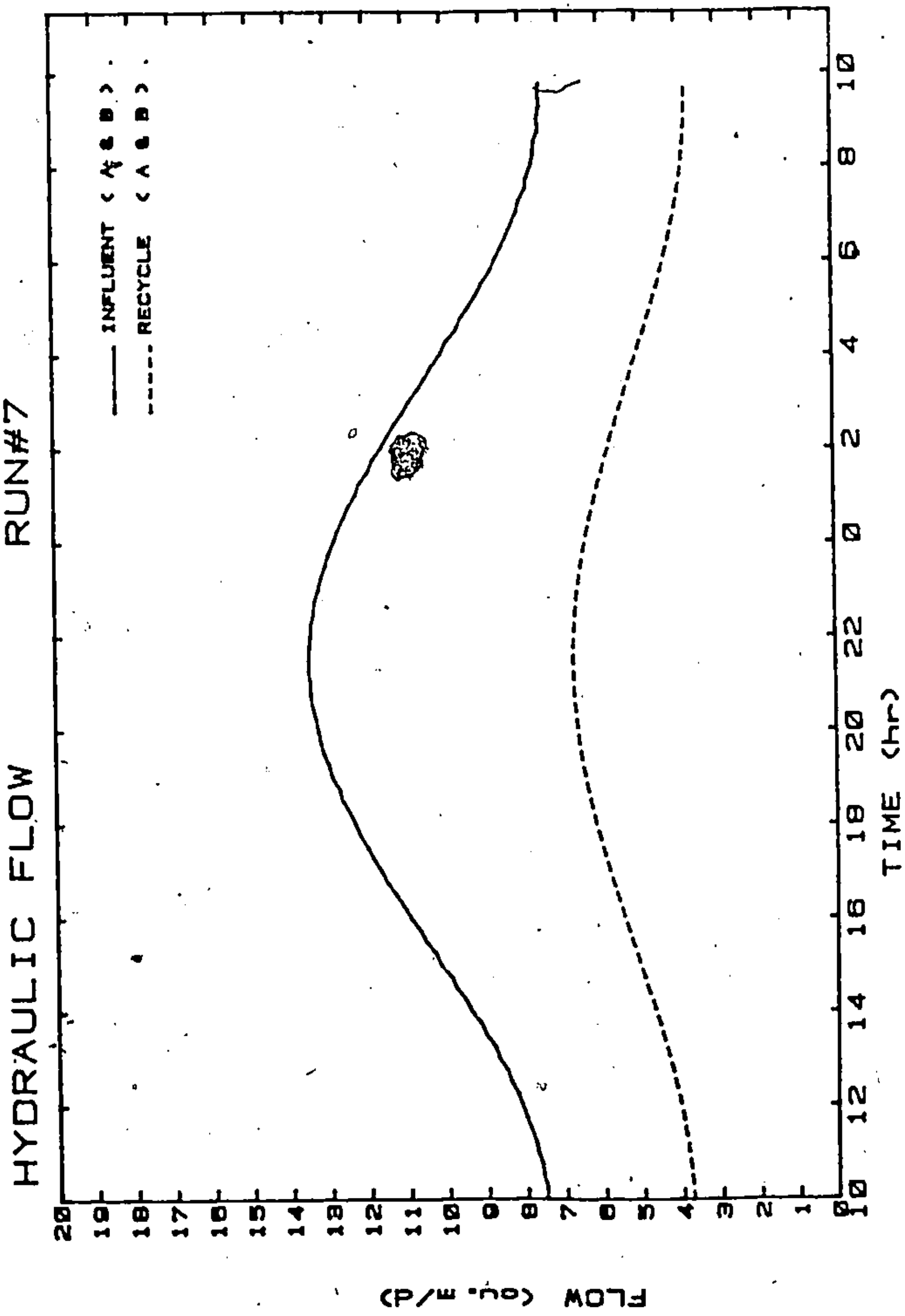


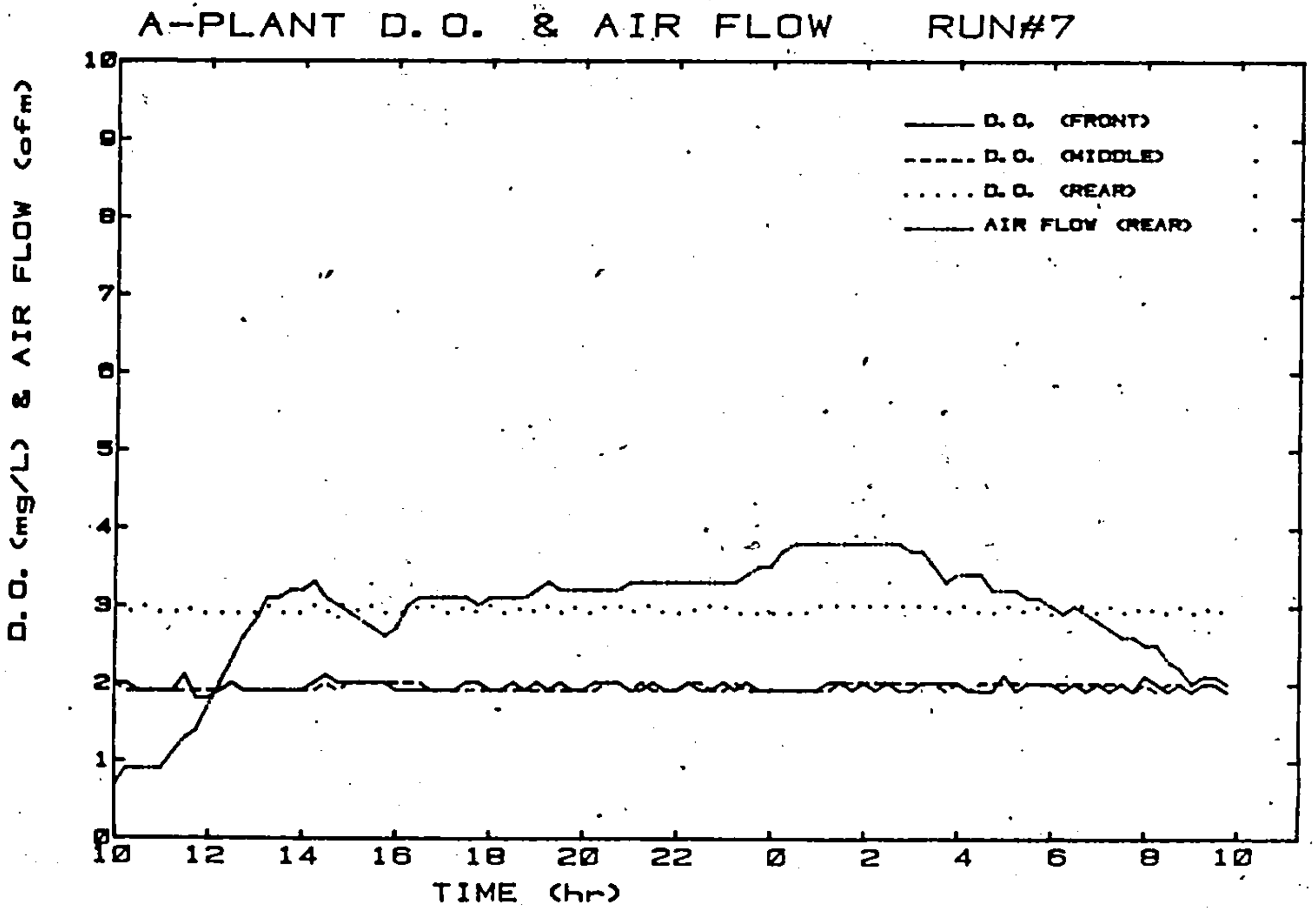
A-PLANT SOLIDS CONCENTRATIONS RUN#7


B-PLANT SOLIDS CONCENTRATIONS RUN#7
RECYCLE S.S.
MLSS (LAB)
SUSPENDED SOLIDS (g/L)
10
9
8
7
6
5
4
3
2
1
0
TIME (hr)
10
12
14
16
18
20
22
0
2
4
6
8
10

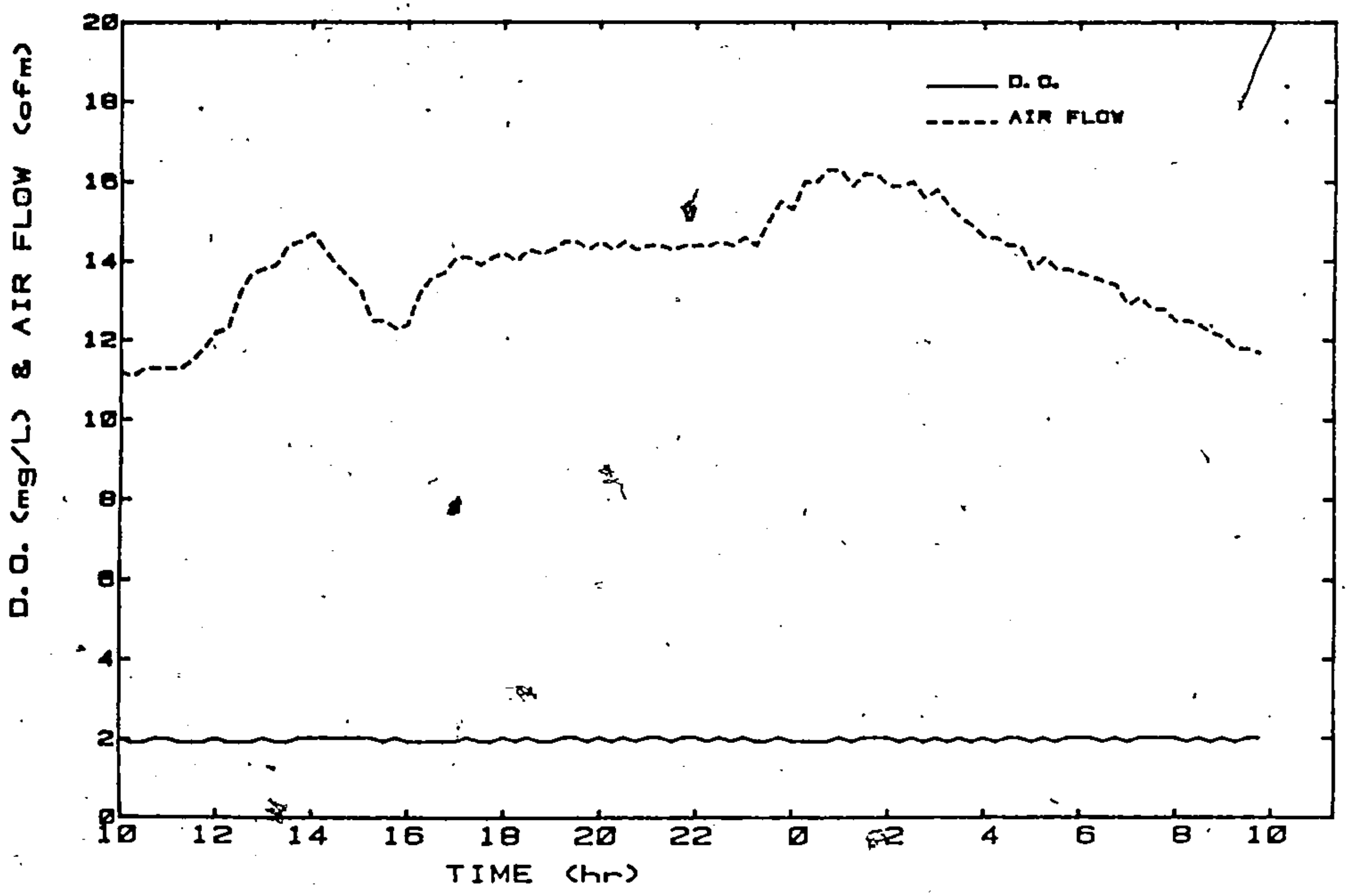


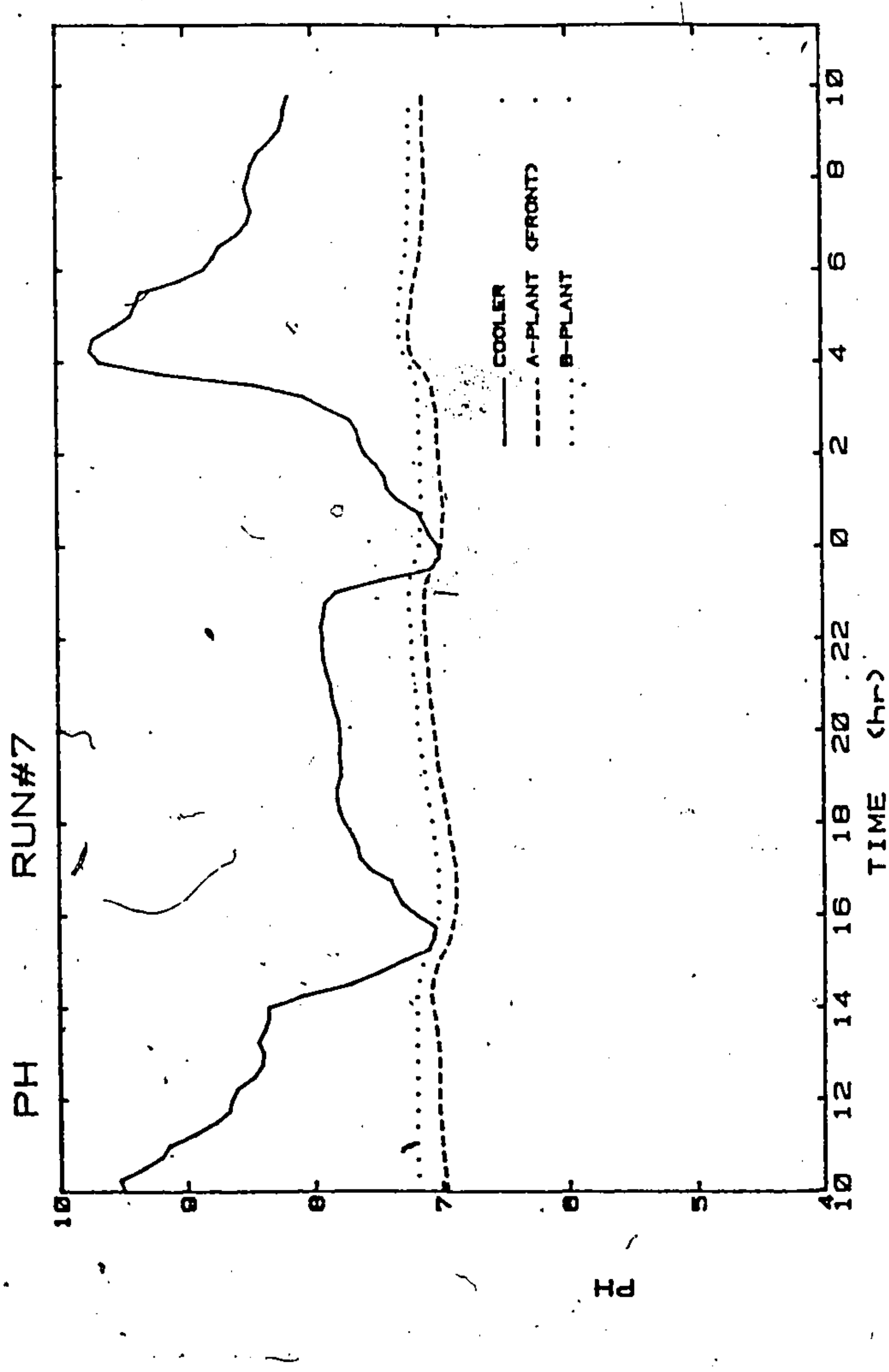
OXYGEN UPTAKE RATE RUN#7

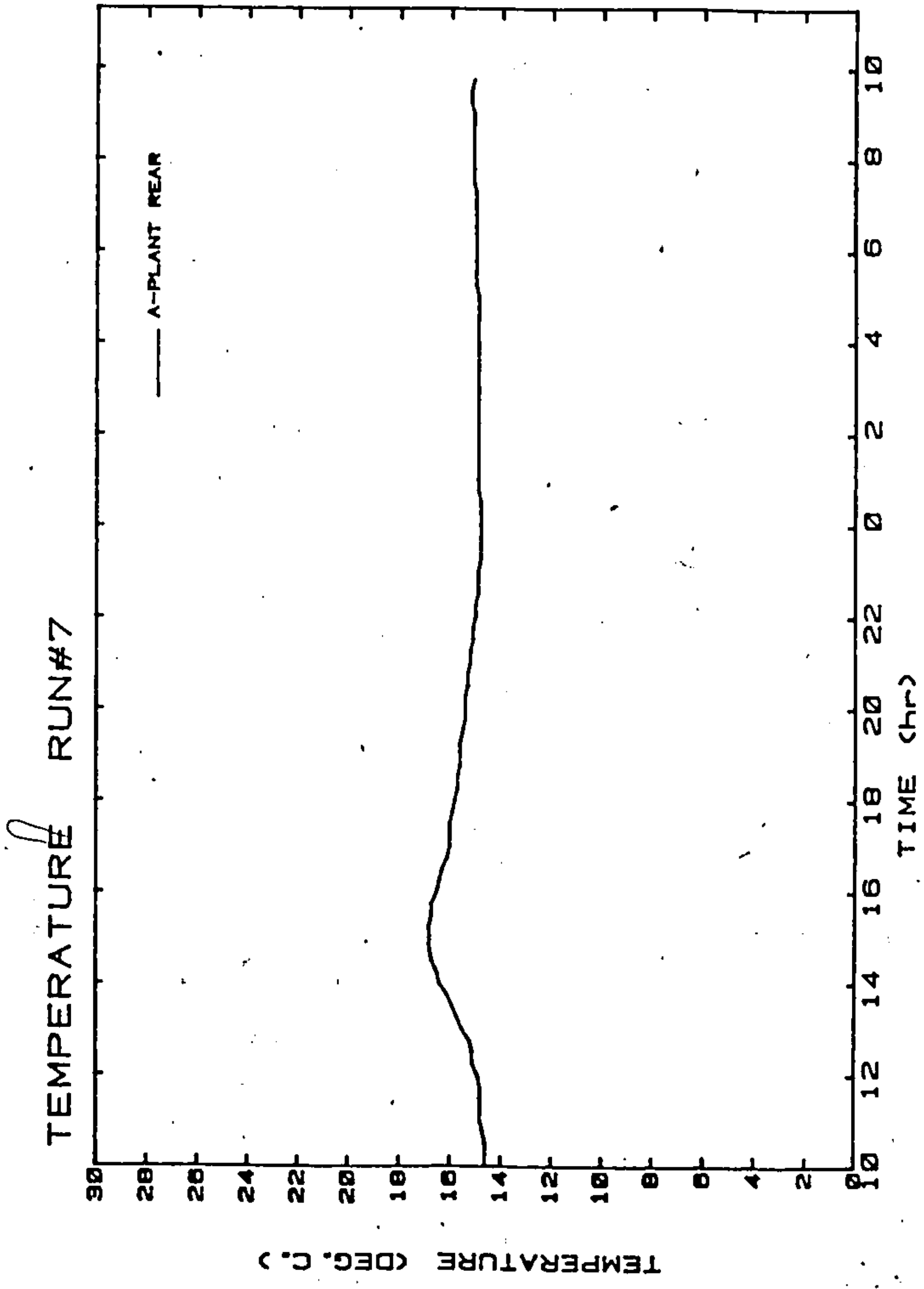

HYDRAULIC FLOW RUN#7
INFLUENT ( A & B ) .
RECYCLE ( A & B ) .
FLOW (cu. m/d)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
TIME (hr)
10
12
14
16
18
20
22
0
2
4
6
8
10


A-PLANT D. O. & AIR FLOW RUN#7
D. O. (FRONT)
D. O. (MIDDLE)
D. O. (REAR)
AIR FLOW (REAR)
D. O. (mg/L) & AIR FLOW (cfm)
0
1
2
3
4
5
6
7
8
9
10
TIME (hr)
10
12
14
16
18
20
22
0
2
4
6
8
10

B-PLANT D.O. & AIR FLOW RUN#7




PH RUN#7
10
9
8
7
6
5
4
PH
10
12
14
16
18
20
22
0
2
4
6
8
10
TIME (hr)
COOLER
A-PLANT (FRONT)
B-PLANT


TEMPERATURE RUN#7

## E.4 Off-Line Sampling Data

Off-line laboratory sampling results are given for both the A and B systems for the period during experiment run #7. Composite 24 hr samples were analysed for the following parameters:

IBOD5U - Influent $BOD_5$ unfiltered (mg/L)
ICODU - Influent COD unfiltered (mg/L)
ITKNU - Influent TCN unfiltered (mg/L)
ITPU - Influent phosphorus unfiltered (mg/L)
IBOD5F - Influent $BOD_5$ filtered (mg/L) -
ICODF - Influent COD filtered (mg/L)
ITKNF - Influent TKN filtered (mg/L)
ITPF - Influent phosphorus filtered (mg/L)
EBOD5U - Effluent $BOD_5$ unfiltered (mg/L)
ECOD - Effluent COD unfiltered (mg/L)
ETKNU - Effluent TKN unfiltered (mg/L)
ETPU - Effluent phosphorus unfiltered (mg/L)
EBOD5F - Effluent $BOD_5$ filtered (mg/L)
ECODF - Effluent COD filtered (mg/L)
ETKNF - Effluent TKN filtered (mg/L)
SVI - Sludge volume index
SRT - Sludge retention time (days)
WASTE VOL - Waste sludge volume (L)
WASTE CONC - Waste sludge TSS (mg/L)
MLSS - Mixed liquor TSS (mg/L)
EFF-SS - Effluent TSS (mg/L)
INF-SS - Influent TSS (mg/L)

-1 or -0.0 indicate that no samples were taken during this period

Three-hour composites were sampled for:

INH3N - Influent ammonia (mg/L)

INO3+2 - Influent $NO_3^{+2}$ (mg/L)

ENH3N - Effluent ammonia (mg/L)

ENO3+2 - Effluent $NO_3^{+2}$

EFF-SS - Effluent TSS

INF-SS - Influent TSS

Hourly samples of influent and effluent total organic carbon were were taken.

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 251

    TIME STAMP = 20/03  9: 0

    DAY     :      79
    MIN     :     540
    IBODSU  mg/l :     225    EBODSU  mg/l :      12    SVI                       :    110
    ICOD U  mg/l :     567    ECOD U  mg/l :     101    SRT   MANUAL  (days)      :   3.31
    ITKN U  mg/l :   34.50    ETKN U  mg/l :   11.30    WASTE VOL. MAN (liters)   :    173
    ITP  U  mg/l :    5.20    ETP  U  mg/l :    1.10    WASTE CONC.MAN     mg/l   :  10100
    IBOD5F  mg/l :      69    EBOD5F  mg/l :       6    BLANKET HEIGHT   meters   :   -.00
    ICOD F  mg/l :     215    ECOD F  mg/l :      52    OUR  mg DO g mlvss hr     :   -.01
    ITKN F  mg/l :   27.10    ETKN F  mg/l :   11.30    MLSS               mg/l   :   2880
    INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS             mg/l   :     -1
    INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS             mg/l   :     17
    ITP F   mg/l :    2.40    ETP F   mg/l :    1.10    INF SS             mg/l   :    218
    ITOC    mg/L:   -1.00     ETOC    mg/L:   -1.00
    IALK        :   -1.00     EALK        :   -1.00

    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 251

    TIME STAMP = 20/03  9: 0

    DAY     :      79
    MIN     :     540
    IBODSU  mg/l :     225    EBODSU  mg/l :      13    SVI                       :    165
    ICOD U  mg/l :     567    ECOD U  mg/l :      98    SRT   MANUAL  (days)      :   2.59
    ITKN U  mg/l :   34.50    ETKN U  mg/l :   12.30    WASTE VOL. MAN (liters)   :    266
    ITP  U  mg/l :    5.20    ETP  U  mg/l :    1.60    WASTE CONC.MAN     mg/l   :   6580
    IBOD5F  mg/l :      69    EBOD5F  mg/l :       5    BLANKET HEIGHT   meters   :   -.00
    ICOD F  mg/l :     215    ECOD F  mg/l :      70    OUR  mg DO g mlvss hr     :   -.00
    ITKN F  mg/l :   27.10    ETKN F  mg/l :   10.40    MLSS               mg/l   :   2536
    INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS             mg/l   :     -1
    INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS             mg/l   :     41
    ITP F   mg/l :    2.40    ETP F   mg/l :    1.20    INF SS             mg/l   :    218
    ITOC    mg/L:   -1.00     ETOC    mg/L:   -1.00
    IALK        :   -1.00     EALK        :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 288

TIME STAMP = 19/03 10: 0

DAY     :       78
MIN     :      600
IBOD5U  mg/l :       -1     EBOD5U  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN      mg/l     :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    14.00     ENH3 N  mg/l :     2.80     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .10     ENO3+2  mg/l :     6.80     EFF SS               mg/l    :     10
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :    154
ITOC    mg/L:     39.00     ETOC    mg/L:    16.00
IALK         :    -1.00     EALK         :   -1.00

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 288

TIME STAMP = 19/03 10: 0

DAY     :       78
MIN     :      600
IBOD5U  mg/l :       -1     EBOD5U  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN      mg/l     :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    14.00     ENH3 N  mg/l :     4.50     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .10     ENO3+2  mg/l :     5.80     EFF SS               mg/l    :     14
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :    154
ITOC    mg/L:     39.00     ETOC    mg/L:    13.00
IALK         :    -1.00     EALK         :   -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 297

TIME STAMP = 19/03 11: 0

DAY     :      78
MIN     :     660
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                        :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters    :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO @ mlvss hr      :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS               mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS             mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS             mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS             mg/l    :     -1
ITOC    mg/L:   48.00     ETOC     mg/L:   16.00
IALK         :  -1.00     EALK          :  -1.00

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 297

TIME STAMP = 19/03 11: 0

DAY     :      78
MIN     :     660
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                        :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters    :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO @ mlvss hr      :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS               mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS             mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS             mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS             mg/l    :     -1
ITOC    mg/L:   48.00     ETOC     mg/L:   21.00
IALK         :  -1.00     EALK          :  -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 298

TIME STAMP = 19/03 12: 0

DAY     :      78
MIN     :     720
IBODSU  mg/l :      -1     EBODSU  mg/l :      -1     SVI                        :     -
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.0
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l   :     -
IBODSF  mg/l :      -1     EBODSF  mg/l :      -1     BLANKET HEIGHT    meters   :   -.0
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr      :   -.0
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l :     -
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS              mg/l   :     -
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS              mg/l   :     -
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l   :     -
ITOC    mg/L:  61.00     ETOC    mg/L:   21.00
IALK        :  -1.00     EALK        :   -1.00

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        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 298

TIME STAMP = 19/03 12: 0

DAY     :      78
MIN     :     720
IBODSU  mg/l :      -1     EBODSU  mg/l :      -1     SVI                        :     -
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.0
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l   :     -
IBODSF  mg/l :      -1     EBODSF  mg/l :      -1     BLANKET HEIGHT    meters   :   -.0
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr      :   -.0
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l :     -
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS              mg/l   :     -
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS              mg/l   :     -
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l   :     -
ITOC    mg/L:  61.00     ETOC    mg/L:   19.00
IALK        :  -1.00     EALK        :   -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 289

TIME STAMP = 19/03 13: 0

DAY     :      78
MIN     :     780
IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    16.50     ENH3 N  mg/l :    3.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .30     ENO3+2  mg/l :    8.30     EFF SS               mg/l    :      8
ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :    292
ITOC    mg/L:   64.00      ETOC    mg/L:   20.00
IALK        :   -1.00      EALK        :   -1.00

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```

```
     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 289

TIME STAMP = 19/03 13: 0

DAY  .  :      78
MIN     :     780
IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    16.50     ENH3 N  mg/l :    7.30     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .30     ENO3+2  mg/l :    5.30     EFF SS               mg/l    :     22
ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :    292
ITOC    mg/L:   64.00      ETOC    mg/L:   14.00
IALK        :   -1.00      EALK        :   -1.00
```

```
      DATA FROM  B  PLANT

      OFFLINE DATA RECORD # 299

TIME STAMP = 19/03 14: 0

DAY     :      78
MIN     :     840
IBOD5U  mg/l :      -1    EBOD5U  mg/l :      -1    SVI                          :     -1
ICOD U  mg/l :      -1    ECOD U  mg/l :      -1    SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00    ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00    ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l     :     -1
IBOD5F  mg/l :      -1    EBOD5F  mg/l :      -1    BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1    ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00    ETKN F  mg/l :    -.00    MLSS                mg/l     :     -1
INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS              mg/l     :     -1
INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS              mg/l     :     -1
ITP F   mg/l :    -.00    ETP F   mg/l :    -.00    INF SS              mg/l     :     -1
ITOC    mg/L:   46.00     ETOC    mg/L:   24.00
IALK        :   -1.00     EALK        :   -1.00

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      DATA FROM  A  PLANT

      OFFLINE DATA RECORD # 299

TIME STAMP = 19/03 14: 0

DAY     :      78
MIN     :     840
IBOD5U  mg/l :      -1    EBOD5U  mg/l :      -1    SVI                          :     -1
ICOD U  mg/l :      -1    ECOD U  mg/l :      -1    SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00    ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00    ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l     :     -1
IBOD5F  mg/l :      -1    EBOD5F  mg/l :      -1    BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1    ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00    ETKN F  mg/l :    -.00    MLSS                mg/l     :     -1
INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS              mg/l     :     -1
INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS              mg/l     :     -1
ITP F   mg/l :    -.00    ETP F   mg/l :    -.00    INF SS              mg/l     :     -1
ITOC    mg/L:   46.00     ETOC    mg/L:   14.00
IALK        :   -1.00     EALK        :   -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 300

TIME STAMP = 19/03 15: 0

DAY    :      78
MIN    :     900
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
ITOC    mg/L:   31.00     ETOC    mg/L:   19.00
IALK        :   -1.00     EALK         :  -1.00

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     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 300

TIME STAMP = 19/03 15: 0

DAY    :      78
MIN    :     900
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :   -1.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
ITOC    mg/L:   31.00     ETOC    mg/L:   13.00
IALK        :   -1.00     EALK         :  -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 290

    TIME STAMP = 19/03 16: 0

    DAY     :      78
    MIN     :     960
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :     -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l     :     -1
    INH3 N  mg/l :   13.00     ENH3 N  mg/l :    4.10     RAS SS              mg/l     :     -1
    INO3+2  mg/l :     .20     ENO3+2  mg/l :    8.60     EFF SS              mg/l     :     14
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l     :    268
    ITOC     mg/L:   50.00    ETOC     mg/L:   15.00
    IALK        :   -1.00     EALK         :   -1.00

    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 290

    TIME STAMP = 19/03 16: 0

    DAY     :      78
    MIN     :     960
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :     -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l     :     -1
    INH3 N  mg/l :   13.00     ENH3 N  mg/l :    4.10     RAS SS              mg/l     :     -1
    INO3+2  mg/l :     .20     ENO3+2  mg/l :    7.50     EFF SS              mg/l     :     24
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l     :    263
    ITOC     mg/L:   50.00    ETOC     mg/L:   13.00
    IALK        :   -1.00     EALK         :   -1.00
```

```
    DATA FROM  B  PLANT

    OFFLINE DATA RECORD # 301

TIME STAMP = 19/03 17: 0

DAY     :      78
MIN     :    1020
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1    SVI                         :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1    SRT   MANUAL  (days)        :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)     :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1    BLANKET HEIGHT   meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr       :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00    MLSS                  mg/l  :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00    RAS SS               mg/l   :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00    EFF SS               mg/l   :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00    INF SS               mg/l   :     -1
ITOC     mg/L:   67.00    ETOC     mg/L:   13.00
IALK         :   -1.00    EALK         :   -1.00

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


    DATA FROM  A  PLANT

    OFFLINE DATA RECORD # 301

TIME STAMP = 19/03 17: 0

DAY     :      78
MIN     :    1020
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1    SVI                         :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1    SRT   MANUAL  (days)        :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)     :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1    BLANKET HEIGHT   meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr       :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00    MLSS                  mg/l  :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00    RAS SS               mg/l   :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00    EFF SS               mg/l   :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00    INF SS               mg/l   :     -1
ITOC     mg/L:   67.00    ETOC     mg/L:   13.00
IALK         :   -1.00    EALK         :   -1.00
```

```
      DATA FROM  B  PLANT

      OFFLINE DATA RECORD # 302

 TIME STAMP = 19/03 18: 0

 DAY     :       78
 MIN     :     1080
 IBODSU  mg/l :       -1     EBODSU  mg/l :       -1     SVI                          :      -1
 ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :    -.00
 ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :      -1
 ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN        mg/l   :      -1
 IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT   meters      :    -.00
 ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :    -.00
 ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                mg/l     :      -1
 INH3 N  mg/l :     -.00     ENH3 N  mg/l :     -.00     RAS SS              mg/l     :      -1
 INO3+2  mg/l :     -.00     ENO3+2  mg/l :     -.00     EFF SS              mg/l     :      -1
 ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS              mg/l     :      -1
 ITOC    mg/L:   78.00      ETOC    mg/L:   16.00
 IALK        :   -1.00      EALK        :   -1.00

 :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


      DATA FROM  A  PLANT

      OFFLINE DATA RECORD # 302

 TIME STAMP = 19/03 18: 0

 DAY     :       78
 MIN     :     1080
 IBODSU  mg/l :       -1     EBODSU  mg/l :       -1     SVI                          :      -1
 ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :    -.00
 ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :      -1
 ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN        mg/l   :      -1
 IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT   meters      :    -.00
 ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :    -.00
 ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                mg/l     :      -1
 INH3 N  mg/l :     -.00     ENH3 N  mg/l :     -.00     RAS SS              mg/l     :      -1
 INO3+2  mg/l :     -.00     ENO3+2  mg/l :     -.00     EFF SS              mg/l     :      -1
 ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS              mg/l     :      -1
 ITOC    mg/L:   78.00      ETOC    mg/L:   14.00
 IALK        :   -1.00      EALK        :   -1.00
```

```
          DATA FROM  B  PLANT

          OFFLINE DATA RECORD # 291

      TIME STAMP = 19/03 19: 0

      DAY     :       78
      MIN     :     1140
      IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                              :     -1
      ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)             :   -.00
      ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)          :     -1
      ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l          :     -1
      IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters          :   -.00
      ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr            :   -.00
      ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                     mg/l    :     -1
      INH3 N  mg/l :    15.00     ENH3 N  mg/l :    5.00     RAS SS                   mg/l    :     -1
      INO3+2  mg/l :      .00     ENO3+2  mg/l :    7.50     EFF SS                   mg/l    :     12
      ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS                   mg/l    :    224
      ITOC     mg/L:   90.00     ETOC     mg/L:   16.00
      IALK         :   -1.00     EALK         :   -1.00

      ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


          DATA FROM  A  PLANT

          OFFLINE DATA RECORD # 291

      TIME STAMP = 19/03 19: 0

      DAY     :       78
      MIN     :     1140
      IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                              :     -1
      ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)             :   -.00
      ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)          :     -1
      ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l          :     -1
      IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters          :   -.00
      ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr            :   -.00
      ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                     mg/l    :     -1
      INH3 N  mg/l :    15.00     ENH3 N  mg/l :    4.80     RAS SS                   mg/l    :     -1
      INO3+2  mg/l :      .00     ENO3+2  mg/l :    7.70     EFF SS                   mg/l    :     26
      ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS                   mg/l    :    224
      ITOC     mg/L:   90.00     ETOC     mg/L:   15.00
      IALK         :   -1.00     EALK         :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 303

    TIME STAMP = 19/03 20: 0

    DAY     :      78
    MIN     :    1200
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :      -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :    -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :      -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :      -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :    -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :    -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l :      -1
    INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS              mg/l  :      -1
    INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS              mg/l  :      -1
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l  :      -1
    ITOC    mg/L:   54.00     ETOC    mg/L:    19.00
    IALK          :  -1.00     EALK          :  -1.00

    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 303

    TIME STAMP = 19/03 20: 0

    DAY     :      78
    MIN     :    1200
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :      -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :    -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :      -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :      -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :    -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :    -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l :      -1
    INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS              mg/l  :      -1
    INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS              mg/l  :      -1
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l  :      -1
    ITOC    mg/L:   54.00     ETOC    mg/L:    19.00
    IALK          :  -1.00     EALK          :  -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 304

TIME STAMP = 19/03 21: 0

DAY     :     78
MIN     :   1260
IBODSU  mg/l :       -1     EBODSU  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN       mg/l    :     -1
IBODSF  mg/l :       -1     EBODSF  mg/l :       -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO @ mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :     -.00     ENH3 N  mg/l :     -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :     -.00     ENO3+2  mg/l :     -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :     -1
ITOC    mg/L:    40.00     ETOC    mg/L:    22.00
IALK         :   -1.00     EALK         :   -1.00

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     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 304

TIME STAMP = 19/03 21: 0

DAY     :     78
MIN     :   1260
IBODSU  mg/l :       -1     EBODSU  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN       mg/l    :     -1
IBODSF  mg/l :       -1     EBODSF  mg/l :       -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO @ mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :     -.00     ENH3 N  mg/l :     -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :     -.00     ENO3+2  mg/l :     -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :     -1
ITOC    mg/L:    40.00     ETOC    mg/L:    26.00
IALK         :   -1.00     EALK         :   -1.00
```

```
DATA FROM  B  PLANT

OFFLINE DATA RECORD # 292

TIME STAMP = 19/03 22: 0

DAY      :      78
MIN      :    1320
IBOD5U  mg/l :       -1      EBOD5U  mg/l :      -1      SVI                              :      -1
ICOD U  mg/l :       -1      ECOD U  mg/l :      -1      SRT   MANUAL  (days)             :    -.00
ITKN U  mg/l :     -.00      ETKN U  mg/l :    -.00      WASTE VOL. MAN (liters)          :      -1
ITP  U  mg/l :     -.00      ETP  U  mg/l :    -.00      WASTE CONC.MAN        mg/l       :      -1
IBOD5F  mg/l :       -1      EBOD5F  mg/l :      -1      BLANKET HEIGHT   meters          :    -.00
ICOD F  mg/l :       -1      ECOD F  mg/l :      -1      OUR  mg DO g mlvss hr            :    -.00
ITKN F  mg/l :     -.00      ETKN F  mg/l :    -.00      MLSS                      mg/l   :      -1
INH3 N  mg/l :    13.50      ENH3 N  mg/l :    7.30      RAS SS                   mg/l    :      -1
INO3+2  mg/l :      .00      ENO3+2  mg/l :    5.20      EFF SS                   mg/l    :      10
ITP F   mg/l :     -.00      ETP F   mg/l :    -.00      INF SS                   mg/l    :     192
ITOC     mg/L:    58.00      ETOC     mg/L:   24.00
IALK         :    -1.00      EALK         :   -1.00

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```

```
DATA FROM  A  PLANT

OFFLINE DATA RECORD # 292

TIME STAMP = 19/03 22: 0

DAY      :      78
MIN      :    1320
IBOD5U  mg/l :       -1      EBOD5U  mg/l :      -1      SVI                              :      -1
ICOD U  mg/l :       -1      ECOD U  mg/l :      -1      SRT   MANUAL  (days)             :    -.00
ITKN U  mg/l :     -.00      ETKN U  mg/l :    -.00      WASTE VOL. MAN (liters)          :      -1
ITP  U  mg/l :     -.00      ETP  U  mg/l :    -.00      WASTE CONC.MAN        mg/l       :      -1
IBOD5F  mg/l :       -1      EBOD5F  mg/l :      -1      BLANKET HEIGHT   meters          :    -.00
ICOD F  mg/l :       -1      ECOD F  mg/l :      -1      OUR  mg DO g mlvss hr            :    -.00
ITKN F  mg/l :     -.00      ETKN F  mg/l :    -.00      MLSS                      mg/l   :      -1
INH3 N  mg/l :    13.50      ENH3 N  mg/l :    6.60      RAS SS                   mg/l    :      -1
INO3+2  mg/l :      .00      ENO3+2  mg/l :    7.00      EFF SS                   mg/l    :      30
ITP F   mg/l :     -.00      ETP F   mg/l :    -.00      INF SS                   mg/l    :     192
ITOC     mg/L:    58.00      ETOC     mg/L:   21.00
IALK         :    -1.00      EALK         :   -1.00
```

```
DATA FROM  B  PLANT

OFFLINE DATA RECORD # 305

TIME STAMP = 19/03 23: 0

DAY    :      78
MIN    :    1380
IBODSU  mg/l :       -1     EBODSU  mg/l :      -1     SVI                           :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)          :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)       :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l       :     -1
IBODSF  mg/l :       -1     EBODSF  mg/l :      -1     BLANKET HEIGHT   meters       :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr         :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l     :     -1
INH3 N  mg/l :     -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l     :     -1
INO3+2  mg/l :     -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l     :     -1
ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l     :     -1
ITOC     mg/L:    88.00    ETOC     mg/L:   27.00
IALK         :    -1.00    EALK         :   -1.00

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DATA FROM  A  PLANT

OFFLINE DATA RECORD # 305

TIME STAMP = 19/03 23: 0

DAY    :      78
MIN    :    1380
IBODSU  mg/l :       -1     EBODSU  mg/l :      -1     SVI                           :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)          :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)       :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN     mg/l       :     -1
IBODSF  mg/l :       -1     EBODSF  mg/l :      -1     BLANKET HEIGHT   meters       :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr         :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l     :     -1
INH3 N  mg/l :     -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l     :     -1
INO3+2  mg/l :     -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l     :     -1
ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l     :     -1
ITOC     mg/L:    88.00    ETOC     mg/L:   20.00
IALK         :    -1.00    EALK         :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 306

     TIME STAMP = 20/03  0: 0

     DAY    :      79
     MIN    :       0
     IBOD5U  mg/l :      -1      EBOD5U  mg/l :      -1     SVI                          :      -1
     ICOD U  mg/l :      -1      ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :    -.00
     ITKN U  mg/l :    -.00      ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :      -1
     ITP  U  mg/l :    -.00      ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :      -1
     IBOD5F  mg/l :      -1      EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :    -.00
     ICOD F  mg/l :      -1      ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :    -.00
     ITKN F  mg/l :    -.00      ETKN F  mg/l :    -.00     MLSS                mg/l     :      -1
     INH3 N  mg/l :    -.00      ENH3 N  mg/l :    -.00     RAS SS              mg/l     :      -1
     INO3+2  mg/l :    -.00      ENO3+2  mg/l :    -.00     EFF SS              mg/l     :      -1
     ITP F   mg/l :    -.00      ETP F   mg/l :    -.00     INF SS              mg/l     :      -1
     ITOC    mg/L:   85.00       ETOC    mg/L:   18.00
     IALK        :   -1.00       EALK        :   -1.00

     ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 306

     TIME STAMP = 20/03  0: 0

     DAY    :      79
     MIN    :       0
     IBOD5U  mg/l :      -1      EBOD5U  mg/l :      -1     SVI                          :      -1
     ICOD U  mg/l :      -1      ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :    -.00
     ITKN U  mg/l :    -.00      ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :      -1
     ITP  U  mg/l :    -.00      ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l     :      -1
     IBOD5F  mg/l :      -1      EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :    -.00
     ICOD F  mg/l :      -1      ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :    -.00
     ITKN F  mg/l :    -.00      ETKN F  mg/l :    -.00     MLSS                mg/l     :      -1
     INH3 N  mg/l :    -.00      ENH3 N  mg/l :    -.00     RAS SS              mg/l     :      -1
     INO3+2  mg/l :    -.00      ENO3+2  mg/l :    -.00     EFF SS              mg/l     :      -1
     ITP F   mg/l :    -.00      ETP F   mg/l :    -.00     INF SS              mg/l     :      -1
     ITOC    mg/L:   85.00       ETOC    mg/L:   19.00
     IALK        :   -1.00       EALK        :   -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 293

TIME STAMP = 20/03  1: 0

DAY     :      79
MIN     :      60
IBOD5U  mg/l :       -1     EBOD5U  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    11.70     ENH3 N  mg/l :     7.10     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .00     ENO3+2  mg/l :     4.10     EFF SS               mg/l    :     10
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :    198
ITOC    mg/L:    81.00     ETOC    mg/L:   23.00
IALK        :    -1.00     EALK        :   -1.00

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 293

TIME STAMP = 20/03  1: 0

DAY     :      79
MIN     :      60
IBOD5U  mg/l :       -1     EBOD5U  mg/l :       -1     SVI                          :     -1
ICOD U  mg/l :       -1     ECOD U  mg/l :       -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :     -.00     ETKN U  mg/l :     -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :     -.00     ETP  U  mg/l :     -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :       -1     EBOD5F  mg/l :       -1     BLANKET HEIGHT    meters     :   -.00
ICOD F  mg/l :       -1     ECOD F  mg/l :       -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :     -.00     ETKN F  mg/l :     -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    11.70     ENH3 N  mg/l :     6.10     RAS SS               mg/l    :     -1
INO3+2  mg/l :      .00     ENO3+2  mg/l :     6.80     EFF SS               mg/l    :     28
ITP F   mg/l :     -.00     ETP F   mg/l :     -.00     INF SS               mg/l    :    196
ITOC    mg/L:    81.00     ETOC    mg/L:   29.00
IALK        :    -1.00     EALK        :   -1.00
```

```
      DATA FROM  B  PLANT

      OFFLINE DATA RECORD # 307

   TIME STAMP = 20/03  2: 0

   DAY    :      79
   MIN    :     120
   IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                          :     -1
   ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
   ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
   ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
   IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT  meters       :   -.00
   ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
   ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
   INH3 N  mg/l :     -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
   INO3+2  mg/l :     -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
   ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
   ITOC     mg/L:   93.00     ETOC     mg/L:   31.00
   IALK         :   -1.00     EALK         :   -1.00

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


      DATA FROM  A  PLANT

      OFFLINE DATA RECORD # 307

   TIME STAMP = 20/03  2: 0

   DAY    :      79
   MIN    :     120
   IBOD5U  mg/l :       -1     EBOD5U  mg/l :      -1     SVI                          :     -1
   ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
   ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
   ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
   IBOD5F  mg/l :       -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT  meters       :   -.00
   ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
   ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
   INH3 N  mg/l :     -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
   INO3+2  mg/l :     -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
   ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
   ITOC     mg/L:   93.00     ETOC     mg/L:   29.00
   IALK         :   -1.00     EALK         :   -1.00
```

```
      DATA FROM  B  PLANT

      OFFLINE DATA RECORD # 308

  TIME STAMP = 20/03  3: 0

  DAY   :       79
  MIN   :      180
  IBODSU  mg/l :      -1    EBODSU  mg/l :      -1    SVI                        :      -1
  ICOD U  mg/l :      -1    ECOD U  mg/l :      -1    SRT   MANUAL  (days)       :    -.00
  ITKN U  mg/l :    -.00    ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)    :      -1
  ITP  U  mg/l :    -.00    ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l   :      -1
  IBODSF  mg/l :      -1    EBODSF  mg/l :      -1    BLANKET HEIGHT    meters   :    -.00
  ICOD F  mg/l :      -1    ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr      :    -.00
  ITKN F  mg/l :    -.00    ETKN F  mg/l :    -.00    MLSS                mg/l   :      -1
  INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS              mg/l   :      -1
  INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS              mg/l   :      -1
  ITP F   mg/l :    -.00    ETP F   mg/l :    -.00    INF SS              mg/l   :      -1
  ITOC    mg/L:   72.00     ETOC    mg/L:   37.00
  IALK        :   -1.00     EALK        :   -1.00

  :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


      DATA FROM  A  PLANT

      OFFLINE DATA RECORD # 308

  TIME STAMP = 20/03  3: 0

  DAY   :       79
  MIN   :      180
  IBODSU  mg/l :      -1    EBODSU  mg/l :      -1    SVI                        :      -1
  ICOD U  mg/l :      -1    ECOD U  mg/l :      -1    SRT   MANUAL  (days)       :    -.00
  ITKN U  mg/l :    -.00    ETKN U  mg/l :    -.00    WASTE VOL. MAN (liters)    :      -1
  ITP  U  mg/l :    -.00    ETP  U  mg/l :    -.00    WASTE CONC.MAN      mg/l   :      -1
  IBODSF  mg/l :      -1    EBODSF  mg/l :      -1    BLANKET HEIGHT    meters   :    -.00
  ICOD F  mg/l :      -1    ECOD F  mg/l :      -1    OUR  mg DO g mlvss hr      :    -.00
  ITKN F  mg/l :    -.00    ETKN F  mg/l :    -.00    MLSS                mg/l   :      -1
  INH3 N  mg/l :    -.00    ENH3 N  mg/l :    -.00    RAS SS              mg/l   :      -1
  INO3+2  mg/l :    -.00    ENO3+2  mg/l :    -.00    EFF SS              mg/l   :      -1
  ITP F   mg/l :    -.00    ETP F   mg/l :    -.00    INF SS              mg/l   :      -1
  ITOC    mg/L:   72.00     ETOC    mg/L:   28.00
  IALK        :   -1.00     EALK        :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 294

     TIME STAMP = 20/03  4: 0

     DAY     :      79
     MIN     :     240
     IBODSU  mg/l :     -1      EBODSU  mg/l :     -1     SVI                          :    -1
     ICOD U  mg/l :     -1      ECOD U  mg/l :     -1     SRT   MANUAL  (days)         :  -.00
     ITKN U  mg/l :   -.00      ETKN U  mg/l :   -.00     WASTE VOL. MAN (liters)      :    -1
     ITP  U  mg/l :   -.00      ETP  U  mg/l :   -.00     WASTE CONC.MAN      mg/l     :    -1
     IBODSF  mg/l :     -1      EBODSF  mg/l :     -1     BLANKET HEIGHT   meters      :  -.00
     ICOD F  mg/l :     -1      ECOD F  mg/l :     -1     OUR  mg DO g mlvss hr        :  -.01
     ITKN F  mg/l :   -.00      ETKN F  mg/l :   -.00     MLSS                 mg/l    :    -1
     INH3 N  mg/l :  11.50      ENH3 N  mg/l :   5.70     RAS SS               mg/l    :    -1
     INO3+2  mg/l :    .60      ENO3+2  mg/l :   4.10     EFF SS               mg/l    :    18
     ITP F   mg/l :   -.00      ETP F   mg/l :   -.00     INF SS               mg/l    :   198
     ITOC    mg/L:  58.00      ETOC    mg/L:  36.00
     IALK        :  -1.00      EALK        :  -1.00

     ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 294

     TIME STAMP = 20/03  4: 0

     DAY     :      79
     MIN     :     240
     IBODSU  mg/l :     -1      EBODSU  mg/l :     -1     SVI                          :    -1
     ICOD U  mg/l :     -1      ECOD U  mg/l :     -1     SRT   MANUAL  (days)         :  -.00
     ITKN U  mg/l :   -.00      ETKN U  mg/l :   -.00     WASTE VOL. MAN (liters)      :    -1
     ITP  U  mg/l :   -.00      ETP  U  mg/l :   -.00     WASTE CONC.MAN      mg/l     :    -1
     IBODSF  mg/l :     -1      EBODSF  mg/l :     -1     BLANKET HEIGHT   meters      :  -.00
     ICOD F  mg/l :     -1      ECOD F  mg/l :     -1     OUR  mg DO g mlvss hr        :  -.00
     ITKN F  mg/l :   -.00      ETKN F  mg/l :   -.00     MLSS                 mg/l    :    -1
     INH3 N  mg/l :  11.50      ENH3 N  mg/l :   5.10     RAS SS               mg/l    :    -1
     INO3+2  mg/l :    .60      ENO3+2  mg/l :   6.90     EFF SS               mg/l    :    18
     ITP F   mg/l :   -.00      ETP F   mg/l :   -.00     INF SS               mg/l    :   198
     ITOC    mg/L:  58.00      ETOC    mg/L:  25.00
     IALK        :  -1.00      EALK        :  -1.00
```

```
      DATA FROM  B  PLANT

      OFFLINE DATA RECORD # 309

   TIME STAMP = 20/03  5: 0

   DAY    :      79
   MIN    :     300
   IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                        :     -1
   ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.00
   ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -1
   ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l   :     -1
   IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters    :   -.00
   ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr      :   -.00
   ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS               mg/l    :     -1
   INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS             mg/l    :     -1
   INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS             mg/l    :     -1
   ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS             mg/l    :     -1
   ITOC    mg/L:   59.00     ETOC    mg/L:   30.00
   IALK       :   -1.00     EALK        :   -1.00

   ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


      DATA FROM  A  PLANT

      OFFLINE DATA RECORD # 309

   TIME STAMP = 20/03  5: 0

   DAY    :      79
   MIN    :     300
   IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                        :     -1
   ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)       :   -.00
   ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)    :     -1
   ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l   :     -1
   IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters    :   -.00
   ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr      :   -.00
   ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS               mg/l    :     -1
   INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS             mg/l    :     -1
   INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS             mg/l    :     -1
   ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS             mg/l    :     -1
   ITOC    mg/L:   59.00     ETOC    mg/L:   23.00
   IALK       :   -1.00     EALK        :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 310

    TIME STAMP = 20/03  6: 0

    DAY    :      79
    MIN    :     360
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                         :     -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :   -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :     -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l   :     -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT     meters   :   -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :   -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l   :     -1
    INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l   :     -1
    INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l   :     -1
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l   :     -1
    ITOC    mg/L:   59.00     ETOC    mg/L:   32.00
    IALK        :   -1.00     EALK        :   -1.00

    :::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 310

    TIME STAMP = 20/03  6: 0

    DAY    :      79
    MIN    :     360
    IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                         :     -1
    ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :   -.00
    ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :     -1
    ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l   :     -1
    IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT     meters   :   -.00
    ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :   -.00
    ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l   :     -1
    INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l   :     -1
    INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l   :     -1
    ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l   :     -1
    ITOC    mg/L:   59.00     ETOC    mg/L:   21.00
    IALK        :   -1.00     EALK        :   -1.00
```

```
        DATA FROM  B  PLANT

        OFFLINE DATA RECORD # 295

    TIME STAMP = 20/03  7: 0

    DAY    :      79
    MIN    :     420
    IBODSU  mg/l :       -1     EBODSU  mg/l :      -1     SVI                         :      -1
    ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :    -.00
    ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :      -1
    ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l    :      -1
    IBODSF  mg/l :       -1     EBODSF  mg/l :      -1     BLANKET HEIGHT    meters    :    -.00
    ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :    -.00
    ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l   :      -1
    INH3 N  mg/l :    10.00     ENH3 N  mg/l :    4.30     RAS SS               mg/l   :      -1
    INO3+2  mg/l :      .60     ENO3+2  mg/l :    5.10     EFF SS               mg/l   :      14
    ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l   :     132
    ITOC    mg/L:    52.00     ETOC     mg/L:   32.00
    IALK        :    -1.00     EALK         :   -1.00

    ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


        DATA FROM  A  PLANT

        OFFLINE DATA RECORD # 295

    TIME STAMP = 20/03  7: 0

    DAY    :      79
    MIN    :     420
    IBODSU  mg/l :       -1     EBODSU  mg/l :      -1     SVI                         :      -1
    ICOD U  mg/l :       -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :    -.00
    ITKN U  mg/l :     -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :      -1
    ITP  U  mg/l :     -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l    :      -1
    IBODSF  mg/l :       -1     EBODSF  mg/l :      -1     BLANKET HEIGHT    meters    :    -.00
    ICOD F  mg/l :       -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :    -.00
    ITKN F  mg/l :     -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l   :      -1
    INH3 N  mg/l :    10.00     ENH3 N  mg/l :    3.80     RAS SS               mg/l   :      -1
    INO3+2  mg/l :      .60     ENO3+2  mg/l :    7.50     EFF SS               mg/l   :      16
    ITP F   mg/l :     -.00     ETP F   mg/l :    -.00     INF SS               mg/l   :     132
    ITOC    mg/L:    52.00     ETOC     mg/L:   20.00
    IALK        :    -1.00     EALK         :   -1.00
```

```
    DATA FROM  B  PLANT

    OFFLINE DATA RECORD # 311

TIME STAMP = 20/03  8: 0

DAY     :      79
MIN     :     480
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     ~~INF SS~~           mg/l    :     -1
ITOC    mg/L:    50.00     ETOC    mg/L:    23.00
IALK        :    -1.00     EALK        :    -1.00

::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

```
    DATA FROM  A  PLANT

    OFFLINE DATA RECORD # 311

TIME STAMP = 20/03  8: 0

DAY     :      79
MIN     :     480
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
ITOC    mg/L:    50.00     ETOC    mg/L:    21.00
IALK        :    -1.00     EALK        :    -1.00
```

```
    DATA FROM  B  PLANT

    OFFLINE DATA RECORD # 312

TIME STAMP = 20/03  9:15

DAY    :      79
MIN    :     555
IBODSU  mg/l :      -1     EBODSU  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBODSF  mg/l :      -1     EBODSF  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
ITOC    mg/L:   53.00     ETOC    mg/L:   27.00
IALK        :   -1.00     EALK        :   -1.00

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::


    DATA FROM  A  PLANT

    OFFLINE DATA RECORD # 312

TIME STAMP = 20/03  9:15

DAY    :      79
MIN    :     555
IBODSU  mg/l :      -1     EBODSU  mg/l :      -1     SVI                          :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)         :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)      :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN       mg/l    :     -1
IBODSF  mg/l :      -1     EBODSF  mg/l :      -1     BLANKET HEIGHT   meters      :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr        :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                 mg/l    :     -1
INH3 N  mg/l :    -.00     ENH3 N  mg/l :    -.00     RAS SS               mg/l    :     -1
INO3+2  mg/l :    -.00     ENO3+2  mg/l :    -.00     EFF SS               mg/l    :     -1
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS               mg/l    :     -1
ITOC    mg/L:   53.00     ETOC    mg/L:   22.00
IALK        :   -1.00     EALK        :   -1.00
```

```
     DATA FROM  B  PLANT

     OFFLINE DATA RECORD # 296

TIME STAMP = 20/03 10: 0

DAY    :     79
MIN    :    600
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                         :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l    :     -1
INH3 N  mg/l :    9.80     ENH3 N  mg/l :    2.30     RAS SS              mg/l    :     -1
INO3+2  mg/l :     .60     ENO3+2  mg/l :    7.20     EFF SS              mg/l    :     12
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l    :    170
ITOC    mg/L:   44.00      ETOC    mg/L:   29.00
IALK        :   -1.00      EALK        :   -1.00

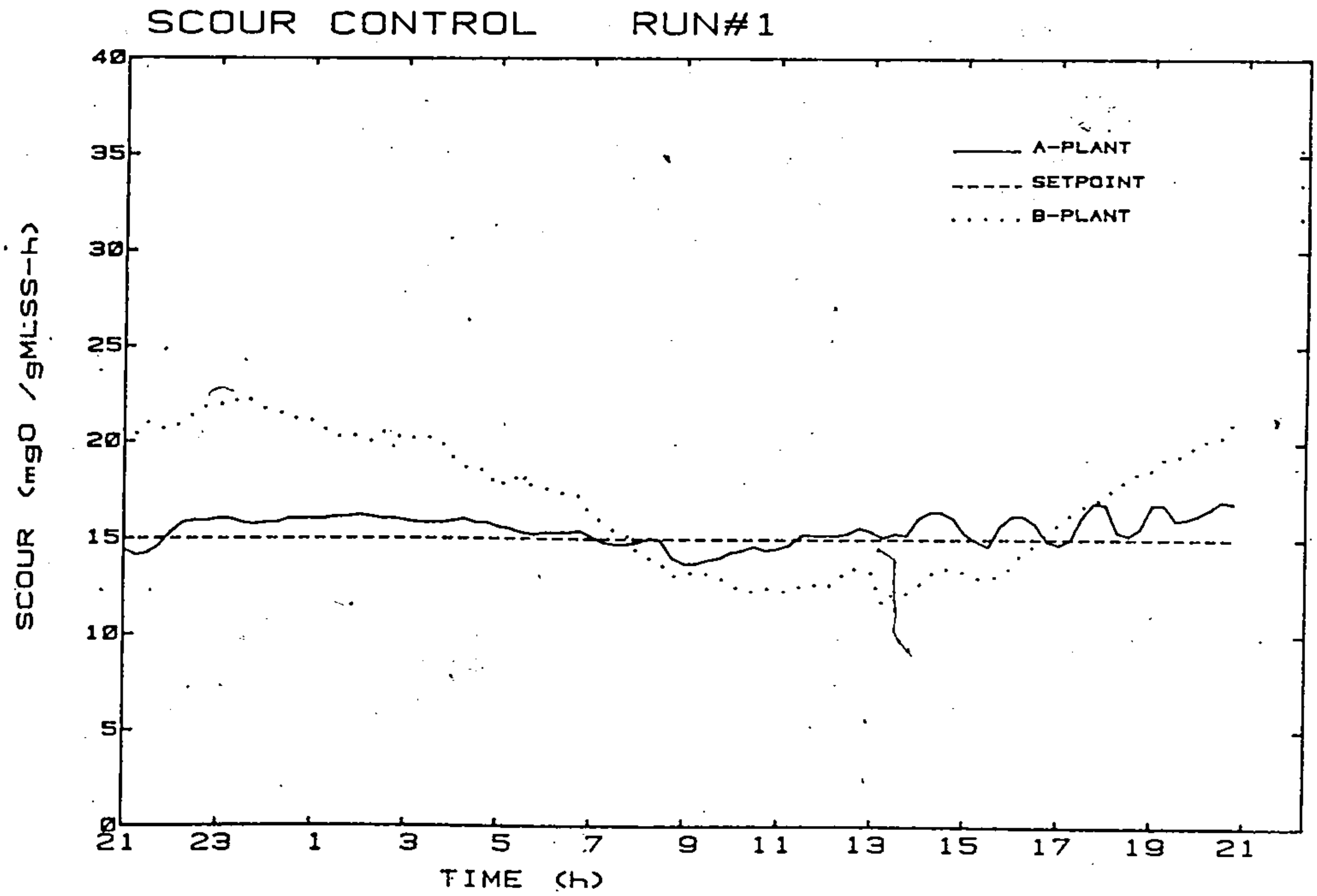
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

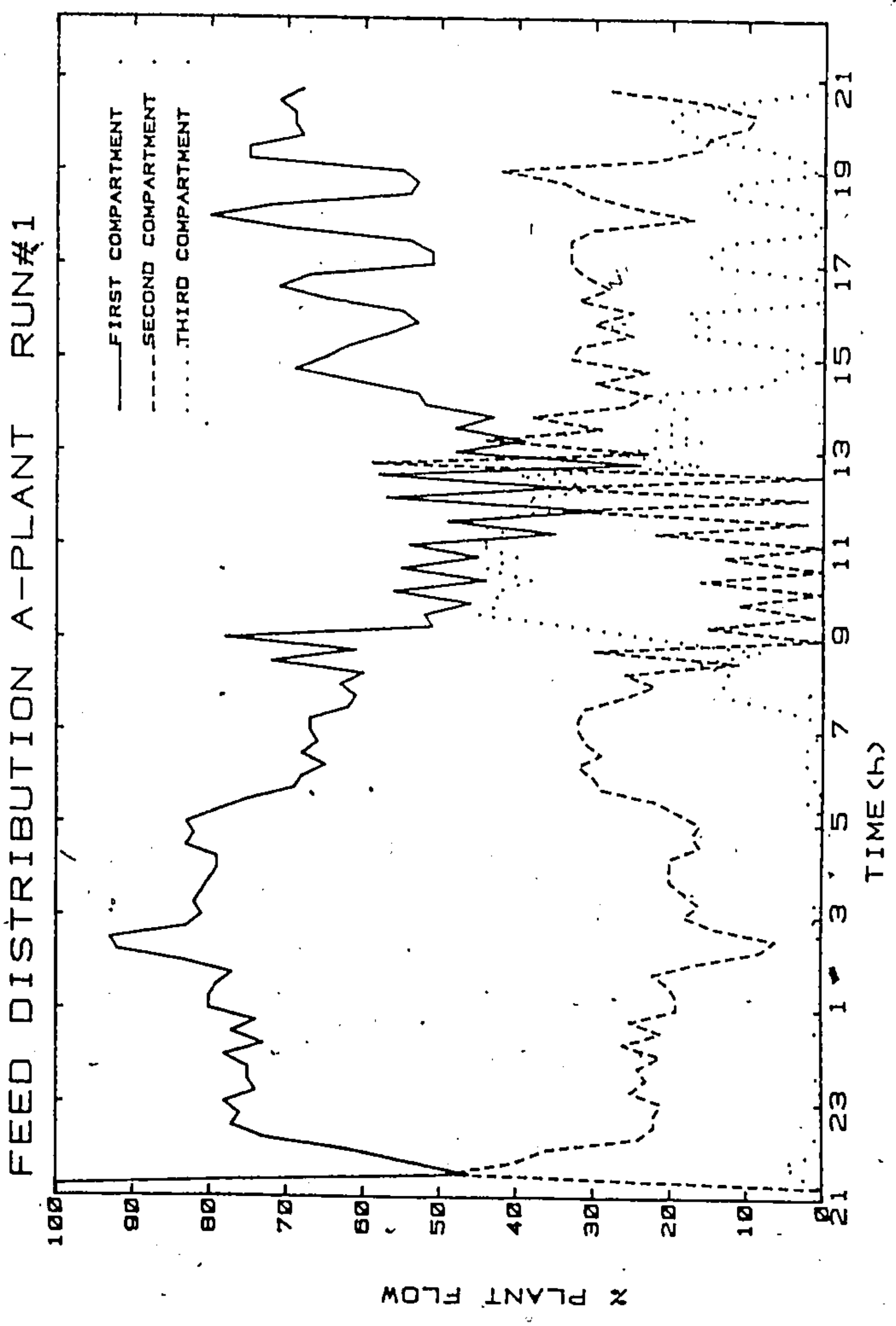

     DATA FROM  A  PLANT

     OFFLINE DATA RECORD # 296

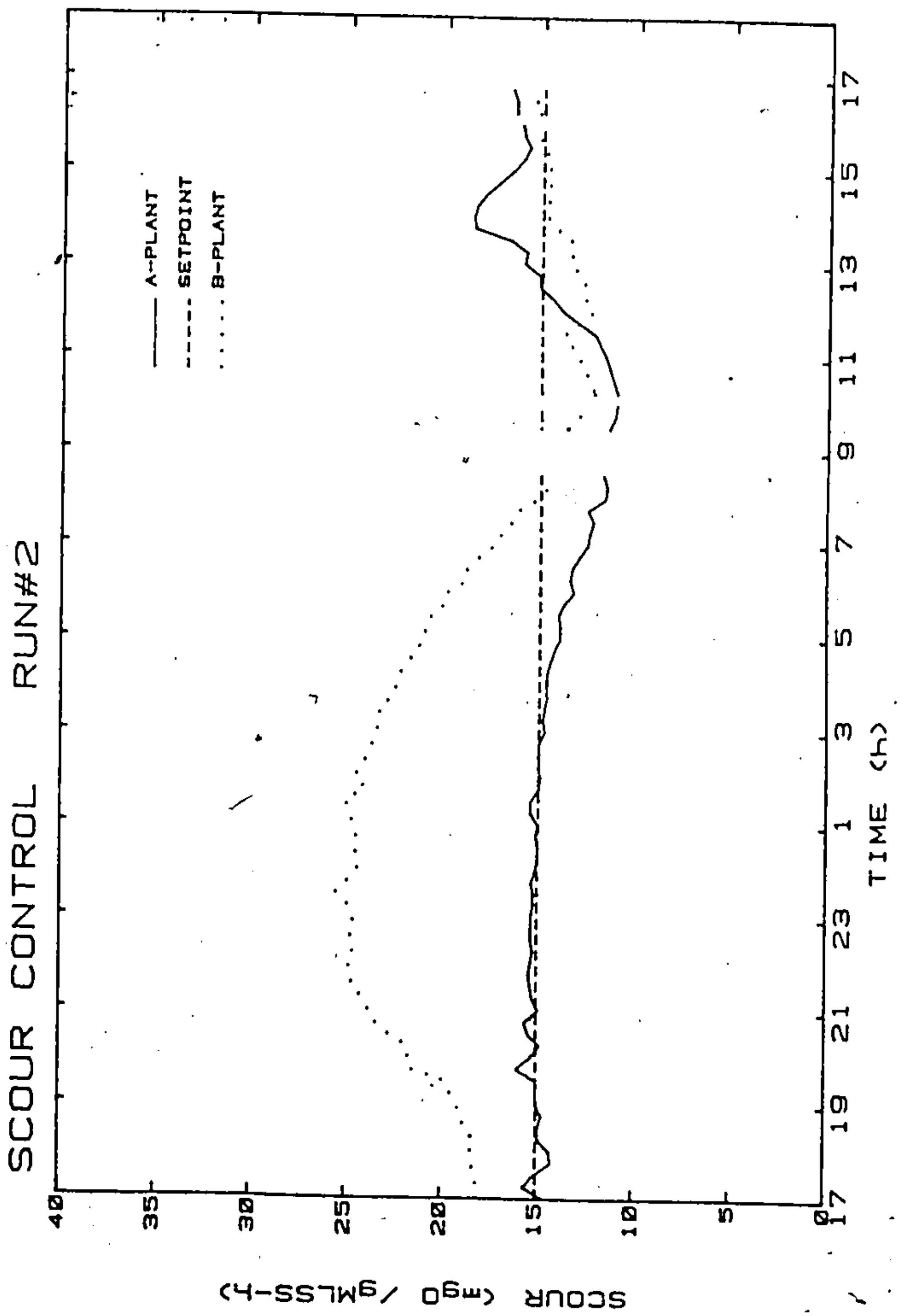
TIME STAMP = 20/03 10: 0

DAY    :     79
MIN    :    600
IBOD5U  mg/l :      -1     EBOD5U  mg/l :      -1     SVI                         :     -1
ICOD U  mg/l :      -1     ECOD U  mg/l :      -1     SRT   MANUAL  (days)        :   -.00
ITKN U  mg/l :    -.00     ETKN U  mg/l :    -.00     WASTE VOL. MAN (liters)     :     -1
ITP  U  mg/l :    -.00     ETP  U  mg/l :    -.00     WASTE CONC.MAN      mg/l    :     -1
IBOD5F  mg/l :      -1     EBOD5F  mg/l :      -1     BLANKET HEIGHT   meters     :   -.00
ICOD F  mg/l :      -1     ECOD F  mg/l :      -1     OUR  mg DO g mlvss hr       :   -.00
ITKN F  mg/l :    -.00     ETKN F  mg/l :    -.00     MLSS                mg/l    :     -1
INH3 N  mg/l :    9.80     ENH3 N  mg/l :    3.00     RAS SS              mg/l    :     -1
INO3+2  mg/l :     .60     ENO3+2  mg/l :    6.80     EFF SS              mg/l    :     16
ITP F   mg/l :    -.00     ETP F   mg/l :    -.00     INF SS              mg/l    :    170
ITOC    mg/L:   44.00      ETOC    mg/L:   26.00
IALK        :   -1.00      EALK        :   -1.00
```

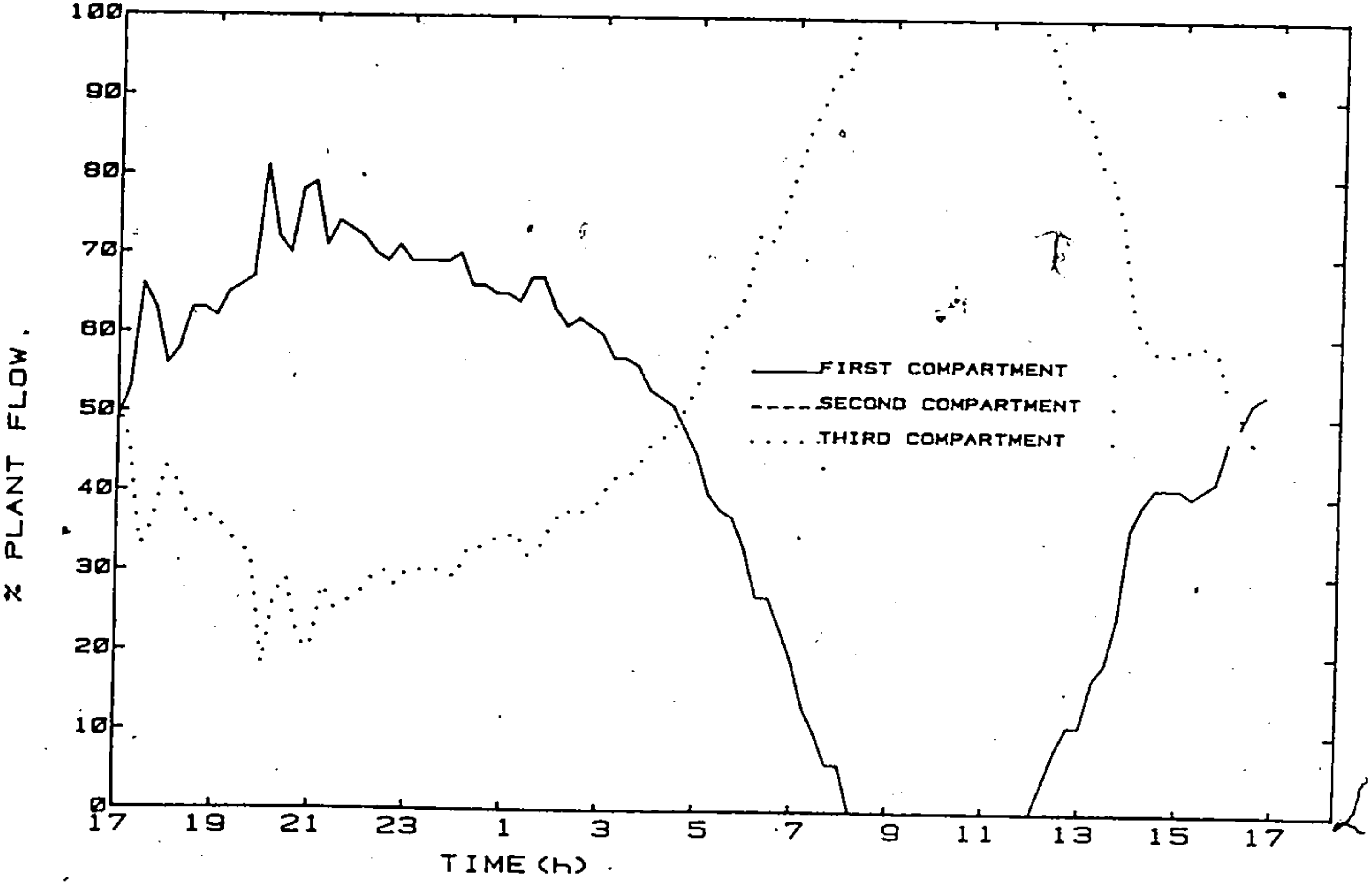

SCOUR CONTROL RUN#1
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
40
35
30
25
20
15
10
5
0
21
23
1
3
5
7
9
11
13
15
17
19
21
TIME (h)

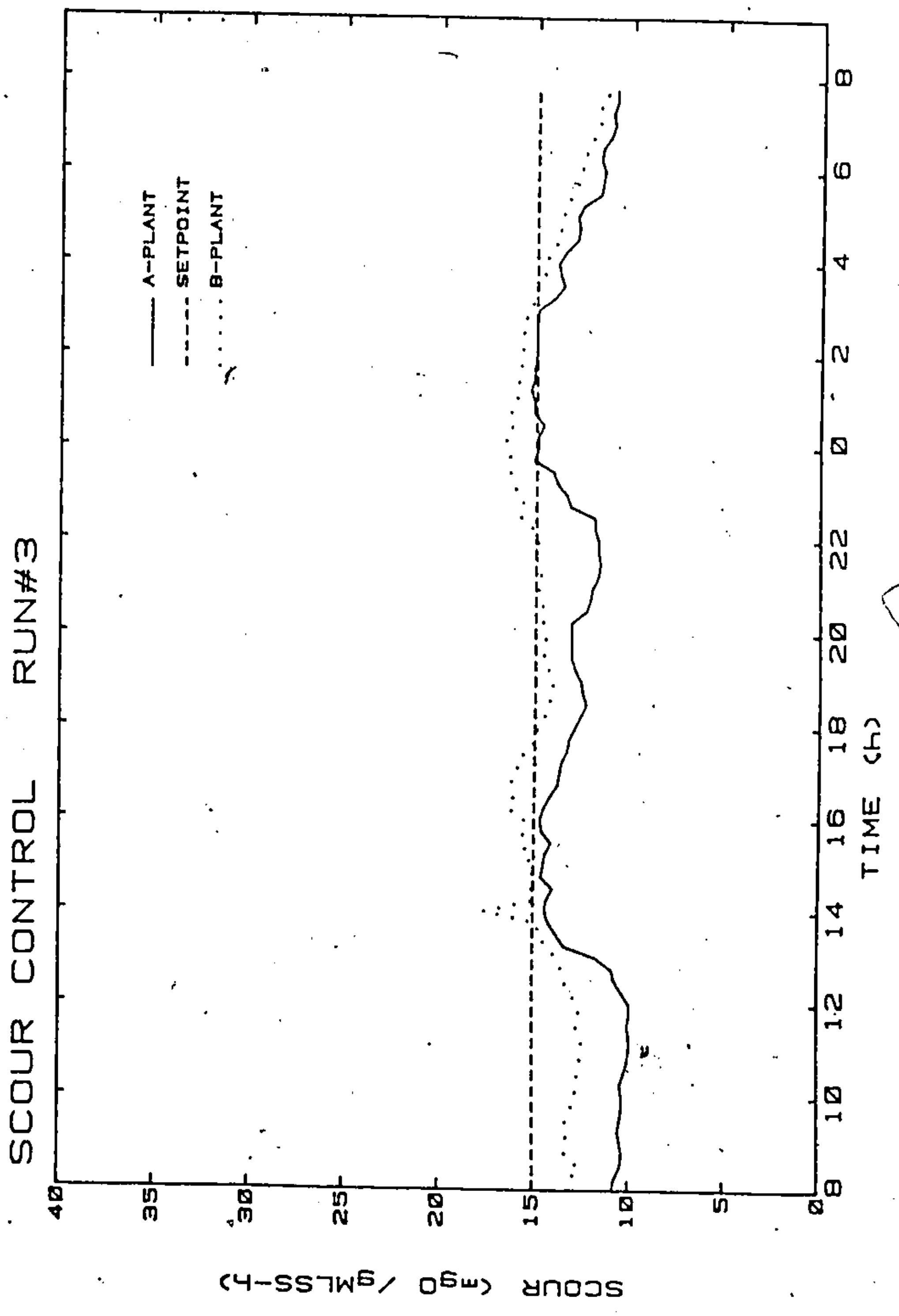

FEED DISTRIBUTION A-PLANT RUN#1
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
100
90
80
70
60
50
40
30
20
10
0
TIME (h)
21
23
1
3
5
7
9
11
13
15
17
19
21

b

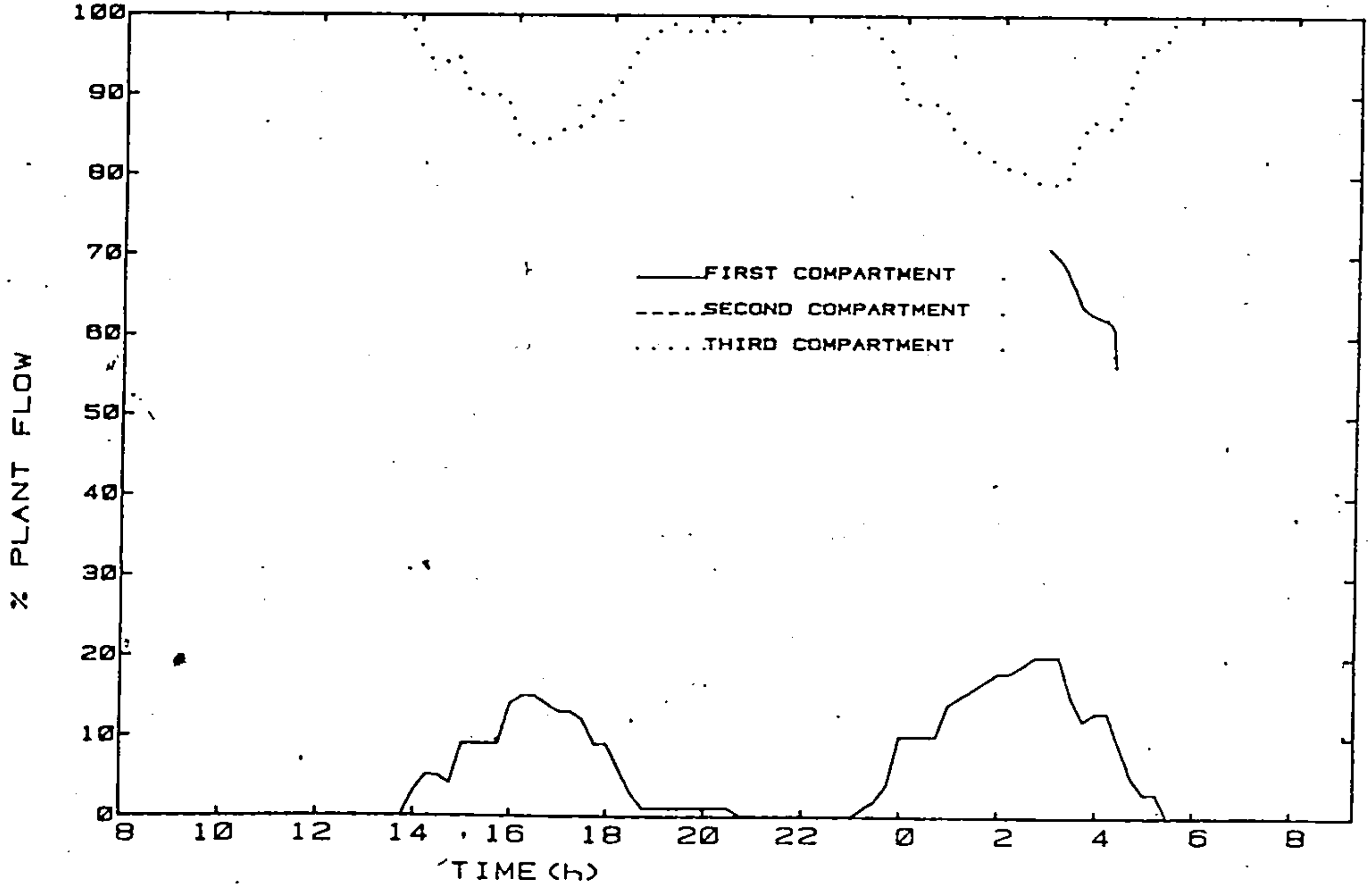

SCOUR CONTROL RUN#2
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
0
5
10
15
20
25
30
35
40
TIME (h)
17
19
21
23
1
3
5
7
9
11
13
15
17

FEED DISTRIBUTION A-PLANT RUN#2

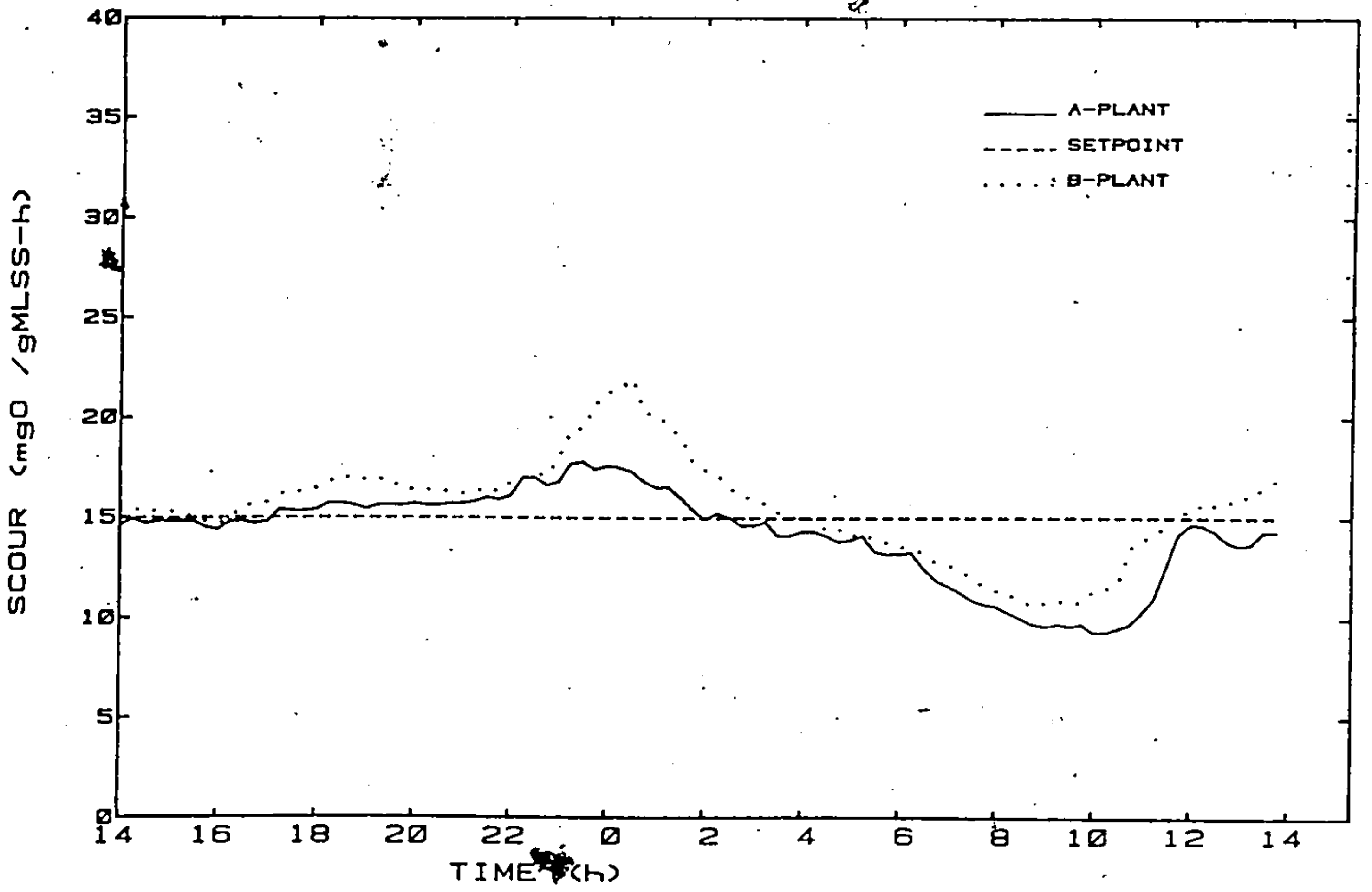


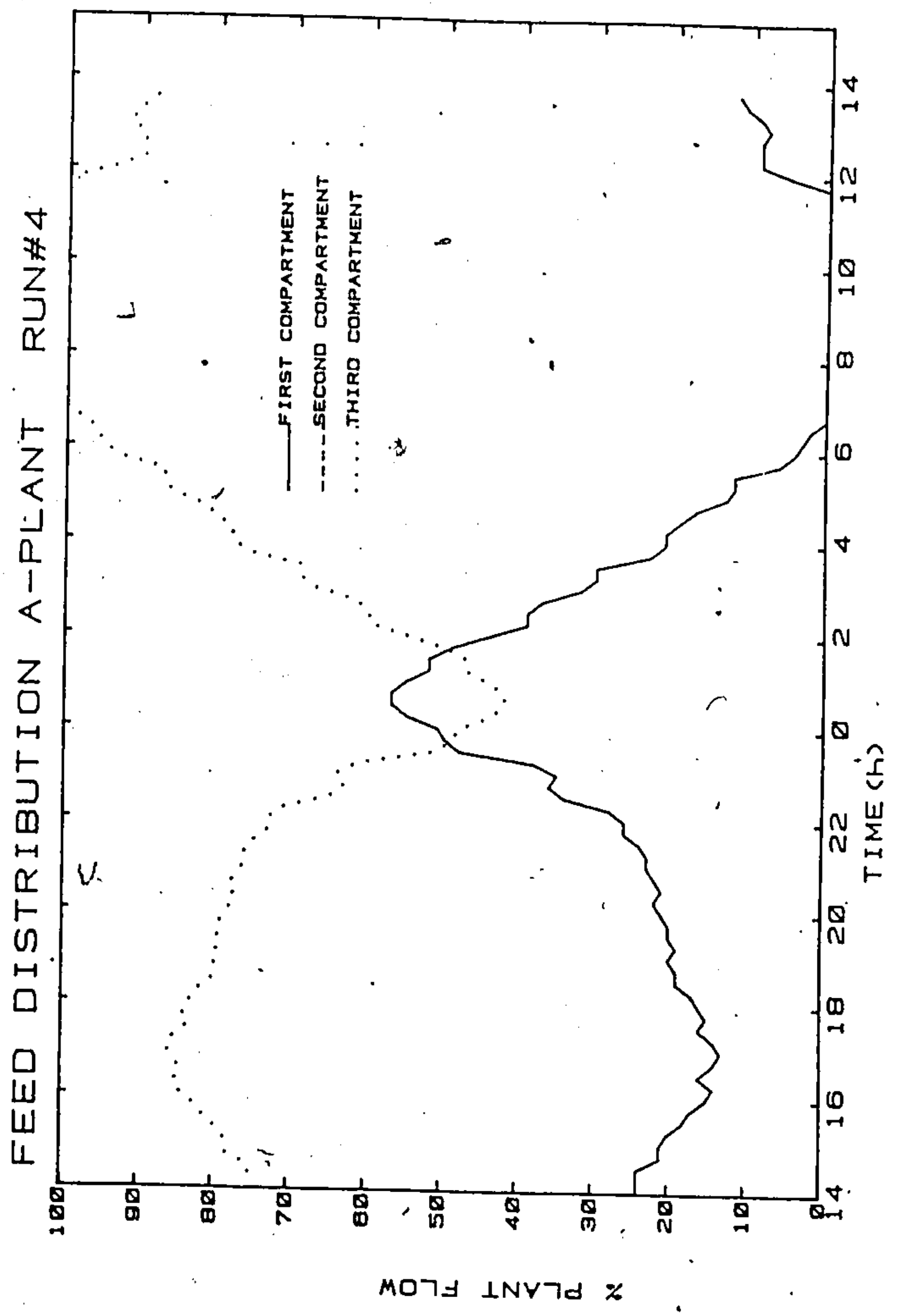

SCOUR CONTROL RUN#3
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
0
5
10
15
20
25
30
35
40
TIME (h)
8
10
12
14
16
18
20
22
0
2
4
6
8

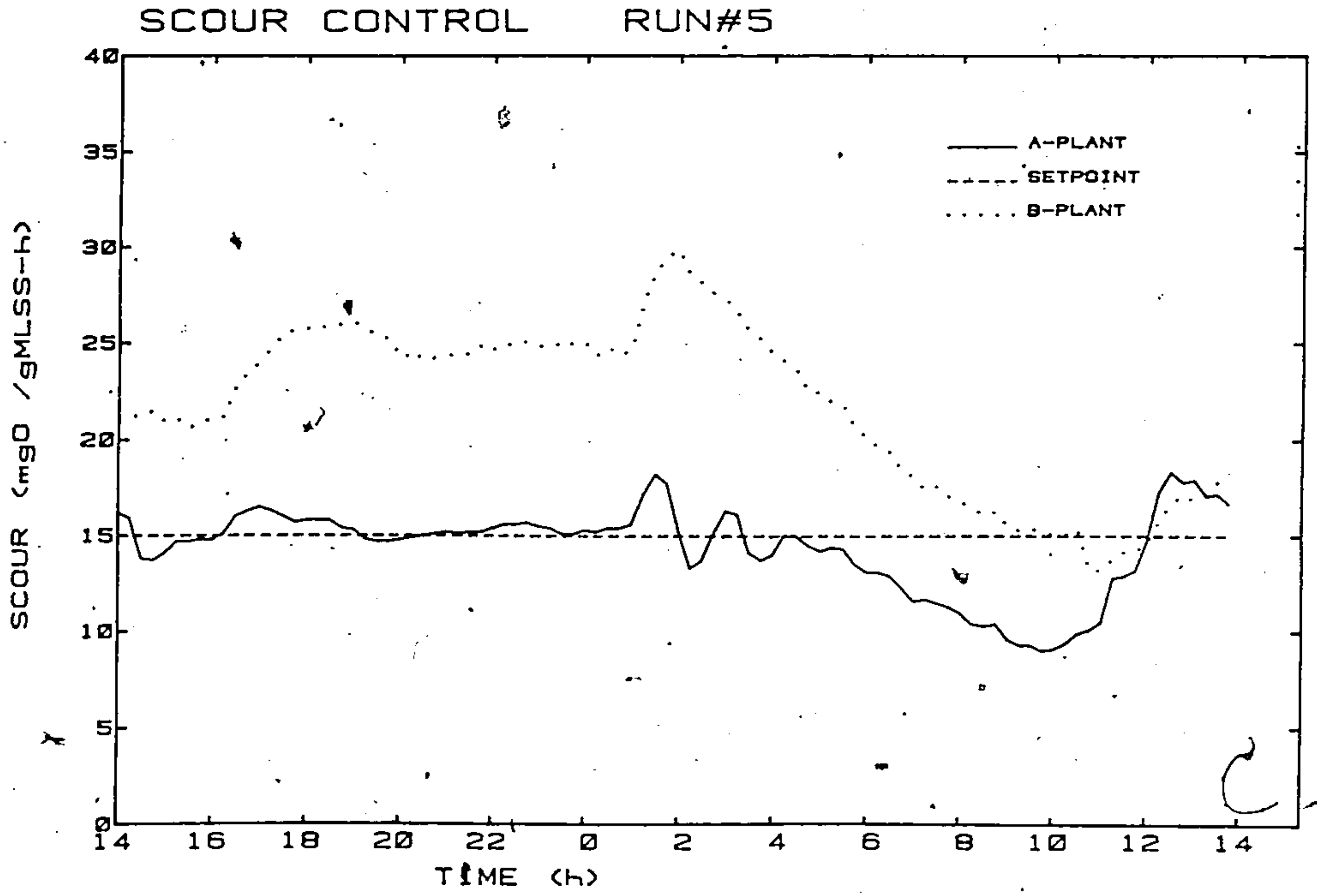
FEED DISTRIBUTION A-PLANT RUN#3

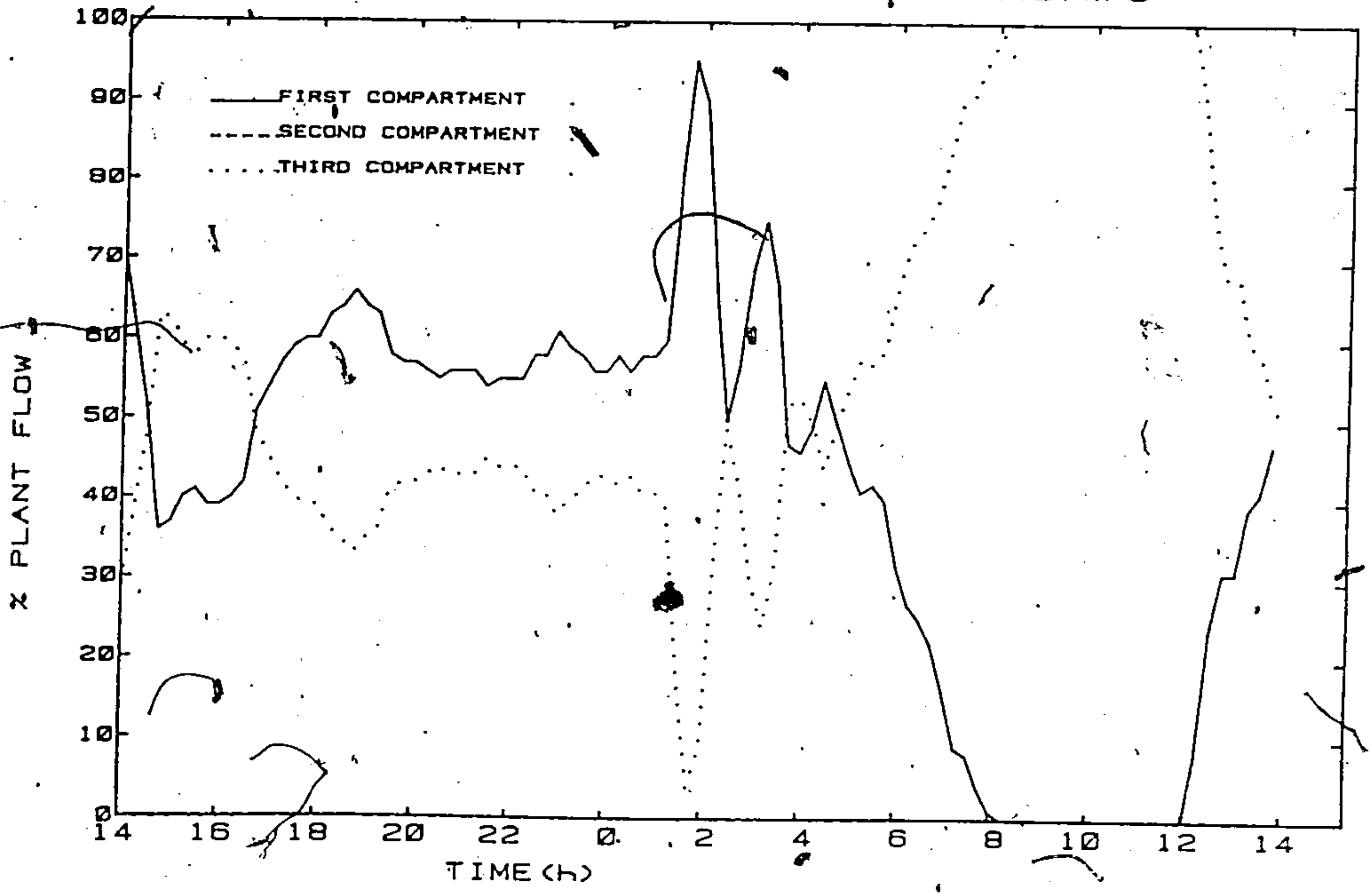


SCOUR CONTROL RUN#4

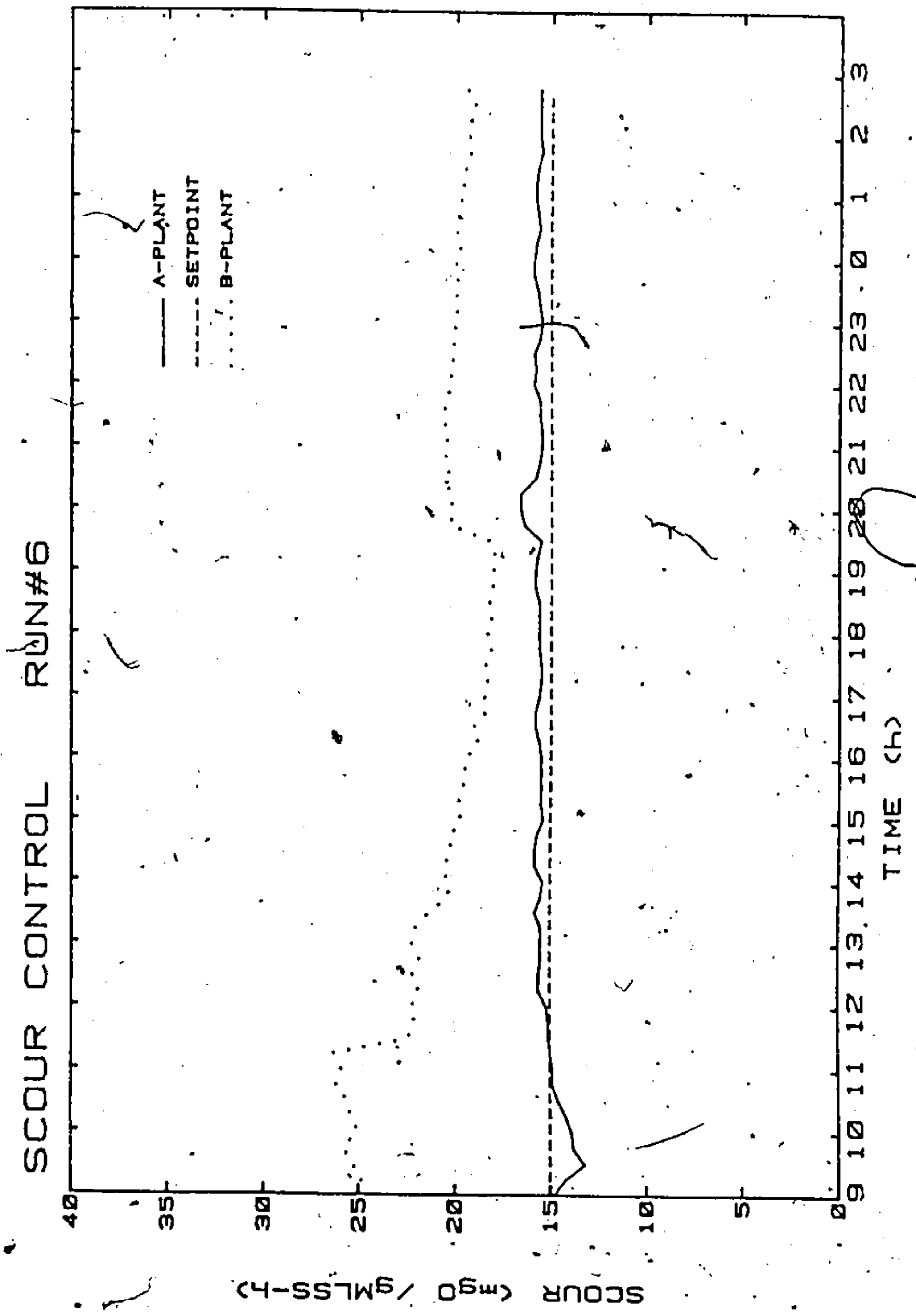


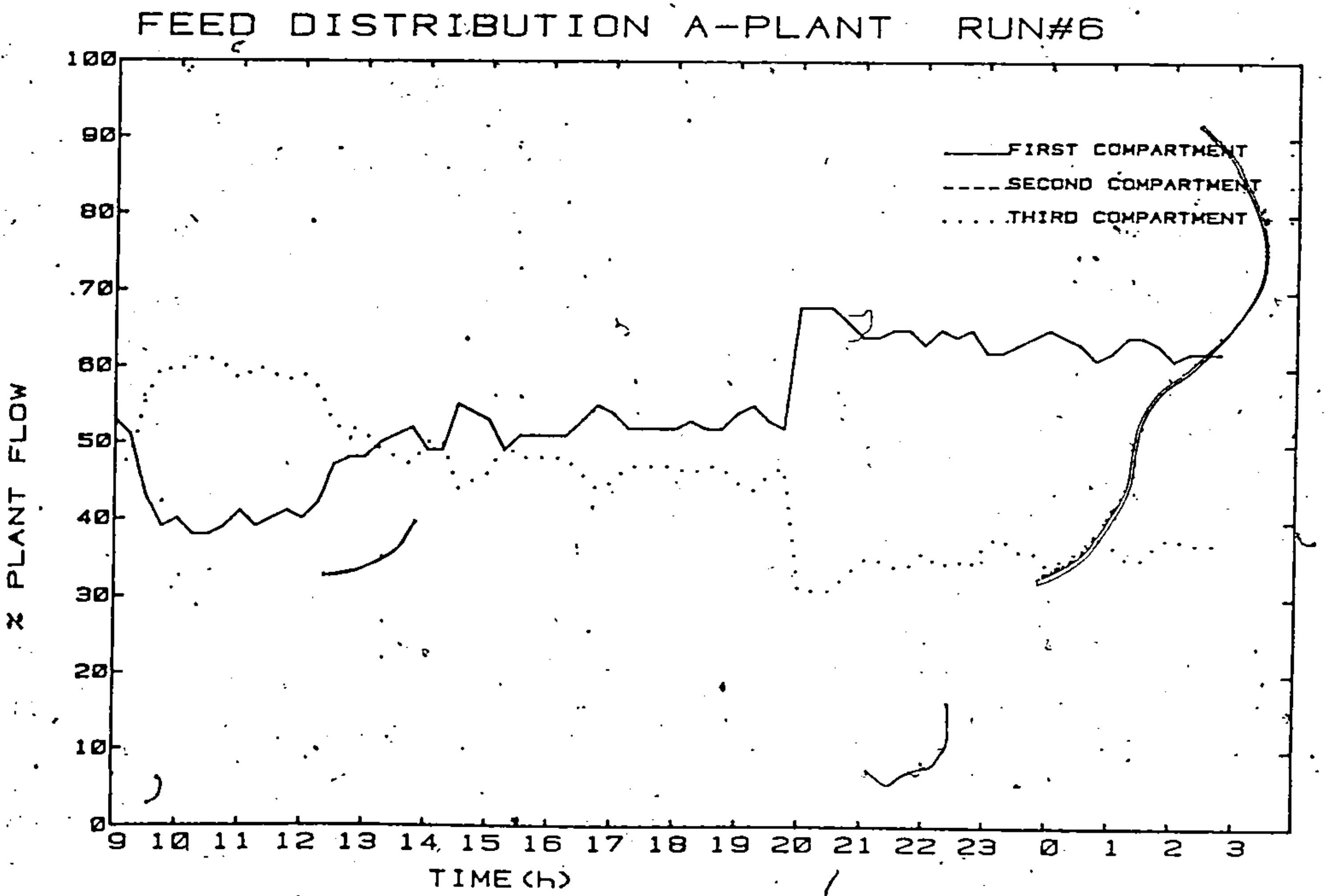

FEED DISTRIBUTION A-PLANT RUN#4
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
100
90
80
70
60
50
40
30
20
10
0
TIME (h)
14
16
18
20
22
0
2
4
6
8
10
12
14

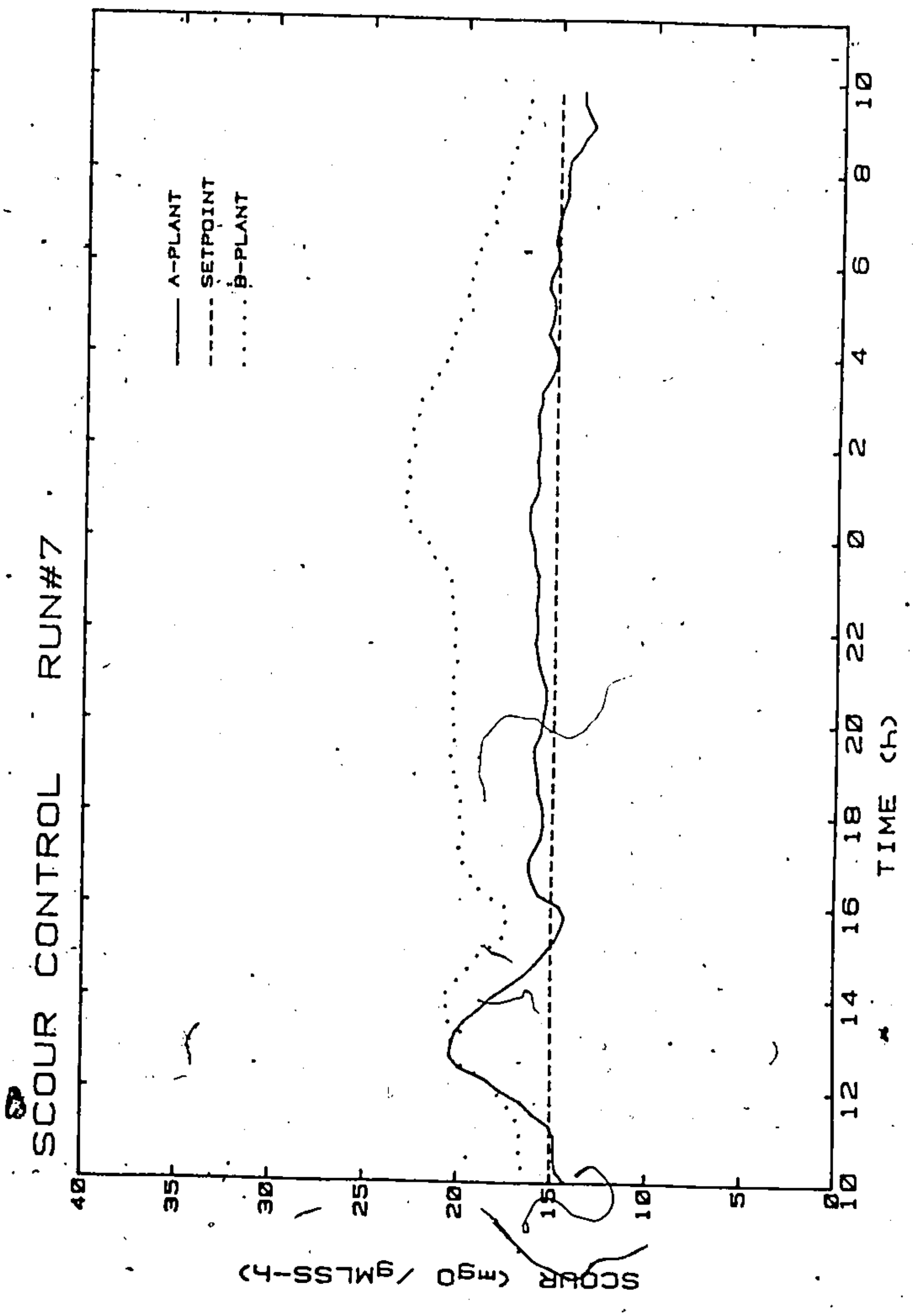

SCOUR CONTROL RUN#5
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
40
35
30
25
20
15
10
5
0
14
16
18
20
22
0
2
4
6
8
10
12
14
TIME (h)



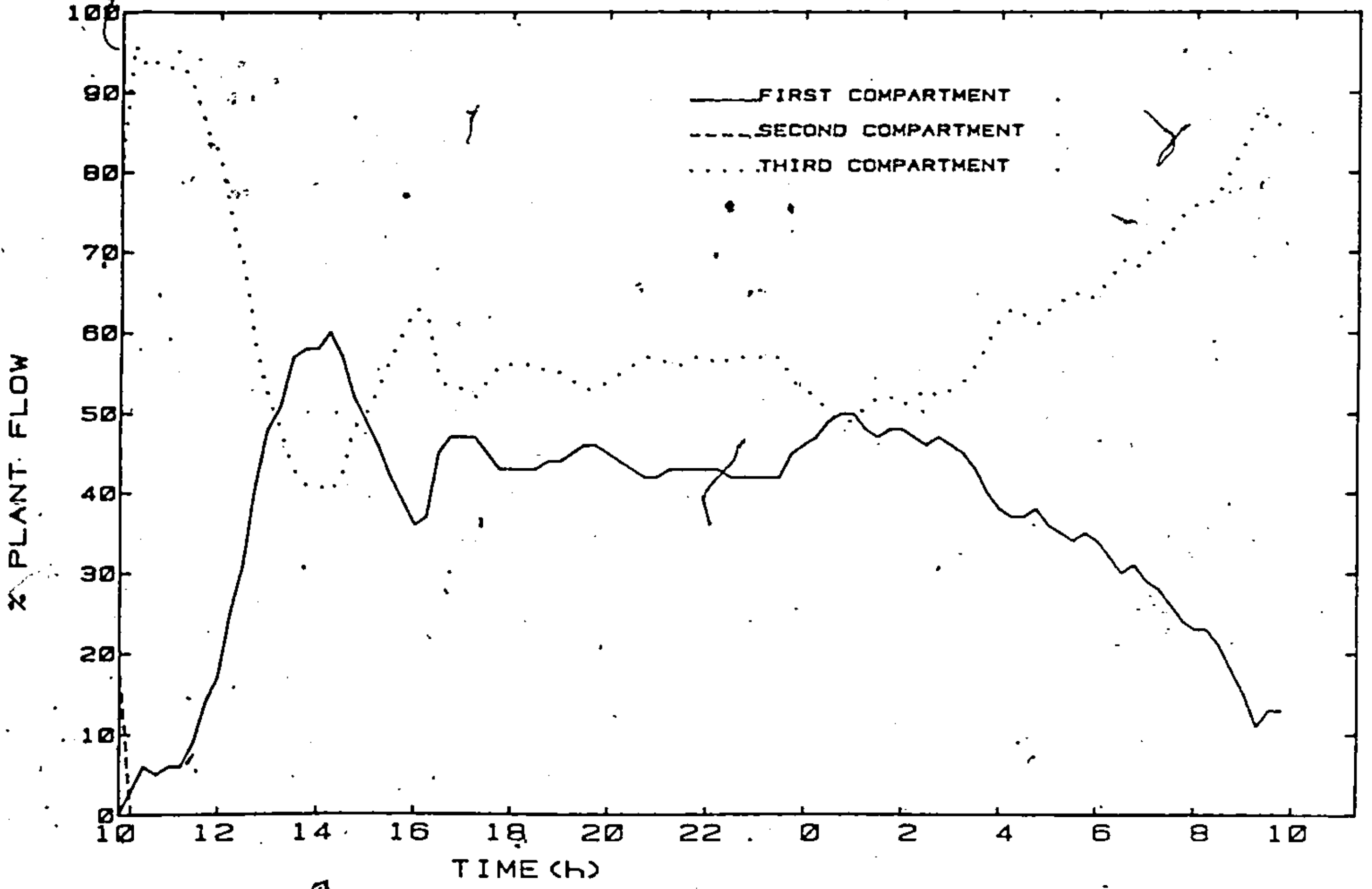
FEED DISTRIBUTION A-PLANT RUN#5

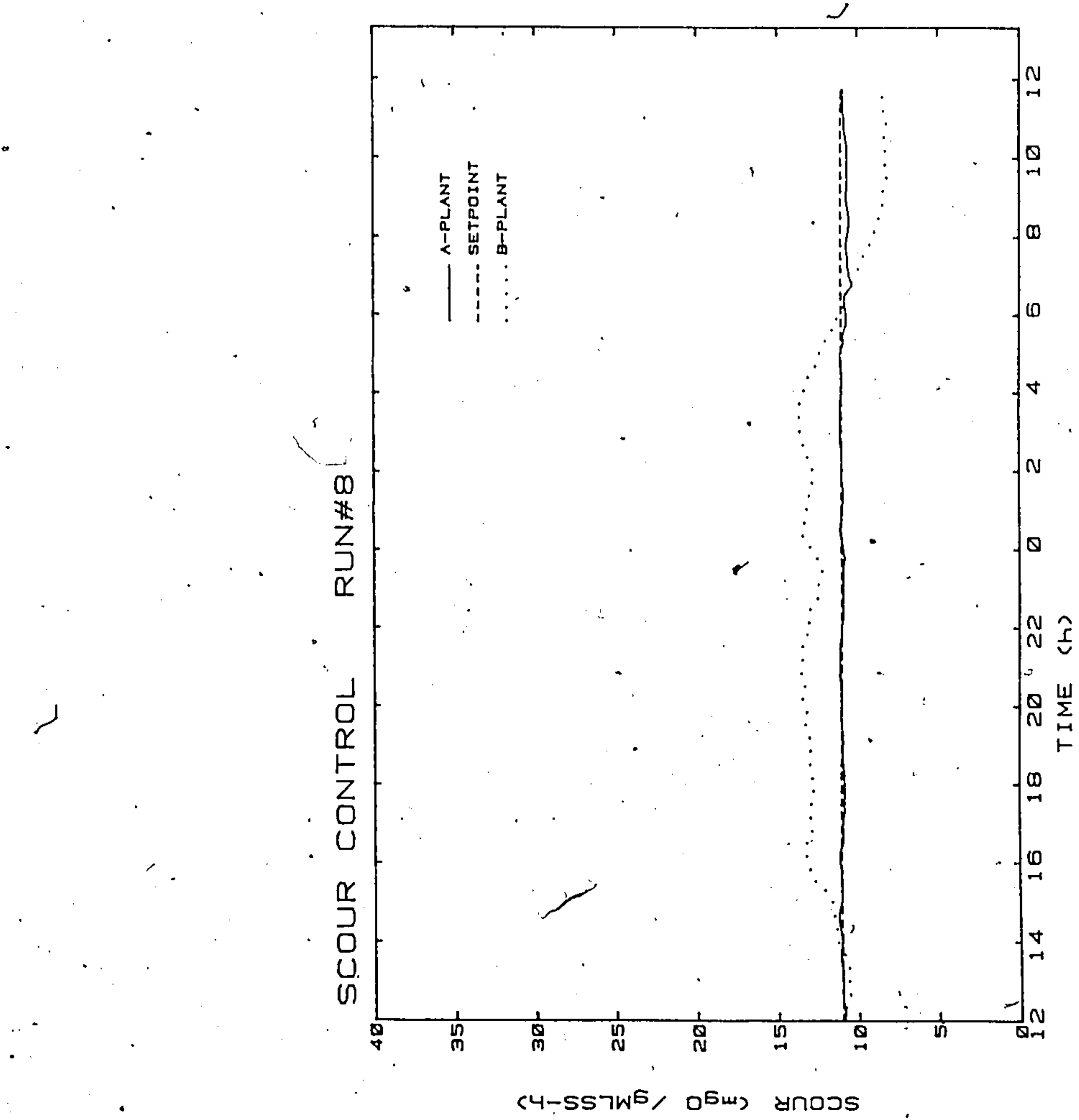

SCOUR CONTROL RUN#6
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
0
5
10
15
20
25
30
35
40
TIME (h)
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3


FEED DISTRIBUTION A-PLANT RUN#6
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
100
90
80
70
60
50
40
30
20
10
0
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
TIME (h)

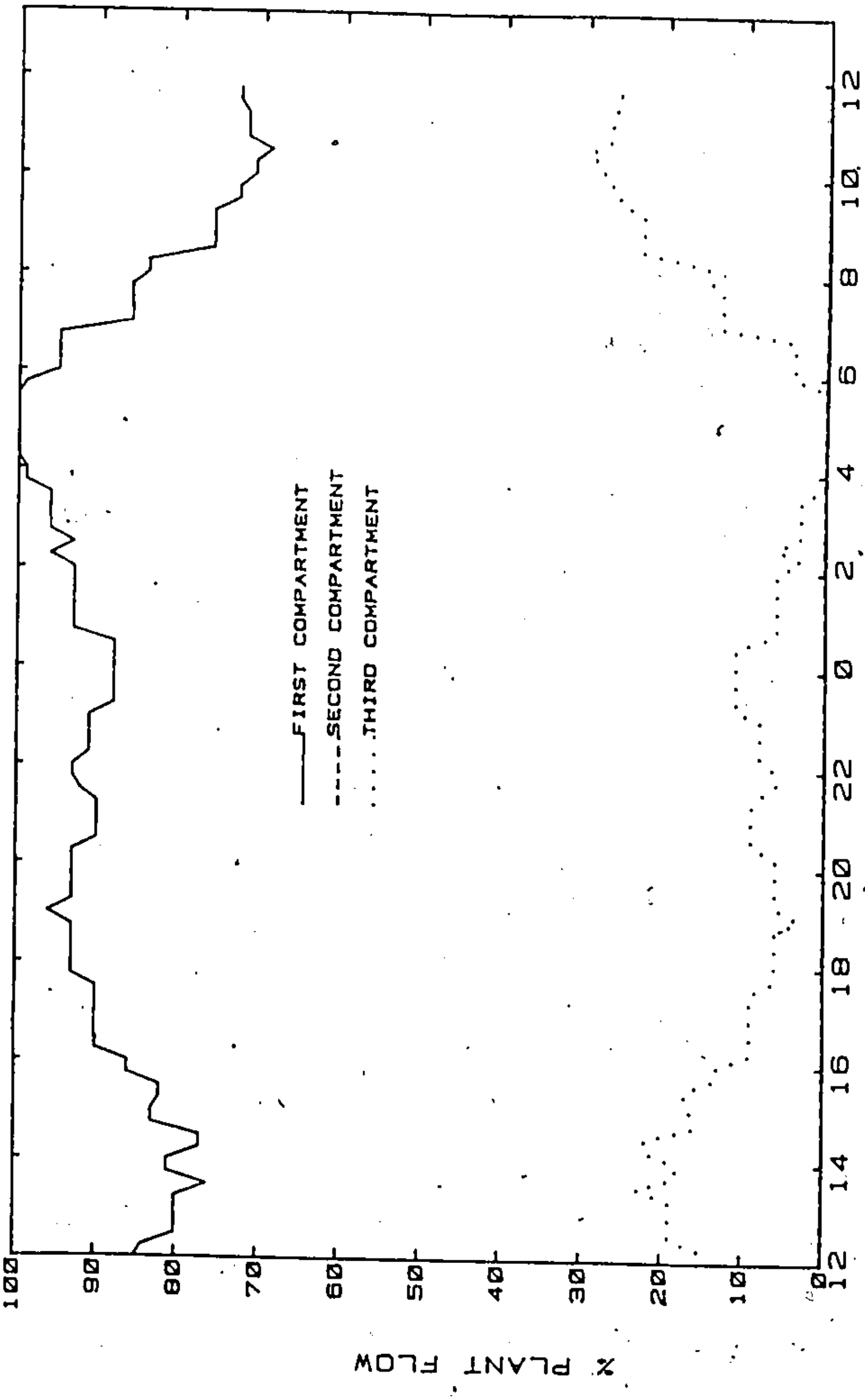

SCOUR CONTROL RUN#7

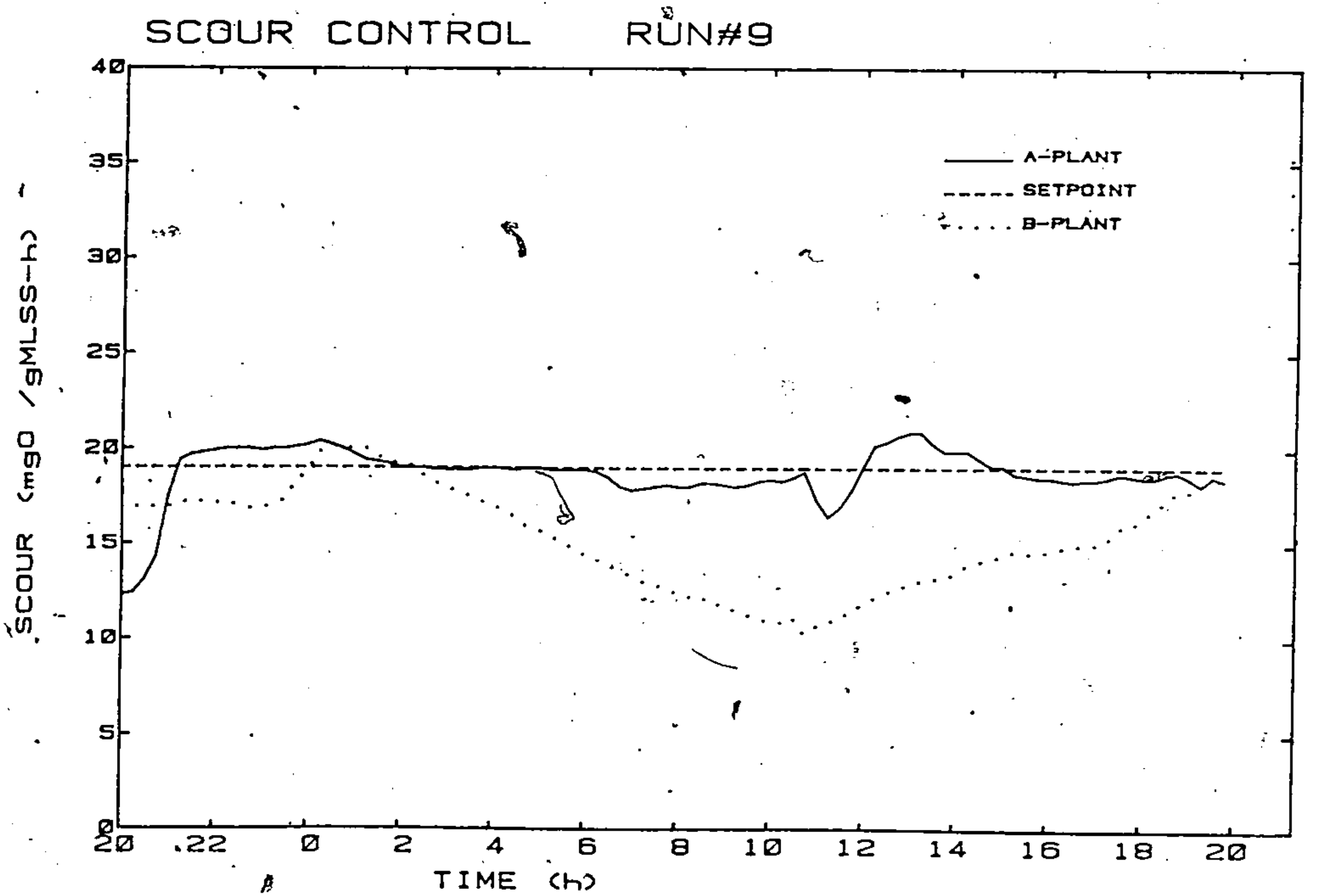
FEED DISTRIBUTION A-PLANT RUN#7

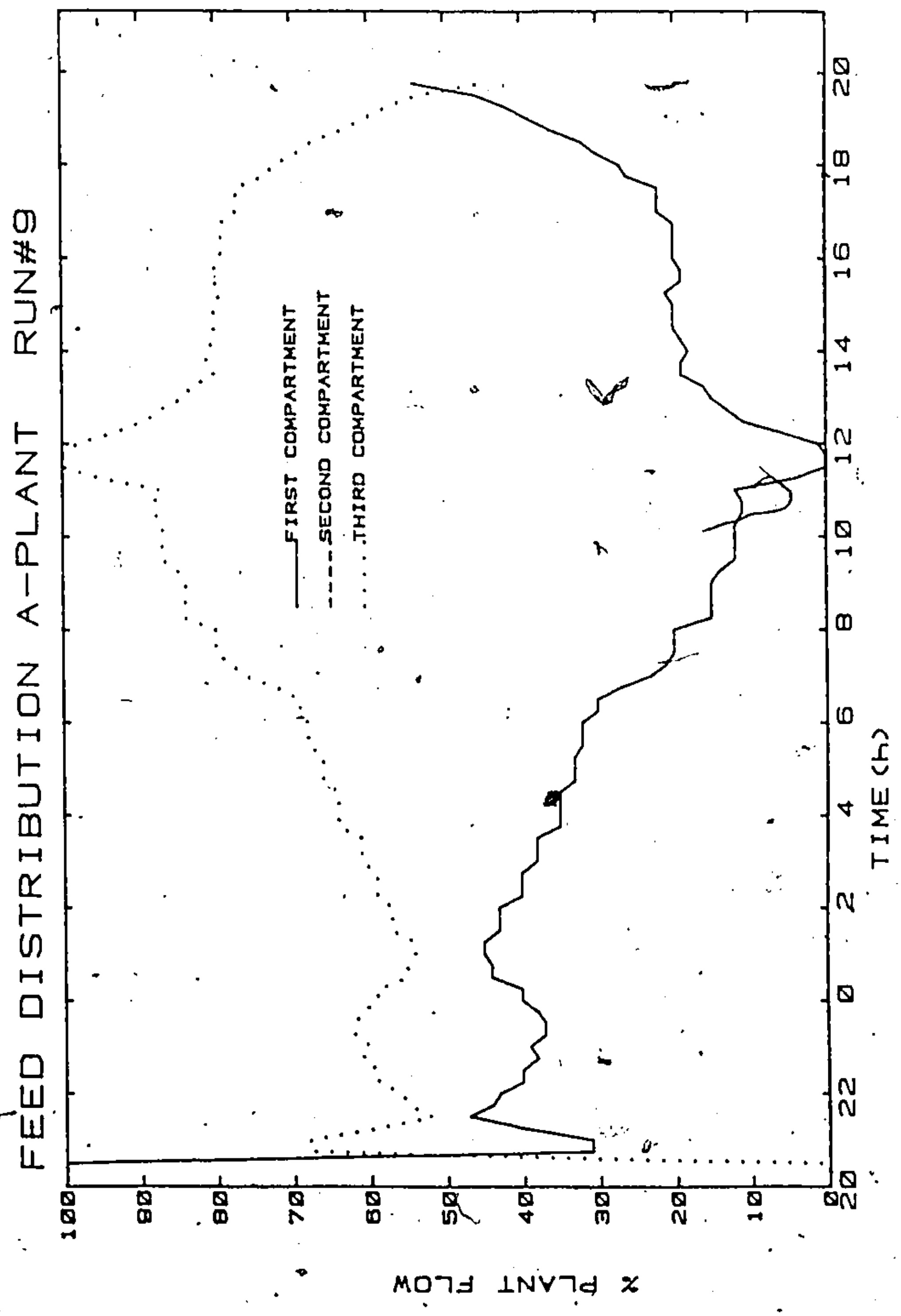


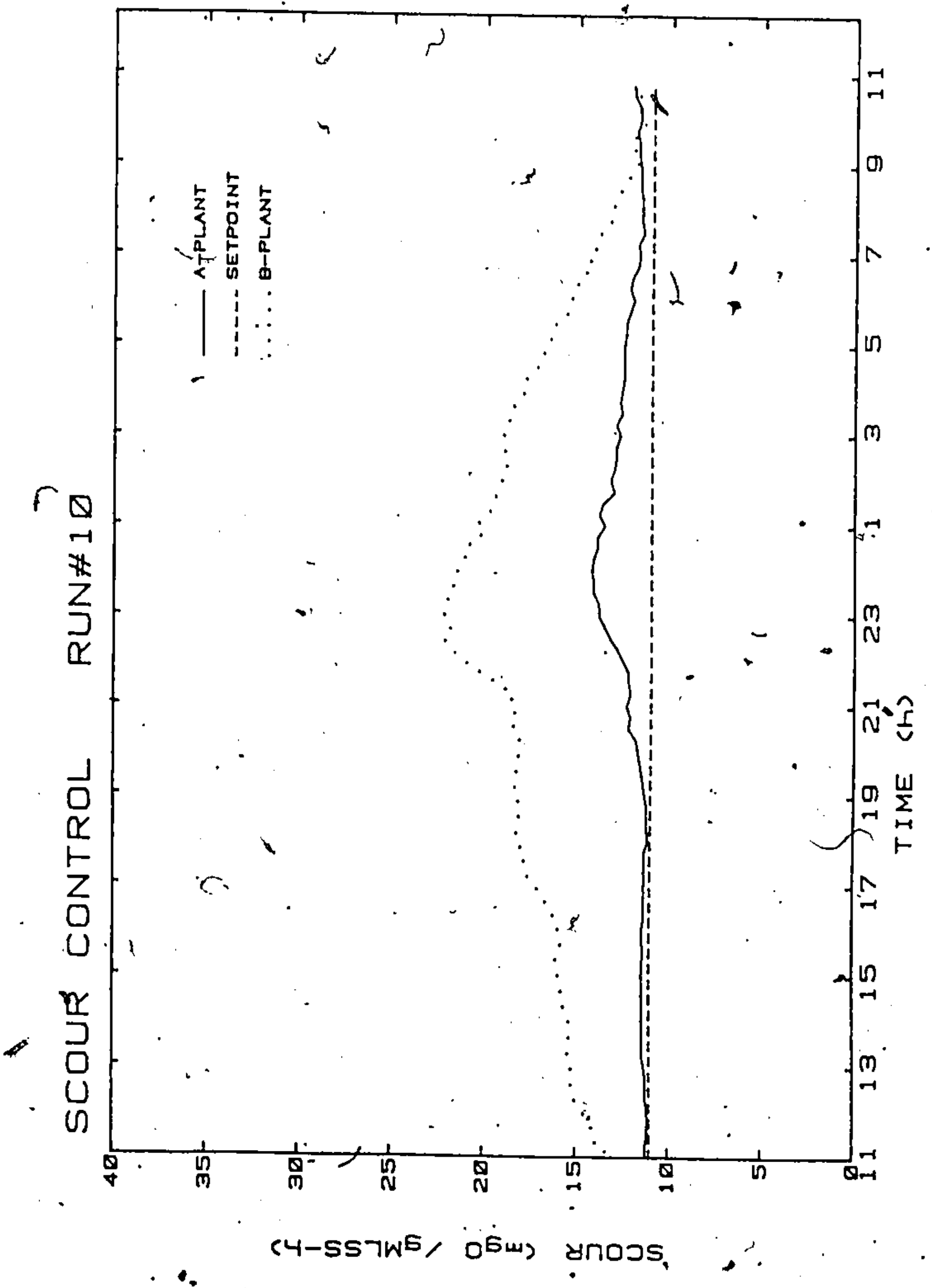

SCOUR CONTROL RUN#8
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
0
5
10
15
20
25
30
35
40
TIME (h)
12
14
16
18
20
22
0
2
4
6
8
10
12

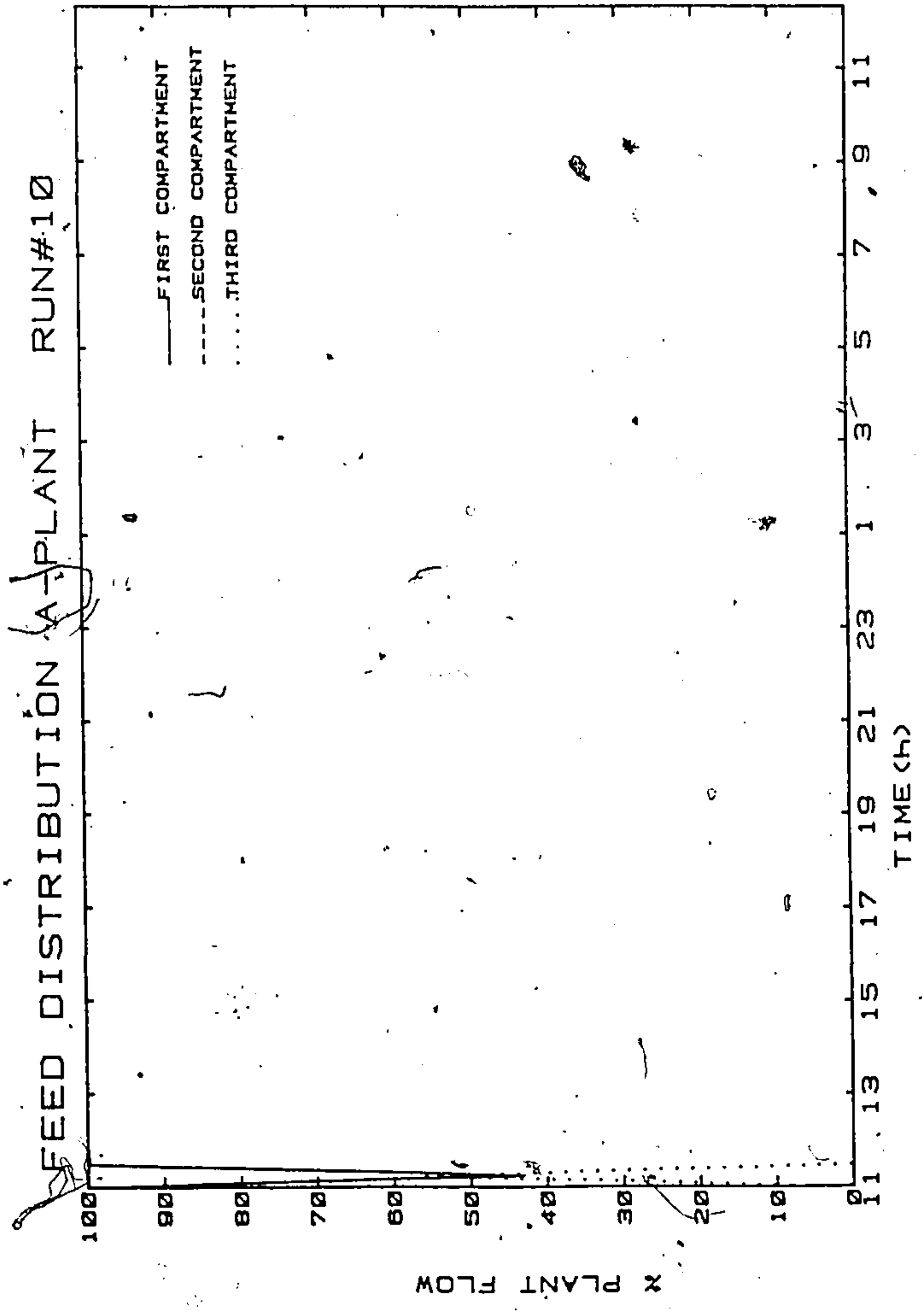
FEED DISTRIBUTION A-PLANT RUN#8

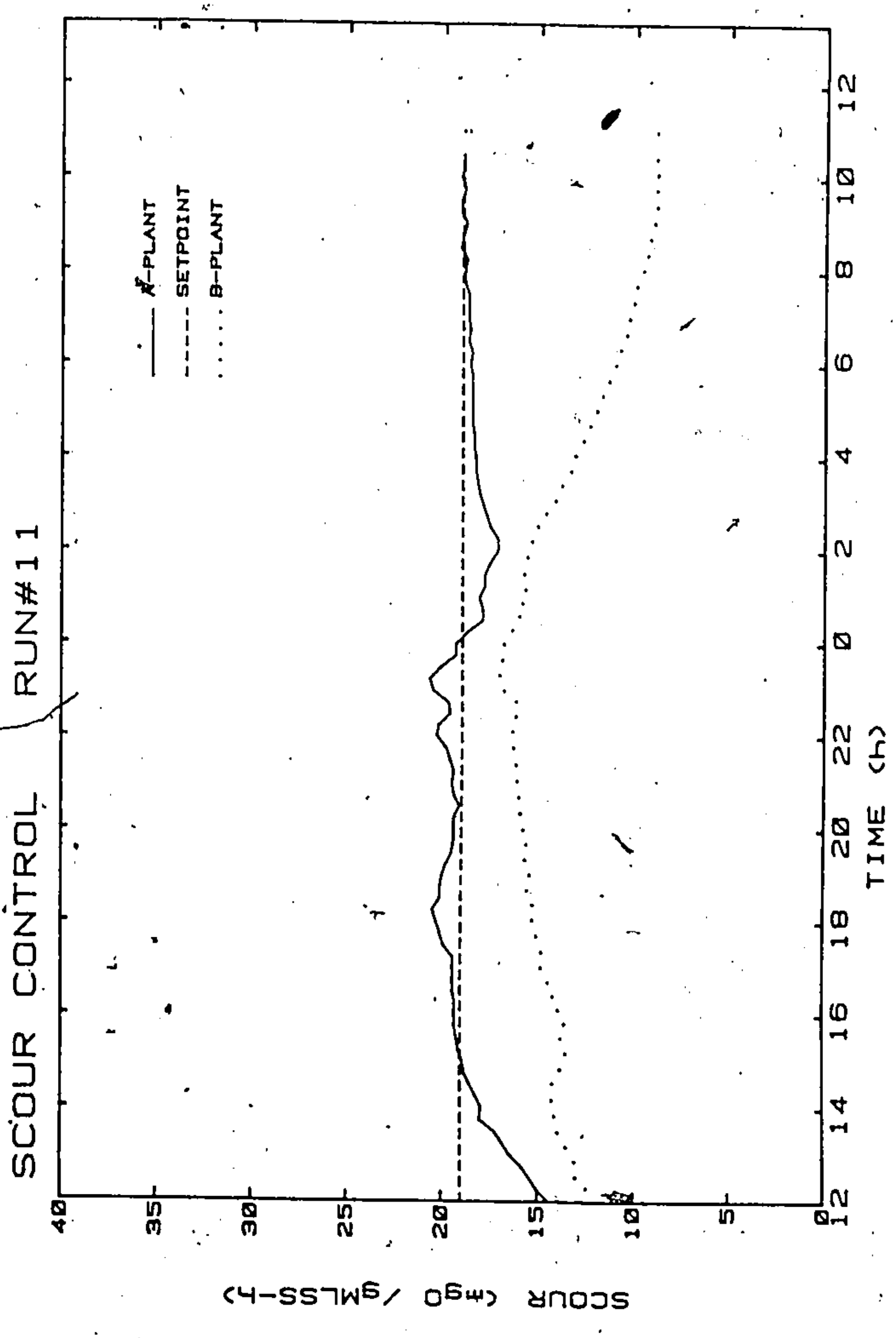


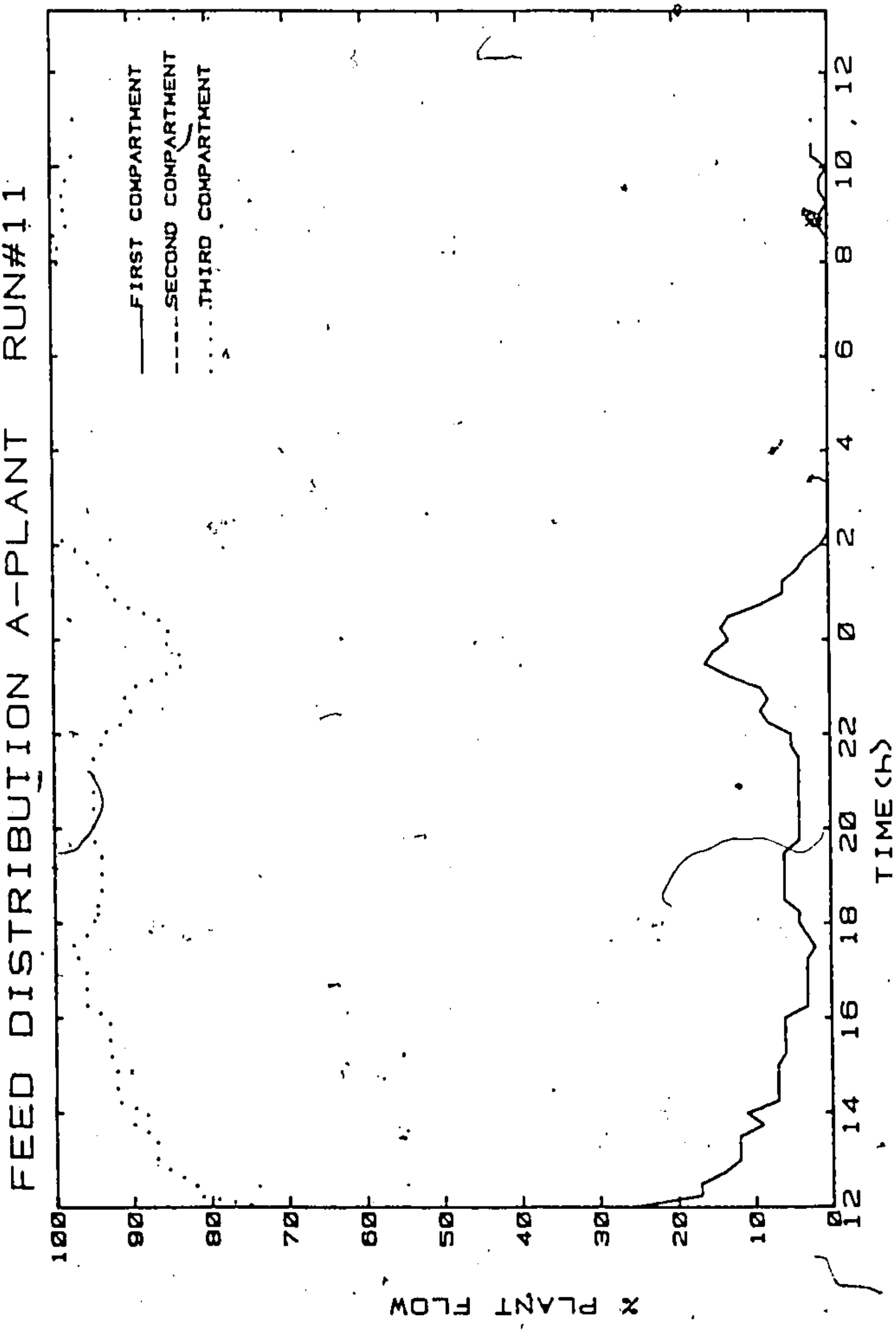

SCOUR CONTROL RUN#9
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
40
35
30
25
20
15
10
5
0
20
.22
0
2
4
6
8
10
12
14
16
18
20
TIME (h)

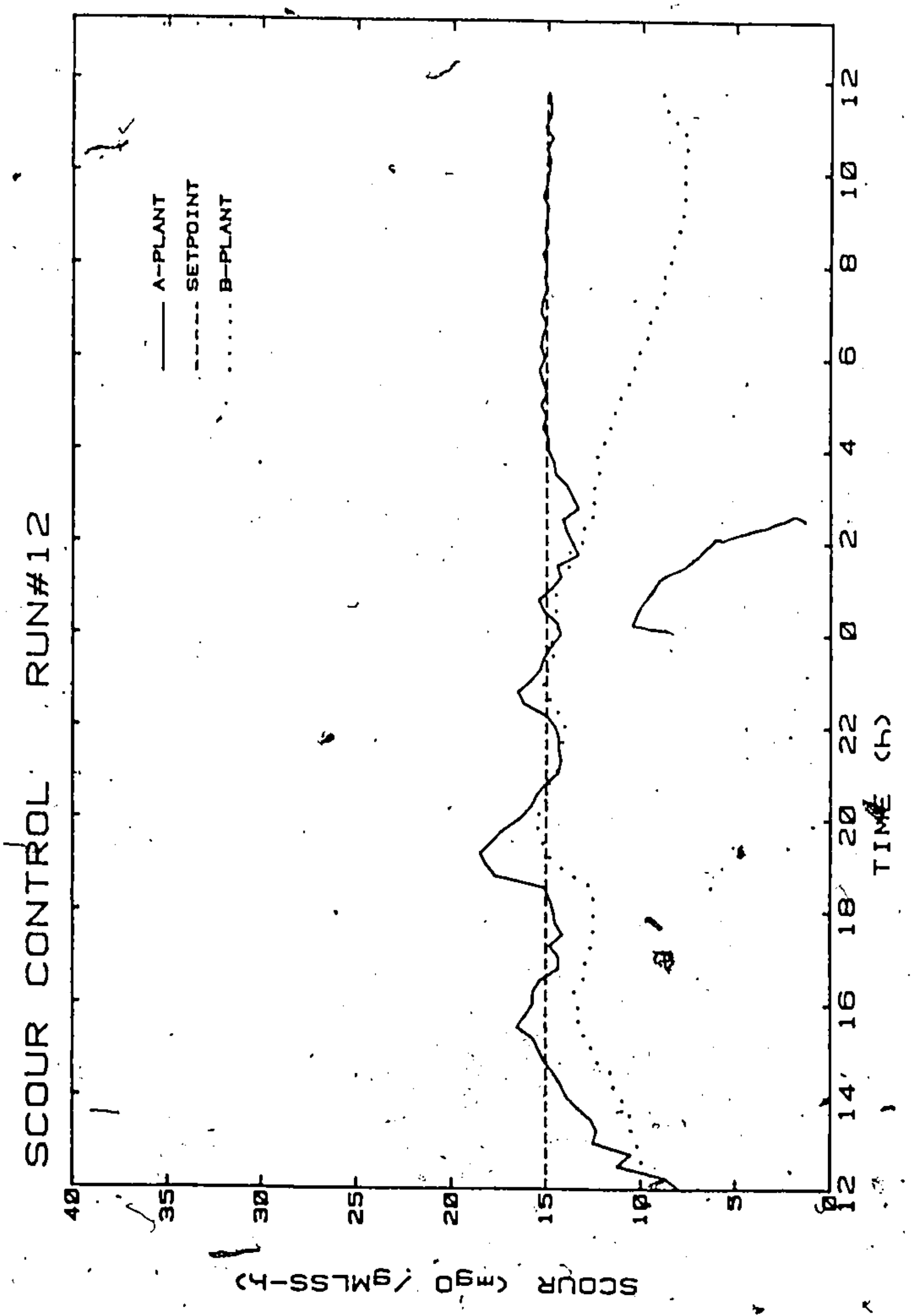

FEED DISTRIBUTION A-PLANT RUN#9
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
100
90
80
70
60
50
40
30
20
10
0
20
22
0
2
4
6
8
10
12
14
16
18
20
TIME (h)


SCOUR CONTROL RUN#10

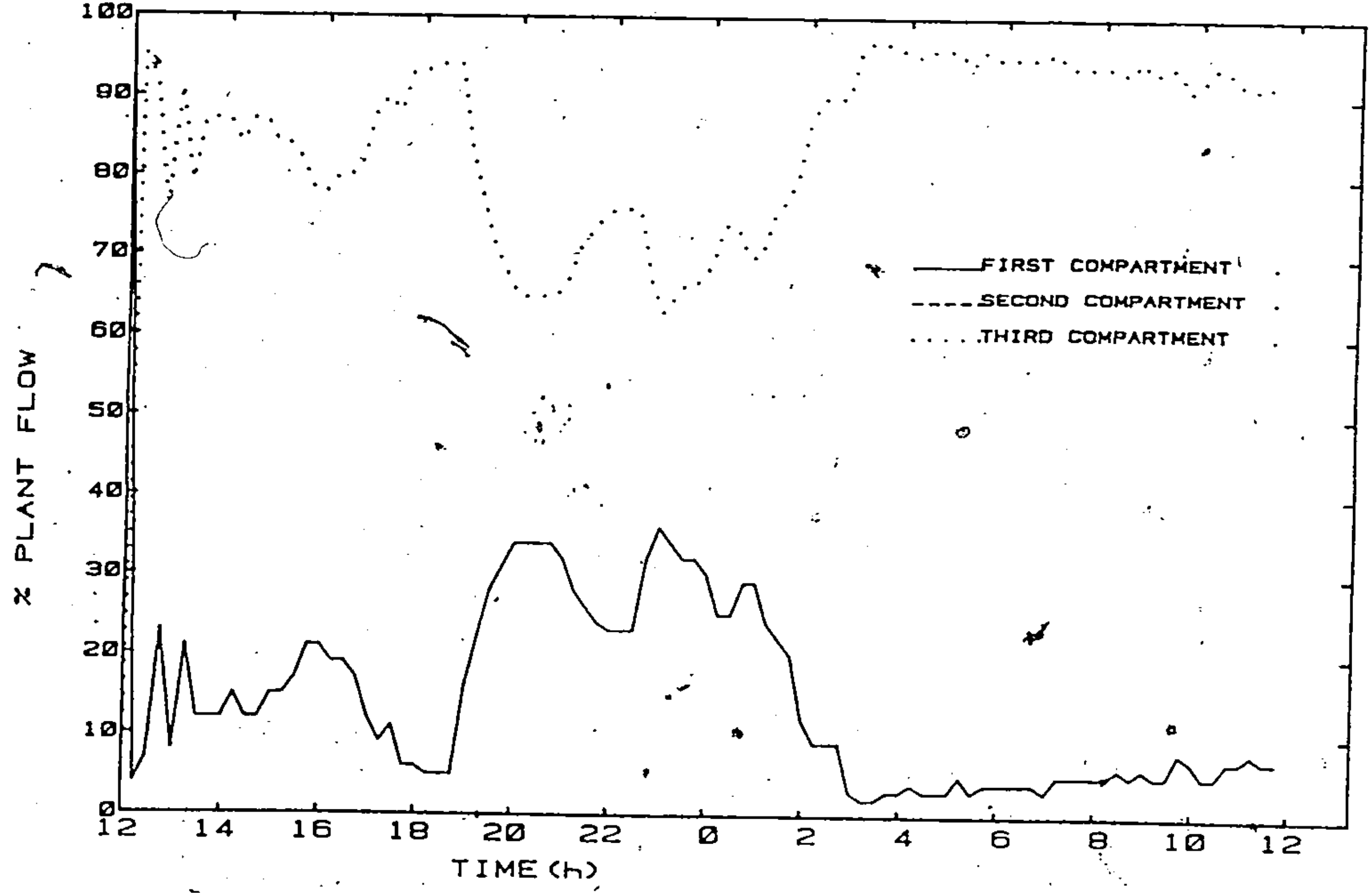

FEED DISTRIBUTION A-PLANT RUN#10
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
100
90
80
70
60
50
40
30
20
10
0
TIME (h)
11
13
15
17
19
21
23
1
3
5
7
9
11


SCOUR CONTROL RUN#11
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
0
5
10
15
20
25
30
35
40
12
14
16
18
20
22
0
2
4
6
8
10
12
TIME (h)


FEED DISTRIBUTION A-PLANT RUN#11
FIRST COMPARTMENT
SECOND COMPARTMENT
THIRD COMPARTMENT
% PLANT FLOW
0
10
20
30
40
50
60
70
80
90
100
TIME (h)
12
14
16
18
20
22
0
2
4
6
8
10
12


SCOUR CONTROL RUN#12
A-PLANT
SETPOINT
B-PLANT
SCOUR (mgO /gMLSS-h)
40
35
30
25
20
15
10
5
0
12
14
16
18
20
22
0
2
4
6
8
10
12
TIME (h)

FEED DISTRIBUTION A-PLANT RUN#12



## G.1 — CLEMSON MODEL

```
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FTN4,X,L
      PROGRAM BIO63 ( ,290)
C
C CLEMSON MODEL
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON TP,TP2,I,LL,M,N,NE,SCOUR(100,4),OUR(100,4)
      COMMON  Q,SI,ALPHA(4),W,CXR,SHR,CTR,CIR,CIN,HL(100,4)
      COMMON CX(100,4),SB(100,4),SH(100,4),CO(100,4),CI(100,4)
      DIMENSION YI(20),DERY(20),AUX(8,20),PRMT(5),IP(5),TITLE(25)
      DIMENSION IDCB(144),JBUF(60),NAME(3)
      EXTERNAL OUTP,MODEL
      DATA NAME/2HBI,2HOL,2H1 /
      DATA TITLE/2HBI,2HO6,2H3 ,2H  ,2H  ,2HSE,2HC ,2HS.,2H3 /
      CALL RMPAR(IP)
      LU=IP(1)
      LL=IP(2)
      NUM=IP(3)
C
C  NUM  - PERIOD OF INTEGRATION
C  LR   - INTERVAL PRINTOUT FOR INTEGRATION
C  N    - NUMBER OF TANKS
C  TP   - INITIAL STARTING TIME
C
C
C  W    - WASTE FLOW RATIO
C  CX   - AERATOR ACTIVE BIOMASS CONC.
C  SM   - AERATOR STORED MASS CONC.
C  CI   - AERATOR INERT BIOMASS(NON-VIABLE) CONC.
C  CT   - MLVSS (CX+SM+CI)
C  CXR - RECYCLE ACTIVE BIOMASS CONC.
C  SHR - RECYCLE STORED MASS CONC.
C  CIR - RECYCLE INERT BIOMASS CONC.
C  CIR - RECYCLE VSS
C
C
      LR=IP(4)
      N=IP(5)
      M=N+1
C
C INITIAL CONDITIONS
C
C
      W=.0220D0
      CXR=3000.D0
      SHR=200.0D0
      CIR=1000.D0
      CTR=CXR+SHR+CIR
      DO 6 K=1,N
      K2=K+N
      K3=K2+N
      K4=K3+N
      K5=K4+N
      YI(K)=1000.D0
      YI(K2)=20.D0
```

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          YI(K3)=100.D0
          YI(K4)=300.D0
          YI(K5)=4.D0
    6     CONTINUE
          TP2=.25D0
          NUM2=NUM*4
          TP=0.D+0
          NE=5
          NDIM=N*NE
C
C  ALPHA- STEP FEED CONTACTING PATTERN
C
          WRITE(LU,820)N
          READ(LU,*)(ALPHA(J),J=1,N)
C
C  Q     - PLANT FLOW
C  SI    - INFLUENT SUBSTRATE CONC.
C  CIN   - INFLUENT INERT BIOMASS CONC.
C
          Q=420.93D0
          SI=130.D0*1.56
          CIN= 70.D0
          I=1
          WRITE(LL,902)TITLE
          WRITE(LL,903)(ALPHA(J),J=1,N)
          WRITE(LL,907)NUM,LR
C
C CALL RUNGE KUTTA INTEGRATION ROUTINE
C
C
          XNUM=NUM
          PRMT(1)=0.D0
          PRMT(2)=XNUM
          PRMT(3)=1.D-02
          PRMT(4)=1.D-03
          PRMT(5)=0.D0
          CALL RUNGE(PRMT,YI,DERY,NDIM,IHLF,MODEL,OUTP,AUX)
C
C  WRITE RESULTS TO DISC FILE
C
          IOP=3B
          CALL OPEN(IDCB,IERR,NAME,IOP)
          IF(IERR.LT.0)WRITE(LL,888)IERR,(JBUF(K),K=1,60)
  888     FORMAT(1X,"ACCESS ERROR$",I5,/,30A2)
          CALL CODE
          WRITE(JBUF,901)TITLE
          CALL WRITF(IDCB,IERR,JBUF,60)
          IF(IERR.LT.0)WRITE(LL,888)IERR,(JBUF(J),J=1,60)
          DO 39 J=1,60
   39     JBUF(J)=2H
          DO 29 I=1,NUM2
          NX=NE+3
          DO 21 I2=1,NX
          GO TO(51,52,53,54,55,56,59,599),I2
   51     CALL CODE
```

```
PAGE 0003  BI063  3:38 PM  WED.,  9  SEP., 1981

                WRITE(JBUF,817)I
                GO TO 57
        52      CALL CODE
                WRITE(JBUF,818)(CX(I,J),J=1,N)
                GO TO 57
        53      CALL CODE
                WRITE(JBUF,818)(SB(I,J),J=1,N)
                GO TO 57
        54      CALL CODE
                WRITE(JBUF,818)(SM(I,J),J=1,N)
                GO TO 57
        55      CALL CODE
                WRITE(JBUF,818)(CI(I,J),J=1,N)
                GO TO 57
        56      CALL CODE
                WRITE(JBUF,818)(CO(I,J),J=1,N)
                GO TO 57
        59      CALL CODE
                WRITE(JBUF,818)(SCOUR(I,J),J=1,N)
                GO TO 57
        599     CALL CODE
                WRITE(JBUF,818)(OUR(I,J),J=1,N)
        57      CONTINUE
                CALL WRITF(IDCB,IERR,JBUF,60)
                IF(IERR.LT.0)WRITE(LL,888)IERR,(JBUF(J),J=1,60)
                DO 58 I3=1,60
        58      JBUF(I3)=2H
        21      CONTINUE
        817     FORMAT(I5)
        28      CONTINUE
                CALL CLOSE(IDCB)
        820     FORMAT(1X,"INPUT DISTRIBUTION PATTERN FOR",1X,I2,1X,"TANKS")
        900     FORMAT(1X,"INPUT TITLE")
        901     FORMAT(25A2)
        902     FORMAT("1",/,15X,25A2, /,100("-"))
        903     FORMAT(1X,"DISTRIBUTION PATTERN=",4(E10.2,1X,))
        908     FORMAT(I4,16(D9.5,1X))
        907     FORMAT(//1X,"INTEGRATIONS  #=",I4,2X,"INTERVAL=",I4,/,100("-"))
        920     FORMAT(A2)
        818     FORMAT(1X,3(F9.3,1X))
        500     STOP
                END

FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

**  NO WARNINGS **  NO ERRORS **   PROGRAM = 01783       COMMON = 08117
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           SUBROUTINE MODEL(T,YI,DERY)
      C
      C RUNGE KUTTA ROUTINE USED TO DEFINE DIFF.EQ.
      C
           IMPLICIT DOUBLE PRECISION (A-H,P-Z)
           COMMON TP,TP2,I,LL,K,N,NE,SCOUR(100,4),OUR(100,4)
           COMMON  Q,SI,ALPHA(4),W,CXR,SHR,CTR,CIR,CIN,ML(100,4)
           DIMENSION D(4),V(4),FS(4),CT(4)
           DIMENSION BETA(5),YI(1),DERY(1)
      C
      C SYSTEM CONSTANTS
      C
      C  VT   - TOTAL REACTOR VOLUME
      C  V    - SINGLE TANK VOLUME
      C  R    - RECYCLE RATIO
      C  SRT  - SLUDGE RETENTION TIME
      C  CXE  - ACTIVE BIOMASS EFFLUENT CONC.
      C  SHE  - STORED MASS EFFLUENT CONC.
      C  CIE  - INERT BIOMASS EFFLUENT CONC.
      C
      C RATE CONSTANTS & YIELDS
      C
      C  UXHAT-MAXIMUM SPECIFIC BIOMASS GROWTH RATE
      C  XKXS -ACTIVE MASS SATURATION COEFFICIENT
      C  DX   -ENDOGENOUS DECAY RATE
      C  RS   -ADSORPTION TRANSFER RATE COEFFICIENT
      C  FSHAT-MAXIMUM FRACTION OF SB TO MLVSS
      C  XKS  -ADSORPTION , ABSORPTION COEFFICIENT
      C  YX   -ACTIVE MASS YIELD
      C  XKLA -OXYGEN TRANSFER RATE
      C  YZ   -INERT MASS YIELD
      C  CS   -OXYGEN SATURATION CONC.
      C
      C
      C
          DATA VT/2200.D0/,R/.30D0/,SRT/72.00D0/
          DATA CXE/10.0D0/,SHE/.660D0/,CIE/3.50D0/
          DATA UXHAT/.30D0/,XKXS/.20D0/,DX/.015D0/,RS/5.D0/,FSHAT/.45D0/
          DATA XKS/150.D0/,YX/.66D0/
          DATA XKLA/5.D0/,YZ/.25D0/,CS/10.D0/
          IF(T.GT.0.D0)GO TO 10
          WRITE(LL,11)R,SRT,CXE,SHE,SI,Q,VT,CIE
   11     FORMAT(//,5X,"SYSTEM CONSTANTS",/,5X,
         ("R          SRT        CXE        SHE",/,5X,4(D9.4,1X),/,5X,
         ("SI         Q          VT         CIE",/,5X,4(D9.4,1X))
          WRITE(LL,12)UXHAT,XKXS,DX,RS,FSHAT,XKS,YX,XKLA,YZ,CS
   12     FORMAT(//,5X,"MODEL CONSTANTS",/,5X,
         ("UXHAT      XKXS       DX         RS         FSHAT      ",
         (/,5X,5(D9.4,1X),/,5X,
         ("XKS        YX         XKLA       YZ         CS         ",
         (/,5X,5(D9.4,1X))
          NDIM=N*NE
          WRITE(LL,13)CXR,SHR,CIR,(YI(KK),KK=1,NDIM)
   13     FORMAT(//,5X,"INITIAL CONDITIONS",/,5X,
         ("CXR        SHR        CIR",/,
```

```
PAGE 0005  MODEL  3:38 PM  WED.,  9  SEP., 1981

         (5X,3(D9.4,1X),/,5X,"YI(N)",/,5(/,5X,3(D9.4,1X)))
          WRITE(LL,14)
     14   FORMAT("1")
C
C
     10   SUM=0.D0
          CTE=CXE+SME+CIE
          DO 20 K=1,N
          DO 21 L2=1,NDIM
     21   YI(L2)=DMAX1(0.D0,YI(L2))
          L=K+1
          K2=K+N
          K3=K2+N
          K4=K3+N
          K5=K4+N
          GO TO (30,40,40,40),K
     30   Z1=CXR
          Z2=YI(N*2)
          Z3=SMR
          Z4=CIR
          Z5=0.D0
          GO TO 50
     40   Z1=YI(K-1)
          Z2=YI(K2-1)
          Z3=YI(K3-1)
          Z4=YI(K4-1)
          Z5=YI(K5-1)
     50   CONTINUE
          CT(K)=YI(K)+YI(K3)+YI(K4)
          FS(K)=YI(K3)/CT(K)
          V(1)=VT/N
          V(2)=VT/N
          V(3)=VT/N
          D(K)=Q/V(K)
          BETA(1)=0.D0
          BETA(L)=BETA(K)+ALPHA(K)
          U1=UXHAT*(FS(K)/(XKXS+FS(K)))
          U2=RS*CT(K)*((FSHAT*(YI(K2)/(XKS+YI(K2))))-FS(K))
C
C ACTIVE BIOMASS BALANCE
C
          DERY(K)=D(K)*((BETA(L-1)+R)*Z1-(BETA(L)+R)*YI(K))+
         ((U1-DX)*YI(K)
C
C SUBSTRATE BALANCE
C
          DERY(K2)=D(K)*(ALPHA(K)*SI+(BETA(L-1)+R)*Z2-(BETA(L)+R)*
         (YI(K2))-U2
C
C STORED MASS BALANCE
C
          DERY(K3)=D(K)*((BETA(L-1)+R)*Z3-(BETA(L)+R)*YI(K3))+
         (U2-(U1*YI(K)/YX)
C
C INERT MASS BALANCE
```

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C
       DERY(K4)=D(K)*(ALPHA(K)*CIN+(BETA(L-1)+R)*Z4-(BETA(L)+R)*
      (YI(K4))+YZ*DX*YI(K)
C
C OXYGEN BALANCE
C
       DERY(K5)=D(K)*((BETA(L-1)+R)*Z5-(BETA(L)+R)*YI(K5))+
      (XKLA*(CS-YI(K5))-(((1.D0-YX)/YX)*U1*YI(K))-(1.D0-YZ)
      (*DX*YI(K)
C
C SCOUR
C
      SCOUR(I,K)=(((1.D0-YX)/YX)*U1+(1.D0-YZ)*DX)*1000.D0
      OUR(I,K)=(SCOUR(I,K)*YI(K)*V(K))/(1000.D0*1000.D0)
      SUM=SUM+CT(K)
      ML(I,K)=CT(K)/.735D0
C
   20 CONTINUE
      CTAVE=SUM/N
      W=(VT*CTAVE-Q*CTE*SRT)/(Q*CTR*SRT-Q*CTE*SRT)
      CXR=((1.D0+R)*YI(N)-(1.D0-W)*CXE)/(R+W)
      NX1=N*3
      SMR=((1.D0+R)*YI(NX1 )-(1.D0-W)*SME)/(R+W)
      NX2=(NE-1)*N
      IF(N.EQ.1)NX2=NE-1
      CIR=((1.D0+R)*YI(NX2)-(1.D0-W)*CIE)/(R+W)
      CTR=SMR+CXR+CIR
      IF(TP.LT.8) GO TO 300
      ALPHA(1)=0.D0
      ALPHA(2)=0.D0
      ALPHA(3)=1.D0
      ALPHA(4)=0.D0
  300 CONTINUE
D     WRITE(LL,396)CTAVE,SUM,W,CTE,SRT,CTR,CXR,CXE,SMR,SME,CIR,CIE
D    (,CTR,YI(NX1 ),YI(NX2)
  396 FORMAT(5X," CTAVE  SUM  W  CTE  SRT  CTR  CXR  CXE  SMR  SME"
     (," CIR  CIE  CTR",15(/,5X,D9.4))
D     WRITE(LL,397)N,NX1,NX2,NE
  397 FORMAT(5X," N NX NX2 NE",5(/,5X,I5))
      RETURN
      END


FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

**  NO WARNINGS **  NO ERRORS **   PROGRAM = 01690      COMMON = 02447
```

```
PAGE 0007  FTN.   3:38 PM  WED.,  9  SEP., 1981

      SUBROUTINE OUTP(T,YI,DERY,IHLF,NDIM,PRMT)
C
C RUNGE KUTTA OUTPUT
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON TP,TP2,I,LL,M,N,NE,SCOUR(100,4),OUR(100,4)
      DIMENSION YI(1),DERY(1)
      IF(T-TP.GE.TP2)CALL PRINT(YI,T,NDIM)
      RETURN
      END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00035      COMMON = 02011
```

```
PAGE 0008  FTN.   3:38 PM  WED.,  9  SEP., 1981

      SUBROUTINE PRINT(YI,T,NDIM)
C
C PRINT ROUTINE
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON TP,TP2,I,LL,M,N,NE,SCOUR(100,4),DUR(100,4)
      COMMON Q,SI,ALPHA(4),W,CXR,SMR,CTR,CIR,CIN,ML(100,4)
      COMMON CX(100,4),SB(100,4),SM(100,4),CO(100,4),CI(100,4)
      DIMENSION YI(1)
      LX=55
      IF(I.NE.100)GO TO 66
      LX=LL
      WRITE(LX,67)
   67 FORMAT("1",1X,"STEADY STATE VALUES ",25A2)
   66 WRITE(LX,900)I
      DO 30 K=1,N
      K2=K+N
      K3=K2+N
      K4=K3+N
      K5=K4+N
      CX(I,K)=YI(K)
      SB(I,K)=YI(K2)*.64
      SM(I,K)=YI(K3)
      CI(I,K)=YI(K4)
      CO(I,K)=ML(I,K)
      SCOUR(I,K)=SCOUR(I,K)*.735
   30 CONTINUE
      WRITE(LX,901)(CX(I,J),J=1,N)
      WRITE(LX,901)(SB(I,J),J=1,N)
      WRITE(LX,901)(SM(I,J),J=1,N)
      WRITE(LX,901)(CI(I,J),J=1,N)
      WRITE(LX,901)(CO(I,J),J=1,N)
      WRITE(LX,901)(SCOUR(I,J),J=1,N)
      WRITE(LX,901)(DUR(I,J),J=1,N)
      WRITE(LX,902)W,CTR
  900 FORMAT(1X,I5)
  901 FORMAT(1X,5(F9.3,1X))
  902 FORMAT(1X,2(F9.3,1X))
      TP=TP+TP2
      I=I+1
      RETURN
      END

 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00432      COMMON = 08447
```

```
      SUBROUTINE RUNGE(PRMT,Y,DERY,NDIM,IHLF,MODEL,OUTP,AUX)
C..........................................................................
C
C
C
C     PURPOSE
C        TO SOLVE A SYSTEM OF FIRST ORDER ORDINARY DIFFERENTIAL
C        EQUATIONS WITH GIVEN INITIAL VALUES
C
C     USAGE
C
C        CALL RUNGE (PARAMETER LIST)
C        PARAMETERS FCT AND OUTP REQUIRE AN EXTERNAL STATEMENT
C
C     DESCRIPTION OF PARAMETERS
C        PRMT   - AN INPUT AND OUTPUT VECTOR WITH DIMENSION GREATER
C                 OR EQUAL TO 5, WHICH SPECIFIES THE PARAMETERS OF
C                 THE INTERVAL AND OF ACCURACY AND WHICH SERVES FOR
C                 COMMUNICATION BETWEEN OUTPUT SUBROUTINE (FURNISHED
C                 BY THE USER) AND SUBROUTINE RUNGE.  EXCEPT PRMT(5)
C                 THE COMPONENTS ARE NOT DESTROYED BY SUBROUTINE
C                 RUNGE AND THEY ARE
C        PRMT(1)- LOWER BOUND OF THE INTERVAL (INPUT)
C        PRMT(2)- UPPER BOUND OF THE INTERVAL (INPUT)
C        PRMT(3)- INITIAL INCREMENT OF THE INDEPENDENT VARIABLE
C                 (INPUT)
C        PRMT(4)- UPPER ERROR BOUND (INPUT).  IF ABSOLUTE ERROR IS
C                 GREATER THAN PRMT(4), INCREMENT GETS HALVED.
C                 IF INCREMENT IS LESS THAN PRMT(3) AND ABSOLUTE
C                 ERROR LESS THAN PRMT(4)/50, INCREMENT GETS DOUBLED
C                 THE USER MAY CHANGE PRMT(4) BY MEANS OF HIS
C                 OUTPUT SUBROUTINE
C        PRMT(5)- NO INPUT PARAMETER.  SUBROUTINE RUNGE INITIALIZES
C                 PRMT(5)=0.  IF THE USER WANTS TO TERMINATE
C                 SUBROUTINE RUNGE AT ANY OUTPUT POINT, HE HAS TO
C                 CHANGE PRMT(5) TO A NON-ZERO BY MEANS OF SUBROUTINE
C                 OUTP.  FURTHER COMPONENTS OF VECTOR PRMT ARE FEASIBLE
C                 IF ITS DIMENSION IS DEFINED GREATER THAN 5.
C                 HOWEVER SUBROUTINE RUNGE DOES NOT REQUIRE AND
C                 CHANGE THEM.  NEVERTHELESS THEY MAY BE USEFUL
C                 FOR HANDING RESULT VALUES TO THE MAIN PROGRAM
C                 WHICH ARE OBTAINED BY SPECIAL MANIPULATIONS WITH
C                 WITH OUTPUT DATA IN SUBROUTINE OUTP.
C        Y      - INPUT VECTOR OF INITIAL VALUES.  (DESTROYED)
C                 LATER ON Y IS THE RESULT VECTOR OF DEPENDENT
C                 VARIABLES COMPUTED AT INTERMEDIATE POINTS X.
C        DERY   - INPUT VECTOR OF ERROR WEIGHTS.  (DESTROYED)
C                 THE SUM OF ITS COMPONENTS MUST BE EQUAL TO 1.
C                 LATER ON DERY IS THE VECTOR OF DERIVATIVES,WHICH
C                 BELONG TO FUNCTION VALUES Y AT A POINT X.
C        NDIM   - AN INPUT VALUE, WHICH SPECIFIES THE NUMBER OF
C                 EQUATIONS IN THE SYSTEM.
C        IHLF   - AN OUTPUT VALUE, WHICH SPECIFIES THE NUMBER OF
C                 BISECTIONS OF THE INITIAL INCREMENT.  IF IHLF GETS
C                 GREATER THAN 10, SUBROUTINE RUNGE RETURNS WITH
```

```
C                  ERROR MESSAGE IHLF=11 INTO MAIN PROGRAM.  ERROR
C                  MESSAGE IHLF=12 OR IHLF=13 APPEARS IN CASE
C                  PRMT(3)=0 OR IN CASE SIGN(PRMT(3)) .NE.SIGN(PRMT(2)-
C                  -PRMT(1) RESPECTIVELY.
C        FCT     - THE NAME OF AN EXTERNAL SUBROUTINE USED.  THIS
C                  SUBROUTINE COMPUTES THE RIGHT HAND SIDES DERY OF
C                  THE SYSTEM TO GIVEN VALUES X AND Y.  ITS PARAMETER
C                  LIST MUST BE X,Y,DERY.  SUBROUTINE FCT SHOULD NOT
C                  DESTROY X AND Y.
C        OUTP    - THE NAME OF AN EXTERNAL OUTPUT SUBROUTINE USED.
C                  ITS PARAMETER LIST MUST BE X,Y,DERY,IHLF,NDIM,PRMT.
C                  NONE OF THESE PARAMETERS (EXCEPT IF NECESSARY,
C                  PRMT(4),PRMT(5),...) SHOULD BE CHANGED BY
C                  SUBROUTINE OUTP.  IF PRMT(5) IS CHANGED TO NON-ZERO
C                  RUNGE IS TERMINATED.
C        AUX     - AN AUXILIARY STORAGE ARRAY WITH 8 ROWS AND NDIM
C                  COLUMNS.
C
C
C     REMARKS
C        THE PROCEDURE TERMINATES AND RETURNS TO CALLING PROGRAM, IF
C        (1) MORE THAN 10BISECTIONS OF THE INITIAL INCREMENT ARE
C            NECESSARY TO GET SATISFACTORY ACCURACY (IHLF=11)
C        (2) INITIAL INCREMENT IS EQUAL TO 0 OR HAS WRONG SIGN
C            (IHLF=12 OR 13)
C        (3) THE WHOLE INTEGRATION INTERVAL IS WORKED THROUGH,
C        (4) SUBROUTINE OUTP HAS CHANGED PRMT(5) TO NON-ZERO
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        THE EXTERNAL SUBROUTINES FCT AND OUTP MUST BE
C        FURNISHED BY THE USER
C
C     METHOD
C        EVALUATION IS DONE BY MEANS OF FOURTH ORDER RUNGE-KUTTA
C        FORMULAE IN THE MODIFICATION DUE TO GILL.  ACCURACY IS
C        TESTED COMPARING THE RESULTS OF THE PROCEDURE WITH SINGLE
C        AND DOUBLE INCREMENT.
C        SUBROUTINE RUNGE AUTOMATICALLY ADJUSTS THE INCREMENT DURING
C        THE WHOLE COMPUTATION BY HALVING OR DOUBLING.  IF MORE THAN
C        10 BISECTIONS OF THE INCREMENT ARE NECESSARY TO GET
C        SATISFACTORY ACCURACY, THE SUBROUTINE RETURNS WITH
C        ERROR MESSAGE IHLF=11 INTO MAIN PROGRAM.
C        TO GET FULL FLEXIBILITY IN OUTPUT, AND OUTPUT SUBROUTINE
C        MUST BE FURNISHED BY THE USER.
C        WILEY, NEW YORK/LONDON,1960,PP.110-120.
C
C.......................................................................
C
C
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
C
      DIMENSION Y(1),DERY(1),AUX(8,1),A(4),B(4),C(4),PRMT(1)
      DO 1 I=1,NDIM
    1 AUX(8,I)=.06666667*DERY(I)
```

```
      X=PRMT(1)
      XEND=PRMT(2)
      H=PRMT(3)
      PRMT(5)=0.
      CALL MODEL(X,Y,DERY)
C
C     ERROR TEST
      IF(H*(XEND-X))38,37,2
C
C     PREPARATIONS FOR RUNGE-KUTTA METHOD
    2 A(1)=.5
      A(2)=.2928932
      A(3)=1.707107
      A(4)=.1666667
      B(1)=2.
      B(2)=1.
      B(3)=1.
      B(4)=2.
      C(1)=.5
      C(2)=.2928932
      C(3)=1.707107
      C(4)=.5
C
C     PREPARATIONS OF FIRST RUNGE-KUTTA STEP
      DO 3 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=0.
    3 AUX(6,I)=0.
      IREC=0
      H=H+H
      IHLF=-1
      ISTEP=0
      IEND=0
C
C
C     START OF A RUNGE-KUTTA STEP
    4 IF((X+H-XEND)*H)7,6,5
    5 H=XEND-X
    6 IEND=1
C
C     RECORDING OF INITIAL VALUES OF THIS STEP
    7 CALL OUTP(X,Y,DERY,IREC,NDIM,PRMT)
      IF(PRMT(5))40,8,40
    8 ITEST=0
    9 ISTEP=ISTEP+1
C
C
C     START OF INNERMOST RUNGE-KUTTA LOOP
      J=1
   10 AJ=A(J)
      BJ=B(J)
      CJ=C(J)
      DO 11 I=1,NDIM
      R1=H*DERY(I)
```

```
      R2=AJ*(R1-BJ*AUX(6,I))
      Y(I)=Y(I)+R2
      R2=R2+R2+R2
   11 AUX(6,I)=AUX(6,I)+R2-CJ*R1
      IF(J-4)12,15,15
   12 J=J+1
      IF(J-3)13,14,13
   13 X=X+.5*H
   14 CALL MODEL(X,Y,DERY)
      GOTO 10
C     END OF INNERMOST RUNGE-KUTTA LOOP
C
C
C     TEST OF ACCURACY
   15 IF(ITEST)16,16,20
C
C     IN CASE ITEST=0 THERE IS NO POSSIBILITY FOR TESTING OF ACCURACY
   16 DO 17 I=1,NDIM
   17 AUX(4,I)=Y(I)
      ITEST=1
      ISTEP=ISTEP+ISTEP-2
   18 IHLF=IHLF+1
      X=X-H
      H=.5*H
      DO 19 I=1,NDIM
      Y(I)=AUX(1,I)
      DERY(I)=AUX(2,I)
   19 AUX(6,I)=AUX(3,I)
      GOTO 9
C
C     IN CASE ITEST=1 TESTING OF ACCURACY IS POSSIBLE
   20 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)21,23,21
   21 CALL MODEL(X,Y,DERY)
      DO 22 I=1,NDIM
      AUX(5,I)=Y(I)
   22 AUX(7,I)=DERY(I)
      GOTO 9
C
C     COMPUTATION OF TEST VALUE DELT
   23 DELT=0.
      DO 24 I=1,NDIM
   24 DELT=DELT+AUX(8,I)*DABS(AUX(4,I)-Y(I))
      IF(DELT-PRMT(4))28,28,25
C
C     ERROR IS TOO GREAT
   25 IF(IHLF-10)26,36,36
   26 DO 27 I=1,NDIM
   27 AUX(4,I)=AUX(5,I)
      ISTEP=ISTEP+ISTEP-4
      X=X-H
      IEND=0
      GOTO 18
C
C     RESULT VALUES ARE GOOD
```

```
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   28 CALL MODEL(X,Y,DERY)
      DO 29 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=AUX(6,I)
      Y(I)=AUX(5,I)
   29 DERY(I)=AUX(7,I)
      CALL OUTP(X-H,Y,DERY,IHLF,NDIM,PRMT)
      IF(PRMT(5))40,30,40
   30 DO 31 I=1,NDIM
      Y(I)=AUX(1,I)
   31 DERY(I)=AUX(2,I)
      IREC=IHLF
      IF(IEND)32,32,39
C
C     INCREMENT GETS DOUBLED
   32 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      IF(IHLF)4,33,33
   33 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)4,34,4
   34 IF(DELT-.02*PRMT(4))35,35,4
   35 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      GOTO 4
C
C
C     RETURNS TO CALLING PROGRAM
   36 IHLF=11
      CALL MODEL(X,Y,DERY)
      GOTO 39
   37 IHLF=12
      GOTO 39
   38 IHLF=13
   39 CALL OUTP(X,Y,DERY,IHLF,NDIM,PRMT)
   40 RETURN
      END


FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

** NO WARNINGS ** NO ERRORS **  PROGRAM = 01220      COMMON = 00000
```

## G.2 — CONTROLLER MODEL

```
PAGE 0001  FTN.   2:29 PM  WED.,  9  SEP., 1981

FTN4,X,L
      BLOCK DATA MMM
C
C DYNAMIC STEP FEED CONTROL
C ON LINE CONTROL OPTIMIZING FLOW TO 1ST AND 3RD
C COMPARTMENTS.
C
C     SUBROUTINES
C       1.BAM-READS INPUT DATA FROM ONLINE FILE
C       2.EXEC-REAL TIME EXEC. CALLS FOR H-P 1000 SYSTEM
C       3.BOX-BOX COMPLEX,NON-LINEAR NUMERICAL OPTIMIZATION
C       4.RUNGE-4TH ORDER RUNGE KUTTA INTEGRATION
C       5.STEP1-OUTPUTS RESULTS TO FILE
C       6.MODEL-RUNGE KUTTA REFERENCE MODEL
C       7.OUTP-SENDS RUNGE KUTTA OUTPUT INTERVAL TO PRINT ROUTINE
C       8.PRINT-PRINTS INTEGRATION RESULTS AT EACH INTEGRATION INT.
C       9.RANDU-RANDOM NUMBER GENERATOR
C       10.LOCK-LOCKS PRINTER
C       11.OPANY-OPENS H-P TYPE 2 FILES
C       12.RDANY-READS H-P TYPE 2 FILES
C       13.ERR-FILE ACCESS ERROR ROUTINE
C       14.RNUM-H-P RESOURCE # ALLOCATION
C
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON /NAMR/ALPHA(3),TP,TP2,V2,V3,V1,LL,LU,Q,R,XRAS
      COMMON /NAME/INTS,REALS,FALPH,MESSR,SEED,LKK
      DIMENSION INTS(36),REALS(1000)
      END

 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 ** NO WARNINGS **  NO ERRORS **

BLOCK COMMON NAMR   SIZE =  00035

BLOCK COMMON NAME   SIZE =  03044
```

```
      PROGRAM FEED9( ,201)
C
C MAIN PROGRAM
C
C VARIABLES
C
C          XNUM-INTEGRATION INTERVAL
C          SETPT-SCOUR SETPOINT
C          XRAS-RECYCLE CC
C          XRQ-COMPACTION RATIO
C          V-COMPARTMENT VOLUME
C          R-RECYCLE RATIO
C          X1-MLSS COMPARTMENT #1
C          X2-MLSS COMPARTMENT #2
C          X3-MLSS COMPARTMENT #3
C          Q-PLANT FLOW
C          QR-RECYCLE FLOW
C          ALPHA-INFLUENT FLOW FRACTION TO EACH COMPARTMENT
C
      IMPLICIT DOUBLE PRECISION(A-H,P-Z)
      COMMON /NAMR/ALPHA(3),TP,TP2,V2,V3,V1,LL,LU,Q,R,XRAS
      COMMON /NAME/INTS,REALS,FALPH,MESSR,SEED,LKK
      DIMENSION IP(5),DERY(3),YI(3),PRMT(5),AUX(8,3),ITIME(5)
      DIMENSION TITLE(40),INTS(36),REALS(1000),VALS(10,30),KEY(15)
      DIMENSION XTIME(5),NAMP(3),XOPT(3),IBUFR(6),OOPT(3),OO2(3)
      DIMENSION NAMB(3),IPRAM(5)
      EXTERNAL OUTP,MODEL
      EQUIVALENCE (REALS(1),VALS(1,1)),(INTS(1),KEY(1))
      EQUIVALENCE (IBUFR(1),OOPT(1)),(IBUFR(3),OOPT(2))
      EQUIVALENCE (IBUFR(5),OOPT(3))
      DATA NAMP/2HFE,2HED,2H9 /
C
C LU-TERMINAL
C LL-OUTPUT DEVISE
C IPRINT-PRINT OPTION
C       =1 PRINT OPTIMIZATION SEARCH DETAILS
C       =0 PRINT ONLY NECESSARY INFORMATION
C LK-LOCK OPTION
C       =1 LOCK OUTPUT DEVISE
C       =0 UNLOCK OUTPUT DEVISE
C
      CALL RMPAR(IP)
      LU=IP(1)
      LL=IP(2)
      IPRINT=IP(3)
      LK=IP(4)
      IST=IP(5)
      WRITE(LU,903)
      READ(LU,902)TITLE
      WRITE(LU,981)
      READ(LU,*)XNUM
      WRITE(LU,982)
      READ(LU,*)SETPT
C
C
```

```
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C REAL TIME SCHEDULING
C
      WRITE(LU,100)
 100  FORMAT(1X,"START TIME (HR. MIN. SEC.)")
      READ(LU,*)IHR,IMIN,ISEC
      WRITE(LU,101)
 101  FORMAT(1X,"PROGRAM CYCLE TIME(MIN)")
      READ(LU,*)IMULT
      CALL EXEC(12,0,3,IMULT,IHR,IMIN,ISEC,0)
      CALL RESS(KLASS)
      LKK=1
      IF(LKK.EQ.1.AND.IST.EQ.1)WRITE(LU,912)
      IF(LKK.EQ.1.AND.IST.EQ.1)READ(LU,*)(002(JJ),JJ=1,3)
 300  CALL EXEC(6,0,1)
 377  CONTINUE
C
      IF(LK.EQ.1)CALL LOCK(LL,NAMP,NAMP,0)
      CALL EXEC(11,ITIME,IYEAR)
      XTIME(4)=ITIME(4)
      XTIME(3)=ITIME(3)
      XTIME(2)=ITIME(2)
      STIME=XTIME(4)*60.+XTIME(3)+XTIME(2)/60.
      IDAY=ITIME(5)
      IMIN=STIME
 981  FORMAT(1X,"INPUT INTEGRATION INTERVAL")
 982  FORMAT(1X,"INPUT SCOUR SETPOINT")
C
C INPUT DATA FROM ONLINE FILE
      CALL BAM(IX1,IXI2,IXI3,OUR,OQ,OQR,OOPT,IFLG,IRAS,IXI4)
      X1=IX1
      XI2=IXI2
      XI3=IXI3
      XRAS=IRAS
      XRQ=XRAS/XI3
      XOUR=OUR
      Q=OQ*60.
      QR=OQR*60.
      DO 400 I=1,3
 400  ALPHA(I)=OOPT(I)
C
      V1=765.10
      V2=734.30
      V3=723.70
C
      R=QR/Q
C
      WRITE(LL,904)TITLE
      WRITE(LL,905)ITIME(4),ITIME(3),ITIME(2)
      WRITE(LL,940)(ALPHA(K),K=1,3)
      WRITE(LL,910)X1,XI2,XI3,Q,QR,R,V1,V2,V3,XRAS,XRQ,IXI4
C
C CALCULATE ACTUAL SCOUR
C
      SCACT=(XOUR/XI3)*1000.D0
C
```

```
PAGE 0004  FEED9  2:29 PM  WED.,  9  SEP., 1981

      C CALCULATE DESIRED SOLIDS IN THIRD TANK BASED ON SETPOINT SCOUR
      C
              XDES=(XOUR*1000.D0)/SETPT
      C
              WRITE(LL,931)XOUR,SCACT,SETPT,XDES
              WRITE(LL,977)XNUM,IMULT
      41      CONTINUE
      C
      C SET OPTIMIZATION
      C           SEE BOX SUBROUTINE FOR PARAMETER DEFINITIONS
      C
              KEY15=1
              ERROR=0.
              ID=1
        10    IF(KEY15.EQ.1)CALL BOX(KEY15,LL,IPRINT,ALPHA)
              IF(KEY15.EQ.12)CALL BOX(KEY15,LL,IPRINT,ALPHA)
              INDEX=INTS(18)
              ALPHA(3)=VALS(1,INDEX)
      C
      C SET RUNGE KUTTA INTEGRATION
      C
              YI(1)=XI
              YI(2)=XI2
              YI(3)=XI3
              TP=0.
              TP2=.2
              NDIM=3
              PRMT(1)=0.D0
              PRMT(2)=XNUM
              PRMT(3)=2.D-01
              PRMT(4)=1.D-02
              PRMT(5)=0.D0
              CALL RUNGE(PRMT,YI,DERY,NDIM,IHLF,MODEL,OUTP,AUX)
      C
      C
      C ERROR/COST FUNCTION
      C
              X3=YI(3)
              ERROR=    (X3-XDES)**2/1000.
              REALS(372)=ERROR
      C
              ~~CALL BOX~~(KEY15,LL,IPRINT,ALPHA)
      C
              IF(KEY15.GE.11)GO TO 200
              GO TO 10
       200    CONTINUE
      C
      C PRINT RESULTS
      C
              XOPT(3)=FALPH
              XOPT(1)=1.D0-XOPT(2)-XOPT(3)
       49     WRITE(LL,900)(XOPT(J),J=1,3)
              CALL EXEC(11,ITIME,IYEAR)
              XTIME(4)=ITIME(4)
              XTIME(3)=ITIME(3)
```

```
      XTIME(2)=ITIME(2)
      FTIME=XTIME(4)*60.+XTIME(3)+XTIME(2)/60.
      TDIFF=FTIME-STIME
      WRITE(LL,946)X3
      WRITE(LL,931)TDIFF
      WRITE(LL,960)
C
      IF(LK.EQ.1)CALL LOCK(LL,NAMP,NAMP,1)
C CONVERT DOUBLE PRECISION TO REAL FOR STORAGE
C
      MLSS1=X1
      DO 201 I=1,3
  201 OOPT(I)=XOPT(I)
      MLSS2=XI2
      MLSS3=XI3
      IRAS=XRAS
      MLSET=XDES
      MESS=MESS1
      OTDIF=TDIFF
      ITDIF=OTDIF*1000.
      OSETP=SETPT
      OXRQ=XRQ
      OSEED=SEED
C
C STORE RESULTS ON DISC FILE
C
      CALL STEP1(IDAY,IMIN,MLSS1,MLSS2,MLSS3,OUR,MLSET,OOPT,OTDIF,
     )OSETP,MESS,IFLG,OQ,OXRQ,IRAS,OSEED)
C
      LKK=LKK+1
      GO TO 300
C
C
  900 FORMAT(///,1X,"TANK DISTRIBUTION AFTER OPTIMIZATION= ",
     (3(F7.2,2X))
  902 FORMAT(40A2)
  903 FORMAT(1X,"INPUT TITLE",////)
  904 FORMAT("1",5X,40A2)
  905 FORMAT(//,1X,"PROGRAM START TIME= ",I4," HRS.",I4," MIN.",I4,
     (" SEC.")
  910 FORMAT(1X,"      MLSS  CONC.      TANK #1= ",F7.2,"mg/L",  1X,
     )"TANK#2= ",F7.2,1X,"TANK#3= ",F7.2,/,1X,"PLANT FLOW= ",F7.2,1X,
     )"RECYCLE FLOW= ",F7.2,1X,"R.RATIO= ",F7.2,/,1X,"VOLUMES= ",3(F7.
     )2,1X),/,1X,"RECYCLE SOLIDS=",F7.2,"mg/L",
     )/,1X,"COMPACTION RATIO=",F7.2,/,1X,"MEASURED SOLIDS=",I5)
  911 FORMAT(///,1X,"PROGRAM FINISH TIME = ",I4," HRS.",I4," MIN.",
     (I4," SEC.")
  912 FORMAT(1X," INPUT INITIAL ALPHAS")
  930 FORMAT(1X,"ELAPSED TIME TO RUN= ",F6.2," MINUTES")
  931 FORMAT(//,1X,"OUR= ",F6.3,1X,"mg/L-hr",/,
     (1X,"ACTUAL SCOUR= ",F6.3,1X,"mgO/gMLSS-hr.",/,1X,"SETPOINT= ",
     (F6.3," mgO/mgSS-hr",/,1X,"DESIRED SOLIDS CONC.= ",F7.2," mg/L")
  940 FORMAT(1X,"INITAL TANK DISTRIBUTION= ",3(F4.2,1X))
  946 FORMAT(1X," FINAL SOLIDS SETPOINT=",F7.2)
  960 FORMAT("1")
```

```
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0250   977  FORMAT(1X,"INTEGRATION INT.=",F7.2,1X," PROGRAM INT.=",I5)
0251        END


  FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


  **  NO WARNINGS **  NO ERRORS **   PROGRAM = 01914      COMMON = 00000
```

```
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       SUBROUTINE MODEL(T,YI,DERY)
       IMPLICIT DOUBLE PRECISION (A-H,P-Z)
C
C RUNGE KUTTA MODEL SUBROUTINE
C
       COMMON /NAMR/ALPHA(3),TP,TP2,V2,V3,V1,LL,LU,Q,R,XRAS
       DIMENSION YI(3),DERY(3)
       DERY(1)=((R*XRAS)-(1.D0          -ALPHA(3)+R)*YI(1))*Q/V1
       DERY(2)=((1.D0          -ALPHA(3)+R)*YI(1)-(1.D0-ALPHA(3)+R)*YI
      )(2))*Q/V2
       DERY(3)=((1.D0-ALPHA(3)+R)*YI(2)-(1.D0+R)*YI(3))*Q/V3
       RETURN
       END

 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00204      COMMON = 00000
```

```
PAGE 0008  FTN.   2:29 PM  WED.,  9  SEP., 1981

      SUBROUTINE OUTP(T,YI,DERY,IHLF,NDIM,PRMT)
C
C OUTPUT ROUTINE FOR RUNGE KUTTA
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON /NAMR/ALPHA(3),TP,TP2,V2,V3,V1,LL,LU,Q,R,XRAS
      DIMENSION YI(1),DERY(1)
      IF(T-TP.GE.TP2)CALL PRINT(YI,DERY,T,NDIM)
      RETURN
      END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00036      COMMON = 00000
```

```
PAGE 0009  FTN.   2:29 PM  WED.,  9  SEP., 1981

      SUBROUTINE PRINT(YI,DERY,T,NDIM)
C
C PRINT ROUTINE FOR RUNGE KUTTA
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      COMMON /NAMR/ALPHA(3),TP,TP2,V2,V3,V1,LL,LU,Q,R,XRAS
      DIMENSION YI(1),DERY(1)
      TP=TP+TP2
      RETURN
      END

 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS ** . PROGRAM = 00015      COMMON = 00000
```

```
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      SUBROUTINE RUNGE(PRMT,Y,DERY,NDIM,IHLF,MODEL,OUTP,AUX)
C
C SEE SUBROUTINE WRITEUP FROM APPENDIX G.1
C......................................................................
C
C
C
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
C
      DIMENSION Y(1),DERY(1),AUX(8,1),A(4),B(4),C(4),PRMT(1)
      DO 1 I=1,NDIM
    1 AUX(8,I)=.06666667*DERY(I)
      X=PRMT(1)
      XEND=PRMT(2)
      H=PRMT(3)
      PRMT(5)=0.
      CALL MODEL(X,Y,DERY)
C
C     ERROR TEST
      IF(H*(XEND-X))38,37,2
C
C     PREPARATIONS FOR RUNGE-KUTTA METHOD
    2 A(1)=.5
      A(2)=.2928932
      A(3)=1.707107
      A(4)=.1666667
      B(1)=2.
      B(2)=1.
      B(3)=1.
      B(4)=2.
      C(1)=.5
      C(2)=.2928932
      C(3)=1.707107
      C(4)=.5
C
C     PREPARATIONS OF FIRST RUNGE-KUTTA STEP
      DO 3 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=0.
    3 AUX(6,I)=0.
      IREC=0
      H=H+H
      IHLF=-1
      ISTEP=0
      IEND=0
C
C
C     START OF A RUNGE-KUTTA STEP
    4 IF((X+H-XEND)*H)7,6,5
    5 H=XEND-X
    6 IEND=1
C
C     RECORDING OF INITIAL VALUES OF THIS STEP
    7 CALL OUTP(X,Y,DERY,IREC,NDIM,PRMT)
```

```
      IF(PRMT(5))40,8,40
    8 ITEST=0
    9 ISTEP=ISTEP+1
C
C
C     START OF INNERMOST RUNGE-KUTTA LOOP
      J=1
   10 AJ=A(J)
      BJ=B(J)
      CJ=C(J)
      DO 11 I=1,NDIM
      R1=H*DERY(I)
      R2=AJ*(R1-BJ*AUX(6,I))
      Y(I)=Y(I)+R2
      R2=R2+R2+R2
   11 AUX(6,I)=AUX(6,I)+R2-CJ*R1
      IF(J-4)12,15,15
   12 J=J+1
      IF(J-3)13,14,13
   13 X=X+.5*H
   14 CALL MODEL(X,Y,DERY)
      GOTO 10
C     END OF INNERMOST RUNGE-KUTTA LOOP
C
C
C     TEST OF ACCURACY
   15 IF(ITEST)16,16,20
C
C     IN CASE ITEST=0 THERE IS NO POSSIBILITY FOR TESTING OF ACCURACY
   16 DO 17 I=1,NDIM
   17 AUX(4,I)=Y(I)
      ITEST=1
      ISTEP=ISTEP+ISTEP-2
   18 IHLF=IHLF+1
      X=X-H
      H=.5*H
      DO 19 I=1,NDIM
      Y(I)=AUX(1,I)
      DERY(I)=AUX(2,I)
   19 AUX(6,I)=AUX(3,I)
      GOTO 9
C
C     IN CASE ITEST=1 TESTING OF ACCURACY IS POSSIBLE
   20 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)21,23,21
   21 CALL MODEL(X,Y,DERY)
      DO 22 I=1,NDIM
      AUX(5,I)=Y(I)
   22 AUX(7,I)=DERY(I)
      GOTO 9
C
C     COMPUTATION OF TEST VALUE DELT
   23 DELT=0.
      DO 24 I=1,NDIM
   24 DELT=DELT+AUX(8,I)*DABS(AUX(4,I)-Y(I))
```

3

```
      IF(DELT-PRMT(4))28,28,25
C
C     ERROR IS TOO GREAT
   25 IF(IHLF-10)26,36,36
   26 DO 27 I=1,NDIM
   27 AUX(4,I)=AUX(5,I)
      ISTEP=ISTEP+ISTEP-4
      X=X-H
      IEND=0
      GOTO 18
C
C     RESULT VALUES ARE GOOD
   28 CALL MODEL(X,Y,DERY)
      DO 29 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=AUX(6,I)
      Y(I)=AUX(5,I)
   29 DERY(I)=AUX(7,I)
      CALL OUTP(X-H,Y,DERY,IHLF,NDIM,PRMT)
      IF(PRMT(5))40,30,40
   30 DO 31 I=1,NDIM
      Y(I)=AUX(1,I)
   31 DERY(I)=AUX(2,I)
      IREC=IHLF
      IF(IEND)32,32,39
C
C     INCREMENT GETS DOUBLED
   32 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      IF(IHLF)4,33,33
   33 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)4,34,4
   34 IF(DELT-.02*PRMT(4))35,35,4
   35 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      GOTO 4
C
C
C     RETURNS TO CALLING PROGRAM
   36 IHLF=11
      CALL MODEL(X,Y,DERY)
      GOTO 39
   37 IHLF=12
      GOTO 39
   38 IHLF=13
   39 CALL OUTP(X,Y,DERY,IHLF,NDIM,PRMT)
   40 RETURN
      END
```

```
FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)
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```
      SUBROUTINE BOX(KEY15,LL,IPRINT,ALPH)
C
C MULTI VARIABLE OPTIMIZATION-FIVE VARIABLES OR LESS
C  FUNCTION ICON DETERMINES IF A CONSTRAINT VIOLATION HAS OCCURRED
C
C
C  RANDOM NUMBER GENERATOR SUBROUTINE INCLUDED
C
C  INITIAL VALUES , STARTING POINTS , AND ERROR ARE PUT INTO THIS
C  SUBROUTINE
C
C  NECESSARY REQUIREMENTS FROM CALLING PROGRAM
C    1.- INDEPENDENT VARIABLES ARE PUT INTO VALS ARRAY
C    2.- OBJECTIVE ERROR FUNCTION PUT IS ASSIGNED TO REALS(372)
C    3.- KEY15 PROGRAM CONTROL PARAMETER
C        a)KEY15=1 START FROM RANDOM BEGINNING
C        b)KEY15)10 LEAVE SUBROUTINE
C
C  CONSTRAINTS
C      a)EXPLICIT-ARE ASSIGNED IN CSTR ARRAY
C      b)IMPLICIT-INCLUDED IN MAIN PROGRAM  ie,IF IMPLICIT CONSTRAINT
C                   VIOLATION DETECTED ADD ONE TO KEY15 CONTROL
C                   PARAMETER
C  FUNCTION IFIN DETERMINES IF THE FINISH CONDITION IS SATISFIED
C ALPHY =RATIO  OF PROJECTION DISTANCE
C CSTR=ARRAY CONTAINING CONSTRAINTS
C ERROR=VARIABLE TO BE MINIMIZED
C INDEX=NUMBER OF REJECTED POINT
C ITERM=MAXIMUM NUMBER OF ITERATIONS BEFORE TERMINATION
C N=NUMBER OF VARIABLES
C M=NUMBER OF REQUIRED POINTS .
C MIN=MINIMUM ABSOLUTE ERROR FOR TERMINATION-
C  MIN2=MINIMUM VARIANCE OF COST VALUES FOR TERMINATION
C  XIX=SEED FOR RANDOM NUMBER GENERATOR
C VINTR=ARRAY CONTAINING CENTROID POINTS
C  THE ARRAY KEY CONTAINS 15 SPARE INTEGER LOCATIONS
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      INTEGER TITLE(20),XIX
      DOUBLE PRECISION MIN,MIN2
      COMMON /NAME/INTS,REALS,FALPH,MESSR,SEED,LKK
      DIMENSION INTS(36),REALS(1000),ALPH(3)
      DIMENSION VALS(10,30),CSTR(10,2),COST(30),SVALS(10),VINTR(10),
     1KEY(15),DATA1(200),DATA2(200)
      EQUIVALENCE (REALS(1),VALS(1,1)),(REALS(301),COST(1)),(REALS(331),
     1SVALS(1)),(REALS(341),VINTR(1)),(REALS(351),CSTR(1,1)),(REALS(371)
     2,MIN),(REALS(372),ERROR),(REALS(373),Y),(REALS(374),WORST),
     3(REALS(375),ALPHY ),(REALS(376),FACTOR),(REALS(377),MIN2),
     4(REALS(401),DATA1(1)),(REALS(601),DATA2(1))
      EQUIVALENCE (INTS(1),KEY(1)),(INTS(16),N),(INTS(17),M),(INTS(18),
     1INDEX),(INTS(19),ITERM),(INTS(20),ITER),(INTS(21),XIX),(INTS(22),
     2IRUN),(INTS(23),NUM),(INTS(24),ISTUCK)
      GOTO(10,265,42,45,105,70,190,200,216,200,270),KEY15
C.. INITIALIZE THE PROGRAM
 10   DO 15 I=1,36
 15   INTS(I)=0
```

```
      DO 20 I=1,1000
 20    REALS(I)=0.D0
      ISEED=17
      SEED=ISEED
      XIX=ISEED
      INDEX=1
      ITER=1
      IRUN=1
      ALPHY =1.3D0
C.. SPECIFY THE FINISH CONDITION
C   JUMP4=1 FOR SIMPLE MINIMUM? JUMP4=2 FOR VARIANCE OF COST VALUE
C   JUMP4=3 FOR OTHER TYPES
      JUMP4=2
C.. READ NUMBER OF VARIABLES
C.. SPECIFY THE NUMBER OF VARIABLES
C   FOR TWO COMPARTMENT OPTIMIZATION N=1
C   FOR THREE COMPARTMENT OPTIMIZATION N=2
C
      N=1
C.. SPECIFY THE NUMBER OF POINTS
      M=N*2
      IF(N.EQ.1) M=3
      OFACT=1./FLOAT(M-1)
      FACTOR=DBLE(OFACT)
C.. SPECIFY THE MAXIMUM NUMBER OF ITERATIONS
       ITERM=150
C.. SPECIFY THE MAXIMUM ERROR
      MIN=.1D0
      MIN2=MIN**2
C.. SPECIFY THE CONSTRAINTS
C CSTR(I,1)'S ARE THE EXPLICIT LOWER CONSTRAINTS
C CSTR(I,2)'S ARE THE EXPLICIT UPPER CONSTRAINTS
      CSTR(1,1)=0.0D0
       CSTR(1,2)=1.0D0
C.. SPECIFY THE STARTING LOCATIONS
      VALS(1,1)=ALPH(3)
C   THE STARTING LOCATION IS ASSUMED TO SATISFY THE CONSTRAINTS
C.. WRITE THE HEADINGS
      WRITE(LL,1040)
 1040  FORMAT(///," MULTIVARIABLE OPTIMIZATION TECHNIQUE-SUPERBOX ",/)
 30    WRITE(LL,1070)
 1070  FORMAT(" ",26X,"CONSTRAINTS",/," VARIABLE",13X,"LOWER",14X,
     1"UPPER")
      DO 40 I=1,N
 40    WRITE(LL,1080) I,(CSTR(1,J),J=1,2)
 1080  FORMAT(1H ,I5,11X,F10.5,9X,F10.5)
      WRITE(LL,1090) N,M,MIN,MIN2,JUMP4,XIX,LKK
 1090  FORMAT(" NUMBER OF VARIABLES=",11X,I3,/," NUMBER OF VERTICIES =",
     110X,I3,7," MINIMUM ABSOLUTE ERROR= ",  6X,D 9.4,/," MINIMUM VARIAN
     2CE OF ERROR =",1X,D 9.4,/," FINISH CRITERIA =",15X,I2,/," XIX =",
     422X,I7,/," LLD =",26X,I2)
      KEY15=3
      RETURN
 42    COST(INDEX)=ERROR
      WRITE(LL,1100)
```

```
1100  FORMAT(//,1X,"USER SUPPLIED STARTING POINT",//)
     WRITE(LL,1170)
     WRITE(LL,1180)
     WRITE(LL,1160) (VALS(I,INDEX),I=1,N)
     WRITE(LL,1190) COST(INDEX)
     JUMP2=ICON(JUMP5)
     IF(JUMP2-1) 55,45,45
45    WRITE(LL,1105)
1105  FORMAT(" THE USER SUPPLIED STARTING POINT DOES NOT SATISFY THE
    1STRAINTS.  A RANDOM POINT WILL BE SUBSTITUTED.")
50    INDEX=0
55    WRITE(LL,1110)
1110  FORMAT(" RANDOMLY GENERATED POINTS")
     WRITE(LL,1170)
     WRITE(LL,1180)
60    INDEX=INDEX+1
70    CONTINUE
C.. CALCULATE M-1 STARTING POINTS
     DO 100 J=1,N
     CALL RANDU(XIX,IY,YFL)
     Y=YFL
     XIX=IY
     IF(LKK.NE.1)GO TO 499
     VALS(J,INDEX)=(CSTR(J,2)-CSTR(J,1))*Y+CSTR(J,1)
     GO TO 498
499  VALS(J,INDEX)=.1D0*Y*VALS(J,1)+VALS(J,1)
     IF(VALS(J,1).GE.9.D0)VALS(J,INDEX)=(CSTR(J,2)-CSTR(J,1))*Y+CSTR
    )(J,1)
     IF(VALS(J,1).LE.1.D0)VALS(J,INDEX)=(CSTR(J,2)-CSTR(J,1))*Y+CSTR
    )(J,1)
498  CONTINUE
100   CONTINUE
     JUMP2=ICON(JUMP5)
     IF(JUMP2.EQ.1) GO TO 70
     KEY15=5
     RETURN
105   COST(INDEX)=ERROR
     WRITE(LL,1160) (VALS(I,INDEX),I=1,N)
     WRITE(LL,1190) COST(INDEX)
     IF(N.GT.5) WRITE(LL,1120)
1120  FORMAT("-----------------------------------------------------
    1--------------------------------------------------------------
    2---------")
     IF(M-INDEX) 110,110,60
110   IF(N.GT.5) WRITE(LL,1130)
1130  FORMAT(25X,2HK6,18X,2HK7,18X,2HK8,18X,2HK9,18X,3HK10)
     IF(IPRINT.EQ.1)WRITE(LL,1134)
1134  FORMAT(///," SEARCH BEGINING  ",//)
     GO TO 140
120   ITER=ITER+1
     COST(INDEX)=ERROR
     IF(IPRINT.EQ.1)WRITE(LL,1160) (VALS(I,INDEX),I=1,N)
     IF(IPRINT.EQ.1)WRITE(LL,1190) COST(INDEX)
     IF(N.GT.5) WRITE(LL,1120)
C.. CHECK FOR TERMINAL CONDITIONS
```

```
      JUMP3=IFIN(JUMP4)
      GO TO (130,230),JUMP3
C..  CHECK ITERATION NUMBER
 130  IF(ITER.GE.ITERM) GO TO 220
C.. FIND WORST VALUE
 140  WORST=COST(1)
      INDEX=1
      DO 150 I=2,M
      IF(WORST.GT.COST(I)) GO TO 150
      WORST=COST(I)
      INDEX=I
 150  CONTINUE
C.. INITILIZE ARRAY AND CALCULATE NEW VALS
      ISTUCK=0
      DO 160 I=1,N
 160  SVALS(I)=0.0D0
      DO 170 I=1,N
      DO 170 J=1,M
 170  SVALS(I)=SVALS(I)+VALS(I,J)
      DO 180 I=1,N
      VINTR(I)=FACTOR*(SVALS(I)-VALS(I,INDEX))
 180  VALS(I,INDEX)=ALPHY *(VINTR(I)-VALS(I,INDEX))+VINTR(I)
C.. CHECK TO SEE IF CONSTRAINTS ARE VIOLATED
      JUMP2=ICON(JUMPS)
      IF(JUMP2.EQ.1) GO TO 200
      KEY15=7
      RETURN
 190  IF(ERROR.LE.COST(INDEX)) GO TO 120
C.. NO IMPROVEMENT-MOVE HALFWAY BACK TO THE CENTROID
      ITER=ITER+1
      IF(IPRINT.EQ.1)WRITE(LL,1132)
 1132 FORMAT(" NO IMPROVEMENT",/)
 200  DO 210 I=1,N
 210  VALS(I,INDEX)=0.5D0*(VALS(I,INDEX)+VINTR(I))
      ISTUCK=ISTUCK+1
      IF(ISTUCK-50) 215,215,217
 215  JUMP2=ICON(JUMPS)
      IF(JUMP2.EQ.1) GO TO 200
      KEY15=9
      RETURN
 216  IF(ITER.GE.ITERM) GO TO 220
      GO TO 190
 217  WRITE(LL,1135) ISTUCK
      MESSR=2
 1135 FORMAT(" THE OPTIMIZATION IS APPARENTLY STUCK.  ISTUCK =",I3)
      GO TO 240
 220  WRITE(LL,1140)
 1140 FORMAT(1H ," THE MAXIMUM NUMBER OF ITERATIONS HAS BEEN EXCEEDED")
      MESSR=1
      GO TO 240
 230  WRITE(LL,1150)
      MESSR=0
 1150 FORMAT(1H ,"THE OPTIMIZATION HAS TERMINATED NORMALLY")
 1160 FORMAT(1X,5D20.6,/,11X,5D20.6  )
 240  WRITE(LL,1170)
```

```
 1170  FORMAT(14X,2HX1,18X,2HX2,18X,2HX3,18X,2HX4,18X,2HX5)
      WRITE(LL,1180)
 1180  FORMAT(1H ,127X,4HCOST)
      DO 250 I=1,N
      WRITE(LL,1160) (VALS(J,I),J=1,N)
      WRITE(LL,1190) COST(I)
 250   IF(N.GT.5) WRITE(LL,1120)
      IF(N.GT.5) WRITE(LL,1130)
 1190  FORMAT(1H ,116X,D15.5)
      WRITE(LL,1200) ITER
 1200  FORMAT(1H ,16HITERATION COUNT=,I5)
      IRUN=IRUN-1
C.. FIND THE LOWEST VALUE OF COST AND PRINT OUT THE VALS
      INDEX=1
      DO 260 I=2,N
 260   IF(COST(INDEX).GT.COST(I)) INDEX=I
      WRITE(LL,1210) INDEX
      WRITE(LL,1170)
      WRITE(LL,1180)
      WRITE(LL,1160) (VALS(I,INDEX),I=1,N)
      FALPH     =VALS(1,INDEX)
      WRITE(LL,1190) COST(INDEX)
      IF(N.GT.5) WRITE(LL,1130)
 1210  FORMAT(" THE VALUE OF INDEX FOR LOWEST COST = ",I2,/," OPTIMAL
     1VALUES ARE")
      IF(IRUN.LE.0) GO TO 270
      WRITE(LL,1120)
      WRITE(LL,1220) IRUN
 1220  FORMAT(" RESTARTING OPTIMIZATION FROM COMPLETELY RANDOM BEGINNING
     1FROM SUPER BOX","   IRUN=",I3)
      ITER =1
      GO TO 50
 265   CONTINUE
      WRITE(LL,1120)
      ITER=1
      WRITE(LL,1230)
 1230  FORMAT(" RESTARTING OPTIMIZATION FROM COMPLETELY RANDOM BEGINNING
     1FROM HP  ")
      GO TO 50
 270   CONTINUE
      KEY15=11
      WRITE(LL,1120)
      RETURN
      END

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 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 02646      COMMON = 00000
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      FUNCTION ICON(JUMPS)
C.. FUNCTION ICON DETERMINES IF A CONSTRAINT VIOLATION HAS OCCURRED
C   ICON=1 IF THE CONSTRAINT HAS BEEN VIOLATED
      IMPLICIT DOUBLE PRECISION (A-H,P-Z)
      DIMENSION INTS(36),REALS(1000)
      DIMENSION VALS(10,30),CSTR(10,2)
      COMMON /NAME/INTS,REALS,FALPH,MESSR,SEED,LKK
      EQUIVALENCE (REALS(1),VALS(1,1)),(REALS(351),CSTR(1,1))
      EQUIVALENCE (INTS(16),N),(INTS(18),INDEX)
      ICON=0
      DO 10 I=1,N
      IF(VALS(I,INDEX).LT.CSTR(I,1)) ICON=1
      IF(VALS(I,INDEX).GT.CSTR(I,2)) ICON=1
      LZ=55
   10 IF(ICON.EQ.1)WRITE(LZ,900)
  900 FORMAT(1X,"EXPLICIT CONSTRAINT VIOLATED")
      RETURN
      END


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**  NO WARNINGS **  NO ERRORS **   PROGRAM = 00113      COMMON = 00000
```

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           FUNCTION IFIN(JUMP4)
     C.. FUNCTION IFIN DETERMINES IF THE FINISH CONDITION IS SATISFIED
     C    IFIN=2 IF THE FINISH CRITERIA HAS BEEN SATISIFIED
     C    IFIN =1 OTHERWISE
           IMPLICIT DOUBLE PRECISION(A-H,P-Z)
           DOUBLE PRECISION MIN,MIN2
           DIMENSION INTS(36),REALS(1000)
           DIMENSION COST(30),KEY(15)
           COMMON /NAME/ INTS,REALS,FALPH,MESSR,SEED,LKK
           EQUIVALENCE (REALS(301),COST(1)),(REALS(371),MIN),(INTS(1),KEY(1))
          1,(INTS(17),M),(INTS(18),INDEX),(REALS(377),MIN2)
           GO TO (100,200,300),JUMP4
      100   IF(COST(INDEX).LT.MIN) GO TO 120
           IFIN=1
           RETURN
      120   IFIN=2
           RETURN
      200   S1=0.
           S2=0.
           DO 220 I=1,M
           S1=S1+COST(I)
      220   S2=S2+COST(I)**2
           V=(S2-S1**2/FLOAT(M))/FLOAT(M-1)
           LZ=55
     D     WRITE(LZ,900)V
     900   FORMAT(90X,"COMPLEX VARIANCE=",D10.4)
           IF(V.LT.MIN2) GO TO 230
           IFIN=1
           RETURN
      230   IFIN=2
           RETURN
      300   CONTINUE
     C.. USER SUPPLIED FINISH CONDITION
           IFIN=1
           RETURN
           END


  FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

  **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00184       COMMON = 00000
```

```
PAGE 0021  FTN.   2:29 PM  WED.,  9  SEP., 1981

           SUBROUTINE RANDU(XIX,IY,YFL)
      C
      C RANDOM # GENERATOR (VALUES ARE FROM 0 TO 1)
           IMPLICIT DOUBLE PRECISION (A-H,P-Z)
           INTEGER XIX
           IY=XIX*131
           IF(IY)1,2,2
        1  IY=IY+32767+1
        2  YFL=IY
           YFL=YFL*3.05176D-05
           RETURN
           END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00643      COMMON = 00000
```

```
PAGE 0022  FTN.   2:29 PM  WED.,  9  SEP., 1981

0776          SUBROUTINE LOCK(IL,NAMP,NAMS,ILL)
0777  C
0778  C THIS SUBROUTINE WILL LOCK OR RELEASE AN INPUT/OUTPUT DEVICE TO THE
0779  C CALLING PROGRAM.IF AN ERROR OCCURS THE PROGRAM SOURCE,TIME,AND ERROR
0780  C CODE IS PRINTED.
0781  C
0782  C PARAMETER LIST
0783  C                  IL-LU# OF INPUT/OUTPUT DEVICE
0784  C                  NAMP-CALLING PROGRAM NAME
0785  C                  NAMS-CALLING SUBROUTINE NAME
0786  C                  ILL-LOCK OR UNLOCK FLAG(0=LOCK,1=UNLOCK)
0787  C                  IT-TIME ARRAY
0788  C                  IOPTN-LURQ. CONTROL PARAMETER
0789  C                  NOLU-# OF DEVICES
0790  C                  LURQ-RTE-4 LIBRARY SUBROUTINE(PG.X-II RTE-4 MANUAL)
0791  C                  ABREG-HP-SUBROUTINE(PG.IV-5 RTE-4 MANUAL)
0792  C                  IY-YEAR
0793  C
0794          DIMENSION NAMP(3),IT(5),NAMS(3)
0795          IF(ILL.EQ.0)IOPTN=40001B
0796          IF(ILL.EQ.1)IOPTN=40000B
0797          NOLU=1
0798          CALL LURQ(IOPTN,IL,NOLU)
0799          GO TO 10
0800          GO TO 20

    . GO TO?
  **LOCK   **WARNING 35 DETECTED AT LINE 0800 COLUMN 11

0801  10      CALL ABREG(IA,IB)
0802          CALL EXEC(11,IT,IY)
0803          WRITE(1,900)
0804          WRITE(1,910)
0805          WRITE(1,920)IA,IL
0806          WRITE(1,930)IT(5),IT(4),IT(3),IT(2)
0807          WRITE(1,940)NAMP,NAMS
0808          WRITE(1,950)
0809  20      CONTINUE
0810  900     FORMAT("1")
0811  910     FORMAT(1X,99("*"),/,45X,"LOCK ERROR",/,99("*"),/,/)
0812  920     FORMAT(30X,"A-REGISTER CONTENTS=",I5," LU=",I5)
0813  930     FORMAT(30X,"TIME(DAY,HR.,MIN.,SEC.)=",4I7)
0814  940     FORMAT(30X,"FROM PROGRAM ",3A2," SUBROUTINE ",3A2)
0815  950     FORMAT(1X,99("*"),"1")
0816          RETURN
0817          END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


 **0001 WARNINGS **  NO ERRORS **   PROGRAM = 00224      COMMON = 00000
```

```
PAGE 0023  FTN.   2:29 PM  WED.,  9  SEP., 1981

           SUBROUTINE BAM(MLSS1,MLSS2,MLSS3,OUR,QA,RASQ,ALPHA,IFLG,IRAS,
          (MLSS4)
      C
      C THIS OPENS ONLINE DATA FILE  , READS LAST RECORD , RETURNS WITH ---
      C        1-MLSS 1ST REACTOR (mg/L)
      C        2-MLSS 2ND REACTOR (mg/L)
      C        3-MLSS 3RD REACTOR (mg/L)
      C        4-OUR 3RD REACTOR(mg/L-hr)
      C        5-RAS FLOW (L/min.)
      C        6-ALPHA(1)
      C        7-ALPHA(2)
      C        8-ALPHA(3)
      C        9-ERROR FLAG - BSM - ERROR (=0)
      C       10-RECYCLE SOLIDS(mg/L)
          DIMENSION ALPHA(3),IDCB(144),NAME(3),IBUF(57),NAMF(3)
          EQUIVALENCE (IBUF(53),X1),(IBUF(21),X2),(IBUF(23),X3)
          EQUIVALENCE (IBUF(15),X4),(IBUF(33),X8)
          DATA NAMF/2HON,2HLI,2HH /,NAME/2H  ,2H  ,2H  /
          IFLG=0
          CALL OPANY(NAME,0,NAMF,0,IFLG,IDCB,1)
          IF(IFLG.EQ.0)GO TO 100
          IFLG=9
          GO TO 1000
      100 CALL RDANY(NAME,NAMF,IDCB,1,IFLG,IBUF,57,2)
          IF(IFLG.EQ.0)GO TO 105
          IFLG=9
          CALL CLOSE(IDCB)
          GO TO 1000
      105 IREC=IBUF(1)
          CALL RDANY(NAME,NAMF,IDCB,IREC,IFLG,IBUF,57,3)
          IF(IFLG.EQ.0)GO TO 110
          IFLG=9
          CALL CLOSE(IDCB)
          GO TO 1000
      110 CALL CLOSE(IDCB)
          MLSS1=IBUF(37)
          MLSS2=IBUF(38)
          MLSS3=INT(X8+.5)
          MLSS4=IBUF(57)
          IRAS=IBUF(40)
          OUR=X1
          QA=X2
          RASQ=X3
          ALPHA(1)=FLOAT(IBUF(55))/100.0
          ALPHA(2)=FLOAT(IBUF(56))/100.0
          ALPHA(3)=X4
     C    WRITE(6,200)(ALPHA(J),J=1,3),MLSS1,MLSS2,MLSS3,OUR,QA,RASQ
      200 FORMAT(1X,"BAM DEBUG",/,1X,9(E12.4,1X))
     1000 RETURN
          END

FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)
```

```
      SUBROUTINE STEP1(IDAY,IMIN,MLSS1,MLSS2,MLSS3,OUR,MLSET,ALPHA,
     )TIME,SCOUR,MESS,IFLG,OQ,OXRQ,IRAS,SEED)
C
C THIS WRITES TO DISC FILE "STEPX" THE FOLLOWING
C        1-MLSS-1ST REACTOR
C        2-MLSS-2ND REACTOR
C        3-MLSS-3RD REACTOR
C        4-ALPHA(1,2,3)
C        5-ELAPSED TIME
C        6-SCOUR SETPOINT
C        7-DESIRED MLSS IN THIRD REACTOR
C        8-OUR 3RD REACTOR
C        9-OPTIMIZATION MESSAGE CODE
C       10-ACTUAL SCOUR
C       11-PLANT FLOW
C       12-COMPACTION RATIO
C       13-RECYCLE SOLIDS
C
C     CREATION --- CR,STEPX:LY:23:2:195:70-----------
C     RECORD 1-WORD 1 CONTAINS LAST WORD WRITTEN TO
C     IF ERROR OCCURS WHEN WRITTING TO FILE IFLG=9
C     MAXIMUM RECORDS=355
      DIMENSION ALPHA(3),IDCB(144),NAME(3),NAMF(3),IBUF(70)
      DATA NAME/2H  ,2H  ,2H  /,NAMF/2HST,2HEP,2HX /
      CALL OPANY(NAME,2HLY,NAMF,0,IFLG,IDCB,1)
      IF(IFLG.NE.0)GO TO 1000
      CALL RDANY(NAME,NAMF,IDCB,1,IFLG,IBUF,70,2)
      IF(IFLG.NE.0)GO TO 1000
      IREC=IBUF(1)
      IREC=IREC+1
      IF(IREC.GE.999)IREC=5
      ASCOU=(OUR/MLSS3)*1000.
      XMIN=IMIN/60.
      LX=53
      WRITE(LX,20)IDAY,XMIN,MLSS1,MLSS2;MLSS3,OUR,MLSET,ALPHA(1),
     )ALPHA(2),ALPHA(3),TIME,SCOUR,MESS,ASCOU,OQ,OXRQ,IRAS,SEED
      CALL ZERO(IBUF,70)
      CALL CODE
      WRITE(IBUF,20)IDAY,XMIN,MLSS1,MLSS2,MLSS3,OUR,MLSET,ALPHA(1),
     )ALPHA(2),ALPHA(3),TIME,SCOUR,MESS,ASCOU,OQ,OXRQ,IRAS,SEED
   20 FORMAT(1X,I3,1X,F4.1,1X,I5,2X,I5,2X,I5,2X,F5.1,2X,I5,4X,F5.3,2X,
     )F5.3,2X,F5.3,3X,F6.2,2X,F6.2,2X,I2,2X,F6.2,2X,F6.2,2X,F6.2,
     )2X,I5,1X,F6.1)
      CALL WRITF(IDCB,IERR,IBUF,70,IREC)
      IF(IERR.LT.0)WRITE(1,25)IERR,IREC
   25 FORMAT(1X,"ERROR ",I5," TRYING TO WRITE TO REC# ",I5,/,1X
     )," IN FILE FEEDX PROGRAM     CALL L.YUST!!!!!!!!!")
      IF(IERR.LT.0)GO TO 1000
      CALL ZERO(IBUF,70)
      IBUF(1)=IREC
      NUM=1
      CALL WRITF(IDCB,IERR,IBUF,70,1)
      IF(IERR.LT.0)WRITE(1,25)IERR,NUM
      IF(IERR.LT.0)GO TO 1000
      CALL CLOSE(IDCB)
```

```
PAGE 0026  STEP1  2:29 PM  WED.,  9  SEP., 1981

              GO TO 500
        1000 CALL CLOSE(IDCB)
              IFLG=9
         500 RETURN
              END


 FTN4 COMPILER: HP92060-16092 REV: 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00650      COMMON = 00000
```

```
PAGE 0027  FTN.   2:29 PM  WED.,  9  SEP., 1981

      SUBROUTINE OPANY(NAMP,ISEC,NAMF,IRN,IFLAG,IDCB1,IPOS)
C
C THIS SUBROUTINE OPENS ANY TYPE 2 FILE NON-EXCLUSIVELY.
C AN ERROR FLAG WILL BE USED TO CHECK IF THE FILE HAS BEEN OPENED
C PROPERLY.IF AN ACCESS ERROR OCURRS SUBROUTINE ERR WILL BE CALLED.
C A CHECK ON THE RESOURCE MANAGEMENT IS USED IF ANOTHER PROGRAM
C IS USING THE FILE WITH THE COOPERATION OF OTHER PROGRAMS IN THE
C SYSTEM.THE FILE WILL THEN BE LOCKED LOCALLY TO CALLING PROGRAM.THE
C RESOURCE NUMBER MUST EVENTUALLY BE RELEASED.
C
C PARAMETER LIST
C               NAMP-PROGRAM CALLING SUBROUTINE
C               NAMS-SUBROUTINE OPANY
C               NAMF-FILE TO BE OPENED
C               ISEC-SECURITY CODE
C               IRN-RESOURCE NUMBER
C               IDCB1-DATA CONTROL BLOCK
C               IERR-EXEC CALL ERROR RETURN
C               ICODE,IOPTN-OCTAL CONTROL WORDS
C               IFLAG=-1,ACCESS ERROR FROM SUBROUTINE ERR
C                    =0,OK
C                    =-2,RN# LOCK ERROR
C               IPOS-PROGRAM LINE SOURCE LOCATOR
C
      DIMENSION IDCB1(144),ITIME(5),IYEAR(1),NAMF(3),NAMP(3),NAMS(3)
      DATA NAMS/2HOP,2HAN,2HY /
      ICODE=040002B
      IF(IRN.EQ.0)GO TO 10
      L=0
      CALL RNUM(ICODE,IRN,L)
      IF(L.EQ.9)IFLAG=-2
 10   IOPTN=000003B
      IFLAG=0
      CALL OPEN(IDCB1,IERR,NAMF,IOPTN,ISEC)
      IF(IERR)30,40,40
 30   CONTINUE
      CALL ERR(NAMF,NAMP,NAMS,IERR,IFLAG,IPOS)
 40   CONTINUE
      RETURN
      END


FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

**  NO WARNINGS **  NO ERRORS **   PROGRAM = 00080     COMMON = 00000
```

```
PAGE 0028  FTN.   2:29 PM  WED.,  9  SEP.,  1981

      SUBROUTINE RDANY(NAMP,NAMF,IDCB1,NUM,IFLAG,IBUF,IL,IPOS)
C
C THIS SUBROUTINE READS A RECORD FROM ANY TYPE 2 DISC FILE.
C THE RECORD CONTENTS ARE RETURNED IN THE ARRAY IBUF WHICH
C ARE LEN RECORDS IN LENGTH.ASSUME THAT THE TYPE 2 FILE HAS
C BEEN PREVIOUSLY OPENED NON-EXCLUSIVELY.IF THE ERROR FLAG
C =-12,AN END OF FILE WAS DETECTED.A RETURN FLAG WILL BE USED
C TO CHECK IF THERE WAS A FILE ACCESS ERROR.IF SO SUBROUTINE
C ERR WILL BE CALLED.
C
C PARAMETER LIST
C             NAMP-PROGRAM CALLING SUBROUTINE
C             NAMF-FILE TO BE READ
C             NAMS-SUBROUTINE RDANY
C             IDCB1-DATA CONTROL BLOCK
C             IERR-EXEC CALL ERROR RETURN
C             IL-RECORD LENGTH
C             NUM-RECORD NUMBER
C             IFLAG=-1,FMP READ ACCESS ERROR
C                  =-12,END OF FILE REACHED
C                  =0,OK
C             I-DISC ACCESS ERROR I.D.
C             IPOS-ERROR SOURCE LOCATOR
C
      DIMENSION IDCB1(144),IBUF(2),NAMP(3),NAMF(3),NAMS(3)
      DATA NAMS/2HRD,2HAN,2HY /
      IFLAG=0
      CALL READF(IDCB1,IERR,IBUF,IL,LEN,NUM)
      IF(IERR.EQ.-12)IFLAG=-12
      IF(IERR)10,20,20
10    CALL ERR(NAMF,NAMP,NAMS,IERR,IFLAG,IPOS)
20    CONTINUE
      RETURN
      END


FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


**  NO WARNINGS **  NO ERRORS **   PROGRAM = 00053      COMMON = 00000
```

```
PAGE 0029  FTN.   2:29 PM  WED.,  9  SEP., 1981

1002          SUBROUTINE ZERO(IBUF,N)
1003          DIMENSION IBUF(1)
1004          DO 100 I=1,N
1005    100   IBUF(I)=2H
1006          RETURN
1007          END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00028      COMMON = 00000
```

```
PAGE 0030  FTN.   2:27 PM  WED.,  9  SEP., 1981

          SUBROUTINE ERR(NAMF,NAMP,NAMS,IERR,IFLAG,IPOS)
C
C THIS SUBROUTINE WILL SEND AN ERROR MESSAGE TO THE LINE
C PRINTER INDICATING THAT THE DISC ACCESS HAS NOT OCCURRED.
C THE ACCESS FILE NAME,ERROR CODE,MAIN PROGRAM NAME,DISC ACCESS #
C AND TIME WILL BE PRINTED.  IF LINE PRINTER IS DOWN WRITE
C INSTEAD TO LU1.
C
C PARAMETER LIST
C                 NAMP-MAIN PROGRAM CALLING SUBROUTINE
C                 NAMS-SUBROUTINE CALLING ERR
C                 NAMF-FILE TO BE OPENED
C                 IFLAG-ERROR FLAG
C                 ITIME-TIME CLOCK ARRAY
C                 IERR-EXEC CALL ERROR RETURN
C                 IPOS-ERROR SOURCE LOCATOR
C
          DIMENSION NAMF(3),NAMS(3),NAMP(3),ITIME(5),IYEAR(1)
          IFLAG=-1
          LU=6
          CALL EXEC(11,ITIME,IYEAR)
          CALL STATS(6B,IF,IEQS)
          IF(IF.EQ.0) GO TO 905
          LU=1
    905   WRITE(LU,900)
          WRITE(LU,910)
          WRITE(LU,920)IERR,IPOS,NAMF
          WRITE(LU,930)ITIME(5),ITIME(4),ITIME(3),ITIME(2),NAMP,NAMS
          WRITE(LU,940)
    900   FORMAT("1")
    910   FORMAT(1X,98("*"),/,35X,"DISC ACCESS ERROR(ERR)",/,99("*"),/)
    920   FORMAT(35X,"ERROR CODE=",I4," LINE LOCATOR=",I4," DISC FILE ",3A
         (2)
    930   FORMAT(35X,"TIME(DAY,HR.,MIN.,SEC.)=",4(I7),/,35X,"PROGRAM ",
         (3A2," SUBROUTINE ",3A2)
    940   FORMAT(1X,98("*"),/)
    1000  RETURN
          END


FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


**  NO WARNINGS **  NO ERRORS **   PROGRAM = 00224     COMMON = 00000
```

```
PAGE 0031  FTN.   2:29 PM  WED.,  9  SEP., 1981

1046          SUBROUTINE RNUM(ICODE,IRN,L)
1047  C
1048  C  THIS SUBROUTINE ATTEMPTS TO LOCK A RESOUBRCE INDICATED BY "IRN"
1049  C  IF L=1 THEN CURRENT RESOURSE # AND STATUS IS WRITTEN TO THE
1050  C  SYSTEM CONSOL.
1051  C
1052  C
1053          CALL RNRQ(ICODE,IRN,ISTAT)
1054          GO TO 101
1055          IF(L.EQ.1)WRITE(1,100)IRN,ISTAT

     IF(?
 **RNUM  **WARNING 35 DETECTED AT LINE 1055 COLUMN 09

1056    100  FORMAT(" RESOURCE #=",I7,/," STATUS RETURN WORD=",I3)
1057          GO TO 130
1058    101  WRITE(1,120)ISTAT
1059    120  FORMAT(1X,"ERROR IN RN# LOCK IN OPANY SUB. ISTAT=",I3)
1060          L=9
1061    130  RETURN
1062          END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


**0001 WARNINGS **  NO ERRORS **   PROGRAM = 00093      COMMON = 00000
```

```
PAGE 0032  FTN.   2:29 PM  WED.,  9  SEP., 1981

          SUBROUTINE RESS(KLASS)
          DIMENSION IDCB(144),IBUF(128),NAME(3),NAMF(3)
     C
     C
     C    THIS SUBROUTINE OPENS THE HEADER FILE AND OBTAINS THE 17 TH
     C    CLASS # ( WORD 17).
     C
     C
          DATA NAME/2HSW,2HTC,2HH /,NAMF/2H#H,2HEA,2HDR/
          CALL OPANY(NAME,2H#H,NAMF,0,IFG,IDCB,1)
          IF(IFG.NE.0)STOP
          CALL RDANY(NAME,NAMF,IDCB,1,IFG,IBUF,128,2)
          IF(IFG.NE.0)CALL CLOSE(IDCB)
          IF(IFG.NE.0)STOP
          KLASS=IBUF(17)+120000B
          CALL CLOSE(IDCB)
          RETURN
          END


 FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

 **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00346      COMMON = 00000
```

## G.3 — UWHAUS

```
PAGE 0001  FTN.    3:46 PM  WED.,  9  SEP., 1981

FTN4,L
      PROGRAM KLAS
      DIMENSION X(100),Y(100),SCRAT(1000),IP(5),XP(1600),YP(1600)
      DIMENSION TH(3),SIGNS(3),DIFF(3),DUMMY(40)
      COMMON X ,YZERO,LL,CS,RR
      EXTERNAL MODEL
      CALL RMPAR(IP)
      LU=IP(1)
      LL=IP(2)
      IF(LL.EQ.0)LL=6
C
C      THIS PROGRAM READS DATA COLLECTED FROM PROGRAM KLA AND OBTAINS
C      THE BEST ESTIMATE OF KLA.
C      TH(1)=XLA  IN MG/L/MIN
C      RR =  RESP. RATE IN mg L min
C      CS=  DO SATURATION POINT
C
      IF(IP(1).EQ.0)LU=1
      WRITE(LU,300)
  300 FORMAT(1X,"ON WHICH LU DOES DATA RESIDE IN ?")
      READ(LU,*)IDAT
      WRITE(LU,301)
  301 FORMAT(1X," WHICH DO DATA  DOF=1  DOR =2  ?")
      READ(LU,*)IDEN
      IF(IDAT.EQ.4.OR.IDAT.EQ.5)IDEN=1
      NP=1
      WRITE(LU,100)
  100 FORMAT(" ENTER NOB + STARTING TIME OF ANALYSIS (HR,MIN,SEC",
     &" PLUS INCREMENT")
      READ(LU,*)N,XX1,XX2,XX3,INC
      TIME1=      XX1*60+XX2+      XX3/60
C
      READ(IDAT,99)DUMMY
      WRITE(LU,98)DUMMY
   99 FORMAT(40A2)
   98 FORMAT(10X,40A2)
      YP(1)=0
      ICOU=1
      XP(1)=0.
      DO 200 I=1,N
      IF(IDAT.EQ.4.OR.IDAT.EQ.5)READ(IDAT,*)XI2,XI3,XI4,DOF
      IF(IDAT.EQ.8)READ(IDAT,*)I1,XI2,XI3,XI4,IC,TM,AFL,DOF,DOR,IM,Q,
     &R,O
      TIME2=      XI2*60+XI3+       XI4/60
      IF(TIME2.LT.TIME1)GO TO 200
      IF(TIME2.EQ.TIME1.AND.IDEN.EQ.1)YP(1)=DOF
      IF(TIME2.EQ.TIME1.AND.IDEN.EQ.2)YP(1)=DOR
      IF(TIME2.EQ.TIME1)GO TO 200
      ICOU=ICOU+1
      XP(ICOU)=TIME2-TIME1
      IF(IDEN.EQ.1)YP(ICOU)=DOF
      IF(IDEN.EQ.2)YP(ICOU)=DOR
  200 CONTINUE
C
C
```

```
PAGE 0002  KLAS   3:17 PM  FRI., 11  SEP., 1981

            ICOUNT=0
            DO 333 I=1,ICOU,INC
            ICOUNT=ICOUNT+1
            X(ICOUNT)=XP(I)
        333 Y(ICOUNT)=YP(I)
      C
      C PRINT DATA
      C
            WRITE(LL,98)DUMMY
            WRITE(LL,9997)
       9997 FORMAT(10X,"      I      X(I)      Y(I)")
            DO 600 I=1,ICOUNT
            WRITE(LL,9998)I,X(I),Y(I)
       9998 FORMAT(10X,I7,2(F9.2,1X))
        600 CONTINUE
      C
      C PREPARE FOR UWHAUS
      C
        740 WRITE(LU,71)
        71  FORMAT(1X," ENTER       TH(1),INITIAL DO CONC,CS AND",
           *" RESP RATE IN mg/L/min")
            READ(LU,*)TH(1),YZERO,CS,RR
      C
      C CALL UWHAUS
      C
        788 SIGNS(1)=1.
            SIGNS(2)=1.
            SIGNS(3)=1.
            DIFF(1)=.01
            DIFF(2)=.01
            DIFF(3)=.01
            EPS1=1.0E-6
            EPS2=1.0E-6
            CALL UWHAUS(1,MODEL,ICOUNT,Y,NP,TH,DIFF,SIGNS,EPS1,EPS2,
           615,.01,10.,SCRAT,LL)
            END

FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

**  NO WARNINGS **  NO ERRORS **   PROGRAM = 09456      COMMON = 00207
```

```
PAGE 0003  FTN.   3:17 PM  FRI., 11  SEP., 1981

           SUBROUTINE MODEL (NPROB,TH,F,NOB,NP)
           COMMON X,YZERO,LL,CS,RR
           DIMENSION TH(1),F(1),X(100)
           A=TH(1)*CS-RR
           B=-TH(1)
           DO 10 I=1,NOB
      C    WRITE(LL,9996)TH(1),TH(2),TH(3),A1,B1,YZERO,X(I),NOB,NP
      C9996 FORMAT(7(F8.3,1X),2I7)
           F(I)=(A/B)*((EXP(B*X(I))*(1+B/A*YZERO))-1)
      C    F(I)=(TH(2)*TH(1)-R)/TH(1)*(1.0-EXP(-TH(1)*X(I)))
      C    WRITE(LL,9990)F(I)
       10  CONTINUE
      9990 FORMAT(10X,F8.3)
           RETURN
           END


  FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

  **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00107      COMMON = 00207
```

```
PAGE 0004  FTN.    3:17 PM  FRI., 11  SEP., 1981

      SUBROUTINE UWHAS(NPROB,MODEL,NOB,Y,NP,TH,DIFF,SIGNS,EPS1,EPS2,
     1  MIT, FLAM, FNU, SCRAT,LL)
      DIMENSION SCRAT(1)
      IA=1
      IB=IA+NP
      IC=IB+N
      ID=IC+NP
      IE=ID+NP
      IF=IE+NP
      IG=IF+NOB
      IH=IG+NOB
      II = IH + NP * NOB
      IJ = IH
          CALL  HAUS9(NPROB,MODEL,NOB,Y,NP,TH,DIFF,SIGNS,EPS1,EPS2,MIT
     1   ,FLAM,FNU,SCRAT(IA), SCRAT(IB), SCRAT(IC), SCRAT(ID),
     2  SCRAT(IE), SCRAT(IF), SCRAT(IG), SCRAT(IH), SCRAT(II),
     3  SCRAT(IJ),LL)
      RETURN
      END

  FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)

  **  NO WARNINGS **  NO ERRORS **  PROGRAM = 00139      COMMON = 00000
```

```
      SUBROUTINE HAU59(NPRBO, MODEL, NBO, Y,NQ,TH,DIFZ,SIGNS,EP1S,EP2S,
     1NIT,FLAM,FNU,   Q,P,E,PHI,TB,F,R,A,D,DELZ,LL)
C
C
C
C     DIMENSION TH(NQ), DIFZ(NQ), SIGNS(NQ), Y(NBO)
C     DIMENSION Q(NQ), P(NQ), E(NQ), PHI(NQ), TB(NQ)
C     DIMENSION F(NBO), R(NBO)
C     DIMENSION A(NQ,NQ), D(NQ,NQ), DELZ(NBO,NQ)
C
C
C
C
      DIMENSION TH(1), DIFZ(1), SIGNS(1), Y(1), Q(1), P(1), E(1),
     1   PHI(1), TB(1), F(1), R(1), A(1), D(1), DELZ(1)
      ACOS(X) = ATAN(SQRT(1.0/X**2 - 1.0))
      NP = NQ
      NPROB = NPRBO
      NOB = NBO
      EPS1 = EP1S
      EPS2 = EP2S
      NPSQ = NP * NP
       NSCRAC = 5*NP+NPSQ +2*NOB+NP*NOB
       WRITE(LL,1000) NPROB, NOB, NP, NSCRAC
      WRITE(LL,1001)
       CALL GASS6(1, NP, TH, TEMP, TKEP,LL)
      WRITE(LL,1002)
       CALL GASS6(1, NP, DIFZ, TEMP, TEMP,LL)
      IF(MIN0(NP-1,50-NP,NOB-NP,NIT-1,999-NIT))99,15,15
 15   IF(FNU-1.0)99, 99, 16
 16   CONTINUE
      DO 19 I=1,NP
      TEMP = ABS(DIFZ(I))
      IF(AMIN1(1.0-TEMP, ABS(TH(I))))99, 99, 19
 19   CONTINUE
      GA = FLAM
      NIT = 1
      LAOS = 0.
      IF(EPS1) 5,70,70
 5    EPS1 = 0
   70 SSQ.= 0
      CALL MODEL(NPROB, TH, F, NOB, NP)
      DO 90 I = 1, NOB
      R(I) = Y(I) - F(I)
   90 SSQ=SSQ+R(I)*R(I)
      WRITE(LL,1003)SSQ
C
C                                                    BEGIN ITERATION
C
 100  GA = GA / FNU
      INTCNT = 0
      WRITE(LL,1004)NIT
 101  JS = 1 - NOB
      DO 136 J=1,NP
      TEMP = TH(J)
```

```
      P(J)=DIFZ(J)*TH(J)
      TH(J)= TH(J)+P(J)
      Q(J)=0
      JS = JS + NOB
      CALL MODEL(NPROB, TH, DELZ(JS), NOB, NP)
      IJ = JS-1
      DO 120 I = 1, NOB
      IJ = IJ + 1
      DELZ(IJ) = DELZ(IJ) - F(I)
  120 Q(J) = Q(J) + DELZ(IJ) * R(I)
      Q(J)= Q(J)/P(J)
C                                                Q=XT*R (STEEPEST DESCENT)
  130 TH(J) = TEMP
      IF(LAOS) 131,131,414
  131 DO 150 I = 1, NP
      DO 151 J=1,I
      SUM = 0
      KJ = NOB*(J-1)
      KI = NOB*(I-1)
      DO 160 K = 1, NOB
      KI = KI + 1
      KJ = KJ + 1
  160 SUM = SUM + DELZ(KI) * DELZ(KJ)
      TEMP= SUM/(P(I)*P(J))
      JI = J + NP*(I-1)
      D(JI) = TEMP
      IJ = I + NP*(J-1)
  151 D(IJ) = TEMP
  150 E(I) = SQRT(D(JI))
  666 CONTINUE
      DO 153  I = 1, NP
      IJ = I-NP
      DO 153 J=1,I
      IJ = IJ + NP
      A(IJ) = D(IJ) / (E(I)*E(J))
      JI = J + NP*(I-1)
  153 A(JI) = A(IJ)
C                                                A= SCALED MOMENT MATRIX
      II = - NP
      DO 155 I=1,NP
      P(I)=Q(I)/E(I)
      PHI(I)=P(I)
      II = NP + 1 + II
  155 A(II) = A(II) + GA
C
      I=1
       CALL MATIN(A, NP, P, I, DET)
C                                                P/E = CORRECTION VECTOR
       STEP=1.0
      SUM1=0.
      SUM2=0.
      SUM3=0.
      DO 231 I=1,NP
      SUM1=P(I)*PHI(I)+SUM1
      SUM2=P(I)*P(I)+SUM2
```

```
      SUM3= PHI(I) * PHI(I) + SUM3
  231 PHI(I) = P(I)
       TEMP = SUM1/SQRT(SUM2*SUM3)
      TEMP = AMIN1(TEMP, 1.0)
      TEMP = 57.295*ACOS(TEMP)
      WRITE(LL,1041) DET, TEMP
  170 DO 220 I = 1, NP
      P(I) = PHI(I) *STEP / E(I)
      TB(I) = TH(I) + P(I)
  220 CONTINUE
      WRITE(LL,7000)
 7000 FORMAT(30H0TEST POINT PARAMETER VALUES    )
      WRITE(LL,2006) (TB(I), I = 1, NP)
      DO 221 I = 1, NP
      IF(SIGNS(I)) 221, 221, 222
  222 IF(SIGN(1.0,TH(I))*SIGN(1.0,TB(I))) 663, 221, 221
  221 CONTINUE
      SUMB=0
      CALL MODEL(NPROB, TB, F, NOB, NP)
      DO 230 I=1,NOB
      R(I)=Y(I)-F(I)
  230 SUMB=SUMB+R(I)*R(I)
      WRITE(LL,1043)SUMB
      IF(SUMB - (1.0+EPS1)*SSQ) 662, 662, 663
  663 IF( AMIN1(TEMP-30.0, GA)) 665, 665, 664
  665 STEP=STEP/2.0
      INTCNT = INTCNT + 1
      IF(INTCNT - 36) 170, 2700, 2700
  664 GA=GA*FNU
      INTCNT = INTCNT + 1
      IF(INTCNT - 36) 666, 2700, 2700
  662 WRITE(LL,1007)
      DO 669 I=1,NP
  669 TH(I)=TB(I)
       CALL GASS0(1, NP, TH, TEMP, TEMP,LL)
      WRITE(LL,1040) GA, SUMB
      IF(EPS2) 229,229,225
  229 IF(EPS1) 270,270,265
  225 DO 240 I = 1, NP
      IF(ABS(P(I))/(1.E-20+ABS(TH(I)))-EPS2) 240, 240, 241
  241 IF(EPS1) 270,270,265
  240 CONTINUE
      WRITE(LL,1009)EPS2
      GO TO 280
  265 IF(ABS(SUMB - SSQ) - EPS1*SSQ) 266, 266, 270
  266 WRITE(LL,1010) EPS1
      GO TO 280
  270 SSQ=SUMB
      NIT=NIT+1
      IF(NIT - MIT) 100, 100, 280
 2700 WRITE(LL,2710)
 2710 FORMAT(//115H0**** THE SUM OF SQUARES CANNOT BE REDUCED TO THE SUM
     1OF SQUARES AT THE END OF THE LAST ITERATION - ITERATING STOPS    /)
C
C                                                    END ITERATION
```

```
C
  280 WRITE(LL,1011)
      WRITE(LL,2001) (F(I), I = 1, NOB)
      WRITE(LL,1012)
      WRITE(LL,2001) (R(I), I = 1, NOB)
      WRITE(LL,1017)
 1017 FORMAT(////," X PRIME-X MATRIX")
      CALL GASSG(4,NP,TEMP,TEMP,D,LL)
      SSQ=SUMB
      IDF=NOB-NP
      WRITE(LL,1015)
      I=0
       CALL MATIN(D, NP, P, I, DET)
      DO 7692 I=1,NP
      II = I + NP*(I-1)
 7692 E(I) = SQRT(D(II))
      DO 340 I=1,NP
      JI = I + NP*(I-1) - 1
      IJ = I + NP*(I-2)
      DO 340 J = I, NP
      JI = JI + 1
      A(JI) = D(JI) / (E(I)*E(J))
      IJ = IJ + NP
  340  A(IJ) = A(JI)
       CALL GASSG(3, NP, TEMP, TEMP, A,LL)
      WRITE(LL,1016)
       CALL GASSG(1, NP, E, TEMP, TEMP,LL)
      IF(IDF) 341, 410, 341
  341 SDEV = SSQ / IDF
      WRITE(LL,1014) SDEV, IDF
       SDEV = SQRT(SDEV)
      DO 391 I=1,NP
      P(I)=TH(I)+2.0*E(I)*SDEV
 391  TB(I)=TH(I)-2.0*E(I)*SDEV
      WRITE(LL,1039)
       CALL GASSG(2, NP, TB, P, TEMP,LL)
      LAGS = 1
      GO TO 101
  414 DO 415 K = 1, NOB
      TEMP = 0
      DO 420 I=1,NP
      DO 420 J=1,NP
      ISUB = K+NOB*(I-1)
      DEBUG1 = DELZ(ISUB)
C     DEBUG1 = DELZ(K + NOB*(I-1))
      ISUB = K+NOB*(J-1)
      DEBUG2 = DELZ(ISUB)
C     DEBUG2 = DELZ(K + NOB*(J-1))
      IJ = I + NP*(J-1)
      DEBUG3 = D(IJ)/(DIFZ(I)*TH(I)*DIFZ(J)*TH(J))
  420 TEMP = TEMP + DEBUG1 * DEBUG2 * DEBUG3
       TEMP = 2.0*SQRT(TEMP)*SDEV
      R(K)=F(K)+TEMP
  415 F(K)=F(K)-TEMP
      WRITE(LL,1008)
```

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      IE=0
      DO 425 I=1,NOB,5
      IE=IE+5
      IF(NOB-IE) 430,435,435
  430 IE=NOB
 435  WRITE(LL,2001) (R(J), J = I, IE)
 425  WRITE(LL,2006) (F(J), J = I, IE)
 410  WRITE(LL,1033) NPROB
      RETURN
 99   WRITE(LL,1034)
      GO TO 410
 1000 FORMAT(38H1NON-LINEAR ESTIMATION, PROBLEM NUMBER   I3,// I5,
     1  14H OBSERVATIONS, I5, 11H PARAMETERS  I7, 17H SCRATCH REQUIRED)
 1001 FORMAT(/25H0INITIAL PARAMETER VALUES  )
 1002 FORMAT(/54H0PROPORTIONS USED IN CALCULATING DIFFERENCE QUOTIENTS )
 1003 FORMAT(/25H0INITIAL SUM OF SQUARES =  E12.4)
 1004 FORMAT(/////45X,13HITERATION NO.  I4)
 1007 FORMAT(/32H0PARAMETER VALUES VIA REGRESSION  )
 1008 FORMAT(////54H0APPROXIMATE CONFIDENCE LIMITS FOR EACH FUNCTION VAL
     1UE     )
 1009 FORMAT(/62H0ITERATION STOPS - RELATIVE CHANGE IN EACH PARAMETER LE
     1SS THAN   E12.4)
 1010 FORMAT(/62H0ITERATION STOPS - RELATIVE CHANGE IN SUM OF SQUARES LE
     1SS THAN   E12.4)
 1011 FORMAT(22H1FINAL FUNCTION VALUES  )
 1012 FORMAT(////10H0RESIDUALS  )
 1014 FORMAT(//24H0VARIANCE OF RESIDUALS =    ,E12.4,1H,I4,
     120H DEGREES OF FREEDOM   )
 1015 FORMAT(////19H0CORRELATION MATRIX   )
 1016 FORMAT(////21H0NORMALIZING ELEMENTS   )
 1033 FORMAT(//19H0END OF PROBLEM NO.  I3)
 1034 FORMAT(/16H0PARAMETER ERROR  )
 1039 FORMAT(/71H0INDIVIDUAL CONFIDENCE LIMITS FOR EACH PARAMETER (ON LI
     1NEAR HYPOTHESIS)    )
 1040 FORMAT(/9H0LAMBDA =E10.3, 4X,33HSUM OF SQUARES AFTER REGRESSION =
     1E15.7)
 1041 FORMAT(14H DETERMINANT =  E12.4, 6X, 25H ANGLE IN SCALED COORD. =
     1  F5.2, 8HDEGREES   )
 1043 FORMAT(28H0TEST POINT SUM OF SQUARES =    E12.4)
 2001 FORMAT(/5E12.4)
 2006 FORMAT(5E12.4)
      END


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** NO WARNINGS ** NO ERRORS **  PROGRAM = 02583     COMMON = 00000
```

```
      SUBROUTINE MATIN(A, NVAR, B, NB, DET)
      DIMENSION A(NVAR, 1), B(NVAR, 1)
       PIVOTM = A(1,1)
       DET = 1.0
      DO 550 ICOL = 1, NVAR
       PIVOT = A(ICOL, ICOL)
      PIVOTM = AMIN1(PIVOT, PIVOTM)
       DET = PIVOT * DET
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
       A(ICOL, ICOL) = 1.0

      PIVOT = AMAX1(PIVOT, 1.E-20)
       PIVOT = A(ICOL, ICOL)/PIVOT
      DO 350 L=1,NVAR
  350  A(ICOL, L) = A(ICOL, L)*PIVOT
      IF(NB .EQ. 0) GO TO 371
      DO 370 L=1,NB
  370  B(ICOL, L) = B(ICOL, L)*PIVOT
C
C     REDUCE NON-PIVOT ROWS
C
  371 DO 550 L1=1,NVAR
       IF(L1 .EQ. ICOL) GO TO 550
       T = A(L1, ICOL)
       A(L1, ICOL) = 0.
      DO 450 L=1,NVAR
  450  A(L1, L) = A(L1, L) - A(ICOL, L)*T
      IF(NB .EQ. 0) GO TO 550
      DO 500 L=1,NB
  500  B(L1, L) = B(L1, L)-B(ICOL,L)*T
  550 CONTINUE
      RETURN
      END
```

```
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** NO WARNINGS ** NO ERRORS **   PROGRAM = 00312      COMMON = 00000
```

```
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             SUBROUTINE CASSO(ITYPE, NQ, A, B, C,LL)
            DIMENSION A(NQ),B(NQ),C(NQ,NQ)
             NP = NQ
             NR = NP/10
             LOW = 1
             LUP = 10
       10   IF( NR )15,20,30
       15   RETURN
       20   LUP=NP
            IF(LOW .GT. LUP) RETURN
       30   WRITE(LL,500) (J,J=LOW,LUP)
            GO TO (40,60,80),ITYPE
       40   WRITE(LL,600)(A(J),J=LOW,LUP)
            GO TO 100
       60   WRITE(LL,600) (B(J),J=LOW,LUP)
            GO TO 40
       80   DO 90 I=LOW,LUP
       90   WRITE(LL,720)I,(C(J,I),J=LOW,I)
            LOW2=LUP+1
            IF(LOW2 .GT. NP) GO TO 100
            DO 95 I=LOW2,NP
       95   WRITE(LL,720)I,(C(J,I),J=LOW,LUP)
      100    LOW = LOW + 10
             LUP = LUP + 10
             NR = NR - 1
             GO TO 10
      500   FORMAT(/5X,I7,9(5X,I7))
      600   FORMAT(5E12.4)
      720   FORMAT(1H0,I3,9(1X,F12.4,1X))
            END


  FTN4 COMPILER: HP92060-16092 REV. 2001 (791101)


  **  NO WARNINGS **  NO ERRORS **   PROGRAM = 00239     COMMON = 00000
```