220.-

RBC PERFORMANCE UNDER TRANSIENT LOADING CONDITIONS

Performance of Rotating Biological Contactors under Transient Loading Conditions

By

Michel P. Filion, B.A.Sc.

A Project Report
Submitted to the School of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
Master of Engineering

McMaster University
November, 1979

Master of Engineering (1979)
(Chemical Engineering)

McMaster University
Hamilton, Ontario

Title	:	Performance of Rotating Biological Contactors under Transient Loading Conditions
Author	:	Michel P. Filion
		B.A. Sc. (University of Waterloo)
Supervisor	:	Professor K.L. Murphy
Number of Pages	:	X, 223

Abstract

This report examines the dynamic response of a 0.5 metre pilot scale rotating biological contactor when operated under transient influent conditions. Experimental data are presented for two modes of operation: carbon oxidation and carbon oxidation plus nitrification. During the carbon oxidation experimental runs, a 2.0 metre RBC was operated in parallel with the 0.5 metre RBC, thus allowing comparisons in the performance of the units.

When the 0.5 metre RBC was operated under nitrifying conditions, it was found that the effluent filterable TKN responded positively to influent variations in filterable TKN loading, TKN concentration and hydraulic loading. Transfer function - noise models were developed which successfully predicted the time varying effluent TKN response. The response in effluent filterable TKN was predicted most precisely by influent TKN loading. Models based on influent TKN concentration and flow were not as precise in predicting effluent response. The effluent response of the 0.5 metre RBC was found to be greater than the response of activated sludge pilot units when operated at similar levels of removal.

When the 0.5 metre RBC was operated in the carbon oxidation mode, significant effluent responses were observed for carbon loading and concentration. Little correlation was found between influent flow and effluent carbon concentration. Operating under identical conditions, the 2.0 m RBC showed significant responses to carbon loading, carbon concentration and flow.

Acknowledgements

The completion of this report could not have been accomplished without the assistance and support of many people. I would like to acknowledge especially:

Dr. Keith Murphy, for his guidance, patience, and counsel through the investigation and writing;

The employees of the Environmental Protection Service, Wastewater Technology Centre, particularly Dr. B.E. Jank and Mr. J.P. Stephenson, for the use of their facilities and for technical support;

McMaster University, the Environmental Protection Service, IEC Consultants, and Central Mortgage and Housing Corporation for their financial support;

And, most importantly, a special thanks to my parents and my wife Ms. Piggie, for their encouragement to complete this work after such a long delay.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

Performance of Rotating Biological Contactors under Transient Loading Conditions

1. INTRODUCTION

The rotating biological contactor (RBC) is an aerobic biological treatment system based on the biosorption principle. It employs captive biological slimes to remove substrate from the liquid wastewater by physical and biochemical means.

RBC treatment design criteria are still in the development stage and have generally been based on hydraulic loading. Early investigations (Antonie, 1970) indicated that BOD_5 and ammonia removal followed first order kinetics. This led to designs based on percentage removal and hydraulic loadings. Further refinement of this approach provided designs based on effluent concentrations and areal hydraulic loadings, with no consideration provided for influent substrate concentrations or mass loadings. Recent publications (Antonie, 1976; Poon et al, 1977) suggest that influent substrate concentrations also have an influence on the design relationships.

Capital costs for the RBC have been shown to decrease linearly with hydraulic capacity (Antonie, 1976), potentially providing relatively inexpensive biological treatment for small communities, work camps, and summer camps. However, wastewaters from these sources tend to have large diurnal flow and substrate concentration fluctuations (Randtke et al, 1977) and if the RBC is to be used in these applications its dynamic behaviour must be evaluated and quantified.

Attempts to date to model the performance of the RBC have been based upon steady-state equations. Of the few kinetic studies reported, the deterministic models which have been developed are based on two general concepts (Friedman et al, 1976; Kornegay, 1969; Famolaro et al, 1976; Hansford et al, 1978):

1. kinetic models for growth, or
2. empirical models based on mass transport concepts.

To describe the removal capability of an RBC using these concepts, deterministic models must attempt to incorporate RBC mixing characteristics, retention time, active biofilm thickness, rotational speed, available surface area, system geometry, and diffusion coefficients for oxygen and substrate transfer. The parameter values describing these characteristics are estimates at best, and introduce potential weaknesses to the models. Further, model parameter values obtained in this fashion will not describe the dynamic relations between influent and effluent when the input to the RBC is highly variable.

An estimate of the stability for a RBC can only be obtained using techniques which elucidate the response to non-steady operation. Incorporation of the process dynamics into a deterministic model yields a complex system of linear differential equations (Kornegay, 1969). Time series analysis is an alternative to be considered as a method to describe the process dynamics. Using this method, insight into the significant influent variables affecting effluent quality, and forecasting of effluent quality for various influent values can be obtained to provide a basis for process assessment and control. Time series analysis as developed by Box and Jenkins (1970) is one approach that can be used to relate influent and effluent variables for actual experimental or operational data. The resulting model may be updated as more information becomes available. Berthoeux _et al_. (1976) and Murphy _et al_. (1977) have previously demonstrated the potential of time series model building for describing wastewater treatment systems.

This study has examined the performance of pilot scale RBCs operating under variable influent loadings of organic carbon and ammonia. The experimental design allowed the use of time series analysis to examine the response of RBCs under non-steady influent conditions and provided a means for assessing design criteria for the RBC. Comparisons of the performance of the pilot scale RBC with a full scale RBC and conventional activated sludge units have been made.

2. LITERATURE REVIEW

2.1 Process Description

The Rotating Biological Contactor (RBC) is an aerobic biological waste treatment system which is based on the "biosorption" principle. By using the adsorptive and absorptive properties of captive biological slimes, organic material is removed from liquid wastes by physical and biochemical means. Each unit consists of a large number of lightweight polyethylene discs which are bonded together in a stack, mounted on a horizontal shaft and placed in a semicircular tank. The discs, which are vacuum-formed in sizes up to four (4) metres in diameter, are slowly rotated while approximately one half of their surface area is submerged in the wastewater. Rotational speeds are generally in the range of 2 to 20 rpm.

Immediately after startup, organisms naturally present in a wastewater begin to adhere to the disc surfaces, and multiply. After a period of 2 to 3 weeks, the unit normally has acclimatized and produces a relatively stable, treated effluent. As the discs rotate, the growth is alternately exposed to the wastewater and atmosphere. The rotating action aerates the wastewater, provides oxygen necessary for organism growth and controls the biomass population. Shearing forces exerted on the biomass cause any excess biomass to slough from the discs into the mixed liquor. The solids remain in suspension until subsequent removal by settling.

RBCs are relatively new to North America. The acceptance and application of new and different methods of wastewater treatment systems has historically taken many years. As a result, the literature available on RBCs is general and tends to concentrate on their many apparent advantages. These may be summarized as follows.

1. The system is not subject to washout conditions because of the large captive biomass.

2. The biomass population for the treatment of domestic wastewaters has been estimated to be the equivalent of 18000 to 30000 mg/L MLSS (Joost, 1969; Welch, 1968). Manufacturers suggest that these large numbers of captive microorganisms will provide a low F/M ratio and enable the system to absorb organic shock loads.

3. Capital investment costs are lower than activated sludge (Antonie, 1977) or trickling filter systems (Winkler, 1974). However, these costs increase linearly with treatment capacity and thus lose their competitive edge for large facilities.

4. Operating and maintenance costs are low, as little power is required to turn the discs, and head loss throughout the plant is minimal.

   Little operator attention is required.

2.2 Historical Development

According to Hartmann (1960) the original concept of the RBC should be creditied to Travis, who, in 1901, tried to increase the efficiency of his "Hydrolytic Tank" by hanging thin wooden strips, called colloid catchers, in the settling compartment of his unit. Solids accumulated on the slats, but did not always slough off, thus causing partial clogging of the unit.

Doman (1929) presented results which were obtained from the operation of what was probably the first RBC to resemble modern units. The RBC consisted of fourteen 20 gague galvanized iron plates (16 inches in diameter) which were rotated in a 4.75 gallon, semi-circular tank. (At that time plastic materials were not available.) Doman obtained organic removal efficiencies characteristic of conventional aerobic treatment processes and identified research needs similar to those being investigated today. (i.e. optimum retention times, speed of rotation, suface area effects and temperature effects). Concurrently, Buswell (1929) reported on a system which he called the "Biologic Wheel" and cited as advantages that:

1. the area requirements were about 1/10 of that needed for a trickling filter,
2. the power costs were low as compared to the activated sludge process, and
3. nitrification was obtained.

The Great Depression and Wold War II delayed further research until Hartmann and Popel began investigating the process at the Technical University of Stuttgart, in 1955. Hartmann (1960) described the operation of two experimental immersion drip filter disc plants. The paper outlined performance characteristics and economics for their use as a sewage treatment system. Subsequent papers by Popel (1964) and Hartmann (1965) indicated that disc filters had become moderately well established on the continent. Lohr (1967) described a prototype RBC plant which used power from the sewage flow to rotate the discs. Reinisch (1969) gave theoretical reasons to support the claims that rotary disc plants were more economical to operate than conventional treatment methods.

In the U.S.A. and Canada, much of the early research was concerned with the use of RBC's for the treatment of wastewaters from small communities or industrial plants (Antonie <u>et</u> <u>al</u>, 1969, 1970). Using designs similar to those used in Germany, these plants were constructed to treat either primary or septic tank effluents. Torpey et al (1972) experimented with multiple staged disc units which included a final stage exposed to light in order to grow algae and thereby remove inorganic nutrients from the sewage.

More recently, Reimer et al (1976) compared the performance of several pilot scale wastewater treatment units. Under nitrifying conditions he concluded that the RBC did not produce as stable an effluent as an activated sludge unit.

Commercial marketing of the RBC began in Europe in 1959 by J. C. Stengelin Ltd., Tuttingen, W. Germany, who now have licences in several countries. By 1973 there were more than 1,000 installations in Europe (primarily West Germany, France and Switzerland) treating domestic, industrial and mixed wastewaters. Treatment capacities varied from that generated by a single residence to 45.4 kg BOD_5 removed per day (Beak, 1973).

Allis - Chalmers Ltd. initially introduced the RBC system to North America in the mid - 1960's and in late 1970, Autotrol Corporation acquired the patents, inventories and contracts from Allis - Chalmers. Other companies now operating in North America include Bio Disc (Ames Crosta Mills Ltd), Rotordisk (CMS Ltd), Euromatic Bio Drum (European Plastic Manufacturing Company), the Rotating Biological Surface (Geo. A. Hormel & Co.), Envirodisc (Envirodisc Corp.), and the Rotating Disc Biological Reactor (Environmental Dynamics Corp.).

2.3 Carbon Oxidation

2.3.1 Design

Hartmann (1965) provided the first detailed account of RBC design practices used in Germany. These designs were introduced to South Africa by Pretorius (1973) and to North America by Steels (1974). The design methods were based on hydraulic loading, inlet BOD_5 concentration, and areal BOD_5 loading, for a town population of 10,000. Multiplication factors were provided for communities of different sizes.

Joost (1969) suggested a steady state design equation based on the assumption that the biochemical reaction taking place is concentration dependent, following a first order equation of the type

$$\% \frac{\text{BOD Reduction}}{\text{Stage}} = K \times C^a \times R^b \times T^c \times \Gamma^d \quad \ldots \quad (1)$$

where: K is the treatability constant,

C is the concentration of the waste material,

R is the physical configuration constant,

T is the wastewater temperature,

Γ is the residence time, and
a, b, c, d are partial regression coefficients.

Unfortunately, data were not provided for the constants a, b, c, d or K. The above equation was solved using multiple regression analysis by Weng and Molof (1974), for a nitrifying system. The results indicated that influent loading, concentration and flow had an effect on effluent quality but no indication was given as to the relative importance of each parameter.

In North America, Antonie (1970) presented data which suggested that BOD_5 removal was a "first order" reaction with respect to BOD_5 concentration. "First order" removal kinetics implies that a given percentage BOD_5 removal is possible regardless of inlet BOD_5 concentration or loading. Therefore, Antonie introduced RBC treatment facility designs based solely on hydraulic loadings and percentage removals. This approach is analagous to the volumetric loading rates once used for activated sludge design and hydraulic loading rates for trickling filter design.

Although many investigators believed hydraulic flow rate to be the determining factor in BOD_5 or COD removal in fixed film systems (i.e. trickling filters), Cook and Kincannon (1971) presented data which indicated that the important design parameter for trickling filters was the organic loading. They recommended that any comparison between trickling filter be made on a g/d-m^3 (lbs/d-1000 ft^3) basis. These results led to a great deal of controversy among researchers as to what the primary design criterion for RBCs should be and how experimental data should be reported.

Since the paper by Antonie (1970), the RBC manufacturers have all tended to use areal hydraulic loading as their primary design basis. It was not until 1976 that data were published indicating that areal mass loading was possibly a better design criterion. Stover and Kincannon (1976) operated a RBC pilot plant on slaughterhouse wastewater. They found that a plot of mass loading versus mass removal followed Monod type kinetics for COD removal. The plot showed less variability than a similar one using hydraulic loading. A limiting removal of 22.5 g COD/d-m^2 was obtained for loadings greater than 50 g COD/d-m^2.

2.3.2 Performance

Because the rotating biological contactor is a relatively new wastewater treatment process, many of the papers published on RBC research are devoted to describing only their effectiveness in treating industrial and municipal wastes, in terms of percentage removals. Pretorius (1971) found that a maximum removal rate of 0.49 g COD/d-g biomass was achievable in his 9 disc RBC system. At the same time Wells (1971) found that for an influent BOD$_5$ concentration of 250 mg/l, it was possible to improve BOD$_5$ removal efficiency from 50% to 83% simply by decreasing the flow rate from 325.9 l/d-m^2 (8.0 U.S. gal/d-ft^2) to 163 l/d-m^2 (4.0 U.S. gal/d-ft^2). The results of Pescod (1972) seemed to verify the "first order" kinetic results obtained by Antonie (1970). When viewed on a stage by stage basis, Pescod was able to obtain 95% COD removal at a loading of 4 kg COD/d-m^2 for organic wastes near 1000 mg/l.

Bruce et al (1973) recommended a maximum daily areal load of 6 g/d-m^2 (1.2 lb. BOD/d-1000 ft^2) in order to obtain the standards set in the U. K.(30 ppm suspended solids, 20 ppm BOD$_5$). The MOE 1974 report recommended that a loading of 20 to 25 g/m^2-d (1 lb BOD$_5$/d-1000 ft^2) should be used to obtain 80 to 90% BOD$_5$ removal efficiency. EPA, on the other hand, simply suggested using an areal hydraulic loading of 61.1 l/d-m^2 (1.5 U.S.gal/d-ft^2)) to obtain 87% BOD$_5$ removal or better.

2.3.3. Diurnal Variability, Hydraulic Pulses and Intermittent Flow

The problems peculiar to isolated sewage treatment plants serving small communities, summer camps and work camps are mainly related to highly variable flow conditions, limited supervision and maintenance. Despite these problems there is normally a requirement that the plant will at all times produce a consistent effluent quality. All of the positive aspects of RBCs indicate that these units should be ideally suited for such applications. In addition, economic studies reveal that RBC construction costs increase linearly with size, suggesting that their use be limited to small treatment applications. (EPS Report No. 4-WP-73-4; Winkler, 1974; Antonie, 1976).

Popel (1964), Markii(1964) and Antonie (1970) investigated RBC effectiveness in situations where cyclic operations, shift work, holidays and weekends tend to create problems of operation. All three investigators reported an increase in BOD_5 or COD removal efficiency during cyclic operation. However, this was not confirmed by NCASI (1974) or Davis (1976) who found an immediate deterioration in organic removal efficiency during hydraulic pulses

Bruce et al (1973) subjected a RBC test unit to diurnal peak flow variations of 3/1/0.6 (maximum/average/minimum) in a rectangular wave pattern. The hydraulic pulse variation was considered to be a reasonable simulation of the flow pattern which would arise from a small community with synchronized activities such as schools and other institutions. The results of the study indicated that the RBC could not produce a stable effluent quality which would meet British effluent standards, although 90% BOD_5 removal was obtained. The report did not specify the influent organic loadings.

Three government institutions have recognized the potential of RBCs as a viable treatment alternative for small communities and initiated investigations into their use.

The EPA (1973) found the RBC process to be relatively well suited to summer camp application where sewage flow was low and fluctuated considerably. It should be noted however, that the hydraulic loadings were 4.9 to 48.9 $l/d\text{-}m^2$ (0.1 to 1.01 US $gal/d\text{-}ft^2$) which are very conservative by manufacturers standards. The MOE (1974), EPS (1974), Bruce (1974) and Antonie (1970b) demonstrated that intermittent flow did not adversely affect organic removal efficiency, although they noted an initial increase in solids concentration where operations were resumed after a two-day stoppage in flow. Forgie (1974) operated a bio-disc unit at a five man workcamp in the Northwest Territories. The unit was subjected to loadings ranging from 4.9 to 19.5 $g/d\text{-}m^2$ BOD_5 (7.3 to 29.2 $g/d\text{-}m^2$ COD). Good percentage removals were obtained at all levels, although effluent concentrations varied considerably.

2.4 Nitrification

Nitrification of wastewaters may be achieved by using the activated sludge, trickling filter or RBC process operating under conditions favorable for the development of nitrifying bacteria. Nitrifying bacteria are strict autotrophs and are distinctly different from the heteretrophic bacteria responsible for the degradation of organic carbonaceous matter. In the RBC process, nitrification has been observed to occur only in the final RBC stages owing to differences in yield between the nitrifiers and heterotrophes (Torpey 1972). Antonie (1972a,1972b) noted that nitrifying bacteria can only begin to compete with the heterotrophes at BOD_5 concentrations of 30 mg/l or less in systems utilizing areal hydraulic loadings ranging from 4.9 to 49 $l/d\text{-}m^2$ (0.1 to 1 U.S. $gal/d\text{-}ft^2$). Torpey (1972) and Weng and Molof (1974) found that the limiting BOD_5 concentration was closer to 15 mg/l and noted that this was equivalent to a COD of 50 mg/l.

2.4.1 Design

Antonie (1970) claimed that ammonia removal kinetics are a first order function of retention time in the RBC system. Design considerations similar to carbon oxidation systems were therefore developed, namely, to base the primary design criterion on the areal hydraulic loading to the unit.

First order removal kinetics were also demonstrated by Stover and Kincannon (1975). They investigated NH_3-N removal at influent loadings of 0.56, 1.12 and 2.25 g NH_3-N/d-m^2. Removal efficiency was shown to decrease from 100% to 51% in a semi-logarithmic fashion when the flow rate was increased four fold. The investigation did not distinguish between the effect of flow and mass loading. Weng and Molof (1974) demonstrated that loading and not flow rate should be the primary design criterion. Nitrification was shown to remain constant when the flow and concentration were varied while maintaining a constant mass loading. However, using designed experiments, Wilson (1975) could not determine if nitrification followed "zero order" or "first order" kinetics. Murphy et al. (1975) compared models based on "zero order", "half order" and "first order" kinetics. The model which was "zero order" with respect to TKN concentration was selected as the best able to describe the data.

2.4.2 Performance

As with carbon oxidation, most of the literature has been devoted to describing reactor performance in terms of percentage removal. Hao and Hendricks (1975) operated a pilot plant RBC in Columbus, Indiana and obtained 92% NH_3-N removal of at an areal flow rate of 0.06 m^3/d-m^2 (1.5 U.S. gal/d-ft^2). An increase to 0.1 m^3/d-m^2 (2.5 U.S. gal/d-ft^2) significantly decreased nitrification. Influent NH_3-N concentrations averaged 8.8 mg/l at the low flow rate and 10.8 mg/l at the high flow rate. Wilson (1975) obtained an average NH_3-N removal rate of 20 mg/h-m^2 (0.10 lb/d-1000 ft^2) from his system with temperatures varying from 7 to 20°C. Variations in mass removal rate at different temperatures were related by an Arrhenius expression. Stover and Kincannon (1975) noted that NO_3-N production decreased with a simultaneous increase in NH_3-N and COD load. They concluded that the increased COD load must have caused the heterotrophs to multiply in the last RBC compartments, subsequently reducing overall nitrification rates.

2.5 Denitrification

In contrast to ammonia removal, complete nitrogen removal may be achieved by the biological nitrification-denitrification process.

Denitrification on a RBC has been demonstrated by Pretorius (1973) and Davis and Pretorius (1974). These papers described the use of an enclosed, partially submerged, anaerobic RBC unit to denitrify a wastewater. They overcame two problems associated with conventional submerged biological bed denitrification processes:

a) clogging of bed voids by the active biomass, and
b) adherence of nitrogen gas to the sloughed biomass.

Shearing of the excess biological growth prevented clogging and exchange of the nitrogen gas to the wastewater and subsequently to the atmosphere prevented adherence. The maximum rate achieved was 250 mg NO_3-N reduced/m^2-h. Below 10°C, a severe inhibition of denitrification occurred.

Soyupak (1976) operated a submerged 0.5 metre RBC to denitrify sewage. He found that denitrification could be expressed as zero order reactions. Denitrification rates were higher than suspended growth or packed column systems. Temperature dependency of the denitrification reaction rates were independent of flow rate in the range of 2.5 to 4.0 l/min and was empirically described using an Arrhenius relationship.

2.6 Steady State Modelling

Success at steady state modelling of RBCs based on empirical, semi-empirical or completely theoretical models is limited. Removal characteristics of conventional treatment systems have been described by biological growth kinetics and the mixing characteristics of the reactor. Using such an approach, models for rotating biological contactors must also incorporate parameters to describe the active biomass thickness, disc rotational speed, available surface area, system geometry, and diffusion coefficients for oxygen and substrate transfer. The methods used to describe these characteristics are at best, estimates, and therefore introduce potential weakness in the models.

Kornegay (1972) developed a kinetic expression for RBC substrate removal assuming Monod kinetics and a completely mixed reactor.

$$F(S_o - S_1) = 2\ PN\ \pi (r_o^2 - r_\mu^2)\left(\frac{S1}{K_g + S_1}\right) \qquad \ldots(2)$$

where: F is the flow rate,

S_o, S_1 are the influent and effluent substrate concentrations,

N is the number of discs,

r_o is the total disc radius,

r_μ is the submerged disc radius,

K_g is the saturation constant,

P is the area capacity constant equal to $\frac{1}{Y_g} \mu_{max} X_f d$,

Y_g is the apparent yield of fixed film organisms,

μ_{max} is the maximum specific growth rate,

d is the active microorganism thickness, and

X_f is the unit mass of biological film.

Kornegay assumed values for the parameters in the model and predicted removal capabilities for a number of theoretical design situations. The information gained from this study was used to determine RBC treatment capacities and design requirements. However, without model calibration using experimental data, the results can only be used to demonstrate a methodology.

A more recent investigation into the kinetic response of RBC's was conducted by Friedman et al (1976). Experimental data were used to calibrate a conventional plug flow "first order" model and an empirical model based on mass transport concepts.

Plug Flow Model

$$C_e = C_b e^{-K_e t} \qquad \ldots \quad (3)$$

Mass Transport Model

$$K_m \left(\frac{1}{C_b} - \frac{1}{C_{bi}}\right) + \text{Ln} \left(\frac{C_{bi}}{Cb}\right)$$

$$= \frac{fh\ K_o^* A_s}{V_1} \theta = \frac{K'' \theta}{V_1} \qquad \ldots \quad (4)$$

where:

C_{bi}, C_b, C_e are the influent, soluble approach, and effluent substrate concentrations,
K_e is the reaction rate constant,
t is the overall time in the system,
K_m is the half saturation constant,
f is the proportionality constant,
h is the effective biomass depth,
K_o^* is the maximum areal removal rate,
A_s is the submerged surface area per disc face or stage,
K'' equals $f.h.K_o^* \cdot As$,
Θ is the average hydraulic retention time per disc face, and
V_1 is the tank liquid volume per disc face.

A general method was presented for obtaining K" from the experimental data. The models were then compared to data collected from independent studies. The mass transport model was shown to be superior in predicting effluent quality on a stage by stage basis.

Grieves (1972) incorporated a mass transport approach and Monod kinetics to develop a steady state model for rotating disc systems. The model is:

$$\frac{C_b}{C_o} = \frac{1}{1 + \frac{N}{F}\left[P_1 \cdot A_s + P_2 \cdot (rpm) \cdot \left(1 - \bar{e}^{\,P_1(A_a)/(P_2)(rpm)}\right)\right]} \quad \ldots (5)$$

where: C_b, C_o are the concentration of the limiting substate in the bulk liquid, and in the raw feed,

N is the number of discs,

F is the flow rate,

A_s is the area of one disc which is exposed to the atmosphere,

A_a is the area of one disc submerged in the bulk liquid,

P_2 is the quantity of liquid film attached to the biological film which enters the reactor per unit time,

P_1 is defined as $\dfrac{K_2 K_1}{1 + K_1}$

K_2 is the liquid film coefficient,

K_1 is defined as $\dfrac{(\hat{\mu})(X)(\Delta z)}{(y)(K_c)(n)(K_L)}$,

$\hat{\mu}$ is the maximum specific growth rate,

X is the organism concentration,

Z is the active depth of biological film,

y is the yield coefficient,

K_c is the saturation constant in the Monod equation, and

n is the efficiency factor.

The model effectively described effluent concentrations obtained by a number of independent investigations for influent substrate concentrations less than 50 mg/l TOC.

2.7 Dynamic Modelling

The steady state models discussed previously have been used to predict the steady state behaviour for either RBC design or operation. Use of steady state models is inconsistent with the variable loading of most biological waste treatment systems. Parameter values which have been obtained for these models will not describe the temporal relationships between influent and effluent when the input to the RBC is highly variable. An estimate of the stability of RBCs can only be obtained by using techniques which elucidate the responses to non-steady operation. This fact was recognized by Grieves (1972) who developed a dynamic mathematical representation of fixed film reactors. The dynamic model was developed from theoretical and empirical considerations of a fixed biological film attached to a rotating surface, and is represented by the following differential equations:

$$\frac{dC_{1,1}}{dt} = \frac{K_L}{\Delta Z_1}[C^* - C_{1,1}] - \frac{D}{\Delta Z_1}\,\frac{C_{1,1} - C_{2,1}}{\frac{1}{2}(\Delta Z_1 + \Delta Z_2)} - \frac{(\hat{\mu})\,(X)\,(C_{1,1})}{(Y)\,[K_c + C_{1,1}]} \qquad \ldots (6)$$

For L = 2 through 5, M = 1

$$\frac{dC_{L,1}}{dt} = \frac{D}{\frac{1}{2}\Delta Z_L}\,\frac{C_{L-1,1} - C_{L,1}}{\Delta Z_{L-1} + \Delta Z_L} - \frac{C_{L,1} - C_{L+1,1}}{\Delta Z_L + \Delta Z_{L+1}} - \frac{(\hat{\mu})\,(X)\,(C_{L,1})}{(Y)\,[K_c + C_{L,1}]} \qquad \ldots (7)$$

For L = 6, M = 1

$$\frac{d\,C_{6,1}}{dt} = \frac{D}{\frac{1}{2}\Delta Z_6} \quad \frac{C_{6,1} - C_{5,1}}{\Delta Z_5 + \Delta Z_6} - \frac{(\hat{\mu})(X)(C_{6,1})}{(Y)[K_c + C_{6,1}]} \qquad \ldots (8)$$

For the liquid film,

$$\frac{d\,C_{LF,\,1}}{dt} = - \frac{K_L}{\delta_L}\,[C_{LF,1} - C_{1,1}] \qquad \ldots (9)$$

For the bulk liquid,

$$\frac{d\,C_b}{dt} = F\,[C_o - C_b]/V_b - F_f[C_b - C_{LF,Q-1}]/V_b - (KL)(A)[C_b^* - C_{1,1}]/V_b \qquad \ldots (10)$$

where:

L	is an element at any depth in the active biological film of thickness ΔZ_L,
M	is the angular position of the liquid film on the biological disc,
C_b, C_o, F, $\hat{\mu}$, X, Y, K_c	have been previously defined in equation 5,
D	is the substrate diffusivity,
$C_{L,M}$	is the limiting substrate concentration in element L, M,
K_L	is the liquid film coefficient,
C*	equals the $C_{LF,M}$ if the element is in the reactor atmosphere,

C^*	equals C_b if the element is submerged in the bulk liquid,
A	is the area in the plane perpendicular to the direction of diffusing limiting substate,
δ_L	is the thickness of an element LF in the liquid film,
V_b	is the volume of bulk liquid in the reactor, and
$C_{LF,1}$	is the concentration of the limiting substrate in the liquid film.

The equations were solved using an analog computer. Values for the parameters used in the model were obtained from literature sources and laboratory data. The adequacy of the model was substantiated with dynamic data generated from two laboratory rotating disc reactors.

2.7.1 Linear Dynamic Stochastic Modelling

The solution of the dynamic model presented by Grieves (1972) is both tedious and time consuming. A simpler mathematical model that would describe the system is desirable. The need for a simple dynamic model for fixed-film systems is even more evident when it is considered that future treatment facilities may be automatically controlled using computers. For successful automatic control, predictive knowledge of the system response to dynamic inputs is necessary.

Time series analysis is a viable alternative to be considered as a method of describing the dynamics of a system, providing insight into the significant influent parameters affecting effluent quality, and forecasting future effluent quality for various influent situations. In addition, once the dynamic transfer function-noise models are developed, they are ideally suited for control purposes. Because time series analysis is simply a statistical approach relating influent and effluent parameters of actual experimental or operational data gathered on a discrete time basis, the model may be updated as more information about the system becomes available.

MacGregor (1975) and Berthoeux et al (1976) successfully developed time series models relating input BOD_5 data to effluent BOD_5. Tan (1975) did not observe any significant dynamic effects in effluent TOC or suspended solids concentration, but did observe significant relationships for effluent NO_2-N + NO_3-N concentration for an activated sludge plant. Up to date literature reviews of dynamic modelling of suspended growth systems were provided by Tan (1975) and Sutton (1976). The state of the art of sewage treatment plant control was reviewed by Olsson (1976).

MacGregor (1975) recommended the use of designed input sequences in order to eliminate the high degree of correlation naturally present in municipal sewage (i.e. flow, organic carbon concentration and ammonia concentration). Sutton (1976) successfully used this design suggestion and was able to describe the dynamic nature of combined and separate nitrifying suspended growth systems. Dynamic models relating total Kjeldahl nitrogen (TKN) concentration to TKN effluent concentration and variations in effluent NO_2-N + NO_3-N concentration to TKN input concentration plus input organic loading (TOC) were developed.

2.7.2 The Box and Jenkins Method of Developing Linear Dynamic Stochastic Models

Data analysis for building dynamic transfer function-noise models involves an iterative procedure to identify tentative models, to estimate model parameters, and to test residuals to determine the adequacy of the fit. These models have the form:

$$Y_t = \frac{(w_o - w_1\beta - w_2\beta^2 - \ldots - w_s\beta^s)\beta^b}{(1-\delta_1\beta-\delta_2\beta^2-\ldots-\delta_r\beta^r)} X_t + N_t \quad \ldots (11)$$

where: X_t is the input deviation from the mean at time t,
Y_t is the output deviation from the mean at time t,
δ, w are the transfer function model parameters,
r, s are the transfer function model orders,
b is the system delay period,
β is the backward shift operator, and

$$N_t = \frac{(1 - \theta_1\beta - \ldots - \theta_q\beta^q)}{(1-\beta)^d (1-\phi_1\beta - \ldots - \phi_p\beta^p)} a_t \quad \ldots (12)$$

where: N_t is the sequence of disturbances in the output which is not explained by X_t,
θ, ϕ are the noise model parameters,
p, d, q are the noise model orders, and
a_t is a white noise sequence of independent random variables with zero mean and constant variance

To identify potential transfer function models, the cross correlation function between influent and effluent variables is used. The cross correlation function between two input-output series (X and Y) separated by a constant lag, k, is given by:

$$\rho_{xy(k)} = \gamma_{xy}(k)/\sigma_x \cdot \sigma_y, \; k = 0, \pm 1, \pm 2, \ldots \pm k \qquad \ldots (13)$$

where: $\gamma_{xy}(k)$ is the cross covariance function between X and Y, and

σ_x, σ_y are the standard deviations of the X and Y series.

The impulse response function, an equivalent form of the cross correlation function, can also be used to interpret the data. Analysis of the cross correlation function or the impulse response function allows the identification of potential transfer function models, the model orders (r,s), the delay period (b), and the initial estimate of the parameter values (ω,δ). The autocorrelation functions of the residuals of the fitted transfer function models are used to identify potential noise models, N_t. Once the parameters of the combined transfer function-noise models are estimated efficiently by using a non-linear least squares technique, model adequacies are verified through diagnostic checks.

Diagnostic checks are made by calculating and examining the results of cross correlations between input and residuals, and by calculating the "S" statistic, which is then compared to the chi-square distribution (X^2) with k - r - s degrees of freedom:

$$S = m \sum_{k=0}^{k} r^2_{x'\hat{a}}(k) \qquad \ldots (14)$$

Noise model verification is obtained by autocorrelating the residuals of the transfer function noise model. A general lack of fit test is obtained by calculating the "Q" statistic which is compared to the chi-square distribution (X^2) with k - p - q degrees of freedom:

$$Q = m \sum_{k=1}^{k} r^2_{\hat{a}\hat{a}}(k) \qquad \ldots (15)$$

A more detailed description of the methods used are provided in Box and Jenkins (1976).

3. EXPERIMENTAL EQUIPMENT AND PROCEDURES

3.1 Pilot Plant Design and Operation

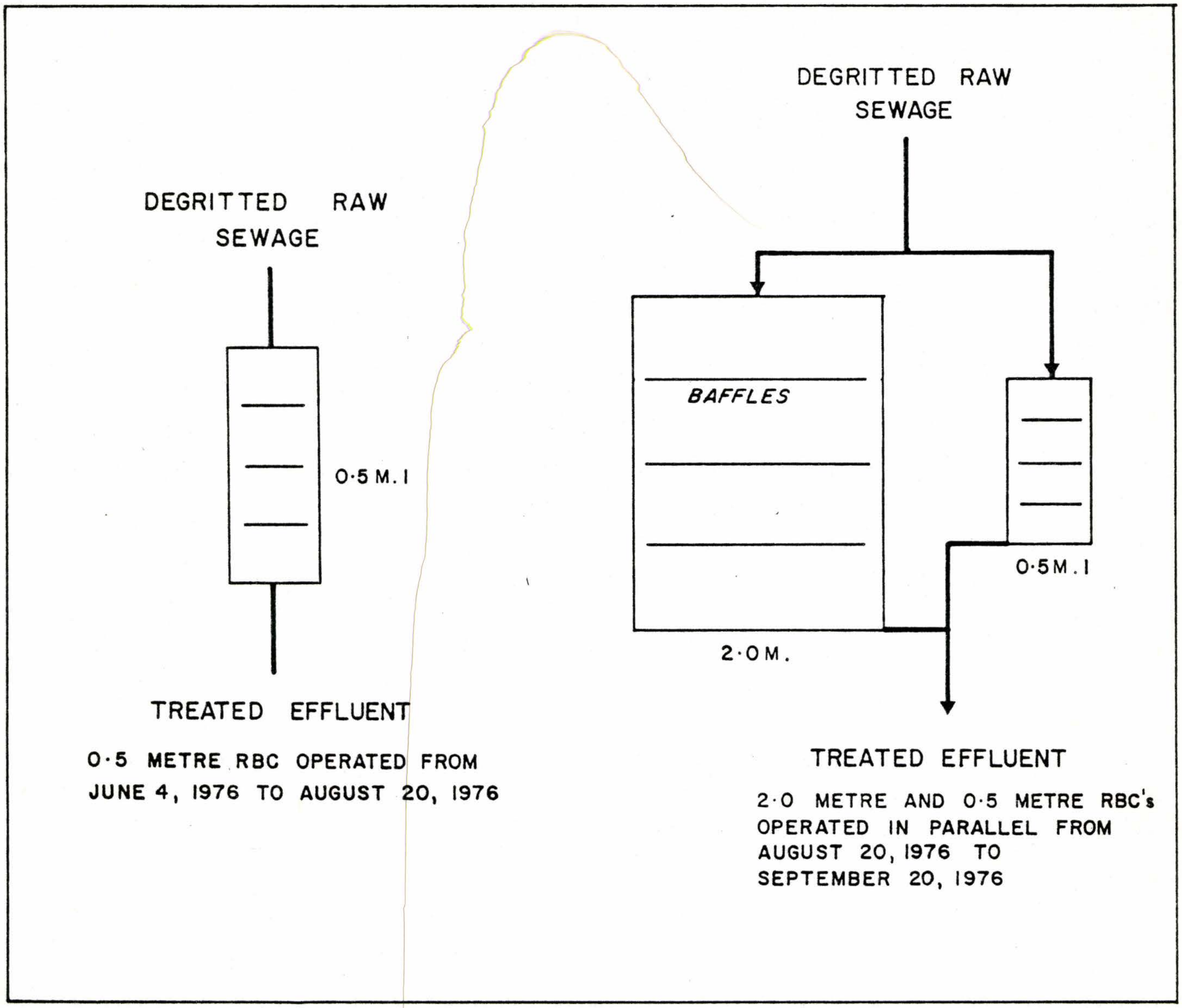
One 0.5 m RBC and one 2.0 m full scale RBC were used during this study. The units were obtained from Autotrol Inc., Milwaukee, Wisconsin. The 0.5 m unit provided 23.23 m^2 (250 ft^2) of available disc surface area, while the 2.0 m unit had 733.93 m^2 (7900 ft^2). Rotational speeds of the large and small unit were fixed at 3 RPM and 13 RPM respectively, thereby providing a peripheral tip velocity of 0.34 m/s (1.12 ft/s).

Feed to the half metre unit was provided by feed scoops or by a variable speed positive displacement pump, depending on the flow rates required. Feed to the 2 m unit was provided by variable speed positive displacement pumps. The influent raw feed used during the course of the experiments was degritted raw sewage from the Burlington Sewage Treatment Plant.

Figure 3.1 presents a schematic diagram of the system used and the identification codes for the units. The 0.5 m unit (0.5 M1) was operated indoors for a period of 2-1/2 months and for the remaining time, 0.5 M1 was run in parallel with the 2 m unit (2.0 M). The biodiscs were covered with hoods to provide insulation and protection from the natural environment (wind, rain, sunlight). All experiments were conducted with the hoods in place.

3.2 Experimental Plan and Start-Up

As previously discussed, the RBC has many inherent positive features which makes its use attractive in small community, workcamp and summercamp applications. Sewage generated by such sources is highly variable in both flow and concentration, and it is desirable to assess the per-



0·5 METRE RBC OPERATED FROM JUNE 4, 1976 TO AUGUST 20, 1976

2·0 METRE AND 0·5 METRE RBC's OPERATED IN PARALLEL FROM AUGUST 20, 1976 TO SEPTEMBER 20, 1976

FIGURE 3·1

PROCESS SCHEMATIC

formance of an RBC under such conditions. Further, there is also a need to examine whether hydraulic or organic loading is the primary design criterion. To satisfy these goals, experiments were designed to permit the use of time series analysis to evaluate the dynamic response of the RBC. The experimental programme was developed to provide data in two modes of operation; carbon oxidation and carbon oxidation plus nitrification.

A summary of the experimental programme is provided in Table 3.1. The experimental designs are discussed in Sections 3.3 and 3.4.

Prior to start-up of each unit, dye studies were performed to characterize the mixing regime of the RBCs. (Series A1, A3, A5). This data also provided an indication of peak residence times which was used in the development of the discrete sampling programme. Results from the dye studies are presented in Appendix D.

Acclimation took place during June, 1976 (series A2) with start-up of 0.5 M1 on June 1. The feed rate was set at approximately 0.8 l/min to allow for the growth of nitrifiers. Almost complete nitrification was achieved in two weeks with the high influent temperatures (28°C) obtained by passing the degritted raw sewage through a heater. The heater was bypassed after two weeks and influent temperatures dropped to normal (18 to 20°C).

The 2.0 metre biodisc (2.0 M) was started up on July 16, 1976 in the carbon oxidation mode, at flow rates of approximately 100 l/min. Acclimation lasted until August 5, 1976. The 2.0 metre unit was not used in this study until September 7, 1976.

Runs in series B1 and C1 extended from June 29 to July 22, 1976. They were followed by an acclimation period

Table 3.1

Summary of Experimental Programme

Operational Mode	Experiment	Run No	Type of Sampling
Carbon Oxidation Plus Nitrification	Hydraulic Characterization 0.5 M1	A1	Grab
Carbon Oxidation Plus Nitrification	Acclimation, 0.5 M1	A2	Grab and 24 hour composites
Carbon Oxidation	Hydraulic Characterization, 2.0 M	A3	Grab
Carbon Oxidation	Acclimation, 2.0 M	A4	Grab and 24 hour composites
Carbon Oxidation Plus Nitrification	Diurnal Influent Variations, 0.5 M1	B1	24 hour composites and hourly grab samples
Carbon Oxidation	Diurnal Influent Variations, 0.5 M1	B2	24 hour composites and hourly grab samples
Carbon Oxidation Plus Nitrification	Dynamic Performance of 0.5 M1	C1	hourly grab samples
Carbon Oxidation	Dynamic Performance of 0.5 M1 operated in parallel with 2.0 m	C2	30 minute grab samples
Carbon Oxidation	Dynamic Performance of 2.0 M Operated in Parallel with 0.5 M1	E2	30 minute grab samples

of 6 days before beginning series B2 (July 28, 1976 to August 9, 1976). Series C2 and E2 were conducted from September 7 to September 10, 1976 and concluded the experimental plan for this study.

3.3 Diurnal Flow Experiments (Series B1 + B2)

As the performance of rotating biological contactors was to be assessed for small community applications, the Series B experiments were designed to simulate the approximate diurnal flow and concentration variation typical of sewage from a small community. The 0.5 M1 was subjected to a sinusoidal flow input which attained max/avg/min peak flow ratios of 2/1/0.5, synchronous with the natural sewage concentration fluctuations of Burlington STP (Figure 3.2). Two average flow rates were employed, 65.1 l/d-m^2 (1.6 U.S. gal/d-ft^2) for nitrification (Series B1) and 208.3 l/d-m^2 (5.1 U.S. gal/d-ft^2) for carbon removal (series B2).

During the course of these runs, 24-hour flow weighted composites and hourly grab samples were obtained from both the influent and effluent of 0.5 M1. The data was used to verify the adequacy of the dynamic transfer function-noise models which were to be developed from the Series C experiments, and also, to assess the performance of the RBC.

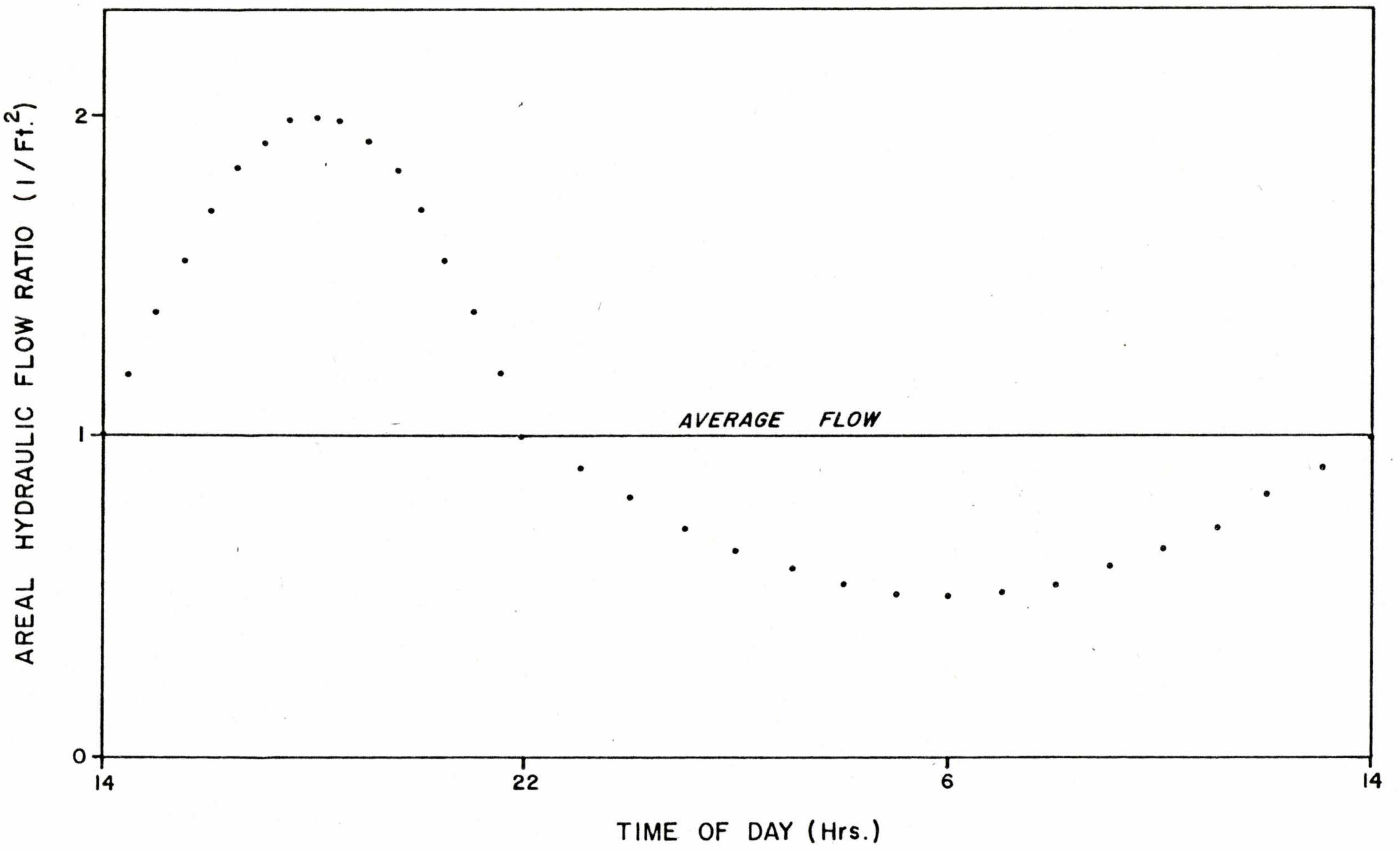
3.4 Dynamic or Non "Steady State" Experimental Design (Series C1, C2, E2)

The purpose of the dynamic experiments was to examine the performance of the 0.5 metre and 2.0 metre RBCs under variable influent conditions and to develop transfer function models which describe the dynamic behaviour of the system. In order to do so, experiments were designed and samples taken according to the following:

- a factorial design was used to separate the effects of the influent variables chosen;

FIGURE 3·2

PLANNED DIURNAL FLOW IMPUT TO 0·5 m RBC FOR PEAK/ AVERAGE/MINIMUM FLOW RATIO OF 2/1/0·5



- step changes in the influent variables were used to obtain the complete response spectrum;
- large numbers of paired samples (>100) were collected at discrete, equispaced time intervals; and,
- the sample interval was chosen consistent with the system response, which required prior knowledge of the residence time at various flow rates.

A two level, three parameter factorial design, presented in Table 3.2 and Figures 3.3 and 3.4, was selected. Three influent variables were chosen: hydraulic loading, filterable organic carbon concentration (TOC) and filterable total Kjeldahl nitrogen concentration (TKN). Experimental design levels are reported in Table 3.2. Loading boundaries (Table 3.2) were chosen to provide adequate system response while operating about the mean design level recommended for these units at municipal sewage treatment plants.

The design, using domestic sewage, required interference with the influent variables. This was accomplished by adding dextrose as an organic carbon spike, and ammonium chloride as a nitrogen spike. Two experiments were run to provide data for dynamic model building at average hydraulic loadings of 224 l/d-m^2 for carbon oxidation and 80 l/d-m^2 for nitrification. The units were run at the centre values of the parameters for two days prior to the start of experiments.

3.5 Feed Characteristics

The RBCs were continuously fed with normal degritted wastewater from Burlington STP. Probability distributions of filtered influent COD, TOC, TKN and suspended solids are given in Figures 3.5, 3.6, 3.7 and 3.8. A correlation of TOC with filtered BOD$_5$ is given in Figure 3.9.

Table 3.2

Design Levels for Experiments C1, C2 and E2

Carbon Oxidation Mode

Influent Variables	C1	C2 and E2 Operating Value	Design Level
Hydraulic Flow Rate	120	305	+
L/Day/m^2	40	143	-
Filtrable OC	50 to 60	80 to 90	+
mg/ℓ	20 to 30	50 to 60	-
Filtrable TKN	50 to 60	25	+
mg/ℓ	20 to 30	10	-
TOC Loading	6.6	26	+
G/Day/m^2	1	8	-
TKN Loading	6.6	7.6	+
G/Day/m^2	1	1.4	-

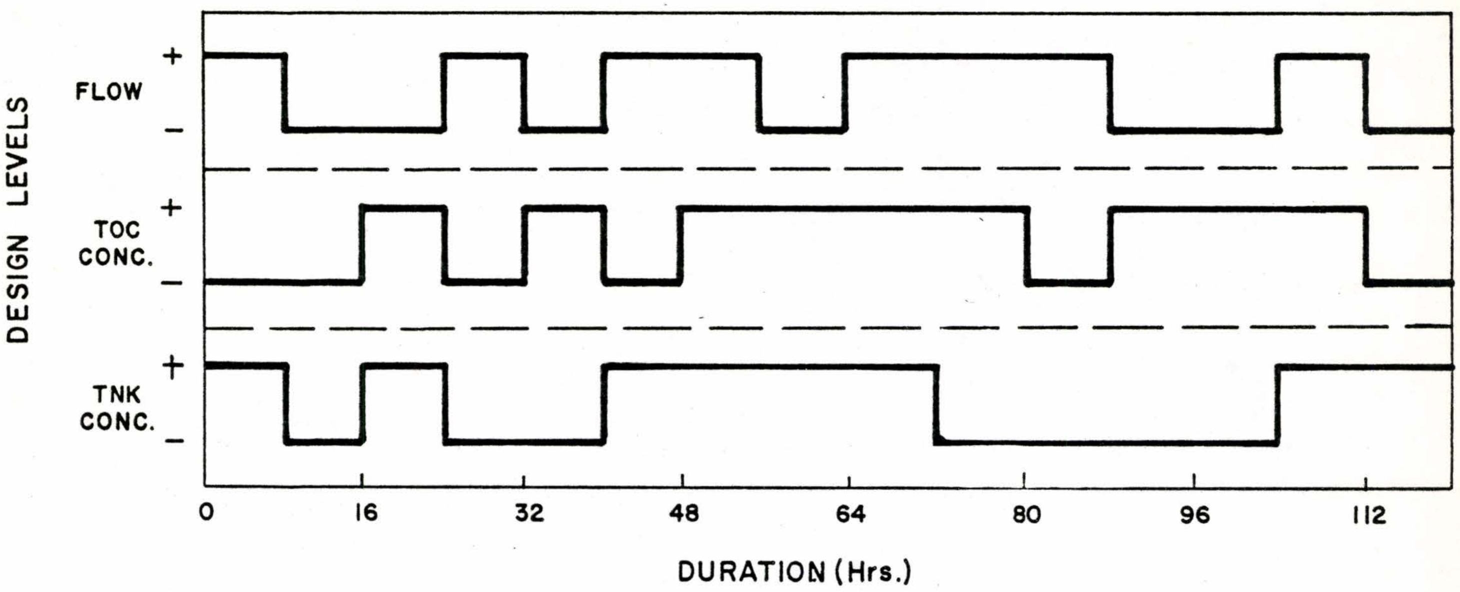


FIGURE 3·3

EXPERIMENT C1 DESIGN, CARBON OXIDATION

PLUS NITRIFICATION MODE

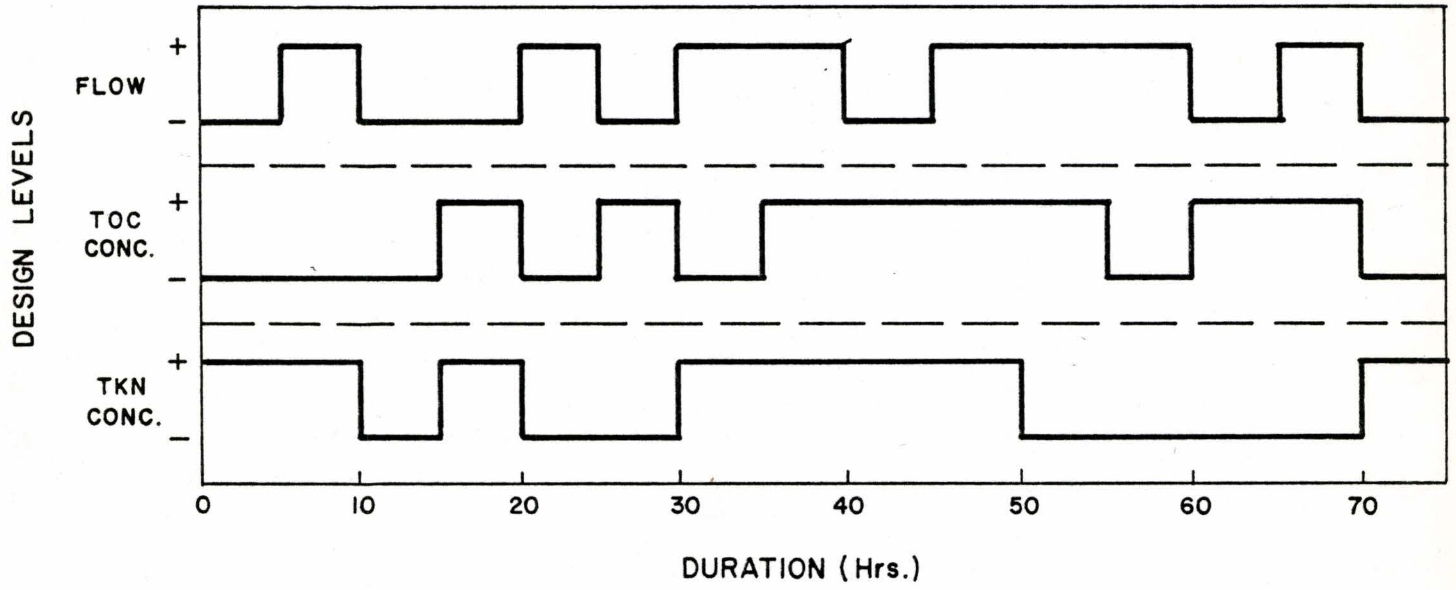


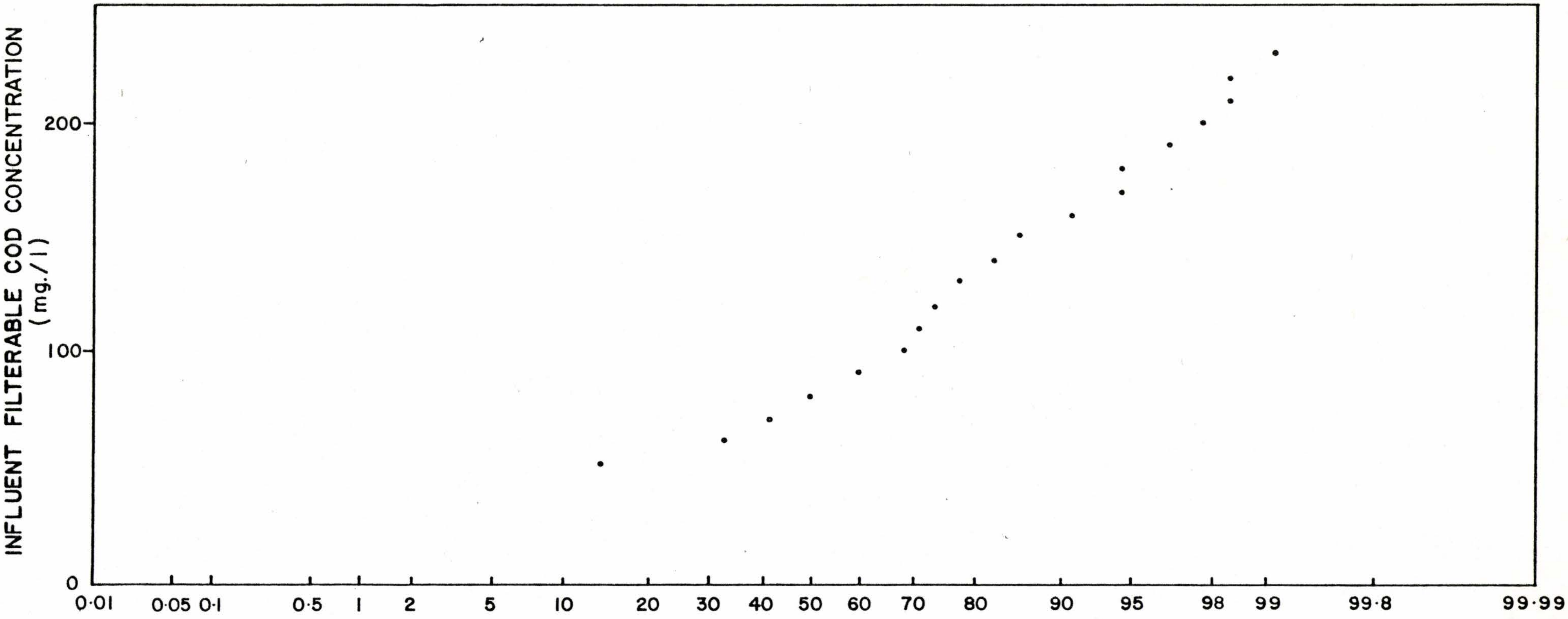
FIGURE 3·4

EXPERIMENT C2 & E2 DESIGN

CARBON OXIDATION MODE

FIGURE 3·5

FILTERABLE COD RAW WASTEWATER CHARACTERISTICS



PERCENT OF OBSERVATIONS LESS THAN OR EQUAL TO STATED VALUE

FIGURE 3·6

FILTERABLE TOC RAW WASTEWATER CHARACTERISTICS

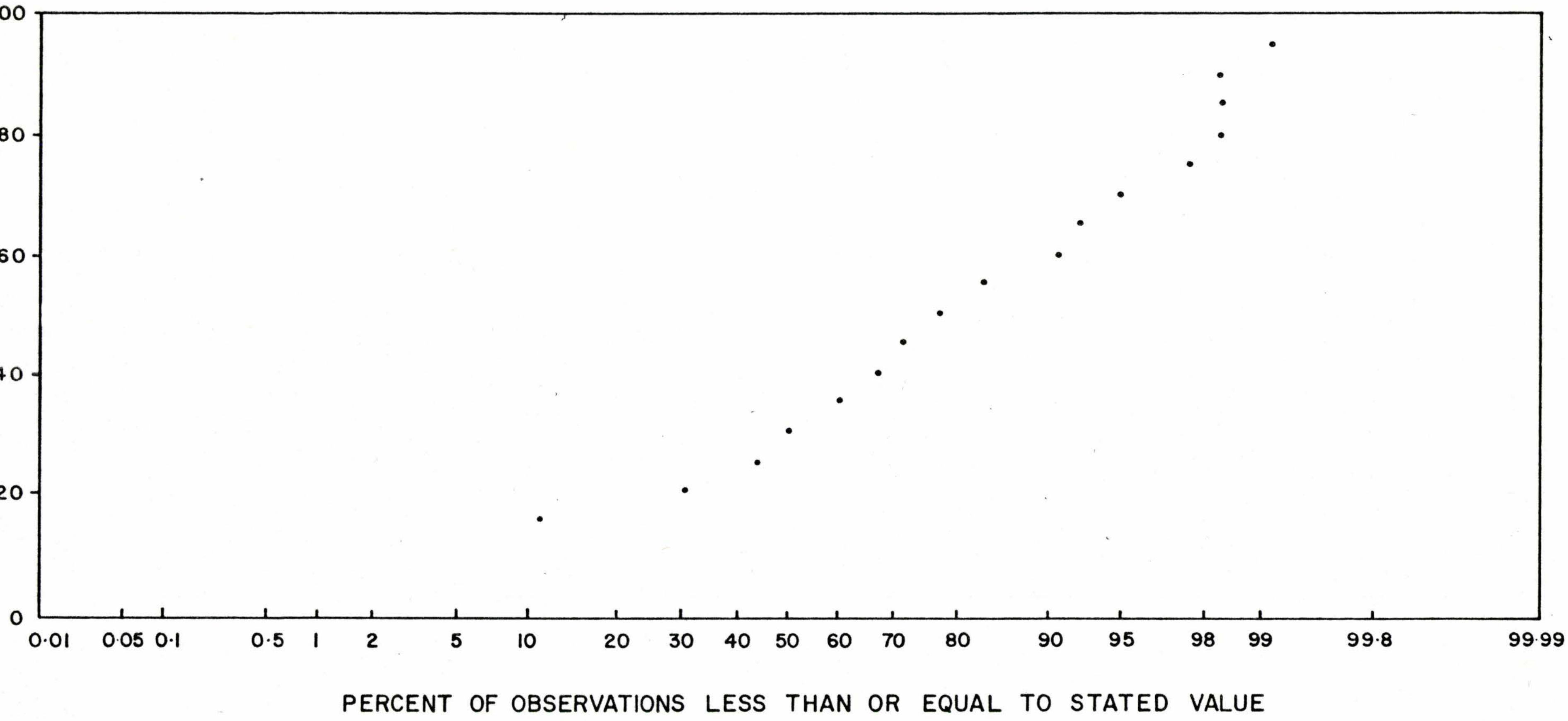


FIGURE 3·7

FILTERABLE TKN RAW WASTEWATER CHARACTERISTICS

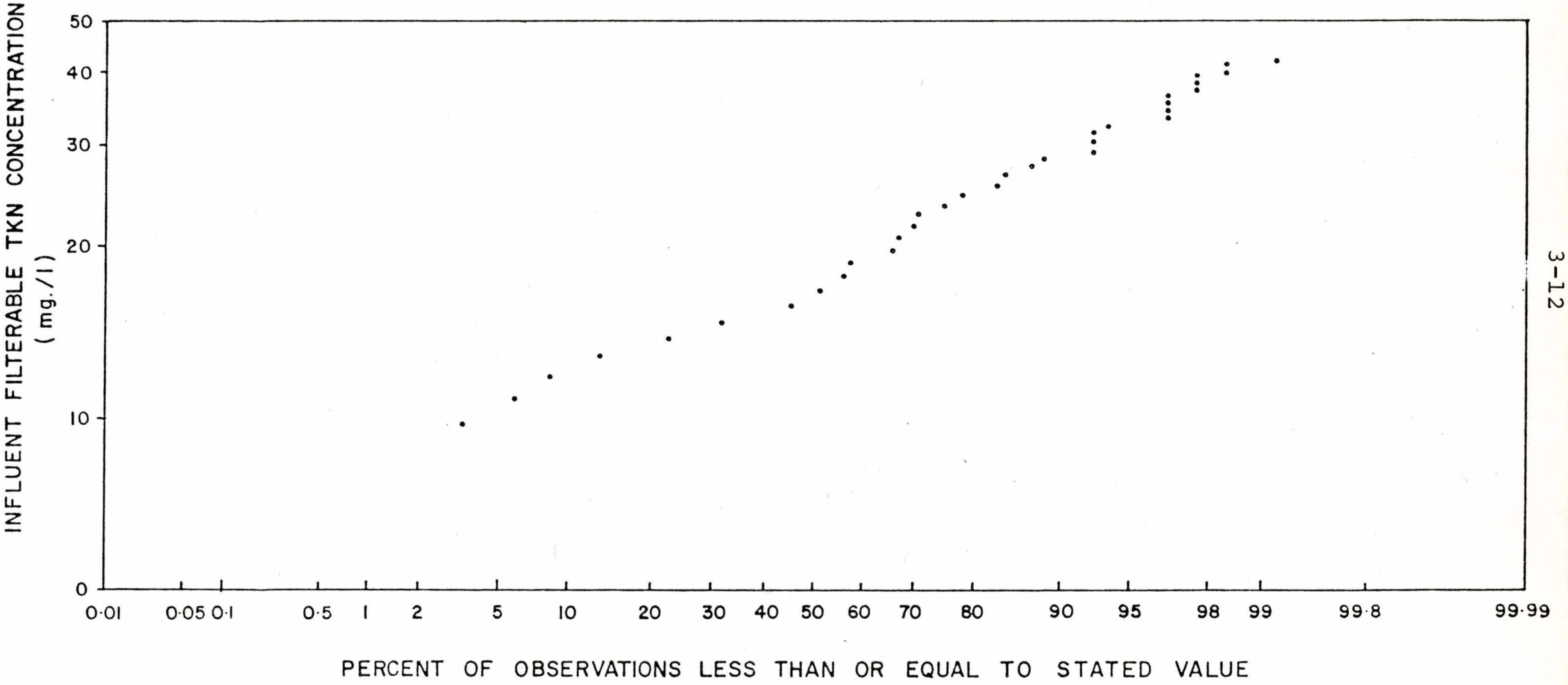


FIGURE 3·8

SUSPENDED SOLIDS RAW WASTEWATER CHARACTERISTICS

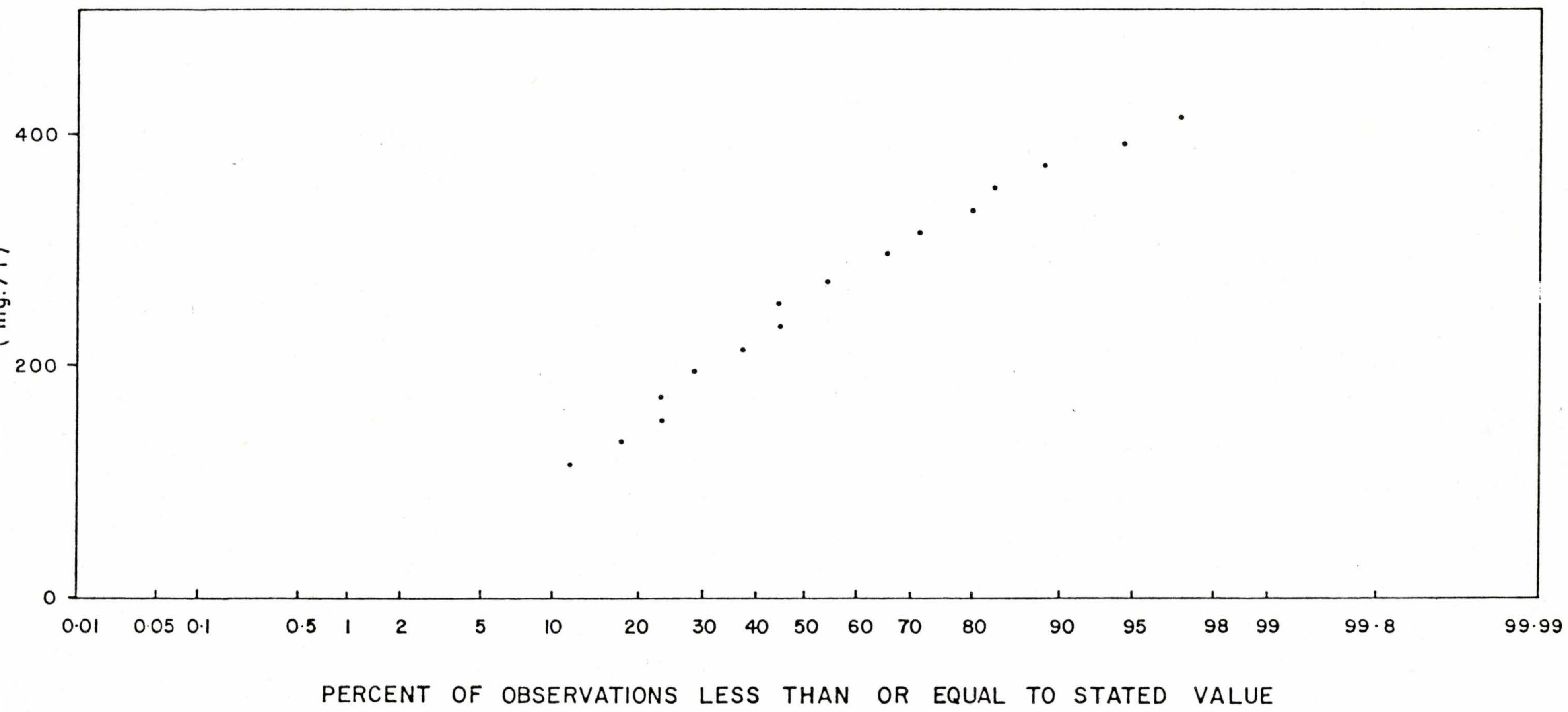
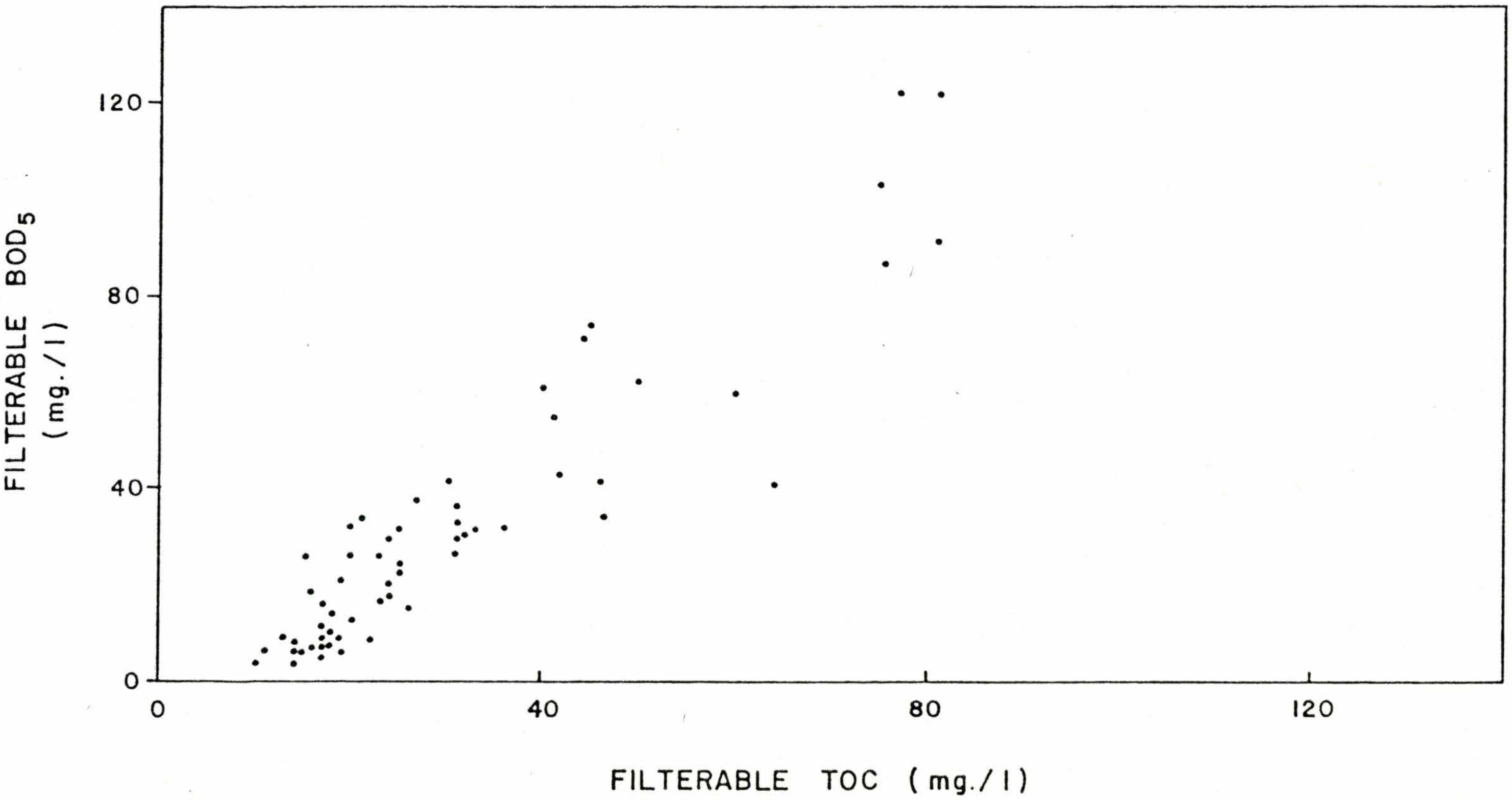


FIGURE 3·9

CORRELATION OF FILTERED BOD_5 WITH FILTERED TOC

SUMMER OF 1976



3.6 Sample Preparation and Analyses

Samples for total organic carbon (TOC) analyses were filtered through 0.45 micron Gelman glass fibre filters followed by acidification to pH 2 with concentrated hydrochloric acid. Filtered COD, NH_3-N, NO_2-N, NO_3-N and TKN samples were frozen along with all BOD samples. Unfiltered COD and TKN samples were acidified to pH 2 with sulphuric acid before storage with the TOC samples at 0°C to 5°C. During the dynamic runs, the filtered COD samples were prepared in the same manner as the TOC samples. All samples were stored in polyethylene bottles.

Further details of the analytical procedures are given in Appendix B.

4. RESULTS AND DISCUSSION

4.1 Dynamic Time Series Data

The designed and observed influent concentration, effluent concentration, and flow rate for experiments C1, C2 and E2 are presented in Figures 4.1, 4.2 and 4.3. The flow rates were obtained by direct measurement during the experiment and were identical to the design levels. All experimental raw data is presented in Appendix A.

Good agreement is indicated between the designed input sequence and the measured influent concentrations, except during the first ten hours of the carbon removal dynamic experiments (Figures 4.2 and 4.3), when the effluent TKN concentrations frequently exceeded influent TKN concentrations. Dilution water was used during this period to reduce influent TOC concentration according to the design. Inadequate mixing was achieved before the influent sample was taken, causing an underestimation of the actual influent concentrations. These data were eliminated before further analysis was undertaken.

An effluent TOC response to the influent TOC and flow fluctuations is observed (Figures 4.2 and 4.3), but it is not apparent which influent variable caused the variation in effluent TOC concentration. The sensitivity of the nitrification process to input variations is apparent in Figure 4.1. Analysis of the data by time series methods should allow an assessment of the system response to hydraulic, organic and inorganic loading variations.

FIGURE 4·1

INPUT AND RESPONSE OF 0·5m RBC, CARBON OXIDATION PLUS NITRIFICATION MODE

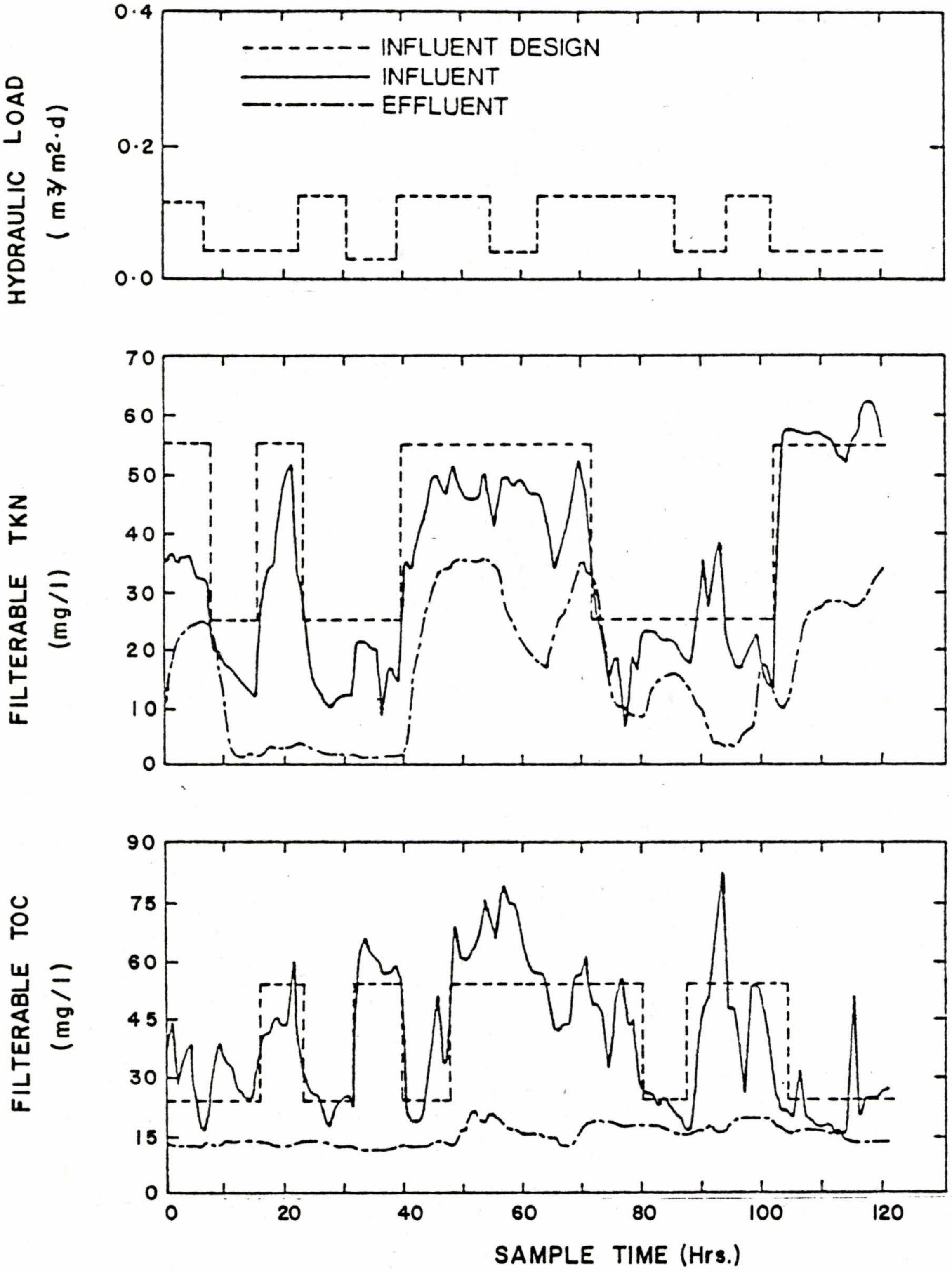


FIGURE 4·2
INPUT AND RESPONSE OF 0·5m RBC, CARBON OXIDATION MODE

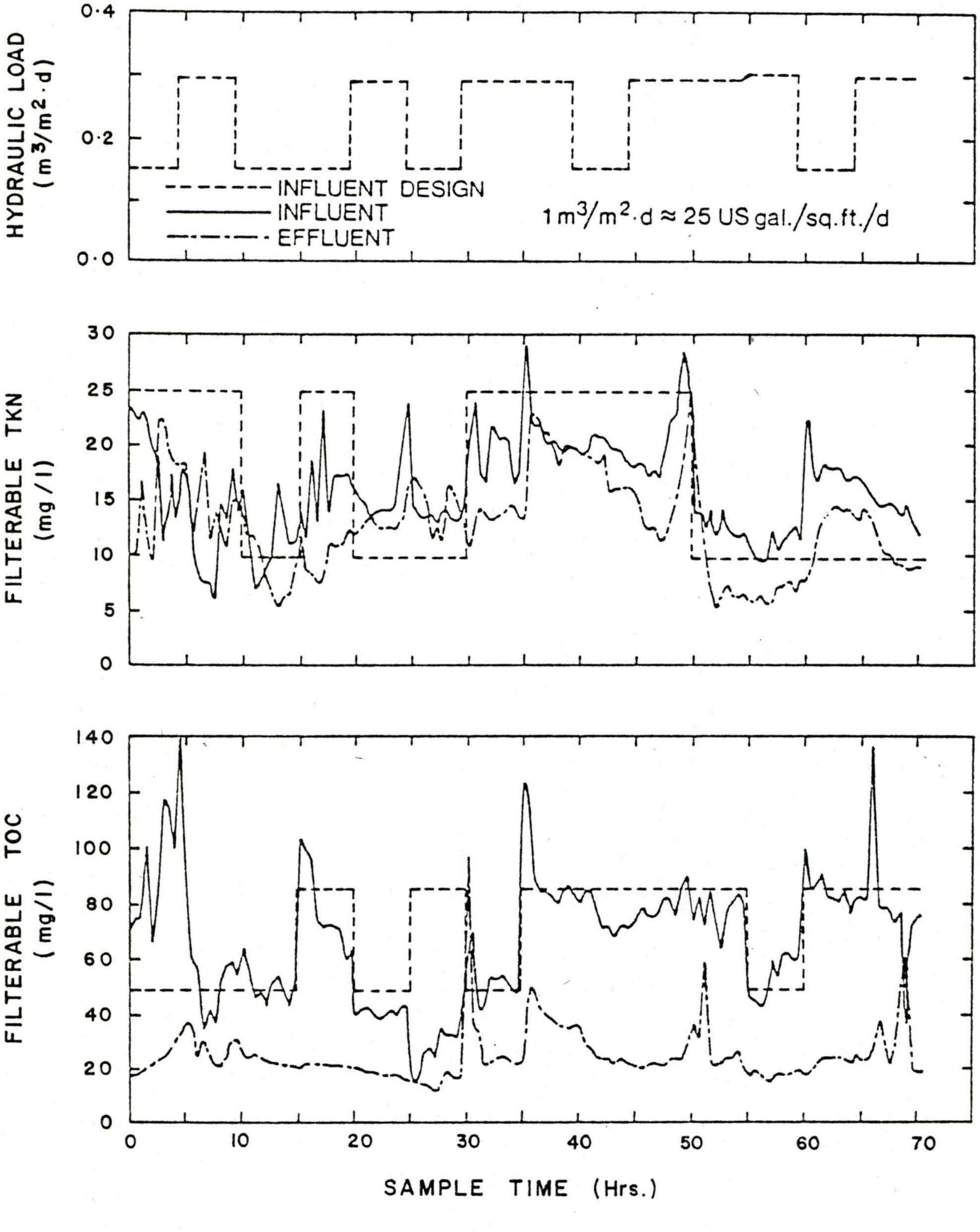
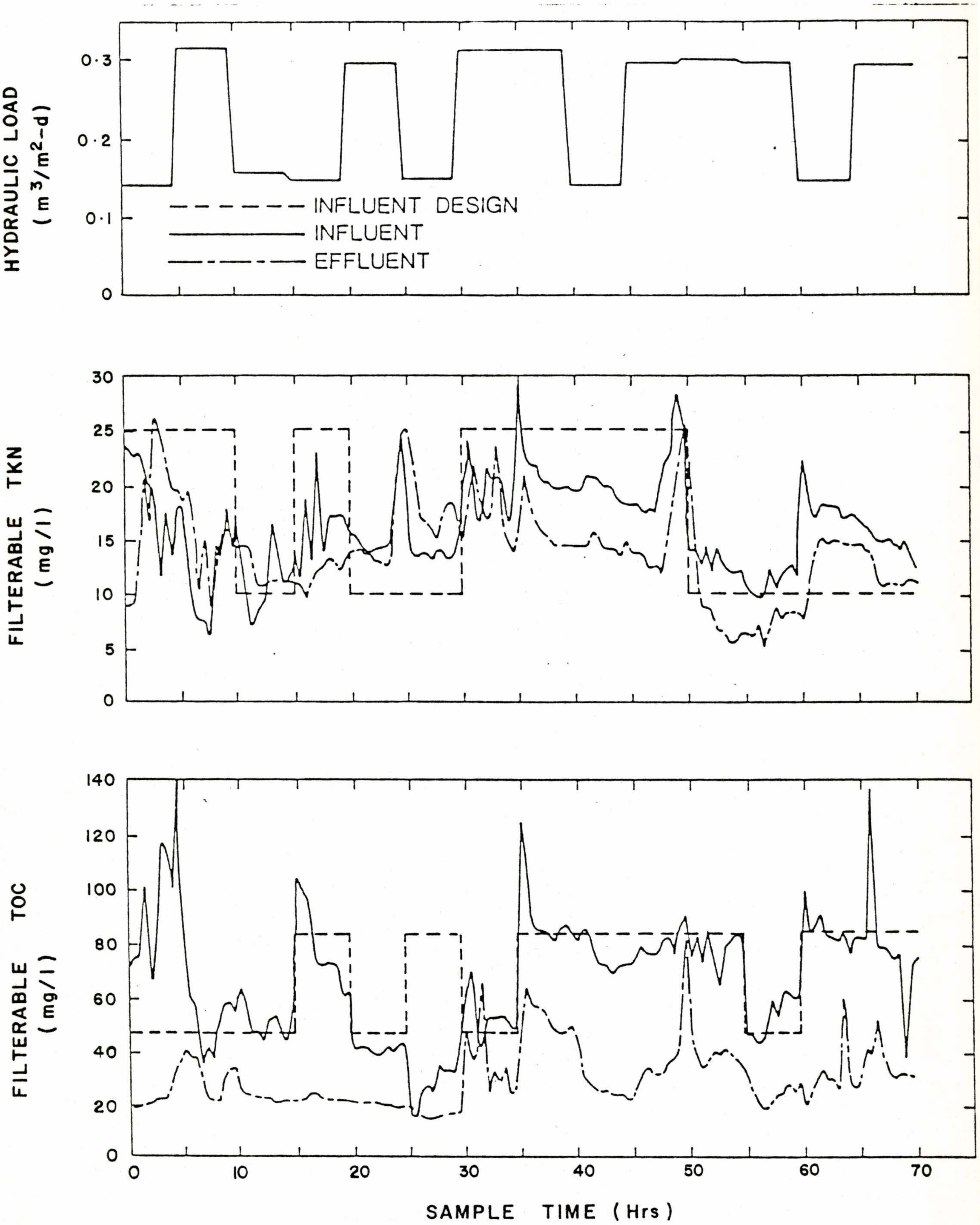


FIGURE 4·3

INPUT AND RESPONSE OF 2·0m RBC, CARBON OXIDATION MODE



4.2 System Response to Hydraulic, Organic and Inorganic Loading Variations

4.2.1 General

The impulse response function allows an assessment of the influent variables affecting effluent quality. It is also used to determine potential transfer function models which will describe the impulse response function and provide initial estimates of the potential transfer function model parameters (r, b, s, w, δ).

In order to verify suspected significant relationships between influent parameters and effluent response, the major relationships of interest were cross-correlated. The results of this initial screening are summarized in Table 4.1. Using Table 4.1, cause and effect relationships can be determined since a factorial design was used successfully in the experimental design.

The data presented in Table 4.1 provide several interesting relationships. During the carbon oxidation operational mode, influent carbon loading and concentration showed a significant correlation with effluent carbon concentration. However, significant effluent responses to dynamic flow conditions were not observed in the 0.5 metre RBC., while they were observed with the 2.0 metre RBC. There are two important ramifications from these observations:

1. The 0.5 metre RBC is used in many situations to obtain pilot scale performance data for the design of treatment plants. Since the performance of the two units have not been shown to be identical, care should be taken in extrapolating performance data.

2. As discussed in Chapter 2, the primary design criterion for RBCs has been based on areal hydraulic loading. However, a significant effluent

TABLE 4.1

SUMMARY OF CROSS CORRELATION RESULTS, FIRST DIFFERENCE*

Influent vs Effluent		Observed Significant Correlations At Low Lags (95% Confidence)	
Load	Conc.	Carbon Oxidation Mode	TKN Removal Mode
COD Load	COD	Yes	Yes
TOC Load	COD	Yes	Yes
NH_3-N Load	COD	Yes	No
TKN Load	COD	Yes	No
Flow	COD	Yes/No	No
COD Load	TOC	Yes	Yes
TOC Load	TOC	Yes	Yes
NH_3-N Load	TOC	Yes	No
TKN Load	TOC	Yes	No
Flow	TOC	Yes/No	No
COD Load	NH_3-N	n/a	Yes
TOC Load	NH_3-N	n/a	Yes
NH_3-N Load	NH_3-N	n/a	Yes
TKN Load	NH_3-N	n/a	Yes
Flow	NH_3-N	n/a	Yes
COD Load	TKN	n/a	Yes
TOC Load	TKN	n/a	Yes
NH_3-N Load	TKN	n/a	Yes
TKN Load	TKN	n/a	Yes
Flow	TKN	n/a	Yes
COD Load	$NO_2 + NO_3$-N	n/a	Yes
TOC Load	$NO_2 + NO_3$-N	n/a	Yes
NH_3-N Load	$NO_2 + NO_3$-N	n/a	No
TKN Load	$NO_2 + NO_3$-N	n/a	No
Flow	$NO_2 + NO_3$-N	n/a	Yes
Conc.	Conc.		
COD	COD	Yes	No
TOC	COD	Yes	No
NH_3-N	COD	No	No
TKN	COD	No	No
COD	TOC	Yes	No
TOC	TOC	Yes	No
NH_3-N	TOC	No	No
TKN	TOC	No	No
COD	NH_3-N	n/a	No
TOC	NH_3-N	n/a	No
NH_3-N	NH_3-N	n/a	Yes
TKN	NH_3-N	n/a	Yes
COD	TKN	n/a	No
TOC	TKN	n/a	No
NH_3-N	TKN	n/a	Yes
TKN	TKN	n/a	Yes
COD	$NO_2 + NO_3$-N	n/a	No
TOC	$NO_2 + NO_3$-N	n/a	No
NH_3-N	$NO_2 + NO_3$-N	n/a	Yes
TKN	$NO_2 + NO_3$-N	n/a	Yes

*This table applies for both 0.5 MI and 2.0M (2.0 M/0.5 MI) in the carbon oxidation mode, and only 0.5 MI in the nitrification mode.

response to hydraulic loading was not observed for carbon oxidation on the 0.5 metre RBC.

While the 0.5 metre RBC was operating under nitrifying conditions, significant effluent carbon responses were not observed to occur in relation to either hydraulic loading variations or carbon concentration (Table 4.1). However, the combined effect of these parameters (carbon loading) did show a significant relationship with effluent carbon concentration. Influent COD and TOC loadings were not excessive during the experiment and were within normal design limits. Such an observation would not be expected with an activated sludge plant operating under nitrifying conditions, and indeed such an effect was not observed by Sutton (1976). The observation indicates that the RBC may be overly sensitive to fluctuating influent loading conditions.

During the carbon oxidation plus nitrification mode of operation, influent ammonia loading, influent ammonia concentration and hydraulic loading showed significant correlations with effluent ammonia concentration (see Table 4.1). The effluent response to these influent conditions will be examined and quantified using time series modelling techniques.

An example of cause and effect is evident during the carbon oxidation plus nitrification operational mode. A significant correlation is observed between influent carbon loadings and effluent ammonia concentration (Table 4.1). However, significant correlations between influent carbon concentration and effluent ammonia concentration were not observed, while hydraulic loading versus effluent ammonia concentration was significant. Since hydraulic loading and substrate concentration were not confounded in the experimental design, it is reasonable to conclude that the significant effects observed must have been caused by hydraulic loading variations.

4.2.2 Impulse Response Functions - Carbon Oxidation Mode

The impulse response weights for influent filterable TOC loading and TOC concentration versus effluent filterable TOC concentration presented in Figure 4.4 indicate that a significant positive response was obtained in the effluent within one-half hour after the step changes occurred. Use of shorter sampling intervals might have defined the time to the maximum response. The response was directly proportional to the influent TOC loading and concentration. No significant effluent TOC response was observed for hydraulic loading to the 0.5 metre RBC.

Significant effluent filterable TOC responses are observed for variations in influent filterable TOC loading, TOC concentration, and flow rate to the 2.0 meter RBC (Figure 4.5). Figure 4.5 also indicates that the response was instantaneous, which is physically impossible. This result is observed because step changes were made 15 minutes before the hour, while discrete sampling was done at half-hour intervals, beginning on the hour. This lag time in sampling can be accounted for during model building, however, transfer function models were not developed for carbon removal as part of this work.

An important sidelight of Table 4.1 and more visually appreciated in Figures 4.4 and 4.5 is the fact that the variations in hydraulic loading did not significantly affect effluent TOC concentration for the 0.5 metre RBC, while it did for the 2.0 metre RBC. Hydraulic design levels were chosen from manufacturers specifications (which are based solely on areal hydraulic loading) to ensure that a response would be observed. These results reflect a difference in performance of the two RBC units and suggest that the design basis of flow per unit area is not comparable for scale-up purposes.

FIGURE 4·4

EFFLUENT TOC IMPULSE RESPONSE WEIGHTS, 0·5m RBC, CARBON OXIDATION MODE, FIRST DIFFERENCE

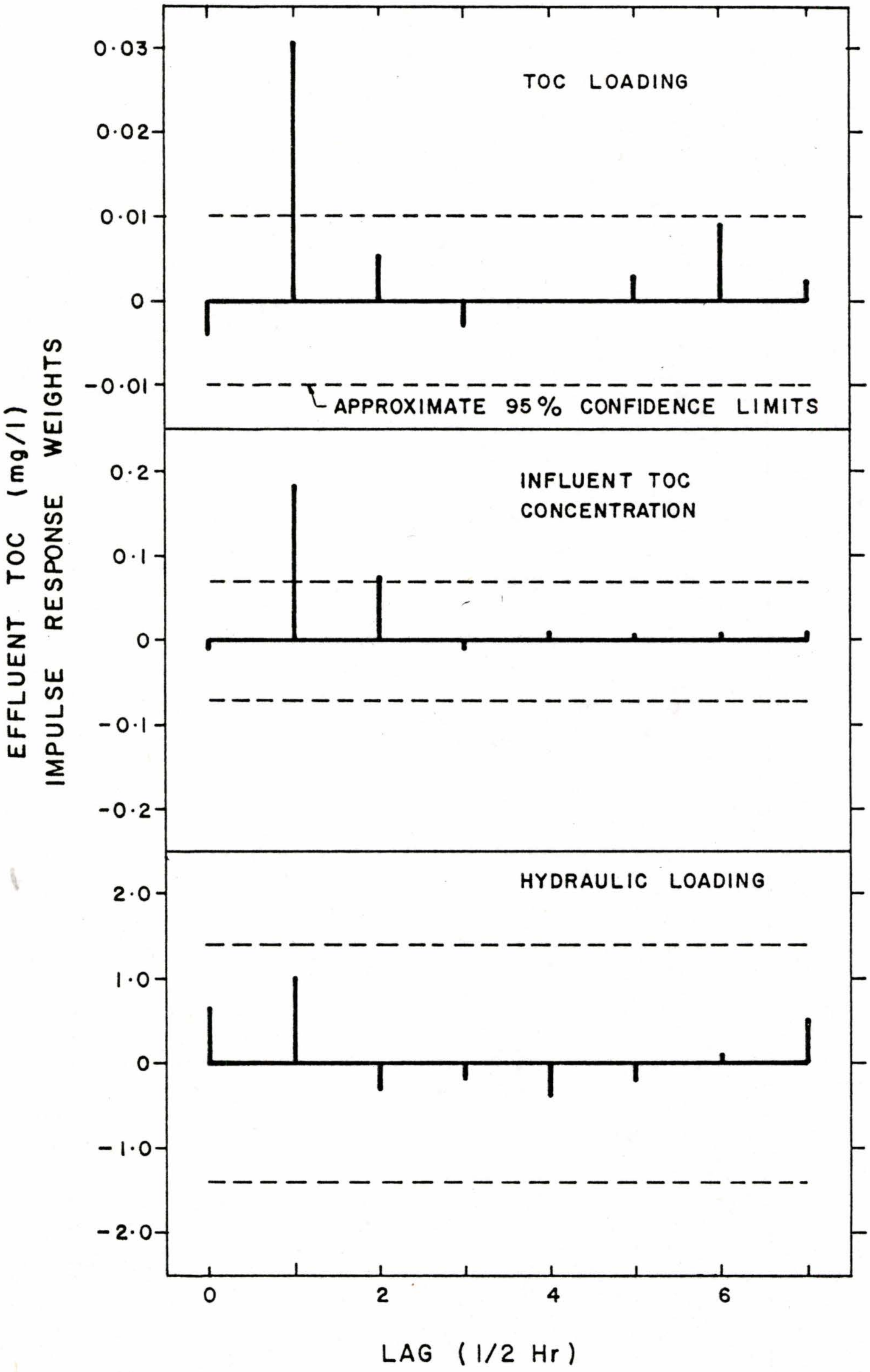
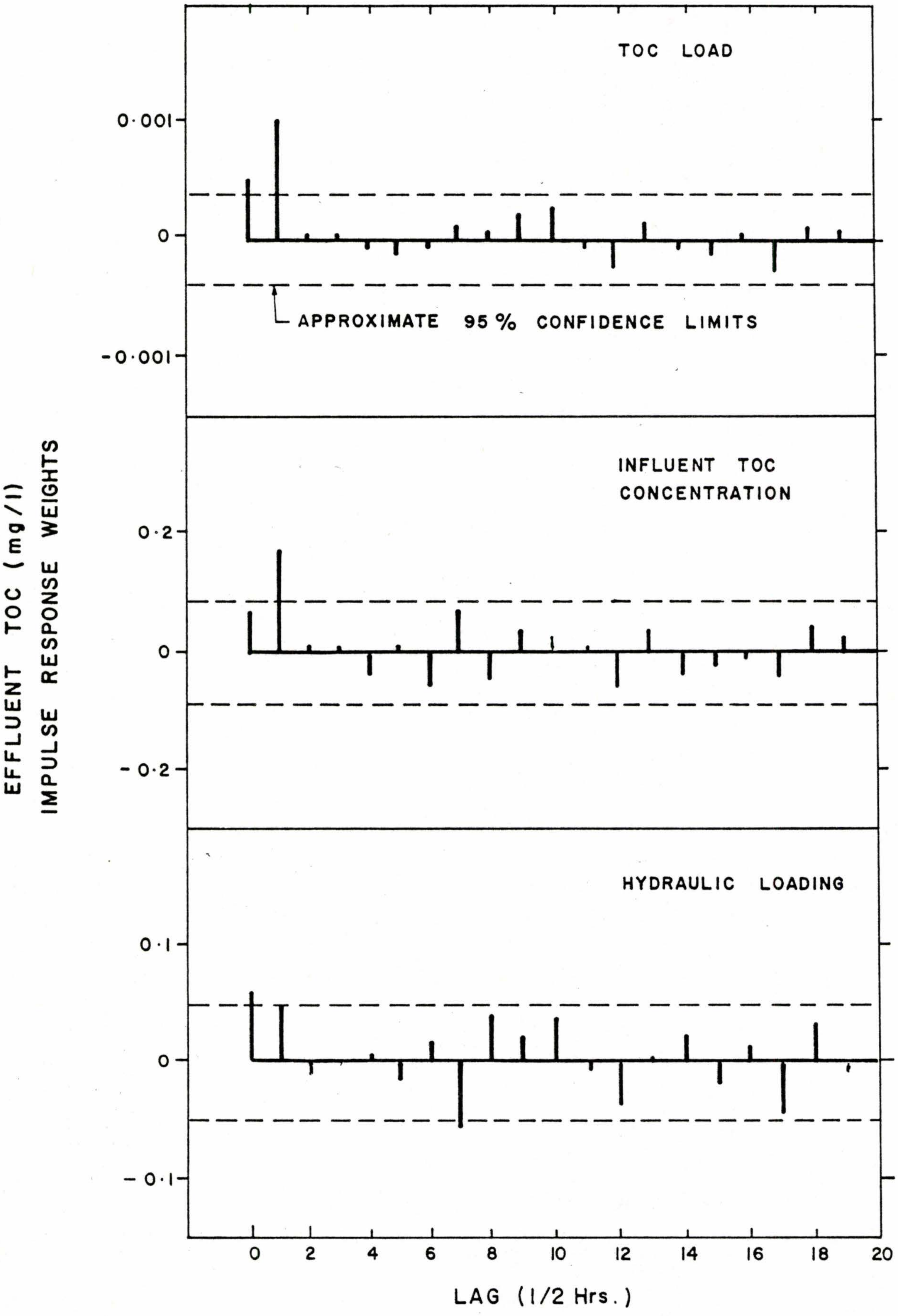


FIGURE 4·5

EFFLUENT TOC IMPULSE RESPONSE WEIGHTS, 2·0m RBC, CARBON OXIDATION MODE, FIRST DIFFERENCE



4.2.3 Impulse Response Functions - Nitrification Mode

The significant positive correlations for filterable TKN loading, TKN concentration, and flow versus effluent filterable TKN concentration are presented in Figure 4.6 for the 0.5 metre RBC. The influent loading and concentration responses were observed to have a duration of about three hours. With flow, the significant TKN effluent response was observed only at a time delay of one hour. Shorter sampling intervals might have defined the time to maximum response.

The impulse response weights for filterable TKN loading, TKN concentration, and flow versus filterable effluent NO_2-N + NO_3-N formation are given in Figure 4.7. A significant positive correlation is observed for influent TKN concentration, as would be expected. A significant negative correlation is observed for hydraulic loading. The combined relationship of TKN loading does not show any significant relationship due to the opposite effects of TKN concentration and hydraulic loading.

Investigations by Davies and Pretorius (1974) suggest that a decrease in NO_2-N + NO_3-N formation coupled with an increase in flow can be explained because of the simultaneous increase in organic loading. It was explained that the increased organic load would enhance the growth of heterotrophs, which would displace nitrifyer growth in the RBC system. As previously noted, the nitrifyers have been observed only in the final compartments of an RBC, while heterotrophs predominate in the initial RBC stages.

This explanation has merit in the long term. However, Table 4.1 indicates that there is no significant correlation at the 95 percent confidence level for TOC concentration versus NO_2-N+NO_3-N formation. Figure 4.7 indicates a negative correlation for flow rate. Since flow

FIGURE 4·6

EFFLUENT TKN IMPULSE RESPONSE WEIGHTS, 0·5m RBC, CARBON OXIDATION PLUS NITRIFICATION MODE, FIRST DIFFERENCE

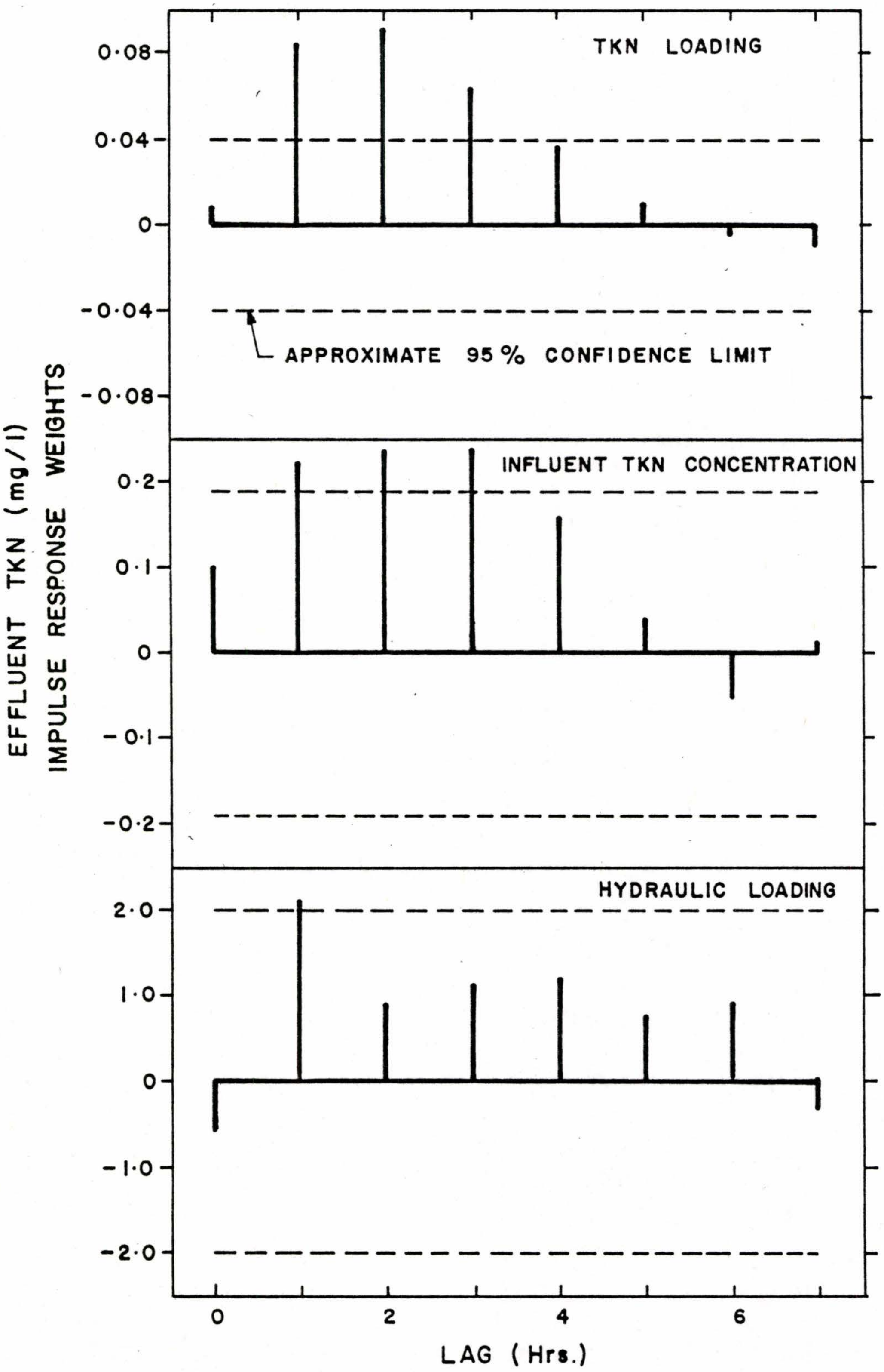
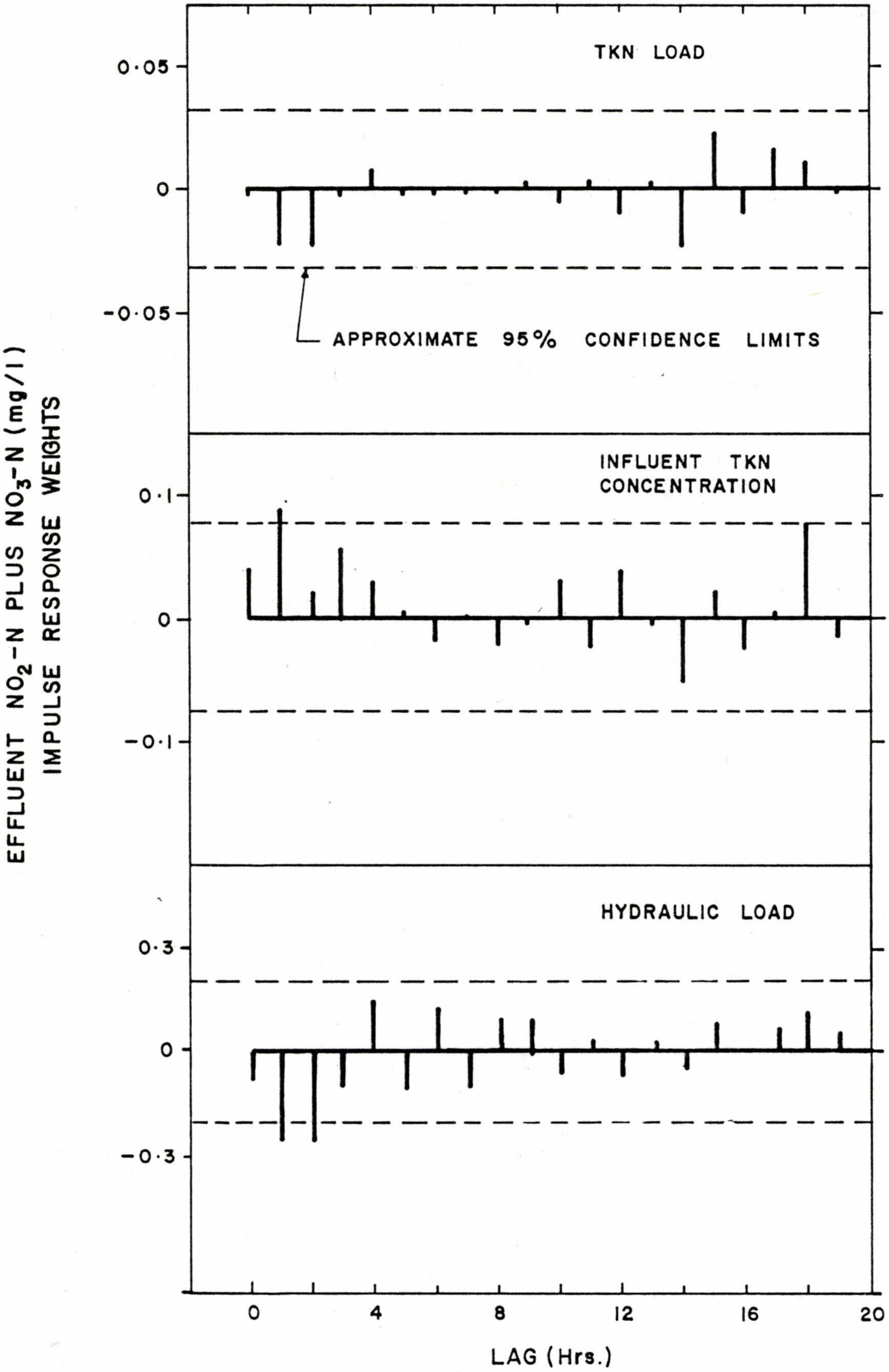


FIGURE 4·7

EFFLUENT NO_2-N PLUS NO_3-N IMPULSE RESPONSE FUNCTIONS OF 0·5m RBC CARBON OXIDATION PLUS NITRIFICATION MODE, FIRST DIFFERENCE



rate and TOC concentration were not confounded in the experimental design, it is reasonable to conclude that the decrease in NO_2-N+NO_3-N formation may be attributed primarily to retention time or flow rate, in the short term.

4.2.4 Discussion

The impulse response functions (Figures 4.4, 4.5, 4.6 and 4.7) would indicate several potential disadvantages of the RBC system. Response to step inputs took place in less than one sampling period. Recovery to new steady-state values was about one hour for carbon oxidation and three hours of carbon oxidation plus nitrification. This indicates that the RBC would be sensitive to influent fluctuations and would provide little reserve capacity to minimize fluctuations in effluent quality. Although these slugs should not seriously affect the biomass, additional treatment capacity or equalization may be required to reduce these fluctuations and improve treatment.

4.3 Dynamic Transfer Function - Noise Model Development

4.3.1 Introduction

The cross correlation results presented in Section 4.2 indicate that there are a several parameters which affect effluent quality. Design parameters for RBCs have been based on areal hydraulic loading, while the effect of concentration and substrate loading have essentially been ignored. Only in the past two years has some emphasis been placed on concentration (Antonie 1976).

Quantification of RBC effluent response to various input parameters can be obtained through the use of the dynamic transfer function - noise (TF-N) models developed in this study. Model development should indicate which of the three influent parameters (flow, concentration, or loading) best describes effluent quality, and therefore, is the best alternative on which to base design.

Transfer function - noise models were developed only for nitrifying conditions, using TKN data.

4.3.2 Model Development

The TF-N models listed in Table 4.2 describe effluent filterable TKN concentration. The models were developed according to the iterative procedure described from the impulse response weights and used as starting values in TSHAUS. The dynamic and noise model parameters were estimated simultaneously. Details of the calculation procedure are provided in Appendix C for a particular example. Diagnostic checks applied to the model residuals confirm both TF model and noise model adequacy at the 95% confidence level (Table 4.3).

4.3.3 Effluent Filterable TKN Models

Filterable influent TKN loading, TKN concentration and hydraulic loading models were found to adequately describe effluent TKN response (Table 4.2). Comparison of the dynamic transfer function-noise models was made through examination of the residual sums of squares. Extra sums of squares testing (Draper and Smith (1968)) was used to differentiate between models of different numbers of parameters. The TKN load model (Model A2) has the lowest residual mean square (Table 4.2) and, of the models considered, best describes effluent TKN concentration. Figure 4.8 demonstrates the good fit of the TF-N model with the experimental data. However, the TF model underestimates the peaks and valleys, while still adequately predicting response times. The sensitivity of the nitrifiers to varying influent loads, and the smooth response patterns as exhibited in Figure 4.8 are noted.

TABLE 4.2

TRANSFER FUNCTION-NOISE MODELS DESCRIBING EFFLUENT FILTERABLE TKN CONCENTRATION

Input/Output Variables*	Model No.	Model	Residuals		
			Sum of Squares	Degrees of Freedom	Variance
TKN LOAD/TKN CONC.	A1	$Y_t = \frac{[(0.08312\pm.01738)+(0.03450\pm0.02426)\beta]\ \beta X_T}{(1-0.5590\pm0.1365\beta)} + \frac{a_t(1-\beta)^{-1}}{(1-0.2339\pm0.1808\beta)}$	306.6	116	2.64
TKN LOAD/TKN CONC.	A2	$Y_t = \frac{[(0.08110\pm0.01724)+(0.0460\pm0.02755)\beta+(0.02815\pm0.02813)\beta^2]}{(1-0.3994\pm0.2390\beta)}\ \beta X_T + \frac{a_t\ (1-\beta)^{-1}}{(1-0.2203\pm0.1823\beta)}$	294.4	115	2.56
Log_{10} TKN LOAD/TKN CONC.	A3	$Y_t = \frac{[(7.134 \pm 1.878)+(3.946\pm2.663)\beta+(2.894\pm2.667)\beta^2]}{(1-0.4476\pm0.2471\beta)}\ \beta X_T + \frac{a_t\ (1-\beta)^{-1}}{(1-0.3401\pm0.1766\beta)}$	374.0	115	3.25

Loading models of the form (0, 2, 1) and (1, 0, 1) were also developed, but inadequacies were found with the transfer function during cross-correlation residual checks.

* Loading units are in g/d, concentration units are in mg/ℓ, flowrate is in ℓ/d.

TABLE 4.2 (Cont'd)

Input/Output Variables*	Model No.	Model	Residuals		
			Sum of Squares	Degrees of Freedom	Variance
TKN CONC./TKN CONC.	B1	$Y_T = \frac{[(0.1066\pm0.0573)+(0.07413\pm0.07367)\beta+(0.0670\pm0.07640)\beta^2]}{(1-0.4148\pm0.4597\beta)}\ \beta X_T + \frac{a_t(1-\beta)^{-1}}{(1-0.5409\pm0.1570\beta)}$	498.5	115	4.33
TKN CONC./TKN CONC.	B2	$Y_T = \frac{[(0.1096\pm0.0578)+(0.04406\pm0.06974)\beta]\beta X_T}{(1-0.7078\pm0.2549\beta)} + \frac{a_t(1-\beta)^{-1}}{(1-0.5334\pm0.1553\beta)}$	509.7	116	4.39
TKN CONC./TKN CONC.	B3	$Y_T = \frac{[(0.1029\pm0.0578)+(0.1064\pm0.0624)\beta+(0.08904\pm0.05776)\beta^2]}{(1-0.4148\pm0.4597\beta)}\ \beta X_T + \frac{a_t(1-\beta)^{-1}}{(1-0.5407\pm0.1564\beta)}$	512.8	116	4.42

Some of the parameters in the above models pass through zero indicating models of the forms (1, 0, 1) and (0, 1, 1). However, models of these forms failed to pass the cross correlation checks between input and residuals and are therefore not reported.

* Loading units are in g/d, concentration units are in mg/ℓ, flow rate in ℓ/d.

TABLE 4.2 (Cont'd)

Input/Output Variables*	Model No.	Model		Residuals	
			Sum of Squares	Degrees of Freedom	Variance
Flow Rate x 10^{-3}/TKN CONC.	C1	$Y_T = \frac{(1.514\pm0.745)\beta X_T}{(1-0.6723\pm0.3327\beta)} + \frac{a_t(1-\beta)^{-1}}{(1-0.5693\pm0.1531\beta)}$	530.5	117	4.53
Flow Rate x 10^{-3}/TKN CONC.	C2	$Y_T = [(0.1282\pm0.0720)+(0.6506\pm0.7204)\beta]\ \beta X_T + \frac{a_t(1-\beta)^{-1}}{(1-0.5891\pm0.1495\beta)}$	540.2	117	4.62
Flow Rate + TKN Conc./ TKN Conc	D	$Y_T = \frac{[(0.09538\pm0.00225)\beta]\ W_T}{(1-0.6306\pm0.0748\beta)} - [0.07762\pm0.04708]\beta^3\ X_T + \frac{a_t}{(1-\beta)}$	321.8	117	2.75

The parameter in model C2 which passes through zero was eliminated, but the new model which was developed, (0, 0, 1), did not pass the model residual checks and is not reported.

* Loading units are in g/d, concentration units are in mg/l, flow rate in l/d.

TABLE 4.3

DIAGNOSTIC CHECKS APPLIED TO THE MODEL RESIDUALS

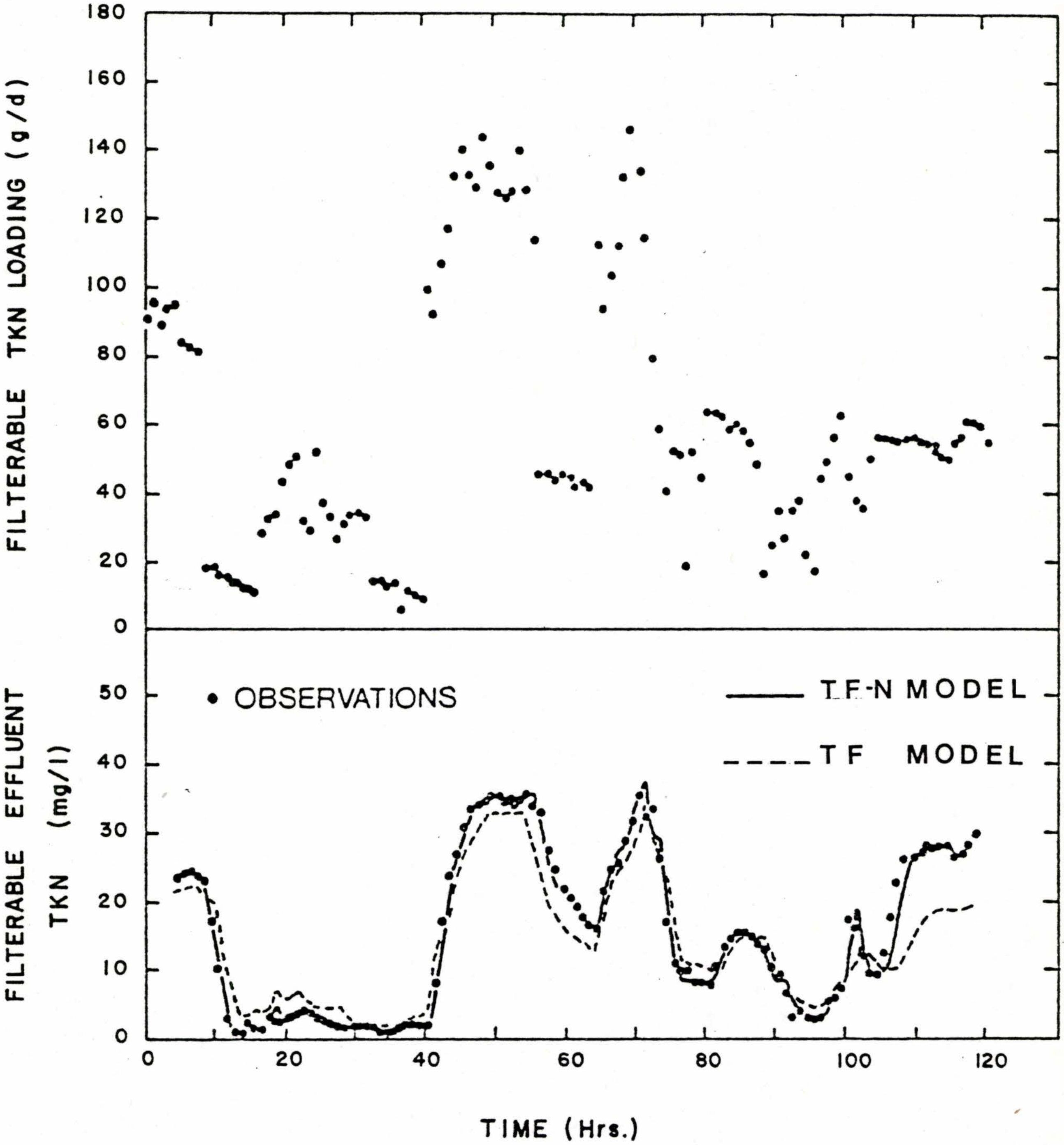
Input Variable	Model No.	Residual Autocorrelation Results		Cross Correlation Results		
		Q	$X^2, \gamma = 0.95$	$Sx^1\hat{a}$	$Sw^1\hat{a}$	$X^2, \gamma = 0.95$
TKN Load	A1	12.8	31.41	25.5		32.67
	A2	14.5	31.41	20.2		32.67
Log TKN Load	A3	14.72	31.41	17.36		32.67
TKN CONC.	B1	22.7	31.41	15.0		32.67
	B2	22.9	31.41	16.9		32.67
	B3	21.3	31.41	16.1		32.67
Flow Rate	C1	12.6	31.41	15.46		32.67
	C2	14.1	31.41	23.1		32.67
Flow Rate + TKN CONC.	D	16.8	31.41	21.7	23.9	32.67

where $Q = n \sum_{k=1}^{20} r^2_{aa}(k)$ $S = n \sum_{k=0}^{20} r^2_{x^1 a}(k)$

$r_{(k)}$ = estimate of cross correlation function at lag K, or the autocorrelation function at lag K.
a = model residuals
x^1 = $(1-B)X$
X = influent condition model was developed for (load or concentration)
w = influent flow condition
K = lag
n = number of observations

FIGURE 4·8

COMPARISON OF EFFLUENT FILTERABLE TKN RESPONSE AND MODEL (A2) FIT



The results demonstrate that effluent filterable TKN concentration is best modelled using influent filterable TKN loading with this technique. Since the TKN load model had the lowest residual mean square, strong consideration should be given to basing RBC design criteria on TKN mass loading rather than hydraulic loading.

4.3.4 TF-N Model Analysis to Determine Response Times

The TF-N models developed in this study can be used to determine the approximate time at which a response in effluent conditions occurs to step changes in influent conditions. The analysis involves the projection of the impulse response function back through the time axis, or by calculation methods using the parameter values of the TF models (see Appendix C). Such an analysis revealed that there is an approximate time delay of 10 minutes before an effluent response occurs to a step change in influent loading. This is fast for an effluent treatment system. Sutton (1976) obtained an approximate 60 minute time delay for his separate activated sludge pilot plant when it was subjected to step inputs in TKN load.

A response to concentration variations in the input was calculated to be in the order of 20 minutes, while the response to hydraulic loading was almost instantaneous. A more accurate indication of the effluent response patterns and the system time delay may have been obtained using a shorter time interval between samples.

4.4 System Response to Natural Diurnal Variations

One of the objectives of this work was to determine the effect of diurnal inputs on instantaneous treatment efficiencies. In conjunction with this objective, it was desired to use an application of time series modelling, namely forecasting, to ensure that the model would describe the effluent variability of the RBC for a completely independent set of data.

The natural diurnal variation in influent flow and concentration normally encountered at a small wastewater treatment plant was approximated on the same 0.5 meter RBC used to collect the dynamic data. The unit was subjected to a sinusoidal variation in flow synchronous to the natural concentration fluctuations of Burlington STP sewage, with a peak/average/minimum flow ratio of 2.5/1/0.5. Influent and effluent concentration and flow were monitored at hourly intervals for a period of 2 days.

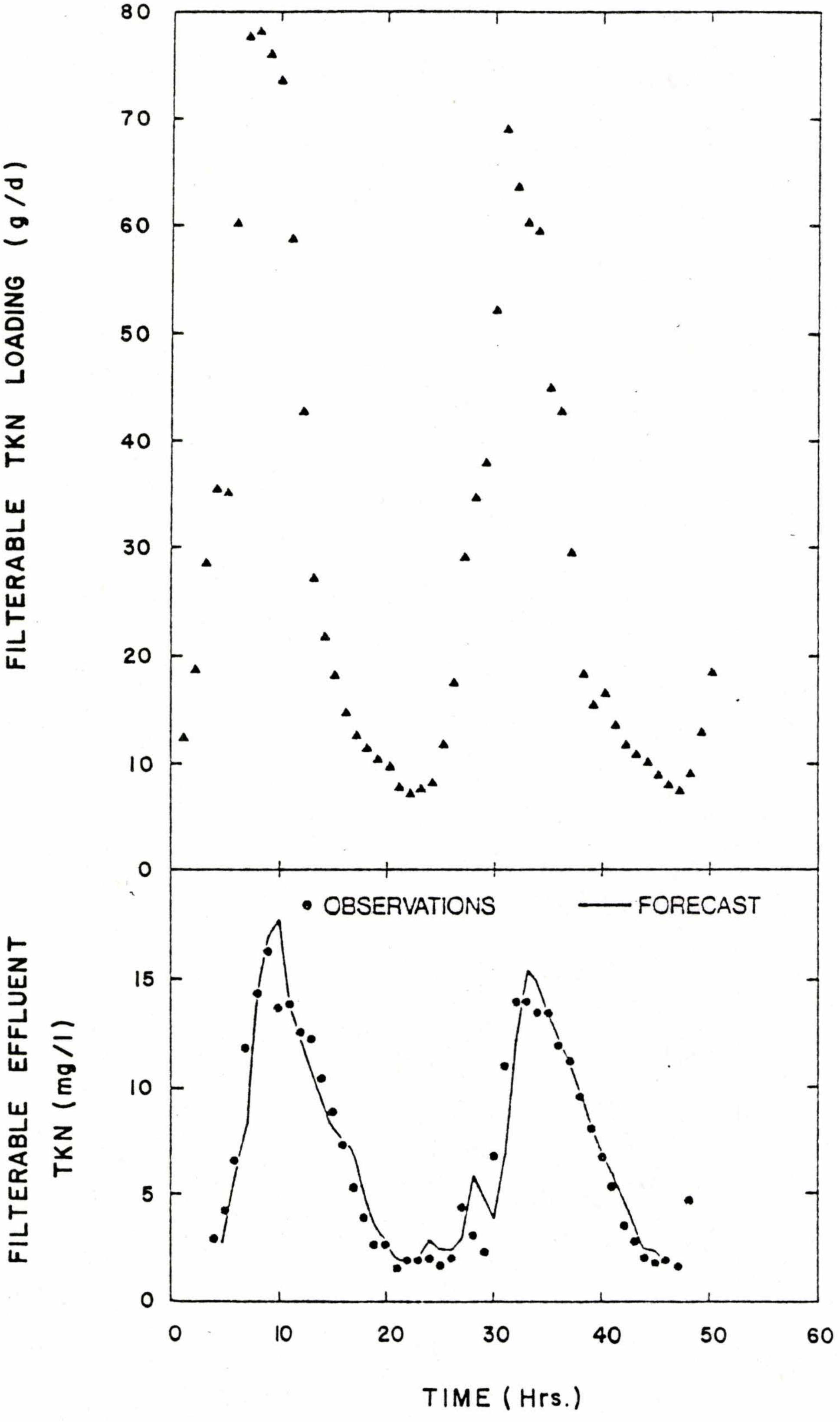
4.4.1 TF-N Model Forecast Results

The forecast filtered effluent TKN concentration successfully predicted the observed daily effluent variation. (Figure 4.9) Response and recovery times agreed with the experimental data and substantiated the transfer function-noise model developed in this study. Fluctuations in effluent concentrations were extremely smooth, which seems to be a characteristic of nitrifying systems. Peak effluent concentrations lagged the influent peak by two hours. Details concerning the forecast procedures are provided in Appendix C.

The large fluctuations in effluent TKN concentration demonstrate the poor treatment performance of the RBC when operated in the nitrification mode under variable loading conditions (Figure 4.9). It is apparent that if stable effluent quality is to be produced using the RBC, process modifications or flow equalization must be provided to damp out any influent fluctuations.

FIGURE 4·9

EFFLUENT FILTERABLE TKN RESPONSE AND FORECAST FOR DIURNAL LOADING



4.5 Comparison of RBC TF-N Models with Activated Sludge

A comparison of the sensitivity of the RBC system to conventional combined and separate nitrifying activated sludge systems may be made by calculating the gains of the TF-N models describing these systems. Dynamic TF-N models describing the effluent TKN response of activated sludge pilot plants were developed by Sutton (1976). The models given in Table 4.4 describe the dynamic relationship of influent TKN load to effluent TKN concentration. The influent flow and concentration data of the pilot plants were of comparable magnitude, and the systems were linear over the flow and concentration regimes investigated.

A comparison of the gains of the activated sludge systems with the RBC indicates that for a unit step change in the influent, 5 to 6 times greater response in effluent TKN concentrations may be expected with the RBC. This confirms the observations of Reimer et al (1975), who operated a pilot plant RBC system in parallel with a pilot plant activated sludge unit. Weiner

Since the response of the RBC to input fluctuations is so much larger than an activated sludge system, greater effluent variability may be expected from an RBC treatment plant, especially when servicing small communities. To stabilize effluent concentrations and to provide consistently good effluent quality, flow equalization should be incorporated into the design of RBC treatment plants.

4.6 Steady State Design

Although steady state design methods cannot describe the temporal relationship in the effluent when the influent to the RBC is variable, the relationship between influent load and mass removal is desirable. Steady state design is feasible as long as the effluent variability is

Table 4.4

Transfer Function-Noise Substrate Loading Models for RBC and Activated Sludge Processes

System	Model	Calculated Gain	Ratio RBC to A/S
RBC	$Y_T = \frac{[(0.08110\pm0.01724)+(0.0460\pm0.02755)\beta+(0.02815\pm0.02813)\beta^2]\beta X_T}{(1-0.3994\pm0.2390\beta)} + \frac{a_t\ (1-\beta)^{-1}}{(1-0.2203\pm0.1823\beta)}$	0.259	
Combined A/S system	$Y_T = \frac{0.011X_{t-1}}{(1-0.786\beta)} + \frac{(1-\beta)^{-1}}{(1-1.066\beta+0.336\beta^2)}a_t$	0.051	5.0/1
Separate A/S System	$Y_T = \frac{(0.012+0.008\beta)}{1-0.550\beta}\beta X_t + \frac{(1-\beta)^{-1}}{(1-1.394\beta+0.540\beta^2)}a_t$	0.044	5.9/1

Where X_t represents time varying influent TKN load, g/d
Y_t represents time varying effluent TKN concentration, mg/ℓ

kept in mind, and steps are taken to reduce influent variability.

The development of dynamic transfer function noise models has indicated that influent mass loading should be considered as the primary design criterion in nitrifying systems. Although this relationship has not been proven for carbon removal, there is a strong indication that this may be the case from Figures 4.4 and 4.5.

A number of mass removal versus influent mass loading plots have been developed using the time series data obtained in this study. Mass removal calculations were based on a lag separation of 1 between influent and effluent for both the carbon oxidation mode and the carbon oxidation plus nitrification mode. This interval corresponds to the average retention times in the system, as determined by the tracer studies (Appendix D). Data points occuring during a step change and up to two hours after the step were not included in the results in order to allow the unit to recover to a "pseudo" steady state condition. All plots were standardized to a unit area basis.

4.6.1 Carbon Oxidation Mode

Figures 4.10 and 4.11 present the TOC and COD mass removal plots for the 0.5 meter RBC. The equivalent TOC and COD mass removal plots for the 2.0 meter RBC, which was run in parallel with the 0.5 meter RBC, are given in Figures 4.12 and 4.13.

Mass carbon removal generally appears to be a linear function with mass loading. However, when the TOC plots (Figures 4.10 and 4.12) are compared with the COD plots (Figures 4.11 and 4.13), respectively, a limiting TOC influent loading condition appears to have been approached on the 2.0 meter and 0.5 meter RBCs.

FIGURE 4·10

STEADY STATE DESIGN DATA FOR FILTERABLE TOC REMOVAL, 0·5m RBC, CARBON OXIDATION MODE

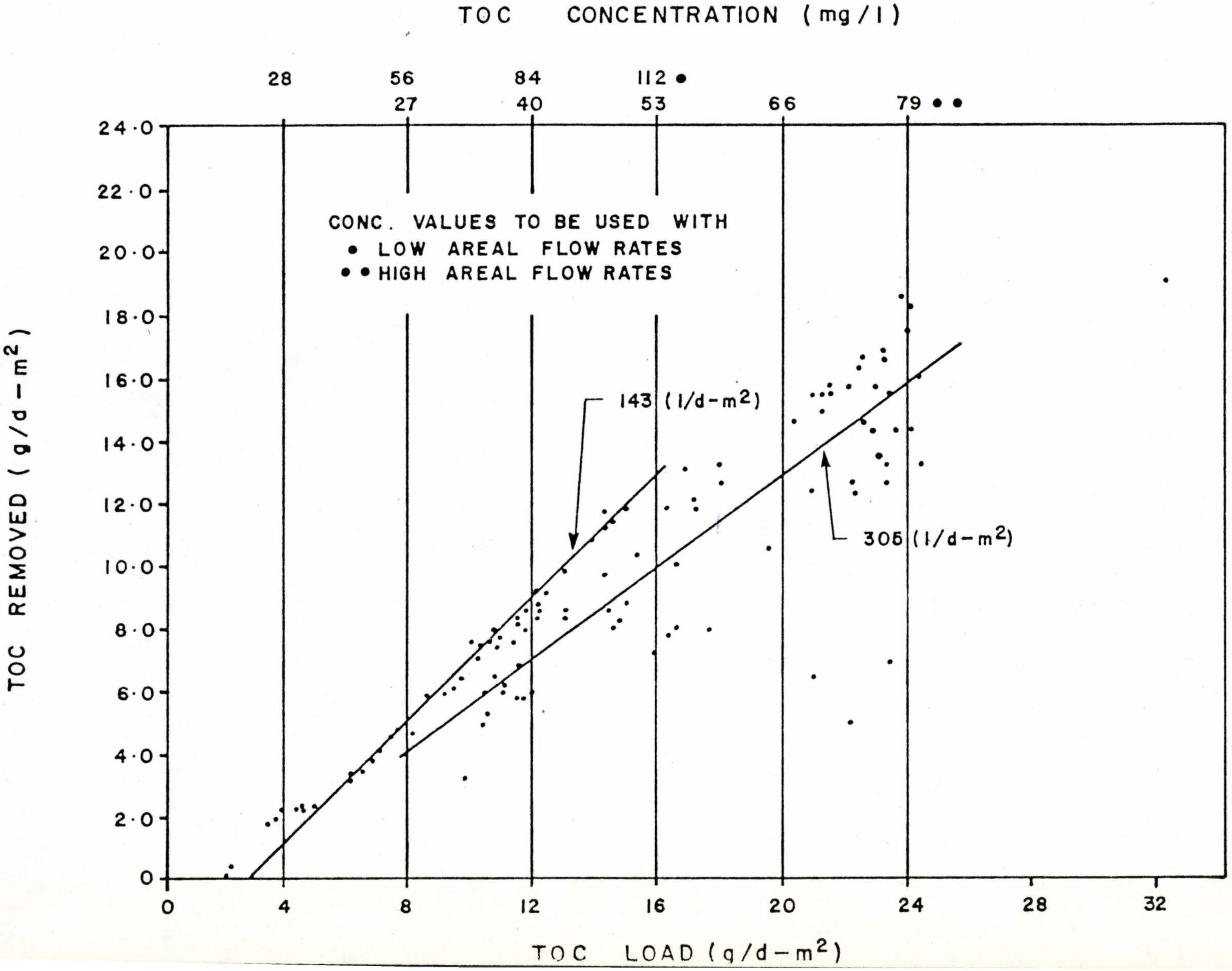


FIGURE 4·11

STEADY STATE DESIGN DATA FOR FILTERABLE COD REMOVAL, 0·5m RBC, CARBON OXIDATION MODE

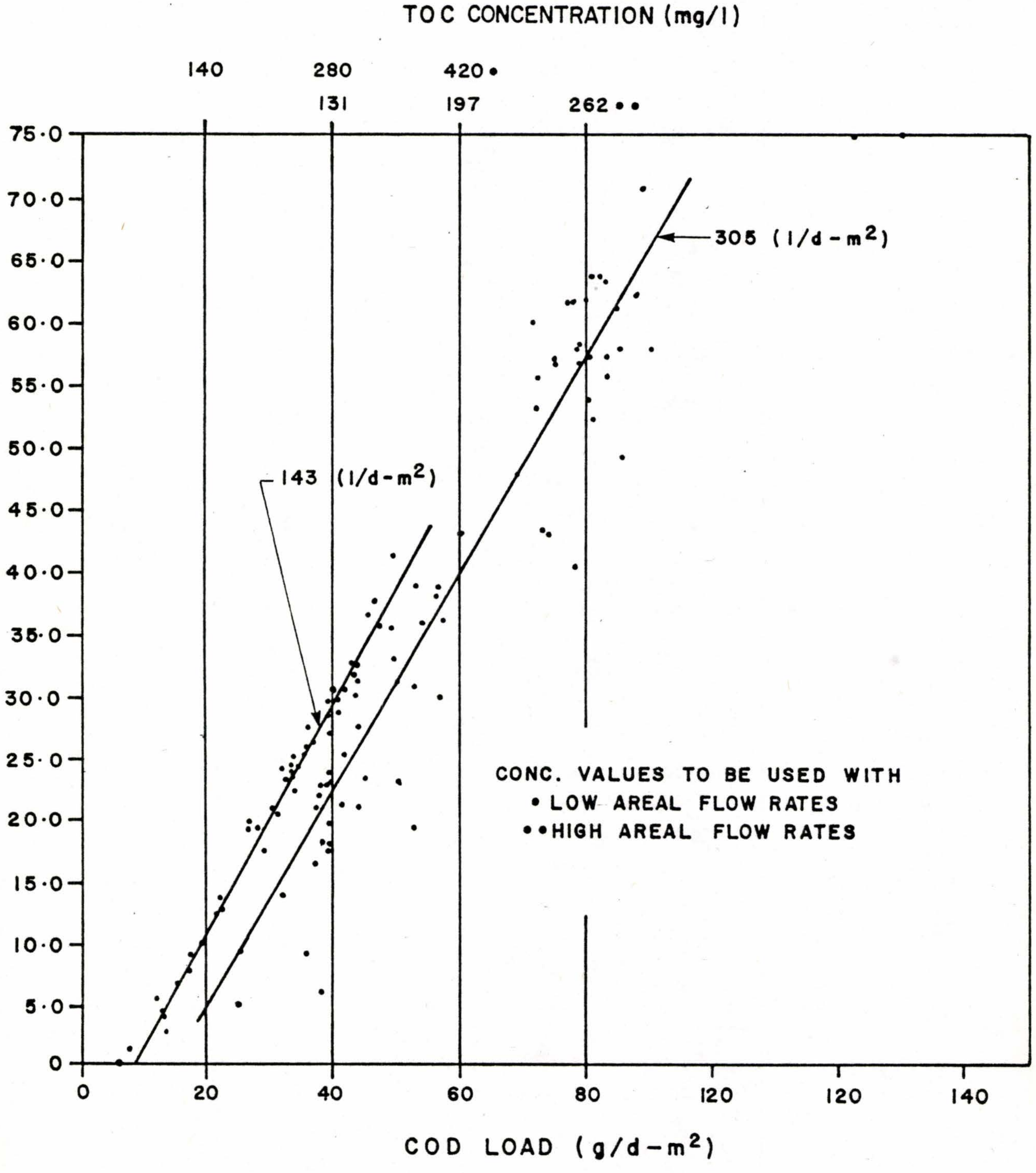


FIGURE 4·12

STEADY STATE DESIGN DATA FOR FILTERABLE TOC REMOVAL, 2·0m RBC, CARBON OXIDATION MODE

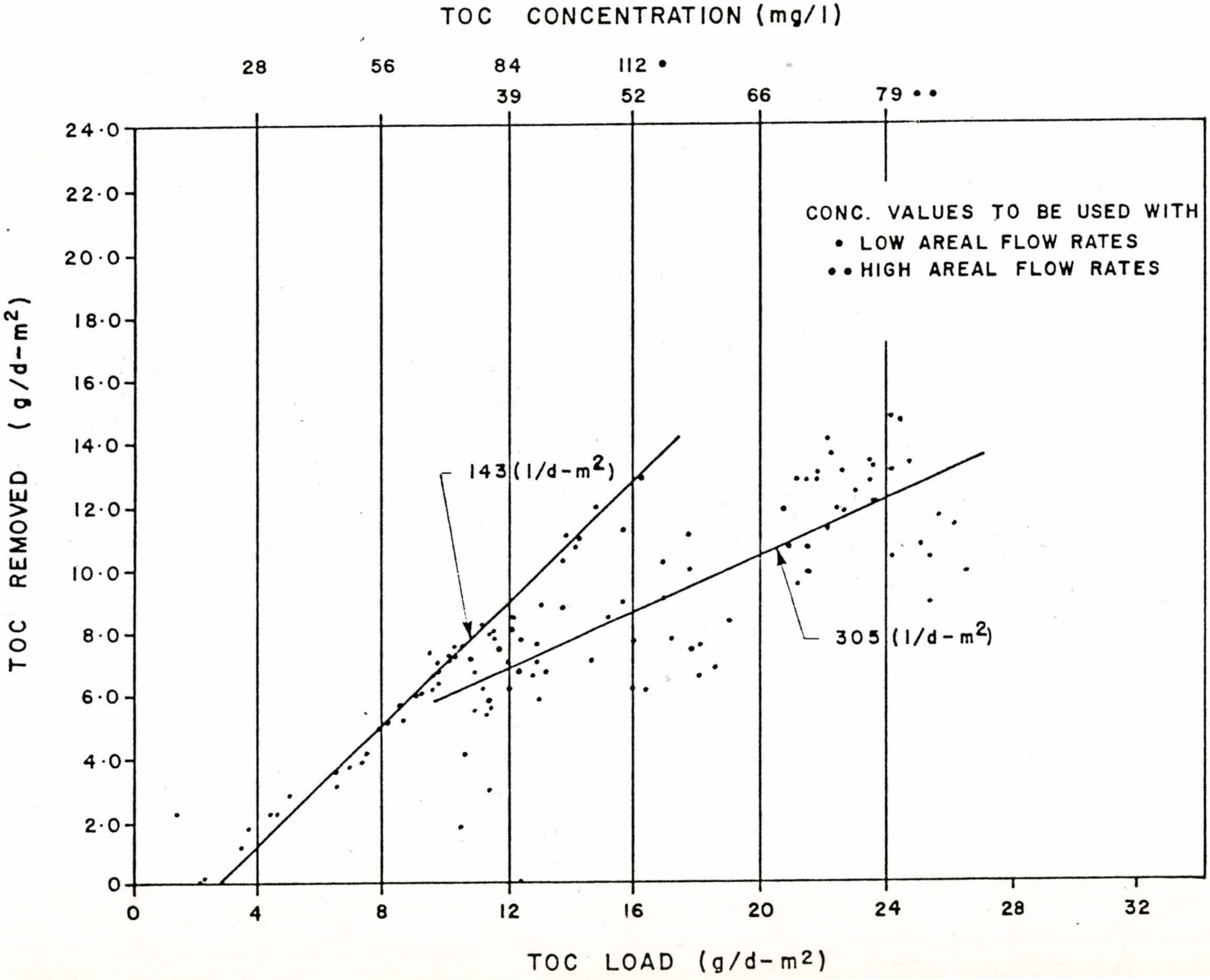
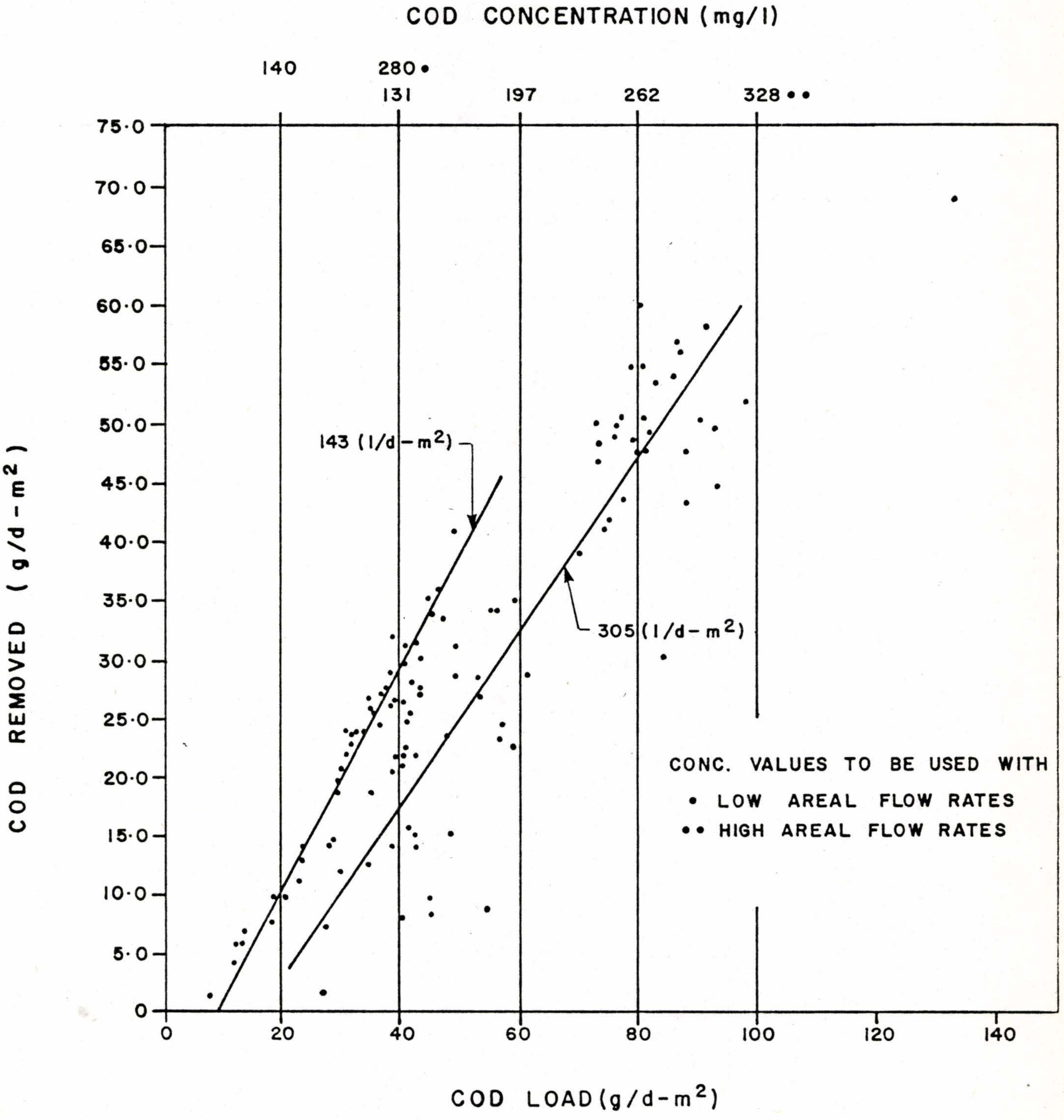


FIGURE 4·13

STEADY STATE DESIGN DATA FOR FILTERABLE COD REMOVAL, 2·0m RBC, CARBON OXIDATION MODE



It is interesting to note that two linear relationships are apparent at low loadings on Figures 4.10 to 4.13. These relationships coincide with the two levels of hydraulic loading used in the experimental designs (143 l/d-m^2 and 305 l/d-m^2). The low hydraulic loading in each case provided for slightly improved treatment efficiency in terms of mass removal and stability. The variability in mass removal at the high loadings indicates that the RBCs were approaching unstable treatment conditions.

The presence of non-biodegradable residual organics is demonstrated by the fact that the plots do not pass through the origin.

4.6.2 Carbon Oxidation Plus Nitrification Mode

Mass loading plots for TOC and COD removal with the 0.5 metre RBC operating in the nitrification mode are given in Figures 4.14 and 4.15. Linear mass removal is apparent on both figures. Two levels of mass removal are apparent at equal mass loadings, with greater mass removal being obtained at the lower hydraulic loading.

The filterable TKN mass removal versus influent TKN load plot is presented in Figure 4.16. In contrast to carbon oxidation, a limiting mass removal was obtained at loadings greater than 2.0 g/d-m^2. Beyond this influent loading, mass removal becomes unstable with a maximum of 2 g/d-m^2 TKN being removed.

As in the carbon oxidation plots, a separate linear relationship exists at low loadings. This line projects through the origin, as would be expected.

FIGURE 4·14

STEADY STATE DESIGN DATA FOR FILTERABLE TOC REMOVAL, 0·5 m RBC, CARBON OXIDATION PLUS NITRIFICATION MODE

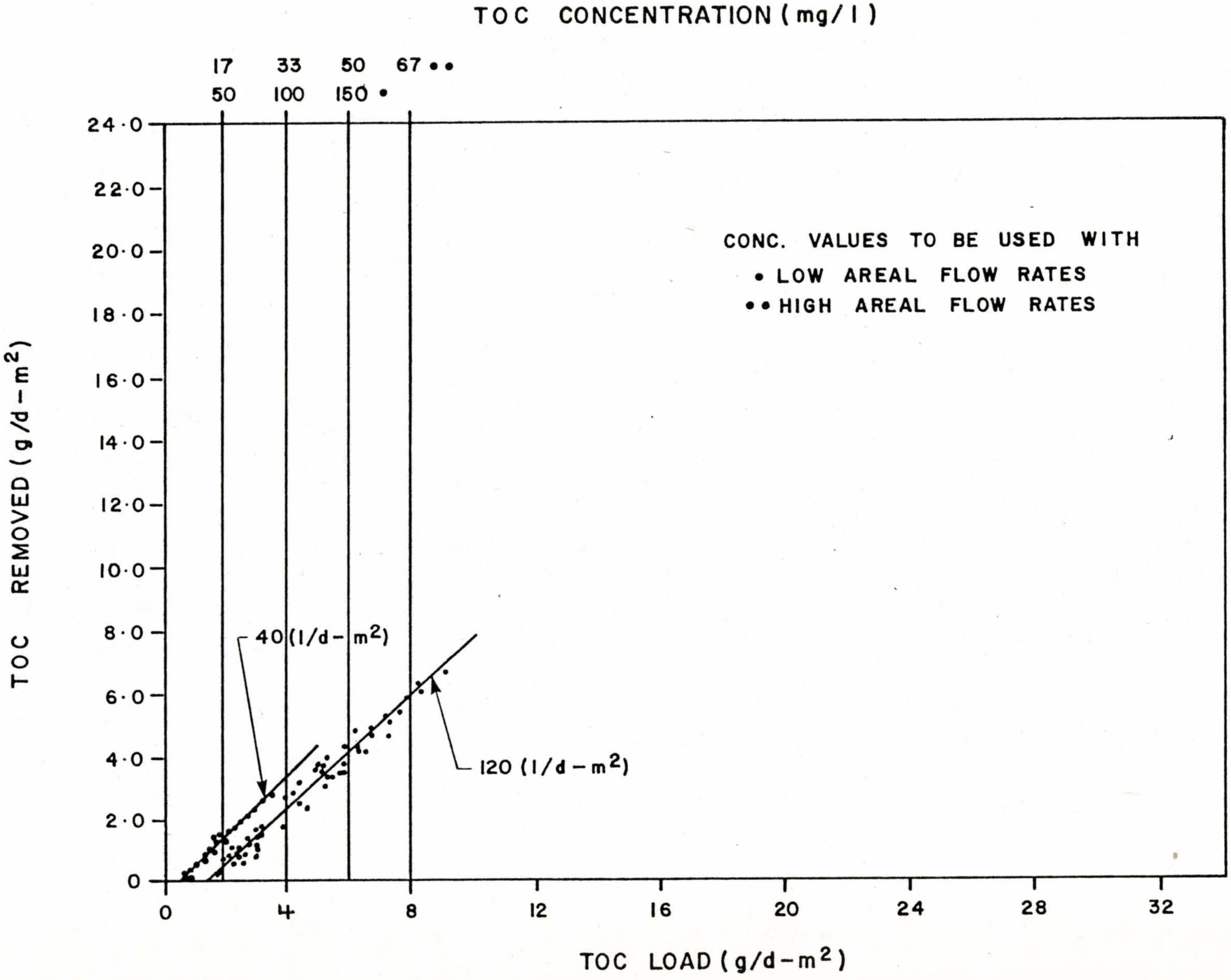


FIGURE 4·15

STEADY STATE DESIGN DATA FOR FILTERABLE COD REMOVAL, 0·5m RBC, CARBON OXIDATION PLUS NITRIFICATION MODE

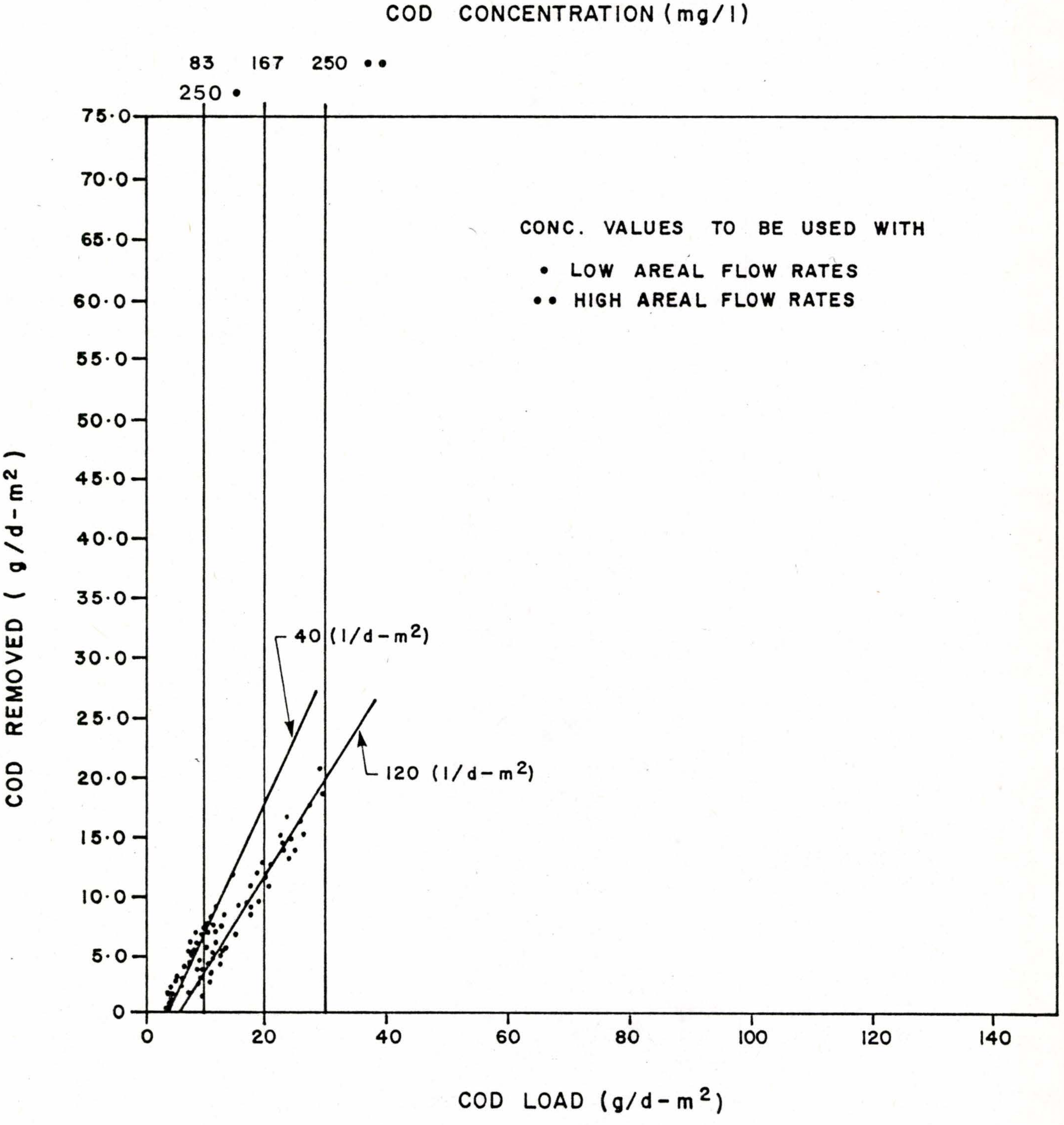
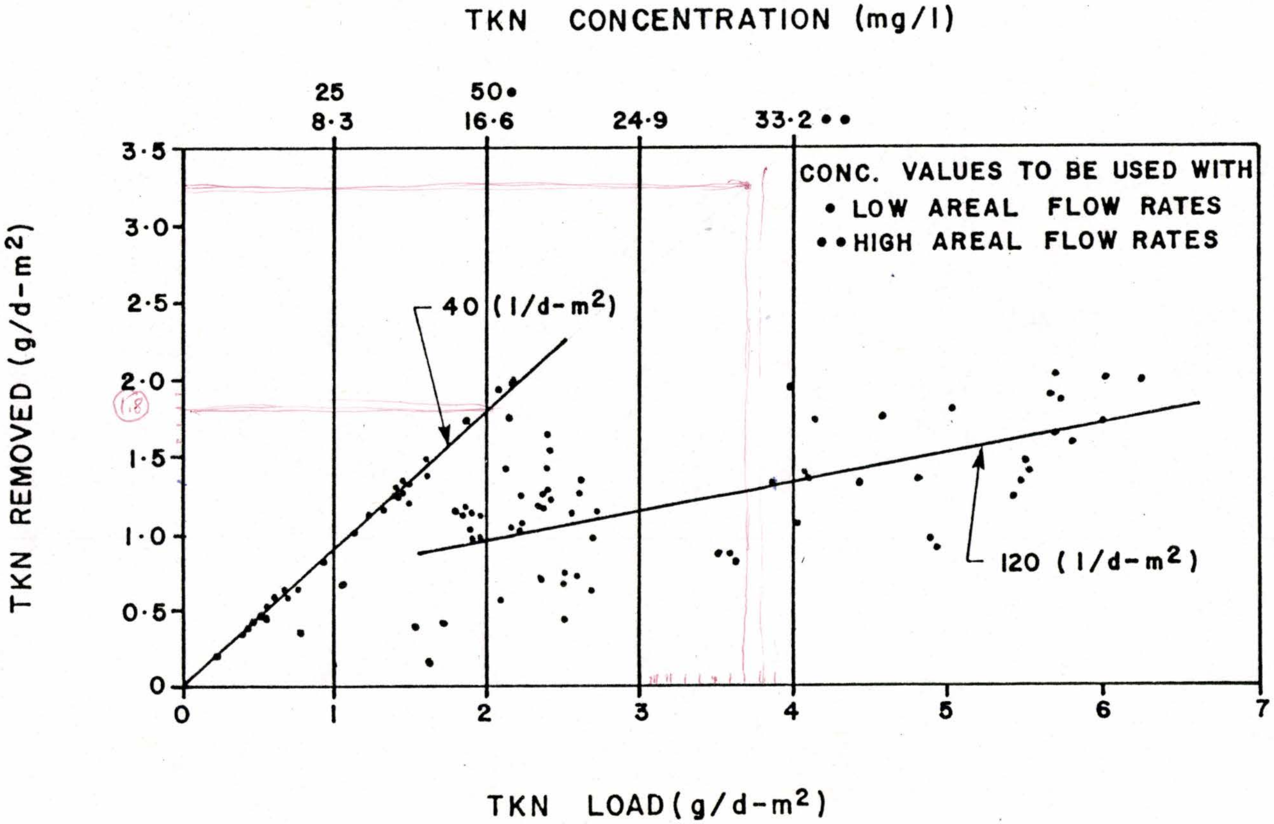


FIGURE 4·16

STEADY STATE DESIGN DATA FOR FILTERABLE TKN REMOVAL, 0·5m RBC, CARBON OXIDATION PLUS NITRIFICATION MODE



4.6.3 Use of Mass Loading Plots in Design

Figures 4.10 to 4.16 may be used for design purposes when considering influent loading conditions of minimal variability. The calculation procedure to determine the bio-disc surface area required to provide effective biological treatment is as follows:

1. Determine the influent concentration and flow rate for design.

2. Determine the effluent quality desired and from this, the mass removal required.

3. Compare the known influent concentration with the concentration isopleths on the plots. This will define the areal mass loading, RBC surface area, areal hydraulic loading and the areal mass removal. If the calculated mass removal is not sufficient to provide the predetermined effluent quality, then a larger surface area is required, thereby reducing the areal mass loading, and improving treatment. An iterative procedure must be continued until adequate mass removal is obtained.

4.7 Scale-Up

Scale-up is always an important consideration in any pilot scale study. Some correlation between the results obtained on a pilot scale unit and a full scale unit is necessary before the results obtained in the study are readily applicable. Since the 0.5 metre RBC and the 2.0 metre RBC were operated in parallel, and their areal loadings were comparable (within 3.5% at the high flow rate and 0.6% at the low flow rate) it was possible to evaluate the mass removal capabilities of the units (Figures 4.17 and 4.18).

FIGURE 4·17

COMPARISON OF TOC MASS REMOVAL 0·5m RBC VERSUS 2·0m RBC

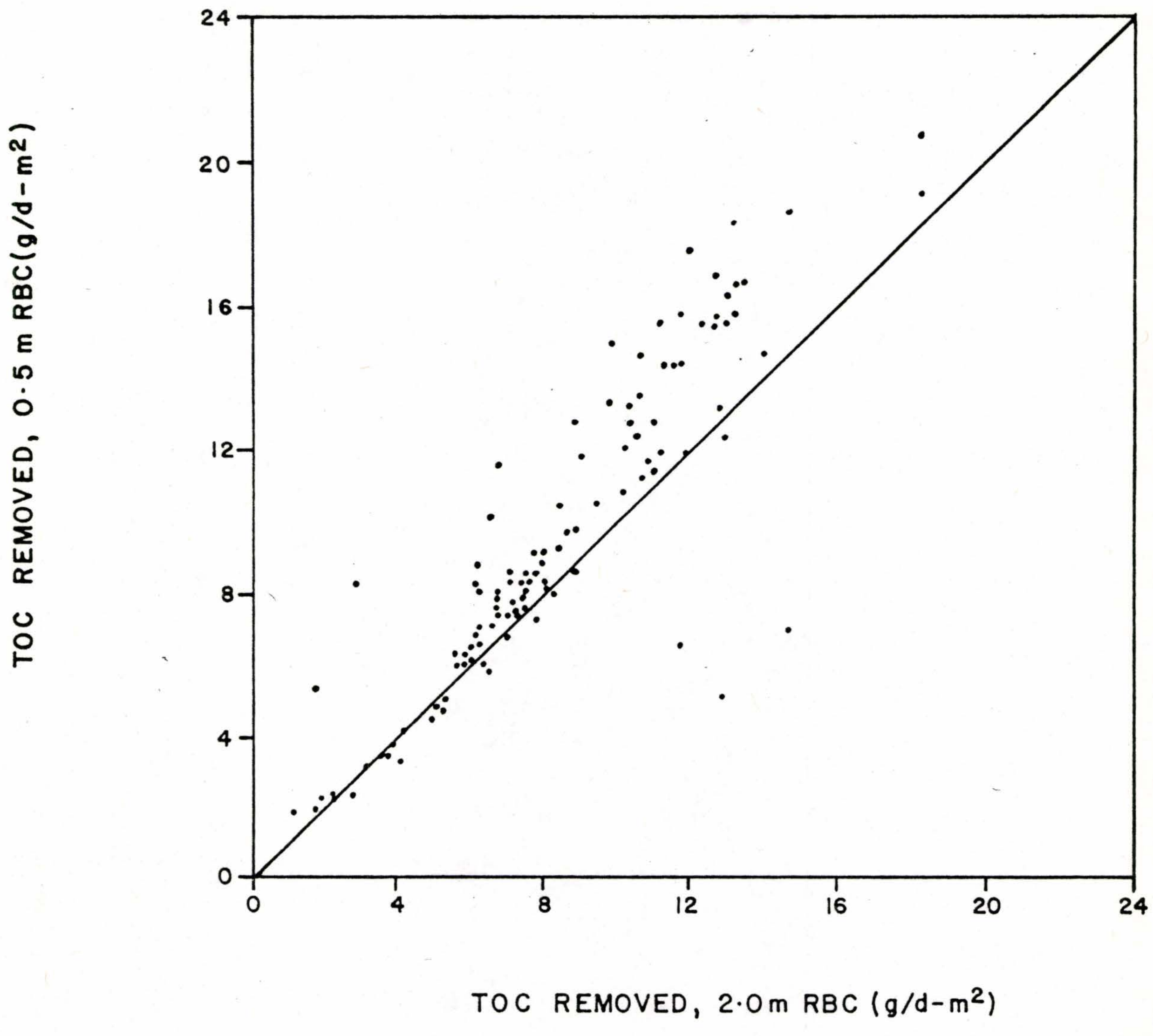
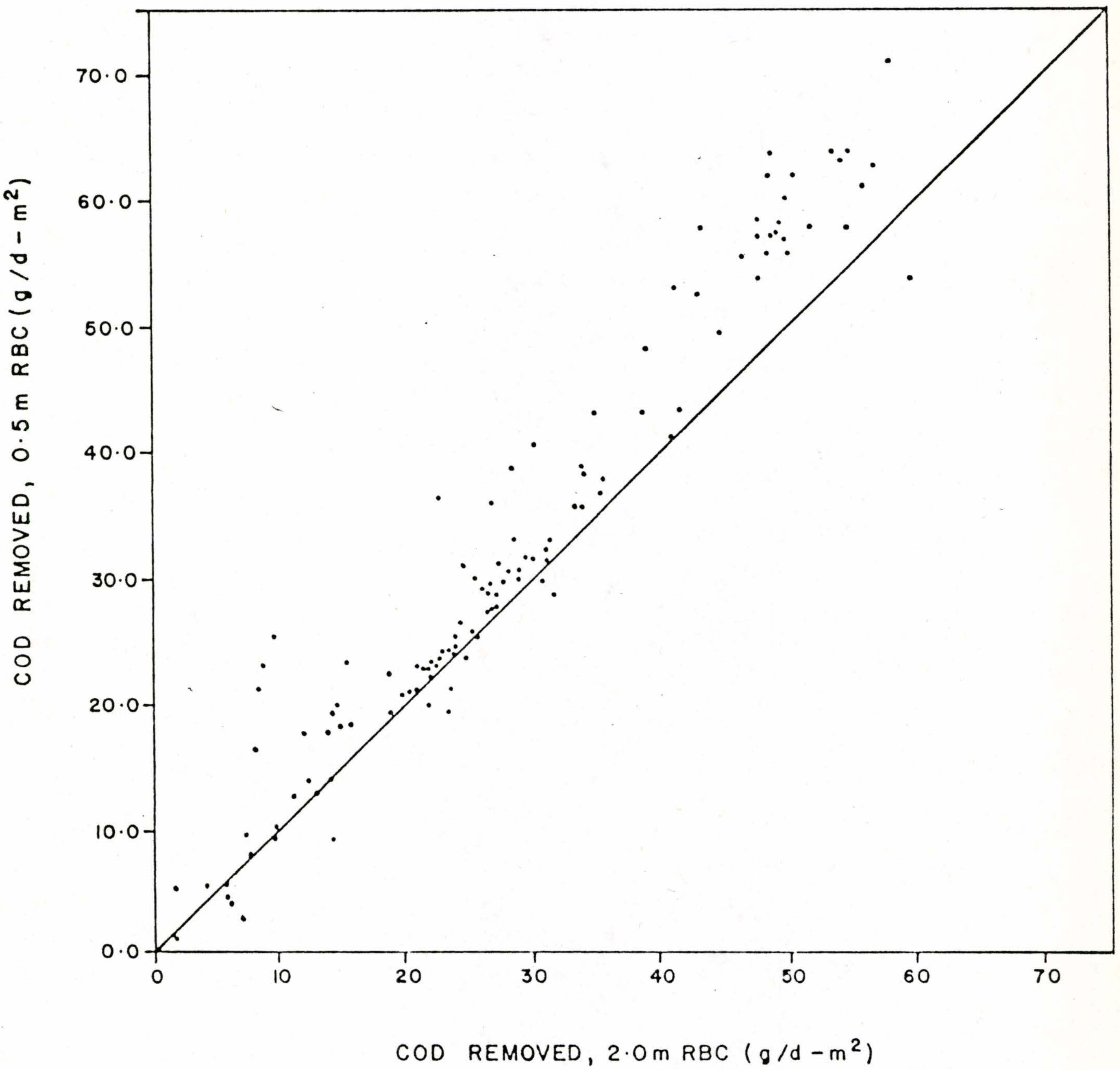


FIGURE 4-18

COMPARISON OF COD MASS REMOVAL 0·5m RBC VERSUS 2·0m RBC



As discussed in Section 4.2.2, a difference in performance of the two RBCs was observed through examination of the cross correlation results (Figures 4.4 and 4.5). The paired data shown on Figures 4.17 and 4.18 for TOC and COD mass removal demonstrate that the 0.5 metre RBC oxidized more carbon per unit surface area than did the 2.0 metre RBC. The difference in mass removal increases with loading to the units.

The mixing characteristics of the two reactors, as determined by dye studies (Appendix D), showed that mixing in the 0.5 metre RBC approached two CSTRs in series, while mixing in the 2.0 metre unit approached plug flow (7 CSTRs in series). If the biological oxidation reaction proceeds by first order kinetics, as indicated by Antonie (1970), then one would expect the 2.0 metre unit to have better removal than the 0.5 metre unit. However, improved performance was not observed, suggesting that the reaction does not follow a first order relationship and/or that some other effect is limiting the reaction.

Chesner and Molof (1976) demonstrated that at increased loading rates, dissolved oxygen concentration tends to decrease. They pointed out that as present design maintains a constant peripheral tip velocity, rotational speeds must decrease with increasing disc diameter, thereby decreasing aeration capacity. A dissolved oxygen limitation may therefore occur as loading and reactor size are increased. Dissolved oxygen was not regularly monitored during the experimental runs; therefore, one can only assume that this would explain the observations.

5.0 Conclusions

An evaluation of the response of rotating biological contactors (RBCs) operated under non-steady influent conditions indicates that:

1. The RBC is sensitive to influent fluctuations of an organic, inorganic and hydraulic nature in terms of maintaining consistently good effluent quality.

2. A statistically adequate representation of the dynamic TKN effluent response can be obtained using time series modelling techniques.

3. More emphasis should be placed on using influent mass loading as a design criteria.

4. The models developed indicate that:

    a) the response in effluent filterable TKN is predicted most precisely by influent filterable TKN loading. Models based on influent TKN concentration and flow were not as precise in predicting effluent response;

    b) positive effluent TKN response can be expected for increases in TKN loading, TKN concentration and hydraulic loading;

    c) effluent response occurs almost instantaneously, with a duration of 3 to 4 hours; and

    d) greater effluent variability may be expected with an RBC as compared to either a separate or combined activated sludge system operating under nitrifying conditions and at similar levels of removal.

5. Cross correlation results for carbon oxidation indicate that:

   a) a positive TOC response can be expected for increases in TOC loading and concentration with the 0.5 metre RBC;

   b) there is little correlation between effluent carbon concentration and hydraulic loading with the 0.5 metre RBC;

   c) a positive TOC response can be expected for increases in TOC loading, concentration and hydraulic loading with the 2.0 metre RBC; and

   d) the duration of the response is on the order of 1 hour.

6. An analysis of the raw data indicated that:

   a) TOC and COD removal is a linear function of mass loading;

   b) TKN mass removal is a linear function of TKN mass loading at loadings below 2.1 g/d-m^2;

   c) TKN mass removal becomes unstable at loadings above 2.1 g/d-m^2. The instability appears to be a function of flow rate rather than mass loading; and

   d) areal organic mass removal was greater for the 0.5 metre unit when operated in parallel with the 2.0 metre unit.

6.0 Recommendations for Future Work

1. A detailed investigation at the pilot scale level to develop further loading data on which to base design, under both nitrifying and carbon oxidation modes of operation is recommended.

2. Develop transfer function-noise models based on the carbon oxidation data obtained in this study and examine the significance of mass carbon loading in design.

3. Develop design criteria for full scale RBCs based on pilot scale operating data. The investigation should encompass the mechanical scale-up consideration on which RBCs are currently designed.

REFERENCES

Ahlberg, N. R. and Kwong, T.S", "Process Evaluation of a Rotating Biological Contactor for Municipal Wastewater Treatment", MOE Pollution Control Planning Branch, Research Paper No. W2041 (1974).

Aluko, T. M., "The use of the Disc Filter for the Aerobic and Anerobic Treatment of Milk Wastes", MSC Thesis, University of Newcastle upon Tyne, UK (1970).

Antonie, R. L. and Welch, F. M., "Preliminary Results of a Novel Biological Process for Treating Dairy Wastes", Proc. 24th Industrial Waste Conference,, Purdue University, 115, May (1969).

Antonie, R. L., "Application of the Bio-Disc Process to Treatment of Domestic Wastewater", 43rd Annual W.P.C.F. Conference, Boston, Oct. (1970).

Antonie, R. L., "Response of the Bio-Disc Process to Fluctuating Wastewater Flows", Proc. 25th. Industrial Waste Conference, Purdue University, 427, May (1970).

Antonie, R. L., "The 'Bio-Disc' Process: New Technology for the Treatment of Biodegradable Industrial Wastewater", Water - 1970, Chem. Eng. Symp. Series, 67, 107, 585, (1971).

Antonie, R. L., and Van Aacken, K. "Rotating Discs Fulfill Dual Wastewater Role", Water and Wastes Engineering, 37, 1, (1971).

Antonie, R. L. "Three Step Biological Treatment with the Bio-Disc Process", Presented at Water Pollution Control Meeting, New York, June (1972).

Antonie, R. L., Kluge, D. L., and Mielke, J. H., "Evaluation of a Rotating Disk Wastewater Treatment Plant", JWPCF, 46, 3, 498, (1974).

Antonie, R. L., "Nitrification of Activated Sludge Effluent: Bio-Surf Process", Water and Sewage Works, 121, 11, 44, (1974).

Antonie, R. L., "Rotating Biological Contractor for Secondary Treatment", Presented at Culp/Wesner/Culp WWT Seminar, South Lake Tahoe, Stateline, Nevada, Oct. (1976).

Autotrol Corporation, "Application of Rotating Disc Process to Municipal Wastewater Treatment", US Gov. WPC Research Series, Project No. 10750 DAM, Nov. (1971).

B.C. Research, "Development of a Biological System for the Treatment of Mill Waste Waters Containing Thiosulfate", Project No. 1525, (1973).

Beak, T. W., Consultants Ltd., "An Evaluation of European Experience with the Rotating Biological Contractor", Environmental Protection Service Report No. EPS4-WP-73-4, Oct., (1973).

Bennet, D. J., Needham, T. and Summer, R. E., "Pilot Application of the Rotating Biological Surface Concept for Secondary Treatment of Insulating Board Mill Effluents", Tappi, 56, 12, 182, (1973).

Berthouex, P. M., Hunter, W. G., Pallesen, L. and Shitt, C. Y., "The Use of Stochastic Models in the Interpretation of Historical Data from Sewage Treatment Plants", Water Research, 10, 689, (1976).

Birks, C.W. and Hynek, R.J., "Treatment of Cheese Processing Wastes by the Bio-Disc Process", Proc. 26th Ind. Waste Conference, Purdue University, 89, May (1971).

Borchardt, J. A., "Observations on the Rotating Biological Disk", Pres. at Amer. Chem. Soc. Meeting, Chicago, Ill., (1970).

Borchardt, J. A., "Biological Waste Treatment Using Rotating Discs", Biotechnol. & Bioeng. Symp., 2, 131, (1971).

Box, G. E. P., and Jenkins, G. M., Time Series Analysis: Forecasting and Control, Revised Edition, Holden Day Inc., San Francisco, Calif. (1976).

Burns, R. J., Cochrane M. W., and Dastel J. A., "Cannery Waste Treatment with RBC and Extended Aeration Plants", Proc. 2nd Natl. Symp. Food Proc. Waste, p.227 (1971).

Buswell, A. M. and Pearson, E.L., "The Nidus (Nest) Rack, a Modern Development of the Travis Colloider", Sewage Works Jour., 1, 2 (1929).

Breed, R. S., Murray, E. G. D., and Smith, N. R., Bergey's Manual of Determinative Bacteriology, 7th Ed., The Williams and Wilkins Co., Baltimore, Maryland (1957).

Bruce, A. M., Brown, B. L., Mann, H. T., "Some Developments in the Treatment of Sewage from Small Communities", The Public Health Engineer, 72, 3, 116 (1973).

Chen, H. T., Fred rickson, E. E., Cormack, J. F. and Young, S. R., "Four Biological Systems for Treating Integrated Paper Mill Effluent", TAPPI, 57, 5, 111 (1974).

Chesner, W. H., and Molof, A. H., "Biological Rotating Disk Scale-up Design: Dissolved Oxygen Effects", Prog. Wat. Tech., 9, 811 (1977).

Chittenden, J. A. and Wells, W. J. Jr., "Rotating Biological Contactors Following Anaerobic Lagoons", JWPCF, 43, 5, 746 (1971).

Chong, T. H. Y., "Evaluation of Package Rotating Biological Contactor Treatment Plants for Northern Communities", Master Thesis, University of Toronto (1974).

Clark, S. E., Coutts, H. J., Christianson, C. D., McFall, W. T., Alter, A. and Scribner, J. W., "Alaskan Industry Experience in Artic Sewage Treatment", Proc. 26th Industrial Waste Conference, Purdue University, 235, May (1971).

Cochrane, M. W., Burm, R. J. and Dostal, K. A., "Cannery Wastewater Treatment with Rotating Biological Contactor and Extended Aeration", U.S. Environmental Protection Agency Report EPA R-2-73-024, April (1973).

Cochrane, M. W. and Dostal, K. A., "RBC Treatment of Simulated Potato Processing Wastes", Proc. 3rd National Symposium on Food Processing Wastes, U.S. Environmental Protection Agency Report EPA-R2-72-018, November (1972).

Davies, R., "Bio-Disc Treats Small Community Wastes", Water and Pollution Control, 111, 2, 20, (1973).

Davies, T. R. and Pretorius, W. A., "Dentrification with a Bacterial Disc Unit", Water Research, 9, 4, 459 (1975).

Doman, J., "Results of Operation of Experimental Contact Filter with Partially Submerged Rotating Plates", Sewage Works Journal, 1 5, 500 (1929).

Draper, N.E., and Smith, H., Applied Regression Analysis, John Wiley and Sons Inc., New York, p.67 (1968).

Environmental Protection Agency, "Combined Sewer Overflow Treatment by the Rotating Biological Contactor Process", Report No. 670/2-74-050, June 1974.

Forgie, D. J. L., "Application of the Rotating Biological Contactor to Individual Household Wastewater Treatment", M.S. Thesis, University of Saskatchewan, (1974).

Forgie, D., Christensen, V., Heuchert, K. and Chong, T., "Workcamp Wastewater Treatment: Rotating Biological Contactor and Physical Chemical Treatment", Pres. at 26th Annual Western Canada Water and Sewage Conference (1974).

Friedman, A. A., Woods, R. C., and Wilbey, R. C., "Kinetic Response of Rotating Biological Contactors". Proc. 31st Industrial Waste Conference, Purdue University, 420, May (1976).

Gillespie, W. J., Marshall, D. W., and Springer, A. M., "A Pilot Scale Evaluation of Rotating Biological Surface Treatment of Pulp and Paper Mill Wastes", Tappi, 57, 9, 112 (1974).

Grieves, C. G., "Dynamic and Steady State Models for the Rotating Biological Disc Reactor", Doctorate Thesis, Clemson University, August (1972).

Haseford, G. S., "A steady State Model for the Rotating Biological Disc Reactor, Part I," University of British Columbia, Dept. of Chemical Eng., Not Published.

Hao, O. and Hendricks, G. F., "Rotating Biological Reactors Remove Nutrients", Water and Sewage Works, 12, 10 and 11, (1975).

Havis, M. P. and Hansford, G. S., "A Study of Substrate Removal in a Microbial Film Reactor", submitted to Water Research (May 1975).

Hartman, H., "Development and Operation of Dipping Filter Plants", Gas-u-Wasserfach (GWF), 101, 12, 281, (1960).

Hartman, H., "The Use of Dipping Contact Filters in Biological Treatment of Sewage", Verbandsbericht Nr. 71/2 des Verbandes Schweizerischer Abwasser Fachleute (1964).

Hartman, H., "Der Tauchtropfkorper" Osterreischische Wasserwirtschaft, 17, (1965).

Hartmann, L., "Influence of Turbulence on the Activity of Bacterial Slimes", JWPCF, 39, 6, 958, (1967).

Hemens, J. and Stander, G. J., "Nutrient Removal from Sewage Effluents by Algal Activity", Adv. in Wat. Pollut. Res., Proc. of the 4th International Conference, Prague, p.701 (1969).

Hoehn, R. C. and Ray, A. D., "Effects of Thickness on Bacterial Film", JWPCF, 45, 11, 2302 (1971).

Jackson, D. F., and Jackson, B. B., "Removal of Phosphates in Wastewater by Periphyton Communities on Rotating Discs", Int. Ver. Theor. Angew. Limnol. Verh., 18, 881 (1972).

Jank, B. E., Hamoda, M.F., Leclair, B. P., "Biological Treatment of Base Metal Mining Industry Effluents Containing Thiosalts", 48th Annual Conf. Wat. Pollut. Control Fed., Miami Beach, October, (1975).

Joost, R. H., "Systemation in Using the Rotating Biological Surface (RBS) Waste Treatment Process", Proc. 24th Ind. Waste Conference, Purdue University, 365, May (1969).

Kato, K. and Sekikawa, Y., "Fixed Activated Sludge Process for Industrial Waste Treatment", Proc. 22nd Industrial Waste Conference, Purdue University, 926, May (1967).

Kershaw, M. A., "Waste Water Treatment", Process Biochemistry, 1, (1970).

Khan, A. N. and Siddiqi, R. H., "Treatment of Wastewater by Biological Discs", Indian Journal of Environmental Health, 14, 289, (1972).

Kolbe, F. F., "A Promising New Unit for Sewage Treatment", Die Siviele Ingenieur in Suid Afrika, p.327, (1965).

Kornegay, B. H. and Andrews, J. F., "Kinetics of Fixed Film Biological Reactors", Proc. 22nd Ind. Waste Conference, Purdue University, 620, May (1967).

Kornegay, B. H., "Characteristics and Kinetics of Fixed Film Biological Reactors," Ph.D. Thesis, Clemson University, (1969).

Kornegay, B. H., "Modeling and Simulation of Fixed-Film Biological Reactors", Pres. at the 8th Annual Workshop of the Association of Environmental Engineering Professors on Mathematical Modeling in Environmental Engineering, (1972).

Krauth, K.H. and Staab, K. F., "Die Leistung Von Tauchtropfkorperanlagen in der Praxis", GWF-Wasser/Abwasser, 114, 34, (1973).

Labella, S. A., Thaker, I. H. and Tehan, J.E., "Treatment of Winnery Wastes by Aerated Lagoon, Activated Sludge, and Rotating Biological Contactor", Proc. 27th Ind. Waste Conference, Purdue University, 803, May (1972).

Labonté, R. "LaVérité sur les Disques Biologiques", *Eau du Quebec*, *3*, 8, (1975).

Lager, J. A. and Smith, W. G., "Urban Stormwater Management and Technology", EPA-670/2-74-040, Program Element No. 1BB034, Contract No. 68-03-0179, (1974).

Lee, E. G. H. and Mueller, J. C., "Rotating Biological Disc Treatment of Kraft Mill Effluents", *Water and Pollution Control*, *113*, 5, 25 (1975).

Levenspiel, O., *Chemical Reaction Engineering*, Second Edition, John Wiley and Sons, Inc., Toronto, Ontario (1972).

Lohr, M., "The Contact Aeration Disk Filter Used in Combination with Preliminary Treatment, Final Sedimentation and Sludge Treatment in Sewage Works for Small Communities", *Gas-u Wasserfach (GWF)*, *108*, 36, 1029, (1967).

Lue-Hing, C., Obayashi, A. W., Zenz, D. R., Washington, B., and Sawyer, B. M., "Nitrification of High Ammonia Content Sludge Supernatant by Use of Rotating Discs", 29th Proc. Ind. Waste Conf., Purdue University, 245, May (1974).

MacGregor, J. F., "Optimal Choice of the Sampling Interval For Discrete Process Control", Department of Chemical Engineering, McMaster University, Feb. (1967).

Malhotra, S. K., Williams, T. C., and Morley, W. L., "Performance of a Bio-Disk Plant in a Northern Michigan Community", Pres. at 1975 WPCF Conference, Miami Florida, Oct. (1975).

Marki, E., "Results of Experiments by EAWAG with the Rotating Biological Filter", *Schweizeriche Zeitschrift Fur Hydrologie*, *26*, 408 (1964).

McAliley, J.E.,"A Pilot Plant Study of a Rotating Biological Surface for Secondary Treatment of Unbleached Kraft Mill Waste", *Tappi*, *57*, 9, 106 (1974).

Murphy, K. L., Sutton, P. M., Wilson, R. W. and Jank, B. E., "Nitrogen Control: Design Considerations for Supported Growth Systems", Pres. at 48th WPCF Conference, Miami, Florida, Oct. (1975).

Murphy, K. L., Sutton, P. M. and Jank B. E., "Dynamic Nature of Nitrifying Biological Suspended Growth Systems", Progress in Water Technology, 9, 279, (1977).

NCASI Technical Report, "A Pilot Investigation of Rotating Biological Surface Treatment of Pulp and Paper Wastes", NCASI Technical Bulletin No. 278 (1974).

Olsson, G., "State of the Art of Sewage Treatment Plant Control", Pres. to 1976 Engineering Foundation Conference on Chemical Process Control, Asilomar Conference Grounds, Pacific Grove, California, Jan. (1976).

Osterman, W. A., and Sullivan, R. A., "Pilot Plant Evaluation of Bio-Surf Biological Treatment System", Pres. at CPPA Tech. Conference, Toronto, Canada, Sept. (1974).

Pescod, M. B. and Nair, J. V., "Biological Disc Filtration for Tropical Waste Treatment-Experimental Studies", Water Research, 6, 1509 (1972).

Popel, Von F., "Aufbav, Abbavleistung und Bemessung von Tauchtropfkorpern, Schweizerische Zeitschrift Fur Hydrologie, 26, 394 (1964).

Piel, K. M. and Gaudy, A.F. "Kinetic Constants for Aerobic Growths of Microbial Populations Selected with Various Single Compounds and with Municipal Wastes as Substrates", Appl. Microbiol, 21, 253 (1971).

Pretorius, W. A., "Some Operational Characteristics of a Bacterial Disc Unit", Water Research, 5, 1141 (1971).

Pretorius, W. A., "The Rotating Disc Unit: A Waste Treatment System for Small Communities", Water Pollution Control, 42, 6, 721 (1973).

Pretorius, W. A., "The Complete Treatment of Raw Sewage with Special Emphasis on Nitrogen Removal", Proc. of the 6th Ind. Conf. on Advances in Water Poll. Res., 685 (1973).

Pretorius, W. A., "Nitrification on the Rotating Disc Unit", Pres. at the 7th Ind. Conf. of Water Poll. Res., Paris (1974).

Reimer, R. E., Wukaseh, R. F., and Horsky, E. E., "Pilot Plant Studies and Process Selection for Nitrification City of Indianapolis, Indiana", Proc. of 31st Annual Ind. Waste Conf. Purdue University, 280, May (1976).

Sach, W. A., and Phillips, S. A., "Evaluation of the Bio-Disc Treatment Process for Summer Camp Application", EPA Report No. EPA-670/2-73-022 (1973).

Steels, I. H., "Design Basis for the Rotating Disc Process", Effluent and Water Treatment Journal, 14, 8, (1974).

Simpson, J. R., "Waste Treatment for Small Communities", Process Biochemistry, 7, 1, 18 (1972).

Stover, E. L. and Kincannon, D. F., "One Step Nitrification and Carbon Removal", Water and Sewage Works, 114, 6, 66 (1975).

Stover, E. L. and Kincannon, D. F., "Evaluating Rotating Biological Contactor Performance", Water and Sewage Works, 123, 3, 88, (1976).

Summer, R. E. and Bennett, D. J., "Pilot Treatability Study of Pulp, Paper and Fiberboard Effluents by Rotating Biological Surface", Pres. at Paper Ind. Air and Stream Improvement Conf., St. Andrews, N.B. (1973).

Sword, B. R., "Dentrification by Anaerobic Filters and Ponds", Bio-Engineering Aspects of Agricultural Drainage, San Joaquin Project, Environmental Protection Agency, 13030 UBH, April (1971).

Sutton, P. M., "Steady State and Dynamic Behavior of Combined and Separate Sludge Carbon Removal - Nitrification Systems", Ph.D. Thesis, McMaster University, Dept. of Chemical Engineering, September (1976).

Tan, T. D., "Dynamic Modelling and Data Analysis of a Wastewater Treatment Plant", Master's Thesis, Dept. of Chemical Engineering, McMaster University, (1976).

Thomas, J. L., and L. G. Koehrsen, "Activated Sludge - Bio-disc Treatment of Distillery Wastewater", EPA-660/ 2-74-014, April (1974).

Timpany, P., "Variation in Axial Mixing in an Aeration Tank", Master's Thesis, Dept. of Chem. Eng., McMaster University (1966).

Torpey, W. N., Heukelekian, H., Kaplovsky, A. and Epstein, R., "Rotating Disks with Biological Growths Prepare Wastewater for Disposal or Reuse", JWPCF, 43, 11, 2181 (1971).

Torpey, W., Heukelekian, H., Kaplovsky, A. J. and Epstein L., "Effects of Exposing Slimes on Rotating Discs to Atmospheres Enriched with Oxygen" Proc. of the 6th Int. Conf. on Adv. in Water Poll. Res., 405, (1972).

Torpey, W. H., H. Heukelekian and A. J. Kaplovsky, "Rotating Biological Disc Wastewater Treatment Process - Pilot Plant Evaluation", EPA Report PB-232-133, No. 670/2-73-027, May (1974).

Welch, F. M., "Preliminary Results of a New Approach in the Aerobic Biological Treatment of Highly Concentrated Wastes", Pres. at 23rd Ind. Waste Conf., Purdue University (1968).

Welch, F. M., "New Approach to Aerobic Treatment of Wastes", Water and Wastes Engineering, 7, 12 (1969).

Welch, F. M., "Potential Use of the Bio-Disc Process in Treating Wastewater from the Canning Industry", Pres. at Conf. on Treatment and Disposal of Wastes from Vegetable Processing, May (1970).

Weng, C. N., "Biological Fixed Film Rotating Disks for Wastewater Treatment", Ph.D. Thesis, New York University, (1972).

Weng, C. and Molof, A. H., "Nitrification in the Biological Fixed Film Rotating Disk System", JWPCF, 46, 7, 1674, (1974).

Wilson, R. W., "Continuous Fixed Film Biological Nitrification and Dentrification of Wastewater", Master Thesis, McMaster University, (1975).

Winkler, W. W. and Welch, F. M., "Energy Conservation Dictates Innovative Treatment Plant Design", Public Works Jour., 3, 86 (1974).

Zanoni, A. E., "Phosphorus Removal by Trickling Filter Slimes", U.S. Environmental Protection Agency Report, EPA-R2-73-279, July (1973).

APPENDIX A

DATA LISTING

This appendix contains a complete listing of the general operating procedures, including flow rates, influent and effluent temperatures, dissolved oxygen concentration, suspended solids, chemical additions, etc. as well as the analytical results obtained during the experimental runs. The results are presented in cronological order. Abbreviations and symbols used in the listings are defined in Appendix E.

Table A-1

GENERAL OPERATING DATA

SERIES A -START UP AND ACCLIMITIZATION

A-1 HYDRAULIC VOLUME AND DYE STUDY(0.5M UNIT)

```
C25 05  0.5 M1 RPM=13.0 WATER.FEED CONNECTED.HOOD INSTALLED
C 31 05 0.5 M1 DYE STUDY AT 0.813 L/M. ~~RAW SEWAGE STARTED AT 1705~~
C01 06  0.5 M1 VOLUME=141.8 LITRES
```

GENERAL OPERATING DATA

A-2 ACCLIMITIZATION PERFORMANCE OF 0.5M1 + 0.5M2 UNITS

```
DAYMON  PILOT SAMPLE   FLOW  PH    ALK  SS VSS 30 MIN  DO   TEMP
        UNIT  IDENTITY L/M         MG/L MG/LMG/L SETTLE MG/L DEG-C
                                                  ML/L

01 06   0.5M1 RFG12    0.76                                  28.5
01 06   0.5M1 EFG12    0.76 7.7                              23.8
01 06   0.5M1 AMB.AIR                                        20.7
01 06   0.5M1 INT.AIR                                        21.4

02 06   0.5M1 RFG08    0.68 6.7                        1.3   28.0
02 06   0.5M1 EFG08    0.68 7.6                        5.9   23.4
02 06   0.5M1 AMB.AIR                                        22.8
02 06   0.5M1 INT.AIR                                        23.2

C LIGHT FILM OF BROWN SLIME APPEARS IN STAGE 1

03 06   0.5M1 RFG08    0.65 7.0                        4.0   26.3
03 06   0.5M1 EFG08    0.65 7.9                        6.0   23.7
03 06   0.5M1 AMB.AIR                                        24.3
03 06   0.5M1 INT.AIR                                        24.1

04 06   0.5M1 RFG08    0.81 7.0                        1.2   25.6
04 06   0.5M1 EFG08    0.81 8.0                        7.1   24.6
04 06   0.5M1 EFC0807  0.81            50  45
04 06   0.5M1 AMB.AIR                                        23.8
04 06   0.5M1 INT.AIR                                        24.3

C GROWTH IS VERY HEAVY IN STG.1 AND LIGHT IN STG.2,3+4
C SECOND BIO SURF INSTALLED(0.5 M2) RPM=13.0 04/06/76

07 06   0.5M1 RFG08    0.81 6.9                        0.8   28.7
07 06   0.5M1 EFG08    0.81 7.1                        6.4   25.2
07 06   0.5M1 AMB.AIR                                        26.0
07 06   0.5M1 INT.AIR                                        25.9

07 06   0.5M2 RFG08    0.90 6.9                        0.8   28.4
07 06   0.5M2 EFG08    0.90 8.0                        6.9   23.6
07 06   0.5M2 AMB.AIR                                        26.0

08 06   0.5M1 RFG08    0.84 6.7                        1.0   25.5
08 06   0.5M1 EFG08    0.84 7.0                        6.1   25.8
08 06   0.5M1 EFC0807  0.84  .         42  34
08 06   0.5M1 AMB.AIR                                        26.4
08 06   0.5M1 INT.AIR                                        26.5

C   HEAVY GROWTH IN FIRST 3 STAGES
```

Table -1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
08 06	0.5M2	RFG08	0.85	6.7					1.0	25.5
08 06	0.5M2	EFG08	0.85	7.6					6.8	24.3
08 06	0.5M2	EFC0807	0.85			~~122~~	~~87~~			
C8 06	0.5M2	AMB.AIR								26.4
~~C GROWTH HEAVY IN STG.1 AND LIGHT IN STG.2,3+4~~										
~~09 06~~	~~0.5M1~~	~~RFG08~~	~~0.77~~	~~6.8~~					~~1.0~~	~~27.2~~
09 06	0.5M1	EFG08	0.77	7.4					5.5	26.3
09 06	0.5M1	AMB.AIR								26.9
~~09 06~~	~~0.5M1~~	~~INT.AIR~~								~~26.8~~
~~09 06~~	~~0.5M2~~	~~RFG08~~	~~0.91~~	~~6.8~~					~~1.0~~	~~27.2~~
09 06	0.5M2	EFG08	0.91	7.3					6.2	24.9
09 06	0.5M2	AMBAIR								26.9
10 06	0.5M1	RFG08	0.75	6.8					1.2	25.8
~~10 06~~	~~0.5M1~~	~~EFG08~~	~~0.75~~	~~7.0~~					~~5.8~~	~~26.1~~
10 06	0.5M1	EFC0807	0.75			68	43			
1C 06	0.5M1	AMB .AIR								26.4
~~1C 06~~	~~0.5M1~~	~~INT.AIR~~								~~26.4~~
~~10 06~~	~~0.5M2~~	~~RFG08~~	~~0.82~~	~~6.8~~					~~1.2~~	~~25.8~~
10 06	0.5M2	EFG08	0.82	7.3					6.5	24.7
10 06	0.5M2	EFC0807	0.82			167	116			
~~10 06~~	~~0.5M2~~	~~AMB.AIR~~								~~26.4~~
C HOOD INSTALLED AT 1130										
11 06	0.5M1	RFG08	0.74	6.8					1.2	27.8
~~11 06~~	~~0.5M1~~	~~EFG08~~	~~0.74~~	~~7.5~~					~~5.5~~	~~26.0~~
11 06	0.5M1	AMB.AIR								25.1
11 06	0.5M1	INT.AIR								25.2
11 06	0.5M2	RFG08	0.85	6.8						27.5
~~11 06~~	~~0.5M2~~	~~EFG08~~	~~0.85~~	~~7.5~~					~~1.2~~	~~25.4~~
11 06	0.5M2	AMB.AIR							6.1	25.1
11 06	0.5M2	INT.AIR								25.2
14 06	0.5M1	RFG08	0.73	6.8					0.4	18.5
~~14 06~~	~~0.5M1~~	~~EFG08~~	~~0.73~~	~~7.0~~					~~6.4~~	~~21.2~~
14 06	0.5M1	AMB.AIR								27.1
14 06	0.5M1	INT.AIR								26.7

C RAW FEED LINE CHANGED CAUSING COOLER TEMPERATURES

Table A-1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C	C
14 06	0.5M2	RFG08	0.80	6.8					0.9	18.7	
14 06	0.5M2	EFG08	0.80	7.0					6.2	21.4	
~~14 06~~	~~0.5M2~~	~~AMB.AIR~~								~~27.1~~	
14 06	0.5M2	INT.AIR								26.7	

~~C RAW FEED LINE CHANGED CAUSING COOLER TMEPERATURES~~

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C	C
~~15 06~~	~~0.5M1~~	~~RFG08~~	~~0.77~~	~~6.7~~					~~0.7~~	~~19.2~~	
15 06	0.5M1	EFG08	0.77	7.1					6.2	21.7	
15 06	0.5M1	EFC0807	0.77			156	125				
~~15 06~~	~~0.5M1~~	~~AMB.AIR~~								~~27.4~~	
15 06	0.5M1	INT.AIR								26.8	
15 06	0.5M2	RFG08	0.80	6.7					1.2	19.5	
15 06	0.5M2	EFG08	0.80	7.0					6.2	22.0	
~~15 06~~	~~0.5M2~~	~~EFC0807~~	~~0.80~~			~~86~~	~~79~~				
15 06	0.5M2	AMB.AIR								27.4	
15 06	0.5M2	INT.AIR								26.9	
16 06	0.5M1	RFG08	0.72	6.9					0.5	19.4	
~~16 06~~	~~0.5M1~~	~~EFG08~~	~~0.72~~	~~7.1~~					~~5.9~~	~~22.5~~	
16 06	0.5M1	AMB.AIR								26.7	
16 06	0.5M1	INT.AIR								26.6	
16 06	0.5M2	RFG08	0.85	6.9					1.4	19.9	
~~16 06~~	~~0.5M2~~	~~EFG08~~	~~0.85~~	~~7.1~~					~~5.8~~	~~22.8~~	
16 06	0.5M2	AMB.AIR								26.7	
16 06	0.5M2	INT.AIR								26.6	
17 06	0.5M1	RFG08	0.78	7.0					0.9	18.9	
~~17 06~~	~~0.5M1~~	~~EFG08~~	~~0.78~~	~~7.3~~					~~6.1~~	~~20.2~~	
17 06	0.5M1	EFC0807	0.78			153	124				
17 06	0.5M1	AMB.AIR								25.1	
~~17 06~~	~~0.5M1~~	~~INT.AIR~~								~~24.2~~	
~~17 06~~	~~0.5M2~~	~~RFG08~~	~~0.87~~	~~7.0~~					~~1.5~~	~~19.4~~	
17 06	0.5M2	EFG08	0.87	7.2					6.4	20.5	
17 06	0.5M2	EFC0807	0.87			207	161				
17 06	0.5M2	AMB.AIR								~~25.1~~	
17 06	0.5M2	INT.AIR								24.2	
18 06	0.5M1	RFG08	0.80	6.9					0.5	18.6	
18 06	0.5M1	EFG08	0.80	7.2					5.7	19.7	
18 06	0.5M1	AMB.AIR								~~24.2~~	
18 06	0.5M1	INT.AIR								23.6	

Table A-1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C	CHE
18 06	0.5M2	RFG08	0.89	6.9					0.7	18.7	
18 06	0.5M2	EFG08	0.89	7.2					5.8	19.9	
18 06	0.5M2	AMB.AIR								24.2	
18 06	0.5M2	INT.AIR								23.8	
21 06	0.5M1	RFG08	0.61	6.8					1.2	18.7	
21 06	0.5M1	EFG08	0.61	7.1					6.2	20.4	
21 06	0.5M1	AMB.AIR								24.2	
21 06	0.5M1	INT.AIR								23.5	
C21 06	0.5M2	PUMP FAILURE DURING WEEKEND - NO MEASUREMENTS TAKEN									
22 06	0.5M1	RFG08	0.61	6.7					1.0	19.3	
22 06	0.5M1	EFG08	0.61	7.0					6.1	21.6	
22 06	0.5M1	EFC0807	0.61			146	112				
22 06	0.5M1	AMB.AIR								25.4	
22 06	0.5M1	INT.AIR								24.9	
22 06	0.5M2	RFG08	0.82	6.7					1.2	19.3	
22 06	0.5M2	EFG08	0.82	7.0					6.2	21.3	
22 06	0.5M2	EFC0807	0.82			292	213				
22 06	0.5M2	AMB.AIR								25.4	
22 06	0.5M2	INT.AIR								25.1	
23 06	0.5M1	RFG08	0.80	6.3					0.8	19.9	
23 06	0.5M1	EFG08	0.80	6.9					5.9	21.7	
23 06	0.5M1	AMB.AIR								25.8	
23 06	0.5M1	INT.AIR								24.8	
23 06	0.5M2	RFG08	0.87	6.3					0.9	19.9	
23 06	0.5M2	EFG08	0.87	6.9					6.0	21.9	
23 06	0.5M2	AMB.AIR								25.8	
23 06	0.5M2	INT.AIR								24.4	
C24 06	0.5 M1+ 0.5M2	DUE TO PUMP PROBLEMS THE COMPOSITE SAMPLES WERE NOT T									
24 06	0.5M1	RFG08		6.4					0.9	18.9	
24 06	0.5M1	EFG08		7.0					6.3	20.1	
24 06	0.5M1	AMB AIR								26.7	
24 06	0.5M1	INT AIR								25.8	
24 06	0.5M2	RFG08		6.4					0.9	18.9	
24 06	0.5M2	EFG08		6.9					6.5	20.3	
24 06	0.5M2	AMB AIR								26.7	
24 06	0.5M2	INT AIR								25.8	

Table A-1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
25 06	0.5M1	RFG08	0.61	6.7					1.3	20.0
25 06	0.5M1	EFG08	0.61	7.0					6.4	22.5
25 06	0.5M1	AME.AIR								26.6
25 06	0.5M1	INT.AIR								26.2
25 06	0.5M2	RFG08	1.01	6.7					1.1	20.2
25 06	0.5M2	EFG08	1.01	7.0					6.2	22.1
25 06	0.5M2	AMB.AIR								26.6
25 06	0.5M2	INT.AIR								26.0

C FURTHER COMPOSITES WERE TAKEN OF BOTH UNITS (0.5M)
C MORE DATA FOR COMPARATIVE PURPOSES

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
16 08	0.5M1		3.27							
16 08	0.5M2		3.27							
17 08	0.5M1	RFG12	3.27	7.6					2.5	21.0
17 08	0.5M1	EFG12	3.27	7.7					5.7	21.3
17 08	0.5M1+2	AMB.AIR								25.0
17 08	0.5M1+2	RFC1009				370	186			
17 08	0.5M2	RFG12	3.25	7.6					2.5	21.0
17 08	0.5M2	EFG12	3.25	77					5.5	21.4
22 08	0.5M1+2	RFC1413				94	84			
22 08	0.5M1		3.27							
22 08	0.5M2		3.25							
23 08	0.5M1+2	RFC1313				98	90			
23 08	0.5M1		3.04							
23 08	0.5M2		3.04							

SAMPLES COLLECTED ON 23/08 SAT IN FRIDGE FOR 24HR.BEFORE PREPARATION.

C 24 08 1500HR. 0.5M1 MOVED OUTSIDE AND CONNECTED TO SAME FEED AS 2.0M

C END OF EXPERIMENT

Table A-1 Cont'd

GENERAL OPERATING DATA

A-3 HYDRAULIC VOLUME AND DYE STUDY OF 2.0M UNIT

07 2.0 M.RAW SEWAGE.STARTED USING FEED SCOOPS. 1300-FEED SHUTOFF
~~07 2.0 M RAW SEWAGE STARTED USING DIRECT FEED RPM=3.0~~
07 2.0 M B10 SURF NOT LEVEL.WIER SET TO MINIMUN HEIGHT
07 2.0 M BASIC VOLUME(NO FLOW CONDITIONS)=3364.0 LITRES
~~07 2.0 M ACCUMULATED SLUDGE IN THE BOTTOM OF EACH STAGE~~
07 2.0 M B10 SURF SHUT OFF FOR 6.0HR WHILE PIPING INSTALLED
07 2.0 M DYE STUDY AT 37.2L/M.HEAD VOL=104.4L.   VOLUME=3468.4 L.
~~07 2.0M DYE STUDY AT 100.3 L/M.HEAD VOL=181.6L.TOTAL VOL=3545.6 L.~~
07 2.0 M PUMP SHUT OFF AT 1400 B10 SURF STILL ROTATING
07 2.0 M PUMP STARTED UP AT 1900.STG1+2 SHOW A HEAVY GROWTH

ND OF EXPERIMENT

Table A-1 Cont'd

GENERAL OPERATING DATA

A-4 ACCLIMITIZATION PERFORMANCE OF 2.0M UNIT

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
07	2.0 M	RFG14	97.38	6.2						18.3
07	2.0 M	EFG14	97.38	6.5						20.6
07	2.0 M	STAGE 1	97.38						2.4	18.9
07	2.0 M	STAGE 4	97.38						4.1	20.3
07	2.0 M	AMB.AIR								29.5
07	2.0 M	RFC0807	99.7	.		288	217			
07	2.0 M	RFG08	99.7	6.3						19.3
07	2.0 M	EFG08	99.7	6.5						19.7
07	2.0 M	STAGE 1	99.7						5.0	19.7
07	2.0 M	STAGE 4	99.7						5.3	19.7
07	2.0 M	AMB.AIR								22.5
07	2.0 M	RFG08	99.7	6.4						19.3
07	2.0 M	EFG08	99.7	6.4						19.3
07	2.0 M	STAGE 1	99.7						4.1	19.1
07	2.0 M	STAGE 4	99.7						5.0	19.2
07	2.0 M	AMB.AIR								20.5

OOD GROWTH IN ALL STAGES

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
07	2.0 M	RFG09	119.7	6.5						19.2
07	2.0 M	RFC0908	119.70			330	250			
07	2.0 M	EFG09	119.7	7.1						18.4
07	2.0 M	STAGE 1	119.7						2.3	18.5
07	2.0 M	STAGE 4	119.7						4.6	18.5
07	2.0 M	AMB.AIR								16.0

LOW RATE INCREASED.RAIN HAS WASHED OFF A GREAT DEAL OF BIOMASS
UMP HAD SHUT OFF DURING THE NIGHT.RESTART AT 0800

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
07	2.0 M	RFG12	99.8	6.5						19.2
07	2.0 M	EFG12	99.8	7.0						20.8
07	2.0 M	STAGE 1	99.8						1.7	20.0
07	2.0 M	STAGE 4	99.8						3.3	20.5
07	2.0 M	AME.AIR								27.0

UMP HAD SHUT OFF DURING THE NIGHT AGAIN.
UE TO PUMP PROBLEMS FLOW REDUCED TO 99.8GPM.

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
08	2.0 M	RFG15	99.8	6.6						18.8
08	2.0 M	EFG15	99.8	6.9						20.6
08	2.0 M	STAGE 1	99.8						1.7	19.6
08	2.0 M	STAGE4	99.						3.6	20.3
08	2.0 M	AMB.AIR								25.5

Table A-1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
03 08	2.0 M	RFG08	111.68	6.8						18.7
03 08	2.0 M	EFG08	111.68	6.8						17.7
03 08	2.0 M	STAGE1	111.68							
03 08	2.0 7	STAGE4	111.68						4.0	17.7
03 08	2.0 M	AMB.AIR								16.0

C FEED PUMP IS PUMPING SOME AIR .MAY AFFECT D.O.

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
04 08	2.0 M	RFG08	122.6	6.7						19.5
04 08	2.0M	RFC0807				200				
04 08	2.0 M	EFG08	122.6	6.8						16.4
04 08	2.0 M	STAGE1	122.6						4.1	18.7
04 08	2.0 M	STAGE4	122.6						4.6	16.4
04 08	2.0 M	AMB.AIR								19.8

C STILL PUMPING AIR. SYSTEM WAS RECALIBRATED IN THE PM OF THE 3RD
C PUMP SHUT OFF DURING THE NIGHT . MAY AFFECT COMPOSITE
C ELECTRICAL FAILURE IN FLOW MONITOR CAUSED SHUT DOWN AT 1400

C PUMP RESTARTED AT 0900. COMPOSITE STARTED AT 1000 -0508

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
05 08	2.0 M	RFG10	124.8	6.7						18.7
05 08	2.0 M	RFC1009				408	351			
05 08	2.0 M	EFG10	124.8	6.8						20.4
05 08	2.0 M	STAGE1	124.8						3.4	19.2
05 08	2.0 M	STAGE4	124.8						4.2	19.4
05 08	2.0 M	AMB.AIR								20.7

C HOOD INSTALLED ON 0608

C END OF EXPERIMENT. A TOTAL OF 4 COMPOSITE SAMPLES WERE COLLECTED

Table A-1 Cont'd

```
                    GENERAL OPERATING DATA

        SERIES-B  DIURNAL FLOW VARIATION (0.5M UNIT)

                  B-1  NITRIFICATION MODE

C25 06  0.5M2 SET AT AVERAGE OF FLOW TO 0.5M1 AUG=1.18L/M
C25 06  0.5MI INSTALLED FLOW SPLITTER AT PEAK/AUG/MIN OF 2/1/0.5
C FLOWS  TO 0.5 M2 MEASURED. TIME=0 IS MIDNIGHT. FLOW=L/M. VOL.IN ML.


C  TIME   FLOW    WEIGHTED VOL           TIME  FLOW    WEIGHTED VOL

C    0    0.813          78                12  0.826          79
C    1    0.704          67                13  0.931          89
C    2    0.636          61                14  1.044         100
C    3    0.567          54                15  1.475         141
C    4    0.522          50                16  1.884         181
C    5    0.522          50                17  2.143         205
C    6    0.522          50                18  2.202         211
C    7    0.522          50                19  2.088         200
C    8    0.545          52                20  1.861         178
C    9    0.590          56.5              21  1.498         143
C   10    0.658          63                22  1.067         100
C   11    0.735          70                23  0.931          89
C  AVERAGE FLOW =1.05L/M

DAYMON  PILOT SAMPLE  FLOW   PH    ALK   SS VSS 30 MIN  DO    TEMP
        UNIT  IDENTITY L/M         MG/L MG/LMG/L SETTLE MG/L DEG-C
                                                ML/L

 29.06  0.5M1 RFG16     .     .                              20.4
 29.06  0.5M1 EFG16     .     .                              21.1
 29 06  0.5M1 AMB.AIR                                         23.3

 29 06  0.5M2 RFG16    1.18                                   20.0
 29 06  0.5M2 EFG16    1.18                                   20.7
 29 06  0.5M2 AMB.AIR                                         23.3


  SAMPLER MALFUNCTION ON 29/06 CAUSED SAMPLE RUN TO BE DISGARDED

C30 06 SAMPLER MALFUNCTION CAUSED COMPOSITE TO BE RESTRARED AT 1300

 30 06  0.5M2 TIME=13  1.18


 02 07  0.5M2 RFG09    1.18 6.7                               19.5
 02 07  0.5M2 EFG09    1.18 7.0                               20.3
 02 07  0.5M2 AMB.AIR                                         23.5


 02 07  0.5M1 RFG09                                           19.7
 02 07  0.5M1 EFG09         7.0                               20.5
 02 07  0.5M1 AMBAIR                                          23.5
```

Table A-1 Cont'd

GENERAL OPERATING DATA

YMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
5 07	0.5M1	RFC1009	.	.		216	162			
5 07	0.5M1	RFG08	.	.						19.6
5 07	0.5M1	EFG08								20.3
5 07	0.5M2	RFC1009				325	235			
5 07	0.5M2	RFG08								19.7
5 07	0.5M2	EFG08								20.3
5 07	0.5M2	AMB AIR								24.4

24HR.COMPOSITES PLUS HOURLY SAMPLING ON 07+08.

YMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
7 07	0.5M1	RFC1009				204	169			
7 07	0.5M2	RFC1009				200	170			
08 07	0.5M1	RFG08		6.4					0.4	20.1
08 07	0.5M1	RFC1009				227	179			
08 07	0.5M1	STAGE 1		6.3					2.8	21.4
08 07	0.5M1	STAGE 4		6.2					4.1	22.4
08 07	0.5M1	AMB.AIR								25.3
08 07	0.5M2	INT.AIR								24.9
08 07	0.5M2	RFG08	1.08	6.3					0.8	20.1
08 07	0.5M2	RFC1009				185	149			
08 07	0.5M2	STAGE 4	1.08	6.0					4.2	21.9
08 07	0.5M2	AMB.AIR								25.3
08 07	0.5M2	INT.AIR								25.0

IT WAS NOT POSSIBLE TO OBTAIN ACCESS TO STAGE 1

YMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
09 07	0.5M1	RFG08		6.4	266				0.5	20.0
09 07	0.5M1	STAGE 1		6.4					3.2	21.0
09 07	0.5M1	STAGE 4		5.9					4.0	21.8
09 07	0.5M1	AMB.AIR								25.8
09 07	0.5M1	INT.AIR								24.9
09 07	0.5M1	EFG08			198					
09 07	0.5M2	RFG08	1.11	6.5	264				1.1	20.2
09 07	0.5M2	STAGE 1	1.11	6.3					4.2	21.6
09 07	0.5M2	AMB.AIR								25.8
09 07	0.5M2	INT.AIR								24.8
09 07	0.5M2	EFG08			179					

ANOTHER COMPOSITE SAMPLE RUN WILL BE DONE AT A LATER DATE

Table A-1 Cont'd

```
                         GENERAL OPERATING DATA

21 07  COMPOSITE SAMPLE 1110 .  22/07 COMPOSTIE SAMPLE TAKEN
 THE FLOW SPLITTER WAS ADDED ON 16/07 AT1500.5DAY ACCLIMITIZATION

AYMON  PILOT SAMPLE   FLOW  PH   ALK  SS VSS 30 MIN  DO   TEMP
       UNIT  IDENTITY L/M        MG/L MG/LMG/L SETTLE MG/L DEG-C
                                              ML/L


21 07  0.5M1 RFG11                                          19.8
21 07  0.5M1 EFG11                                          20.9
21 07  0.5M1 AMB.AIR                                        24.1

21 07  0.5M2 RFG11                                          19.8
21 07  0.5M2 EFG11                                          20.7

22 07  0.5M1 RFG08                                          19.4
22 07  0.5M1 EFG0,                                          20.3
22 07  0.5M1 AMB.AIR                                        22.8

22 07 0.5M2  RFG08                                          19.4
22 07  0.5M2 EFG08                                          20.6

   END OF EXPERIMENT
```

Table A-1 Cont'd

GENERAL OPERATING DATA

SERIES B-2 ORGANIC CARBON REMOVAL MODE

TIME	FLOW (L/M)	WEIGHTED VOL. (MLS)	TIME	FLOW (L/M)	WEIGHTED VOL. (MLS)
0	2.52	74	13	3.06	90
1	2.22	65	14	3.42	100
2	2.06	60.7	15	4.65	137
3	1.91	56	16	5.86	172
4	1.84	54	17	6.54	192
5	182	53	18	6.81	200
6	1.82	53	19	6.58	193
7	1.82	53	20	6.36	173
8	1.82	53	21	4.99	141
9	1.91	56	22	3.40	100
10	2.04	60	23	2.84	83
11	2.27	67	24	2.52	74
12	2.63	77	AVERAGE=3.36 L/M.		

AYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
23/07 TO 28/07 . ACCLIMITIZATION										
23 07	0.5M2		3.13							
23 07	0.5M1	FLOW FROM FLOW CONTROLLER. FLOWS ARE LISTED .								
28 07	24HR. COMPOSITE BEGAN AT 0900									
28 07	0.5M1	RFC0908				275	241			
28 07	0.5M1	EFC0908				202				
28 07	0.5M2	RFC0908				146	130			
28 07	0.5M2	EFC0908				333				
29 07	0.5M1	1000	2.0							
29 07	0.5M1	RFG09		6.9						
29 07	0.5M1	EFG09		6.8						
29 07	0.5M1	STAGE1							3.7	20.8
29 07	0.5M1	STAGE4							4.3	21.2
29 07	0.5M1	AMB.AIR								23.1
29 07	0.5M2	RFG09	3.4	6.9						
29 07	0.5M2	EFG09	3.4	6.8						
29 07	0.5M2	STAGE1	3.4	6.8						20.8
29 07	0.5M2	STAGE4	3.4	6.8					4.2	20.7
29 07	0.5M2	AMB.AIR								23.1
30 07	WASTED SLUDGE FROM THE SEWAGE PLANT IN THE INFLUENT AT 0900									
04 08	0.5M1	STAGE1		6.5					1.8	20.4
04 08	0.5M1	STAGE4		7.0					3.8	21.0
04 08	0.5M1+2	AMB.AIR								22.8
04 08	0.5M2	STAGE1		6.5					1.8	20.2
04 08	0.5M2	STAGE4		6.9					3.8	21.0

Table A-1 Cont'd

GENERAL OPERATING DATA

DAYMON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C
04 08	0.5M1	RFC0908				253	181			
04 08	0.5M1	EFC0908				197				
04 08	0.5M2	RFC0908				256				
04 08	0.5M2	EFC0908				228				
05 08	0.5M1	1530	5.13							
05 08	0.5M1	RFG15		6.0					1.4	20.4
05 08	0.5M1	EFG15		6.06					3.0	21.2
05 08	0.5M2	RFG15	3.27	6.0					1.4	20.4
05 08	0.5M2	EFG15	3.27	6.8					3.1	21.5
06 08	0.5M1	RFG		6.7					1.7	20.5
06 08	0.5M1	EFG		6.9					3.0	20.8
06 08	0.5M1+2AMB.AIR									23.5
06 08	0.5M2	RFG15	3.5	6.7					1.7	20.5
06 08	0.5M2	EFG15	3.5	6.79					2.9	20.2
07 08	0.5M1	RFG13		6.7						20.6
07 08	0.5M1	EFG13		6.9						21.1
07 08	0.5M2	RFG13	3.47	6.7						20.6
07 08	0.5M2	EFG13	3.47	6.9						21.0
09 08	0.5M1	1530	5.08							
09 08	0.5M1	RFG								20.8
09 08	0.5M1	EFG								21.0
09 08	0.5M1+2AMB.AIR									24.3
09 08	0.5M2	EFG09	3.44							21.2
09 08	0.5M2	RFG09	3.44							20.8

END OF EXPERIMENT

Table A-1 Cont'd

```
                         GENERAL OPERATING DATA

          SERIES C  DYNAMIC RESPONSE (0.5M UNIT)

           C-1  NITRIFICATION MODE

 07  AVERAGE FLOW SET AT 1.3 L/M
LL CHANGES TO FLOW DURING THIS RUN WERE MADE 15 MIN.BEFORE THE HOUR
LL SPIKE  CHANGES  DURING THIS RUN WERE MADE 10 MIN.BEFORE THE HOUR
H4CL=3G/L; NAHCO3= 9.0 G/L, DEXTROSE= 5G/L. THIS SOLUTION WAS ADDED AT 1100HR
N 10/07 AT A FLOW RATE OF 12.9 ML/MIN UNTIL 2345HR ON 11/07
SPIKE CONCENTRATIONS. TKN SPIKE=7.71G NH4CL + 23.13G NAHCO3 IN ONE LITRE
                      TOC SPIKE=7.0G DEXTROSE IN ONE LITRE
HESE ARE THE CONCENTRATIONS USED FROM 12/07 TO 17/07

F=FLOW OF RAW FEED IN L/M , DW=FLOW OF DILUTION WATER IN L/M
OC=FLOW OF TOC SPIKE IN ML/MIN , TKN=FLOW OF TKN SPIKE IN ML/MIN

MON  PILOT SAMPLE  FLOW  PH   ALK  SS VSS 30 MIN  DO   TEMP   CHEMICALS
     UNIT  IDENTITY L/M       MG/L MG/LMG/L SETTLE MG/L DEG-C
                                            ML/L               RF    DW   TOCTKN

 07  0.5MI   0                                                .672  0     0  14.2
 07  0.5MI  1200                                              .672 .46   0  14.2
 07  0.5MI  1600                                              1.83 1.14     28.4
 07  0.5M1 RFG12           6.8  368                   19.0
 07  0.5MI EFG12           7.0  190                   20.3

 07  0.5MI   0       .     .                                  .672  0    0     0
 07  0.5MI  0800                                              .672  0 14.2 14.2
 07  0.5M1  1600                                              1.97 1.14 0   0
 07  0.5MI RFG10           7.6  390              3    20.5
 07  0.5MI EFG10           7.3  230              4.3  21.0

 07  0.5MI   0                                                .454  0   14.2  0
 07  0.5MI  0800                                              1.94  0    0  28.4
 07  0.5MI  1200                                              1.94 1.14 39.7  0
 07  0.5MI  1600                                              1.94  0   26.1  0
 07  0.5MI RFG10                                      21.5
 07  0.5MI EFG10                                      22.5

 07  0.5MI   0                                                .633 0  13.0 17.0
 07  0.5MI  0800                                              1.94 0  26.0 34.0
 07  0.5MI  1300                                              1.94 0   0   26.1
 07  0.5MI  1600                                              1.94 0   0     0
 07  0.5MI RFG14           7.2                        20.5
 07  0.5MI EFG14           7.1  360                   21.0

 07  0.5MI   0       .     .                                  1.94  0    0     0
 07  0.5MI  0800                                              .672  0  13.0   0
 07  0.5MI  1200                                              .672 0.57 13.0 0
 07  0.5M1  1400                                              .672 0.57 0   0
 07  0.5MI  1600                                              1.94  0    0     0
```

Table A-1 Cont'd

GENERAL OPERATING DATA

ION	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C	CHEMICALS RF	DW	TOC	TKN
07	0.5M1	RFG14								21.0				
07	0.5M1	EFG14								22.1				
07	0.5MI	0									.672	0	0	22.7
07	0.5MI	1600	END OF EXPERIMENT								0	0	0	0

Table A-1 Cont'd

```
                     GENERAL OPERATING DATA
                          C-2 AND E-2
 ORGANIC CARBON REMOVAL MODE. 2.0M + 0.5M UNITS RUN IN PARALLEL


 09 BEGAN EXPERIMENT AT 1000HR.ALL CHANGES MADE 15 MIN. BEFORE THE HOUR.
    SAMPLERS STARTED 4 MIN.BEFORE SAMPLE TIME FOR 8 MIN. GRAB.
    RF=FLOW OF SEWAGE.(L/M) DW=FLOW OF DILUTION WATER.(L/M)
    TOC=FLOW OF TOC SPIKE.(ML/M)  TKN=FLOW OF TKN SPIKE.(ML/M)
    CONCENTRATION OF SPIKES.   TOC=100G. DEXTROSE/L.   TKN=30.8G.NH4CL/L.
    BOTH UNITS RUN AT AVERAGE FLOW(113.5L/M+3.4L/M)FROM 1500 03/09 UNTIL
    1000 07/09. TOC SPIKE AT 123ML/M FROM 0800 06/09 UNTIL 1000 07/09.
    DILUTION WATER MAY HAVE A COOLING AFFECT ON THE RAW FEED.

MON  PILOT SAMPLE   FLOW  PH    ALK  SS VSS 30 MIN  DO    TEMP   CHEMICALS
     UNIT  IDENTITY L/M        MG/L MG/LMG/L SETTLE MG/L DEG-C
                                             ML/L             RF     DW  TOCTKN

 09      1000-1500HR.                                         74.9    0   66

 09  2.0M      1230 69.5
 09  0.5M      1245  2.31

 09      1500-2000HR.                                         123    36   40

 09  0.5M      1515  4.58
 09  2.0M      1520157.1
 09 0.5+2M RFG1600         6.8                           20.3
 09  2.0M  EFG2600         6.9                           19.6
 09  2.0M  STAGE1                                        19.0
 09  0.5M  EFG1600         7.0                           20.6

 09      2000-0100HR.                                         56.7 19.0   30

 09  0.5M      2015  2.3
7 09  2.0M      2240 77.5
7 09 0.5+2M RFG20                                         20.4
7 09 0.5+2M AMB.AIR                                       23.0
7 09  2.0M STAGE1                                         19.0
7 09  2.0M STAGE4                                         19.0
7 09  2.0M  EFG2000                                       19.0
7 09  0.5M  EFG2000                                       19.2

8 09      0100-0600HR.                                         75      0  122

8 09  0.5M      0200  2.32
8 09  2.0M      0350 72.6
8 09 0.5+2M RFG0630                                        20.3
8 09 0.5+2M AMB.AIR                                        28.5
8 09  2.0M  STAGE1                                         20.0
8 09  2.0M  STAGE4                                         19.5
8 09  0.5M  EFG0630                                        19.0
8 09  2.0M  EFG0630                                        19.5

8 09      0600-1100HR.                                         159    0      140

8 09  0.5M      0900  4.5
8 09  2.0M      0910147.0
```

Table A-1 Cont'd

GENERAL OPERATING DATA

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	ML/L 30 MIN SETTLE	DO MG/L	TEMP DEG-C	RF CHEMICALS	OW	TOCTKN
09	1100-1600HR.										37.5	37.5	130
09	0.5M	1230	2.31										
09	2.0M	1230	73.6										
~~09~~	~~0.5+2M~~	~~AMB.AIR~~								~~28.0~~			
09	0.5+2M	RFG1230		6.9						20.0			
09	2.0M	STAGE1								16.8			
~~09~~	~~2.0M~~	~~STAGE4~~								~~17.4~~			
09	2.0M	EFG1230		6.9						17.4			
09	0.5M	EFG1230		6.9						18.6			
09	1600-2100HR.										125	36	82
~~09~~	~~0.5M~~	~~1620~~	~~4.62~~										
09	2.0M	1620	155.0										
09	0.5+2M	RFG1830								20.0			
~~09~~	~~2.0M~~	~~STAGE1~~								~~18.7~~			
09	2.0M	STAGE4								18.7			
09	2.0M	EFG1830								18.7			
~~09~~	~~0.5M~~	~~EFG1830~~								~~19.1~~			
09	1830	WARMER DILUTION WATER INSTALLED.											
~~09~~	~~2100-0200HR.~~										~~159~~	~~0~~	~~265~~
09	0.5M	2145	4.5										
~~09~~	~~2.0M~~	~~2145~~	~~154.5~~										
09	0.5+2M	RFG2200								20.5			
09	0.5+2M	AMB.AIR								18.0			
~~09~~	~~2.0M~~	~~STAGE1~~								~~20.5~~			
09	2.0M	STAGE4								20.5			
09	2.0M	EFG2200								20.5			
~~09~~	~~0.5M~~	~~EFG2200~~								~~20.5~~			
09	0200-0700HR.										75	0	130
09	0.5M	EFG0600								20.2			
09	2.0M	EFG0600								20.2			
~~09~~	~~2.0M~~	~~STAGE1~~								~~20.2~~			
09	2.0M	STAGE4								20.2			
09	2.0M	0550	69.2										
~~09~~	~~2.0M~~	~~0550~~	~~2.31~~										
09	0700-1200HR.										159	0	259
09	2.0M	1025	146.5										
09	0.5M	1111	4.6										

Table A-1 Cont'd

GENERAL OPERATING DATA

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW L/M	PH	ALK MG/L	SS MG/L	VSS MG/L	30 MIN SETTLE ML/L	DO MG/L	TEMP DEG-C	CHEMICALS RF	DW	TOC	TKN
09	1200-1700										79.5	79.5	250	
~~09~~	~~2.0M~~	~~1235~~	~~149.1~~											
09	0.5M	1235	4.6											
09	0.5+2M	RFG1245								19.7				
~~09~~	~~0.5+2M~~	~~AMB.AIR~~								~~23.5~~				
09	2.0M	STAGE1								18.2				
09	2.0M	STAGE4								18.8				
~~09~~	~~2.0M~~	~~EFG1245~~								~~19.0~~				
09	0.5M	EFG1245								19.2				
09	1700-2200										79.5	79.5	132	
~~09~~	~~0.5M~~	~~1700~~	~~4.7~~											
09	2.0M	1700	147.3											
09	0.5+2M	AMB.AIR								22.5				
~~09~~	~~0.5+2M~~	~~RFG1700~~								~~20.2~~				
09	0.5M	EFG1700								18.7				
09	2.0M	STAGE1								18.3				
~~09~~	~~2.0M~~	~~STAGE4~~								~~18.3~~				
09	2.0M	EFG1700								18.3				
~~09~~	~~2200-0300HR.~~										~~75~~	~~0~~	~~122~~	
09	0.5M	2245	2.3											
~~09~~	~~2.0M~~	~~2244~~	~~72.4~~											
09	0.5+2M	RFG2245								20.7				
09	0.5+2M	AMB.AIR								20.0				
~~09~~	~~0.5M~~	~~EFG2245~~								~~20.3~~				
09	2.0M	STAGE1								20.3				
09	2.0M	STAGE4								20.3				
~~09~~	~~2.0M~~	~~EFG2245~~								~~20.3~~				
09	2.0M	0230	70.5											
09	0.5M	0230	2.3											
09	0300-0800HR.										159	0	260	
~~09~~	~~0.5+2M~~	~~RFG0423~~								~~20.5~~				
09	0.5+2M	AMB.AIR								15.5				
09	2.0M	STAGE1								20.6				
~~09~~	~~2.0M~~	~~STAGE4~~								~~20.4~~				
09	0.5M	EFG0423								19.5				
09	0.5M	0730	4.66											
~~09~~	~~2.0M~~	~~0730~~	~~145.3~~											
09	0800HR. END OF EXPERIMENT													

Table A-2

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES A1 + A2 (ACCLIMATIZATION)

MON	PILOT UNIT	SAMPLE IDENTITY	SETTLED SAMPLE			UNFILTERED SAMPLE			FILTERED SAMPLE						
			BOD	COD	TKN	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
06	.5M1	EFC0908				35	204	20.7	15	46	26	13.0	0.2	0.2	16.2
06	.5M1+2	RFC0908						.				14.6	0.1	0.1	.
06	.5M1	EFC0908				19	108	20.6	7	21	18	13.0	0.4	0.2	15.8
06	.5M1+2	RFC0908				91	293	26.2	33	105	31	17.0	0.1	1.6	19.9
06	.5M1	EFC0908				16	96	3.8	5	33	17	0.8	10.1	0.0	2.3
06	.5M2	EFC0908				30	138	19.6	9	75	22	15.0	0.4	0.0	15.4
06	.5M1+2	RFC0908				100	264	24.1	32	92	33	16.0	0.0	0.0	17.9
06	.5M1	EFC0908				16	75	6.2	6	59	15	0.8	17.0	1.5	1.7
06	.5M2	EFC0908				35	205	18.9	9	54	19	12.0	1.2	0.0	13.6
06	.5M1+2	RFC0908						.				18.0	0.0	0.0	.
06	.5M1	EFC0908				15	96	4.4	4	75	10	2.0	3.6	8.0	3.3
06	.5M2	EFC0908				18	155	5.5	4	54	10	1.0	9.1	0.0	2.7
06	.5M1	EFC0908				23	192	6.1	3	42	10	1.0	2.9	7.8	2.6
06	.5M2	EFC0908				23	172	9.7	5	46	10	1.0	9.7	0.0	2.2
06	.5M1+2	RFC0908				100	310	25.2	32	96	36	19.0	0.0	0.2	19.2
06	.5M1	EFC0908				42	190	6.4	4	54	10	0.9	1.0	6.7	1.6
06	.5M2	EFC0908				34	206	4.7	4	54	10	0.7	5.6	1.3	3.0
08	.5M1+2M	RFC1009			27.9	109	233	31.8		90	32	20.0	0.0	0.5	21.4
08	.5M1	EFC1009	22	46	20.8	109		22.1		60	17	14.0	0.3	0.6	18.8
08	.5M2	EFC1009	18	37	21.6			23.1		60	18	18.0	0.1	0.2	19.4
08	.5M1+2M	RFC1413		108		56	226	22.1		63	19	15.0	0.2	0.3	17.4
08	.5M1	EFC1413		133	17.6			19.7		49	14	13.0	1.2	1.1	15.1
08	.5M2	EFC1413	22	97	19.5			21.6		50	15	14.0	0.5	0.8	15.6

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES B1 (COMPOSITES)

MON	PILOT UNIT	SAMPLE IDENTITY	SETTLED SAMPLE			UNFILTERED SAMPLE			FILTERED SAMPLE						
			BOD	COD	TKN	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
06	.5M1	RFC0908			17.8	81	194	51.8		64	32	11.0	0.1	0.6	15.8
06	.5M1	EFC0908	8	69	5.5			19.9		49	14	4.6	1.0	4.2	4.8
06	.5M2	RFC0908			16.8	72	205	24.2		62	26	11.0	0.1	0.7	16.2
06	.5M2	EFC0908	11	117	7.3			11.8		42	14	1.0	1.5	2.9	5.2
07	.5M1	RFC0908			13.9	103	320	25.4		66	32	5.0	0.0	0.2	9.5
~~07~~	~~.5M1~~	~~EFC0908~~	~~12~~	~~75~~	~~5.9~~			~~8.0~~		~~32~~	~~15~~	~~2.9~~	~~0.8~~	~~3.3~~	~~3.0~~
07	.5M2	RFC0908			17.8	78	219	17.3		59	27	8.0	0.0	0.4	9.6
~~07~~	~~.5M2~~	~~EFC0908~~	~~9~~	~~65~~	~~3.2~~			~~4.8~~		~~41~~	~~13~~	~~0.6~~	~~0.6~~	~~3.2~~	~~1.7~~
~~07~~	~~.5M1~~	~~RFC0908~~			~~25.5~~	~~119~~	~~340~~	~~27.4~~		~~73~~	~~46~~	~~18.5~~	~~0.0~~	~~0.3~~	~~20.4~~
07	.5M1	EFC0908	14	103	12.3			15.2		66	27	7.0	0.1	5.3	10.0
~~07~~	~~.5M2~~	~~RFC0908~~			~~22.9~~	~~88~~	~~298~~	~~24.7~~		~~68~~	~~39~~	~~14.0~~	~~0.0~~	~~0.2~~	~~19.8~~
07	.5M2	EFC0908	10	77	8.3			11.2		58	22	4.0	0.7	5.9	7.3
07	.5M1	RFC0908			27.2	137	376	30.1		70	48	16.0	0.1	0.1	20.1
07	.5M1	EFC0908	19	89	10.9			16.7		54	22	7.2	0.5	4.6	9.0
07	.5M2	RFC0908			23.5	103	322	25.1		56	37	14.0	0.0	0.0	17.1
07	.5M2	EFC0908	14	94	6.7			11.2		49	16	3.4	0.9	5.3	4.9
07	.5M1	RFC0908			24.7	131	359	30.3		0	40	15.0	0.4	0.3	19.6
~~07~~	~~.5M1~~	~~EFC0908~~	~~30~~	~~98~~	~~12.3~~			~~15.3~~		~~0~~	~~18~~	~~7.2~~	~~0.7~~	~~4.4~~	~~9.2~~
07	.5M2	RFC0908			27.5	119	290	26.3		0	36	15.0	0.2	0.0	17.2
~~07~~	~~.5M2~~	~~EFC0908~~	~~37~~	~~83~~	~~5.9~~			~~10.1~~		~~0~~	~~15~~	~~3.0~~	~~1.5~~	~~5.3~~	~~4.3~~
~~07~~	~~.5M1~~	~~RFC1110~~		~~299~~		~~148~~	~~448~~	~~315~~		~~148~~	~~50~~	~~28.0~~	~~0.4~~	~~0.7~~	~~29.8~~
07	.5M1	EFC1110	30	120	16.0			23.0		78	21	10.8	2.6	2.8	14.2
~~07~~	~~.5M2~~	~~RFC1110~~		~~237~~		~~134~~	~~415~~	~~24.8~~		~~130~~	~~38~~	~~21.0~~	~~0.3~~	~~0.5~~	~~21.9~~
07	.5M2	EFC1110	11	87	5.8			11.7		65	17	4.0	1.2	2.7	4.2

FEED AND EFFLUENT SAMPLES IN .5M1 WERE INTERCHANGED BY ACCIDENT

MON	PILOT UNIT	SAMPLE IDENTITY	SETTLED BOD	SETTLED COD	SETTLED TKN	UNFILTERED BOD	UNFILTERED COD	UNFILTERED TKN	FILTERED BOD	FILTERED COD	FILTERED TOC	FILTERED NH3N	FILTERED NO2N	FILTERED NO3N	FILTERED TKN
07	.5M1	RFC1110		440	33.8			38.2		390	50	29.0	0.1	0.6	31.7
07	.5M1	EFC1110		315		145	369	27.9		162		7.0	2.5	2.2	9.2
07	.5M2	RFC1110		203		30	427	28.4		148	40	17.0	0.0	0.3	20.2
07	.5M2	EFC1110	144	71	4.2			7.6		63	18	3.0	2.0	4.9	4.4

Table A-2 Cont'd

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES B2 (COMPOSITES)

MON	PILOT UNIT	SAMPLE IDENTITY	SETTLED SAMPLE			UNFILTERED SAMPLE			FILTERED SAMPLE						
			BOD	COD	TKN	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
07	.5M1	RFC0908		230		106	255	25.8		101	31	21.0	0.0	0.0	21.9
07	.5M1	EFC0908	34	142	23.3			27.3		70	24	17.0	0.6	0.1	19.5
07	.5M2	RFC0908		180		105	272	26.7		75	30	14.0	0.0	0.0	19.9
07	.5M2	EFC0908	23	105	18.8			22.6		49	20	11.0	0.5	0.1	13.8
07	.5M1	RFC0908		192		114	293	21.3		88	25	14.0	0.1	0.5	17.7
~~07~~	~~.5M1~~	~~EFC0908~~	~~24~~	~~88~~	~~14.8~~		~~167~~	~~18.4~~		~~50~~	~~18~~	~~12.0~~	~~0.6~~	~~0.1~~	~~13.0~~
07	.5M2	RFC0908		117	17.8	29	251	25.9		60	18	13.3	0.6	0.1	15.9
~~07~~	~~.5M2~~	~~EFC0908~~	~~116~~	~~192~~	~~21.2~~		~~393~~	~~24.3~~		~~72~~	~~22~~	~~13.0~~	~~0.3~~	~~0.0~~	~~15.6~~
~~08~~	~~.5M1~~	~~RFC0908~~		~~241~~		~~109~~	~~328~~	~~29.1~~		~~98~~	~~34~~	~~13.0~~	~~0.0~~	~~0.4~~	~~16.1~~
08	.5M1	EFC0908	37	183	24.4			26.9		66	22	18.0	0.2	0.3	22.0
~~08~~	~~.5M2~~	~~RFC0908~~		~~261~~		~~79~~	~~274~~	~~26.4~~		~~82~~	~~29~~	~~17.0~~	~~0.0~~	~~0.2~~	~~21.3~~
08	.5M2	EFC0908	22	129	21.4			22.7		57	17	14.0	0.1	0.3	19.3
08	.5M1	RFC1514		266		109	353	31.3		91	29	18.0	0.0	0.4	23.5
08	.5M1	EFC1514	24	141	21.5			22.8		60	18	14.0	0.1	0.3	18.9
08	.5M2	RFC1514		224		106	295	29.2		74	25	18.0	0.0	0.3	21.2
08	.5M2	EFC1514	32	174	23.8			20.3		66	19	11.0	0.1	0.3	16.9
08	.5M1	RFC0908		213		131	303	30.9		84	33	19.0	0.0	0.2	23.2
~~08~~	~~.5M1~~	~~EFC0908~~	~~38~~	~~160~~	~~24.3~~			~~29.3~~		~~65~~	~~22~~	~~15.0~~	~~0.1~~	~~0.4~~	~~19.3~~
08	.5M2	RFC0908		225		103	254	26.8		74	26	18.0	0.0	0.2	20.8
~~08~~	~~.5M2~~	~~EFC0908~~	~~23~~	~~98~~	~~23.8~~			~~25.1~~		~~60~~	~~19~~	~~18.6~~	~~0.0~~	~~0.3~~	~~24.3~~
~~08~~	~~.5M1~~	~~RFC1009~~		~~242~~		~~103~~	~~303~~	~~27.0~~		~~93~~	~~32~~	~~23.0~~	~~0.0~~	~~0.4~~	~~24.1~~
08	.5M1	EFC1009	33	168	21.7			25.6		74	21	19.0	0.4	0.4	19.1
~~08~~	~~.5M2~~	~~RFC1009~~		~~213~~		~~72~~	~~250~~	~~23.5~~		~~76~~	~~30~~	~~20.0~~	~~0.0~~	~~0.2~~	~~20.9~~
08	.5M2	EFC1009	23	131	19.7			23.4		71	20	17.0	0.4	0.4	17.8

Table A-2 Cont'd

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES B1 (HOURLY)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
7	07	.5M1	RFG 900	0.130					41	15	8.3	0.3	0.6	11.3
7	07	.5M1	RFG1000	0.145					49	16	11.0	0.2	0.3	13.0
7	07	.5M1	RFG1100	0.162					49	15	15.0	0.0	0.1	17.6
7	07	.5M1	RFG1200	0.182					86	31	20.0	0.0	0.0	24.0
7	07	.5M1	RFG1300	0.210					102	47	23.0	0.2	0.0	25.8
7	07	.5M1	RFG1400	0.229					90	43	20.0	0.0	0.0	23.5
7	07	.5M1	RFG1500	0.324					169	78	21.0	0.0	0.0	28.4
7	07	.5M1	RFG1600	0.414					159	92	21.0	0.0	0.0	28.7
7	07	.5M1	RFG1700	0.471					153	70	19.0	0.0	0.0	25.3
7	07	.5M1	RFG1800	0.484					135	72	18.0	0.0	0.1	24.0
7	07	.5M1	RFG1900	0.459					142	74	19.0	0.0	0.0	24.5
7	07	.5M1	RFG2000	0.409					96	67	18.0	0.0	0.1	21.9
7	07	.5M1	RFG2100	0.329					98	58	16.0	0.0	0.0	19.9
7	07	.5M1	RFG2200	0.235					90	53	14.0	0.0	0.0	17.6
7	07	.5M1	RFG2300	0.205					57	39	13.0	0.0	0.0	16.2
7	07	.5M1	RFG2400	0.179					74	37	12.0	0.0	0.0	15.4
8	07	.5M1	RFG 100	0.155					65	32	13.0	0.0	0.0	14.5
8	07	.5M1	RFG -20	0.140					57	24	13.0	0.0	0.0	13.7
8	07	.5M1	RFG 300	0.125					51	23	12.0	0.0	0.0	14.1
8	07	.5M1	RFG 400	0.115					59	24	13.0	0.0	0.0	14.0
8	07	.5M1	RFG 500	0.115					53	19	12.0	0.0	0.0	13.0
8	07	.5M1	RFG 600	0.115					41	17	10.0	0.0	0.0	10.2
8	07	.5M1	RFG 700	0.115					45	17	9.0	0.1	0.0	9.4
8	07	.5M1	RFG 800	0.120					43	16	9.0	0.2	0.5	9.7
8	07	.5M1	RFG 900	0.130					47	15	8.0	0.3	0.3	9.9
8	07	.5M1	RFG1000	0.145					42	16	10.0	0.2	0.2	12.6
8	07	.5M1	RFG1100	0.162					48	17	14.0	0.2	0.0	16.8
8	07	.5M1	RFG1200	0.182					53	41	21.0	0.0	0.1	24.5
8	07	.5M1	RFG1300	0.210					73	50	22.0	0.0	0.0	25.4
8	07	.5M1	RFG1400	0.229					62	53	23.0	0.0	0.0	25.3
8	07	.5M1	RFG1500	0.324					82	60	20.0	0.0	0.0	24.6
8	07	.5M1	RFG1600	0.414					121	75	21.0	0.0	0.0	25.5
8	07	.5M1	RFG1700	0.471					101	59	18.0	0.0	0.0	20.7
8	07	.5M1	RFG1800	0.484					95	56	16.0	0.0	0.0	19.0
8	07	.5M1	RFG1900	0.459					190	61	18.0	0.1	0.9	19.8
8	07	.5M1	RFG2000	0.409					89	48	14.0	0.9	0.0	16.8
8	07	.5M1	RFG2100	0.329					95	57	16.0	0.1	0.0	20.0
8	07	.5M1	RFG2200	0.235					82	51	16.0	0.0	0.0	19.3
8	07	.5M1	RFG2300	0.205					62	33	12.0	0.0	0.0	13.8
8	07	.5M1	RFG2400	0.179					55	30	12.0	0.0	0.1	13.3
9	07	.5M1	RFG 100	0.155					69	41	14.0	0.0	0.0	16.6
9	07	.5M1	RFG 200	0.140					77	42	13.0	0.0	0.0	15.0
9	07	.5M1	RFG 300	0.125					54	24	13.0	0.5	0.0	14.6
9	07	.5M1	RFG 400	0.115					56	24	12.0	0.8	0.1	14.6
9	07	.5M1	RFG 500	0.115					54	31	12.0	0.4	0.4	13.8
9	07	.5M1	RFG 600	0.115					54	16	9.0	0.6	1.4	11.9
9	07	.5M1	RFG 700	0.115					49	16	8.0	0.3	2.1	10.9
9	07	.5M1	RFG 800	0.120					49	18	8.0	0.5	2.2	9.8
9	07	.5M1	RFG 900	0.130					45	14	2.0	8.0	14.1	11.0
9	07	.5M1	RFG1000	0.145					48	15	9.0	0.4	3.3	13.8
9	07	.5M1	RFG1100	0.162					63	22	11.0	0.3	1.0	17.7

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES B1 (HOURLY)

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE			FILTERED SAMPLE						
				BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
7	07	.5M1 EFG 900	0.130					57	15	0.9	0.2	7.1	1.4
~~7~~	~~07~~	~~.5M1 EFG1000~~	~~0.145~~					~~49~~	~~14~~	~~0.7~~	~~0.2~~	~~7.3~~	~~1.1~~
7	07	.5M1 EFG1100	0.162					45	14	0.8	0.3	7.4	1.8
7	07	.5M1 EFG1200	0.182					41	14	1.2	0.3	7.8	2.1
~~7~~	~~07~~	~~.5M1 EFG1300~~	~~0.210~~					~~41~~	~~14~~	~~2.3~~	~~0.5~~	~~8.3~~	~~3.0~~
7	07	.5M1 EFG1400	0.229					41	15	4.1	0.6	8.2	4.3
7	07	.5M1 EFG1500	0.324					41	15	6.5	0.6	7.8	6.6
~~7~~	~~07~~	~~.5M1 EFG1600~~	~~0.414~~					~~57~~	~~18~~	~~10.3~~	~~0.5~~	~~4.0~~	~~11.8~~
7	07	.5M1 EFG1700	0.471					57	22	12.8	0.5	2.0	14.4
7	07	.5M1 EFG1800	0.484					55	25	13.5	0.4	1.7	16.3
~~7~~	~~07~~	~~.5M1 EFG1900~~	~~0.459~~					~~61~~	~~25~~	~~12.5~~	~~0.4~~	~~1.5~~	~~13.7~~
7	07	.5M1 EFG2000	0.409					61	28	12.5	0.5	1.7	13.9
7	07	.5M1 EFG2100	0.329					57	22	11.9	0.5	1.9	12.7
~~7~~	~~07~~	~~.5M1 EFG2200~~	~~0.235~~					~~45~~	~~19~~	~~10.6~~	~~0.5~~	~~2.4~~	~~12.3~~
7	07	.5M1 EFG2300	0.205					45	17	9.0	0.5	3.3	10.5
7	07	.5M1 EFG2400	0.179					41	17	7.4	0.5	4.2	8.9
~~8~~	~~07~~	~~.5M1 EFG 100~~	~~0.155~~					~~45~~	~~18~~	~~5.7~~	~~0.6~~	~~5.0~~	~~7.3~~
8	07	.5M1 EFG 200	0.140					45	16	4.0	0.6	5.8	5.4
8	07	.5M1 EFG 300	0.125					41	17	2.6	0.6	6.6	3.9
~~8~~	~~07~~	~~.5M1 EFG 400~~	~~0.115~~					~~42~~	~~16~~	~~1.4~~	~~0.6~~	~~7.3~~	~~2.7~~
8	07	.5M1 EFG 500	0.115					46	16	1.1	0.5	7.5	2.7
8	07	.5M1 EFG 600	0.115					44	17	0.6	0.4	7.5	1.6
~~8~~	~~07~~	~~.5M1 EFG 700~~	~~0.115~~					~~44~~	~~15~~	~~0.6~~	~~0.3~~	~~7.3~~	~~2.0~~
8	07	.5M1 EFG 800	0.120					10	13	0.5	0.3	7.1	2.1
8	07	.5M1 EFG 900	0.130					53	14	0.9	0.3	6.4	2.2
~~8~~	~~07~~	~~.5M1 EFG1000~~	~~0.145~~					~~51~~	~~13~~	~~0.7~~	~~0.3~~	~~6.4~~	~~1.7~~
8	07	.5M1 EFG1100	0.162					51	14	0.6	0.3	7.1	2.1
8	07	.5M1 EFG1200	0.182					67	13	3.4	1.1	8.7	4.4
~~8~~	~~07~~	~~.5M1 EFG1300~~	~~0.210~~					~~49~~	~~13~~	~~1.7~~	~~0.8~~	~~8.8~~	~~3.1~~
8	07	.5M1 EFG1400	0.229					47	13	0.9	0.5	8.0	2.3
8	07	.5M1 EFG1500	0.324					46	14	5.7	1.0	7.7	6.8
~~8~~	~~07~~	~~.5M1 EFG1600~~	~~0.414~~					~~50~~	~~16~~	~~9.1~~	~~0.8~~	~~5.2~~	~~11.1~~
8	07	.5M1 EFG1700	0.471					54	19	12.0	0.7	3.1	13.9
8	07	.5M1 EFG1800	0.484					55	18	12.0	0.7	2.2	14.0
~~8~~	~~07~~	~~.5M1 EFG1900~~	~~0.459~~					~~55~~	~~25~~	~~12.0~~	~~0.7~~	~~2.1~~	~~13.5~~
8	07	.5M1 EFG2000	0.409					55	25	12.0	0.9	2.3	13.5
8	07	.5M1 EFG2100	0.329					55	19	10.0	0.8	2.7	12.0
~~8~~	~~07~~	~~.5M1 EFG2200~~	~~0.235~~					~~52~~	~~21~~	~~10.0~~	~~0.8~~	~~3.2~~	~~11.3~~
8	07	.5M1 EFG2300	0.205					52	17	8.6	0.8	3.9	9.6
8	07	.5M1 EFG2400	0.179					49	16	7.0	0.8	5.0	8.1
~~9~~	~~07~~	~~.5M1 EFG 100~~	~~0.155~~					~~50~~	~~17~~	~~5.4~~	~~0.9~~	~~5.8~~	~~6.7~~
9	07	.5M1 EFG 200	0.140					49	16	3.9	0.9	6.6	5.4
9	07	.5M1 EFG 300	0.125					53	16	2.4	0.9	7.5	3.6
~~9~~	~~07~~	~~.5M1 EFG 400~~	~~0.115~~					~~53~~	~~15~~	~~1.2~~	~~0.8~~	~~8.3~~	~~2.9~~
9	07	.5M1 EFG 500	0.115					53	16	0.7	0.6	8.6	2.1
9	07	.5M1 EFG 600	0.115					53	16	0.5	0.4	8.4	1.9
~~9~~	~~07~~	~~.5M1 EFG 700~~	~~0.115~~					~~53~~	~~17~~	~~0.4~~	~~0.4~~	~~8.4~~	~~2.0~~
9	07	.5M1 EFG 800	0.120					53	17	0.3	0.3	8.3	1.8
9	07	.5M1 EFG 900	0.130					53	13	3.7	0.5	1.0	4.8
~~9~~	~~07~~	~~.5M1 EFG1000~~	~~0.145~~					~~52~~	~~13~~	~~0.7~~	~~0.3~~	~~7.7~~	~~4.5~~
9	07	.5M1 EFG1100	0.162					49	13	0.6	0.3	7.7	5.0

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES 82 (HOURLY)

Y MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE BOD	COD	TKN	FILTERED SAMPLE BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
3 08	.5M1	RFG09	0.42					119	31	12.0	0.3	0.2	14.1
3 08	.5M1	RFG10	0.45					46	13	12.0	0.2	0.0	13.8
~~3 08~~	~~.5M1~~	~~RFG11~~	~~0.50~~					~~51~~	~~14~~	~~15.0~~	~~0.2~~	~~0.0~~	~~16.2~~
3 08	.5M1	RFG12	0.58					59	17	19.0	0.1	0.0	21.3
3 08	.5M1	RFG13	0.675					118	38	31.0	0.2	0.1	33.0
~~3 08~~	~~.5M1~~	~~RFG14~~	~~0.754~~					~~158~~	~~53~~	~~36.0~~	~~0.1~~	~~0.0~~	~~37.3~~
3 08	.5M1	RFG15	1.025					184	64	41.0	0.0	0.0	42.8
3 08	.5M1	RFG16	1.29					168	59	31.0	0.0	0.0	33.1
~~3 08~~	~~.5M1~~	~~RFG17~~	~~1.44~~					~~150~~	~~50~~	~~26.0~~	~~0.0~~	~~0.0~~	~~27.9~~
3 08	.5M1	RFG18	1.50					128	31	22.0	0.0	0.0	23.0
3 08	.5M1	RFG19	1.45					168	60	28.0	0.0	0.0	29.7
~~3 08~~	~~.5M1~~	~~RFG20~~	~~1.41~~					~~160~~	~~52~~	~~26.0~~	~~0.1~~	~~0.1~~	~~27.6~~
3 08	.5M1	RFG21	1.1					158	51	26.0	0.1	0.1	27.7
3 08	.5M1	RFG22	0.75					132	37	22.0	0.1	0.1	23.9
~~13 08~~	~~.5M1~~	~~RFG23~~	~~0.625~~					~~98~~	~~27~~	~~15.0~~	~~0.1~~	~~0.0~~	~~17.2~~
13 08	.5M1	RFG24	0.555					92	24	14.0	0.0	0.1	15.1
14 08	.5M1	RFG01	0.49					84	32	14.0	0.1	0.1	15.2
~~14 08~~	~~.5M1~~	~~RFG02~~	~~0.455~~					~~96~~	~~27~~	~~14.0~~	~~0.1~~	~~0.0~~	~~15.4~~
14 08	.5M1	RFG03	0.42					80	22	14.0	0.1	0.0	15.0
14 08	.5M1	RFG04	0.405					70	18	14.0	0.1	0.1	15.3
~~14 08~~	~~.5M1~~	~~RFG05~~	~~0.40~~					~~59~~	~~16~~	~~14.0~~	~~0.1~~	~~0.3~~	~~15.2~~
14 08	.5M1	RFG06	0.40					53	15	13.0	0.1	0.4	14.5
14 08	.5M1	RFG07	0.40					50	14	12.0	0.1	0.4	13.2
~~14 08~~	~~.5M1~~	~~RFG08~~	~~0.40~~					~~50~~	~~14~~	~~12.0~~	~~0.1~~	~~0.5~~	~~13.0~~
14 08	.5M1	RFG09	0.42					45	14	11.0	0.2	0.6	12.
14 08	.5M1	RFG10	0.45					66	18	12.0	0.2	0.5	13.8
~~14 08~~	~~.5M1~~	~~RFG11~~	~~0.50~~					~~82~~	~~24~~	~~17.0~~	~~0.7~~	~~0.0~~	~~19.2~~
14 08	.5M1	RFG12	0.58					89	22	19.0	0.5	0.1	22.0
14 08	.5M1	RFG13	0.675					148	37	27.0	0.0	0.0	29.
~~14 08~~	~~.5M1~~	~~RFG14~~	~~0.754~~					~~224~~	~~67~~	~~37.0~~	~~0.0~~	~~0.0~~	~~41.0~~
14 08	.5M1	RFG15	1.025					164	46	32.0	0.0	0.0	33.
14 08	.5M1	RFG16	1.29					206	57	31.0	0.0	0.0	32.
~~14 08~~	~~.5M1~~	~~RFG17~~	~~1.44~~					~~182~~	~~53~~	~~33.0~~	~~0.0~~	~~0.0~~	~~33.~~
14 08	.5M1	RFG18	1.50					130	35	22.0	0.0	0.0	23.
14 08	.5M1	RFG19	1.45					160	55	28.0	0.0	0.0	29.
~~14 08~~	~~.5M1~~	~~RFG20~~	~~1.41~~					~~122~~	~~35~~	~~19.0~~	~~0.4~~	~~0.0~~	~~19.~~
14 08	.5M1	RFG21	1.1					114	31	15.0	0.5	1.4	16.
14 08	.5M1	RFG22	0.75					109	31	14.0	0.3	0.1	15.
~~14 08~~	~~.5M1~~	~~RFG23~~	~~0.625~~					~~100~~	~~29~~	~~14.0~~	~~0.2~~	~~0.1~~	~~15.~~
14 08	.5M1	RFG24	0.555					100	48	13.0	0.2	0.0	14.
15 08	.5M1	RFG01	0.49					89	30	14.0	0.1	0.0	15.
~~15 08~~	~~.5M1~~	~~RFG02~~	~~0.455~~					~~88~~	~~24~~	~~14.0~~	~~0.1~~	~~0.2~~	~~15.~~
15 08	.5M1	RFG03	0.42					81	21	15.0	0.1	0.3	15.
15 08	.5M1	RFG04	0.405					74	21	14.0	0.2	0.4	15.
~~15 08~~	~~.5M1~~	~~RFG05~~	~~0.40~~					~~69~~	~~23~~	~~14.0~~	~~0.2~~	~~0.5~~	~~15.~~
15 08	.5M1	RFG06	0.40					65	20	13.0	0.2	0.5	14.
15 08	.5M1	RFG07	0.40					55	17	13.0	0.1	0.8	13.
~~15 08~~	~~.5M1~~	~~RFG08~~	~~0.40~~					~~54~~	~~20~~	~~11.0~~	~~0.2~~	~~0.9~~	~~12.~~
15 08	.5M1	RFG09	0.42					52	17	14.0	0.6	0.8	15.
15 08	.5M1	RFG10	0.45					54	15	11.0	0.3	0.7	12.
~~15 08~~	~~.5M1~~	~~RFG11~~	~~0.50~~					~~56~~	~~16~~	~~15.0~~	~~0.2~~	~~0.4~~	~~15.~~
15 08	.5M1	RFG12	0.58					71	21	19.0	0.2	0.2	19.
15 08	.5M1	RFG13	0.675					96	25	25.0	0.5	0.2	26.

ANALYTICAL RESULTS - SERIES B2 (HOURLY)

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE			FILTERED SAMPLE						
				BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
08	.5M1	RFG14	0.754					131	37	25.0	0.0	0.0	26.0
08	.5M1	RFG15	1.025					133	37	27.0	0.0	0.0	27.7
08	.5M1	RFG16	1.29					194	57	29.0	0.0	0.0	29.5
08	.5M1	RFG17	1.44					146	42	24.0	0.1	0.1	25.5
08	.5M1	RFG18	1.50					135	34	20.0	0.1	0.0	21.6
08	.5M1	RFG19	1.45					160	50	28.0	0.0	0.0	29.5
08	.5M1	RFG20	1.41					139	40	23.0	0.2	0.0	24.0
08	.5M1	RFG21	1.1					88	27	18.0	0.6	0.4	19.3
08	.5M1	RFG22	0.75					127	39	19.0	0.3	0.1	19.3
08	.5M1	RFG23	0.625					117	27	18.0	0.3	0.1	19.1
08	.5M1	RFG24	0.555					78	33	15.0	0.4	0.2	15.5
08	.5M1	RFG01	0.49					74	20	14.0	0.4	0.4	15.3
08	.5M1	RFG02	0.455					79	21	16.0	0.3	0.3	16.7
08	.5M1	RFG03	0.42					71	20	16.0	0.2	0.2	17.3
08	.5M1	RFG04	0.405					63	19	16.0	0.1	0.1	17.2
08	.5M1	RFG05	0.40					61	19	16.0	0.1	0.2	16.9
08	.5M1	RFG06	0.40					55	16	15.0	0.1	0.3	16.1
08	.5M1	RFG07	0.40					55	15	14.0	0.2	0.4	15.0
08	.5M1	RFG08	0.40					56	14	13.0	0.2	0.5	14.4

08	.5M1	EFG09	0.42					83	23	5.0	2.7	0.6	7.1
08	.5M1	EFG10	0.45					46	14	5.0	3.3	0.6	6.8
08	.5M1	EFG11	0.50					43	14	6.0	3.7	0.8	7.8
08	.5M1	EFG12	0.58					41	13	9.0	3.3	0.7	10.3
08	.5M1	EFG13	0.675					48	15	15.0	1.9	0.3	16.9
08	.5M1	EFG14	0.754					65	21	22.0	0.4	0.2	23.2
08	.5M1	EFG15	1.025					89	27	26.0	0.0	0.0	27.8
08	.5M1	EFG16	1.29					115	38	27.0	0.0	0.0	28.9
08	.5M1	EFG17	1.44					115	37	24.0	0.0	0.0	26.1
08	.5M1	EFG18	1.50					90	25	18.0	0.0	0.0	20.0
08	.5M1	EFG19	1.45					116	38	22.0	0.0	0.0	23.7
08	.5M1	EFG20	1.41					111	33	22.0	0.0	0.0	23.9
08	.5M1	EFG21	1.1					86	24	17.0	0.0	0.0	19.1
08	.5M1	EFG22	0.75					85	25	16.0	0.0	0.0	17.6
08	.5M1	EFG23	0.625					73	21	14.0	0.0	0.0	14.9
08	.5M1	EFG24	0.555					65	21	13.0	0.0	0.2	14.7
08	.5M1	EFG01	0.49					57	20	12.0	0.2	0.2	13.7
08	.5M1	EFG02	0.455					60	18	11.0	0.4	0.2	12.9
08	.5M1	EFG03	0.42					59	19	11.0	0.5	0.2	12.8
08	.5M1	EFG04	0.405					55	17	11.0	0.8	0.3	12.8
08	.5M1	EFG05	0.40					54	16	10.0	0.8	0.3	12.1
08	.5M1	EFG06	0.40					49	17	10.0	0.9	0.4	11.9
08	.5M1	EFG07	0.40					50	16	9.0	1.1	0.4	10.9
08	.5M1	EFG08	0.40					46	16	9.0	1.4	0.5	11.0
08	.5M1	EFG09	0.42					47	14	9.0	1.1	0.5	10.6
08	.5M1	EFG10	0.45					45	13	9.0	1.0	0.6	10.5
08	.5M1	EFG11	0.50					44	13	9.0	1.2	0.4	10.9
08	.5M1	EFG12	0.58					49	16	12.0	0.9	0.3	13.5
08	.5M1	EFG13	0.675					50	16	16.0	0.9	0.3	18.0
08	.5M1	EFG14	0.754					75	20	20.0	0.2	0.1	22.2
08	.5M1	EFG15	1.025					102	27	23.0	0.0	0.0	24.9
08	.5M1	EFG16	1.29					141	39	25.0	0.0	0.0	25.9
08	.5M1	EFG17	1.44					166	43	29.0	0.0	0.0	31.1
08	.5M1	EFG18	1.50					119	32	21.0	0.0	0.0	22.7

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES B2 (HOURLY)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE BOD	UNFILTERED SAMPLE COD	UNFILTERED SAMPLE TKN	FILTERED SAMPLE BOD	FILTERED SAMPLE COD	FILTERED SAMPLE TOC	FILTERED SAMPLE NH3N	FILTERED SAMPLE NO2N	FILTERED SAMPLE NO3N	FILTERED SAMPLE TKN
4	08	.5M1	EFG19	1.45					96	27	21.0	0.0	0.0	22.4
~~4~~	~~08~~	~~.5M1~~	~~EFG20~~	~~1.41~~					~~88~~	~~22~~	~~19.0~~	~~0.0~~	~~0.0~~	~~19.9~~
4	08	.5M1	EFG21	1.1					92	28	15.0	0.0	0.0	16.6
4	08	.5M1	EFG22	0.75					75	20	15.0	0.0	0.0	16.5
~~4~~	~~08~~	~~.5M1~~	~~EFG23~~	~~0.625~~					~~64~~	~~20~~	~~15.0~~	~~0.0~~	~~0.0~~	~~16.2~~
4	08	.5M1	EFG24	0.555					60	19	14.0	0.2	0.1	15.8
5	08	.5M1	EFG01	0.49					57	19	13.0	0.2	0.1	14.5
~~5~~	~~08~~	~~.5M1~~	~~EFG02~~	~~0.455~~					~~57~~	~~17~~	~~13.0~~	~~0.3~~	~~0.0~~	~~14.2~~
5	08	.5M1	EFG03	0.42					58	19	13.0	0.5	0.0	13.9
5	08	.5M1	EFG04	0.405					55	17	13.0	0.6	0.1	14.2
~~5~~	~~08~~	~~.5M1~~	~~EFG05~~	~~0.40~~					~~52~~	~~16~~	~~13.0~~	~~0.7~~	~~0.1~~	~~14.3~~
5	08	.5M1	EFG06	0.40					52	16	13.0	0.8	0.1	14.1
5	08	.5M1	EFG07	0.40					50	19	12.0	0.9	0.1	13.8
~~5~~	~~08~~	~~.5M1~~	~~EFG08~~	~~0.40~~					~~50~~	~~16~~	~~11.0~~	~~1.0~~	~~0.2~~	~~12.9~~
5	08	.5M1	EFG09	0.42					43	13	11.0	0.1	0.2	12.3
5	08	.5M1	EFG10	0.45					44	13	11.0	0.6	0.4	11.9
~~5~~	~~08~~	~~.5M1~~	~~EFG11~~	~~0.50~~					~~45~~	~~14~~	~~11.0~~	~~0.7~~	~~0.3~~	~~12.6~~
5	08	.5M1	EFG12	0.58					46	13	13.0	0.8	0.3	14.9
5	08	.5M1	EFG13	0.675					47	14	17.0	0.7	0.3	20.0
~~5~~	~~08~~	~~.5M1~~	~~EFG14~~	~~0.754~~					~~58~~	~~15~~	~~21.0~~	~~0.5~~	~~0.3~~	~~23.3~~
5	08	.5M1	EFG15	1.025					60	18	21.0	0.3	0.2	22.7
5	08	.5M1	EFG16	1.29					90	21	24.0	0.0	0.0	25.7
~~5~~	~~08~~	~~.5M1~~	~~EFG17~~	~~1.44~~					~~92~~	~~22~~	~~23.0~~	~~0.0~~	~~0.0~~	~~24.1~~
5	08	.5M1	EFG18	1.50					97	22	20.0	0.0	0.0	21.0
5	08	.5M1	EFG19	1.45					109	24	24.0	0.0	0.0	25.7
~~5~~	~~08~~	~~.5M1~~	~~EFG20~~	~~1.41~~					~~103~~	~~31~~	~~23.0~~	~~0.0~~	~~0.0~~	~~23.7~~
5	08	.5M1	EFG21	1.1					68	19	17.0	0.0	0.2	18.
5	08	.5M1	EFG22	0.75					77	20	17.0	0.0	0.1	18.5
~~5~~	~~08~~	~~.5M1~~	~~EFG23~~	~~0.625~~					~~82~~	~~19~~	~~16.0~~	~~0.0~~	~~0.2~~	~~17.~~
5	08	.5M1	EFG24	0.555					64	17	15.0	0.0	0.3	15.
6	08	.5M1	EFG01	0.49					54	16	14.0	0.1	0.3	14.
~~6~~	~~08~~	~~.5M1~~	~~EFG02~~	~~0.455~~					~~51~~	~~15~~	~~14.0~~	~~0.2~~	~~0.3~~	~~14.~~
6	08	.5M1	EFG03	0.42					51	14	14.0	0.3	0.2	15.
6	08	.5M1	EFG04	0.405					52	15	15.0	0.3	0.3	16.
~~6~~	~~08~~	~~.5M1~~	~~EFG05~~	~~0.40~~					~~54~~	~~15~~	~~15.0~~	~~0.4~~	~~0.3~~	~~15.~~
6	08	.5M1	EFG06	0.40					52	15	14.0	0.4	0.4	15.
6	08	.5M1	EFG07	0.40					50	14	14.0	0.6	0.3	14.
~~6~~	~~08~~	~~.5M1~~	~~EFG08~~	~~0.40~~					~~50~~	~~14~~	~~13.0~~	~~0.7~~	~~0.4~~	~~13.~~

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES C2 + E2 (30 MIN)

MON	PILOT SAMPLE UNIT IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
		IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
09	.5M1+2MRFG1000						222	69	22.0	0.0	0.0	23.3
09	.5M1+2MRFG1030						250	74	21.0	0.0	0.0	22.0
09	.5M1+2MRFG1100						231	74	22.0	0.0	0.0	22.8
09	.5M1+2MRFG1130						277	100	20.0	0.0	0.0	21.7
09	.5M1+2MRFG1200						212	65	18.0	0.0	0.0	19.5
09	.5M1+2MRFG1230						272	80	16.0	0.0	0.0	17.8
09	.5M1+2MRFG1300						328	117	10.0	0.0	0.0	11.1
09	.5M1+2MRFG1330						340	113	16.0	0.0	0.0	17.2
09	.5M1+2MRFG1400						300	99	12.0	0.0	0.0	13.1
09	.5M1+2MRFG1430						363	145	17.0	0.0	0.0	18.0
09	.5M1+2MRFG1500						175	78	17.0	0.0	0.0	17.9
09	.5M1+2MRFG1530						131	58	9.0	0.0	0.3	11.1
09	.5M1+2MRFG1600						144	55	7.0	0.0	0.0	7.9
09	.5M1+2MRFG1630						86	34	6.0	0.0	0.0	7.1
09	.5M1+2MRFG1700						111	41	7.0	0.0	0.0	7.4
09	.5M1+2MRFG1730						87	36	4.0	0.0	0.0	5.8
09	.5M1+2MRFG1800						129	51	13.0	0.0	0.0	14.4
09	.5M1+2MRFG1830						184	57	12.0	0.0	0.0	12.9
09	.5M1+2MRFG1900						144	58	16.0	0.0	0.0	17.6
09	.5M1+2MRFG1930						186	53	13.0	0.0	0.0	13.9
09	.5M1+2MRFG2000						184	63	14.0	0.0	0.0	15.5
09	.5M1+2MRFG2030						182	56	9.0	0.0	0.0	10.6
09	.5M1+2MRFG2100						148	45	5.0	0.0	0.0	6.6
09	.5M1+2MRFG2130						132	47	7.0	0.0	0.0	7.7
09	.5M1+2MRFG2200						117	42	8.0	0.0	0.0	9.0
09	.5M1+2MRFG2230						152	51	9.0	0.0	0.0	9.9
09	.5M1+2MRFG2300						192	53	15.0	0.0	0.0	16.3
09	.5M1+2MRFG2330						151	48	12.0	0.0	0.0	13.1
09	.5M1+2MRFG2400						118	42	9.0	0.0	0.0	10.7
09	.5M1+2MRFG0030						140	51	9.0	0.0	0.0	11.2
09	.5M1+2MRFG0100						342	103	12.0	0.0	0.0	13.5
09	.5M1+2MRFG0130						320	98	9.0	0.0	0.0	11.2
09	.5M1+2MRFG0200						312	95	17.0	0.0	0.0	18.3
09	.5M1+2MRFG0230						230	73	11.0	0.0	0.0	12.7
09	.5M1+2MRFG0300						230	70	21.0	0.0	0.0	23.0
09	.5M1+2MRFG0330						235	72	12.0	0.0	0.0	13.7
09	.5M1+2MRFG0400						246	71	15.0	0.0	0.2	16.9
09	.5M1+2MRFG0430						242	70	16.0	0.0	0.2	16.9
09	.5M1+2MRFG0500						207	59	16.0	0.0	0.1	17.2
09	.5M1+2MRFG0530						201	62	15.0	0.0	0.0	16.1
09	.5M1+2MRFG0600						131	39	14.0	0.0	0.0	15.1
09	.5M1+2MRFG0630						141	41	14.0	0.0	0.0	14.6
09	.5M1+2MRFG0700						139	41	12.0	0.0	0.0	13.3
09	.5M1+2MRFG0730						137	39	13.0	0.0	0.0	13.7
09	.5M1+2MRFG0800						133	37	13.0	0.0	0.1	14.1
09	.5M1+2MRFG0830						135	39	13.0	0.0	0.3	13.9
09	.5M1+2MRFG0900						140	41	13.0	0.1	0.3	13.9
09	.5M1+2MRFG0930						119	38	14.0	0.0	0.1	14.8
09	.5M1+2MRFG1000						102	42	18.0	0.0	0.2	20.7
09	.5M1+2MRFG1030						125	42	19.0	0.0	0.1	23.7
09	.5M1+2MRFG1100						37	14	10.0	0.0	0.1	13.8
09	.5M1+2MRFG1130						39	15	11.0	0.0	0.2	13.0
09	.5M1+2MRFG1200						52	25	11.0	0.0	0.1	13.5

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES C2 + E2 (30 MIN)

MON	PILOT SAMPLE UNIT IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE BOD	UNFILTERED SAMPLE COD	UNFILTERED SAMPLE TKN	FILTERED SAMPLE BOD	FILTERED SAMPLE COD	FILTERED SAMPLE TOC	FILTERED SAMPLE NH3N	FILTERED SAMPLE NO2N	FILTERED SAMPLE NO3N	FILTERED SAMPLE TKN
09	.5M1+2MRFG1230						81	27	11.0	0.0	0.1	13.5
~~09~~	~~.5M1+2MRFG1300~~						~~51~~	~~23~~	~~10.0~~	~~0.0~~	~~0.0~~	~~12.6~~
09	.5M1+2MRFG1330						92	34	12.0	0.0	0.0	13.9
09	.5M1+2MRFG1400						89	31	13.0	0.0	0.0	13.4
~~09~~	~~.5M1+2MRFG1430~~						~~86~~	~~31~~	~~11.0~~	~~0.0~~	~~0.0~~	~~12.8~~
09	.5M1+2MRFG1500						79	30	12.0	0.0	0.7	13.1
09	.5M1+2MRFG1530						104	39	13.0	0.2	0.6	14.3
~~09~~	~~.5M1+2MRFG1600~~						~~185~~	~~62~~	~~19.0~~	~~0.5~~	~~0.6~~	~~20.5~~
09	.5M1+2MRFG1630						200	69	22.0	0.0	0.1	23.8
09	.5M1+2MRFG1700						138	40	16.0	0.0	0.1	17.1
~~09~~	~~.5M1+2MRFG1730~~						~~125~~	~~42~~	~~16.0~~	~~0.0~~	~~0.0~~	~~16.3~~
09	.5M1+2MRFG1800						138	52	19.0	0.0	0.1	21.5
09	.5M1+2MRFG1830						138	52	19.0	0.3	4.8	20.1
~~09~~	~~.5M1+2MRFG1900~~						~~158~~	~~53~~	~~19.0~~	~~0.1~~	~~2.3~~	~~20.6~~
09	.5M1+2MRFG1930						155	51	18.0	0.1	0.5	20.1
09	.5M1+2MRFG2000						134	48	14.0	0.0	0.2	16.2
~~09~~	~~.5M1+2MRFG2030~~						~~145~~	~~46~~	~~16.0~~	~~0.0~~	~~0.4~~	~~17.7~~
09	.5M1+2MRFG2100						438	123	28.0	0.0	0.1	29.0
09	.5M1+2MRFG2130						278	115	18.0	0.0	0.0	22.0
~~09~~	~~.5M1+2MRFG2200~~						~~306~~	~~87~~	~~19.0~~	~~0.0~~	~~0.0~~	~~21.4~~
09	.5M1+2MRFG2230						322	83	19.0	0.0	0.0	21.7
09	.5M1+2MRFG2300						263	83	18.0	0.0	0.0	19.9
~~09~~	~~.5M1+2MRFG2330~~						~~290~~	~~82~~	~~19.0~~	~~0.0~~	~~0.0~~	~~20.2~~
09	.5M1+2MRFG2400						288	79	18.0	0.0	0.1	19.2
09	.5M1+2MRFG0030						298	84	18.0	0.0	0.1	19.2
~~09~~	~~.5M1+2MRFG0100~~						~~305~~	~~86~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.8~~
09	.5M1+2MRFG0130						296	82	18.0	0.0	0.0	19.2
09	.5M1+2MRFG0200						280	79	18.0	0.0	0.0	18.8
~~09~~	~~.5M1+2MRFG0230~~						~~298~~	~~84~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.4~~
09	.5M1+2MRFG0300						300	083	19.0	0.0	0.0	20.8
09	.5M1+2MRFG0330						268	75	19.0	0.0	0.0	20.5
~~09~~	~~.5M1+2MRFG0400~~						~~230~~	~~70~~	~~18.0~~	~~0.0~~	~~0.0~~	~~20.4~~
09	.5M1+2MRFG0430						230	71	18.0	0.0	0.0	19.5
09	.5M1+2MRFG0500						237	67	18.0	0.0	0.0	19.5
~~09~~	~~.5M1+2MRFG0530~~						~~224~~	~~70~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.2~~
09	.5M1+2MRFG0600						230	71	17.0	0.0	0.0	18.1
09	.5M1+2MRFG0630						236	70	17.0	0.0	0.0	17.7
~~09~~	~~.5M1+2MRFG0700~~						~~252~~	~~73~~	~~17.0~~	~~0.0~~	~~0.0~~	~~18.2~~
09	.5M1+2MRFG0730						263	78	17.0	0.0	0.4	18.1
09	.5M1+2MRFG0800						263	75	16.0	0.0	0.2	17.0
~~09~~	~~.5M1+2MRFG0830~~						~~253~~	~~74~~	~~16.0~~	~~0.0~~	~~0.4~~	~~17.6~~
09	.5M1+2MRFG0900						253	75	16.0	0.0	0.2	16.9
09	.5M1+2MRFG0930						280	81	18.0	0.1	0.4	19.3
~~09~~	~~.5M1+2MRFG1000~~						~~276~~	~~81~~	~~21.0~~	~~0.0~~	~~0.1~~	~~22.2~~
09	.5M1+2MRFG1030						242	74	18.0	0.0	0.0	23.0
09	.5M1+2MRFG1100						280	85	25.0	0.0	0.0	28.4
~~09~~	~~.5M1+2MRFG1130~~						~~310~~	~~89~~	~~24.0~~	~~0.0~~	~~0.0~~	~~25.1~~
09	.5M1+2MRFG1200						255	73	10.0	0.0	0.0	13.5
09	.5M1+2MRFG1230						270	82	12.0	0.0	0.1	13.8
~~09~~	~~.5M1+2MRFG1300~~						~~253~~	~~71~~	~~11.0~~	~~0.0~~	~~0.0~~	~~12.2~~
09	.5M1+2MRFG1330						292	84	12.0	0.0	0.1	14.1
09	.5M1+2MRFG1400						276	75	9.0	0.1	0.1	11.6
~~09~~	~~.5M1+2MRFG1430~~						~~200~~	~~63~~	~~12.0~~	~~0.0~~	~~0.0~~	~~14.1~~
09	.5M1+2MRFG1500						312	77	10.0	0.0	0.1	12.3
09	.5M1+2MRFG1530						296	80	11.0	0.0	0.1	11.6

ANALYTICAL RESULTS - SERIES C2 + E2 (30 MIN)

Y	MON	PILOT SAMPLE UNIT IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
			IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
9	09	.5M1+2MRFG1600						282	83	9.0	0.0	0.0	11.5
~~9~~	~~09~~	~~.5M1+2MRFG1630~~						~~296~~	~~79~~	~~10.0~~	~~0.0~~	~~0.3~~	~~12.0~~
9	09	.5M1+2MRFG1700						170	45	8.0	0.0	0.2	10.1
9	09	.5M1+2MRFG1730						148	44	7.0	0.1	0.4	9.4
~~9~~	~~09~~	~~.5M1+2MRFG1800~~						~~136~~	~~41~~	~~7.0~~	~~0.1~~	~~0.3~~	~~9.2~~
9	09	.5M1+2MRFG1830						148	44	7.0	0.1	0.6	9.5
9	09	.5M1+2MRFG1900						180	58	11.0	0.1	0.5	12.1
~~9~~	~~09~~	~~.5M1+2MRFG1930~~						~~168~~	~~52~~	~~10.0~~	~~0.1~~	~~0.4~~	~~10.2~~
9	09	.5M1+2MRFG2000						192	61	11.0	0.1	0.3	11.5
9	09	.5M1+2MRFG2030						190	61	12.0	0.1	0.3	12.1
~~9~~	~~09~~	~~.5M1+2MRFG2100~~						~~204~~	~~58~~	~~12.0~~	~~0.1~~	~~0.2~~	~~12.6~~
9	09	.5M1+2MRFG2130						210	60	11.0	0.1	0.2	11.2
9	09	.5M1+2MRFG2200						296	99	19.0	0.0	0.1	22.2
~~9~~	~~09~~	~~.5M1+2MRFG2230~~						~~290~~	~~84~~	~~16.0~~	~~0.0~~	~~0.0~~	~~17.7~~
9	09	.5M1+2MRFG2300						282	86	15.0	0.0	0.0	16.5
9	09	.5M1+2MRFG2330						302	90	18.0	0.0	0.0	18.2
~~9~~	~~09~~	~~.5M1+2MRFG2400~~						~~272~~	~~81~~	~~15.0~~	~~0.0~~	~~0.0~~	~~17.7~~
0	09	.5M1+2MRFG0030						276	80	15.0	0.0	0.0	17.7
0	09	.5M1+2MRFG0100						282	79	15.0	0.0	0.0	17.7
~~0~~	~~09~~	~~.5M1+2MRFG0130~~						~~270~~	~~84~~	~~15.0~~	~~0.0~~	~~0.0~~	~~16.5~~
0	09	.5M1+2MRFG0200						254	75	16.0	0.0	0.0	17.1
0	09	.5M1+2MRFG0230						280	81	16.0	0.0	0.0	16.9
~~0~~	~~09~~	~~.5M1+2MRFG0300~~						~~270~~	~~82~~	~~16.0~~	~~0.0~~	~~0.0~~	~~16.3~~
0	09	.5M1+2MRFG0330						286	80	15.0	0.0	0.0	15.8
0	09	.5M1+2MRFG0400						448	136	13.0	0.0	0.4	15.0
~~0~~	~~09~~	~~.5M1+2MRFG0430~~						~~302~~	~~78~~	~~13.0~~	~~0.0~~	~~0.6~~	~~14.~~
0	09	.5M1+2MRFG0500						282	77	12.0	0.1	0.5	14.6
0	09	.5M1+2MRFG0530						276	77	13.0	0.1	0.6	14.8
~~0~~	~~09~~	~~.5M1+2MRFG0600~~						~~268~~	~~72~~	~~12.0~~	~~0.1~~	~~0.6~~	~~14.~~
0	09	.5M1+2MRFG0630						276	76	13.0	0.0	0.3	13.5
0	09	.5M1+2MRFG0700						184	36	13.0	0.0	0.4	14.
~~0~~	~~09~~	~~.5M1+2MRFG0730~~						~~236~~	~~71~~	~~12.0~~	~~0.0~~	~~0.3~~	~~12.~~
0	09	.5M1+2MRFG0800						252	74	11.0	0.0	0.4	11.

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES C2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
17	09	.5M1	EFG1000	0.508					54	17	9.0	0.2	0.3	9.
17	09	.5M1	EFG1030	0.508					55	17	9.0	0.2	0.3	10.
17	09	.5M1	EFG1100	0.508					59	19	16.0	0.4	0.2	16.
17	09	.5M1	EFG1130	0.508					66	20	10.0	0.1	0.1	10.
17	09	.5M1	EFG1200	0.508					64	21	8.0	0.0	0.1	9.
17	09	.5M1	EFG1230	0.508					70	23	20.0	0.1	0.3	22.
17	09	.5M1	EFG1300	0.508					66	24	20.0	0.0	0.3	21.
17	09	.5M1	EFG1330	0.508					80	26	17.0	0.0	0.2	18.
17	09	.5M1	EFG1400	0.508					93	31	17.0	0.0	0.1	17.
17	09	.5M1	EFG1430	0.508					92	32	17.0	0.0	0.2	18.
17	09	.5M1	EFG1500	1.01					105	36	15.0	0.0	0.1	16.
17	09	.5M1	EFG1530	1.01					95	35	9.0	0.0	0.2	10.
17	09	.5M1	EFG1600	1.01					110	23	14.0	0.0	0.2	15.
17	09	.5M1	EFG1630	1.01					70	30	18.0	0.0	0.3	19.
17	09	.5M1	EFG1700	1.01					69	23	9.0	0.0	0.2	11.
17	09	.5M1	EFG1730	1.01					63	21	12.0	0.0	0.2	13.
17	09	.5M1	EFG1800	1.01					55	19	11.0	0.2	0.3	11.
17	09	.5M1	EFG1830	1.01					72	23	10.0	0.1	0.3	10.
17	09	.5M1	EFG1900	1.01					76	30	13.0	0.3	0.2	14.
17	09	.5M1	EFG1930	1.01					56	30	14.0	0.2	0.3	14.
17	09	.5M1	EFG2000	0.507					43	24	12.0	0.2	0.3	14.
17	09	.5M1	EFG2030	0.507					47	22	11.0	0.2	0.3	11.
17	09	.5M1	EFG2100	0.507					49	24	10.0	0.2	0.3	11.
17	09	.5M1	EFG2130	0.507					62	22	7.0	0.1	0.2	9.
17	09	.5M1	EFG2200	0.507					63	21	5.0	0.0	0.2	7.
17	09	.5M1	EFG2230	0.507					63	21	5.0	0.2	0.2	6.
17	09	.5M1	EFG2300	0.507					63	20	4.0	0.1	0.1	5.
17	09	.5M1	EFG2330	0.507					58	20	5.0	0.1	2.0	6.
17	09	.5M1	EFG2400	0.507					56	20	5.0	0.1	0.2	6.
18	09	.5M1	EFG0030	0.507					55	19	9.0	0.2	0.2	9.
18	09	.5M1	EFG0100	0.511					53	19	9.0	0.2	0.3	11.
18	09	.5M1	EFG0130	0.511					57	21	7.0	0.2	0.2	8.
18	09	.5M1	EFG0200	0.511					60	21	7.0	0.1	0.2	7.
18	09	.5M1	EFG0230	0.511					59	21	6.0	0.1	0.1	7.
18	09	.5M1	EFG0300	0.511					57	21	7.0	0.1	0.1	7.
18	09	.5M1	EFG0330	0.511					58	20	10.0	0.1	0.3	11.
18	09	.5M1	EFG0400	0.511					67	20	9.0	0.1	0.1	10.
18	09	.5M1	EFG0430	0.511					68	20	10.0	0.1	0.2	10.
18	09	.5M1	EFG0500	0.511					67	20	11.0	0.2	0.2	12.
18	09	.5M1	EFG0530	0.511					63	19	11.0	0.3	0.1	11.
18	09	.5M1	EFG0600	0.991					61	19	11.0	0.1	0.2	11.
18	09	.5M1	EFG0630	0.991					57	18	12.0	0.1	0.1	12.
18	09	.5M1	EFG0700	0.991					59	17	12.0	0.1	0.1	13.
18	09	.5M1	EFG0730	0.991					58	17	11.0	0.1	0.1	12.
18	09	.5M1	EFG0800	0.991					56	17	11.0	0.1	0.1	12.
18	09	.5M1	EFG0830	0.991					55	16	11.0	0.2	0.1	12.
18	09	.5M1	EFG0900	0.991					54	17	11.0	0.1	0.1	12.
18	09	.5M1	EFG0930	0.991					56	17	11.0	0.1	0.2	12.
18	09	.5M1	EFG1000	0.991					40	15	13.0	0.3	0.4	13.
18	09	.5M1	EFG1030	0.991					40	14	15.0	0.1	0.2	16.
18	09	.5M1	EFG1100	0.509					51	16	16.0	0.0	0.2	17.
18	09	.5M1	EFG1130	0.509					48	14	16.0	0.0	0.3	16.
18	09	.5M1	EFG1200	0.509					44	13	11.0	0.1	0.3	14.

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES C2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
8	09	.5M1	EFG1230	0.509					44	12	9.0	0.1	0.4	11.3
~~8~~	~~09~~	~~.5M1~~	~~EFG1300~~	~~0.509~~					~~43~~	~~12~~	~~10.0~~	~~0.2~~	~~0.3~~	~~12.4~~
8	09	.5M1	EFG1330	0.509					42	11	10.0	0.2	0.4	11.0
8	09	.5M1	EFG1400	0.509					73	18	15.0	0.0	0.3	16.3
~~8~~	~~09~~	~~.5M1~~	~~EFG1430~~	~~0.509~~					~~61~~	~~16~~	~~14.0~~	~~0.0~~	~~0.2~~	~~15.7~~
8	09	.5M1	EFG1500	0.509					56	15	13.0	0.0	0.5	13.7
8	09	.5M1	EFG1530	0.509					42	15	11.0	0.1	0.5	12.5
~~8~~	~~09~~	~~.5M1~~	~~EFG1600~~	~~1.00~~					~~342~~	~~96~~	~~9.0~~	~~0.1~~	~~0.3~~	~~10.6~~
8	09	.5M1	EFG1630	1.00					117	34	12.0	0.0	0.1	13.5
8	09	.5M1	EFG1700	1.00					94	32	13.0	0.0	0.3	14.4
~~8~~	~~09~~	~~.5M1~~	~~EFG1730~~	~~1.00~~					~~69~~	~~20~~	~~11.0~~	~~0.1~~	~~0.2~~	~~13.3~~
8	09	.5M1	EFG1800	1.00					93	21	11.0	0.1	0.3	12.9
8	09	.5M1	EFG1830	1.00					76	23	13.0	0.1	0.4	13.5
~~8~~	~~09~~	~~.5M1~~	~~EFG1900~~	~~1.00~~					~~74~~	~~23~~	~~13.0~~	~~0.4~~	~~1.6~~	~~13.7~~
8	09	.5M1	EFG1930	1.00					76	22	13.0	0.4	0.9	14.3
8	09	.5M1	EFG2000	1.00					81	21	13.0	0.1	0.4	14.2
~~8~~	~~09~~	~~.5M1~~	~~EFG2030~~	~~1.00~~					~~70~~	~~19~~	~~12.0~~	~~0.1~~	~~0.3~~	~~13.0~~
8	09	.5M1	EFG2100	0.991					87	23	12.0	0.0	0.4	13.4
8	09	.5M1	EFG2130	0.991					132	49	19.0	0.1	0.2	22.7
~~8~~	~~09~~	~~.5M1~~	~~EFG2200~~	~~0.991~~					~~134~~	~~47~~	~~20.0~~	~~0.0~~	~~0.1~~	~~22.4~~
8	09	.5M1	EFG2230	0.991					130	40	19.0	0.0	0.1	21.1
8	09	.5M1	EFG2300	0.991					115	38	18.0	0.0	0.0	20.9
~~8~~	~~09~~	~~.5M1~~	~~EFG2330~~	~~0.991~~					~~110~~	~~36~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.5~~
8	09	.5M1	EFG2400	0.991					103	34	16.0	0.0	0.0	17.9
9	09	.5M1	EFG0300	0.991					96	34	18.0	0.0	0.0	19.7
~~9~~	~~09~~	~~.5M1~~	~~EFG0100~~	~~0.991~~					~~99~~	~~33~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.6~~
9	09	.5M1	EFG0130	0.991					98	35	18.0	0.0	0.0	19.6
9	09	.5M1	EFG0200	0.509					103	34	18.0	0.0	0.0	19.3
~~9~~	~~09~~	~~.5M1~~	~~EFG0230~~	~~0.509~~					~~80~~	~~27~~	~~18.0~~	~~0.0~~	~~0.0~~	~~18.7~~
9	09	.5M1	EFG0300	0.509					78	25	18.0	0.0	0.0	18.6
9	09	.5M1	EFG0330	0.509					75	22	17.0	0.0	0.0	17.9
~~9~~	~~09~~	~~.5M1~~	~~EFG0400~~	~~0.509~~					~~71~~	~~22~~	~~18.0~~	~~0.0~~	~~0.0~~	~~19.1~~
9	09	.5M1	EFG0430	0.509					68	22	14.0	0.0	0.1	15.6
9	09	.5M1	EFG0500	0.509					63	20	15.0	0.0	0.1	15.9
~~9~~	~~09~~	~~.5M1~~	~~EFG0530~~	~~0.509~~					~~69~~	~~23~~	~~15.0~~	~~0.0~~	~~0.1~~	~~15.9~~
9	09	.5M1	EFG0600	0.509					64	21	15.0	0.0	0.2	16.2
9	09	.5M1	EFG0630	0.509					63	20	14.0	0.0	0.1	15.8
~~9~~	~~09~~	~~.5M1~~	~~EFG0700~~	~~1.01~~					~~62~~	~~19~~	~~14.0~~	~~0.0~~	~~0.1~~	~~15.1~~
9	09	.5M1	EFG0730	1.01					41	19	11.0	0.0	0.1	12.7
9	09	.5M1	EFG0800	1.01					63	21	11.0	0.0	0.1	12.1
~~9~~	~~09~~	~~.5M1~~	~~EFG0830~~	~~1.01~~					~~64~~	~~21~~	~~11.0~~	~~0.0~~	~~0.1~~	~~12.5~~
9	09	.5M1	EFG0900	1.01					59	20	10.0	0.0	0.1	11.1
9	09	.5M1	EFG0930	1.01					56	20	10.0	0.0	0.1	11.6
~~9~~	~~09~~	~~.5M1~~	~~EFG1000~~	~~1.01~~					~~63~~	~~23~~	~~12.0~~	~~0.0~~	~~0.1~~	~~13.5~~
9	09	.5M1	EFG1030	1.01					77	22	14.0	0.0	0.0	15.3
9	09	.5M1	EFG1100	1.01					74	22	17.0	0.0	0.0	18.3
~~9~~	~~09~~	~~.5M1~~	~~EFG1130~~	~~1.01~~					~~92~~	~~29~~	~~21.0~~	~~0.0~~	~~0.0~~	~~21.6~~
9	09	.5M1	EFG1200	1.01					109	35	20.0	0.0	0.0	22.2
9	09	.5M1	EFG1230	1.01					103	30	11.0	0.0	0.1	14.6
~~9~~	~~09~~	~~.5M1~~	~~EFG1300~~	~~1.01~~					~~54~~	~~58~~	~~7.0~~	~~0.0~~	~~0.0~~	~~10.3~~
9	09	.5M1	EFG1330	1.01					67	20	5.0	0.0	0.0	6.6
9	09	.5M1	EFG1400	1.01					70	20	4.0	0.0	0.0	5.0
~~9~~	~~09~~	~~.5M1~~	~~EFG1430~~	~~1.01~~					~~72~~	~~21~~	~~4.0~~	~~0.0~~	~~0.0~~	~~6.3~~
9	09	.5M1	EFG1500	1.01					74	23	4.0	0.0	0.0	7.3
9	09	.5M1	EFG1530	1.01					64	22	4.0	0.0	0.0	6.0

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES C2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE BOD	UNFILTERED SAMPLE COD	UNFILTERED SAMPLE TKN	FILTEPED SAMPLE BOD	FILTEPED SAMPLE COD	TOC	NH3N	NO2N	NO3N	TKN
9	09	.5M1	EFG1600	1.01					82	25	3.0	0.0	0.0	6.0
9	09	.5M1	EFG1630	1.01					58	18	4.0	0.0	0.1	6.4
9	09	.5M1	EFG1700	1.04					54	15	4.0	0.0	0.1	5.5
9	09	.5M1	EFG1730	1.04					64	18	3.0	0.0	0.2	5.5
9	09	.5M1	EFG1800	1.04					55	16	4.0	0.0	0.0	6.3
9	09	.5M1	EFG1830	1.04					36	13	3.0	0.2	0.0	5.4
9	09	.5M1	EFG1900	1.04					42	15	4.0	0.2	0.2	5.5
9	09	.5M1	EFG1930	1.04					48	17	5.0	0.1	0.3	7.1
9	09	.5M1	EFG2000	1.04					56	17	5.0	0.1	0.2	7.0
9	09	.5M1	EFG2030	1.04					60	16	6.0	0.1	0.1	7.7
9	09	.5M1	EFG2100	1.04					61	18	6.0	0.0	0.3	6.4
9	09	.5M1	EFG2130	1.04					58	18	6.0	0.0	0.2	7.8
9	09	.5M1	EFG2200	0.507					59	16	6.0	0.0	0.0	7.3
9	09	.5M1	EFG2230	0.507					68	18	8.0	0.1	0.1	9.0
9	09	.5M1	EFG2300	0.507					79	21	9.0	0.0	0.0	12.0
9	09	.5M1	EFG2330	0.507					83	23	11.0	0.0	0.0	13.2
9	09	.5M1	EFG2400	0.507					83	22	12.0	0.0	0.1	14.0
	09	.5M1	EFG0030	0.507					83	22	11.0	0.0	1.3	14.5
	09	.5M1	EFG0100	0.507					77	23	12.0	0.0	0.1	13.8
	09	.5M1	EFG0130	0.507					75	22	11.0	0.1	0.1	14.3
	09	.5M1	EFG0200	0.507					72	20	11.0	0.1	0.2	13.8
	09	.5M1	EFG0230	0.507					71	24	11.0	0.0	0.4	13.0
	09	.5M1	EFG0300	1.03					73	21	11.0	0.0	0.1	14.4
	09	.5M1	EFG0330	1.03					71	22	11.0	0.0	0.4	13.5
	09	.5M1	EFG0400	1.03					89	27	11.0	0.0	0.3	12.6
	09	.5M1	EFG0430	1.03					112	36	10.0	0.0	0.3	10.8
	09	.5M1	EFG0500	1.03					88	29	8.0	0.0	0.6	9.9
	09	.5M1	EFG0530	1.03					63	20	8.0	0.0	0.1	10.0
	09	.5M1	EFG0600	1.03					79	27	7.0	0.0	1.4	9.0
	09	.5M1	EFG0630	1.03					56	50	7.0	0.0	0.1	9.0
	09	.5M1	EFG0700	1.03					57	59	7.0	0.0	0.1	8.4
	09	.5M1	EFG0730	1.03					61	18	7.0	0.1	0.1	8.9
	09	.5M1	EFG0800	1.03					59	18	7.0	0.0	0.1	8.9

BIO-SURF PILOT PLANT TESTING
1976
ANALYTICAL RESULTS - SERIES E2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
7	09	2M	EFG1000	15.37					47	17	7.0	0.1	0.1	8.4
7	09	2M	EFG1030	15.37					49	17	8.0	0.0	0.2	8.6
7	09	2M	EFG1100	15.37					~~57~~	~~20~~	~~11.0~~	~~0.0~~	~~0.2~~	~~12.4~~
7	09	2M	EFG1130	15.37					59	20	20.0	0.1	0.1	21.3
7	09	2M	EFG1200	15.37					68	20	15.0	0.0	0.2	16.2
~~7~~	~~09~~	~~2M~~	~~EFG1230~~	~~15.37~~					~~70~~	~~22~~	~~24.0~~	~~0.1~~	~~0.1~~	~~26.1~~
7	09	2M	EFG1300	15.37					72	21	22.0	0.1	0.1	24.1
7	09	2M	EFG1330	15.37					82	24	19.0	0.0	0.0	21.2
~~7~~	~~09~~	~~2M~~	~~EFG1400~~	~~15.37~~					~~98~~	~~32~~	~~19.0~~	~~0.0~~	~~0.0~~	~~19.2~~
7	09	2M	EFG1430	15.37					116	36	17.0	0.0	0.0	19.2
7	09	2M	EFG1500	34.60					169	41	16.0	0.0	0.0	18.0
~~7~~	~~09~~	~~2M~~	~~EFG1530~~	~~34.60~~					~~147~~	~~36~~	~~19.0~~	~~0.0~~	~~0.0~~	~~19.6~~
7	09	2M	EFG1600	34.60					132	37	15.0	0.0	0.0	16.1
7	09	2M	EFG1630	34.60					117	30	9.0	0.0	0.1	9.7
~~7~~	~~09~~	~~2M~~	~~EFG1700~~	~~34.60~~					~~81~~	~~21~~	~~13.0~~	~~0.0~~	~~0.2~~	~~14.9~~
7	09	2M	EFG1730	34.60					71	20	7.0	0.0	0.0	8.0
7	09	2M	EFG1800	34.60					64	19	10.0	0.0	0.3	11.1
~~7~~	~~09~~	~~2M~~	~~EFG1830~~	~~34.60~~					~~103~~	~~31~~	~~14.0~~	~~0.0~~	~~0.5~~	~~15.3~~
7	09	2M	EFG1900	34.60					105	33	15.0	0.0	0.1	15.9
7	09	2M	EFG1930	34.60					113	34	12.0	0.0	0.5	13.6
~~7~~	~~09~~	~~2M~~	~~EFG2000~~	~~17.11~~					~~93~~	~~24~~	~~13.0~~	~~0.0~~	~~0.7~~	~~13.8~~
7	09	2M	EFG2030	17.11					89	22	13.0	0.1	0.4	13.8
7	09	2M	EFG2100	17.11					90	22	13.0	0.1	0.4	14.1
~~7~~	~~09~~	~~2M~~	~~EFG2130~~	~~17.11~~					~~76~~	~~21~~	~~9.0~~	~~0.1~~	~~0.2~~	~~10.2~~
7	09	2M	EFG2200	17.11					69	22	9.0	0.1	0.1	10.2
7	09	2M	EFG2230	17.11					68	22	10.0	0.1	0.1	10.7
~~7~~	~~09~~	~~2M~~	~~EFG2300~~	~~17.11~~					~~68~~	~~19~~	~~11.0~~	~~0.1~~	~~0.2~~	~~11.1~~
7	09	2M	EFG2330	17.11					70	20	10.0	0.1	0.1	11.1
7	09	2M	EFG2400	17.11					60	21	10.0	0.1	0.1	10.6
~~8~~	~~09~~	~~2M~~	~~EFG0030~~	~~17.11~~					~~55~~	~~19~~	~~10.0~~	~~0.1~~	~~0.2~~	~~10.9~~
8	09	2M	EFG0100	16.00					62	21	9.0	0.1	0.1	10.1
8	09	2M	EFG0130	16.00					56	20	10.0	0.0	0.0	10.7
~~8~~	~~09~~	~~2M~~	~~EFG0200~~	~~16.00~~					~~71~~	~~24~~	~~09.0~~	~~0.0~~	~~0.0~~	~~9.2~~
8	09	2M	EFG0230	16.00					66	24	11.0	0.0	0.0	11.1
8	09	2M	EFG0300	16.00					64	21	11.0	0.0	0.1	12.1
~~8~~	~~09~~	~~2M~~	~~EFG0330~~	~~16.00~~					~~65~~	~~21~~	~~12.0~~	~~0.0~~	~~0.0~~	~~12.2~~
8	09	2M	EFG0400	16.00					68	20	12.0	0.0	0.1	13.1
8	09	2M	EFG0430	16.00					70	21	11.0	0.0	0.0	12.6
~~8~~	~~09~~	~~2M~~	~~EFG0500~~	~~16.00~~					~~64~~	~~20~~	~~11.0~~	~~0.0~~	~~0.0~~	~~11.7~~
8	09	2M	EFG0530	16.00					62	20	12.0	0.0	0.0	12.9
8	09	2M	EFG0600	32.40					61	19	12.0	0.0	0.0	13.7
~~8~~	~~09~~	~~2M~~	~~EFG0630~~	~~32.40~~					~~61~~	~~19~~	~~13.0~~	~~0.0~~	~~0.1~~	~~13.9~~
8	09	2M	EFG0700	32.40					64	20	12.0	0.0	0.1	13.1
8	09	2M	EFG0730	32.40					64	20	12.0	0.0	0.0	13.4
~~8~~	~~09~~	~~2M~~	~~EFG0800~~	~~32.40~~					~~65~~	~~20~~	~~11.0~~	~~0.0~~	~~0.0~~	~~12.6~~
8	09	2M	EFG0830	32.40					58	18	11.0	0.1	0.1	12.5
8	09	2M	EFG0900	32.40					61	19	11.0	0.0	0.0	12.1
~~8~~	~~09~~	~~2M~~	~~EFG0930~~	~~32.40~~					~~55~~	~~17~~	~~12.0~~	~~0.0~~	~~0.0~~	~~12.9~~
8	09	2M	EFG1000	32.40					55	17	18.0	0.0	0.0	20.1
8	09	2M	EFG1030	32.40					61	19	20.0	0.0	0.0	24.8
8	09	2M	EFG1100	16.20					~~60~~	~~19~~	~~24.0~~	~~0.0~~	~~0.0~~	~~25.1~~
8	09	2M	EFG1130	16.20					50	16	20.0	0.0	0.2	21.8
8	09	2M	EFG1200	16.20					40	14	14.0	0.0	0.3	16.6

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES E2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
8	09	2M	EFG1230	16.20					42	13	16.0	0.1	0.3	16.2
~~8~~	~~09~~	~~2M~~	~~EFG1300~~	~~16.20~~					~~42~~	~~14~~	~~14.0~~	~~0.1~~	~~0.6~~	~~15.5~~
8	09	2M	EFG1330	16.20					42	15	11.0	0.3	0.4	14.5
8	09	2M	EFG1400	16.20					45	15	15.6	0.1	0.4	17.1
8	09	2M	EFG1430	16.20					~~49~~	~~16~~	~~18.0~~	~~0.1~~	~~0.3~~	~~18.2~~
8	09	2M	EFG1500	16.20					47	16	18.0	0.1	0.4	18.3
8	09	2M	EFG1530	16.20					51	15	14.0	0.1	0.5	15.6
~~8~~	~~09~~	~~2M~~	~~EFG1600~~	~~34.10~~					~~540~~	~~46~~	~~13.0~~	~~0.0~~	~~0.0~~	~~15.1~~
8	09	2M	EFG1630	34.10					109	35	18.0	0.0	0.0	19.1
8	09	2M	EFG1700	34.10					106	38	19.0	0.0	0.0	21.5
~~8~~	~~09~~	~~2M~~	~~EFG1730~~	~~34.10~~					~~67~~	~~64~~	~~18.0~~	~~0.0~~	~~0.0~~	~~18.4~~
8	09	2M	EFG1800	34.10					79	23	14.0	0.0	0.0	16.4
8	09	2M	EFG1830	34.10					93	32	15.0	0.0	0.5	16.8
~~8~~	~~09~~	~~2M~~	~~EFG1900~~	~~34.10~~					~~89~~	~~27~~	~~22.0~~	~~0.2~~	~~2.4~~	~~23.3~~
8	09	2M	EFG1930	34.10					108	33	14.0	0.1	0.4	15.6
8	09	2M	EFG2000	34.10					78	22	13.0	0.0	0.1	14.1
~~8~~	~~09~~	~~2M~~	~~EFG2030~~	~~34.10~~					~~83~~	~~25~~	~~12.0~~	~~0.0~~	~~0.0~~	~~13.1~~
8	09	2M	EFG2100	34.00					143	46	15.0	0.0	0.0	16.3
8	09	2M	EFG2130	34.00					211	63	19.0	0.0	0.0	20.8
~~8~~	~~09~~	~~2M~~	~~EFG2200~~	~~34.00~~					~~179~~	~~55~~	~~16.0~~	~~0.0~~	~~0.0~~	~~17.7~~
8	09	2M	EFG2230	34.00					159	55	15.0	0.0	0.0	16.2
8	09	2M	EFG2300	34.00					152	54	14.0	0.0	0.0	15.0
~~8~~	~~09~~	~~2M~~	~~EFG2330~~	~~34.00~~					~~136~~	~~49~~	~~14.0~~	~~0.0~~	~~0.0~~	~~15.1~~
8	09	2M	EFG2400	34.00					148	47	13.0	0.0	0.0	13.9
9	09	2M	EFG0030	34.00					131	45	13.0	0.0	0.0	14.2
~~9~~	~~09~~	~~2M~~	~~EFG0100~~	~~34.00~~					~~133~~	~~46~~	~~13.0~~	~~0.0~~	~~0.0~~	~~14.1~~
9	09	2M	EFG0130	34.00					143	49	13.0	0.0	0.0	14.1
9	09	2M	EFG0200	15.20					120	42	13.0	0.0	0.0	14.1
~~9~~	~~09~~	~~2M~~	~~EFG0230~~	~~15.20~~					~~89~~	~~30~~	~~13.0~~	~~0.0~~	~~0.0~~	~~14.1~~
9	09	2M	EFG0300	15.20					81	27	13.0	0.0	0.0	13.7
9	09	2M	EFG0330	15.20					72	25	14.0	0.0	0.0	15.6
~~9~~	~~09~~	~~2M~~	~~EFG0400~~	~~15.20~~					~~70~~	~~23~~	~~14.0~~	~~0.0~~	~~0.0~~	~~14.9~~
9	09	2M	EFG0430	15.20					65	25	13.0	0.0	0.2	13.6
9	09	2M	EFG0500	15.20					63	22	12.0	0.0	0.0	13.6
~~9~~	~~09~~	~~2M~~	~~EFG0530~~	~~15.20~~					~~63~~	~~23~~	~~13.0~~	~~0.0~~	~~0.1~~	~~13.8~~
9	09	2M	EFG0600	15.20					63	22	12.0	0.0	0.0	13.1
9	09	2M	EFG0630	15.20					58	20	13.0	0.0	0.1	14.6
~~9~~	~~09~~	~~2M~~	~~EFG0700~~	~~32.30~~					~~58~~	~~23~~	~~12.0~~	~~0.0~~	~~0.0~~	~~13.3~~
9	09	2M	EFG0730	32.30					79	29	12.0	0.0	0.0	13.3
9	09	2M	EFG0800	32.30					94	33	12.0	0.0	0.0	12.9
~~9~~	~~09~~	~~2M~~	~~EFG0830~~	~~32.30~~					~~91~~	~~30~~	~~11.0~~	~~0.0~~	~~0.0~~	~~11.9~~
9	09	2M	EFG0900	32.30					86	30	11.0	0.0	0.0	12.6
9	09	2M	EFG0930	32.30					92	31	10.0	0.0	0.1	11.2
~~9~~	~~09~~	~~2M~~	~~EFG1000~~	~~32.30~~					~~105~~	~~35~~	~~13.0~~	~~0.0~~	~~0.0~~	~~14.1~~
9	09	2M	EFG1030	32.30					111	37	15.0	0.0	0.0	17.8
9	09	2M	EFG1100	32.30					107	40	17.0	0.0	0.0	19.9
~~9~~	~~09~~	~~2M~~	~~EFG1130~~	~~32.30~~					~~73~~	~~38~~	~~20.0~~	~~0.0~~	~~0.0~~	~~24.6~~
9	09	2M	EFG1200	32.80					122	45	21.0	0.0	0.0	24.2
9	09	2M	EFG1230	32.80					113	37	10.0	0.0	0.0	13.0
~~9~~	~~09~~	~~2M~~	~~EFG1300~~	~~32.80~~					~~105~~	~~32~~	~~6.0~~	~~0.0~~	~~0.1~~	~~8.3~~
9	09	2M	EFG1330	32.80					113	35	6.0	0.0	0.1	8.6
9	09	2M	EFG1400	32.80					108	39	5.0	0.0	0.1	7.6
9	09	2M	EFG1430	32.80					~~114~~	~~37~~	~~5.0~~	~~0.0~~	~~0.1~~	~~6.2~~
9	09	2M	EFG1500	32.80					123	40	5.0	0.0	0.0	6.2
9	09	2M	EFG1530	32.80					114	37	4.0	0.0	0.0	5.0

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES E2 (30 MIN)

MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE IGPM	UNFILTERED SAMPLE BOD	UNFILTERED SAMPLE COD	UNFILTERED SAMPLE TKN	FILTERED SAMPLE BOD	FILTERED SAMPLE COD	FILTERED SAMPLE TOC	FILTERED SAMPLE NH3N	FILTERED SAMPLE NO2N	FILTERED SAMPLE NO3N	FILTERED SAMPLE TKN
09	2M	EFG1230	16.20					42	13	16.0	0.1	0.3	16.2
09	2M	EFG1300	16.20					42	14	14.0	0.1	0.6	15.5
09	2M	EFG1330	16.20					42	15	11.0	0.3	0.4	14.5
09	2M	EFG1400	16.20					45	15	15.6	0.1	0.4	17.1
09	2M	EFG1430	16.20					49	16	18.0	0.1	0.3	18.2
09	2M	EFG1500	16.20					47	16	18.0	0.1	0.4	18.3
09	2M	EFG1530	16.20					51	15	14.0	0.1	0.5	15.6
09	2M	EFG1600	34.10					540	46	13.0	0.0	0.0	15.1
09	2M	EFG1630	34.10					109	35	18.0	0.0	0.0	19.1
09	2M	EFG1700	34.10					106	38	19.0	0.0	0.0	21.5
09	2M	EFG1730	34.10					67	64	18.0	0.0	0.0	18.4
09	2M	EFG1800	34.10					79	23	14.0	0.0	0.0	16.4
09	2M	EFG1830	34.10					93	32	15.0	0.0	0.5	16.8
09	2M	EFG1900	34.10					89	27	22.0	0.2	2.4	23.3
09	2M	EFG1930	34.10					108	33	14.0	0.1	0.4	15.6
09	2M	EFG2000	34.10					78	22	13.0	0.0	0.1	14.1
09	2M	EFG2030	34.10					83	25	12.0	0.0	0.0	13.1
09	2M	EFG2100	34.00					143	46	15.0	0.0	0.0	16.3
09	2M	EFG2130	34.00					211	63	19.0	0.0	0.0	20.8
09	2M	EFG2200	34.00					179	55	16.0	0.0	0.0	17.7
09	2M	EFG2230	34.00					159	55	15.0	0.0	0.0	16.2
09	2M	EFG2300	34.00					152	54	14.0	0.0	0.0	15.0
09	2M	EFG2330	34.00					136	49	14.0	0.0	0.0	15.1
09	2M	EFG2400	34.00					148	47	13.0	0.0	0.0	13.9
09	2M	EFG0030	34.00					131	45	13.0	0.0	0.0	14.2
09	2M	EFG0100	34.00					133	46	13.0	0.0	0.0	14.1
09	2M	EFG0130	34.00					143	49	13.0	0.0	0.0	14.1
09	2M	EFG0200	15.20					120	42	13.0	0.0	0.0	14.1
09	2M	EFG0230	15.20					89	30	13.0	0.0	0.0	14.1
09	2M	EFG0300	15.20					81	27	13.0	0.0	0.0	13.7
09	2M	EFG0330	15.20					72	25	14.0	0.0	0.0	15.6
09	2M	EFG0400	15.20					70	23	14.0	0.0	0.0	14.9
09	2M	EFG0430	15.20					65	25	13.0	0.0	0.2	13.6
09	2M	EFG0500	15.20					63	22	12.0	0.0	0.0	13.6
09	2M	EFG0530	15.20					63	23	13.0	0.0	0.1	13.8
09	2M	EFG0600	15.20					63	22	12.0	0.0	0.0	13.1
09	2M	EFG0630	15.20					58	20	13.0	0.0	0.1	14.6
09	2M	EFG0700	32.30					58	23	12.0	0.0	0.0	13.3
09	2M	EFG0730	32.30					79	29	12.0	0.0	0.0	13.3
09	2M	EFG0800	32.30					94	33	12.0	0.0	0.0	12.9
09	2M	EFG0830	32.30					91	30	11.0	0.0	0.0	11.9
09	2M	EFG0900	32.30					86	30	11.0	0.0	0.0	12.6
09	2M	EFG0930	32.30					92	31	10.0	0.0	0.1	11.2
09	2M	EFG1000	32.30					105	35	13.0	0.0	0.0	14.1
09	2M	EFG1030	32.30					111	37	15.0	0.0	0.0	17.8
09	2M	EFG1100	32.30					107	40	17.0	0.0	0.0	19.9
09	2M	EFG1130	32.30					73	88	20.0	0.0	0.0	24.6
09	2M	EFG1200	32.80					122	45	21.0	0.0	0.0	24.2
09	2M	EFG1230	32.80					113	37	10.0	0.0	0.0	13.0
09	2M	EFG1300	32.80					105	32	6.0	0.0	0.1	8.3
09	2M	EFG1330	32.80					113	35	6.0	0.0	0.1	8.6
09	2M	EFG1400	32.80					108	39	5.0	0.0	0.1	7.6
09	2M	EFG1430	32.80					114	37	5.0	0.0	0.1	5.2
09	2M	EFG1500	32.80					123	40	5.0	0.0	0.0	6.2
09	2M	EFG1530	32.80					114	37	4.0	0.0	0.0	5.0

Table A-2 Cont'd

ANALYTICAL RESULTS - SERIES E2 (30 MIN)

Y	MON	PILOT UNIT	SAMPLE IDENTITY	FLOW RATE	UNFILTERED SAMPLE			FILTERED SAMPLE						
				IGPM	BOD	COD	TKN	BOD	COD	TOC	NH3N	NO2N	NO3N	TKN
9	09	2M	EFG1600	32.80					106	35	4.0	0.0	0.0	5.7
~~9~~	~~09~~	~~2M~~	~~EFG1630~~	~~32.80~~					~~100~~	~~33~~	~~6.0~~	~~0.0~~	~~0.0~~	~~6.3~~
9	09	2M	EFG1700	32.40					96	30	6.0	0.0	0.0	6.1
9	09	2M	EFG1730	32.40					63	22	4.0	0.0	0.1	5.7
~~9~~	~~09~~	~~2M~~	~~EFG1800~~	~~32.40~~					~~55~~	~~18~~	~~5.0~~	~~0.1~~	~~0.0~~	~~6.9~~
9	09	2M	EFG1830	32.40					45	16	4.0	0.0	0.2	4.7
9	09	2M	EFG1900	32.40					54	20	5.0	0.1	0.0	6.8
~~9~~	~~09~~	~~2M~~	~~EFG1930~~	~~32.40~~					~~82~~	~~23~~	~~6.0~~	~~0.0~~	~~0.1~~	~~8.6~~
9	09	2M	EFG2000	32.40					70	23	6.0	0.0	0.1	7.3
9	09	2M	EFG2030	32.40					75	27	6.0	0.0	0.1	8.2
~~9~~	~~09~~	~~2M~~	~~EFG2100~~	~~32.40~~					~~73~~	~~23~~	~~6.0~~	~~0.0~~	~~0.1~~	~~8.0~~
9	09	2M	EFG2130	32.40					84	27	7.0	0.0	0.1	8.4
9	09	2M	EFG2200	15.95					61	18	6.0	0.0	0.1	7.2
~~9~~	~~09~~	~~2M~~	~~EFG2230~~	~~15.95~~					~~77~~	~~23~~	~~8.0~~	~~0.0~~	~~0.5~~	~~10.1~~
9	09	2M	EFG2300	15.95					95	28	10.0	0.0	0.5	13.4
9	09	2M	EFG2330	15.95					98	32	11.0	0.0	0.1	14.9
~~9~~	~~09~~	~~2M~~	~~EFG2400~~	~~15.95~~					~~92~~	~~28~~	~~12.0~~	~~0.0~~	~~0.1~~	~~14.0~~
0	09	2M	EFG0030	15.95					88	29	13.0	0.0	0.1	14.6
0	09	2M	EFG0100	15.95					86	24	12.0	0.0	0.2	14.6
~~0~~	~~09~~	~~2M~~	~~EFG0130~~	~~15.95~~					~~66~~	~~59~~	~~12.0~~	~~0.0~~	~~0.3~~	~~14.0~~
0	09	2M	EFG0200	15.95					48	25	12.0	0.0	0.2	14.0
0	09	2M	EFG0230	15.95					84	25	12.0	0.0	0.2	14.0
~~0~~	~~09~~	~~2M~~	~~EFG0300~~	~~32.00~~					~~92~~	~~29~~	~~12.0~~	~~0.1~~	~~0.0~~	~~14.6~~
0	09	2M	EFG0330	32.00					118	40	11.0	0.0	1.0	13.5
0	09	2M	EFG0400	32.00					114	37	11.0	0.0	0.5	13.3
~~0~~	~~09~~	~~2M~~	~~EFG0430~~	~~32.00~~					~~149~~	~~51~~	~~10.0~~	~~0.0~~	~~0.2~~	~~10.9~~
0	09	2M	EFG0500	32.00					104	37	09.0	0.0	0.1	10.0
0	09	2M	EFG0530	32.00					91	30	8.0	0.0	0.9	10.7
~~0~~	~~09~~	~~2M~~	~~EFG0600~~	~~32.00~~					~~85~~	~~28~~	~~9.0~~	~~0.0~~	~~0.1~~	~~10.6~~
0	09	2M	EFG0630	32.00					92	31	8.0	0.0	0.1	10.2
0	09	2M	EFG0700	32.00					106	31	8.0	0.0	0.4	10.9
~~0~~	~~09~~	~~2M~~	~~EFG0730~~	~~32.00~~					~~91~~	~~30~~	~~8.0~~	~~0.0~~	~~0.2~~	~~10.8~~
0	09	2M	EFG0800	32.00					88	29	8.0	0.0	0.1	10.5

APPENDIX B
ANALYTICAL PROCEDURES

Total Kjeldahl Nitrogen

Total kjeldahl nitrogen analyses (organic plus ammonia nitrogen) were performed according to Technicon Auto-analyser Industrial Method 146-71A. Essentially this procedure consists of digestion of organic matter at 380°C followed by measurement of the ammonia produced using the Berthelot reaction in which the formation of a blue indophenol complex occurs when ammonia reacts with sodium phenate followed by the addition of sodium hypochlorite. Glycine standards were used for calibration. For keeping unfiltered samples homogenized in the sample cups the system has two air aspirators. One aspirator provides complete mixing in the cup being sampled while the second aspirator mixes the next cup on the tray.

Ammonia

Analyses of ammonia nitrogen were conducted using Technicon Auto-analyser Industrial Method 98-70W. This is essentially the same technique employed for Total kjeldahl nitrogen with the omission of the selenium dioxide/surphuric acid/perchloric acid digestion step which ammonifies the organic nitrogen fraction. Ammonium chloride standards provided calibration.

Nitrate

Technicon Auto-analyser Industrial Method 100-70W was used for nitrite-nitrogen determinations. This technique involves a reaction between nitrite and sulphanilamide under acid conditions to form a diazo compound which in turn is coupled with N-1-naphthylethylenediamine to form a reddish purple azo dye. Colourimetric determination is then made on the sample.

Nitrate plus Nitrite

Nitrate plus nitrite-nitrogen analyses were performed using Technicon Auto-analyser Industrial Method 100-70W. In this method, the nitrate-nitrogen is reduced to nitrite in the copper-cadium reduction column. The sample is then analysed for nitrite nitrogen as described previously.

Chemical Oxygen Demand (COD)

COD determinations on 24 hour composite samples were done according to the dichromate reflux method described in "Standard Methods" (1971). During the dynamic experiments, when as many as 600 samples were collected for COD analyses in the space of 3-5 days, a less time consuming analytical technique was employed. A modified version of Technicon Auto-analyser Industrial Method No. 268-73W was adapted for COD analysis and a Technicon Solid prep 11 sampler was introduced in place of the normal sampler. Standard solutions were prepared using ammonium chloride. The standards were first analysed using the "Standard Methods" rèflux technique and then analysed on the Technicon equipment. The standard peaks produced on the Technicon System were then calibrated against the "Standard Methods" results.

This complicated approach was necessary since the sample digestion time in the Auto-analyser was shorter than that in the standard reflux test. This resulted in a lower degree of reaction completion with the Auto-analyser when heterogeneous sewage samples were tested. With this procedure modification in effect, Auto-analyser COD results for sewage samples were generally only 5 to 7 percent lower than results obtained via the "Standard Methods" technique.

Biochemical Oxygen Demand (BOD)

The 5 day, 20°C BOD determinations were performed according to the method described in "Standard Methods" pages 489-495 (1971).

Total Organic Carbon (TOC)

Twenty micro-litre samples previously acidified and purged were injected into a Beckman Infrared Carbon Analyser. The resulting peaks were compared to a calibration curve prepared from standards using anhydrous potassium biphthalate.

Suspended Solids

GELMAN .45 micron glass fibre filters were dried, Previously Washed, for at least two hours in a 103 degree C oven. They were then cooled in a dessicator and weighed. Suspended solids determinations were made by filtering a minimum of 10 ml of solution through a filter. The filter was then re-dried at 103 degrees for two or more hours, dessicated for 15 minutes and re-weighed. The increase in weight was taken as a measure of the suspended solids.

Dissolved Oxygen

An Electromic Instruments Ltd. Dissolved Oxygen Metre Model 15A was used for dissolved oxygen determinations. It was found necessary to calibrate the probe roughly once a week.

Temperature

The D.O. metre also included a temperature probe and this was used for measurement of the feed stream and the reactor temperatures. Occasionally, a mercury thermometer was also used.

pH

pH was measured using an Orion Specific Ion Meter (Model 401) together with Fisher Combination electrodes (Cat. le-639-90).

Alkalinity

By using the Orion pH meter, 50 ml samples were titrated to a pH of 4.8 by addition of .02 N sulphuric acid. Results were expressed as mg/l of calcium carbonate.

APPENDIX C

CALCULATION PROCEDURES

Identification of the Transfer Function Model: TKN Load vs TKN Concentration

After sufficient differencing to induce stationarity in the data, the impulse response weights of the cross correlation function (Figure 4.1) were examined in order to identify the transfer function model orders (r, s, b). In this case the model orders may be tentatively identified as a (1, 1, 1) or a (1, 2, 1) process (Figure 4.1). In order to determine which model provided the best representation of the data, the models must be built and checked, and the residual sums of squares of the models compared.

The sample calculation will continue with the (1, 1, 1) model form. The preliminary transfer function model may therefore be identified as

$$Y_t = \frac{(W_0 - W_1 \ \beta) \ \beta X_t}{(1 - \delta_1 \ \beta)} \qquad \ldots \text{(C-1)}$$

The preliminary estimates of the above model parameters were calculated from the impulse response weights:

$$W_0 = v_{j=b} = 0.083$$

$$\delta_1 \ W_0 - W_1 = v_{j=b+1} = 0.088$$

$$\delta_1 \ v_{j-1} = v_{j=b+1} = 0.065$$

Identification of the Noise Model

The model under consideration is

$$Y_t = \frac{W(\beta)}{\delta(\beta)} X_{t-b} + N_t \qquad \ldots (C\text{-}2)$$

where N_t is to be parsimoniously represented as

$$N_t = \frac{\theta(\beta)}{\Delta^d \varnothing(\beta)} a_t \qquad \ldots (C\text{-}3)$$

Having already identified the transfer function model, N_t may be obtained from

$$N_t = Y_t - \delta_1 Y_{t-1} - w_o X_{t-1} + w_1 X_{t-2} + \delta_1 N_{t-1} \quad \ldots (C\text{-}4)$$

Plots of the autocorrelation and partial autocorrelation functions of the noise sequence are given in Figure C-1. Examination of these functions reveals a decaying autocorrelation function which becomes negligible after lag 1. A single significant spike at lag 1 is noted for the partial autocorrelation function. This is indicative of an autoregressive process of order 1 (AR(1)).

Therefore, $N_t = \dfrac{a_t}{(1 - \varnothing_1 \beta)}$ ... (C-5)

with $\varnothing_1 = \rho_1 = 0.219$

Our tentatively identified model is therefore

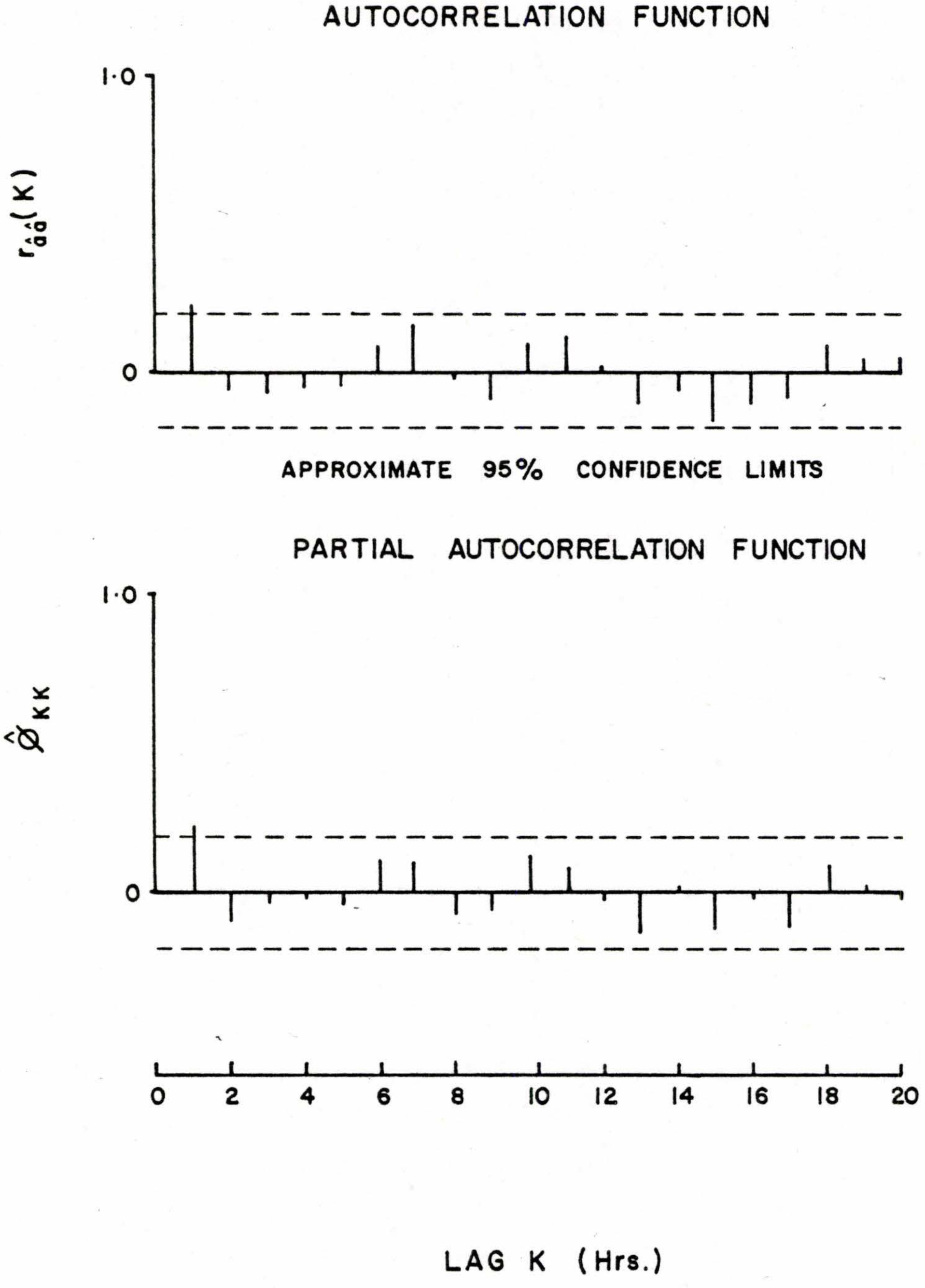
$$Y_t = \frac{(w_o - w_1 \beta) \beta X_t}{(1 - \delta_1 \beta)} + \frac{a_t}{(1 - \varnothing_1 \beta)} \quad \ldots (C\text{-}6)$$

Fitting and Applying Residual Checks to the Combined Transfer Function - Noise Model (TF-N)

The initial parameter estimates obtained from the previous

FIGURE C-1

AUTOCORRELATION AND PARTIAL AUTOCORRELATION FUNCTIONS OF TKN LOAD MODEL NOISE SEQUENCE



AUTOCORRELATION FUNCTION

PARTIAL AUTOCORRELATION FUNCTION

sections were used as starting values in TS HAUS (TS HAUS is an efficient non-linear least squares program developed for use with time series analysis). The dynamic and noise parameters were estimated simultaneously. The parameter estimates and their approximate 95% confidence limits appear in Table C-1A.

TABLE C-1A

SAMPLE CALCULATION MODEL ESTIMATES

Model	Initial Estimates		Final Estimates	95% Confidence Interval
(1,1,1)	w_o	0.083	0.08312	± 0.01738
	w_1	-0.0267	-0.03450	± 0.02426
	δ_1	0.739	0.5590	± 0.1365
	ϕ_1	0.219	0.2339	± 0.1808

The two most frequent checks applied to diagnose transfer function noise model adequacy (or inadequacy as the case may be) are the autocorrelation function $r_{\hat{a}\hat{a}}(k)$ of the residuals from the fitted model and the cross correlation function between prewhitened input (or in our case the first difference Δx_t) and the model residuals. Assuming the form of the TF - N model is correct and that the parameter values are known, then the estimated autocorrelation function of the residuals will not be correlated and will be distributed normally about zero with variance n^{-1}, where n is the number of data points in the series. These checks are presented in Figures C-2 and C-3. The results in Figures C-2 and C-3 indicate that there is no serious transfer function model or noise model inadequacy and that the chosen models adequately represent the data.

FIGURE C-2

AUTOCORRELATION OF THE FITTED TKN LOAD TF-N MODEL RESIDUALS

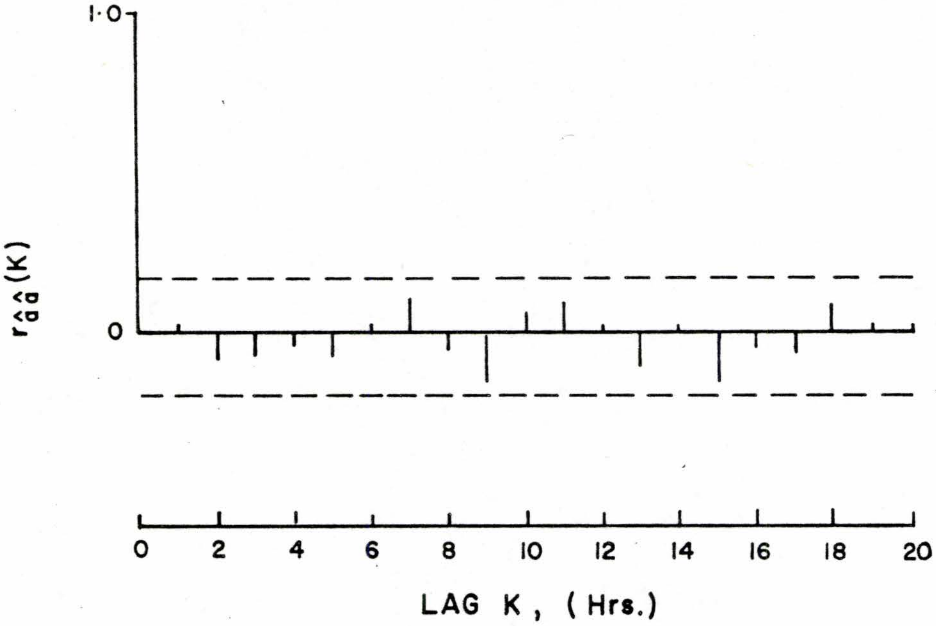
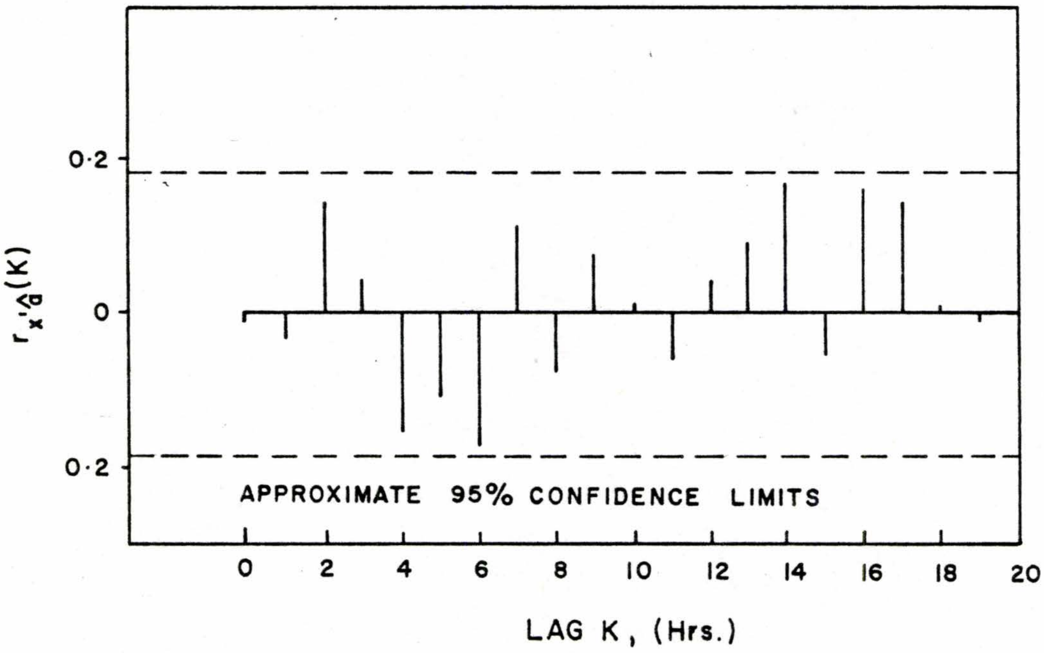


FIGURE C-3

CROSS CORRELATION MODEL CHECK, ∇X_t vs. TF-N MODEL RESIDUALS



A further assessment of the residuals involves taking the first k autocorrelations and computing the Q statistic. Comparing the result to the chi-square distribution (x^2) with k-p-q degrees of freedom, where p + q is the total number of parameters of the noise model, determines the significance of the residuals. In a similar manner the significance of the cross correlations between residuals and the stationary input series for each variable can be computed by comparing the S statistic to the chi-square (x^2) distribution. These results were presented in Table 4.3 for the models obtained in this work.

A complete listing of the computer programs used is provided in Tables Cl, C2, C3 and C4.

Forecasting System Response to Impulse Forcings

The forecasted effluent values discussed in Section 4.4.1 were determined using the minimum mean square error forecast with leading indicators, as developed by Box and Jenkins 1976, pgs. 402 to 405. The model used the following as input data:

1) past values of influent TKN load in g/day at discrete 1 hour time intervals

2) past values of effluent TKN concentration in mg/l at discrete time intervals

3) initial estimates for the error function, a_t.

The initial estimates used in (3) above were obtained by calculating residuals for the forecast and the experimental data with a_t initially set at zero. Calculated residuals were used to replace the estimate of zero and calculations were continued in this iterative fashion.

A listing of the computer program and the plotting routine used is provided in Table C-5.

Transfer Function Calculation Procedures to Determine Response Times (From Box and Jenkins (1976)

The continuous system satisfying

$$(1+TD)Y(t) = g\ X\ (t-b-c) \qquad \ldots\ (C-7)$$

is for a pulsed input, discretely coincident with the discrete system satisfying

$$(1-\delta\beta)Y_t = (W_o - W_1\ \beta)\ X_{t-b-1+} \qquad \ldots\ (C-8)$$

where

$$\delta_1 = e^{-1/T},\quad W_o = g\ (1-\delta^{1-c}),$$

$$W_1 = g\ (\delta - \delta^{1-c})$$

The gain, g and the fractional time delay of the system, c, are independent of the sample interval. T is the average residence time in the system.

The constants for loading model A1 (Table 4.2) are as follows:

$$W_o = 0.08312$$
$$W_1 = -0.03450$$
$$\delta_1 = 0.559$$

Therefore $g = \frac{W_o - W_1}{\delta^1} = 0.210$

For the relationship:

$$W_o = g\ (1-\delta^{1-c}) \qquad \ldots\ (C\text{-}9)$$

the only unknown is the fractional time delay, c. Substituting into equation C-9,

$$c = 0.134$$

Since discrete sampling took place at hourly intervals, the approximate time delay of the system is about 10 minutes for loading influent variations.

Table C-1

Computer Program Used For Cross Correlations and Matrix Inversion, Sample Output For Model A-1

```
C      CROSS CORRELATIONS AND  V  WEIGHTS FOR SSC SYSTEM FILTER
C      LOADING VERSUS EFFLUENT FILTERABLE TKN
       DIMENSION A(14,I21),X(121),Y(121),Z(121),W(I21)
C
C
C
C      NL = NUMBER OF LAGS
C
C
C
       DATA NOB/121/,NL/20/
       READ 1,((A(I,J),I=1,7),J=1,NOB)
       READ 2,((A(I,J),I=8,14),J=1,NOB)
    1  FORMAT(26X,F5.3,19X,F4.0,1X,F3.0,1X,4F5.1)
    2  FORMAT(26X,F5.3,21X,F3.0,1X,F3.0,1X,4F5.1)
    3  READ 4,(IX,IY,IW)
    4  FORMAT(3I2)
       PRINT 4,IX,IY,IW
       IF(IFEOF(60).EQ.-1) STOP
       PRINT 12
   12  FORMAT(28X,10HFILTERABLE,31X,10HFILTERABLE)
       PRINT 11
   11  FORMAT(10X,14HFLOW(IGAL/MIN),3X,12HRF TKN(MG/L),5X,
      115HLOADING(GM/DAY),8X,13HEFF TKN(MG/L))
       PRINT 9
    9  FORMAT(16X,1HX,16X,1HY,19X,1HZ,19X,1HW)
       SW=0.0
       SZ=0.0
       DO 5 K=1,NOB
       X(K)=A(IX,K)
       Y(K)=A(IY,K)
       W(K)=A(IW,K)
       Z(K)=(X(K)*Y(K))*6.552
       SZ=SZ+Z(K)
       SW=SW+W(K)
       PRINT 10,(X(K),Y(K),Z(K),W(K))
   10  FORMAT(9X,F10.2,7X,F10.2,10X,F10.2,10X,F10.2)
    5  CONTINUE
       AW=SW/FLOAT(NOB)
       AZ=SZ/FLOAT(NOB)
       PRINT 101
  101  FORMAT(///,24X,6HZ MEAN,15X,6HW MEAN)
       PRINT 102,AZ,AW
  102  FORMAT(/,20X,F10.3,10X,F10.3)
       DO 81 K=1,NOB
       W(K)=W(K)-AW
   81  Z(K)=Z(K)-AZ
       CALL IDENT TF(Z,W,NOB,NL,1)
       GO TO 3
       END

    USASI FORTRAN DIAGNOSTIC RESULTS FOR FTN.MAIN

          NO ERRORS
```

```
      SUBROUTINE IDENT TF(X,Y,NOB,NL,NDIFF)
C      IDENTIFICATION OF THE IMPULSE RESPONSE
C      BY INVERSION OF MATRIX
C      THIS SUBROUTINE REQUIRES THE SSPLIB
C      SSPLIB MUST BE ATTACHED
      COMMON SDA,SDX
      DIMENSION X(1),Y(1),AC(60),GAM(20,20),VGAM(400)
      DIMENSION CC1(21),CC2(21),L(400),M(400),V(20),VN(20)
      NDATA=NOB
      ND=0
      PRINT 18
   18 FORMAT(52H1    CROSS CORRELATIONS AT + AND - LAGS FOR NDIFF = 0)
    6 CALL CROSS(X,Y,NOB,NL,CC1,CC2)
      CALL ACORR(X,AC,SDZ,NOB,NL)
C      BUILDING THE MATRIX OF INPUT AUTOCORRELATION GAM
      NLL=NL-1
      DO 10 J=1,NLL
      GAM(J,J)=1.0
      II=NL-J+1
      DO 20 I=2,II
      IW=I+J-1
   20 GAM(IW,J)=AC(I-1)
   10 CONTINUE
      GAM(NL,NL)=1.0
      DO 30 J=2,NL
      JJ=J-1
      DO 40 I=1,JJ
   40 GAM(I,J)=GAM(J,I)
   30 CONTINUE
      PRINT 42,((GAM(I,J),I=1,NL),J=1,NL)
   42 FORMAT(10X,20F6.2)
C      TRANSFORMING GAM TO A VECTOR MATRIX VGAM
      DO 50 J=1,20
      DO 60 I=1,20
      IR=NL*(J-1)+I
      VGAM(IR)=GAM(I,J)
   60 CONTINUE
   50 CONTINUE
C      INVERSION OF MATRIX
C      MINV AND GMPRD ARE IBM SCIENTIFIC SUBROUTINES
      N=NL*NL
      CALL MINV(VGAM,NL,D,L,M)
      PRINT 51,D
   51 FORMAT(//////////,10X,4H D =,E20.8)
      NLL=NL*NL
      PRINT 42,(VGAM(I),I=1,NLL)
C       CALCULATION OF THE TRANSFER FUNCTION PARAMETERS
      CALL GAS003(VGAM,CC2,V,NL,NL,1)
      CALL GAS003(VGAM,CC1,VN,NL,NL,1)
      DO 16 I=1,NL
      V(I)=V(I)*SDA/SDX
   16 VN(I)=VN(I)*SDA/SDX
C      PLOTTING PARAMETERS V
      PRINT 8,ND
    8 FORMAT(///,10X,38H V WEIGHTS AT + AND - LAGS  FOR NDIFF=,I2)
      CL=SQRT(VGAM(1)/FLOAT(NOB))*SDA*2.0/SDX
      CLN=-CL
      DO 2 K=1,NL
      T=FLOAT(K)
      TT=-T
      KK=K-1
      K1=-KK
    2 PRINT 4,K1,VN(K),KK,V(K)
    4 FORMAT(5X,I3,5X,F6.3,10X,I3,5X,F6.3)
      PRINT 12,CL
   12 FORMAT(//,53H APPROX. 95 PER CENT CONF LIMIT ON IMPULSE RESPONS
     1,F10.3)
      NDATA=NDATA-1
      ND=ND+1
      IF(ND.GT.NDIFF)GO TO 100
      DO 41 I=1,NDATA
      X(I)=X(I+1)-X(I)
   41 Y(I)=Y(I+1)-Y(I)
      PRINT 19
   19 FORMAT(52H1    CROSS CORRELATIONS AT + AND - LAGS FOR NDIFF = 1)
      GO TO 6
```

```
      SUBROUTINE ACORR(Z,AC,SDZ,N,NL)
      DIMENSION Z(1),AC(1)
      NL1 = NL+1
      TN = N
      SZ = 0.
      DO 13 I=1,N
   13 SZ = SZ+Z(I)
      ZBAR = SZ/TN
      DO 10 JJ=1,NL1
      J = JJ-1
      SZZ = 0.
      NN = N-J
      DO 11 I=1,NN
      K=I+J
   11 SZZ=SZZ+(Z(I)-ZBAR)*(Z(K)-ZBAR)
   10 AC(JJ) = SZZ/TN
      SDZ = SQRT(AC(1))
      VZ = AC(1)
      DO 12 J=1,NL
   12 AC(J) = AC(J+1)/VZ
      RETURN
      END
```

```
 USASI FORTRAN DIAGNOSTIC RESULTS FOR ACORR

       NO ERRORS
```

```
      SUBROUTINE CROSS(X,A,NOB,NL,CC1,CC2)
      COMMON SDA,SDX
      DIMENSION X(NOB),A(NOB)
      DIMENSION CC1(41),CC2(41)
C      CC1 ARE CROSSCORRELATIONS AT NEGATIVE LAGS
C      CC2 ARE CROSSCORRELATION AT POSITIVE LAGS
      CALL CRCORR(X,A,CC2,SDX,SDA,NOB,NL)
      CALL CRCORR(A,X,CC1,SDA,SDX,NOB,NL)
      PRINT 6
    6 FORMAT(79H    CROSS-CORRELATIONS BETWEEN MANIPULATED VARIABLES
     1RESIDUALS    X(T)*A(T+K),//)
      NL1 = NL+1
      DO 7 K=1,NL1
      KK = K-1
      K1 = -KK
    7 PRINT 8 , K1,CC1(K),KK,CC2(K)
    8 FORMAT (5X,I3,5X,F6.3,10X,I3,5X,F6.3)
      CL = 2.0/SQRT(FLOAT(NOB))
      PRINT 12 , CL
   12 FORMAT(//,55H APPROX. 95 PERCENT CONF. LIMIT ON CROSS-CORRELATI
     1 =,F6.3)
      PRINT 9, SDX,SDA
    9 FORMAT(/,28H STANDARD DEVIATIONS  S(X) =,F12.4,5X,6HS(A) =,E12.
      Q = 0.
      DO 10 J=1,NL1
   10 Q = Q+            CC2(J)*CC2(J)
      Q = Q*FLOAT(NOB)
      NDF = NL+1
      PRINT 11, Q,NDF
   11 FORMAT(/,25H CHI SQUARED STATISTIC = ,F6.2,/,10H BASED ON(,I2,4
     1NO. OF DYNAMIC PARAMETERS) DEGREES OF FREEDOM)
      RETURN
      END
```

```
 USASI FORTRAN DIAGNOSTIC RESULTS FOR CROSS

       NO ERRORS
```

```
N 0001            SUBROUTINE CRCORR(X,Y,CC,SDX,SDY,N,NL)
N 0002            DIMENSION X(N),Y(N),CC(1)
N 0003            SX = 0.
N 0004            SY = 0.
N 0005            SXX = 0.
N 0006            SYY = 0.
N 0007            DO 2 I=1,N
N 0008            SX = SX+X(I)
N 0009            SY = SY+Y(I)
N 0010            SXX = SXX+X(I)*X(I)
N 0011          2 SYY = SYY+Y(I)*Y(I)
N 0012            TN = N
N 0013            SDX = SQRT((SXX-SX*SX/TN)/TN)
N 0014            SDY = SQRT((SYY-SY*SY/TN)/TN)
N 0015            NL1 = NL+1
N 0016            DO 3 K=1,NL1
N 0017            SXY = 0.
N 0018            NN = N-K+1
N 0019            DO 4 I=1,NN
N 0020            KK = I+K-1
N 0021          4 SXY = SXY+(X(I)-SX/TN)*(Y(KK)-SY/TN)
N 0022          3 CC(K) = (SXY/TN)/(SDX*SDY)
N 0023            RETURN
N 0024            END

     USASI FORTRAN DIAGNOSTIC RESULTS FOR CRCORR

          NO ERRORS

LIB,PDIR

                           FILTERABLE                                                    FILTERABLE
   FLOW(IGAL/MIN)       RF TKN(MG/L)         LOADING(GM/DAY)                        EFF TKN(MG/L)
          X                   Y                     Z                                     W
         0.40               85.00                223.88                                50.00
         0.40              107.00                281.83                                47.00
         0.40               99.00                260.76                                42.00
         0.40              100.00                263.39                                45.00
         0.40              115.00                302.90                                39.00
         0.40               78.00                205.44                                42.00
         0.40               60.00                158.03                                39.00
         0.40               70.00                184.37                                44.00
         0.15              105.00                102.79                                39.00
         0.15              118.00                114.42                                39.00
         0.15              113.00                109.58                                44.00
         0.15              109.00                105.70                                47.00
         0.15               94.00                 91.15                                45.00
         0.15               93.00                 90.18                                45.00
         0.15               85.00                 82.42                                48.00
         0.15              105.00                101.82                                47.00
         0.15              190.00                184.24                                47.00
         0.15              170.00                164.85                                50.00
         0.15              178.00                172.61                                50.00
         0.15              170.00                164.85                                52.00
         0.15              170.00                164.85                                50.00
         0.15              225.00                218.18                                50.00
         0.15              130.00                126.06                                53.00
         0.15              122.00                118.30                                56.00
         0.43               89.00                252.49                                50.00
         0.43               76.00                215.61                                43.00
         0.43               70.00                198.59                                45.00
         0.43               72.00                204.27                                39.00
         0.43               82.00                232.64                                41.00
         0.43               93.00                263.84                                36.00
         0.43               90.00                255.33                                33.00
         0.43               79.00                224.12                                34.00
         0.10              218.00                142.83                                33.00
         0.10              278.00                182.15                                34.00
         0.10              250.00                163.80                                42.00
         0.10              250.00                163.80                                39.00
         0.10              250.00                163.80                                41.00
         0.10              235.00                153.97                                42.00
         0.10              232.00                152.01                                47.00
         0.10              232.00                152.01                                5
```

Table C-1 Cont'd

```
          V WEIGHTS AT + AND - LAGS  FOR NDIFF= 1
     -0       0.003             0      -0.001
     -1       0.004             1      -0.022
     -2      -0.007             2      -0.017
     -3      -0.003             3      -0.009
     -4      -0.008             4       0.006
     -5       0.003             5      -0.005
     -6       0.015             6      -0.006
     -7       0.015             7      -0.004
     -8       0.014             8      -0.001
     -9       0.003             9       0.004
    -10      -0.003            10      -0.002
    -11      -0.004            11      -0.014
    -12      -0.006            12       0.002
    -13      -0.002            13      -0.002
    -14      -0.011            14      -0.015
    -15      -0.021            15       0.012
    -16       0.009            16      -0.010
    -17       0.002            17       0.014
    -18      -0.007            18       0.007
    -19      -0.002            19      -0.005

APPROX. 95 PER CENT CONF LIMIT ON IMPULSE RESPONSE =      0.023
1 714
                                 FILTERABLE                                          FILTERAB
        FLOW(IGAL/MIN)      RF TKN(MG/L)       LOADING(GM/DAY)               EFF TKN(MG
              X                   Y                    Z                            W
            0.40               34.40                90.61                        9.50
            0.40               36.20                95.35                       16.20
            0.40               33.70                88.76                       21.00
            0.40               35.60                93.77                       22.20
            0.40               35.80                94.29                       23.30
            0.40               31.60                83.23                       24.00
            0.40               31.30                82.44                       24.40
            0.40               30.60                80.60                       23.80
            0.15               18.70                18.13                       23.00
            0.15               18.60                18.04                       17.00
            0.15               16.40                15.90                       10.10
            0.15               15.70                15.22                        2.60
            0.15               14.10                13.67                        0.90
            0.15               12.90                12.51                        0.60
            0.15               12.20                11.83                        2.20
            0.15               11.00                10.67                        1.00
            0.15               28.80                27.93                        1.10
            0.15               33.20                32.19                        3.00
            0.15               34.30                33.26                        2.30
            0.15               44.20                42.86                        2.30
            0.15               49.20                47.71                        2.90
            0.15               51.30                49.75                        3.10
            0.15               32.50                31.52                        3.70
            0.15               29.00                28.12                        3.30
            0.43               18.10                51.35                        2.70
            0.43               13.00                36.88                        2.20
            0.43               11.40                32.34                        1.80
            0.43                9.20                26.10                        1.40
            0.43               10.70                30.36                        1.30
            0.43               11.60                32.91                        1.40
            0.43               11.80                33.48                        1.40
            0.43               11.40                32.34                        1.30
            0.10               21.10                13.82                        1.20
            0.10               21.10                13.82                        0.60
            0.10               19.40                12.71                        0.70
            0.10               19.50                12.78                        1.00
            0.10                8.00                 5.24                        1.40
            0.10               16.70                10.94                        1.50
            0.10               14.80                 9.70                        1.50
            0.10               13.30                 8.71                        1.50
            0.43               35.20                98.48                        1.50
            0.43               32.90                92.04                        7.70
            0.43               37.90               106.03                       16.90
            0.43               41.60               116.38                       23.40
            0.43               47.10               131.77                       26.60
            0.43               49.80               139.33                       30.40
            0.43               47.20               132.05                       33.20
            0.43               45.70               127.86                       33.70
            0.43               51.00               142.68                       34.20
            0.43               48.10               134.57                       35.20
            0.43               45.20               126.46                       35.10
```

Table C-1 Cont'd

0.43	40.40	113.03	33.60
0.14	49.00	44.95	32.60
0.14	46.90	44.85	27.20
0.14	47.10	43.20	24.50
0.14	48.50	44.49	21.80
0.14	47.60	43.66	20.20
0.14	45.60	41.83	19.00
0.14	46.10	42.29	17.60
0.14	44.70	41.00	16.30
0.43	39.80	111.35	15.90
0.43	33.20	92.88	21.40
0.43	36.60	102.40	24.60
0.43	39.70	111.07	25.60
0.43	47.00	131.49	28.60
0.43	51.80	144.92	31.40
0.43	47.40	132.61	35.40
0.43	40.60	113.59	32.00
0.43	28.00	78.34	33.20
0.43	20.60	57.63	25.90
0.43	14.10	39.45	17.00
0.43	18.30	51.20	10.70
0.43	18.00	50.36	9.50
0.43	6.50	18.19	9.50
0.43	18.30	51.20	8.00
0.43	15.60	43.64	8.00
0.43	22.50	62.95	7.60
0.43	22.40	62.67	10.30
0.43	22.10	61.83	13.00
0.43	20.60	57.63	14.10
0.43	21.20	59.31	15.10
0.43	20.60	57.63	15.20
0.43	19.30	54.00	14.70
0.43	17.20	48.12	13.60
0.15	16.40	15.90	12.60
0.15	24.80	24.05	10.10
0.15	35.00	33.94	8.90
0.15	26.70	25.89	6.30
0.15	34.90	33.84	2.90
0.15	37.90	36.75	3.50
0.15	22.10	21.43	2.70
0.15	18.00	17.45	2.70
0.43	15.60	43.64	2.80
0.43	17.40	48.68	5.10
0.43	19.80	55.39	5.70
0.43	22.10	61.83	7.10
0.43	15.70	43.92	17.00
0.43	13.20	36.93	16.00
0.43	12.50	34.97	11.80
0.15	51.00	49.45	9.20
0.15	57.30	55.56	9.00
0.15	56.80	55.08	12.10
0.15	56.50	54.79	17.70
0.15	55.90	54.21	22.80
0.15	56.60	54.88	26.10
0.15	56.70	54.98	25.30
0.15	55.90	54.21	26.60
0.15	55.10	53.43	27.90
0.15	54.40	52.75	27.50
0.15	52.00	50.42	27.90
0.15	51.00	49.45	27.90
0.15	55.10	53.43	26.50
0.15	57.00	55.27	26.70
0.15	61.80	59.93	28.10
0.15	61.60	59.73	29.50
0.15	60.20	58.38	31.70
0.15	55.50	53.82	33.10

Z MEAN	W MEAN
58.817	15.603

Table C-1 Cont'd

```
CROSS CORRELATIONS AT + AND - LAGS FOR NDIFF = 0
CROSS-CORRELATIONS BETWEEN MANIPULATED VARIABLES  + RESIDUALS   X(T)*A(

   -0        0.720            0        0.720
   -1        0.628            1        0.810
   -2        0.530            2        0.837
   -3        0.430            3        0.808
   -4        0.326            4        0.734
   -5        0.234            5        0.634
   -6        0.161            6        0.528
   -7        0.107            7        0.423
   -8        0.086            8        0.325
   -9        0.064            9        0.222
  -10        0.052           10        0.146
  -11        0.037           11        0.092
  -12        0.026           12        0.061
  -13        0.018           13        0.047
  -14        0.013           14        0.040
  -15        0.009           15        0.040
  -16       -0.001           16        0.034
  -17       -0.014           17        0.032
  -18       -0.031           18        0.024
  -19       -0.048           19        0.007
  -20       -0.063           20       -0.016

APPROX. 95 PERCENT CONF. LIMIT ON CROSS-CORRELATIONS = 0.182

STANDARD DEVIATIONS  S(X) =      37.2113      S(A) =  0.1163E+02

CHI SQUARED STATISTIC = 498.93
BASED ON(21 NO. OF DYNAMIC PARAMETERS) DEGREES OF FREEDOM
          1.00   0.89   0.79   0.67   0.54   0.41   0.27   0.14   0.02  -0.02  -0.0
          0.89   1.00   0.89   0.79   0.67   0.54   0.41   0.27   0.14   0.02  -0.0
          0.79   0.89   1.00   0.89   0.79   0.67   0.54   0.41   0.27   0.14   0.0
          0.67   0.79   0.89   1.00   0.89   0.79   0.67   0.54   0.41   0.27   0.1
          0.54   0.67   0.79   0.89   1.00   0.89   0.79   0.67   0.54   0.41   0.2
          0.41   0.54   0.67   0.79   0.89   1.00   0.89   0.79   0.67   0.54   0.4
          0.27   0.41   0.54   0.67   0.79   0.89   1.00   0.89   0.79   0.67   0.5
          0.14   0.27   0.41   0.54   0.67   0.79   0.89   1.00   0.89   0.79   0.6
          0.02   0.14   0.27   0.41   0.54   0.67   0.79   0.89   1.00   0.89   0.7
         -0.02   0.02   0.14   0.27   0.41   0.54   0.67   0.79   0.89   1.00   0.8
         -0.05  -0.02  -0.02   0.14   0.27   0.41   0.54   0.67   0.79   0.89   1.0
         -0.05  -0.05  -0.02   0.02   0.14   0.27   0.41   0.54   0.67   0.79   0.8
         -0.06  -0.05  -0.05  -0.02   0.02   0.14   0.27   0.41   0.54   0.67   0.7
         -0.05  -0.06  -0.05  -0.05  -0.02   0.02   0.14   0.27   0.41   0.54   0.6
         -0.02  -0.05  -0.06  -0.05  -0.05  -0.02   0.02   0.14   0.27   0.41   0.5
         -0.01  -0.02  -0.05  -0.06  -0.05  -0.05  -0.02   0.02   0.14   0.27   0.4
          0.02  -0.01  -0.02  -0.05  -0.06  -0.05  -0.05  -0.02   0.02   0.14   0.2
          0.04   0.02  -0.01  -0.02  -0.05  -0.06  -0.05  -0.05  -0.02   0.02   0.1
          0.05   0.04   0.02  -0.01  -0.02  -0.05  -0.06  -0.05  -0.05  -0.02   0.0
          0.05   0.05   0.04   0.02  -0.01  -0.02  -0.05  -0.06  -0.05  -0.05  -0.0
```

NOTE: The following 9 columns of these matricies are provided on the next page.

```
D =          0.53549951E-14
  6.24  -5.76  -0.43   0.02   0.23  -0.11   0.10   0.31   2.56  -2.29   0.1
 -5.76  11.55  -5.36  -0.46  -0.18   0.34  -0.21  -0.19  -2.05   4.67  -2.4
 -0.43  -5.36  11.57  -5.32  -0.51  -0.21   0.38  -0.25  -0.39  -1.85   4.6
  0.02  -0.46  -5.32  11.39  -5.19  -0.37  -0.39   0.46  -0.14  -0.54  -1.8
  0.23  -0.18  -0.51  -5.19  11.30  -5.29  -0.23  -0.44   0.48  -0.12  -0.5
 -0.11   0.34  -0.21  -0.37  -5.29  11.20  -5.15  -0.30  -0.56   0.63  -0.1
  0.10  -0.21   0.38  -0.39  -0.23  -5.15  11.01  -5.06  -0.15  -0.74   0.6
  0.31  -0.19  -0.25   0.46  -0.44  -0.30  -5.06  10.99  -4.98  -0.21  -0.7
  2.56  -2.05  -0.39  -0.14   0.48  -0.56  -0.15  -4.98  11.99  -5.84  -0.1
 -2.29   4.67  -1.85  -0.54  -0.12   0.63  -0.74  -0.21  -5.84  12.71  -5.8
  0.12  -2.40   4.65  -1.83  -0.55  -0.14   0.65  -0.75  -0.17  -5.87  12.7
 -0.84   0.88  -2.25   4.26  -1.59  -0.24  -0.56   0.78  -0.88  -0.17  -5.8
  0.59  -1.37   0.73  -1.81   3.97  -1.93   0.22  -0.72   0.78  -0.75  -0.2
  0.46   0.17  -1.41   0.79  -1.83   3.93  -1.86   0.22  -0.56   0.65  -0.7
 -1.10   1.48   0.24  -1.40   0.74  -1.82   3.93  -1.93  -0.24  -0.14   0.6
  0.80  -1.85   1.43   0.22  -1.36   0.74  -1.83   3.97  -1.59  -0.55  -0.1
  0.75   0.11  -1.91   1.47   0.22  -1.40   0.79  -1.31   4.26  -1.83  -0.5
 -1.06   1.73   0.18  -1.91   1.43   0.24  -1.41   0.73  -2.25   4.65  -1.8
  0.27  -1.31   1.73   0.11  -1.85   1.48   0.17  -1.37   0.88  -2.40   4.6
 -0.05   0.27  -1.06   0.75   0.80  -1.10   0.46   0.59  -0.84   0.12  -2.2
```

Table C-1 Cont'd

.05	-0.06	-0.05	-0.02	-0.01	0.02	0.04	0.05	0.05
.05	-0.05	-0.06	-0.05	-0.02	-0.01	0.02	0.04	0.05
.02	-0.05	-0.05	-0.06	-0.05	-0.02	-0.01	0.02	0.04
.02	-0.02	-0.05	-0.05	-0.06	-0.05	-0.02	-0.01	0.02
.14	0.02	-0.02	-0.05	-0.05	-0.06	-0.05	-0.02	-0.01
.27	0.14	0.02	-0.02	-0.05	-0.05	-0.06	-0.05	-0.02
.41	0.27	0.14	0.02	-0.02	-0.05	-0.05	-0.06	-0.05
.54	0.41	0.27	0.14	0.02	-0.02	-0.05	-0.05	-0.06
.67	0.54	0.41	0.27	0.14	0.02	-0.02	-0.05	-0.05
.79	0.67	0.54	0.41	0.27	0.14	0.02	-0.02	-0.05
.89	0.79	0.67	0.54	0.41	0.27	0.14	0.02	-0.02
.00	0.89	0.79	0.67	0.54	0.41	0.27	0.14	0.02
.89	1.00	0.89	0.79	0.67	0.54	0.41	0.27	0.14
.79	0.89	1.00	0.89	0.79	0.67	0.54	0.41	0.27
.67	0.79	0.89	1.00	0.89	0.79	0.67	0.54	0.41
.54	0.67	0.79	0.89	1.00	0.89	0.79	0.67	0.54
.41	0.54	0.67	0.79	0.89	1.00	0.89	0.79	0.67
.27	0.41	0.54	0.67	0.79	0.89	1.00	0.89	0.79
.14	0.27	0.41	0.54	0.67	0.79	0.89	1.00	0.89
.02	0.14	0.27	0.41	0.54	0.67	0.79	0.89	1.00

.84	0.59	0.46	-1.10	0.80	0.75	-1.16	0.27	-0.05
.88	-1.37	0.17	1.48	-1.85	0.11	1.73	-1.31	0.27
.25	0.73	-1.41	0.24	1.43	-1.91	0.18	1.73	-1.06
.26	-1.81	0.79	-1.40	0.22	1.47	-1.91	0.11	0.75
.59	3.97	-1.83	0.74	-1.36	0.22	1.43	-1.85	0.80
.24	-1.93	3.93	-1.82	0.74	-1.40	0.24	1.48	-1.10
.56	0.22	-1.86	3.93	-1.83	0.79	-1.41	0.17	0.46
.78	-0.72	0.22	-1.93	3.97	-1.81	0.73	-1.37	0.59
.88	0.78	-0.56	-0.24	-1.59	4.26	-2.25	0.88	-0.84
.17	-0.75	0.65	-0.14	-0.55	-1.83	4.65	-2.40	0.12
.84	-0.21	-0.74	0.63	-0.12	-0.54	-1.85	4.67	-2.29
.99	-4.98	-0.15	-0.56	-0.48	-0.14	-0.39	-2.05	2.56
.98	10.99	-5.06	-0.30	-0.44	0.46	-0.25	-0.19	0.31
.15	-5.06	11.01	-5.15	-0.23	-0.39	0.38	-0.21	0.10
.56	-0.30	-5.15	11.20	-5.29	-0.37	-0.21	0.34	-0.11
.48	-0.44	-0.23	-5.29	11.30	-5.19	-0.51	-0.18	0.23
.14	0.46	-0.39	-0.37	-5.19	11.39	-5.32	-0.46	0.02
.39	-0.25	0.38	-0.21	-0.51	-5.32	11.57	-5.36	-0.43
.05	-0.19	-0.21	0.34	-0.18	-0.46	-5.36	11.55	-5.76
.56	0.31	0.10	-0.11	0.23	0.02	-0.43	-5.76	6.24

Table C-1 Cont'd

```
          V WEIGHTS AT + AND - LAGS  FOR NDIFF= 0
   -0       0.260            0      0.025
   -1       0.012            1      0.091
   -2       0.003            2      0.088
   -3      -0.011            3      0.053
   -4      -0.022            4      0.029
   -5      -0.037            5      0.006
   -6      -0.040            6     -0.009
   -7      -0.041            7     -0.008
   -8       0.130            8      0.028
   -9       0.008            9      0.006
  -10       0.033           10      0.013
  -11      -0.041           11     -0.015
  -12      -0.003           12     -0.004
  -13       0.004           13      0.001
  -14      -0.038           14      0.006
  -15       0.001           15      0.011
  -16       0.048           16      0.011
  -17      -0.002           17      0.015
  -18       0.011           18      0.011
  -19      -0.050           19     -0.043

APPROX. 95 PER CENT CONF LIMIT ON IMPULSE RESPONSE =      0.142
```

Table C-1 Cont'd

```
CROSS CORRELATIONS AT + AND - LAGS FOR NDIFF = 1
CROSS-CORRELATIONS BETWEEN MANIPULATED VARIABLES  + RESIDUALS   X(T)*A(

   -0        0.042         0      0.042
   -1        0.049         1      0.438
   -2        0.015         2      0.407
   -3        0.032         3      0.337
   -4       -0.095         4      0.228
   -5       -0.159         5      0.048
   -6       -0.141         6      0.022
   -7       -0.263         7     -0.064
   -8       -0.043         8      0.032
   -9       -0.082         9     -0.178
  -10        0.014        10     -0.143
  -11       -0.038        11     -0.145
  -12       -0.020        12     -0.122
  -13       -0.037        13     -0.048
  -14       -0.021        14     -0.057
  -15        0.040        15      0.049
  -16        0.023        16     -0.029
  -17        0.039        17      0.074
  -18       -0.003        18      0.141
  -19        0.005        19      0.051
  -20        0.038        20     -0.013

APPROX. 95 PERCENT CONF. LIMIT ON CROSS-CORRELATIONS = 0.182

STANDARD DEVIATIONS  S(X) =      16.9733     S(A) =  0.3288E+01

CHI SQUARED STATISTIC =  79.49
BASED ON(21 NO. OF DYNAMIC PARAMETERS) DEGREES OF FREEDOM
         1.00 -0.01  0.08  0.03  0.00  0.04 -0.04 -0.02 -0.35 -0.05 -0.1
        -0.01  1.00 -0.01  0.08  0.03  0.00  0.04 -0.04 -0.02 -0.35 -0.0
         0.08 -0.01  1.00 -0.01  0.08  0.03  0.00  0.04 -0.04 -0.02 -0.3
         0.03  0.08 -0.01  1.00 -0.01  0.08  0.03  0.00  0.04 -0.04 -0.0
         0.00  0.03  0.08 -0.01  1.00 -0.01  0.08  0.03  0.00  0.04 -0.0
         0.04  0.00  0.03  0.08 -0.01  1.00 -0.01  0.08  0.03  0.00  0.0
        -0.04  0.04  0.00  0.03  0.08 -0.01  1.00 -0.01  0.08  0.03  0.0
        -0.02 -0.04  0.04  0.00  0.03  0.08 -0.01  1.00 -0.01  0.08  0.0
        -0.35 -0.02 -0.04  0.04  0.00  0.03  0.08 -0.01  1.00 -0.01  0.0
        -0.05 -0.35 -0.02 -0.04  0.04  0.00  0.03  0.08 -0.01  1.00 -0.0
        -0.12 -0.05 -0.35 -0.02 -0.04  0.04  0.00  0.03  0.08 -0.01  1.0
         0.02 -0.12 -0.05 -0.35 -0.02 -0.04  0.04  0.00  0.03  0.08 -0.0
        -0.04  0.02 -0.12 -0.05 -0.35 -0.02 -0.04  0.04  0.00  0.03  0.0
        -0.14 -0.04  0.02 -0.12 -0.05 -0.35 -0.02 -0.04  0.04  0.00  0.0
         0.09 -0.14 -0.04  0.02 -0.12 -0.05 -0.35 -0.02 -0.04  0.04  0.0
        -0.04  0.09 -0.14 -0.04  0.02 -0.12 -0.05 -0.35 -0.02 -0.04  0.0
         0.00 -0.04  0.09 -0.14 -0.04  0.02 -0.12 -0.05 -0.35 -0.02 -0.0
         0.05  0.00 -0.04  0.09 -0.14 -0.04  0.02 -0.12 -0.05 -0.35 -0.0
         0.02  0.05  0.00 -0.04  0.09 -0.14 -0.04  0.02 -0.12 -0.05 -0.3
        -0.05  0.02  0.05  0.00 -0.04  0.09 -0.14 -0.04  0.02 -0.12 -0.0
```

NOTE: The final 9 columns of these matrices are provided on the next page.

```
         D =         0.11456284E+00
         1.23  0.05 -0.05 -0.02  0.01 -0.03  0.01  0.06  0.48  0.10  0.1
         0.05  1.23  0.04 -0.06 -0.03  0.01 -0.03  0.01  0.08  0.49  0.1
        -0.05  0.04  1.23  0.04 -0.06 -0.03  0.01 -0.03 -0.01  0.07  0.4
        -0.02 -0.06  0.04  1.23  0.05 -0.06 -0.03  0.01 -0.04 -0.02  0.0
         0.01 -0.03 -0.06  0.05  1.20  0.04 -0.05 -0.05  0.01 -0.03 -0.0
        -0.03  0.01 -0.03 -0.06  0.04  1.20  0.04 -0.05 -0.07  0.01 -0.0
         0.01 -0.03  0.01 -0.03 -0.05  0.04  1.19  0.05 -0.05 -0.07  0.0
         0.06  0.01 -0.03  0.01 -0.05 -0.05  0.05  1.18  0.07 -0.04 -0.0
         0.48  0.08 -0.01 -0.04  0.01 -0.07 -0.05  0.07  1.37  0.11  0.0
         0.10  0.49  0.07 -0.02 -0.03  0.01 -0.07 -0.04  0.11  1.38  0.1
         0.11  0.10  0.48  0.07 -0.03 -0.04  0.02 -0.08  0.00  0.12  1.3
        -0.05  0.10  0.10  0.48  0.06 -0.04 -0.04  0.01 -0.10  0.00  0.1
         0.05 -0.07  0.08  0.10  0.41  0.03  0.00 -0.09  0.01 -0.08 -0.0
         0.13  0.05 -0.08  0.08  0.09  0.41  0.04  0.00 -0.04  0.02 -0.0
        -0.10  0.13  0.05 -0.08  0.08  0.09  0.41  0.03 -0.04 -0.04  0.0
         0.06 -0.10  0.13  0.05 -0.07  0.08  0.09  0.41  0.06 -0.03 -0.0
         0.19  0.06 -0.11  0.12  0.05 -0.08  0.08  0.10  0.48  0.07 -0.0
        -0.01  0.19  0.07 -0.11  0.13  0.05 -0.08
```

.02	-0.04	-0.14	0.09	-0.04	0.00	0.05	0.02	-0.05
.12	0.02	-0.04	-0.14	0.09	-0.04	0.00	0.05	0.02
.05	-0.12	0.02	-0.04	-0.14	0.09	-0.04	0.00	0.05
.35	-0.05	-0.12	0.02	-0.04	-0.14	0.09	-0.04	0.00
.02	-0.35	-0.05	-0.12	0.02	-0.04	-0.14	0.09	-0.04
.04	-0.02	-0.35	-0.05	-0.12	0.02	-0.04	-0.14	0.09
.04	-0.04	-0.02	-0.35	-0.05	-0.12	0.02	-0.04	-0.14
.00	0.04	-0.04	-0.02	-0.35	-0.05	-0.12	0.02	-0.04
.03	0.00	0.04	-0.04	-0.02	-0.35	-0.05	-0.12	0.02
.08	0.03	0.00	0.04	-0.04	-0.02	-0.35	-0.05	-0.12
.01	0.08	0.03	0.00	0.04	-0.04	-0.02	-0.35	-0.05
.00	-0.01	0.08	0.03	0.00	0.04	-0.04	-0.02	-0.35
.01	1.00	-0.01	0.08	0.03	0.00	0.04	-0.04	-0.02
.08	-0.01	1.00	-0.01	0.08	0.03	0.00	0.04	-0.04
.03	0.08	-0.01	1.00	-0.01	0.08	0.03	0.00	0.04
.00	0.03	0.08	-0.01	1.00	-0.01	0.08	0.03	0.00
.04	0.00	0.03	0.08	-0.01	1.00	-0.01	0.08	0.03
.04	0.04	0.00	0.03	0.08	-0.01	1.00	-0.01	0.08
.02	-0.04	0.04	0.00	0.03	0.08	-0.01	1.00	-0.01
.35	-0.02	-0.04	0.04	0.00	0.03	0.08	-0.01	1.00

.05	0.05	0.13	-0.10	0.06	0.19	-0.01	0.04	0.06
.10	-0.07	0.05	0.13	-0.10	0.06	0.19	-0.00	0.04
.10	0.08	-0.08	0.05	0.13	-0.11	0.07	0.19	-0.01
.48	0.10	0.08	-0.08	0.05	0.12	-0.11	0.06	0.19
.06	0.41	0.09	0.08	-0.07	0.05	0.13	-0.10	0.06
.04	0.03	0.41	0.09	0.08	-0.06	0.05	0.13	-0.10
.04	0.00	0.04	0.41	0.09	0.08	-0.08	0.05	0.13
.01	-0.09	0.00	0.03	0.41	0.10	0.08	-0.07	0.05
.10	0.01	-0.04	-0.04	0.06	0.48	0.10	0.10	-0.05
.00	-0.08	0.02	-0.04	-0.03	0.07	0.48	0.10	0.11
.11	-0.04	-0.07	0.01	-0.03	-0.02	0.07	0.49	0.10
.37	0.07	-0.03	-0.07	0.01	-0.04	-0.01	0.08	0.48
.07	1.18	0.05	-0.05	-0.05	0.01	-0.03	0.01	0.06
.05	0.05	1.19	0.04	-0.05	-0.03	0.01	-0.03	0.01
.07	-0.05	0.04	1.20	0.04	-0.06	-0.03	0.01	-0.03
.01	-0.05	-0.05	0.04	1.20	0.05	-0.06	-0.03	0.01
.04	0.01	-0.03	-0.06	0.05	1.23	0.04	-0.06	-0.02
.01	-0.03	0.01	-0.03	-0.06	0.04	1.23	0.04	-0.05
.08	0.01	-0.03	0.01	-0.03	-0.06	0.04	1.23	0.05
.48	0.05	0.01	-0.03	0.01	-0.02	-0.05	0.05	1.23

```
                  V WEIGHTS AT + AND - LAGS  FOR NDIFF= 1
           -0         0.003              0         0.006
           -1         0.004              1         0.083
           -2         0.008              2         0.088
           -3         0.005              3         0.065
           -4        -0.021              4         0.037
           -5        -0.039              5         0.008
           -6        -0.036              6        -0.001
           -7        -0.054              7        -0.010
           -8        -0.005              8         0.015
           -9        -0.009              9         0.007
          -10         0.011             10         0.022
          -11        -0.004             11         0.014
          -12        -0.009             12         0.000
          -13        -0.023             13         0.001
          -14        -0.021             14         0.005
          -15        -0.015             15         0.011
          -16        -0.001             16         0.003
          -17        -0.004             17         0.019
          -18        -0.001             18         0.033
          -19        -0.006             19         0.009

APPROX. 95 PER CENT CONF LIMIT ON IMPULSE RESPONSE =      0.039
1 1 1

   STOP
```

Table C-2

Main Program Used For Estimation of the Noise Model
With Output for Model A-1

```
      PROGRAM MAIN
C
C
      COMMON X(141),Y(141)
      EXTERNAL MODELA,MODELB,MODELC,MODELCD
      DIMENSION SCRAT(1000),TH(8),A(14,141)
      READ 3, EPS1,EPS2,FLAM,FNU,MIT,NPROB,NOB,NP
      READ 1,((A(I,J),I=1,7),J=1,NOB)
      READ 2,((A(I,J),I=8,14),J=1,NOB)
C
C
C  X DESIGNATES THE INFLUENT SERIES AND Y THE EFFLUENT SERIES
C
C
      AX=0.0
      AY=0.0
      DO 5 I=1,NOB
      X(I)=A(1,I)+A(7,I)*6.552
      Y(I)=A(14,I)
      AX=AX+X(I)
      AY=AY+Y(I)
    5 CONTINUE
      PRINT 4
      DO 9 I=1,NOB
    9 PRINT 7,X(I),Y(I)
C
C
C  SUBTRACTING THE MEAN FROM THE SERIES
C
C
      BX=AX/FLOAT(NOB)
      BY=AY/FLOAT(NOB)
      DO 6 J=1,NOB
      X(J)=X(J)-BX
      Y(J)=Y(J)-BY
    6 CONTINUE
      CALL DIFF(NOB)
      NP=3
      TH(1)=.083
      TH(2)=-.068
      TH(3)=-.055
      CALL TSHAUS(NPROB,MODELA,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SCRAT,
      NPROB=2
      NP=2
      TH(1)=.083
      TH(2)=1.06
      CALL TSHAUS(NPROB,MODELB,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SCRAT)
      NPROB=3
      NP=3
      TH(1)=.083
      TH(2)=-.0267
      TH(3)=0.739
      CALL TSHAUS(NPROB,MODELC,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SCRAT)
      NPROB=4
      NP=4
      TH(1)=0.083
      TH(2)=-.0408
      TH(3)=.0613
      TH(4)=0.569
      CALL TSHAUS(NPROB,MODELCD,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SCRAT
    1 FORMAT(26X,F5.3,19X,F4.0,1X,F3.0,1X,4F5.1)
    2 FORMAT(26X,F5.3,21X,F3.0,1X,F3.0,1X,4F5.1)
    3 FORMAT(4F10.3,4I4)
    4 FORMAT(1H1,19X,18H TKN LOAD - GM/DAY,15X,20H EFFLUENT TKN - PPM.
     *//)
    7 FORMAT(23X,E12.4,20X,E12.4)
      STOP
      END

USASI FORTRAN DIAGNOSTIC RESULTS FOR MAIN

    NO ERRORS
```

Table C-2 Cont'd

```
      SUBROUTINE DIFF(NOB)
      COMMON X(141),Y(141)
      NOB=NOB-1
      DO 1 II=1,NOB
      X(II)=X(II+1)-X(II)
    1 Y(II)=Y(II+1)-Y(II)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR DIFF

       NO ERRORS

      SUBROUTINE MODELA(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.
      A(2)=0.
      A(3)=0.
      DO 1 I=4,NOB
    1 A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)+TH(3)*X(I-3)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELA

       NO ERRORS

      SUBROUTINE MODELB(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.0
      DO 1 I=2,NOB
    1 A(I) = Y(I)-TH(1)*X(I-1)-TH(2)*Y(I-1)+TH(2)*A(I-1)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELB

       NO ERRORS
```

```
          SUBROUTINE MODELC(NPROB,TH,A,NOB,NP)
          COMMON X(141),Y(141)
          DIMENSION A(1),TH(1)
          A(1)=0.
          A(2)=0.
          DO 1 I=3,NOB
    1     A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)-TH(3)*Y(I-1)+TH(3)*A(I-
          RETURN
          END

USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELC

     NO ERRORS
```

```
          SUBROUTINE MODELCD(NPROB,TH,A,NOB,NP)
          COMMON X(141),Y(141)
          DIMENSION A(1),TH(1)
          A(1)=0.
          A(2)=0.
          A(3)=0.
          DO 1 I=4,NOB
    1     A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)+TH(3)*X(I-3)-TH(4)*Y(I-1)+TH(
         2)*A(I-1)
          RETURN
          END

USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELCD

     NO ERRORS
```

TKN LOAD - G/DAY	EFFLUENT TKN - PPM
0.9661E+02	0.9500E+01
0.9535E+02	0.1620E+02
0.8876E+02	0.2100E+02
0.9377E+02	0.2220E+02
0.9429E+02	0.2330E+02
0.6323E+02	0.2400E+02
0.6244E+02	0.2440E+02
0.8350E+02	0.2380E+02
0.1813E+02	0.2300E+02
0.1804E+02	0.1700E+02
0.1590E+02	0.1010E+02
0.1522E+02	0.2500E+01
0.1357E+02	0.9000E+00
0.1251E+02	0.6000E+00
0.1133E+02	0.2200E+01
0.1167E+02	0.1000E+01
0.2793E+02	0.1100E+01
0.3219E+02	0.3000E+01
0.3326E+02	0.2300E+01
0.4256E+02	0.2300E+01
0.4771E+02	0.2900E+01
0.4975E+02	0.3100E+01
0.3152E+02	0.3700E+01
0.2612E+02	0.3300E+01
0.5135E+02	0.2700E+01
0.3638E+02	0.2200E+01
0.3234E+02	0.1800E+01
0.2610E+02	0.1400E+01
0.3036E+02	0.1300E+01
0.3291E+02	0.1400E+01
0.3348E+02	0.1400E+01
0.7234E+02	0.1300E+01
0.1362E+02	0.1200E+01
0.1382E+02	0.6000E+00
0.1271E+02	0.7000E+00
0.1276E+02	0.1000E+01
0.5242E+01	0.1400E+01
0.1094E+02	0.1500E+01
0.9697E+01	0.1500E+01
0.8714E+01	0.1500E+01
0.9648E+02	0.1500E+01
0.9204E+02	0.7700E+01
0.1060E+03	0.1690E+02
0.1164E+03	0.2340E+02
0.1318E+03	0.2860E+02
0.1393E+03	0.3040E+02
0.1321E+03	0.3320E+02
0.1279E+03	0.3370E+02
0.1427E+03	0.3420E+02
0.1346E+03	0.3520E+02
0.1265E+03	0.3510E+02
0.1255E+03	0.3420E+02
0.1270E+03	0.3470E+02
0.1390E+03	0.3450E+02
0.1276E+03	0.3540E+02
0.1130E+03	0.3350E+02
0.4495E+02	0.3260E+02
0.4435E+02	0.2720E+02
0.4320E+02	0.2450E+02
0.4449E+02	0.2180E+02
0.4356E+02	0.2020E+02
0.4163E+02	0.1900E+02
0.4229E+02	0.1760E+02
[illegible]	0.1630E+02
0.1113E+03	0.1590E+02
0.9238E+02	0.2140E+02
0.1024E+03	0.2460E+02
0.1111E+03	0.2560E+02
0.1315E+03	0.2360E+02
0.1449E+03	0.3140E+02
0.1326E+03	0.3540E+02
0.1136E+03	0.3200E+02
0.7834E+02	0.3320E+02
0.5763E+02	0.2590E+02
0.3945E+02	0.1700E+02
0.5122E+02	0.1170E+02
0.5036E+02	0.9500E+01
0.1319E+02	0.9500E+01
[illegible]	[illegible]

0.6295E+02	0.7600E+01
0.6267E+02	0.1030E+02
0.6133E+02	0.1300E+02
0.5763E+02	0.1410E+02
0.5831E+02	0.1510E+02
0.5763E+02	0.1520E+02
0.5400E+02	0.1470E+02
0.4812E+02	0.1360E+02
0.1592E+02	0.1260E+02
0.2405E+02	0.1010E+02
0.3394E+02	0.8900E+01
0.2569E+02	0.6300E+01
0.3334E+02	0.2900E+01
0.3675E+02	0.3500E+01
0.2143E+02	0.2700E+01
0.1745E+02	0.2700E+01
0.4354E+02	0.2800E+01
0.4368E+02	0.5100E+01
0.5539E+02	0.5700E+01
0.6183E+02	0.7100E+01
0.4392E+02	0.1700E+02
0.3593E+02	0.1600E+02
0.3497E+02	0.1180E+02
0.4945E+02	0.9200E+01
0.5555E+02	0.8000E+01
0.5508E+02	0.1210E+02
0.5479E+02	0.1770E+02
0.5421E+02	0.2280E+02
0.5438E+02	0.2510E+02
0.5493E+02	0.2530E+02
0.5421E+02	0.2660E+02
0.5343E+02	0.2790E+02
0.5275E+02	0.2750E+02
0.5042E+02	0.2790E+02
0.4945E+02	0.2790E+02
0.5343E+02	0.2550E+02
0.5527E+02	0.2570E+02
0.5993E+02	0.2810E+02
0.5973E+02	0.2950E+02
0.5838E+02	0.3170E+02
0.5382E+02	0.3310E+02

Table C-2 Cont'd

```
NON-LINEAR ESTIMATION, PROBLEM NUMBER  5

 120 OBSERVATIONS,     3 PARAMETERS                    504 SCRATCH REQUIRED

INITIAL PARAMETER VALUES
     1           2           3
 0.8330E-01 -0.2670E-01  0.7390E+00

INITIAL SUM OF SQUARES =  0.4295E+03



                                                   ITERATION NO.    1
DETERMINANT =  0.2334E+00          ANGLE IN SCALED COORD. =40.58DEGREES
TEST POINT PARAMETER VALUES
 0.8009E-01 -0.2987E-01  0.6059E+00

TEST POINT SUM OF SQUARES =  0.3320E+03

PARAMETER VALUES VIA REGRESSION
     1           2           3
 0.8009E-01 -0.2987E-01  0.6059E+00

LAMBDA = 0.100E-02                     SUM OF SQUARES AFTER REGRESSION
                                                =332.04


                                                   ITERATION NO.    2
DETERMINANT =  0.2563E+00          ANGLE IN SCALED COORD. =32.50DEGREES
TEST POINT PARAMETER VALUES
 0.8296E-01 -0.4295E-01  0.5121E+00
TEST POINT SUM OF SQUARES =  0.3248E+03

PARAMETER VALUES VIA REGRESSION
     1           2           3
 0.8296E-01 -0.4295E-01  0.5121E+00
                                      SUM OF SQUARES AFTER REGRESSION
LAMBDA = 0.100E-03                              =324.76



                                                   ITERATION NO.    3
DETERMINANT =  0.2889E+00          ANGLE IN SCALED COORD. =48.88DEGREES

TEST POINT PARAMETER VALUES
 0.8356E-01 -0.3998E-01  0.5328E+00
TEST POINT SUM OF SQUARES =  0.3245E+03

PARAMETER VALUES VIA REGRESSION
     1           2           3
 0.8356E-01 -0.3998E-01  0.5328E+00

LAMBDA = 0.100E-04                   SUM OF SQUARES AFTER REGRESSION
                                              =324.52


                                                   ITERATION NO.    4
DETERMINANT =  0.2791E+00          ANGLE IN SCALED COORD. =36.32DEGREES
```

```
TEST POINT SUM OF SQUARES =  0.3245E+03

PARAMETER VALUES VIA REGRESSION

      1            2            3
 0.8356E-01 -0.4114E-01  0.5252E+00

LAMBDA = 0.100E-05                         SUM OF SQUARES AFTER REGRESSION
                                                   =324.50


                                                ITERATION NO.   5
DETERMINANT =   0.2825E+00         ANGLE IN SCALED COORD. =34.45DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4074E-01  0.5278E+00

TEST POINT SUM OF SQUARES =  0.3245E+03

PARAMETER VALUES VIA REGRESSION

      1            2            3
 0.8357E-01 -0.4074E-01  0.5278E+00

LAMBDA = 0.100E-06                         SUM OF SQUARES AFTER REGRESSION
                                                   =324.49


                                                ITERATION NO.   6
DETERMINANT =   0.2813E+00         ANGLE IN SCALED COORD. =34.51DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.2813E+00         ANGLE IN SCALED COORD. =34.51DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.2813E+00         ANGLE IN SCALED COORD. =34.51DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.2813E+00         ANGLE IN SCALED COORD. =34.51DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.2815E+00         ANGLE IN SCALED COORD. =34.50DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.2832E+00         ANGLE IN SCALED COORD. =34.47DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4088E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.3008E+00         ANGLE IN SCALED COORD. =34.13DEGREES

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4087E-01  0.5269E+00

TEST POINT SUM OF SQUARES =  0.3245E+03
DETERMINANT =   0.5042E+00         ANGLE IN SCALED COORD. =31.17DEGREES

TEST POINT PARAMETER VALUES
```

```
DETERMINANT =  0.6201E+01        ANGLE IN SCALED COORD. =18.48DEGREES

TEST POINT PARAMETER VALUES
 0.8358E-01 -0.4075E-01  0.5276E+00

TEST POINT SUM OF SQUARES =  0.3245E+03

TEST POINT PARAMETER VALUES
 0.8357E-01 -0.4074E-01  0.5277E+00

TEST POINT SUM OF SQUARES =  0.3245E+03

PARAMETER VALUES VIA REGRESSION

     1           2           3
 0.8357E-01 -0.4074E-01  0.5277E+00

LAMBDA = 0.100E+01                    SUM OF SQUARES AFTER REGRESSION
                                                =324.49

ITERATION STOPS - RELATIVE CHANGE IN SUM OF SQUARES LESS THAN  0.1000E-0
```

Table C-2 Cont'd

```
FINAL RESIDUAL VALUES
  0.0000E+00  0.0000E+00 -0.9757E+00 -0.1960E+00 -0.2329E+00  0.8109E+0
 -0.4412E+01  0.7320E-01  0.7930E+00  0.2337E+01 -0.7069E+00  0.4651E+0
 -0.1364E+01 -0.5930E+00  0.4111E+00  0.8544E+00 -0.1536E+01 -0.6637E+0
 -0.3164E+00 -0.1425E+00  0.9713E+00  0.1684E+01  0.1229E+01  0.9301E+0
 -0.1182E+01  0.2185E+01  0.1892E+01 -0.5668E+00  0.5185E-01 -0.4360E+0
 -0.1639E+00  0.1289E+01  0.1337E+00  0.1371E-01 -0.1799E+01  0.6635E+0
 -0.2004E+00 -0.6856E+00 -0.8866E+00 -0.9322E-01 -0.1648E+00 -0.1112E+0
 -0.4866E+01  0.2516E+01 -0.2884E+01 -0.3403E+01 -0.1036E+01  0.1337E+0
  0.1037E+01  0.1086E+01  0.3297E+00  0.9734E+00  0.1193E+00 -0.4179E+0
 -0.2483E+01 -0.3068E+01  0.4384E+00 -0.1452E+01  0.8177E+00  0.1488E+0
 -0.7263E+00 -0.2741E+01 -0.1382E+01 -0.5878E+00  0.1742E+01  0.4675E+0
  0.1307E+01 -0.2397E+00  0.5413E+00  0.2967E+00 -0.1066E+01  0.8265E-0
```

NOTE: The final 4 columns of this matrix are given on page C-31

```
CORRELATION MATRIX
         1           2           3

  1   1.0000
  2   0.3948      1.0000
  3   0.0068      0.7107      1.0000


NORMALIZING ELEMENTS
      1           2           3
 0.5360E-02  0.7620E-02  0.3581E-01

VARIANCE OF RESIDUALS =  0.2773E+01, 117 DEGREES OF FREEDOM

INDIVIDUAL CONFIDENCE LIMITS FOR EACH PARAMETER (ON LINEAR HYPOTHESIS)
      1           2           3
 0.1014E+00 -0.1536E-01  0.6469E+00
 0.6572E-01 -0.6512E-01  0.4084E+00
```

0.1335E+00	-0.2267E+00	-0.4021E+00	-0.1393E+01
0.7081E+00	-0.2389E+01	-0.1154E+01	-0.6547E+00
0.4192E+00	0.1039E+01	0.5996E+00	-0.1232E+00
0.1007E+01	0.3091E+00	0.3467E-01	0.1513E+00
-0.9074E+00	0.4044E+00	-0.1136E+00	-0.6164E+00
0.1771E+01	0.3865E+01	0.9061E+00	0.2628E+00
-0.1318E+01	0.6644E+00	-0.4926E+00	0.3082E+00
0.9299E+00	0.1714E+01	0.2477E+00	-0.9831E+00
-0.6643E+00	-0.1415E+00	0.6649E+00	0.1218E+01
0.1006E+01	-0.1571E+01	-0.5119E+00	0.6080E+01
0.4656E+01	0.3126E+01	0.7525E-01	0.1984E+00
0.1022E+01	0.7365E+00	0.1676E+01	0.1245E+01

Table C-2 Cont'd

```
 AUTO AND PARTIAL CORRELATIONS OF THE RESIDUALS
-----------------------------------------------------------------------------
        I                  AUTO                 PARTIAL

        1                 0.219                  0.219
        2                -0.045                 -0.098
        3                -0.064                 -0.033
        4                -0.043                 -0.027
-----------------------------------------------------------------------------
        5                -0.042                 -0.035
        6                 0.089                  0.106
        7                 0.140                  0.094
        8                -0.016                 -0.067
-----------------------------------------------------------------------------
        9                -0.087                 -0.052
       10                 0.075                  0.126
       11                 0.117                  0.081
       12                 0.127                 -0.015
-----------------------------------------------------------------------------
       13                -0.097                 -0.123
       14                -0.040                  0.008
       15                -0.139                 -0.113
       16                -0.073                 -0.017
-----------------------------------------------------------------------------
       17                -0.049                 -0.105
       18                 0.089                  0.079
       19                 0.045                  0.031
       20                 0.043                  0.062
-----------------------------------------------------------------------------
       21                 0.048                  0.031
       22                -0.007                 -0.012
       23                 0.062                  0.135
       24                 0.095                  0.086
-----------------------------------------------------------------------------
       25                 0.003                 -0.030
       26                -0.124                 -0.139
       27                -0.072                  0.005
       28                 0.095                  0.107
-----------------------------------------------------------------------------
       29                -0.021                 -0.121
       30                 0.108                  0.049

-----------------------------------------------------------------------------
APPROX. 95 PERCENT CONF. LIMIT ON CORRELATIONS = 0.183

CHI-SQUARED STATISTIC =  26.46
BASED ON (30 - NO. OF STOCHASTIC PARAMETERS) DEGREES OF FREEDOM
-----------------------------------------------------------------------------
```

Table C-3
Computer Program Used For The Simultaneous TF-N Model Parameter Estimation and Residual Checks With Output for Model A-1 Sample

```
      PROGRAM MAIN
C
C
      COMMON X(141),Y(141)
      EXTERNAL MODELA,MODELB,MODELC,MODELAA,MODELCD,MODELBB
      DIMENSION SCRAT(1000),TH(8),A(14,141)
      READ 3, EPS1,EPS2,FLAM,FNU,MIT,NPROB,NOB,NP
      READ 1,((A(I,J),I=1,7),J=1,NOB)
      READ 2,((A(I,J),I=8,14),J=1,NOB)
C
C
C  X DESIGNATES THE INFLUENT SERIES AND Y THE EFFLUENT SERIES
C
C
      AX=0.0
      AY=0.0
      DO 5 I=1,NOB
      X(I)=A(1,I)*A(7,I)*6.552
      Y(I)=A(14,I)
      AX=AX+X(I)
      AY=AY+Y(I)
    5 CONTINUE
      PRINT 4
      DO 9 I=1,NOB
    9 PRINT 7,X(I),Y(I)
C
C
C  SUBTRACTING THE MEAN FROM THE SERIES
C
C
      BX=AX/FLOAT(NOB)
      BY=AY/FLOAT(NOB)
      DO 6 J=1,NOB
      X(J)=X(J)-BX
      Y(J)=Y(J)-BY
    6 CONTINUE
      CALL DIFF(NOB)
      NP=4
      TH(1)=0.08263
      TH(2)=0.08041
      TH(3)=-0.05346
      TH(4)=0.192
      CALL TSHAUS(NPROB,MODELA,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,S(
      NZERO=1
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
      NPROB=2
      TH(1)=.1905
      TH(2)=1.06
      TH(3)=.895
      NP=3
      CALL TSHAUS(NPROB,MODELB,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,S(
      NZERO=2
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
      NPROB=3
      TH(1)=.08357
      TH(2)=-.04074
      TH(3)=.5277
      TH(4)=.219
      NP=4
      CALL TSHAUS(NPROB,MODELC,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SC
      NZERO=3
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
      NPROB=4
      TH(1)=.0817
      TH(2)=-.04937
      TH(3)=-.03234
      TH(4)=.3679
      TH(5)=1.208
      NP=5
```

```
      CALL TSHAUS(NPROB,MODELCD,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SC
      NZERO=4
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
      NPROB=11
      NP=5
      TH(1)=0.06263
      TH(2)=0.06041
      TH(3)=+0.05946
      TH(4)=0.2
      TH(5)=-.125
      CALL TSHAUS(NPROB,MODELAA,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SC
      NZERO=5
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
      NPROB=21
      NP=2
      TH(1)=.1905
      TH(2)=1.06
      CALL TSHAUS(NPROB,MODELBB,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,SC
      NZERO=2
      IG=5*NP+1+NZERO
      NOB=NOB-NZERO
      CALL CROSS(X(NZERO),SCRAT(IG),NOB,20)
      NOB=NOB+NZERO
    1 FORMAT(25X,F5.3,19X,F4.0,1X,F3.0,1X,4F5.1)
    2 FORMAT(25X,F5.3,21X,F3.0,1X,F3.0,1X,4F5.1)
    3 FORMAT(4F10.3,4I4)
    4 FORMAT(1H1,13X,18H TKN LOAD - GM/DAY,15X,20H EFFLUENT TKN - P
     *//)
    7 FORMAT(23X,E12.4,20X,E12.4)
      STOP
      END
```

```
USASI FORTRAN DIAGNOSTIC RESULTS FOR MAIN

      NO ERRORS
```

Table C-3 Cont'd

```
ANSI FORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPT


                 SUBROUTINE DIFF(NOB)
                 COMMON X(141),Y(141)
                 NOB=NOB-1
                 DO 1 II=1,NOB
                 X(II)=X(II+1)-X(II)
        1        Y(II)=Y(II+1)-Y(II)
                 RETURN
                 END

     USASI FORTRAN DIAGNOSTIC RESULTS FOR DIFF

          NO ERRORS
```

```
ANSI FORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPT


                 SUBROUTINE MODELA(NPROB,TH,A,NOB,NP)
                 COMMON X(141),Y(141)
                 DIMENSION A(1),TH(1)
                 A(1)=0.
                 A(2)=0.
                 A(3)=0.
                 A(4)=0.
                 DO 1 I=5,NOB
        1        A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)+TH(3)*X(I-3)
                2-TH(4)*Y(I-1)
                3 +TH(1)*TH(4)*X(I-2)-TH(2)*TH(4)*X(I-3)-TH(3)*TH(4)*X(I-4)
                 RETURN
                 END

     USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELA

          NO ERRORS
```

```
ANSI FORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPT


                 SUBROUTINE MODELB(NPROB,TH,A,NOB,NP)
                 COMMON X(141),Y(141)
                 DIMENSION A(1),TH(1)
                 A(1)=0.0
                 A(2)=0.
                 DO 1 I=3,NOB
        1        A(I) = Y(I)-TH(1)*X(I-1)-TH(2)*Y(I-1)+TH(2)*A(I-1)
                2 -TH(3)*Y(I-1)+TH(3)*TH(2)*Y(I-2)
                3 +TH(1)*TH(3)*X(I-2)
                 RETURN
                 END

     USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELB

          NO ERRORS
```

```
RTRAN(2.3)/MASTER        INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPTION IS

      SUBROUTINE MODELCD(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.
      A(2)=0.
      A(3)=0.
      A(4)=0.
      DO 1 I=5,NOB
    1 A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)+TH(3)*X(I-3)-TH(4)*Y(I-1)+TH(4
     2)*A(I-1)
     3 -TH(5)*Y(I-1)+TH(5)*TH(4)*Y(I-2)
     4 +TH(1)*TH(5)*X(I-2)-TH(2)*TH(5)*X(I-3)-TH(3)*TH(5)*X(I-4)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELCD

      NO ERRORS
```

```
RTRAN(2.3)/MASTER        INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPTION IS

      SUBROUTINE MODELC(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.
      A(2)=0.
      A(3)=0.
      DO 1 I=4,NOB
    1 A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)-TH(3)*Y(I-1)+TH(3)*A(I-1)
     2 -TH(4)*Y(I-1)+TH(4)*TH(3)*Y(I-2)
     3  +TH(1)*TH(4)*X(I-2)-TH(2)*TH(4)*X(I-3)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELC

      NO ERRORS
```

```
FORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPTION IS

      SUBROUTINE MODELAA(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.
      A(2)=0.
      A(3)=0.
      A(4)=0.
      A(5)=0.
      DO 1 I=6,NOB
    1 A(I)=Y(I)-TH(1)*X(I-1)+TH(2)*X(I-2)+TH(3)*X(I-3)-TH(4)*Y(I-1)-TH
     *)*Y(I-2)
     2 +TH(1)*TH(4)*X(I-2)-TH(2)*TH(4)*X(I-3)-TH(3)*TH(4)*X(I-4)
     3 +TH(1)*TH(5)*X(I-3)-TH(2)*TH(5)*X(I-4)-TH(3)*TH(5)*X(I-5)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELAA

      NO ERRORS
```

```
ORTRAN(2.3)/MASTER      INTEGER WORD SIZE = 1 , * OPTION IS  OFF , 0 OPTION IS

      SUBROUTINE MODELBB(NPROB,TH,A,NOB,NP)
      COMMON X(141),Y(141)
      DIMENSION A(1),TH(1)
      A(1)=0.
      A(2)=0.
      DO 1 I=3,NOB
    1 A(I) = Y(I)-TH(1)*X(I-1)-TH(2)*Y(I-1)+TH(2)*A(I-1)
     2  +A(I-1)-TH(2)*A(I-2)
      RETURN
      END

 USASI FORTRAN DIAGNOSTIC RESULTS FOR MODELBB

      NO ERRORS
```

Table C-3 Cont'd

TKN LOAD - GM/DAY	EFFLUENT TKN - PPM.
0.9061E+02	0.9500E+01
0.9535E+02	0.1620E+02
0.8876E+02	0.2100E+02
0.9377E+02	0.2220E+02
0.9429E+02	0.2330E+02
0.8323E+02	0.2400E+02
0.8244E+02	0.2440E+02
0.8060E+02	0.2380E+02
0.1813E+02	0.2300E+02
0.1804E+02	0.1700E+02
0.1590E+02	0.1010E+02
0.1522E+02	0.2500E+01
0.1367E+02	0.9000E+00
0.1251E+02	0.6000E+00
0.1183E+02	0.2200E+01
0.1067E+02	0.1000E+01
0.2793E+02	0.1100E+01
0.3219E+02	0.3000E+01
0.3326E+02	0.2300E+01
0.4286E+02	0.2300E+01
0.4771E+02	0.2900E+01
0.4975E+02	0.3100E+01
0.3152E+02	0.3700E+01
0.2812E+02	0.3300E+01
0.5135E+02	0.2700E+01
0.3688E+02	0.2200E+01
0.3234E+02	0.1800E+01
0.2610E+02	0.1400E+01
0.3036E+02	0.1300E+01
0.3291E+02	0.1400E+01
0.3348E+02	0.1400E+01
0.3234E+02	0.1300E+01
0.1382E+02	0.1200E+01
0.1382E+02	0.6000E+00
0.1271E+02	0.7000E+00
0.1278E+02	0.1000E+01
0.5242E+01	0.1400E+01
0.1094E+02	0.1500E+01
0.9697E+01	0.1500E+01
0.8714E+01	0.1500E+01
0.9848E+02	0.1500E+01
0.9204E+02	0.7700E+01
0.1060E+03	0.1690E+02
0.1164E+03	0.2340E+02
0.1318E+03	0.2660E+02
0.1393E+03	0.3040E+02
0.1321E+03	0.3320E+02
0.1279E+03	0.3370E+02
0.1427E+03	0.3420E+02
0.1346E+03	0.3520E+02
0.1265E+03	0.3510E+02
0.1256E+03	0.3420E+02
0.1270E+03	0.3470E+02
0.1390E+03	0.3450E+02
0.1276E+03	0.3540E+02
0.1130E+03	0.3360E+02
0.4495E+02	0.3260E+02
0.4485E+02	0.2720E+02
0.4320E+02	0.2450E+02
0.4449E+02	0.2180E+02
0.4366E+02	0.2020E+02
0.4183E+02	0.1900E+02
0.4229E+02	0.1760E+02
0.4100E+02	0.1630E+02
0.1113E+03	0.1590E+02
0.9288E+02	0.2140E+02
0.1024E+03	0.2460E+02
0.1111E+03	0.2560E+02
0.1315E+03	0.2860E+02
0.1449E+03	0.3140E+02
0.1326E+03	0.3540E+02
0.1136E+03	0.3200E+02
0.7834E+02	0.3320E+02
0.5763E+02	0.2590E+02
0.3945E+02	0.1700E+02
0.5120E+02	0.1070E+02
0.5036E+02	0.9500E+01
0.1819E+02	0.9500E+01
0.5120E+02	0.8000E+01
0.4364E+02	[illegible]

0.6295E+02	0.7600E+01
0.6267E+02	0.1030E+02
0.6183E+02	0.1300E+02
0.5763E+02	0.1410E+02
0.5931E+02	0.1510E+02
0.5763E+02	0.1520E+02
0.5400E+02	0.1470E+02
0.4812E+02	0.1360E+02
0.1590E+02	0.1260E+02
0.2405E+02	0.1010E+02
0.3394E+02	0.8900E+01
0.2589E+02	0.6300E+01
0.3384E+02	0.2900E+01
0.3675E+02	0.3500E+01
0.2143E+02	0.2700E+01
0.1745E+02	0.2700E+01
0.4364E+02	0.2800E+01
0.4868E+02	0.5100E+01
0.5539E+02	0.5700E+01
0.6183E+02	0.7100E+01
0.4392E+02	0.1700E+02
0.3693E+02	0.1600E+02
0.3497E+02	0.1180E+02
0.4945E+02	0.9200E+01
0.5556E+02	0.9000E+01
0.5508E+02	0.1210E+02
0.5479E+02	0.1770E+02
0.5421E+02	0.2280E+02
0.5488E+02	0.2610E+02
0.5498E+02	0.2630E+02
0.5421E+02	0.2560E+02
0.5343E+02	0.2790E+02
0.5275E+02	0.2750E+02
0.5042E+02	0.2790E+02
0.4945E+02	0.2790E+02
0.5343E+02	0.2650E+02
0.5527E+02	0.2670E+02
0.5993E+02	0.2810E+02
0.5973E+02	0.2950E+02
0.5838E+02	0.3170E+02
0.5382E+02	0.3310E+02

Table C-3 Cont'd

```
NON-LINEAR ESTIMATION, PROBLEM NUMBER  3

 120 OBSERVATIONS,     4 PARAMETERS                   636 SCRATCH REQUIRED

 INITIAL PARAMETER VALUES

        1           2           3           4
  0.8357E-01 -0.4074E-01  0.5277E+00  0.2190E+00

 INITIAL SUM OF SQUARES =  0.3076E+03



                                                    ITERATION NO.    1
 DETERMINANT =   0.3975E+00        ANGLE IN SCALED COORD. =18.40DEGREES

 TEST POINT PARAMETER VALUES
  0.8298E-01 -0.3341E-01  0.5684E+00  0.2235E+00

 TEST POINT SUM OF SQUARES =  0.3068E+03

 PARAMETER VALUES VIA REGRESSION

        1           2           3           4
  0.8298E-01 -0.3341E-01  0.5684E+00  0.2235E+00

 LAMBDA = 0.100E-02                                              SUM OF SQUA
                                                After Regression = 306.7

                                                    ITERATION NO.    2
 DETERMINANT =   0.3725E+00        ANGLE IN SCALED COORD. =38.75DEGREES

 TEST POINT PARAMETER VALUES
  0.8316E-01 -0.3529E-01  0.5535E+00  0.2365E+00

 TEST POINT SUM OF SQUARES =  0.3067E+03

 PARAMETER VALUES VIA REGRESSION

        1           2           3           4
  0.8316E-01 -0.3529E-01  0.5535E+00  0.2365E+00

 LAMBDA = 0.100E-03                                              SUM OF SQUA
                                                After Regression = 306.6

                                                    ITERATION NO.    3
 DETERMINANT =   0.3873E+00        ANGLE IN SCALED COORD. =32.57DEGREES

 TEST POINT PARAMETER VALUES
  0.8310E-01 -0.3424E-01  0.5610E+00  0.2327E+00

 TEST POINT SUM OF SQUARES =  0.3067E+03

 PARAMETER VALUES VIA REGRESSION

        1           2           3           4
  0.8310E-01 -0.3424E-01  0.5610E+00  0.2327E+00

 LAMBDA = 0.100E-04                                              SUM OF SQUAR
                                                After Regression =306.65

                                                    ITERATION NO.    4
 DETERMINANT =   0.3811E+00        ANGLE IN SCALED COORD. =35.82DEGREES

 TEST POINT PARAMETER VALUES
  0.8314E-01 -0.3471E-01  0.5574E+00  0.2348E+00
```

```
TEST POINT SUM OF SQUARES =  0.3067E+03

PARAMETER VALUES VIA REGRESSION

      1            2             3            4
 0.8314E-01 -0.3471E-01  0.5574E+00  0.2348E+00

LAMBDA = 0.100E-05                                SUM OF SQUARE
                                   After Regression = 306.65



                                           ITERATION NO.   5
DETERMINANT =   0.3841E+00        ANGLE IN SCALED COORD. =34.96DEGREES

TEST POINT PARAMETER VALUES
 0.8312E-01 -0.3449E-01  0.5591E+00  0.2338E+00

TEST POINT SUM OF SQUARES =  0.3066E+03

PARAMETER VALUES VIA REGRESSION

      1            2             3            4
 0.8312E-01 -0.3449E-01  0.5591E+00  0.2338E+00

LAMBDA = 0.100E-06                                SUM OF SQUARE
                                   After Regression = 306.65



                                           ITERATION NO.   6
DETERMINANT =   0.3827E+00        ANGLE IN SCALED COORD. =35.27DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3460E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.3827E+00        ANGLE IN SCALED COORD. =35.27DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3460E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.3827E+00        ANGLE IN SCALED COORD. =35.27DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3460E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.3827E+00        ANGLE IN SCALED COORD. =35.27DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3460E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.3830E+00        ANGLE IN SCALED COORD. =35.26DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3460E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.3853E+00        ANGLE IN SCALED COORD. =35.23DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3459E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.4090E+00        ANGLE IN SCALED COORD. =34.85DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3459E-01  0.5583E+00  0.2343E+00

TEST POINT SUM OF SQUARES =  0.3066E+03
DETERMINANT =   0.6960E+00        ANGLE IN SCALED COORD. =31.52DEGREES
TEST POINT PARAMETER VALUES
```

```
DETERMINANT =  0.1315E+02        ANGLE IN SCALED COORD. =16.41DEGREES

TEST POINT PARAMETER VALUES
 0.8313E-01 -0.3450E-01  0.5589E+00  0.2340E+00

TEST POINT SUM OF SQUARES =  0.3066E+03

TEST POINT PARAMETER VALUES
 0.8312E-01 -0.3450E-01  0.5590E+00  0.2339E+00

TEST POINT SUM OF SQUARES =  0.3066E+03

PARAMETER VALUES VIA REGRESSION

        1          2           3           4
 0.8312E-01 -0.3450E-01  0.5590E+00  0.2339E+00

LAMBDA = 0.100E+01                                SUM OF SQUARES
                                          After Regression = 306.65

ITERATION STOPS - RELATIVE CHANGE IN SUM OF SQUARES LESS THAN  0.1000E-0
```

```
FINAL RESIDUAL VALUES
 0.0000E+00  0.0000E+00  0.0000E+00  0.4975E+00  0.9057E-01  0.9914E+0
-0.3983E+01  0.1206E+01  0.8634E+00  0.2213E+01 -0.1209E+01  0.6822E+0
-0.1151E+01 -0.2882E+00  0.5131E+00  0.6554E+00 -0.1737E+01 -0.2273E+0
-0.2649E+00 -0.6238E-01  0.9922E+00  0.1387E+01  0.8607E+00  0.6677E+0
-0.1173E+01  0.2804E+01  0.1242E+01 -0.1180E+01  0.1311E+00 -0.4974E+0
-0.9157E-01  0.1276E+01 -0.1701E+00  0.1063E-02 -0.1755E+01  0.1043E+0
-0.1510E+00 -0.5668E+00 -0.6809E+00  0.1522E+00 -0.9219E-01 -0.7992E+0
-0.4973E+01  0.3514E+01 -0.3615E+01 -0.2877E+01 -0.2672E+00  0.1612E+0
 0.1323E+01  0.9181E+00  0.5514E-01  0.8709E+00 -0.1454E+00 -0.4494E+0
-0.2673E+01 -0.2404E+01  0.1152E+01 -0.1503E+01  0.1167E+01  0.1232E+0
-0.2640E+01 -0.2685E+01 -0.7779E+00 -0.3533E+00  0.1979E+01  0.4288E+0
 0.1254E+01 -0.6135E+00  0.6060E+00  0.1667E+00 -0.1144E+01  0.3357E+0
```

NOTE: The final 4 olumns of this matrix are on the next page.

```
CORRELATION MATRIX
          1              2              3              4

  1  1.0000
  2  0.1944         1.0000
  3 -0.1021         0.7028         1.0000
  4 -0.1447         0.0054         0.0115         1.0000


NORMALIZING ELEMENTS
       1           2           3           4
 0.5346E-02  0.7461E-02  0.4199E-01  0.5560E-01


VARIANCE OF RESIDUALS =  0.2644E+01, 116 DEGREES OF FREEDOM

INDIVIDUAL CONFIDENCE LIMITS FOR EACH PARAMETER (ON LINEAR HYPOTHESIS)
       1           2           3           4
 0.1005E+00 -0.1024E-01  0.6955E+00  0.4147E+00
 0.6574E-01 -0.5876E-01  0.4225E+00  0.5312E-01
```

-0.3499E-01	-0.2156E+00	-0.3510E+00	-0.1510E+01
0.6224E+00	-0.2469E+01	-0.5905E+00	-0.6013E+00
0.5072E+00	0.9188E+00	0.3442E+00	-0.2266E+00
0.8116E+00	0.6683E-01	0.7318E-02	0.1505E+00
-0.8862E+00	0.4935E+00	-0.2833E+00	-0.5685E+00
0.1526E+01	0.3219E+01	0.1235E+00	0.1742E+00
-0.1210E+01	0.9360E+00	-0.6762E+00	0.4404E+00
0.7751E+00	0.1558E+01	-0.2062E+00	-0.8400E+00
-0.6005E+00	0.6953E-03	0.8866E+00	0.9076E+00
0.6687E+00	-0.1682E+01	-0.1377E+00	0.8196E+01
0.3543E+01	0.2017E+01	-0.6720E+00	0.1743E+00
0.1025E+01	0.5066E+00	0.1517E+01	0.8400E+00

```
AUTO AND PARTIAL CORRELATIONS OF THE RESIDUALS

       I                AUTO                PARTIAL

       1                0.018                0.018
       2               -0.080               -0.080
       3               -0.050               -0.048
       4               -0.029               -0.034
       5               -0.067               -0.075
       6                0.066                0.061
       7                0.119                0.104
       8               -0.033               -0.035
       9               -0.112               -0.095
      10                0.075                0.085
      11                0.099                0.099
      12                0.021                0.029
      13               -0.101               -0.112
      14                0.006                0.003
      15               -0.136               -0.115
      16               -0.031               -0.011
      17               -0.059               -0.123
      18                0.098                0.047
      19                0.023                0.031
      20                0.026                0.054
      21                0.042                0.042
      22               -0.033               -0.037
      23                0.055                0.110
      24                0.092                0.112
      25                0.017                0.030
      26               -0.117               -0.126
      27               -0.076               -0.047
      28                0.140                0.147
      29               -0.073               -0.102
      30                0.155                0.092

APPROX. 95 PERCENT CONF. LIMIT ON CORRELATIONS = 0.183

CHI-SQUARED STATISTIC =   22.73
BASED ON (30 - NO. OF STOCHASTIC PARAMETERS) DEGREES OF FREEDOM
```

```
              CROSS-CORRELATIONS BETWEEN MANIPULATED VARIABLES AND RESIDUA

      -0        -0.007              0        -0.007
      -1         0.038              1        -0.028
      -2         0.025              2         0.148
      -3        -0.003              3         0.047
      -4         0.145              4        -0.15[illegible]
      -5        -0.035              5        -0.11[illegible]
      -6        -0.037              6        -0.170
      -7         0.176              7         0.115
      -8        -0.014              8        -0.072
      -9         0.090              9         0.078
     -10        -0.048             10         0.012
     -11         0.031             11        -0.053
     -12         0.048             12         0.046
     -13         0.055             13         0.098
     -14        -0.115             14         0.174
     -15        -0.042             15        -0.049
     -16         0.001             16         0.170
     -17        -0.041             17         0.15[illegible]
     -18         0.036             18         0.011
     -19        -0.041             19        -0.004
     -20        -0.124             20        -0.004

APPROX. 95 PERCENT CONF. LIMIT ON CROSS-CORRELATIONS =  0.185
STANDARD DEVIATIONS  S(X) =  0.1723E+02       S(A) =  0.1614E+01

CHI-SQUARED STATISTIC =  21.33 BASED ON 21 DEGREES OF FREEDOM
```

Table C-4
Subroutine TSHAUS

```
      SUBROUTINE TSHAUS(NPROB,MODEL,NOB,NP,TH,EPS1,EPS2,MIT,FLAM,FNU,
     1 SCRAT)
C     RESIDUALS ARE RETURNED IN SCRAT(IG)  WHERE IG=5*NP+1
      DIMENSION SCRAT(1)
      IA =1
      IB=I A+NP
      IC=I B+NP
      ID=I C+NP
      IE=ID+NP
      IG  =  IE+NP
      IH=IG+NOB
      II  =  IH  +  NP  *  NOB
      IJ  =  IH
           CALL   HAUSTS(NPROB,MODEL,NOB,   NP,TH,             EPS1,EPS2,MIT
     1,FLAM,FNU,   SCRAT(IA),  SCRAT(IB),  SCRAT(IC),  SCRAT(ID),
     2  SCRAT(IE),             SCRAT(IG),  SCRAT(IH),  SCRAT(II),SCRAT(IJ))
      CALL  IDENT(SCRAT(IG),NOB,20,2)
      RETURN
      END
      SUBROUTINE HAUSTS(NPRBO, MODEL, NBO,    NQ,TH,             EP1S,EP2S,
     1MIT,FLAM,FNU,    Q,P,E,PHI,TB,   R,A,D,DELZ)
C                FORTRAN II VERSION
C     ADAPTED FOR THE CDC 6400   (J. F. MACGREGOR  9/72)
C
C     DIMENSION TH(NQ), R(NBO)
C     DIMENSION Q(NQ), P(NQ), E(NQ), PHI(NQ), TB(NQ)
C     DIMENSION A(NQ,NQ), D(NQ,NQ), DELZ(NBO,NQ)
      DIMENSION TH(1),                             Q(1), P(1), E(1),
     1   PHI(1), TB(1),         R(1), A(1), D(1), DELZ(1)
      DIMENSION AC(31),PP(31)
      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  +   NOB+NP*NOB
       PRINT 1000, NPROB, NOB, NP, NSCRAC
      PRINT  1001
       CALL  GASS60(1, NP, TH, TEMP, TMEP)
      IF(MINO(NP-1,50-NP,NOB-NP,MIT-1,999-MIT))99,15,15
  15  IF(FNU-1.0)99, 99, 16
  16  CONTINUE
      DO 19 I=1,NP
      IF( ABS(TH(I)) )   99,99,19
  19  CONTINUE
      GA  =  FLAM
      NIT  =  1
      IF(EPS1)  5,70,70
  5   EPS1  =  0
   70 SSQ  =  0
      CALL  MODEL(NPROB, TH, R, NOB, NP)
      DO 90 I  =  1, NOB
   90 SSQ=SSQ+R(I)*R(I)
      PRINT  1003, SSQ
```

```
 100  GA = GA / FNU
      INTCNT = 0
      PRINT 1004, NIT
 101  JS = 1 - NOB
      DO 130 J=1,NP
      TEMP = TH(J)
      P(J) = 0.01*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) = R(I) - DELZ(IJ)
 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
 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)
      PRINT 1041, DET, TEMP
  170 DO 220 I = 1, NP
      P(I) = PHI(I) *STEP / E(I)
      TB(I) = TH(I) + P(I)
  220 CONTINUE
      PRINT 7000
 7000 FORMAT(30H0TEST POINT PARAMETER VALUES      )
      PRINT 2006, (TB(I), I = 1, NP)
      SUMB=0
      CALL MODEL(NPROB, TB, R, NOB, NP)
      DO 230 I=1,NOB
  230 SUMB=SUMB+R(I)*R(I)
      PRINT 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 PRINT 1007
      DO 669 I=1,NP
  669 TH(I)=TB(I)
       CALL GASS60(1, NP, TH, TEMP, TEMP)
      PRINT 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
      PRINT 1009, EPS2
      GO TO 280
  265 IF(ABS(SUMB - SSQ) - EPS1*SSQ) 266, 266, 270
  266 PRINT 1010, EPS1
      GO TO 280
  270 SSQ=SUMB
      NIT=NIT+1
      IF(NIT - MIT) 100, 100, 280
 2700 PRINT 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 PRINT 1011
      PRINT 2001, (R(I), I = 1, NOB)
      SSQ=SUMB
      IDF=NOB-NP
      PRINT 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 GASS60(3, NP, TEMP, TEMP, A)
      PRINT 1016
       CALL GASS60(1, NP, E, TEMP, TEMP)
      IF(IDF) 341, 410, 341
 341  SDEV = SSQ / IDF
      PRINT 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
      PRINT 1039
       CALL GASS60(2, NP, TB, P, TEMP)
      CALL ACORR(R,AC,SDF,NOB,30)
      CALL PARTAL(AC,PP,30)
      PRINT 59
   59 FORMAT(1H1,47H AUTO AND PARTIAL CORRELATIONS OF THE RESIDUALS,//
     19X,1HI,14X,4HAUTO,14X,7HPARTIAL//)
      DO 58 I=1,30
   58 PRINT 57 , I,AC(I),PP(I)
   57 FORMAT (8X,I2,13X,F5.3,13X,F6.3)
      CL = 2.0/SGRT(FLCAT(NOB))
      PRINT 54,CL
   54 FORMAT(//50H APPROX. 95 PERCENT CONF. LIMIT ON CORRELATIONS = ,F5.
     13)
      CHI = 0.
      DO 56 I=1,30
   56 CHI = CHI+AC(I)*AC(I)
      CHI = CHI*FLOAT(NOB)
      PRINT 55, CHI
   55 FORMAT(/25H CHI-SQUARED STATISTIC = ,F6.2/65H BASED ON (30 - NO. O
     1F STOCHASTIC PARAMETERS) DEGREES OF FREEDOM /)
  410 CONTINUE
      RETURN
   99 PRINT 1034
      GO TO 410
 10000FORMAT(38H1NON-LINEAR ESTIMATION, PROBLEM NUMBER   I3,// I5,
     1  14H OBSERVATIONS, I5, 11H PARAMETERS  I14, 17H SCRATCH REQUIRED)
 1001 FORMAT(/25H0INITIAL PARAMETER VALUES  )
 1003 FORMAT(/25H0INITIAL SUM OF SQUARES =    E12.4)
 1004 FORMAT(/////45X,13HITERATION NO.   I4)
 1007 FORMAT(/32H0PARAMETER VALUES VIA REGRESSION  )
 10090FORMAT(/62H0ITERATION STOPS - RELATIVE CHANGE IN EACH PARAMETER LE
     1SS THAN    E12.4)
 10100FORMAT(/62H0ITERATION STOPS - RELATIVE CHANGE IN SUM OF SQUARES LE
     1SS THAN    E12.4)
 1011 FORMAT(22H1FINAL RESIDUAL 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    )
 1034 FORMAT(/16H0PARAMETER ERROR   )
 10390FORMAT(/71H0INDIVIDUAL CONFIDENCE LIMITS FOR EACH PARAMETER (ON LI
     1NEAR HYPOTHESIS)    )
 10400FORMAT(/9H0LAMBDA =E10.3,40X,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(/10E12.4)
 2006 FORMAT(10E12.4)
      END
      SUBROUTINE MATIN(A, NVAR, B, NB, DET)
      DIMENSION A(NVAR, 1), B(NVAR, 1)
      COMMON/GASPAR/DUMIES(7), PIVOTM
       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
       SUBROUTINE GASS60(ITYPE, NQ, A, B, C)
      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   PRINT 500, (J,J=LOW,LUP)
      GO TO (40,60,80),ITYPE
 40   PRINT 600,(A(J),J=LOW,LUP)
      GO TO 100
 60   PRINT 600, (B(J),J=LOW,LUP)
      GO TO 40
 80   DO 90 I=LOW,LUP
 90   PRINT 720,I,(C(J,I),J=LOW,I)
      LOW2=LUP+1
      IF(LOW2 .GT. NP) GO TO 100
      DO 95 I=LOW2,NP
 95   PRINT 720,I,(C(J,I),J=LOW,LUP)
 100   LOW = LOW + 10
       LUP = LUP + 10
       NR = NR - 1
       GO TO 10
 500  FORMAT(/I8,9I12)
 600  FORMAT(10E12.4)
 720  FORMAT(1H0,I3,1X,F7.4,9F12.4)
  1   CONTINUE
      RETURN
      END
      SUBROUTINE CROSS(X,A,NOB,NL)
      DIMENSION X(NOB),A(NOB)
      DIMENSION CC1(41),CC2(41)
      CALL CRCORR(X,A,CC2,SDX,SDA,NOB,NL)
      CALL CRCORR(A,X,CC1,SDA,SDX,NOB,NL)
      PRINT 6
    6 FORMAT (1H1,10X,78H CROSS-CORRELATIONS BETWEEN MANIPULATED VARIABL
     1ES AND RESIDUALS     X(T)*A(T+K),//)
      NL1 = NL+1
      DO 7 K=1,NL1
      KK = K-1
      K1 = -KK
    7 PRINT 8 , K1,CC1(K),KK,CC2(K)
    8 FORMAT (5X,I3,5X,F6.3,10X,I3,5X,F6.3)
      CL = 2.0/SQRT(FLOAT(NOB))
      PRINT 12 , CL
   12 FORMAT(//56H APPROX. 95 PERCENT CONF. LIMIT ON CROSS-CORRELATIONS
     1= ,F6.3)
      PRINT 9, SDX,SDA
    9 FORMAT ( /28H STANDARD DEVIATIONS  S(X) =,E12.4,5X,6HS(A) =,E12.4
     1)
      Q = 0.
      DO 10 J=1,11
   10 Q = Q+CC1(J)*CC1(J)+CC2(J)*CC2(J)
      Q = (Q-CC1(1)*CC1(1))*FLOAT(NOB)
      NDF = 21
      PRINT 11, Q,NDF
   11 FORMAT (/25H CHI-SQUARED STATISTIC = ,F6.2,10H BASED ON ,I2,20H DE
     1GREES OF FREEDOM /)
      RETURN
      END
      SUBROUTINE CRCORR(X,Y,CC,SDX,SDY,N,NL)
      DIMENSION X(N),Y(N),CC(1)
      SX = 0.
      SY = 0.
      SXX = 0.
```

```
      SYY = 0.
      DO 2 I=1,N
      SX  = SX+X(I)
      SY  = SY+Y(I)
      SXX = SXX+X(I)*X(I)
    2 SYY = SYY+Y(I)*Y(I)
      TN = N
      SDX = SQRT((SXX-SX*SX/TN)/TN)
      SDY = SQRT((SYY-SY*SY/TN)/TN)
      NL1 = NL+1
      DO 3 K=1,NL1
      SXY = 0.
      NN = N-K+1
      DO 4 I=1,NN
      KK = I+K-1
    4 SXY = SXY+(X(I)-SX/TN)*(Y(KK)-SY/TN)
    3 CC(K) = (SXY/TN)/(SDX*SDY)
      RETURN
      END
      SUBROUTINE IDENT(Z,NOB,NL,NDIFF)
      DIMENSION Z(1),AC(60),PP(60)
      DIMENSION W(400)
      NDATA = NOB
      NO = 0
      NZ=NL+1
      DO 10 I=1,NOB
   10 W(I)=Z(I)
      PRINT 30
   30 FORMAT(1H1,10X,49H AUTO AND PARTIAL CORRELATIONS OF ORIGINAL SERIE
     1S,//)
      GO TO 20
   41 PRINT 31
   31 FORMAT(1H1,10X,61H AUTO AND PARTIAL CORRELATIONS OF FIRST DIFFEREN
     1CES OF SERIES,//)
      GO TO 20
   42 PRINT 32
   32 FORMAT(1H1,10X,62H AUTO AND PARTIAL CORRELATIONS OF SECOND DIFFERE
     1NCES OF SERIES,//)
   20 PRINT 33
   33 FORMAT(9X,1HI,14X,4HAUTO,14X,7HPARTIAL,//   )
      CALL ACORR(W,AC,SDZ,NDATA,NL)
  113 FORMAT(1H1,4HTEST)
      CALL PARTAL(AC,PP,NL)
      DO 58 I=1,NL
   58 PRINT 57 , I,AC(I),PP(I)
   57 FORMAT (8X,I2,13X,F6.3,13X,F6.3)
      PRINT 59, AC(NZ)
   59 FORMAT(//22H MEAN OF THE SERIES = ,E12.5)
      CL = 2.0/SQRT(FLOAT(NDATA))
      PRINT 54,CL
   54 FORMAT(//50H APPROX. 95 PERCENT CONF. LIMIT ON CORRELATIONS = ,F5.
     13)
      PRINT 60, SDZ
   60 FORMAT(/31H STANDARD DEVIATION OF SERIES =,E14.7)
      CHI = 0.
      DO 56 I=1,NL
   56 CHI = CHI+AC(I)*AC(I)
      CHI = CHI*FLOAT(NDATA)
      PRINT 55, CHI,NL
```

```
55 FORMAT(/25H CHI-SQUARED STATISTIC = ,F6.2,10H BASED ON ,I2,19H DEG
  1REESS OF FREEDOM,/)
   NDATA = NDATA-1
   ND = ND+1
   IF(ND.GT.NDIFF) GO TO 100
   DO 40 I=1,NDATA
40 W(I)=W(I+1)-W(I)
   GO TO (41,42), ND
100 RETURN
   END
   SUBROUTINE ACORR(Z,AC,SDZ,N,NL)
   DIMENSION Z(1),AC(1)
   NL1 = NL+1
   TN = N
   SZ = 0.
   DO 13 I=1,N
13 SZ = SZ+Z(I)
   ZBAR = SZ/TN
   DO 10 JJ=1,NL1
   J = JJ-1
   SZZ = 0.
   NN = N-J
   DO 11 I=1,NN
   K=I+J
11 SZZ=SZZ+(Z(I)-ZBAR)*(Z(K)-ZBAR)
10 AC(JJ) = SZZ/TN
   SDZ = SQRT(AC(1))
   VZ = AC(1)
   DO 12 J=1,NL
12 AC(J) = AC(J+1)/VZ
   RETURN
   END
   SUBROUTINE PARTAL(R,PAUTO,M)
   DIMENSION R(1),PAUTO(1),PHAT(40),PHATN(40)
   PAUTO(1) = R(1)
   PHAT(1) = R(1)*(1.-R(2))/(1.-R(1)**2)
   PHAT(2) = (R(2)-R(1)**2)/(1.-R(1)**2)
   PAUTO(2) = PHAT(2)
   DO 4 I=3,M
   L = I-1
   FNUM = 0.
   DENOM = 0.
   DO 1 J=1,L
   K = I-J
   FNUM = PHAT(J)*R(K)+FNUM
 1 DENOM = DENOM+PHAT(J)*R(J)
   PHATN(I) = (R(I)-FNUM)/(1.-DENOM)
   PAUTO(I) = PHATN(I)
   DO 2 J=1,L
   K = I-J
 2 PHATN(J) = PHAT(J)-PHATN(I)*PHAT(K)
   DO 3 J=1,I
 3 PHAT(J) = PHATN(J)
 4 CONTINUE
   RETURN
   END
```

Table C-5
Forecast Program Used To Predict Effluent Response

```
      PROGRAM TST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION TITLX(2),TITLY(2),DATA(1000),A(14,141)
      DIMENSION C1(141),C2(141),B1(141),B2(141)
      DIMENSION          X(141),Y(141),FS(141)
      REAL N(141)
      DIMENSION TH(10),TIME(141)
      COMMON/AAB/NTY,XORG
      COMMON/AAA/XMIN,XMAX,V,NTX,XSCALE,NPLTS
      DATA NS/0/,NF/141/,YORG/0.00/,NTOT/02/,NTX/12/,NOB/141/
      NTOT=3
      XSCALE=10.
      NTX=13
      NOB=121
      NPT=0
      CALL INIT(NTOT)
      READ (5,10) ((A(I,J),I=1,7),J=1,NOB)
      READ (5,10) ((A(I,J),I=8,14),J=1,NOB)
      READ (5,12) YSCALE,NTY,TITLX(1),TITLX(2),TITLY(1),TITLY(2)
      IFLAG=0
      NPT=NPT+1
      DO 15 I=1,NOB
      Y(I)=A(14,I)
      X(I)=A(7,I)*A(1,I)*6.552
       TIME(I)=I-1
15    CONTINUE
      NOB=NOB-6
      CALL PLDTA(IFLAG,NPT,NS,NOB,YSCALE,YORG,TITLX,TITLY,Y(5),TIME(5))
      PRINT(6,30)
      PRINT(6,31)
      IFLAG=1
      NPT=NPT+1
      FS(1)=0.
      FS(2)=0.
      FS(3)=0.
      FS(4)=0.
      FS(5)=0.
      N(5)=0.
      TH(5)=0.2203
      TH(4)=0.3994
      TH(3)=-0.02815
      TH(2)=-0.046
      TH(1)=0.0811
16    CONTINUE
      NOB=NOB+6
      DO 83 I=6,NOB
      FS(I)=(TH(4)+TH(5))*Y(I-1)-TH(4)*TH(5)*Y(I-2)+TH(1)*X(I-1)-TH(2)*
     2X(I-2)-TH(3)*X(I-3)-TH(5)*(TH(1)*X(I-2)-TH(2)*X(I-3)-TH(3)*X(I-4))
     3-TH(4)*N(I-1)
     4 +Y(I-1)-TH(4)*Y(I-2)-TH(5)*Y(I-2)+TH(4)*TH(5)*Y(I-3)
     5 -TH(1)*X(I-2)+TH(1)*TH(5)*X(I-3)+TH(3)*X(I-4)+TH(2)*X(I-3)-TH(2)*
     6 TH(5)*X(I-4)-TH(3)*TH(5)*X(I-5)
      N(I)=Y(I)-FS(I)
83    CONTINUE
10    FORMAT(26X,F5.3,19X,F4.0,1X,F3.0,1X,4F5.1)
11    FORMAT(26X,F5.3,21X,F3.0,1X,F3.0,1X,4F5.1)
12    FORMAT(F5.1,I5,4A10)
30    FORMAT(1H1,48H EFFLUENT TKN    INFLUENT TKN LOAD    FORECAST TKN/)
31    FORMAT(52H             MG/L              GM/DAY                MG/L    ///)
32    FORMAT(F10.2,3X,F10.2,1X,F10.2,4X,F10.2)
33    FORMAT(1H1,15H AVERAGE VALUES,//,F10.2,3X,F10.2,1X,F10.2,4X,F10.2)
34    FORMAT(3F15.2)
37    FORMAT(1H1,15H AVERAGE VALUES,//,F10.2,5X,F10.2)
      DO 35 I=1,NOB
35    TIME(I)=I-1
      NOB=NOB-6
      CALL PLDTA(IFLAG,NPT,NS,NOB,YSCALE,YORG,TITLX,TITLY,FS(5),TIME(5))
      NPT=NPT+1
      NOB=NOB+6
      DO 36 I=1,NOB
36    TIME(I)=I-1
      IFLAG=0
      READ (5,12) YSCALE,NTY,TITLX(1),TITLX(2),TITLY(1),TITLY(2)
      CALL PLDTA(IFLAG,NPT,NS,NOB,YSCALE,YORG,TITLX,TITLY,X,TIME)
      STOP
      END
```

```
      SUBROUTINE INIT(NTOT)
      COMMON/AAB/NTY,XORG
      COMMON/AAA/XMIN,XMAX,V,NTX,XSCALE,NPLTS
C     THIS SUBROUTINE INITIALIZES THE PLOT ROUTINE
C
C     A MAXIMUM OF 1000 POINTS MAY BE PLOTTED PER CALL TO PLDTA
C     THE CALL TO THIS SUBROUTINE MUST BE THE FIRST EXECUTABLE STATEMENT
C     IN THE MAIN PROGRAM
C     AS OF OCTOBER 20 1976 THE CONTROL CARDS NECESSARY TO PLOT ON
C     THE BENSEN-LEHNER ARE
C     ACCN,MT1.
C     ATTACH,PLOTLIB,ID=QPAK.
C     OTHER CONTROL CARDS
C     FTN.
C     LDSET(LIB=PLOTLIB)
C     LGO.
C
C     NTX - NUMBER OF TIC MARKS ON X AXIS
C     EVERY TIC MARK IS 10 MM FROM THE NEXT AND IS ANNOTATED
C        XSCALE IS THE INCREMENT IN THE X DIRECTION
C     IE THE TIC MARKS ARE / 10 20 ETC IF XSCALE S 10.
C     NPLTS - NUMBER OF PLOTS DESIRED INCLUDED ANY PLOTS TO BE SUPERIMP
C     OSED
C     INITIALIZE PLOT ROUTINE TO CENTIMETERS
      XORG=0.0
      XL=XORG+NTX*XSCALE
      XMAX=1.1*XL
      V=XORG-10*XSCALE
      XMIN=V
      NPLTS=NTOT
      RETURN
      END
```

```
      SUBROUTINE PLDTA(IFLAG,NPT,NS,NOB,YSCALE,YORG,TITLX,TITLY,DATA,TIM
     *E)
      DIMENSION TITLX(2),TITLY(2),FMT(5)
      COMMON/AAB/NTY,XORG
      COMMON/AAA/XMIN,XMAX,V,NTX,XSCALE,NPLTS
      DIMENSION Z(1000),TIME(1000),DATA(1000),DIST(1000),SLOPE(1000)
      DATA FMT/≠(F5.2)≠,≠(F5.2)≠,≠(F4.1)≠,≠(F4.1)≠,≠(F5.0)≠/
C
C      NPT - NUMBER OF CURRENT DATA SET
C     IFLAG - IF NON ZERO THEN CURRENT PLOT SUPERIMPOSED ON LAST GRID
C     NS - THE FIRST ABSCISSA VALUE IE 0 OR 10 OR 15
C     NOB - NUMBER OF DATA POINTS TO BE PLOTTED
C     YSCALE - THE INCREMENT PER TIC MARK ALONG THE ORDINATE AXIS
C     YORG - ORIGIN OF THE PLOT IN DATA UNITS  THEREFORE THE VALUES ALONG
C     THE ORDINATE WILL BE     YORG     YORG+YSCALE     YORG+2*YSCALE . .
C     YORG+5*YSCALE
C     TITLX - A 20 CHARACTER TITLE TO BE PRINTED ON THE ABSCISSA
C     TITLX - A 20 CHARACTER TITLE TO BE PRINTED ON THE ORDINATE
C     DATA - A VECTOR CONTAINING THE ORDINATE VALUES TO BE PLOTTED
C     THE FIRST ELEMENT CORRESPONDS TO THE NS TH DATA POINT
C     NTY - NO. OF TICS IN Y DIRECTION
C
C
      WRITE(6,6001)NPT,NOB,YORG,YSCALE
 6001 FORMAT(1H1,///,20X,≠PLOT NUMBER≠,I2,//,20X,≠NUMBER OBS ≠I4,
     1/,20X,≠ORIGIN OF ORDINATE AXIS≠,F10.6/,20X,≠INCR ORDINATE AXIS≠,
     2F10.6)
      WRITE(6,6002)
 6002 FORMAT(1H0,20X,≠DATA FOR PLOTTING≠)
      WRITE(6,6003)(DATA(L),L=1,NOB)
 6003 FORMAT(1H ,7E10.4)
      IF(NPT.NE.1)GO TO 20
C     INITIALIZE PLOT BOUNDARIES ON FIRST PLOT ONLY
      CALL PLOT(0.,0.,-20)
      CALL PLOT(0.,0.,3)
      GO TO 30
   20 CONTINUE
      IF(IFLAG.NE.0)GO TO 10
C     INCREMENT NUMBER OF INDIVIDUAL GRIDS
      CALL PLOT(DXL+10.,0.,-3)
   30 CONTINUE
      XNTY=NTY
      W=YORG-(XNTY-1.)*YSCALE/2.
      YMIN=W
      YL=YORG+YSCALE*(XNTY-1.)
      YMAX=YL*1.1
      CALL PLTIN(XSCALE,YSCALE,V,W,XMIN,XMAX,YMIN,YMAX)
C     PLACE GRID ON X AND Y AXIS
C     DETERMINE DATA ORIGIN IN PLOTTER UNITS
      CALL UNITTO(XORG,YORG,DX,DY)
      CALL PLOT(DX,DY,3)
C     DETERMINE END POINTS OF AXIS IN PLOTTER UNITS
      DXL=DX+NTX
      DYL=DY+NTY
      CALL PLOT(DXL,DY,2)
C     PLACE TIC MARKS ALONG AXIS
      Y=DY-.1
```

```
      DO 39 I=1,NTX
      X=DX+I
      CALL MATH(X,Y,.1,90.,2)
   39 CONTINUE
C     DRAW Y AXIS
      CALL PLOT(DX,DY,3)
      CALL PLOT(DX,DYL,2)
C     PLACE Y AXIS AT RIGHT HAND EDGE OF X AXIS
      CALL PLOT(DXL,DY,3)
      CALL PLOT(DXL,DYL,2)
C     PLACE LINE ACROSS THE TOP OF GRAPH
      CALL PLOT(DX,DYL,3)
      CALL PLOT(DXL,DYL,2)
C     INSERT TIC MARK AR RIGHT HAND EDGE
      XX=DXL
      DO 49 I=1,NTY
      Y=DY+I
      Y=Y-0.05
      CALL MATH(XX,Y,.1,0.,2)
   49 CONTINUE
C     PLACE TIC MARKS AT LEFT HAND EDGE
      X=DX-.1
      DO 50 I=1,NTY
      Y=DY+I
      Y=Y-0.05
      CALL MATH(X,Y,.1,0.,2)
   50 CONTINUE
C     INSERT SCALE ON X AXIS
C     PLACE / ON AXIS
      Y=DY-.5
      CALL SYMBOL(DX,Y,.20,1H0,90.,1)
C     INSERT NO ALONG AXIS
      Y=DY-1.
      DO 59 I=2,NTX,2
      X=DX+I
      NUM=XSCALE*I
      CALL INUMBR(X,Y,.2,NUM,0.,4H(I4))
   59 CONTINUE
      X=DX-1.5
C     PUT NO ALONG Y AXIS
      NTY=NTY+1
      DO 69 I=1,NTY
      Y=DY+I-1
      YVAL=YORG+(I-1)*YSCALE
      CALL NUMBER(X,Y,.2,YVAL,0.,6H(F6.1))
   69 CONTINUE
C     INSERT TITLE ON X AXIS
      X=DX+0.3*NTX
      Y=DY-1.5
      CALL SYMBOL(X,Y,.25,TITLX,0.,20)
      X=DX-1.8
      Y=DY+0.5
      CALL SYMBOL(X,Y,.25,TITLY,90.,20)
   10 CONTINUE
C     PLOT DATA WITHIN GRID
      DO 9 J=1,NOB
      YD=DATA(J)
```

```
      TD=TIME(J)
C     CONSTRAIN PEN MOVEMENT
      IF(YD.GT.YL)YD=YL
      IF(YD.LT.YORG)YD=YORG
C     CONVERT TO PLOTTER UNITS
      CALL UNITTO(TD,YD,TP,YP)
      TIME(J)=TP
      Z(J)=YP
    9 CONTINUE
C     PLOT DATA
      IF(IFLAG.NE.0)GO TO 78
      DO 597 ML=1,NOB
      ZZ1=TIME(ML)
      ZZ2=Z(ML)
  597 CALL GRAF(ZZ1,ZZ2,.15,1)
      GO TO 79
   78 IF(IFLAG.EQ.1) CALL MPLOT(TIME,Z,NOB)
      IF(IFLAG.EQ.2) CALL GRAF(TIME,Z,.15,1)
C     CHECK TO SEE IF MAXIMUM NUMBER OF PLOTS HAS BEEN REACHED
   79 IF(NPLTS.NE.NPT)RETURN
      CALL PLOT(DXL+20.,0.,3)
      CALL PLOT(X,Y,999)
      RETURN
      END
```

```
      SUBROUTINE NUMBER(X,Y,HEIGHT,ANUM,THETA,FMT)
      DIMENSION BCD(1)
      ENCODE(10,FMT,BCD)ANUM
      CALL SYMBOL(X,Y,HEIGHT,BCD,THETA,10)
      RETURN
      END
```

```
      SUBROUTINE INUMBR(X,Y,HEIGHT, NUM,THETA,FMT)
      DIMENSION BCD(1)
      ENCODE(10,FMT,BCD)NUM
      CALL SYMBOL(X,Y,HEIGHT,BCD,THETA,10)
      RETURN
      END
```

APPENDIX D

REACTOR RETENTION TIMES & MIXING CHARACTERISTICS

Dye studies were performed on the 0.5 metre RBC and the 2.0 metre RBC for two reasons:

1. The tracer studies provided an indication of peak retention times and RBC response to influent spikes. This then provided the basic information necessary for choosing discrete time intervals for the dynamic experiments.

2. To identify the mixing characteristics of each RBC, which previously had been shown to approximate two CSTR's in series for a 0.5 metre RBC.

Dye studies were performed with a Turner Model III flowmeter. Samples (200 ml) were obtained at discrete time intervals so as not to miss the peak. Fresh water was used to feed the RBC's except in the case of 2.0 m which was being acclimatized at the same time with raw sewage. The 0.5 metre RBCs did not have a biological growth on them at the time the dye studies were conducted. Calibration curves were determined using dye solutions of known concentration. To initiate each study a slug of dye of known concentration was added to the RBC inlet. The RBC was stopped for approximately 10 seconds for this purpose.

The results of the studies and further details of each study are included in Tables D1, D2, D3, D4 and D5. A computer listing of the program used is presented in Table D6. Flow conditions for both the carbon oxidation and carbon oxidation plus modes were investigated.

A description of the flow models used to develop the computer program is given below.

Tanks in Series Model Theory

The final effluent of a system of j equal sized CSTR's in series can be found from the following equation:

$$\frac{C}{C_o} = \frac{j^j \theta^{j-1}}{(j-1)!} e^{-j\theta} \quad \text{...(D-1)}$$

where: C = effluent tracer concentration
θ = dimensionless time
j = number of tanks
C_o = the quantity of tracer added divided by the volume of the entire system.

This applies only to a pulse input of tracer. In this type of system, as j approaches large values (say > 15), the flow regime approximates plug flow whereas, when j is equal to 1, the flow is completely mixed. If the time at which the peak dye concentration occurs is known, the above equation can be solved for j by taking the derivative and equating the result to zero. Theta peak is determined by dividing the peak time by the residence time. The final form of the equation is:

$$j = \frac{1}{1-\theta} \quad \text{... (D-2)}$$

Dispersion Model Theory

The dispersion model is developed in such a way that it assumes plug flow for a given reactor system with the inclusion of a term which describes the degree of molecular disperson or deviation from the ideal. The general equation of this model is:

$$D \frac{\partial^2 c}{\partial x^2} - u \frac{\partial C}{\partial x} - \frac{\partial C}{\partial t} = o \qquad \text{...(D-3)}$$

where: u = mean displacement velocity

C = concentration

$\frac{\partial C}{\partial x}$ = concentration gradient

$\frac{\partial C}{\partial t}$ = reaction term

D = turbulence expression

The solution of this equation for a tracer pulse input to a closed vessel given by Mjjachi (1953) is quoted by Timpany (1):

$$\frac{C}{Co} = 2 \sum_{n=1}^{\infty} \frac{U_n(U \sin U_n + \cos U_n)}{(U^2 + 2U + U_n^2)} \text{ EXP } \frac{U-(U^2+Un^2)\theta}{2U} \qquad \text{...(D-4)}$$

where: $U_n = \text{COT}^{-1} \left(\frac{Un}{U} - \frac{U}{U_n} \right) /2$

$U = \frac{UL}{2D}$

L = tank length

The value U_n is best calculated by trial and error using an iterative approach. Also, the summation in equation 4 is taken to some reasonably large but finite value for practical purposes.

Instead of determining a value for D by the normal variance technique suggested by Levenspiel (1967), a correlation between peak time and D/UL developed by Timpany (1966) was used. Proper use of the variance method for D/UL calculation generally requires concentration data to be entered for at least seven detention times which is rarely practical. Since the concentration data approached zero after two detentions times data for about three detention times were used.

Table D-1

Tracer Response Analysis, 0.5 Ml, At 0.82 L/min.

```
                    TRACER RESPONSE ANALYSIS

                 Rotating Biological Contactor
                   HYDRAULIC CHARACTERIZATION

       TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE
REACTOR OPERATION AND TEST CONDITIONS


        VOLUME OF REACTOR =  141.80LITRES
        HYDRAULIC LOADING =    0.82LITRES/MIN
        THEORETICAL DET   =  173.99MIN
        DYE INJECTION     =  0.0030LITRES
        CONC OF DYE ADDED =  0.238E+07PPB
        DYE / TANK VOLUME =   50.35PPB


TEST RESULTS AND CALCULATED VALUES


        DYE PEAK TIME       =    85.00MIN
        PEAK/THEOR DET      =    0.489

        PEAK/MEAN DYE RES =    0.596MIN
        MEAN DYE RESIDENCE = 142.50MIN
        PER DYE RECOVERY   =  94.314P
        FR. STAGNANT ZONE =    0.181

        CSTR S IN SERIES USING THEORETICAL RES. =      1.96
        CSTR S IN SERIES USING MEAN DYE RES.    =      2.48
        D/UL VALUE USING THEORETICAL RESIDENCE  =  0.3336E+00
        D/UL VALUE USING MEAN DYE RESIDENCE     =  0.2282E+00
```

Table D-1 Cont'd

EXPERIMENTAL RESULTS C/CO VERSUS THETA

THETA	C/CO
0.043	0.016
0.086	0.079
0.129	0.179
0.172	0.318
0.216	0.447
0.259	0.560
0.302	0.671
0.345	0.735
0.338	0.777
0.431	0.804
0.474	0.814
0.517	0.814
0.560	0.804
0.603	0.789
0.647	0.767
0.690	0.737
0.733	0.715
0.776	0.693
0.819	0.672
0.862	0.655
0.905	0.622
0.948	0.591
0.991	0.556
1.035	0.526
1.078	0.496
1.121	0.467
1.164	0.439
1.207	0.412
1.250	0.385
1.293	0.361
1.437	0.297
1.581	0.240
1.724	0.199
1.868	0.166
2.012	0.131
2.155	0.099
2.299	0.076
2.443	0.055

CALCULATED C/CO VERSUS THETA VALUES FOR CSTR IN SERIES MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
THETA	C/CO	THETA	C/CO
0.000	0.000	0.000	0.000
0.050	0.181	0.050	0.181
0.100	0.327	0.100	0.327
0.150	0.444	0.150	0.444
0.200	0.536	0.200	0.536
0.250	0.607	0.250	0.607
0.300	0.659	0.300	0.659
0.350	0.695	0.350	0.695
0.400	0.719	0.400	0.719
0.450	0.732	0.450	0.732
0.500	0.736	0.500	0.736
0.550	0.732	0.550	0.732
0.600	0.723	0.600	0.723
0.650	0.709	0.650	0.709
0.700	0.690	0.700	0.690
0.750	0.669	0.750	0.669
0.800	0.646	0.800	0.646
0.850	0.621	0.850	0.621
0.900	0.595	0.900	0.595
0.950	0.568	0.950	0.568
1.000	0.541	1.000	0.541
1.200	0.435	1.200	0.435
1.400	0.341	1.400	0.341
1.600	0.261	1.600	0.261
1.800	0.197	1.800	0.197
2.000	0.147	2.000	0.147
2.200	0.108	2.200	0.108
2.400	0.079	2.400	0.079
2.600	0.057	2.600	0.057
2.800	0.041	2.800	0.041
3.000	0.030	3.000	0.030
3.200	0.021	3.200	0.021
3.400	0.015	3.400	0.015
3.600	0.011	3.600	0.011
3.800	0.008	3.800	0.008
4.000	0.005	4.000	0.005
4.200	0.004	4.200	0.004

```
                 CALCULATED C/CO VERSUS THETA VALUES
          FOR DISPERSION MODEL

   THEORETICAL DETENTION                    ACTUAL DETENTION

      0.100          0.025                     0.100          0.001
      0.200          0.363                     0.200          0.112
      0.300          0.717                     0.300          0.442
      0.400          0.884                     0.400          0.748
      0.500          0.914                     0.500          0.917
      0.600          0.872                     0.600          0.962
      0.700          0.797                     0.700          0.929
      0.800          0.713                     0.800          0.854
      0.900          0.628                     0.900          0.761
      1.000          0.550                     1.000          0.664
      1.100          0.478                     1.100          0.572
      1.200          0.415                     1.200          0.488
      1.300          0.359                     1.300          0.413
      1.400          0.311                     1.400          0.349
      1.500          0.269                     1.500          0.293
      1.600          0.232                     1.600          0.245
      1.700          0.201                     1.700          0.206
      1.800          0.173                     1.800          0.173
      1.900          0.150                     1.900          0.144
      2.000          0.129                     2.000          0.120
      2.100          0.112                     2.100          0.101
      2.200          0.096                     2.200          0.084

      2.300          0.083                     2.300          0.070
      2.400          0.072                     2.400          0.058
      2.500          0.062                     2.500          0.049
      2.600          0.054                     2.600          0.041
      2.700          0.046                     2.700          0.034
      2.800          0.040                     2.800          0.028
      2.900          0.035                     2.900          0.024
      3.000          0.030                     3.000          0.020
```

Table D-2

Tracer Response Analysis, 0.5 M2, At 2.33 L/min.

```
                    TRACER RESPONSE ANALYSIS

                 Rotating Biological Contactor
                  HYDRAULIC CHARACTERIZATION

       TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE
   REACTOR OPERATION AND TEST CONDITIONS

           VOLUME OF REACTOR =  131.40LITRES
           HYDRAULIC LOADING =    2.33LITRES/MIN
           THEORETICAL DET   =   56.39MIN
           DYE INJECTION     =  0.0030LITRES
           CONC OF DYE ADDED =  0.238E+07PPB
           DYE / TANK VOLUME =   54.34PPB

   TEST RESULTS AND CALCULATED VALUES

           DYE PEAK TIME        =   39.00MIN
           PEAK/THEOR DET       =   0.692

           PEAK/MEAN DYE RES =    0.591MIN
           MEAN DYE RESIDENCE =   66.00MIN
           PER DYE RECOVERY   =  80.247%
           FR. STAGNANT ZONE  =  -0.170

           CSTR S IN SERIES USING THEORETICAL RES.  =      3.24
           CSTR S IN SERIES USING MEAN DYE RES.     =      2.44
           D/UL VALUE USING THEORETICAL RESIDENCE   =  0.1444E+00
           D/UL VALUE USING MEAN DYE RESIDENCE      =  0.2344E+00
```

EXPERIMENTAL RESULTS C/CO VERSUS THETA

THETA	C/CO
0.106	0.023
0.213	0.104
0.319	0.29[illegible]
0.426	0.409
0.532	0.466
0.638	0.492
0.745	0.497
0.851	0.482
0.958	0.455
1.064	0.420
1.170	0.386
1.277	0.355
1.383	0.324
1.489	0.298
1.596	0.271
1.702	0.247
1.809	0.223
1.915	0.199
2.021	0.179
2.128	0.158
2.234	0.143
2.341	0.129
2.447	0.114
2.553	0.105
2.660	0.093
2.766	0.086
2.873	0.078
2.979	0.07[illegible]
3.085	0.067
3.192	0.056
3.546	0.036
3.901	0.024

CALCULATED C/CO VERSUS THETA VALUES
FOR CSTR IN SERIES MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
THETA	C/CO	THETA	C/CO
0.000	0.000	0.000	0.000
0.050	0.029	0.050	0.181
0.100	0.100	0.100	0.327
0.150	0.194	0.150	0.444
0.200	0.296	0.200	0.536
0.250	0.399	0.250	0.607
0.300	0.494	0.300	0.659
0.350	0.579	0.350	0.695
0.400	0.651	0.400	0.719
0.450	0.709	0.450	0.732
0.500	0.753	0.500	0.736
0.550	0.784	0.550	0.732
0.600	0.803	0.600	0.723
0.650	0.811	0.650	0.709
0.700	0.810	0.700	0.690
0.750	0.800	0.750	0.669
0.800	0.784	0.800	0.646
0.850	0.762	0.850	0.621
0.900	0.735	0.900	0.595
0.950	0.705	0.950	0.568
1.000	0.672	1.000	0.541
1.200	0.531	1.200	0.435
1.400	0.397	1.400	0.341
1.600	0.284	1.600	0.261
1.800	0.198	1.800	0.197
2.000	0.134	2.000	0.147
2.200	0.089	2.200	0.108
2.400	0.058	2.400	0.079
2.600	0.037	2.600	0.057
2.800	0.024	2.800	0.041
3.000	0.015	3.000	0.030
3.200	0.009	3.200	0.021
3.400	0.006	3.400	0.015
3.600	0.004	3.600	0.011
3.800	0.002	3.800	0.008
4.000	0.001	4.000	0.005
4.200	0.001	4.200	0.004

CALCULATED C/CO VERSUS THETA VALUES FOR DISPERSION MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
0.100	0.000	0.100	0.001
0.200	0.013	0.200	0.122
0.300	0.194	0.300	0.457
0.400	0.522	0.400	0.758
0.500	0.821	0.500	0.919
0.600	0.995	0.600	0.959
0.700	1.044	0.700	0.922
0.800	1.004	0.800	0.845
0.900	0.914	0.900	0.753
1.000	0.801	1.000	0.657
1.100	0.683	1.100	0.566
1.200	0.573	1.200	0.483
1.300	0.473	1.300	0.410
1.400	0.337	1.400	0.347
1.500	0.315	1.500	0.292
1.600	0.254	1.600	0.246
1.700	0.204	1.700	0.206
1.800	0.163	1.800	0.173
1.900	0.131	1.900	0.145
2.000	0.104	2.000	0.121
2.100	0.083	2.100	0.101
2.200	0.066	2.200	0.085
2.300	0.052	2.300	0.071
2.400	0.041	2.400	0.059
2.500	0.033	2.500	0.050
2.600	0.026	2.600	0.041
2.700	0.021	2.700	0.035
2.800	0.016	2.800	0.029
2.900	0.013	2.900	0.024
3.000	0.010	3.000	0.020

Table D-3

Tracer Response Analysis, o.5 M2, At 3.46 L/min.

```
                    TRACER RESPONSE ANALYSIS

                  Rotating Biological Contactor
                    HYDRAULIC CHARACTERIZATION

        TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE

 REACTOR OPERATION AND TEST CONDITIONS


        VOLUME OF REACTOR =  133.50LITRES
        HYDRAULIC LOADING =    3.46LITRES/MIN
        THEORETICAL DET   =   38.58MIN
        DYE INJECTION     =  0.0030LITRES
        CONC OF DYE ADDED =  0.233E+07PPB
        DYE / TANK VOLUME =   53.48PPB


 TEST RESULTS AND CALCULATED VALUES


        DYE PEAK TIME       =   22.00MIN
        PEAK/THEOR DET      =   0.570

        PEAK/MEAN DYE RES  =   0.629MIN
        MEAN DYE RESIDENCE =  35.00MIN
        PER DYE RECOVERY   =  71.957%
        FR. STAGNANT ZONE  =   0.093

        CSTR S IN SERIES USING THEORETICAL RES.  =     2.33
        CSTR S IN SERIES USING MEAN DYE RES.     =     2.69
        D/UL VALUE USING THEORETICAL RESIDENCE   =  0.2590E+00
        D/UL VALUE USING MEAN DYE RESIDENCE      =  0.1956E+00
```

EXPERIMENTAL RESULTS C/CO VERSUS THETA

THETA	C/CO
0.078	0.000
0.156	0.113
0.233	0.265
0.311	0.425
0.389	0.524
0.467	0.570
0.544	0.593
0.622	0.599
0.700	0.566
0.778	0.524
0.855	0.486
0.933	0.441
1.011	0.402
1.089	0.362
1.166	0.318
1.244	0.285
1.322	0.256
1.400	0.229
1.477	0.206
1.555	0.187
1.633	0.168
1.711	0.153
1.788	0.136
1.866	0.122
1.944	0.110
2.022	0.099
2.099	0.090
2.177	0.081
2.255	0.074
2.333	0.067
2.592	0.048
2.851	0.038
3.110	0.033
3.369	0.029
3.628	0.024
3.888	0.019

Table D-3 Cont'd

CALCULATED C/CO VERSUS THETA VALUES
FOR CSTR IN SERIES MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
THETA	C/CO	THETA	C/CO
0.000	0.000	0.000	0.000
0.050	0.181	0.050	0.029
0.100	0.327	0.100	0.100
0.150	0.444	0.150	0.194
0.200	0.536	0.200	0.296
0.250	0.607	0.250	0.399
0.300	0.659	0.300	0.494
0.350	0.695	0.350	0.579
0.400	0.719	0.400	0.651
0.450	0.732	0.450	0.709
0.500	0.736	0.500	0.753
0.550	0.732	0.550	0.784
0.600	0.723	0.600	0.803
0.650	0.709	0.650	0.811
0.700	0.690	0.700	0.810
0.750	0.669	0.750	0.800
0.800	0.646	0.800	0.784
0.850	0.621	0.850	0.762
0.900	0.595	0.900	0.735
0.950	0.568	0.950	0.705
1.000	0.541	1.000	0.672
1.200	0.435	1.200	0.531
1.400	0.341	1.400	0.397
1.600	0.261	1.600	0.284
1.800	0.197	1.800	0.198
2.000	0.147	2.000	0.134
2.200	0.108	2.200	0.089
2.400	0.079	2.400	0.058
2.600	0.057	2.600	0.037
2.800	0.041	2.800	0.024
3.000	0.030	3.000	0.015
3.200	0.021	3.200	0.009
3.400	0.015	3.400	0.006
3.600	0.011	3.600	0.004
3.800	0.008	3.800	0.002
4.000	0.005	4.000	0.001
4.200	0.004	4.200	0.001

CALCULATED C/CO VERSUS THETA VALUES
FOR DISPERSION MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
0.100	0.002	0.100	0.000
0.200	0.160	0.200	0.057
0.300	0.515	0.300	0.352
0.400	0.794	0.400	0.681
0.500	0.925	0.500	0.896
0.600	0.944	0.600	0.980
0.700	0.896	0.700	0.969
0.800	0.816	0.800	0.902
0.900	0.724	0.900	0.808
1.000	0.632	1.000	0.706
1.100	0.546	1.100	0.606
1.200	0.468	1.200	0.514
1.300	0.399	1.300	0.433
1.400	0.339	1.400	0.362
1.500	0.237	1.500	0.301
1.600	0.243	1.600	0.250
1.700	0.205	1.700	0.207
1.800	0.173	1.800	0.171
1.900	0.146	1.900	0.141
2.000	0.123	2.000	0.116
2.100	0.104	2.100	0.096
2.200	0.088	2.200	0.079
2.300	0.074	2.300	0.065
2.400	0.062	2.400	0.053
2.500	0.052	2.500	0.044
2.600	0.044	2.600	0.036
2.700	0.037	2.700	0.030
2.800	0.031	2.800	0.024
2.900	0.026	2.900	0.020
3.000	0.022	3.000	0.016

Table D-4

Tracer Response Analysis, 2.0 M, At 37.2 L/min.

```
                    TRACER RESPONSE ANALYSIS
--------------------------------------------------------------------

              ROTATING BIOLOGICAL CONTACTOR
                HYDRAULIC CHARACTERIZATION
--------------------------------------------------------------------

       TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE
--------------------------------------------------------------------
   REACTOR OPERATION AND TEST CONDITIONS
--------------------------------------------------------------------

          VOLUME OF REACTOR = 3468.40LITRES
          HYDRAULIC LOADING =   37.20LITRES/MIN
          THEORETICAL DET   =   93.24MIN
          DYE INJECTION     =  0.0013LITRES
          CONC OF DYE ADDED =  0.238E+09PPB
          DYE / TANK VOLUME =   85.77PPB

--------------------------------------------------------------------
   TEST RESULTS AND CALCULATED VALUES
--------------------------------------------------------------------

          DYE PEAK TIME       =   74.00MIN
          PEAK/THEOR DET      =   0.794

          PEAK/MEAN DYE RES   =   0.725MIN
          MEAN DYE RESIDENCE  = 102.00MIN
          PER DYE RECOVERY    =  91.978
          FR. STAGNANT ZONE   =  -0.094

          CSTR S IN SERIES USING THEORETICAL RES.   =       4.85
          CSTR S IN SERIES USING MEAN DYE RES.      =       3.64
          D/UL VALUE USING THEORETICAL RESIDENCE    =  0.8835E-01
          D/UL VALUE USING MEAN DYE RESIDENCE       =  0.1327E+00
```

EXPERIMENTAL RESULTS C/CO VERSUS THETA

THETA	C/CO
0.064	0.000
0.129	0.000
0.193	0.062
0.257	0.145
0.322	0.248
0.386	0.348
0.450	0.43[illegible]
0.515	0.497
0.579	0.563
0.644	0.615
0.708	0.651
0.772	0.673
0.837	0.575
0.901	0.565
0.965	0.646
1.030	0.625
1.094	0.600
1.158	0.575
1.223	0.546
1.287	0.513
1.351	0.484
1.416	0.447
1.480	0.416
1.544	0.385
1.609	0.356
1.673	0.327
1.738	0.300
1.802	0.273
1.866	0.248
1.931	0.228
2.145	0.169
2.360	0.124
2.574	0.084
2.789	0.050
3.003	0.022

CALCULATED C/CO VERSUS THETA VALUES FOR CSTR IN SERIES MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
THETA	C/CO	THETA	C/CO
0.000	0.000	0.000	0.000
0.050	0.001	0.050	0.004
0.100	0.008	0.100	0.029
0.150	0.031	0.150	0.079
0.200	0.077	0.200	0.153
0.250	0.146	0.250	0.245
0.300	0.235	0.300	0.347
0.350	0.340	0.350	0.451
0.400	0.451	0.400	0.551
0.450	0.553	0.450	0.643
0.500	0.668	0.500	0.722
0.550	0.762	0.550	0.787
0.600	0.840	0.600	0.835
0.650	0.901	0.650	0.870
0.700	0.944	0.700	0.890
0.750	0.969	0.750	0.896
0.800	0.977	0.800	0.890
0.850	0.970	0.850	0.874
0.900	0.949	0.900	0.850
0.950	0.918	0.950	0.818
1.000	0.877	1.000	0.781
1.200	0.659	1.200	0.607
1.400	0.456	1.400	0.433
1.600	0.286	1.600	0.290
1.800	0.159	1.800	0.186
2.000	0.095	2.000	0.115
2.200	0.051	2.200	0.068
2.400	0.027	2.400	0.040
2.600	0.013	2.600	0.023
2.800	0.007	2.800	0.013
3.000	0.003	3.000	0.007
3.200	0.002	3.200	0.004
3.400	0.001	3.400	0.002
3.600	0.000	3.600	0.001
3.800	0.000	3.800	0.001
4.000	0.000	4.000	0.000
4.200	0.000	4.200	0.000

CALCULATED C/CO VERSUS THETA VALUES FOR DISPERSION MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
0.100	0.000	0.100	0.000
0.200	0.001	0.200	0.007
0.300	0.041	0.300	0.127
0.400	0.245	0.400	0.427
0.500	0.596	0.500	0.759
0.600	0.931	0.600	0.987
0.700	1.133	0.700	1.080
0.800	1.185	0.800	1.063
0.900	1.123	0.900	0.978
1.000	0.994	1.000	0.859
1.100	0.839	1.100	0.731
1.200	0.634	1.200	0.607
1.300	0.543	1.300	0.496
1.400	0.422	1.400	0.400
1.500	0.324	1.500	0.320
1.600	0.245	1.600	0.254
1.700	0.184	1.700	0.200
1.800	0.137	1.800	0.157
1.900	0.101	1.900	0.123
2.000	0.074	2.000	0.095
2.100	0.055	2.100	0.074
2.200	0.040	2.200	0.058
2.300	0.029	2.300	0.045
2.400	0.021	2.400	0.035
2.500	0.015	2.500	0.027
2.600	0.011	2.600	0.021
2.700	0.008	2.700	0.016
2.800	0.006	2.800	0.012
2.900	0.004	2.900	0.010
3.000	0.003	3.000	0.007

Table D-5

Tracer Response Analysis, 2.0 M, At 100.6 L/min.

```
             TRACER RESPONSE ANALYSIS

           ROTATING BIOLOGICAL CONTACTOR
            HYDRAULIC CHARACTERIZATION

    TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE

      REACTOR OPERATION AND TEST CONDITIONS

           VOLUME OF REACTOR = 3545.60LITRES
           HYDRAULIC LOADING =  100.56LITRES/MIN
           THEORETICAL DET   =   35.26MIN
           DYE INJECTION     =  0.0013LITRES
           CONC OF DYE ADDED = 0.238E+09PPB
           DYE / TANK VOLUME =   83.91PPB

      TEST RESULTS AND CALCULATED VALUES

           DYE PEAK TIME       =   30.50MIN
           PEAK/THEOR DET      =   0.865

           PEAK/MEAN DYE RES =   0.762MIN
           MEAN DYE RESIDENCE =  40.00MIN
           PER DYE RECOVERY  =  91.351
           FR. STAGNANT ZONE =  -0.134

           CSTR S IN SERIES USING THEORETICAL RES.  =      7.41
           CSTR S IN SERIES USING MEAN DYE RES.     =      4.21
           D/UL VALUE USING THEORETICAL RESIDENCE   =  0.6257E-01
           D/UL VALUE USING MEAN DYE RESIDENCE      =  0.1026E+00
```

Table D-5 Cont'd

EXPERIMENTAL RESULTS C/CO VERSUS THETA

THETA	C/CO
0.085	0.000
0.170	0.010
0.255	0.061
0.340	0.151
0.425	0.334
0.511	0.454
0.596	0.546
0.681	0.622
0.766	0.664
0.851	0.689
0.936	0.687
1.021	0.668
1.106	0.643
1.191	0.601
1.276	0.553
1.361	0.495
1.446	0.440
1.532	0.394
1.617	0.360
1.702	0.313
1.787	0.277
1.872	0.245
1.957	0.224
2.042	0.196
2.127	0.173
2.212	0.152
2.297	0.131
2.382	0.113
2.467	0.095
2.553	0.080
2.836	0.043
3.120	0.025
3.403	0.014
3.687	0.005

CALCULATED C/CO VERSUS THETA VALUES FOR CSTR IN SERIES MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
THETA	C/CO	THETA	C/CO
0.000	0.000	0.000	0.000
0.050	0.000	0.050	0.004
0.100	0.001	0.100	0.029
0.150	0.005	0.150	0.079
0.200	0.018	0.200	0.153
0.250	0.049	0.250	0.245
0.300	0.102	0.300	0.347
0.350	0.181	0.350	0.451
0.400	0.285	0.400	0.551
0.450	0.407	0.450	0.643
0.500	0.540	0.500	0.722
0.550	0.674	0.550	0.787
0.600	0.800	0.600	0.836
0.650	0.912	0.650	0.870
0.700	1.002	0.700	0.890
0.750	1.068	0.750	0.896
0.800	1.109	0.800	0.890
0.850	1.124	0.850	0.874
0.900	1.116	0.900	0.850
0.950	1.088	0.950	0.818
1.000	1.043	1.000	0.781
1.200	0.768	1.200	0.607
1.400	0.478	1.400	0.433
1.600	0.262	1.600	0.290
1.800	0.131	1.800	0.186
2.000	0.061	2.000	0.115
2.200	0.027	2.200	0.058
2.400	0.011	2.400	0.040
2.600	0.004	2.600	0.023
2.800	0.002	2.800	0.013
3.000	0.001	3.000	0.007
3.200	0.000	3.200	0.004
3.400	0.000	3.400	0.002
3.600	0.000	3.600	0.001
3.800	0.000	3.800	0.001
4.000	0.000	4.000	0.000
4.200	0.000	4.200	0.000

CALCULATED C/CO VERSUS THETA VALUES FOR DISPERSION MODEL

THEORETICAL DETENTION		ACTUAL DETENTION	
0.100	0.000	0.100	0.000
0.200	0.000	0.200	0.002
0.300	0.007	0.300	0.072
0.400	0.102	0.400	0.325
0.500	0.393	0.500	0.676
0.600	0.804	0.600	0.964
0.700	1.147	0.700	1.112
0.800	1.313	0.800	1.129
0.900	1.299	0.900	1.054
1.000	1.164	1.000	0.929
1.100	0.972	1.100	0.787
1.200	0.769	1.200	0.648
1.300	0.586	1.300	0.522
1.400	0.433	1.400	0.413
1.500	0.312	1.500	0.323
1.600	0.221	1.600	0.250
1.700	0.154	1.700	0.193
1.800	0.106	1.800	0.147
1.900	0.072	1.900	0.112
2.000	0.049	2.000	0.085
2.100	0.033	2.100	0.064
2.200	0.022	2.200	0.048
2.300	0.015	2.300	0.036
2.400	0.010	2.400	0.027
2.500	0.006	2.500	0.020
2.600	0.004	2.600	0.015
2.700	0.003	2.700	0.011
2.800	0.002	2.800	0.008
2.900	0.001	2.900	0.006
3.000	0.001	3.000	0.005

TABLE D-6 TRACER RESPONSE ANALYSIS COMPUTER PROGRAM

```
C     THE TWO CHIEF REFERENCES USED FOR THIS PROGRAMME ARE
C
C          1. LEVENSPIEL , CHEMICAL REACTION ENGINEERING , CHAPTER 9
C
C          2. TIMPANY , VARIATION IN AXIAL MIXING IN AN AERATION
C             TANK. MASTERS THESIS, DEPT. OF CHEM ENG., MCMASTER
C             UNIVERSITY , 1966.
C
C     THE D/UL VALUE FOR THE DISPERSION MODEL IS SOLVED BY USING THE
C     CORRELATIONS OF PEAK TIME VERSUS D/UL DEVELOPED BY TIMPANY.(PP 31 -
C
C     THE CSTR IN SERIES MODEL IS SOLVED BY TAKING THE DERIVATIVE OF
C     EQUATION 9-35 IN LEVENSPIEL  -  EQUATING THE RESULT TO ZERO AND
C     SOLVING FOR THE NUMBER OF EQUAL TANKS IN SERIES, J , IN TERMS
C     OF THETA.THETA IS FOUND BY DIVIDING THE PEAK DYE TIME BY THE
C     THEORETICAL RESIDENCE TIME.
C
C     THE C/CO VALUES FOR THE DISPERSION MODEL ARE SOLVED BY ITERATION
C     USING EQUATION 8 IN CHAPTER 2 OF TIMPANY.
C
C     THE C/CO VALUES FOR THE CSTR IN SERIES MODEL ARE SOLVED USING
C     EQUATION 9-35 IN LEVENSPIEL FOR VARIOUS VALUES OF THETA.
C
C
      DIMENSION C(500),CUL(500),TANKS(5),AW(5),DULP(5),THETA(2,100)
      DIMENSION CCO(2,100),U(500),AMU(5,500),COCO(5,500),CCI(100)
      DIMENSION TTB(100),TBAR(2),RATIO(500),BETA(500),ETA(500)
      DIMENSION BLUE(100)
      DIMENSION CE(200)
C
C     VOLT=TANK VOLUME IN LITRES             VFLR=FLOW IN LITRES/MIN
C     TPEAK=PEAK TIME IN MINUTES             DYIN=AMOUNT OF DYE IN LITRES
C     DYCON=CONC OF DYE IN PPB               DT=MINUTES BETWEEN DATA PTS
C     N=NUMBER OF DATA PTS
C     C(I)=CONC OF DYE IN EFFLUENT PPB
C
      DO 545 IJKJ=1,3
      READ  1,VOLT,VFLR,TPEAK,DYIN,DYCON,DT
      PRINT 1,VOLT,VFLR,TPEAK,DYIN,DYCON,DT
      READ  2,N
      PRINT 2,N
      READ  3,(C(I),I=1,N)
      PRINT 3,(C(I),I=1,N)
C
C     PERCENT DYE RECOVERY
C
      AMT= C(1)*DT*VFLR*10.**(-6)
      CUL(1) = AMT
      DO 100 I=2,N
      AMT=.5*(C(I)+C(I-1))*DT*VFLR*10.**(-6)
      LUL = I-1
      CUL(I) = CUL(LUL)+AMT
  100 CONTINUE
      DYE = DYCON*DYIN*10.**(-6)
      PER = CUL(N)/DYE*100.
C
C     CALCULATION OF MEAN RESIDENCE TIME OF THE TOTAL DYE RETRIEVED
C     CALCULATION OF PERCENT STAGNANT ZONE
C
```

```
      TBAR(1) = VOLT/VFLR
      ANT = 1.
      I = 1
      ZONE = CUL(N)/2.
  201 IF(CUL(I).GT.ZONE) GO TO 200
      ANT = ANT + 1.
      I = I +1
      GO TO 201
  200 TBAR(2) = ANT*DT
      DEAD = (TBAR(1)-TBAR(2))/TBAR(1)
C
C     CALCULATION NUMBER OF TANKS IN SERIES
C
      TP1 = TPEAK/TBAR(1)
      TP2 = TPEAK/TBAR(2)
      TANKS(1) = 1./(TP1*(1./TP1-1.))
      TANKS(2) = 1./(TP2*(1./TP2-1.))
C
C     TRUNCATE TO NEAREST WHOLE NUMBER OF TANKS
C
      AW(1) = TANKS(1)
      AA = 1.5
  203 IF(AW(1).LT.AA) GO TO 202
      AA = AA + 1.
      GO TO 203
  202 AW(1) = AA - .5
      AW(2) = TANKS(2)
      AA = 1.5
  205 IF(AW(2).LT.AA) GO TO 204
      AA = AA + 1.
      GO TO 205
  204 AW(2) = AA - .5
C
C     CALCULATION OF TIMPANY≠S PEAK TIME D/UL VAULES
C
      IF((TP1.GT.0.03).AND.(TP1.LT.0.3)) GO TO 206
      IF((TP1.GT.0.3).AND.(TP1.LT.0.8)) GO TO 207
      GO TO 208
  206 DULP(1)= .2*(TP1**(-1.34))
      GO TO 209
  207 DULP(1) = 4.027*(10.**(-2.09*TP1))
      GO TO 209
  208 PRINT 300
      IF(TP1.LE.0.03) GO TO 206
      GO TO 207
  209 CONTINUE
      IF((TP2.GT.0.03).AND.(TP2.LE.0.3)) GO TO 210
      IF((TP2.GT.0.3).AND.(TP2.LE.0.8)) GO TO 211
      GO TO 213
  210 DULP(2) = .2*(TP2**(-1.34))
      GO TO 214
  211 DULP(2) = 4.027*(10.**(-2.09*TP2))
      GO TO 214
  213 PRINT 300
      IF(TP2.LE.0.03) GO TO 210
      GO TO 211
  214 CONTINUE
C
C     CALCULATION OF  C/CO VS THETA VALUES FOR CSTR MODELS
```

```
C     DERIVATIVE AT PEAK DYE CONC METHOD USED
C
      DO 101 I=1,2
      X=AW(I)**AW(I)
      XX=1.
      BB=1.
  216 IF(AW(I).EQ.BB) GO TO 215
      XX=XX*(AW(I)-BB)
      BB=BB+1.
      GO TO 216
  215 FACT = XX
      THETA(I,1) =0.
      DO 102 J=2,21
      THETA(I,J) = THETA(I,J-1) + .05
  102 CCO(I,J)= X/XX*THETA(I,J)**(AW(I)-1.)*EXP(-AW(I)*THETA(I,J))
      DO 103 J= 22,37
      THETA(I,J) = THETA(I,J-1) + .2
  103 CCO(I,J)= X/XX*THETA(I,J)**(AW(I)-1.)*EXP(-AW(I)*THETA(I,J))
  101 CONTINUE
C
C     CLACULATION OF ACTUAL C/CO VALUES FROM EXPERIMENTAL DATA
C
      CNOT = DYIN*DYCON/VOLT
      MM = 0
      DRAG = 0.
      NN = 0
      DO 104 I = 1,30
      NN = NN + 3
      MM = MM + 1
      RATIO(MM) = C(NN)/CNOT
      DRAG = DRAG + 3*DT
      BETA(MM)= DRAG/TBAR(1)
  104 ETA(MM) = DRAG/TBAR(2)
      IM = (N- 90)/10 + 29
      DO 105 I = 31, IM
      MM = MM + 1
      DRAG = DRAG + 10.*DT
      NN = NN + 10
      RATIO(MM) = C(NN)/CNOT
      BETA(MM) = DRAG/TBAR(1)
      ETA(MM) = DRAG/CNOT
  105 CONTINUE
C
C     CALCULATION OF C/CO VALUES VS THETA FOR D/UL METHOD
C
C
      M = 1
   40 I=1
      AMU(M,I)=1.4
      U(M)=.5/DULP(M)
   45 AMU(M,I)=AMU(M,I)-.001
      FR= COS(AMU(M,I))/SIN(AMU(M,I))
      FR= FR - AMU(M,I)*DULP(M)+ .25/(AMU(M,I)*DULP(M))
      IF(FR)45,45,50
   50 AMU(M,I) = AMU(M,I) + .00001
      FR = COS(AMU(M,I))/SIN(AMU(M,I))
      FR= FR - AMU(M,I)*DULP(M) + .25/(AMU(M,I)*DULP(M))
      IF(FR)55,50,50
   55 AMU(M,I) = AMU(M,I) - .0000001
```

```
      FR = COS(AMU(M,I))/SIN(AMU(M,I))
      FR = FP - AMU(M,I)*DULP(M) + .25/(AMU(M,I)*DULP(M))
      IF(FR)55,55,60
   60 I= I + 1
      AMU(M,I) = AMU(M,I-1)+3.1417
      IF(I.LE.50) GO TO 45
      M = M + 1
      IF(M.LE.2) GO TO 40
      DO 80 M=1,2
  999 ZETA = 0.0
      DO 70 K=1,30
      ZETA = ZETA + .1
      COCO(M,K) = 0.0
      DO 65 I=1,50
      A=2.0*AMU(M,I)*(U(M)*SIN(AMU(M,I)) + AMU(M,I)*COS(AMU(M,I)))
      B=EXP(U(M)-((U(M)**2 + AMU(M,I)**2)/(2.0*U(M)))*ZETA)
      D=U(M)**2 + 2.0*U(M) + AMU(M,I)**2
  998 CE(I) = A*B/D
      COCO(M,K) = COCO(M,K) + CE(I)
   65 CONTINUE
   67 CONTINUE
   70 CONTINUE
   80 CONTINUE
C
C     PRINT INSTRUCTIONS AND DATA PRESENTATION FORMAT
C
      PRINT 700
  700 FORMAT(1H1,42X,24HTRACER RESPONSE ANALYSIS///)
      PRINT 701
  701 FORMAT(40X,29H                FLUIDIZED BED)
      PRINT 702
  702 FORMAT(42X,26HHYDRAULIC CHARACTERIZATION///)
      PRINT 703
  703 FORMAT(30X,≠TEST METHOD USING A PULSE INPUT OF RODAMINE WT DYE≠,/)
      PRINT 704
  704 FORMAT(23X,37HREACTOR OPERATION AND TEST CONDITIONS///)
      PRINT 705,VOLT
  705 FORMAT(31X,20HVOLUME OF REACTOR = ,F7.2,6HLITRES)
      PRINT 706,VFLR
  706 FORMAT(31X,20HHYDRAULIC LOADING = ,F7.2,10HLITRES/MIN)
      PRINT 707,TBAR(1)
  707 FORMAT(31X,20HTHEORETICAL DET    = ,F7.2,3HMIN)
      PRINT 708,DYIN
  708 FORMAT(31X,20HDYE INJECTION      = ,F7.4,6HLITRES)
      PRINT 709,DYCON
  709 FORMAT(31X,20HCONC OF DYE ADDED = ,E10.3,3HPPB)
      PRINT 710,CNOT
  710 FORMAT(31X,20HDYE / TANK VOLUME = ,F7.2,3HPPB,///)
      PRINT 711
  711 FORMAT(23X,34HTEST RESULTS AND CALCULATED VALUES,///)
      PRINT 712,TPEAK
  712 FORMAT(31X,20HDYE PEAK TIME      = ,F7.2,3HMIN)
      PRINT 713,TP1
  713 FORMAT(31X,20HPEAK/THEOR DET     = ,F7.3/)
      PRINT 714,TP2
  714 FORMAT(31X,20HPEAK/MEAN DYE RES = ,F7.3,3HMIN)
      PRINT 715,TBAR(2)
  715 FORMAT(31X,≠MEAN DYE RESIDENCE =≠,F7.2,≠MIN≠)
      PRINT 716,PER
```

```
 716 FORMAT(31X,20HPER DYE RECOVERY   = ,F7.3,1H→)
     PRINT 717,DEAD
 717 FORMAT(31X,20HFR. STAGNANT ZONE = ,F7.3,/)
     PRINT 718,TANKS(1)
 718 FORMAT(31X,42HCSTR S IN SERIES USING THEORETICAL RES. = ,F7.2)
     PRINT 719,TANKS(2)
 719 FORMAT(31X,42HCSTR S IN SERIES USING MEAN DYE RES.    = ,F7.2)
     PRINT 720,CULP(1)
 720 FORMAT(31X,42HD/UL VALUE USING THEORETICAL RESIDENCE  = ,E11.4)
     PRINT 721,DULP(2)
 721 FORMAT(31X,42HD/UL VALUE USING MEAN DYE RESIDENCE     = ,E11.4)
     PRINT 722
 722 FORMAT(31X,38HEXPERIMENTAL RESULTS C/CO VERSUS THETA,/////)
     PRINT 723
 723 FORMAT(14X,5HTHETA,15X,4HC/CO,///)
     PRINT 724,(BETA(I),RATIO(I),I=1,MM)
 724 FORMAT(15X,F5.3,15X,F5.3)
     PRINT 725
 725 FORMAT(31X,35HCALCULATED C/CO VERSUS THETA VALUES)
     PRINT 726
 726 FORMAT(37X,24HFOR CSTR IN SERIES MODEL,/////)
     PRINT 727
 727 FORMAT(12X,≠THEORETICAL DETENSION                  ACTUAL DETENSION≠,//)
     PRINT 728
 728 FORMAT(15X,5HTHETA,6X,4HC/CO,15X,5HTHETA,6X,4HC/CO,///)
     PRINT 729,(THETA(1,J),CCO(1,J),THETA(2,J),CCO(2,J),J=1,37)
 729 FORMAT(15X,F5.3,6X,F5.3,15X,F5.3,6X,F5.3)
     PRINT 725
     PRINT 730
 730 FORMAT(26X,20HFOR DISPERSION MODEL,////)
     PRINT 727
     BLUE(1)= .1
     DO 731 K=2,30
     BLUE(K)= BLUE(K-1) + .1
 731 CONTINUE
     PRINT 729,(BLUE(K),COCO(1,K),BLUE(K),COCO(2,K),K=1,30)
   1 FORMAT(4F10.4,E10.2,F10.4)
   2 FORMAT(I10)
   3 FORMAT(2X,5F10.3)
 300 FORMAT(10X,44HPEAK TIME OUTSIDE LIMIT FOR D/UL CALCULATION)
545  CONTINUE
     STOP
     END
        FINIS
$X,LGO
```

APPENDIX E
ABBREVIATIONS AND SYMBOLS

Abbreviations and symbols appearing in this report are defined within the text, with the exception of those used in Appendix A, "Data Listing". These are defined below:

Amb. AIR - ambient air
ALK - alkalinity
DO - dissolved oxygen
DW - flow of dilution water in L/m
EFC 0807 - effluent composite sample from 0800 hours to 0700 hours
EFG 1200 - effluent grab sample taken at 1200 hours
INT. AIR - internal air i.e. air within the hood enclosing the RBC
RF - flow of raw feed in L/m
RFC 0807 - raw feed composite sample taken between 0800 hours and 0700 hours
RFG 1200 - raw feed grab sample taken at 1200 hours
STG - RBC stage
SS - suspended solids
VSS - volatile suspended solids
30 min settle - 30 minute settling test in 1 litre graduated cylinder