OPTIMAL CONTROL OF AN OIL REFINERY WASTE TREATMENT FACILITY: A TOTAL ECOSYSTEM APPROACH

By

GREGORY DEAN MARTIN

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Oklahoma State University

Stillwater, Oklahoma

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Thesis Approved:

Robert J. Mulholland
Thesis Adviser

Charles M. Bacon

Henry R. Sebesta

N N Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

In recent years systems modeling and digital simulation have become important tools in the study of ecology. The modeling of biological populations began with the work of Lotka (20) and Volterra (34), and led to relatively recent simulations of ecosystems utilizing the digital computer (7,12,13,14,15,26,27,32,37). Referring to the synthesis of whole ecosystems, Smith (30) argues "systems oriented techniques with high speed computers offer the only means by which this can be accomplished". This is certainly not, however, the limit of digital simulation capabilities. Many authors have suggested using computer ecosystem models in studying proposed management or control policies (7,26,30). Although the efforts to date have been limited, the ultimate goal of this activity is the optimal design and control of ecological systems (27). Watt (37) treats resource management as an optimization problem: how to maximize a rate of harvest, or how to minimize the density of a pest. He used a mathematical model of the system to predict the effects of different management policies on yield (19). Davidson and Clymer (7) express the desirability of applying computer simulation to ecosystems, particularly in the area of environmental problems. An interesting application of this type would be the optimal control of a pollution abatement ecosystem. An example of this approach is the subject of this thesis.

The particular system of interest is a series of effluent holding

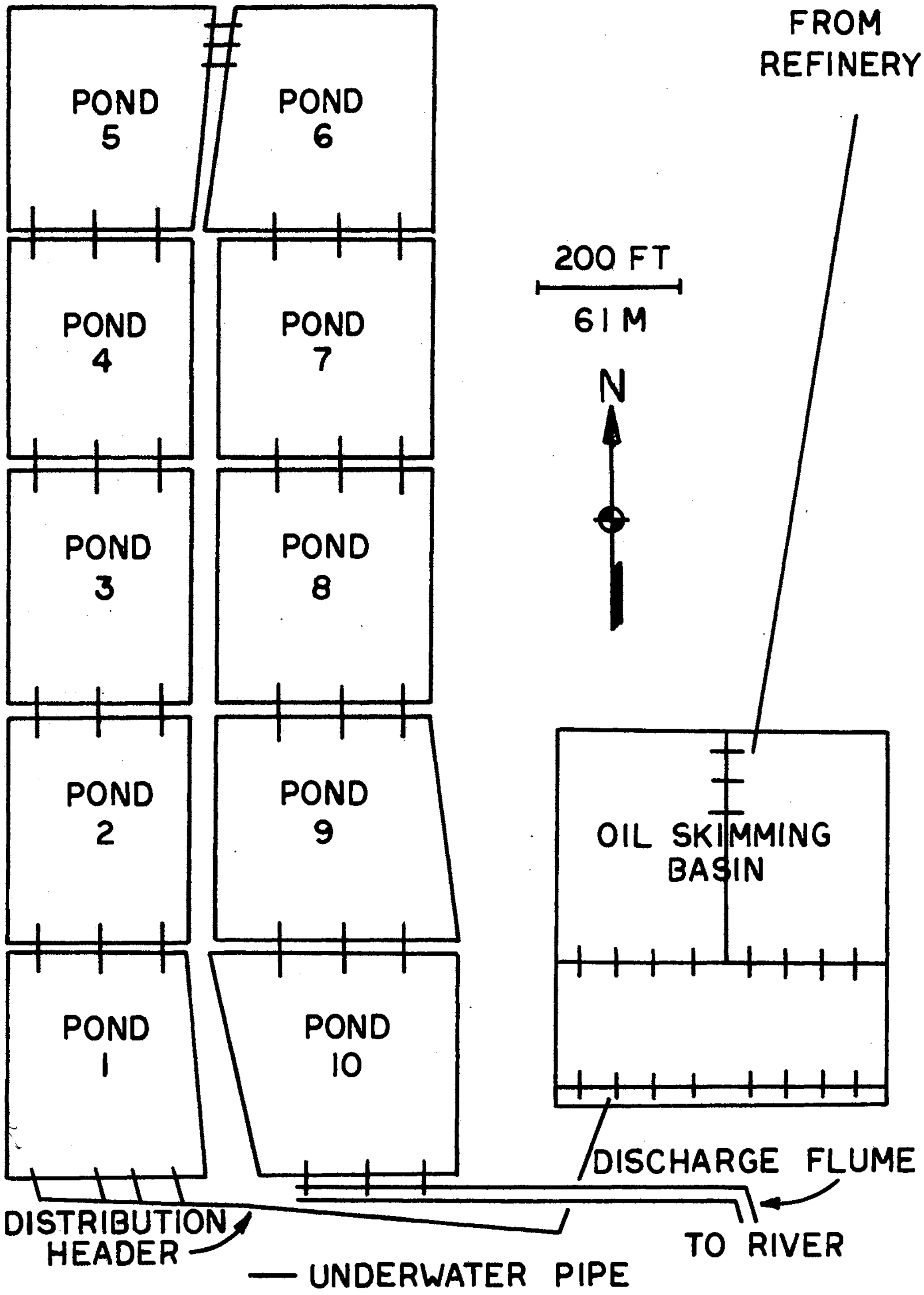


Figure 1. Holding Pond System

There has been no attempt to continuously monitor or regulate biological processes in the system. In this study a differential equation model was developed for this ecosystem and a control philosophy adopted. Control possibilities and indicators of effluent quality were reviewed, evolving into a control scheme and performance index. Digital simulation offered verification of the model and prediction of system performance was carried out by applying a search algorithm to find the minimal "cost" control policy.

Modeling of the system was carried out in three steps. First, a model for pond ten was formulated as a class project in a joint effort between the Departments of Electrical Engineering and Zoology, Oklahoma State University. Using the procedure verified by the class project, models were then developed for two upstream ponds in the system, ponds four and seven. The three models were then linked to form a series similar in function to the actual system, hopefully simulating the important biological succession effect.

Before going into some of the modeling preliminaries, a few definitions and some of the ecological terminology will be presented. The following basic concepts can be found, Odum (25).

Definitions

Ecosystem

Any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles within the system.

Trophic Structure

The aggregation of organisms into two functional components - autotrophic and heterotrophic. The autotrophic component consists of primary producers with the heterotrophic components consisting of primary, secondary, and tertiary consumers and decomposers.

Diversity Index

Mathematical expression describing community structure in terms of number of species and the apportionment of individuals among species. A low species diversity corresponds to a few species with many individuals while a high diversity would be evidenced by many species with few individuals in each. Species diversity is correlated with ecosystem stability, but it is not certain to what extent this relationship is causal.

Standing Crop

Magnitude of a particular entity in the ecosystem, indicating biotic (living) population or abiotic (non-living) intensity at a particular instant in time. Measured in units of biomass, for example, per unit area (gm/m^2).

Average Standing Crop

Average of the standing crop per unit time, i.e., week, month, year.

P/R Ratio, Productivity/Respiration Ratio

The ratio of gross primary production of oxygen to community respiration including the oxygen demand of inorganic and organic compounds. This ratio should remain close to 1.0 in a steady-state ecological system. When import of organic material occurs such as in the present study, the ratio is less than unity. However, the ratio returns to unity as oxygen demand is curbed.

Q-10 Factor

A factor indicating the influence of temperature on the growth of a population. Often accepted to be 2.0, so that an increase in temperature of ten degrees Centigrade would double the population's growth rate.

Turnover Rate

The fraction of the total amount of a substance in a compartment which leaves (or enters) in a given length of time at equilibrium. For example, assume a particular compartment has a standing crop of 10 gm/m^2. A flux of 1 gm/day out would correspond to a turnover rate of .1 $gm/m^2/day$.

Of the concepts defined above, perhaps the most important is that of the ecosystem. The ecosystem is the basic functional unit in ecology, since it includes both organisms (biotic communities) and the abiotic environment, each influencing the properties of the other and both necessary for maintenance of life (25). The systems approach to ecology, fostering the ecosystem concept, results in a modeling viewpoint similar to the basic engineering systems approach. System boundaries, inputs, outputs, characteristic functions, states and system parameters are considered (30). For the submodels formulated later, the boundary of each pond ecosystem was considered as the waters edge. The primary ecosystem drivers were the inputs of light and temperature, while the ecosystem outputs consisted of the standing crop values.

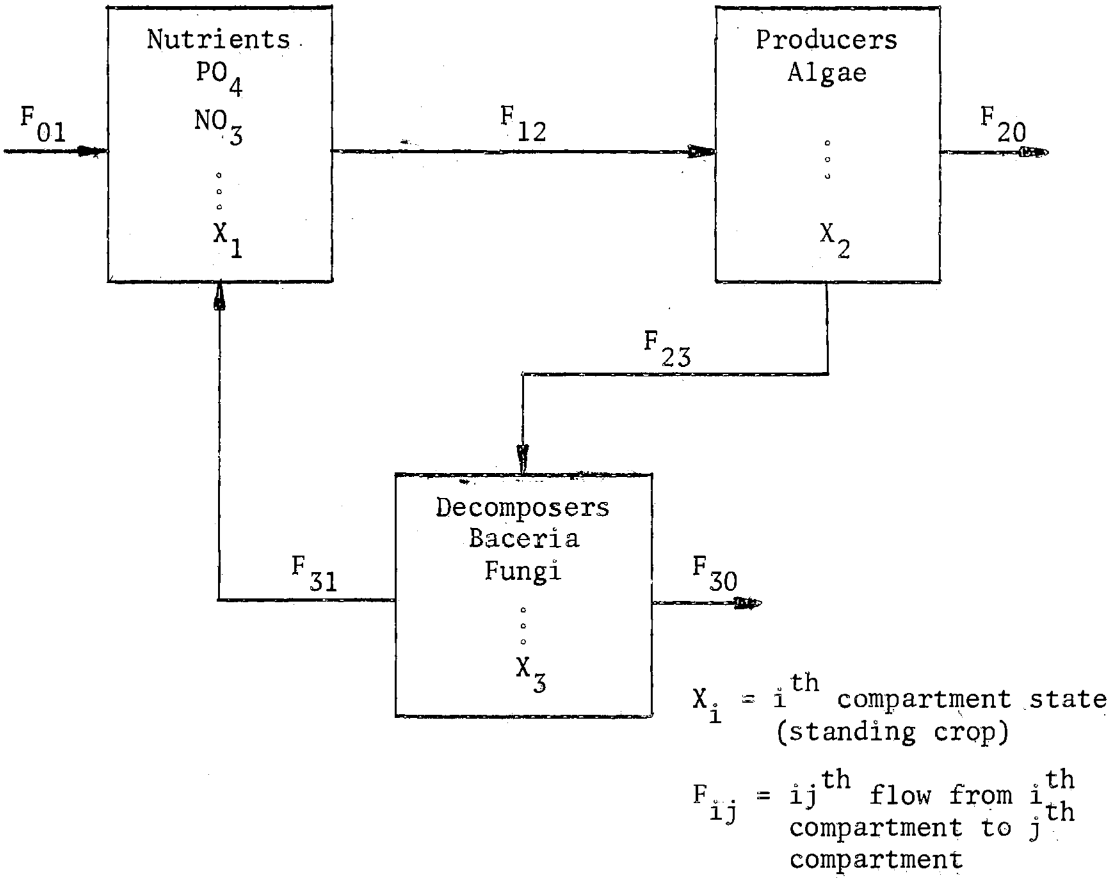
As in most modeling efforts, assumptions must be made to reduce the complexity of the realization to a feasible modeling form. This should be accomplished while retaining, and hopefully exposing, the dominant characteristics controlling the system function. Patten (27) has guided much of the work in the ecosystems field and is used here as the primary source of methodology. Listed below are the assumptions made (7):

1. all variables uniformly distributed;
2. diurnal (daily) frequencies were not of interest;
3. growth and reproduction need not be distinguished; and
4. the species are divided into functional groups.

A "functional group" is a lumped set of species which have the same or similar function within the ecosystem. This approach is analogous to the "lumped parameter" assumption commonly used in engineering. An example of such lumping would be a decomposer group made up of various types of bacteria which have the same function in the ecosystem.

The concept of functional groups is further extended through the application of the compartment approach (27), wherein a compartment including several lumped species is represented by a single standing crop, expressed in units of biomass. In this way, one can systematically identify the states of the ecosystem to be modeled.

Interactions between these states are indicated as flows connecting the compartments of the model (see Figure 2). These flows arise as a result of trophic considerations, predator-prey feeding rates, mortality rates, etc. Depending on the type of model the flows can represent biomass, energy, uptake of nutrients, numbers, or any one of a number of flux types (18). In this work the flow values represent biomass fluxes based on a monthly time scale. This monthly temporal reference allows the populations to behave like a continuous rather than discrete variable, an approach used by Ulanowicz (32).



X_i = i^{th} compartment state (standing crop)

F_{ij} = ij^{th} flow from i^{th} compartment to j^{th} compartment

Figure 2. Simple Compartment Model

Thus far the boundaries, significant states and interactions of the ecosystem have been identified. This information is now used to formulate a differential state equation model of the form:

$$\dot{X}_i = \sum_{j=1}^{n} a_{ji} X_j - \sum_{j=0}^{n} a_{ij} X_i + b_{oi} \quad ,$$

$$i = 1, 2, \ldots, n$$

$$j = 0, 1, \ldots, n$$

$$a_{ji} = a_{ji}(X_i, t)$$

$$a_{ij} = a_{ij}(X_j, t) \quad .$$

This may be written compactly in the familiar matrix form:

$$\dot{\underline{X}} = \underline{A}\,\underline{X} + \underline{b} \tag{1}$$

describing the compartment dynamics. Presented here are some widely accepted guidelines for this formulation which follow directly from the previous modeling steps.

Consider again Figure 2 and the flows between compartments, in particular the flow from X_1 to X_2. X_1 in this case is the "donor" state and X_2 the "recipient", for obvious reasons. To consider this flow dependent only upon the magnitude of the X_1 state, or X_1 standing crop, the state equation describing the simple ecosystem would be as follows:

$$\dot{X}_1 = - a_1 X_1 + F_{01}$$

$$\dot{X}_2 = a_1 X_1 - F_{23} - F_{20} \quad ,$$

where

$$a_1 = \frac{F_{12}}{X_1^*} \quad .$$

Here X_1^* is defined as the average standing crop of X_1.

Through this process the resulting equation is said to be "donor controlled" for the flow from X_1 to X_2. It is clear that an ecosystem model based on this type of rule will be a linear model, the $\underline{A}$ matrix being a matrix of constants. Similarly, if the flows are defined as being dependent upon the magnitudes of the recipient compartments (X_2 in this case) the model will still be linear but the $\underline{A}$ matrix would differ. Moreover, it is clear that at the average standing crop values, $\underline{\dot{X}} = 0$ and equilibrium is achieved.

Another variety of linear model which has been used to some extent is the combination donor-recipient controlled model, for which some types of flows are ruled donor controlled and others recipient. An example of this modeling procedure would be to let biotic flows be donor controlled and abiotic, recipient controlled.

In addition to linear models, there is another class of models whose flow descriptions are based on both standing crops, resulting in non-linear state equations. In this case, the state equations for the system shown in Figure 2 would appear as shown below:

$$\begin{aligned} \dot{X}_1 &= - a_1 X_1 X_2 + F_{01} \\ \dot{X}_2 &= a_1 X_1 X_2 - F_{23} - F_{20} \quad , \end{aligned} \tag{2}$$

where

$$a_1 = \frac{F_{12}}{X_1^* X_2^*} \quad .$$

Here it should be pointed out that there are reasons for assuming one class of models over another. The linear class is often favored in systems analysis for its mathematical simplicity and the well-developed mathematical tools which can be brought to bear on linear systems. While mathematically simple, and probably applicable in certain limited cases, it is conceptually unsatisfying to think of a predator-prey relationship as always independent of one of the interacting species. This objection is removed by invoking the Lotka-Volterea hypothesis (20) which states that the biomass flux between two interacting populations varies as the product of the interacting biomasses (32). This, of course, leads to the nonlinear form displayed in Equation (2). The model presented in this thesis evolved into the nonlinear type.

The $\underline{b}$ vector and the addition of the effects of light and temperature will be discussed in Chapter II, which presents the details of the ecosystem model formulation. In Chapter III the control strategy and ecosystem performance index will be defined, the optimization of which will be analyzed in Chapter IV. Chapter V presents the conclusions and recommendations for further work with various simulation results given in Appendices A through C.

CHAPTER II

FORMULATION OF THE ECOSYSTEM MODEL

The discussion in Chapter I considered the general procedures widely used in formulation of ecosystem models. The three submodels presented in this chapter followed these guidelines. Linking of the submodels was accomplished to produce a total ecosystem model for the holding pond series. Computer simulation was performed to verify the dynamic response of the model. The simulation results for the pond ten submodel are given in Appendix B.

The Pond Ten Submodel

As noted previously, the submodel for pond ten was the result of a group effort involving students and faculty of the Departments of Electrical Engineering and Zoology, Oklahoma State University. Considerable amounts of data for the pond system had been accumulated by members of the Zoology Department in previous studies (3,4,11,22,28,36). This data and the general literature on zoology were the primary sources of information used to arrive at the parameters in the submodel.

Having agreed that the waters edge would be the ecosystem boundary for pond ten, the next step was to identify the system states. The functional group and compartment concepts directed this effort.

The class was divided into teams representing the different trophic levels, abiotic components, producers, heribores, carnivores, and decomposers. The teams worked independently and jointly confirmed their findings at regular class meetings. After identifying the system states, the teams proceeded to quantify the corresponding average standing crops.

Since light, the primary input for the ecosystem, enters on a horizontal basis, average standing crops were measured per unit area (24). The units of measurement chosen for the average standing crops were gm/m^2 (dry weight). Assuming the pond depth to be an average of two meters, the average standing drop values were actually double the population densities in gm/m^3 or mg/l.

Next, the teams appraised the ecosystem interactions, or flows between the model compartments. Most of the flow magnitudes were found in the literature, but some were estimated. The teams worked together in this phase and came to agreement concerning common flows. Under the assumption that the pond system was in steady-state, the sum of flows into a compartment minus the sum out was equal to zero. The pond ten submodel flow diagram is presented in Figure 3, with flow magnitudes, trophic levels, and average standing crops included. The bluegill fish compartment was added as an indicator of effluent quality.

Making use of the average standing crop and flow information available, the teams proceeded to calculate the rate parameters, or elements of the $\underline{A}$ matrix. This necessitated the decision as to what class of model to assume, basically linear or nonlinear. The group agreed to use the linear approach of the combination form, assuming that abiotic flows were recipient controlled, while biotic flows were donor controlled. The state equations arrived at are presented below:

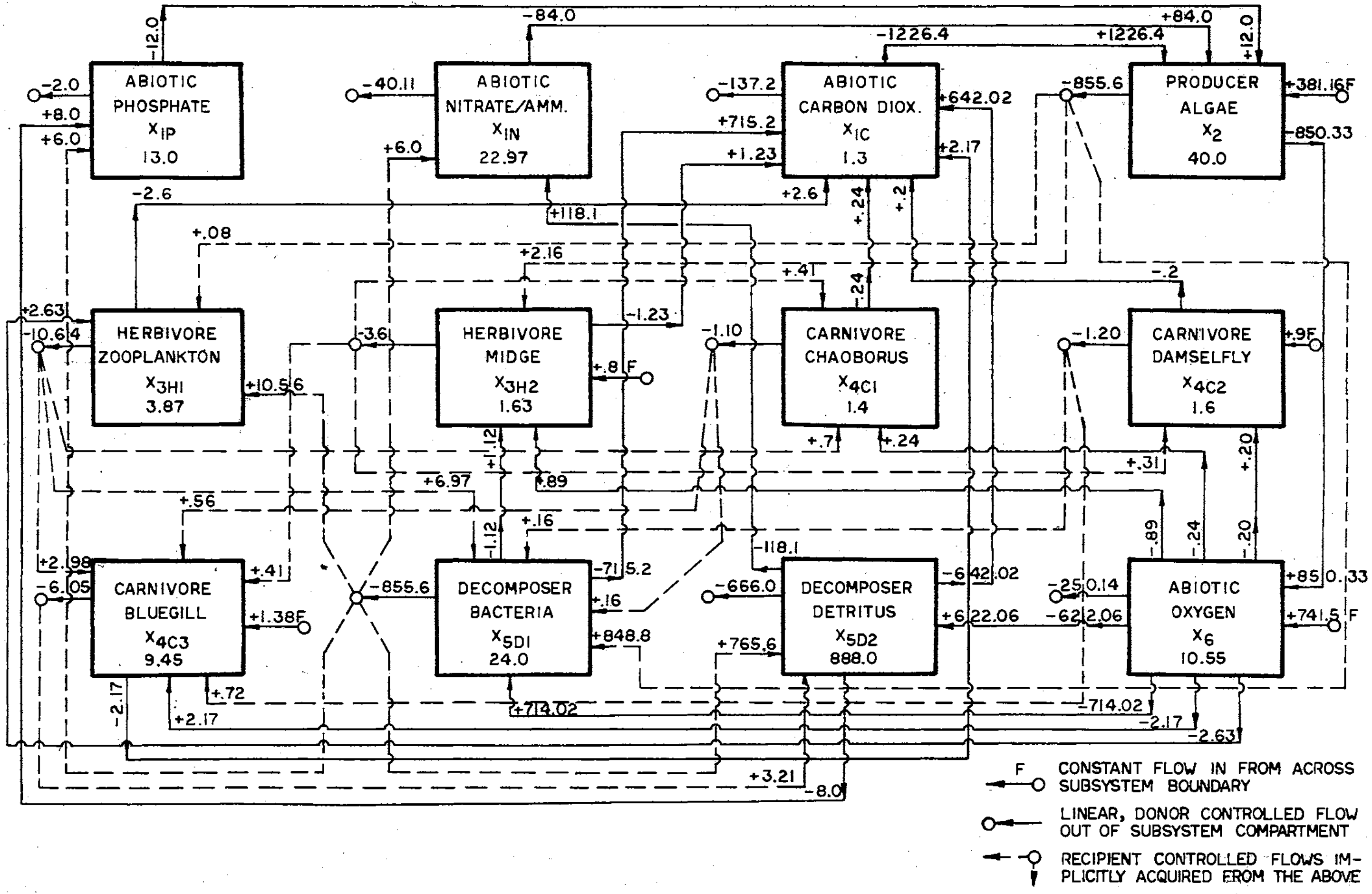


Figure 3. Pond Ten Flow Diagram

$$\dot{X}_{1P} = .25\ X_{5D1} + .009\ X_{5D2} - .3\ X_2 - .1532\ X_{1P}$$

$$\dot{X}_{1N} = .25\ X_{5D1} + .133\ X_{5D2} - 2.1\ X_2 - 1.746\ X_{1N}$$

$$\begin{aligned}\dot{X}_{1C} = {} & - 105.546\ X_{1C} - 30.66\ X_2 + .68\ X_{3H1} + .745\ X_{3H2} \\ & + .171\ X_{4C1} + .125\ X_{4C2} + .23\ X_{4C3} + 29.8\ X_{5D1} \\ & + .723\ X_{5D2}\end{aligned}$$

$$\dot{X}_{2} = - 9.529\ X_2 + 381.16$$

$$\dot{X}_{3H1} = - 2.75\ X_{3H1} + .44\ X_{5D1} + .00206\ X_2$$

$$\dot{X}_{3H2} = - 2.5\ X_{3H2} + .054\ X_2 + .0468\ X_{5D1} + .7987$$

$$\dot{X}_{4C1} = - .789\ X_{4C1} + .18\ X_{3H1} + .25\ X_{3H2}$$

$$\dot{X}_{4C2} = - .752\ X_{4C2} + .19\ X_{3H2} + .9$$

$$\begin{aligned}\dot{X}_{4C3} = {} & - .64\ X_{4C3} + .77\ X_{3H1} + .25\ X_{3H2} + .4\ X_{4C1} \\ & + .45\ X_{4C2} + 1.38\end{aligned}$$

$$\begin{aligned}\dot{X}_{4D1} = {} & - 35.65\ X_{4D1} + 21.22\ X_2 + 1.8\ X_{3H1} + .114\ X_{4C1} \\ & + .097\ X_{4C2}\end{aligned}$$

$$\dot{X}_{5D2} = - .165\ X_{5D2} + 31.9\ X_{5D1} + .43\ X_{4C3} - 623.14$$

$$\begin{aligned}\dot{X}_{6} = {} & - 100.0\ X_6 + 21.3\ X_2 - .68\ X_{3H1} - .548\ X_{3H2} \\ & - .171\ X_{4C1} - .125\ X_{4C2} - .23\ X_{4C3} - 29.8\ X_{5D1} \\ & - .7\ X_{5D2} + 1550.0 \quad .\end{aligned}$$

Note that the b̲ vector of Equation (1) in Chapter I here can be interpreted as consisting of the balancing flow values for the compartment equations.

At this point the ecosystem model response was simulated using an IBM 360-65 digital computer and Continuous Systems Modeling Program (CSMP). The integration routine used was Runge-Kutta with variable step-size. Initial conditions were chosen reasonably close to the average standing crops (steady states). Simulation trajectories settled at the steady states, as expected, and the rate of settlement was related directly to the turnover rates. This provided a method of verifying the turnover times corresponding to the various compartments.

The diagonal terms of the A matrix correspond to the "time constant dominators" of the model, and some of these were adjusted to obtain what the teams believed to be the correct turnover rates (or reciprocal times). For example, the decoupled algae compartment's turnover time was changed to slightly less than one day by adjusting the corresponding diagonal element in the A matrix.

The "tuned" model which resulted would, given a set of initial conditions, seek the average standing crops. The next step accounted for the inputs of light and temperature determined as causal functions of time.

Light input was considered as a flow addition to the algae compartment (this proved to be in error, and will be discussed later in this chapter), thus the light influx in langleys/m^2/month was merely added into the algae state equation.

Temperature influence was introduced through the Q-10 factor (27), as defined in Chapter I. A factor of the form:

$$Q\text{-}10 = 2.0^{\left(\frac{T - T_{avg}}{10.0}\right)}$$

was used in the model. Here T designates the pond water temperature in degrees Centigrade and T_{avg} denotes the time integrated yearly average of T. All of the biotic state equations were multiplied by this factor which prescribed the temperature influence on the growth rate of a state or compartment. It is clear that, for a ten degree rise in temperature, the factor doubles, resulting in biotic growth rate doubling. This temperature dependence is usually referenced to some nominal temperature. Here, the reference used was the average pond water temperature, and at that temperature the factor is equal to unity.

With these input considerations included, the state equations [Equation (1)] become:

$$\dot{X}_{1P} = .25\ X_{5D1} + .009\ X_{5D2} - .3\ X_2 - .1532\ X_{1P}$$

$$\dot{X}_{1N} = .25\ X_{5D1} + .133\ X_{5D2} - 2.1\ X_2 - 1.746\ X_{1N}$$

$$\begin{aligned}\dot{X}_{1C} = &- 105.546\ X_{1C} - 30.66\ X_2 + .68\ X_{3H1} + .745\ X_{3H2} \\ &+ .171\ X_{4C1} + .125\ X_{4C2} + .23\ X_{4C3} + 29.8\ X_{4D1} \\ &+ .723\ X_{5D2}\end{aligned}$$

$$\dot{X}_2 = (- 0.529\ X_2 + \text{LIGHT})(\text{Q-10})$$

$$\dot{X}_{3H1} = (- 2.75\ X_{3H1} + .44\ X_{5D1} + .00206\ X\ )(\text{Q-10})$$

$$\dot{X}_{3H2} = (- 2.50\ X_{3H2} + .054\ X_2 + .0468\ X_{5D1} + .7987)(\text{Q-10})$$

$$\dot{X}_{4C1} = (- .789\ X_{4C1} + .18\ X_{3H1} + .25\ X_{3H2})(\text{Q-10})$$

$$\dot{X}_{4C2} = (- .752\ X_{4C2} + .19\ X_{3H2} + .9)(\text{Q-10})$$

$$\begin{aligned}\dot{X}_{4C3} = &(- .64\ X_{4C3} + .77\ X_{3H1} + .25\ X_{3H2} + .4\ X_{4C1} \\ &+ .45\ X_{4C2} + 1.38)(\text{Q-10})\end{aligned}$$

$$\dot{X}_{5D1} = (- 35.65\ X_{5D1} + 21.22\ X_2 + 1.8\ X_{3H1} + .114\ X_{4C1} + .097\ X_{4C2})(Q-10)$$

$$\dot{X}_{5D2} = - .165\ X_{5D2} + 31.9\ X_{5D1} + .43\ X_{4C3} - 623.14$$

$$\dot{X}_6 = - 100.0\ X_6 + 21.3\ X_2 - .68\ X_{3H1} - .548\ X_{3H2} - 171\ X_{4C1} - .125\ X_{4C2} - .23\ X_{4C3} - 29.8\ X_{5D1} - .7\ X_{5D2} + 1550.0 \quad .$$

Pond water temperature and light as functions of time were generated for simulation purposes by a quadratic interpolation of the data used.

With these changes, the revised model was simulated and the trajectories checked. Computer printouts revealed that some of the abiotic states went negative and the model was unstable. Also, there was no coupling between biotic and abiotic compartments. Alleviation of these problems required that the model be changed to a nonlinear one. The abiotic flow controls were redefined to the nonlinear predator-prey type. This action led to the following submodel representation for pond ten:

$$\dot{X}_{1P} = - .1532\ X_{1P} + .24\ X_{5D1} + .009\ X_{5D2} - .23\ X_{1P}\ X_2$$

$$\dot{X}_{1N} = - 1.746\ X_{1N} + .25\ X_{5D1} + .133\ X_{5D2} - .0914\ X_{1N}\ X_2$$

$$\dot{X}_{1C} = - 105.546\ X_{1C} - 23.58\ X_{1C}\ X_2 + .523\ X_{1C}\ X_{3H1} + .58\ X_{1C}\ X_{3H2} + .131\ X_{1C}\ X_{4C1} + .096\ X_{1C}\ X_{4C2} + .1777\ X_{1C}\ X_{4C3} + 22.93\ X_{1C}\ X_{5D1} + .556\ X_{1C}\ X_{5D2}$$

$$\dot{X}_{3H1} = (- 2.75\ X_{3H1} + .44\ X_{5D1} + .0645\ X_{3H1}\ X_6 + .00206\ X_2 - .523\ X_{3H1}\ X_{1C})(Q-10)$$

$$\dot{X}_{3H2} = (- 2.216\ X_{3H2} + .054\ X_2 + .0468\ X_{5D1} + .0579\ X_{3H2}\ X_6 - .58\ X_{3H2}\ X_{1C})(Q\text{-}10)$$

$$\dot{X}_{4C1} = (- .789\ X_{4C1} + .18\ X_{3H1} + .25\ X_{3H2} + .016\ X_{4C1}\ X_{1C} - .131\ X_{4C1}\ X_{1C})(Q\text{-}10)$$

$$\dot{X}_{4C2} = (- .752\ X_{4C2} + .19\ X_{3H2} + .0118\ X_{4C2}\ X_6 - .096\ X_{4C2}\ X_{1C} + .9)(Q\text{-}10)$$

$$\dot{X}_{4C3} = (- .64\ X_{4C3} + .77\ X_{3H1} + .25\ X_{3H2} + .4\ X_{4C1} + .45\ X_{4C2} + .0218\ X_{4C3}\ X_6 - .1769\ X_{4C3}\ X_{1C} + 1.38)(Q\text{-}10)$$

$$\dot{X}_{5D1} = (- 35.65\ X_{5D1} + 21.22\ X_2 + 1.8\ X_{3H1} + .114\ X_{4C1} + .097\ X_{4C2} + 2.82\ X_{5D1}\ X_6 - 22.92\ X_{5D1}\ X_{1C})(Q\text{-}10)$$

$$\dot{X}_{5D2} = - .75\ X_{5D2} - .000069\ X_{5D2}\ X_{1P} - .0058\ X_{5D2}\ X_{1N} - .556\ X_{5D2}\ X_{1C} + .0664\ X_{5D2}\ X_6 + 31.9\ X_{5D1} + .43\ X_{4C3}$$

$$\dot{X}_6 = - 23.71\ X_6 + 2.047\ X_6\ X_2 - .0645\ X_6\ X_{3H1} - .052\ X_6\ X_{3H2} - .0165\ X_6\ X_{4C1} - .0118\ X_6\ X_{4C2} - .0218\ X_6\ X_{4C3} - 2.82\ X_6\ X_{5D1} - .0664\ X_6\ X_{5D2} + 741.5 .$$

Simulation results now indicated that the changes were effective in eliminating the problems encountered with the linear model. Runs of approximately two years in model time showed the relative magnitudes of the standing crops and state fluctuations were as observed in the real system. However, there were phase problems (i.e., food chain lags reversed) between some compartments.

At this point the group project ended, with a reasonably successful submodel for pond ten, the last in the holding pond series. The modeling effort which follows was carried out independently with assistance and recommendations from some of the individuals of the group.

Formulation of the Two Upstream Submodels

Before proceeding with the development of the models for ponds four and seven, the pond ten submodel was modified slightly. The light input was reevaluated and some minor compartment changes made. These resulted in a simulated response closer to the dynamics expected from the actual ecosystem.

Considerations concerning the inclusion of light influx as a flow into the algae compartment led to somewhat of a dilemma. Light added in this manner could be interpreted as adding an energy flux into a biomass rate representation. To correct this situation light influence was changed to a form which introduced its effect by regulating algae's fixation of carbon from CO_2 through the photosynthetic process. This method of representation more closely models the actual mechanism involved. A normalized light parameter (light/avg. light) multiplying the flow of CO_2 to algae modulated the CO_2 uptake by algae in the model. As with previous average values, the light average refers to the time integrated yearly average.

In addition to the changes concerning light input, the detritus and bacteria (actually suspended detritus and detridal sediment) compartments were lumped due to their very similar functions in the pond ten model. The revised pond ten flow diagram is shown in Figure 4 with the corresponding state equations presented on the following page.

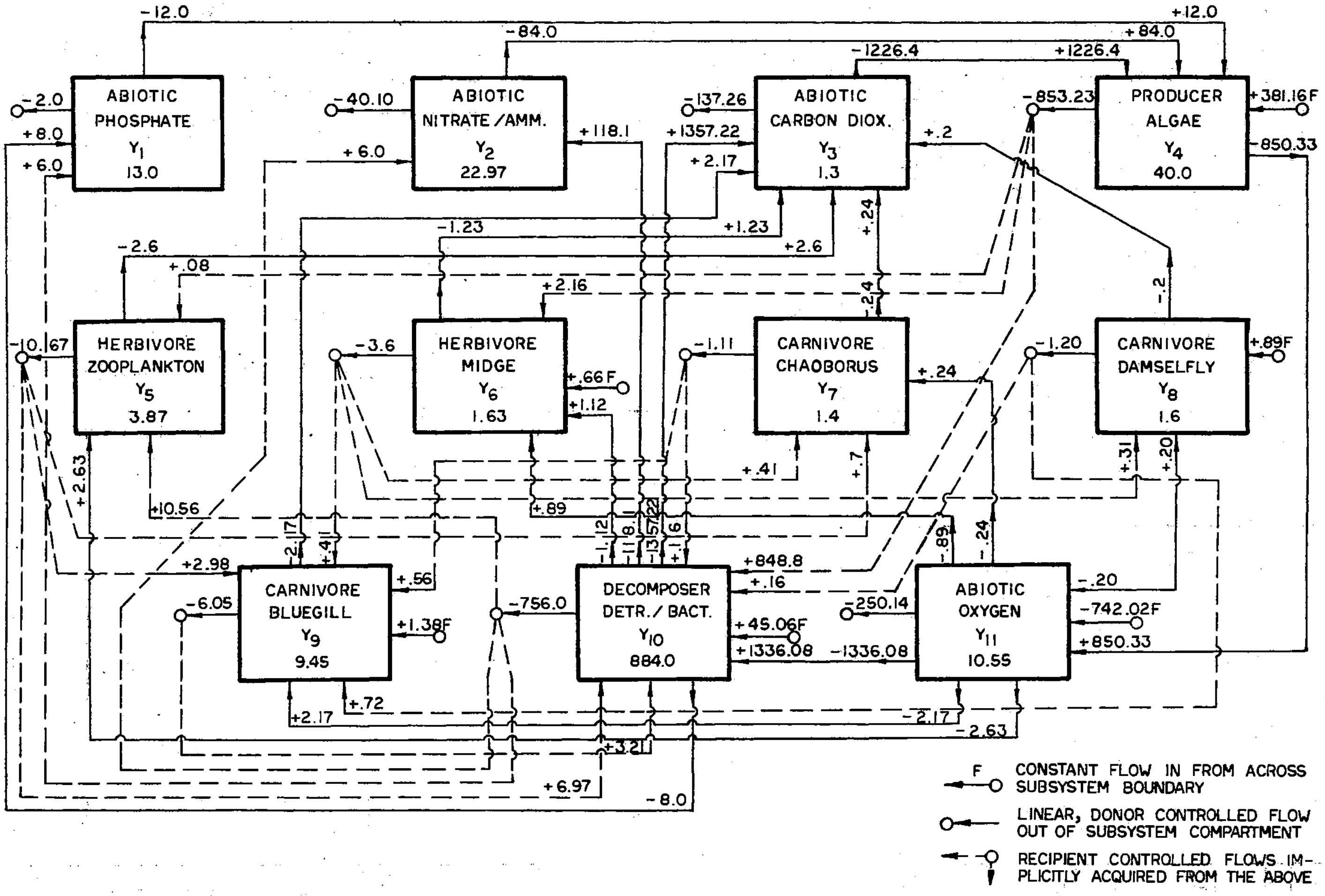


Figure 4. Pond Ten Flow Diagram (Revised)

$$\dot{Y}_1 = .15385\ Y_1 - .02308\ Y_1\ Y_4 + .00905\ Y_{10} + .00679\ Y_{10}$$

$$\dot{Y}_2 = -\ 1.74576\ Y_2 - 0.9142\ Y_2\ Y_4 + .13360\ Y_{10} + .00679\ Y_{10}$$

$$\begin{aligned} \dot{Y}_3 = {} & -\ 105.58462\ Y_3 - 23.58462\ Y_3\ Y_4\ X_4 + .17664\ Y_3\ Y_9 \\ & + .09615\ Y_3\ Y_8 + 1.18101\ Y_3\ Y_{10} + .13187\ Y_3\ Y_7 \\ & + .58046\ Y_3\ Y_6 + .51680\ Y_3\ Y_5 \end{aligned}$$

$$\begin{aligned} \dot{Y}_4 = {} & (23.58462\ Y_3\ Y_4\ X_4 + .09412\ Y_2\ Y_4 + .02308\ Y_1\ Y_4 \\ & - 21.33075\ Y_4 - 2.01500\ Y_4\ Y_{11} + 381.16)(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_5 = {} & (-\ 2.75711\ Y_5 - .51680\ Y_3\ Y_5 + .00200\ Y_4 + .01195\ Y_{10} \\ & + .06442\ Y_5\ Y_{11})(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_6 = {} & (-\ 2.20859\ Y_6 - .58046\ Y_3\ Y_6 + .05400\ Y_4 + .05175\ Y_6\ Y_{11} \\ & + .00127\ Y_{10} + .66)(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_7 = {} & (-\ .79286\ Y_7 - .13187\ Y_3\ Y_7 + .18088\ Y_5 + .25153\ Y_6 \\ & + .01625\ Y_7\ Y_{11})(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_8 = {} & (-\ .75000\ Y_8 + .01185\ Y_8\ Y_{11} + .19018\ Y_6 - .09615\ Y_3\ Y_8 \\ & + .89)(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_9 = {} & (-\ .64021\ Y_9 + .20569\ Y_{11} + .45000\ Y_8 + .40000\ Y_7 \\ & - .17664\ Y_3\ Y_9 + .25153\ Y_6 + .77003\ Y_5 + 1.38)(X_3) \end{aligned}$$

$$\begin{aligned} \dot{Y}_{10} = {} & (-\ .85520\ Y_{10} - .00127\ Y_{10} - 1.18101\ Y_3\ Y_{10} - .00582\ Y_{10}\ Y_2 \\ & + .11429\ Y_7 + .14326\ Y_{10}\ Y_{11} + 1.80103\ Y_5 - .00070\ Y_{10}\ Y_1 \\ & + 21.22000\ Y_4 + .10000\ Y_8 + 45.06)(X_3) \end{aligned}$$

$$\begin{aligned}\dot{Y}_{11} = &- 23.70995\ Y_{11} - .02177\ Y_{11}\ Y_9 - .06442\ Y_5\ Y_{11} \\ &- .14326\ Y_{10}\ Y_{11} - .05175\ Y_6\ Y_{11} - .01625\ Y_7\ Y_{11} \\ &- .01185\ Y_8\ Y_{11} + 2.01500\ Y_4\ Y_{11} + 742.02 \quad .\end{aligned}$$

X_3 represents the Q-10 factor while X_4 designates the light factor in the above equations.

Simulations from this point made use of the Dynamic Simulation Program (DYSIMP) (29), available at the Oklahoma State University computer facility. This was preferred to CSMP because it offered optimization capabilities, and was less expensive. The integration routine used by this package was fixed stepsize Runge-Kutta. Due to this fixed stepsize, periodic checks were made throughout the remaining course of this work to insure numerical accuracy. The checks were made by varying the stepsize and noting the corresponding change in simulation output.

The results of the simulation showed the changes made in the pond ten submodel helped the phase situation and that the model for pond ten was essentially stable. However, initial conditions were chosen at the steady state values, since it is characteristic of nonlinear models to have system trajectories altered by a change in initial conditions. A program listing and simulation output are presented in Appendix A.

Making use of the verified submodel for pond ten, submodels for ponds four and seven were synthesized. The modeling steps established by the group effort were repeated in developing these submodels. The assumption made here was that the trophic structure in all three ponds was similar. Under this assumption, the fact that upstream ponds contained progressively fewer species and were less diverse did not lead to flow determination difficulties. In both instances, the eliminated compartments and respective flows were simply discarded while maintaining all other flow interactions recognized in the pond ten submodel.

The modeling steps followed are outlined below:

1. determine system states;
2. find average standing crop values;
3. establish balanced flow interactions;
4. formulate the state equations;
5. test the homogeneous model (without light and temperature inputs);
6. include the effects of light and temperature; and
7. verify the final pond submodel.

Identification of the significant state variables in the upstream pond submodels demonstrated that three of the compartments included in the pond ten submodel should be eliminated in one or both of the upstream submodels. Bluegill fish and Chaoborus were excluded in both submodels, and the damselfly compartment was eliminated from the pond four submodel. The average standing crops for all three ponds are listed in Table I, with the corresponding references.

The next step in the modeling process was to determine the flows connecting the compartments in each of the submodels. The assumption of similar trophic structure fixed the flow interaction web, but to quantify the flows the following scheme was employed.

Flows in the two upstream submodels were also linear donor-recipient controlled. The donor controlled flows in ponds four and seven were scaled proportionately to the ones in ten by a ratio of the respective average standing crops. For example, assume a flow from zooplankton to Chaoborus in pond ten of 40.0 $gm/m^2/mo$, while the average standing crop of zooplankton there is 20.0 gm/m^2. This would imply a corresponding flow in pond seven, where the average standing crop of zooplankton is 10.0 gm/m^2, of 20.0 $gm/m^2/mo$. This scheme was also used in finding the recipient controlled flow values. It was assumed the ponds were all in steady-state so that net flow into each compartment would equal zero. The flow diamgrams for ponds seven and four are illustrated in Figures 5 and 6, respectively.

TABLE I

POND AVERAGE STANDING CROPS[1]

Compartment	Pond 4	State	Pond 7	State	Pond 10	State	Reference
Phosphate	24.92	1	16.25	1	13.0	1	4
Nitrate/Ammonia	32.0	2	27.0	2	22.97	2	4
Carbon Dioxide	4.3	3	2.1	3	1.3	3	16
Algae	35.21	4	47.43	4	40.0	4	4, 22
Zooplankton	.99	5	3.35	5	3.87	5	22
Midges	.7	6	1.02	6	1.63	6	31
Chaoborus	-	-	-	-	1.4	7	-
Damselfly	-	-	.41	7	1.6	8	11
Bluegill Fish	-	-	-	-	9.45	9	17
Detritus/Bacteria	1722.0	7	1219.0	8	884.0	10	6, 24, 27
Oxygen	4.1	8	11.0	9	10.55	11	4

[1] (gm/m^2).

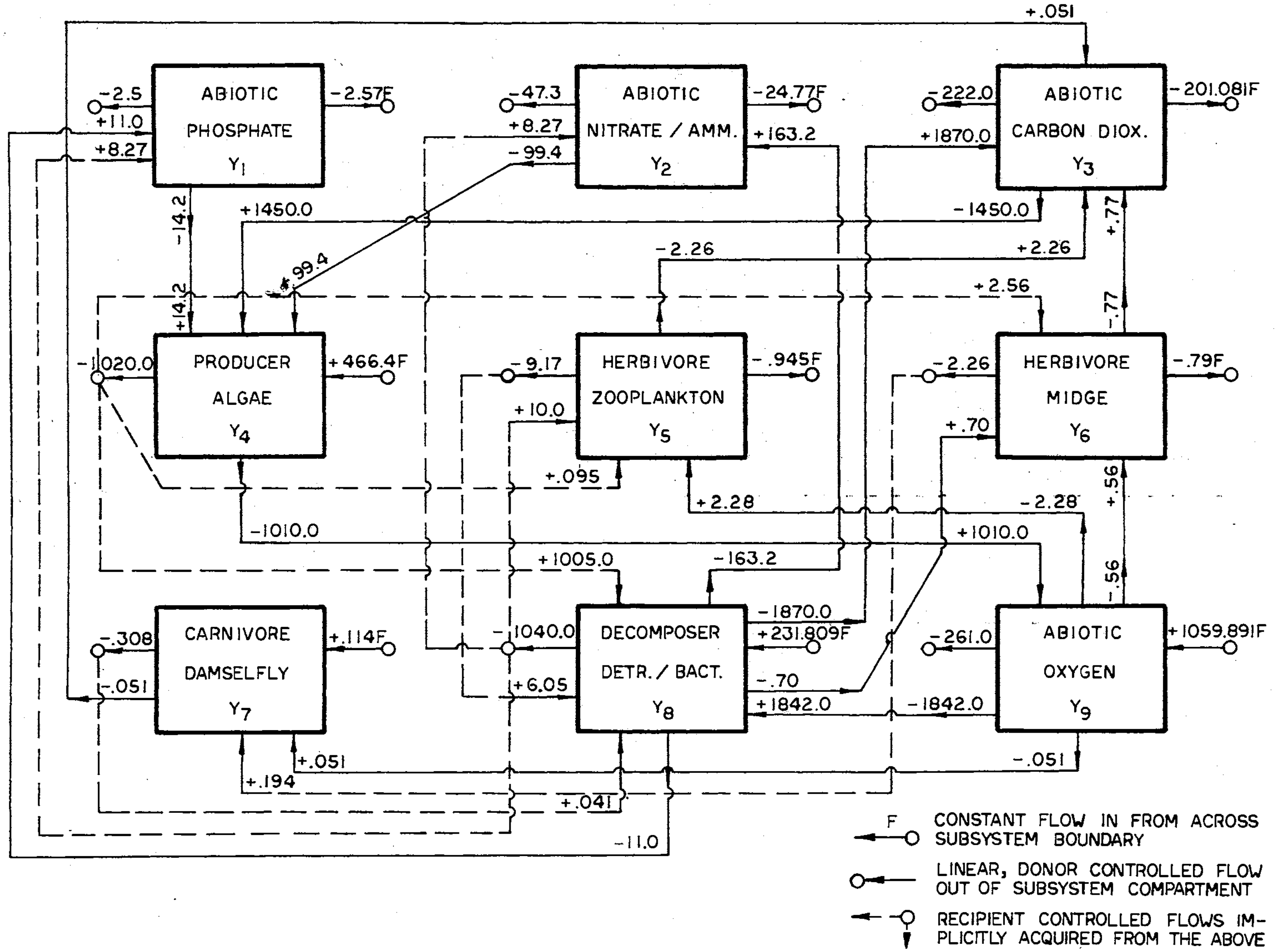


Figure 5. Pond Seven Flow Diagram

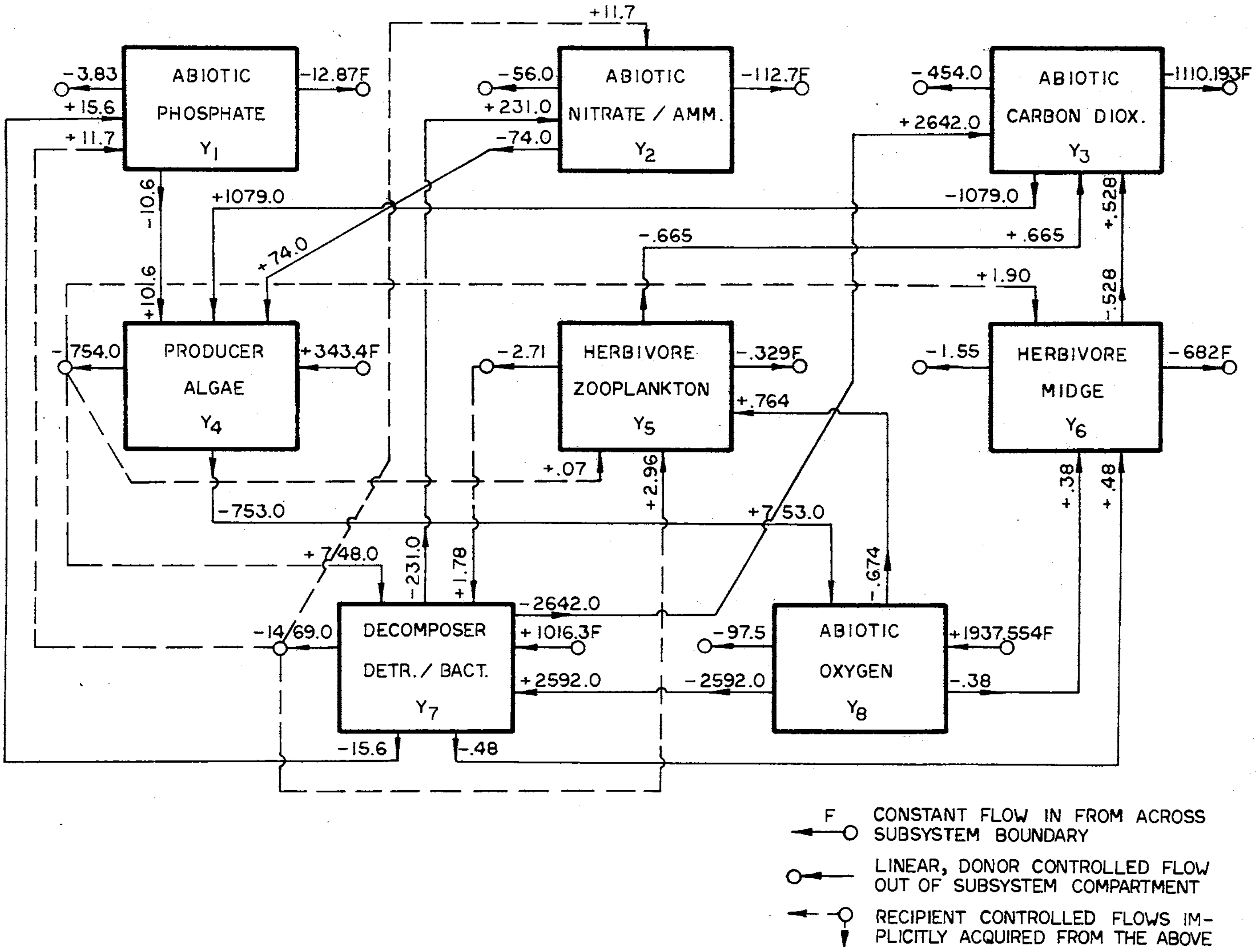


Figure 6. Pond Four Flow Diagram

By extending the concept of similar trophic structure, the assumption was made that the flow "controls", linear or nonlinear, donor or recipient, were also similar. This led to the formulation of the "undriven" state equations similar to those for the original pond ten submodel (undriven).

Testing these homogeneous submodels through simulation was performed by setting the initial conditions equal to or close to the average standing crops. Instabilities due to modeling were observed. Apparently excluding some of the state compartments and compensating for their absence led to unstable models.

The homogeneous submodels for ponds four, seven and ten (included for reference) were linearized around their respective average standing crops to resolve the stability of their equilibria (1). This is a common method used in the study of nonlinear systems which has been applied recently in the analysis of ecosystem models (33,35). The linear systems analysis program Basic Matrix (BASMAT) (21) was utilized to calculate the eigenvalues of the linearized $\underline{A}$ matrices of the three pond submodels.

It was found that instabilities in the submodels for ponds four and seven were due to the CO_2 compartments, and increasing the diagonal terms in the respective locations stabilized the submodels. It should be pointed out that the stability referenced to in those linearized submodels corresponds only to local stability in the nonlinear case (1,35).

Upon elimination of the modeling stability problems, the upstream submodels were modified to include the inputs of light and temperature, just as had been done for the pond ten submodel. The representations for both of these inputs were identical to those used for the pond ten formulation. Completed state equations for the upstream pond submodels are presented below.

Pond seven:

$$\dot{Y}_1 = -\ .15385\ Y_1 + .00902\ Y_8 + .00678\ Y_8 - .01842\ Y_1\ Y_4 - 2.57$$

$$\dot{Y}_2 = -\ 1.75185\ Y_2 + .00678\ Y_8 - .07762\ Y_2\ Y_4 + .13388\ Y_8 - 24.77$$

$$\begin{aligned}\dot{Y}_3 = &-\ 201.46714\ Y_3 + 0.5923\ Y_3\ Y_7 - 14.55779\ Y_3\ Y_4\ X_4 \\ &+ .73050\ Y_3\ Y_8 + .35948\ Y_3\ Y_6 + .32125\ Y_3\ Y_5\end{aligned}$$

$$\begin{aligned}\dot{Y}_4 = &(.01842\ Y_1\ Y_4 + 14.55779\ Y_3\ Y_4\ X_4 + .07762\ Y_2\ Y_4 \\ &- 21.50538\ Y_4 - 1.93587\ Y_4\ Y_9 + 466.40)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_5 = &(.00200\ Y_4 - .32125\ Y_3\ Y_5 - 2.73731\ Y_5 + .06187\ Y_5\ Y_9 \\ &+ .00820\ Y_8 - .945)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_6 = &(-\ 2.21569\ Y_6 + .05397\ Y_4 - .35948\ Y_3\ Y_6 + .00057\ Y_8 \\ &+ .04991\ Y_6\ Y_9 - .79)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_7 = &(-\ .75122\ Y_7 - .05923\ Y_3\ Y_7 + .01131\ Y_7\ Y_9 + .19020\ Y_6 \\ &+ .114)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_8 = &(.85316\ Y_8 + 21.18912\ Y_4 + 1.80597\ Y_5 - .00496\ Y_2\ Y_8 \\ &- .73050\ Y_3\ Y_8 - .00057\ Y_8 + .13737\ Y_8\ Y_9 \\ &- .00056\ Y_8\ Y_1 + .10000\ Y_7 + 231.009)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_9 = &-\ 23.72727\ Y_9 - .01131\ Y_7\ Y_9 - .13737\ Y_8\ Y_9 \\ &+ 1.93587\ Y_4\ Y_9 - .06187\ Y_5\ Y_9 - .04991\ Y_6\ Y_9 + 1095.891 \quad .\end{aligned}$$

Pond four:

$$\dot{Y}_1 = -\ .15369\ Y_1 + .00079\ Y_7 + .00906\ Y_7 - .01208\ Y_1\ Y_4 - 12.87$$

$$\dot{Y}_2 = -1.75000\,Y_2 + .00679\,Y_7 - .06568\,Y_2\,Y_4 + .13415\,Y_7 - 112.7$$

$$\begin{aligned}\dot{Y}_3 = {} & -363.76581\,Y_3 - 7.12668\,Y_3\,Y_4\,X_4 + .35681\,Y_3\,Y_7 \\ & + .15621\,Y_3\,Y_5 + .17542\,Y_3\,Y_6\end{aligned}$$

$$\begin{aligned}\dot{Y}_4 = {} & (-21.41437\,Y_4 + .06568\,Y_2\,Y_4 + 7.12668\,Y_3\,Y_4\,X_4 \\ & + .01208\,Y_1\,Y_4 - 5.21609\,Y_4\,Y_8 - 343.40)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_5 = {} & (-2.73737\,Y_5 - .15621\,Y_3\,Y_5 + .00199\,Y_4 + .00172\,Y_7 \\ & + .16606\,Y_5\,Y_8 - .329)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_6 = {} & (-2.21429\,Y_6 + .05396\,Y_4 - .17542\,Y_3\,Y_6 + .13240\,Y_6\,Y_8 \\ & + .00029\,Y_7 - .682)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_7 = {} & (-.85308\,Y_7 + 21.24396\,Y_4 - .00419\,Y_7\,Y_2 - .35681\,Y_3\,Y_7 \\ & + 1.79798\,Y_5 + .36713\,Y_7\,Y_8 - .00029\,Y_7 - .00036\,Y_7\,Y_1 \\ & + 1016.3)(X_3)\end{aligned}$$

$$\begin{aligned}\dot{Y}_8 = {} & -23.78049\,Y_8 - .13240\,Y_6\,Y_8 - .16605\,Y_5\,Y_8 + 5.21609\,Y_4\,Y_8 \\ & - .36713\,Y_7\,Y_8 + 1937.554 \quad .\end{aligned}$$

In both submodel formulations X_3 is defined as the Q-10 factor and X_4 indicates the light input parameter.

Light data for all three ponds were considered to be equivalent, since it was certainly reasonable to assume that light influx per unit area would be identical in each pond. However, this uniformity did not hold true for water temperature, since the flow was characteristically warmer upstream, reaching ambient as it flowed through the series (31). Thus, independent pond water temperature data was provided for each pond in degrees Farenheit (converted to degrees Centigrade by the model data input routine). The data used for both inputs is condensed in Table II.

TABLE II

WATER TEMPERATURE AND LIGHT DATA - ALL PONDS

Time (mo.) 0.0 = Oct. 1, 1961	Pond Water Temperature (31) (°F)			Light (4) (Langleys/day/m^2)
	Pond 4	Pond 7	Pond 10	
0.0	58.0	55.0	55.0	548.0
0.5	46.0	43.5	44.0	475.0
1.0	41.0	37.0	36.0	470.0
1.5	40.0	35.8	34.0	360.0
2.0	41.0	36.0	34.0	345.0
2.5	48.5	44.0	42.0	320.0
3.0	59.0	53.0	50.0	305.0
3.5	56.0	53.0	50.0	300.0
4.0	55.0	53.0	50.0	308.0
4.5	62.5	56.0	53.8	376.0
5.0	65.0	58.5	57.0	430.0
5.5	63.5	59.5	58.2	475.0
6.0	62.0	60.0	60.0	518.0
6.5	66.5	66.0	67.0	540.0
7.0	76.0	75.0	74.0	580.0
7.5	80.0	79.5	79.0	608.0
8.0	82.0	82.0	82.0	640.0
8.5	85.8	84.5	84.5	660.0
9.0	87.0	86.0	86.0	685.0
9.5	85.8	84.0	84.5	695.0
10.0	82.0	81.0	81.0	690.0
10.5	73.0	74.5	73.5	673.0
11.0	68.0	67.0	65.0	640.0
11.5	63.5	60.0	60.0	600.0
12.0	Same as 0.0, Repeat			

Linear interpolation through the data supplied the simulation with causal functions of time for light influx and the pond temperatures. Thus, the light regulator and Q-10 factors could all be calculated at each integration step.

Verification of the individual upstream submodels followed. Simulated responses matched the data and expected dynamics. The trajectories oscillated yearly around the average standing crops while magnitudes of fluctuation seemed to be reasonable. More important, phase relationships in the food chain were plausible, with algal blooms occurring when expected.

With the three submodels now complete, linking to form an overall ecosystem model for the holding pond series proceeded.

Linking of the Three Submodels

In choosing the linking method a compromise had to be made between depicting as nearly as possible the pond series ecosystem function and satisfying the limitations imposed by the algorithms used. Several linking attempts were evaluated before the final method was chosen. This method was to link the ponds by abiotic flows, neglecting the import or export of biotic states. These flows were delayed to produce the correct temporal relationship between the submodels, since it took approximately eight days for the effluent to flow through the pond series.

To clarify the motivation behind this modeling notion, it is necessary to look once again at the flow diagrams for ponds seven and four (Figures 5 and 6). Note that in each abiotic compartment of these submodels, there is an exiting flow proportional to the respective standing crop magnitude which is assumed to flow out of the subsystem. Certainly a portion of this flow will enter into the adjacent downstream pond. Thus, a percentage of each of these flows proportional to the upstream standing crops, enters into the downstream pond subsystem, with an associated transport delay.

To illustrate how this action was achieved in the model, consider one of the abiotic flows from pond to pond. The upstream influence on a corresponding downstream compartment is effected by adding a flow term to that compartment which is delayed by an amount consistent with the effluent flow rate through the system. This addition, which is proportional to the upstream standing crop, must be normalized by subtracting a nominal flow from the downstream compartment, this nominal flow being proportional to the upstream average standing crop. This is necessary since merely adding a flow into the downstream compartment would unbalance the total flux at system equilibrium, which must equal zero. The pond submodel state equations would thus be revised as shown by the following example.

Pond four: $\dot{Y}_k = \ldots\ldots - a_{ko} Y_k$

Pond seven: $\dot{Y}_k = \ldots\ldots + K_k a_{ko} Y_k - K_k a_{ko} Y_k^*$

Here the k^{th} state is linked between the two ponds with Y_k^* designating the average standing crop of Y_k in pond four. Note that the linking will essentially have no effect on the ponds downstream unless the abiotic state magnitudes upstream are reasonably far from their respective average standing crops. This scheme was used to link the abiotic compartments of all three pond submodels. The overall linking mechanism is diagrammed in Figure 7.

Before the completed model could be simulated, the linking

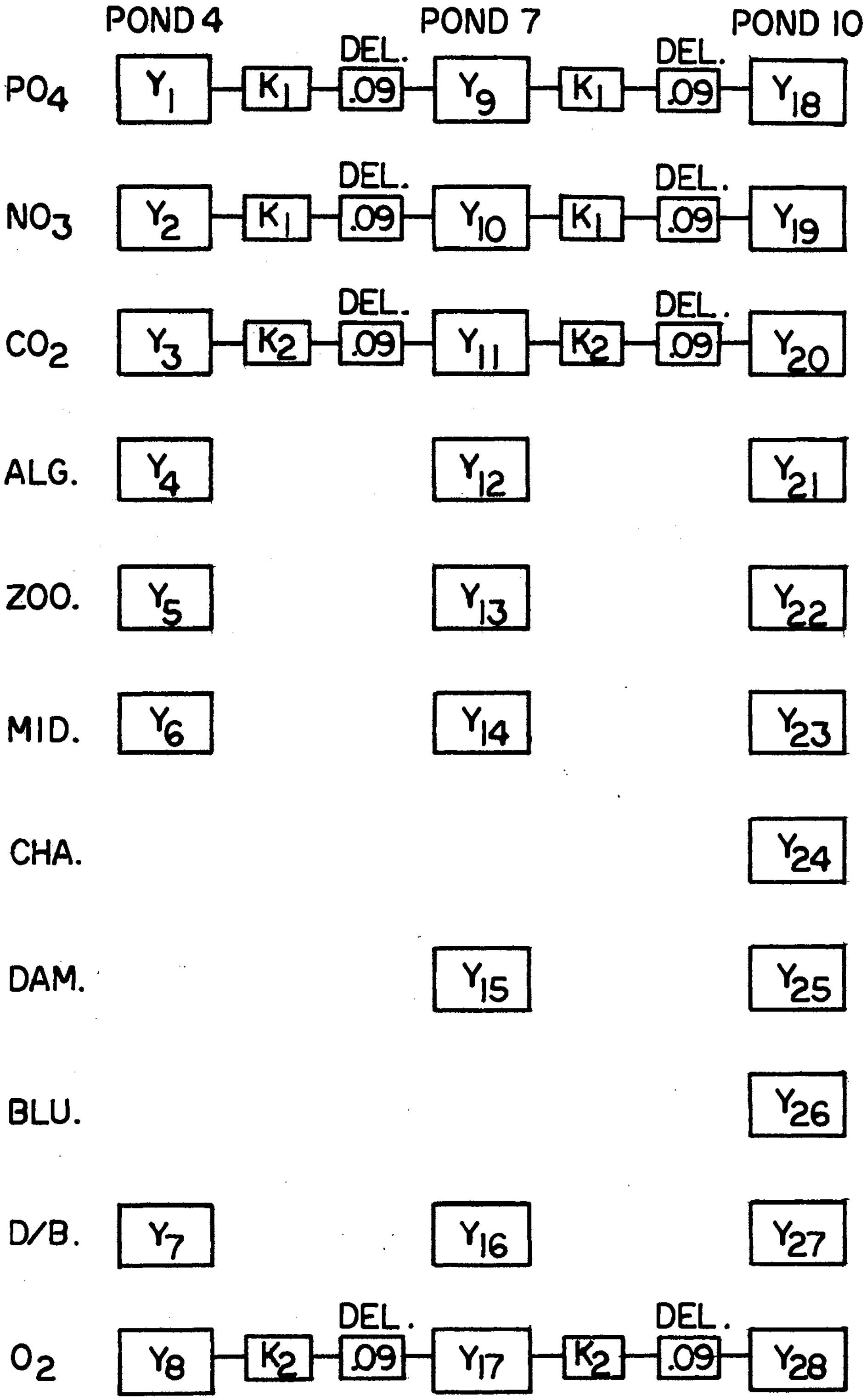


Figure 7. Pond Submodel Linking Scheme

percentages and delay duration had to be evaluated.

The linking percentages indicate the fraction of abiotic flows reaching the downstream ponds. Remembering that there are actually two ponds between each adjacent pair included in the model, the linking influence would be diminished cubically. For example, assume that 75% of the flow out of the CO_2 compartment in pond four reaches pond five. Then 75% of this addition would reach pond six, and so on, resulting in $(.75)^3(100)\%$ of the original flow effecting the pond seven CO_2 compartment. In addition to this fact, the possibility of different percentages for different abiotic flows was considered.

Here it was assumed that the two dissolved gases, CO_2 and O_2, could be assigned equivalent percentage rates, since both diffuse out of the pond system. Alternatively, NO_3 and PO_4 were also assigned equivalent percentage rates. The percentages were left as parameters in the model so adjustments could be facilitated. The parameter values chosen were .05 for CO_2 and .30 for NO_3 and PO_4.

The delay time was assumed to be .09 mo (approximately 3 days) since the subsystems divided the pond series into three segments, and flow through the entire system took approximately eight days.

Simulation results corresponding to one year model time revealed that the model behavior closely resembled the actual pond ecosystem dynamics. Linking did have effects on the response of the downstream submodels. The completed model in this sense replicated the pond series behavior. Simulation output and program listing are included in Appendix B.

The simulations also indicated that the model was sensitive to CO_2 linking, the same compartment which had been adjusted previously.

Probably this was due to its highly nonlinear form and relatively quick time constants (linearization reference). This problem will be discussed further in Chapter IV.

The control scheme and performance index developments will be presented next in Chapter III.

CHAPTER III

CONTROL STRATEGY AND DEVELOPMENT OF THE PERFORMANCE INDEX

Formulation of the total ecosystem model for the holding pond series was presented in Chapter II. In this chapter a control philosophy is developed for the ecosystem, which is based on increasing the action of bio-degradation on the effluent water. Using the model, the resulting control scheme will be evaluated by simulation in Chapter IV. To facilitate quantification of the control strategy comparisons, a performance index is derived. The index includes both biotic indicators and control "costs" as measurements of ecosystem performance.

The Control Structure

There are many proven methods of management of waste treatment facilities. These include aeration, activated carbon treatment, microstraining, effluent distribution and coagulation by polymers (9). Also, the semi-natural engineered pond ecosystem appears to be one of the most inexpensive modes of waste treatment. Although these methods have been in use for several years, testing of control schemes by ecosystem model simulations is relatively unexplored. Watt (37) has considered ecosystem management (harvest rate) through simulation while several authors (7,26, 30) have suggested the need for this type of effort in studying many of our environmental problems. Before going into the particular control philosophy adopted in this work, some general remarks will be presented on the requirements the resulting control scheme must meet.

The control scheme must include states or inputs which can be easily measured and economically implemented in the real system, while being directly represented in the model. Controls are desired which will enhance biological action, thus improving the quality of the final effluent. The control scheme was structured with automatic control in mind, limiting direct influence to abiotic states with no biotic manipulation (i.e., dredging of detritus, fishing).

There were five basic control possiblities which could influence the biological action of the pond series and be directly represented in the model. A list of the candidate policies were:

1. lighting;
2. heating;
3. nutrient (NO_3, PO_4) addition;
4. aeration; and
5. flow regulation.

Three of these candidates were removed from consideration as possible controls due to their lack of feasibility. Lighting was ruled out because to effectively influence the photosynthetic process artificially would require that the pond system be virtually covered with high intensity lamps. The cost insued here would certainly be prohibitive. Both heating and nutrient addition were eliminated due to the nature of the effluent. The flow was both naturally warmer than required for biological influence and nutrient rich as a result of the refinery processes. Thus, addition of either heat or nutrients as controls to this primarily warm, eutrophic environment would be ineffective. It should be mentioned here that although heat would improve the pond operation during a short period in the winter, at this time additional heated water from the refinery is not available.

Aeration and flow delay were included because both could economically be accomplished and had direct influence on the biological action (3, 4,22). Aeration was controlled continuously by feedback monitoring of the oxygen standing crop in pond ten. This can be accomplished with existing oxygen level detectors (8). A feedback structure was constructed by introducing a gain which multiplied the difference between the oxygen level in pond ten and a set point which was arbitrarily chosen. This product represented the feedback aeration rate applied to pond four.

Flow delay was accomplished by allowing a variable delay of abiotic flows which linked the submodel series. This control method was also readily attainable through flow regulation in the actual system.

A diagram of the control scheme is shown in Figure 8. Now that this control scheme foundation has been defined, the performance index development will be presented.

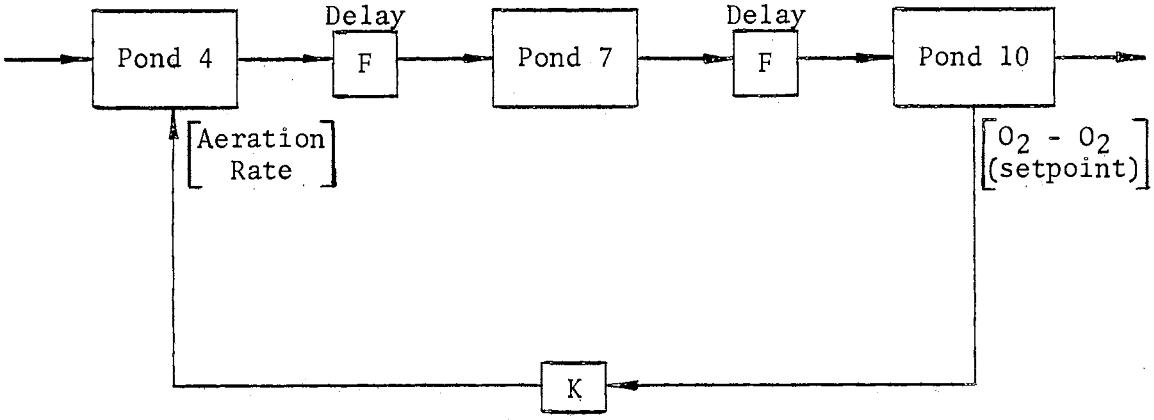


Figure 8. Control Structure

Development of the Performance Index

A performance index (performance measure, figure of merit, cost function) is simply a number whose magnitude is an index of the merit or desirability of a solution to a problem (23). Minimizing (or maximizing) the index with respect to the control parameters corresponds to the determination of an optimum solution. Usually the performance index is manufactured to contain "trade offs" in system performance level and "cost" of control. It consists of indicators of system performance and "cost" contributions which are both scaled and weighted respectively to emphasize desired results in performance or control.

Frequently a performance index can be developed which is explicit in the parameters or variables to be optimized. This leads to the possibility of analytical solutions to the extremum problem for which there are a variety of approaches to solution (i.e., Lagrange multipliers). Usually, such an explicit formulation is not possible and a searching procedure is used to seek the optimum in an organized manner.

Optimization of the ecosystem performance with respect to the control scheme is approached here via a computer search utilizing such a performance index. Applications of this nature have been suggested by Watt (37). Minimization of the index corresponds to the lowest point on the merit surface (assuming unimodality) (38) generated by the function $PI(X_1, X_2)$, where X_1 is the oxygen feedback gain and X_2 the flow delay time. This minimum represents the best combination of the control parameters for the particular problem posed, and the lowest "cost" attained in the search.

The structure of the performance index included effluent water quality indicators and control cost rates (and penalties). These contributions were summed by the integral form presented below:

$$PI = \int_{t_0}^{t_f} [\sum_{i=1}^{n} (w_i\ u_i)^2 + \sum_{j=1}^{m} (w_j\ v_j)^2]dt \quad , \qquad (3)$$

where

t_0 = initial time;

t_f = final time;

u_i = the i^{th} control cost (normalized);

w_i = related weight;

v_j = the j^{th} system indicator (normalized);

w_j = related weight;

n = the number of cost contributions; and

m = the number of indicator contributions.

The integral is used to provide a measure of the cumulative effects of cost, etc., while the independent summing emphasizes the individual influence of each constituent (u, v) (23). The "trade off" here was that effluent water quality increase as a result of control effort was balanced against the costs of that effort (and penalties). The integral was included in the ecosystem model as another state equation, integrated in time along with the ecosystem simulated response.

The performance index constituents are basically of two types, effluent quality indicators and costs of control effort (or penalties).

The notion of indicators of ecosystem quality has been presented in previous studies focused on this effluent holding pond series (3,4,5,11, 22,28,31,36). As with the admissible control policies, the indicators were required to be easily measurable in the real system, and applicable in the model. The indicators used refer to pond ten only, since interest was directed to the exiting effluent water quality. The indicators previously considered for this pond system are listed in Table III with respective references.

Many of the proposed indicators of effluent quality were disregarded for the simple reason that there was no accomodation included in the model for their computation. Ph, sulfates, chloride, dissolved solids, euphotic zone, phenol, alkalinity, chlorophyll/ash free dry weight, boron, oil, and SAR fell into this category. Many of these seem to be quite important in judging the quality of the effluent water, and the lack of their presence in the pond system model might seem unfounded. However, their effects are included implicitly in the biological actions of the model through the flow structure and data incorporated. So their exclusion does not negate the validity of the model, or its ability to resolve an optimal control strategy by predicting its effect.

The oxygen demands (BOD, COD, IOD) were excluded from consideration as effluent quality indicators because of their interpretations in the real ecosystem. It was clear that attempts to arrive at estimates for these proposed indicators from the information provided by the model would produce misleading values. Moreover, oxygen concentration was not used as an indicator since it may not reflect effluent toxicity. It is included directly as part of the control scheme, thus being indirectly used as an indicator.

Although species diversity is a good indicator of effluent quality and biotic stability, it was not used here due to the difficulty encountered in its measurement. Numerous samples are required which involve tedious identification. In this respect this proposed indicator was disregarded because of a lack of feasibility in its determination.

TABLE III

INDICATORS OF EFFLUENT WATER QUALITY

Indicator	Desired Level	Range	Reference(s)
Species Diversity	High	5.0-7.0 Species/Cycle	11,22,28
P/R Ratio	∿1.0	0.0-4.5	3,4,10,22,28
Bluegill Fish	High	0.0-10.0 gm/m^3	--
Zooplankton	High	0.0-4.0 gm/m^3	22,28
Bio. Ox. Demand (BOD)	Low	8.0-28.0 ppm	4,6,28
Ph	∿7.0	6.9-8.6	6,22,28,36
Sulfates	Low	6.2-344.0 mg/ℓ	6,36
Chloride	Low	20.0-1700.0 mg/ℓ	6,36
Dissolved Solids	Low	157.0-3390.0 mg/ℓ	36
Euphotic Zone	High	.5-1.88 m	22
Phenol	Low	0.0-1.0 ppm	4,22,28,31
Nitrate (Available Nitrogen, Ammonia)	Low	0.0-21.0 mg	4,6,28,36
Chem. Ox. Demand (COD)	Low	120.0-130.0 ppm	4,6,28
Alkalinity	Low	0.0-160.0 ppm	6,28
Chlorophyll/Ash Free Dry Weight	--	0.0-0.015	4,22
Boron	Low	0.0-0.06 mg/ℓ	36
Oil	Low	1.0-6.0 ppm	6
Inorg. Ox. Demand (IOD)	Low	0.0-3.0 ppm	6
Dissolved Oxygen	High	2.5-6.5 ppm	6
Sodium Absoprtion Ratio	Low	5.4-25.0	36

Bluegill fish, heuristically included in the model for the purpose of indicating effluent water quality, depicted the long term effects of pollution. This longer sensitivity was complemented by the inclusion of zooplankton as an indicator, which possessed a relatively fast turnover rate, resulting in a quick response to "slugs" of toxic effluent (22). Both bluegill and zooplankton could easily be sampled in the real system and monitored continuously or sampled in the simulation model.

P/R ratio was used as a measure of ecosystem stability. A P/R ratio greater than one indicates an autotrophic shift with more oxygen produced than consumed while a ratio less than one indicates a heterotrophic shift or an oxygen deficit. The ratio would approach unity in a balanced steady state system with no import or export (2). However, at ecosystem equilibrium, export equals import, and their effects cancel. During periods when sufficient time was allowed for the community to stabilize the pond system was effective in treating the effluent water and the P/R ratio approached unit at the end of holding time (3,4). A graph of productivity and respiration for this pond ecosystem is shown in Figure 9 (5). Observe that productivity peaks in pond seven, and that the P/R ratio tends toward unity as the flow nears the end of the holding pond series.

The P/R ratio can be easily measured in the actual ecosystem and is obtainable from the information provided by the model. In the real system P/R could be evaluated by regular sampling or continuous monitoring of oxygen level with application of the diurnal curve method. Eley (10) provides a computer algorithm for this method which, given daily O_2 data, will evaluate the P/R ratio. Note that the control structure already provides the monitoring of oxygen level required here. In the simulation

P/R can be calculated by evaluating continuously the ratio of oxygen flow from algae to oxygen (productivity) over the sum of flows of oxygen to the various compartments (respiration). Details of the procedure are presented below:

$$P/R = \frac{F_{21-28} + C}{\sum_{i=22}^{27} F_{28-i}} \qquad i, 22, \ldots, 27$$

$$= \frac{2.01500\ Y_{21} + 46.617971}{(.021776Y_{26}+.0644164Y_{22}+.143261Y_{27}+.051755Y_{23}+.016249Y_{24}+.011848Y_{25})} \quad . \quad (4)$$

Here Y_{28} has been cancelled in both numerator and denominator; F_{21-28} represents net production, and respiration by algae is not included in the denominator. Thus, this ratio is approximately equivalent to the actual P/R ratio as per definition, since the flows involved are large. The constant in the numerator was added, so that, evaluated at the average standing crop magnitudes, the P/R ratio would equal unity.

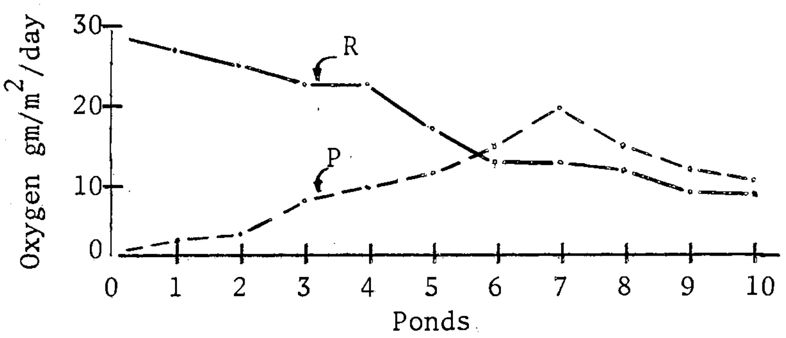


Figure 9. Productivity-Respiration for the Pond Series

Nitrate (including nitrogen contained in ammonia) was used as an indicator, being easily sampled in both pond ten and its submodel in the simulation. A maximum allowable level for this indicator has been prescribed by the State of Oklahoma (36), see Table III. It is certainly possible that in the near future, fines will be levied for violation of guidelines such as this. As an outcome of this line of thinking, the influence of nitrate (or ammonia) on the performance index consisted of introducing a set cost, representing a monthly penalty rate, when the nitrate standing crop magnitude rose above the set standard. No penalty would be introduced if the standing crop remained below the set point. In this respect, the nitrate (or ammonia) contribution to the performance index represents a penalty, or cost which can indirectly be offset by control effort. The direct costs of this control will be discussed next.

The controls which have been selected are feedback aeration and flow delay adjustment. The associated costs may readily be deduced in the ecosystem application and continuously calculated in the simulation. Aeration cost rates considered the options of mechanical or diffusion aerators and the flow delay cost allowed for the burden of low flow rate on the refinery operations.

Performance Contribution Weighting

With the constituents of the performance index defined, each contributor was normalized so that at ecosystem equilibrium (at the average standing crops), its value would equal one or zero. This was necessary so that weighting of the individual performance index contributions could be accomplished (38). The biotic indicators, fish and zooplankton, were normalized using the following procedure:

$$v_i = \frac{Y_i^*}{Y_i} \quad ,$$

where

Y_i^* = i^{th} average standing crop value;

Y_i = i^{th} standing crop value; and

v_i = as given by Equation (3).

In order to maximize Y_i one would minimize the reciprocal, and at equilibrium the indicator value would equal unity.

The ecosystem stability indicator, P/R ratio, was subtracted from one to normalize its value since its equilibrium magnitude was prescribed to be unity, and deviations far from one were undesirable. The structure of the nitrate penalty guaranteed it to equal one or zero in "normalized" form, depending on whether the limit of allowable nitrate had been exceeded or not. At ecosystem equilibrium, both of these normalized forms equaled zero.

The costs of control, as with the nitrate penalty, were already in a "normalized" form due to their direct relatability to expense in dollars.

With the normalization forms constructed, weights were determined for the various u's and v's [see Equation (3)]. Weighting of control costs and penalty was done by setting the corresponding weight values equal to the expected costs per month. Aeration costs (mechanical, diffusion) were calculated from data provided by Davis (9). The cost of flow control and the nitrate penalty were estimated. The biotic weights (P/R, fish, zooplankton) were estimated and are subject to conjecture. The relative values of these ecosystem quality indicators has not been considered previously, but determinations of this kind are required in this type of performance index application. If the weights arrived at for these indicators seem high, one might consider the costs of advertising which could be offset by publicity benefits of biotic quality signs (e.g., fish in the last pond). In this era of ecological emphasis, such an indication of unpolluted effluent release can easily rationalize these weights. The weight values imposed are given in Table IV. The square roots were used for the performance index weighting so that the evaluated integral would directly represent cumulative cost trade offs.

TABLE IV

PERFORMANCE INDEX CONTRIBUTORS AND WEIGHTS

Contributor	Normalized Form	Notation (Eq. 3)	Weight ($/mo)	Approx. $\sqrt{\text{weight}}$
Aeration Cost				
Diffusion	--	u_1	44.7	7.0
Mechanical	--		34.4	6.0
Flow Delay Cost	Delay/Nominal Delay	u_2	50.0	7.0
Nitrate (Ammonia) Penalty	--	v_1	30000.0	170.0
P/R	(1.0 - P/R)	v_2	100.0	10.0
Bluegill Fish	Y_{26}/Y^*_{26}	v_3	40.0	6.0
Zooplankton	Y_{22}/Y^*_{22}	v_4	40.0	6.0

The form and all of the components of the performance index have been defined and evaluated. Now, with all of the contributions and weights included, the index described by Equation (3) appears in the simulation as shown below:

$$PI = \int_{t_0}^{t_f} \{[P_7 (\frac{3.87}{Y_{22}})]^2 + [P_8 (\frac{9.45}{Y_{26}})]^2 + [P_9(1.0 - P/R)]^2$$

$$+ [P_{10}]^2 + [P_{11} (\frac{P_{12}}{.090})]^2 + [P_{13} X_{39}]^2\}dt \qquad ,$$

where

P_7 = 40.0;

Y_{22} = zooplankton standing crop in pond 10;

P_8 = 40.0;

Y_{26} = fish standing crop in pond 10;

P_9 = 100.0;

P/R = as given by Equation (4);

$$P_{10} = \begin{cases} 30000.0 & \text{if } NO_3 \text{ standing crop in pond 10 } (Y_{19}) \text{ is above the} \\ & \text{upper limit } P_{15} = 24.0 \\ 0 & \text{otherwise;} \end{cases}$$

P_{11} = 50.0;

P_{12} = delay time;

P_{13} = 34.0; and

X_{39} = oxygen feedback flow ($gm/m^2/mo$).

The ecosystem performance optimization utilizing this index and the control scheme presented in this chapter will be discussed in Chapter IV.

CHAPTER IV

ECOSYSTEM PERFORMANCE OPTIMIZATION

Using the control scheme and performance index developed in Chapter III, optimization of the ecosystem performance is discussed in this chapter. A computer search was conducted over the control parameter plane to seek the optimal control. Each evaluation of the index determining one point on the merit surface corresponded to one pair of the control parameters, and a simulation of one half year of model time. Minimization of the performance index indicated the best parameter combination and most suitable ecosystem response. The simulation listing and results of the search are presented in Appendix C.

Preparation of the Model for Optimization

The search procedure selected for the optimization was a Grid (23) method. This method seeks an extremum by conducting a series of alternating grid and star patterned performance index evaluations of progressively decreasing size over the control parameter plane (in this two dimensional case). There were three reasons for selecting this method. First, the nature of the merit surface was totally unpredictable; perhaps the only thing known about it was that it would be continuous. This prevented the application of many of the searching methods with faster convergence requiring knowledge or determination of derivatives. The second reason was that this search will seldom encounter numerical difficulty or stall out. The third reason was that a Grid search by its design gives one an overall picture of the merit surface, since individual trial points are spaced relatively far apart.

Upon selection of the search algorithm, the model was prepared for the optimization simulation runs. Output limiters placing bounds on the magnitudes of the states were installed. The limiters were used because of the suspected local stability of the model, with ecosystem states remaining well behaved within a neighborhood of the equilibrium (or average standing crops). Upper bounds were chosen by considering past simulation results and minimum bounds were all set at zero. These limiters were installed merely as safeguards, and it was observed later that they did not influence the model simulation results significantly.

Model Sensitivity to Control

Before further optimization considerations, the ecosystem model was checked for sensitivity to control effort. This was done to determine magnitudes of the control parameters required to affect the performance "trade offs" discussed in Chapter III. Knowledge of these magnitudes would lead to suitable first guesses for the ranges over which the two parameters, aeration feedback gain and flow delay time, would be allowed to vary in the search.

The sensitivity investigations were carried out by conducting small one dimensional searches, fixing one control parameter while varying the other. In other words, the checks ran along the axes of the control parameter plane, or lines of zero control effort in one variable. From these preliminary sensitivity checks it was evident that the model was relatively insensitive to oxygen feedback of small magnitudes, and to moderate delay parameter adjustment. These conclusions spurred an investigation of the response of the pond four submodel to oxygen addition, the function of the feedback.

The pond four submodel was unlinked from the series and simulated independently to determine the effects of adding an input flow into the oxygen compartment. Results indicated that addition of this flow, even in relatively large amounts, had a small effect on increasing the standing crop of oxygen in that pond. The supplementary flux seemed to "flow through" the oxygen compartment, with most of the subsequent biomass ending up in the detritus/bacteria compartment. This was certainly interesting but not surprising. In fact, this behavior could be expected in an ecosystem of this type. This model behavior resulted primarily from the nonlinear nature of the oxygen compartment.

Lack of response to oxygen feedback in the pond four submodel led to a far greater insensitivity in the downstream submodels. The linking diminished the effects of feedback and there resulted almost no influence on the oxygen standing crop in pond ten. To create a more sensitive model, two actions were taken. The linking parameter value for oxygen was increased to 1.0, the maximum possible, and the oxygen feedback was applied to all three ponds, not only pond four.

The O_2 linking increase brought out somewhat of a problem, due to the sensitivity of the model series to CO_2 linking, mentioned near the end of Chapter III. This created a conflict because the linking of both of these compartments thorughout the model was controlled by a common parameter. Thus, to maintain a linking value of 1.0 for O_2 while having a relatively small CO_2 link for model stability, an additional linking parameter was installed for O_2 alone. The value of the CO_2 parameter was left at .05, and the NO_3 - PO_4 parameter was increased to .50.

The feedback modification in the control structure followed precisely the form established in Chapter III, with the exception that the feedback aeration was split between submodels. Cost weighting in the performance index corresponding to the aeration contribution was adjusted accordingly. The revised control scheme appears as shown in the following diagram (Figure 10). The model optimization program listing is presented in the first of Appendix C.

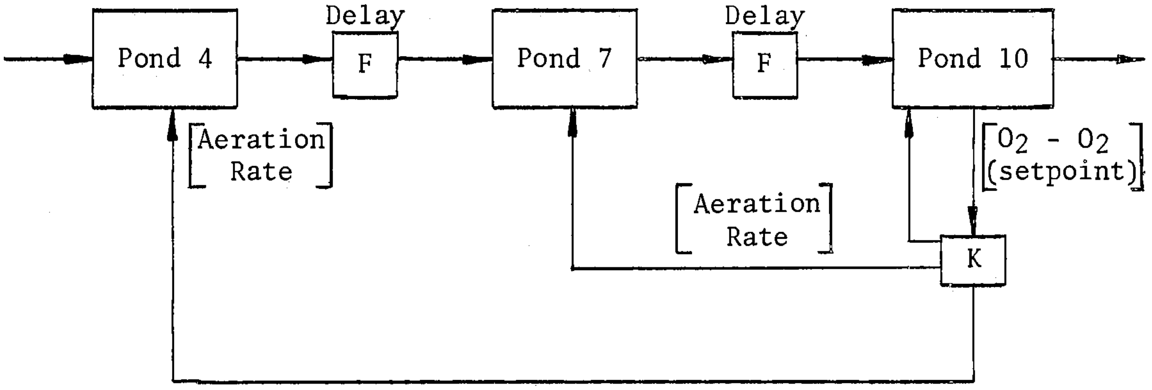


Figure 10. Modified Control Structure

With these revisions included in the model, the procedure of investigating its sensitivity to control was repeated. Results indicated the model was considerably more sensitive to control effort. Although the controls now had desirable effects on the ecosystem model response (i.e., increasing the standing crop of bluegill in pond ten), the performance index weighting was imbalanced, providing too much influence to the costs and penalty. Thus, the next action taken was to investigate the relative ranges of fluctuation for the performance index constituents. This led to the determination of weighting modifications (or scaling) to correct the imbalance.

A small two dimensional search was conducted to evaluate the performance index contribution ranges. The simulations revealed that fluctuations of the cost of control far outweighed those of the indicator contributions, due to their respective weighting factors. This caused the search algorithm to seek the "zero control effort" corner of the control parameter plane, as the minimum performance index magnitude.

Less expensive one dimensional searches were used to pinpoint the trouble. Their results showed that varying the oxygen feedback and delay parameters over a very wide range (0.0 - 600.0; .090 - 1.0) incurred large fluctuations in cost with small fluctuations in indicator response. Observing the individual performance index contributions and noting the ranges allowed in the control inputs, the contributor sensitivities were deduced. These sensitivities are listed in Table V (a), with the weighting factors used given for later comparison.

It was obvious from this information there existed a considerable imbalance in the contributions to the performance index. To alleviate this problem the weights were modified (or scaled) so that the sensitivities listed in Table V (a) would transform into approximately equivalent contribution changes. The modified weights with resulting sensitivity values are given in Table V (b).

Simulations now indicated the weighting modifications led to the performance index "trade offs" necessary to eliminate the characteristic of minimization at the "zero control corner" of the parameter plane.

Subsequent one dimensional searches along the control plane

TABLE V

PERFORMANCE INDEX CONTRIBUTION SENSITIVITIES[1,2]

Contribution	Weight	Range
	(a) Original	
Aeration Cost	18.0	∿700.0
Flow Delay Cost	7.0	∿100.0
Nitrate Penalty	170.0	--
P/R	10.0	∿ .30
Bluegill	6.0	∿ .30
Zooplankton	6.0	∿ .45

Contribution	Weight	Range	Scale Factor
	(b) Modified		
Aeration Cost	.90	∿35.0	.05
Flow Delay Cost	5.0	∿72.0	.715
Nitrate Penalty	30.0	--	.176
P/R	1000.0	∿30.0	100.0
Bluegill	400.0	∿20.0	66.7
Zooplankton	400.0	∿30.0	66.7

---

[1] To control.

[2] Oxygen Feedback Range = 0.0 - 600.0; Delay Range = .090 - 1.0.

boundaries were now conducted over a model time period of six months. This was done because for approximately the first six months the oxygen level in the pond ten submodel would not fall below the set point, regardless of delay parameter value. Thus, lack of oxygen feedback led to near duplication of simulated responses for the early months in all parameter variable runs. Therefore, only the last six months of the cycle were simulated only to save costs. The searches revealed that along the control boundaries, local minima were included in the large ranges of control tested. In other words, the minimum values of the performance index had been bracketed along the control parameter axes. The results are illustrated in Figure 11. Note that along the delay time axis the bracketing is implicit.

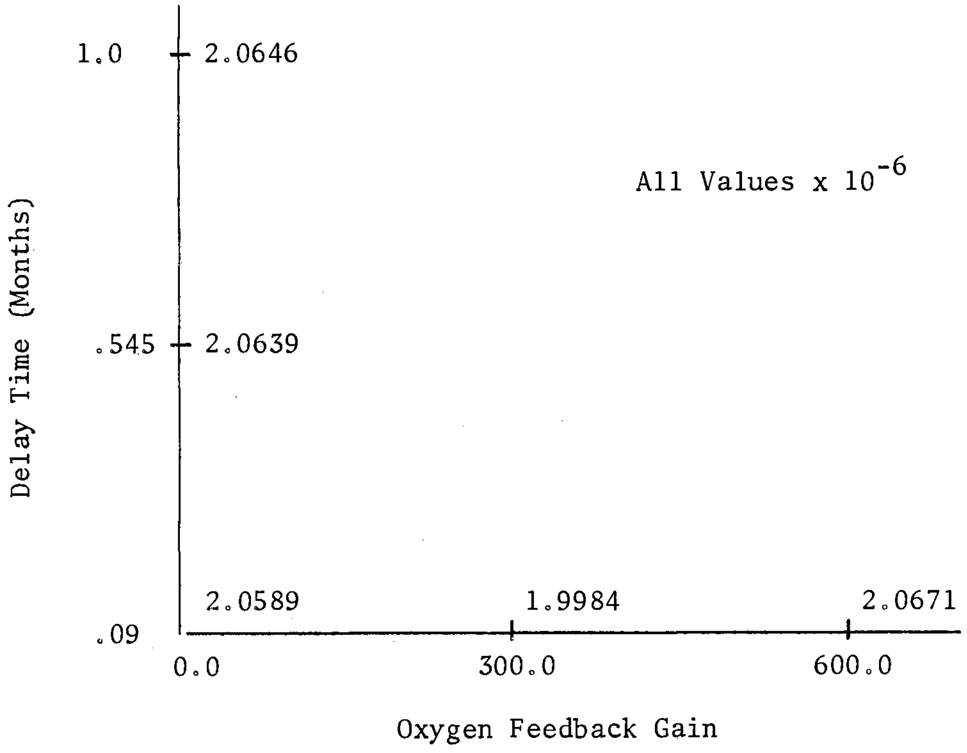


Figure 11. Boundary Minimization Bracketing

Optimization Results

A large two parameter optimization series was now conducted. The computer output from this search is included in Appendix C. It indicated conclusively that an optimum does exist in the overall region specified. An illustration of the merit surface evaluations and their locations is provided in Figure 12.

The minimum performance index value found was 1.9817×10^6 at (66.0, .3933). Notice that the minimum is surrounded by evaluations of higher magnitude. Converging further to the optimum by specifying a smaller fractional reduction would now be possible but was not done here. It is obvious that the location of the minimum is subject to influence by the weighting factors. Further investigation is not merited here due to question of significance of the numbers used and those which would result.

These results do show, however, that this minimization technique was successful in finding the optimal control strategy for the ecosystem problem posed. Not only was the minimum performance value bracketed by the fourth evaluation group, but by considering Figure 12 there is no implication that the merit surface is other than unimodal. Also, the applicability of ecosystem models and simulations to the study of real environmental problems is clearly demonstrated. Utilizing models to predict ecosystem control policy effects should certainly prove successful in future studies concerned with alleviating our environmental problems brought on by waste pollution. Recommendations for future work are reflected in the following chapter.

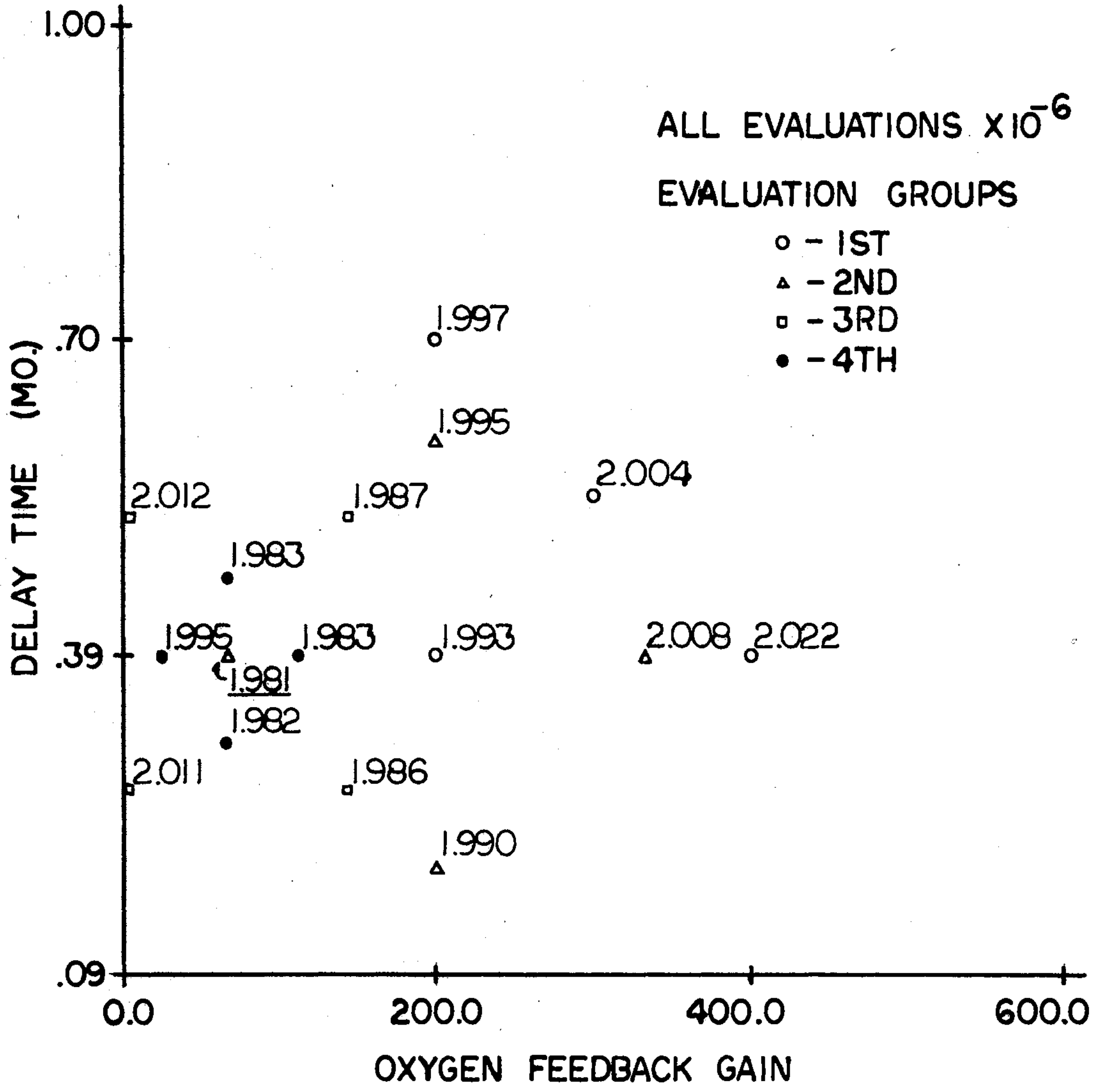


Figure 12. Optimization Results

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A total ecosystem model has been developed for a particular pollution abatement ecosystem consisting of a series of oil refinery effluent holding ponds. Simulations were performed using a digital computer, and the model response was verified with the observed behavior of the pond series.

A control philosophy and a measure of ecosystem performance were adopted. The control parameters considered were the pond series flow rate and feedback aeration, both of which influence effluent treatment by biological activity. Control costs and direct biological indicators are included as contributions to the performance index.

An optimization search utilizing the computer was conducted in order to maximize the ecosystem performance. The minimization of the performance index corresponded to attaining the optimal control parameter combination.

Although this thesis considered a particular ecosystem problem, many of the approaches taken and techniques applied here serve as a basis for extended efforts in this field. Computer simulations will surely play an increasingly important role in the study and analysis of ecological systems. The application of an ecological performance index is necessary in the evaluation of possible control schemes, and control in the environmental sense is certainly of the utmost value. However, before more exacting work can be done in these areas, ecosystem modeling itself must be clarified and methodized. Thus, all the recommendations made here concern the ecosystem modeling process.

Recommendations for Further Study

The following points must be considered in further research into the topic:

1. The characteristics and attributes of ecosystem models resulting from application of the various popular modeling forms (linear, nonlinear, donor controlled, etc.) need to be studied in a comparative light. The fundamental decision of which model type can replicate actual ecosystem dynamics in general must be reconciled.

2. Much of the difficulty involved in ecological modeling is deciding which communities to include as state variables and then how to measure them efficiently. Criteria for selecting the populations which dominate the ecosystem dynamics should be outlined, so that future work in this field will be more organized.

3. In most cases to date, ecosystem models have been developed from insufficient data and partial guesswork. This emphasizes the need for refined procedures for data collection and assimilation for the modeling effort. Time series data to accomodate the ecosystem identification process undoubtedly would assist the ecosystem modeler.

4. The possibility of "fitting" ecosystem models to that data, (using tools such as the method of least squared error) as opposed to intuitive formulations needs to be explored. If conclusive evidence is found that data fitting can result in plausible ecosystem realizations, the modeling process involved will be greatly simplified.

5. Testing procedures should be developed for the purpose of model verification. Introducing inputs or disturbances which can be facilitated in both the actual ecosystem and its model counterpart would be a possible testing method.

6. It may become advantageous to consider ecosystem observability and controllability. Research in this area could directly influence work in the related fiedls described by recommendations 1 and 2.

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APPENDIX A

POND TEN SIMULATION RESULTS

The program listing and computer output for the pond ten submodel simulation are presented here. The listing provides the DYSIMP user deck (FORTRAN IV) and complete data for the simulation problem. Output is given in both graphic and tabular forms.

```
                              80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890


              DYSIMP USER DECK


      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      READ (NR,2000) M
      DO 2002 I=1,M
      READ(NR,2001)T(I),WT10(I),SOL(I)
 2002 WT10(I)=(WT10(I)-32.0)*(5.0/9.0)
      IER=0
      IXVAL=1
      CALL DYSIMP(IXVAL,IER)
 2001 FORMAT(3F10.0)
 2000 FORMAT(I5)
      STOP
      END

      FUNCTION W10(TIME)
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W10=WT10(M)
      RETURN
    2 W10=WT10(1)
      RETURN
    3 W10=WT10(J-1)+(TIME-T(J-1))*(WT10(J)-WT10(J-1))/(T(J)-T(J-1))
      RETURN
      END

      FUNCTION SOLI(TIME)
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) SOLI=SOL(M)
      RETURN
    2 SOLI=SOL(1)
      RETURN
    3 SOLI=SOL(J-1)+(TIME-T(J-1))*(SOL(J)-SOL(J-1))/(T(J)-T(J-1))
      RETURN
      END

      SUBROUTINE DERFUN
      DIMENSION YINPUT(45),F(45)
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      EQUIVALENCE(YINPUT(1),F(1))
      F(1)=-.15385*Y(1)-.02308*Y(1)*Y(4)+.00905*Y(10)+.00679*Y(10)
      F(2)=-1.74576*Y(2)-.09142*Y(2)*Y(4)+.13360*Y(10)+.00679*Y(10)
```

```
                              80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      F(3)=-105.58462*Y(3)-23.58462*Y(3)*Y(4)*X(4)+.17664*Y(3)*Y(9)
     1+.09615*Y(3)*Y(8)+1.18101*Y(3)*Y(10)+0.13187*Y(3)*Y(7)+.58046
     1*Y(3)*Y(6)+.51680*Y(3)*Y(5)
      F(4)=(+23.58462*Y(3)*Y(4)*X(4)+.09412*Y(2)*Y(4)+.02308*Y(1)*Y(4)
     1-21.33075*Y(4)-2.01500*Y(4)*Y(11)+381.16)*X(3)
      F(5)=(-2.75711*Y(5)-.51680*Y(3)*Y(5)+.00200*Y(4)+.01195*Y(10)
     1+.06442*Y(5)*Y(11))*X(3)
      F(6)=(-2.20859*Y(6)-.58046*Y(3)*Y(6)+.05400*Y(4)+.05175*Y(6)
     1*Y(11)+.00127*Y(10)+.66)*X(3)
      F(7)=(-.79286*Y(7)-0.13187*Y(3)*Y(7)+.18088*Y(5)+.25153*Y(6)
     1+.01625*Y(7)*Y(11))*X(3)
      F(8)=(-.75000*Y(8)+.01185*Y(8)*Y(11)+.19018*Y(6)-.09615*Y(3)*Y(8)
     1+.89)*X(3)
      F(9)=(-.64021*Y(9)+.20569*Y(11)+.45000*Y(8)+.40000*Y(7)-.17664
     1*Y(3)*Y(9)+.25153*Y(6)+.77003*Y(5)+1.38)*X(3)
      F(10)=(-.85520*Y(10)-.00127*Y(10)-1.18101*Y(3)*Y(10)-.00582
     1*Y(10)*Y(2)+.11429*Y(7)+.14326*Y(10)*Y(11)+1.80103*Y(5)-.00070
     1*Y(10)*Y(1)+21.22000*Y(4)+.10000*Y(8)+45.06)*X(3)
      F(11)=-23.70995*Y(11)-.02177*Y(11)*Y(9)-.06442*Y(5)*Y(11)
     1-.14326*Y(10)*Y(11)-.05175*Y(6)*Y(11)-.01625*Y(7)*Y(11)-.01185
     1*Y(8)*Y(11)+2.01500*Y(4)*Y(11)+742.02
      DO 1 I=1,NY
      IEQ=NYP2+I
    1 Y(IEQ)=YINPUT(I)
      RETURN
      END

      SUBROUTINE XVAL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      X(1)=W10(Y(NYP1))
      X(2)=SOLI(Y(NYP1))
      X(3)=2.0**(-(16.0301-X(1))/10.0)
      X(4)=X(2)/508.7910
      RETURN
      END

      SUBROUTINE INTDEL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      COMMON/CDELAY/DELAYV(4000),LABELD(25,4),IDTYPE(25),NO,NDY,NDMAX,
     1IDELAY,TIME(25)
      J=LABELD(1,1)
      K=LABELD(1,2)
      DO 1 I=J,K
    1 DELAYV(I)=P(2)
      RETURN
      END
      SUBROUTINE PARADJ
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT10(100),SOL(100),M
      READ(NR,1) P(1)
    1 FORMAT(1F10.0)
      RETURN
```

```
                                   80/80 LIST

         00000000011111111112222222222333333333344444444445555555555666666666677777777778
         12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 109          END
 110
 111
 112              DATA
 113
 114
 115        49
 116           0.0      55.0      548.0
 117           0.5      44.0      475.0
 118           1.0      36.0      420.0
 119           1.5      34.0      380.0
 120           2.0      34.0      345.0
 121           2.5      42.0      320.0
 122           3.0      50.0      305.0
 123           3.5      50.0      300.0
 124           4.0      50.0      308.0
 125           4.5      53.8      376.0
 126           5.0      57.0      430.0
 127           5.5      58.2      475.0
 128           6.0      60.0      518.0
 129           6.5      67.0      540.0
 130           7.0      74.0      580.0
 131           7.5      79.0      608.0
 132           8.0      82.0      640.0
 133           8.5      84.5      660.0
 134           9.0      86.0      685.0
 135           9.5      84.5      695.0
 136          10.0      81.0      690.0
 137          10.5      73.5      673.0
 138          11.0      65.0      640.0
 139          11.5      60.0      600.0
 140          12.0      55.0      548.0
 141          12.5      44.0      475.0
 142          13.0      36.0      420.0
 143          13.5      34.0      380.0
 144          14.0      34.0      345.0
 145          14.5      42.0      320.0
 146          15.0      50.0      305.0
 147          15.5      50.0      300.0
 148          16.0      50.0      308.0
 149          16.5      53.8      376.0
 150          17.0      57.0      430.0
 151          17.5      58.2      475.0
 152          18.0      60.0      518.0
 153          18.5      67.0      540.0
 154          19.0      74.0      580.0
 155          19.5      79.0      608.0
 156          20.0      82.0      640.0
 157          20.5      84.5      660.0
 158          21.0      86.0      685.0
 159          21.5      84.5      695.0
 160          22.0      81.0      690.0
 161          22.5      73.5      673.0
 162          23.0      65.0      640.0
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                                   80/80 LIST

         00000000011111111112222222222333333333344444444445555555555666666666677777777778
         12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 163          23.5      60.0      600.0
 164          24.0      55.0      548.0
 165     1 1 1 1 0 0 0 0 0     POND TEN SUBMODEL RESPONSE
 166        11   4   0  40        0.3      23.9      .005
 167          13.0     22.97       1.3      40.0      3.87      1.63       1.4       1.6
 168          9.45     884.0     10.55
 169         2   3   6   7   8  10  11
 170         1   4   5   9
 171
 172
 173
 174
 175
```

```
DYSIMP SIMULATION PROGRAM        POND TEN SUBMODEL RESPONSE                                         PAGE  1  OF RUN  1

ORDER OF SYSTEM        =          11
NUMBER OF X'S          =           4
NUMBER OF PARAMETERS   =           0
OUTPUT INTERVAL        =          40
INITIAL TIME           =  3.0000E-01
FINAL TIME             =  2.3900E 01
INTEGRATION STEP       =  5.0000E-03

INITIAL Y VALUES

Y( 1) =  1.300000E 01     Y( 2) =  2.296999E 01     Y( 3) =  1.299999E 00     Y( 4) =  4.000000E 01     Y( 5) =  3.870000E 00
Y( 6) =  1.629999E 00     Y( 7) =  1.400000E 00     Y( 8) =  1.599999E 00     Y( 9) =  9.450000E 00     Y(10) =  6.840000E 02
Y(11) =  1.055000E 01

INITIAL X VALUES

X( 1) =  9.111113E 00     X( 2) =  5.042000E 02     X( 3) =  6.190390E-01     X( 4) =  9.909770E-01
```

```
 DYSIMP SIMULATION PROGRAM        POND TEN SUBMODEL RESPONSE                                        PAGE  2  OF RUN  1
 TIME
 Y(12)          Y( 2)            Y( 3)            Y( 6)            Y( 7)            Y( 8)            Y(10)            Y(11)
3.000E-01   2.2969986E 01   1.2999992E 00   1.6299992E 00   1.3999996E 00   1.5999994E 00   8.8400000E 02   1.0549999E 01
5.000E-01   2.2523712E 01   1.5452833E 00   1.6292334E 00   1.3984213E 00   1.5987988E 00   8.7879492E 02   1.1407966E 01
7.000E-01   2.1802261E 01   1.6831970E 00   1.6293020E 00   1.3955774E 00   1.5968294E 00   8.7219067E 02   1.2261787E 01
9.000E-01   2.1042908E 01   1.8928490E 00   1.6276855E 00   1.3915243E 00   1.5941849E 00   8.6347998E 02   1.3287692E 01
1.100E 00   2.0277023E 01   2.1229868E 00   1.6237631E 00   1.3863306E 00   1.5909348E 00   8.5281738E 02   1.4461823E 01
1.300E 00   1.9607605E 01   2.3543901E 00   1.6167784E 00   1.3799152E 00   1.5870886E 00   8.4017749E 02   1.5676118E 01
1.500E 00   1.8969666E 01   2.6375694E 00   1.6054831E 00   1.3720341E 00   1.5824957E 00   8.2474878E 02   1.7190857E 01
1.700E 00   1.8359161E 01   2.9439516E 00   1.5888720E 00   1.3624620E 00   1.5770521E 00   8.0622778E 02   1.8890152E 01
1.900E 00   1.7767273E 01   3.3161993E 00   1.5651760E 00   1.3507690E 00   1.5705137E 00   7.8360840E 02   2.0967972E 01
2.100E 00   1.7184784E 01   3.7198191E 00   1.5323372E 00   1.3363914E 00   1.5625830E 00   7.5596265E 02   2.3287354E 01
2.300E 00   1.6667587E 01   4.0892029E 00   1.4863014E 00   1.3175735E 00   1.5524654E 00   7.2115771E 02   2.5392227E 01
2.500E 00   1.6156433E 01   4.4891672E 00   1.4230299E 00   1.2925510E 00   1.5393448E 00   6.7711108E 02   2.7623108E 01
2.700E 00   1.5677150E 01   4.6859512E 00   1.3427601E 00   1.2601881E 00   1.5230455E 00   6.2544702E 02   2.8802704E 01
2.900E 00   1.5225950E 01   4.7912226E 00   1.2494783E 00   1.2195997E 00   1.5036383E 00   5.6892017E 02   2.9344788E 01
3.100E 00   1.4772553E 01   4.7432680E 00   1.1489010E 00   1.1707535E 00   1.4815941E 00   5.1115405E 02   2.9170044E 01
3.300E 00   1.4375542E 01   4.5563831E 00   1.0588818E 00   1.1198263E 00   1.4603834E 00   4.6242822E 02   2.8232605E 01
3.500E 00   1.4017642E 01   4.3907003E 00   9.8203391E-01   1.0689468E 00   1.4407501E 00   4.2267139E 02   2.7479736E 01
3.700E 00   1.3733637E 01   4.0767765E 00   9.2010045E-01   1.0199814E 00   1.4236813E 00   3.9282300E 02   2.6271286E 01
3.900E 00   1.3541568E 01   3.8172331E 00   8.7331593E-01   9.7423482E-01   1.4096470E 00   3.7223926E 02   2.5273514E 01
4.100E 00   1.3453323E 01   3.3298445E 00   8.4116632E-01   9.3252486E-01   1.3990698E 00   3.6092065E 02   2.3776810E 01
4.300E 00   1.3687384E 01   2.7196903E 00   8.3112717E-01   8.9714962E-01   1.3948917E 00   3.6580640E 02   2.1340469E 01
4.500E 00   1.4172242E 01   2.3109312E 00   8.3903897E-01   8.6769319E-01   1.3955021E 00   3.8252930E 02   1.9553070E 01
4.700E 00   1.4810309E 01   2.0731878E 00   8.5994190E-01   8.4387439E-01   1.3990145E 00   4.0657104E 02   1.8271118E 01
4.900E 00   1.5539954E 01   1.6768673E 00   8.9098954E-01   8.2604128E-01   1.4044695E 00   4.3571313E 02   1.7118912E 01
5.100E 00   1.6343689E 01   1.7230425E 00   9.3017834E-01   8.1481010E-01   1.4114628E 00   4.6869922E 02   1.6063660E 01
5.300E 00   1.7171280E 01   1.5992537E 00   9.7454786E-01   8.1051254E-01   1.4193878E 00   5.0330176E 02   1.5136230E 01
5.500E 00   1.8010315E 01   1.4846811E 00   1.0223074E 00   8.1308740E-01   1.4281435E 00   5.3884375E 02   1.4255745E 01
5.700E 00   1.8849976E 01   1.3843946E 00   1.0722055E 00   8.2229632E-01   1.4376717E 00   5.7482886E 02   1.3447642E 01
5.900E 00   1.9682770E 01   1.2919540E 00   1.1232815E 00   8.3788800E-01   1.4479399E 00   6.1089697E 02   1.2696923E 01
6.100E 00   2.0491440E 01   1.2288742E 00   1.1747742E 00   8.5962802E-01   1.4588766E 00   6.4649219E 02   1.2071075E 01
6.300E 00   2.1197556E 01   1.1895361E 00   1.2289772E 00   8.8851857E-01   1.4707012E 00   6.8211328E 02   1.1585269E 01
6.500E 00   2.1839050E 01   1.1507797E 00   1.2852592E 00   9.2519337E-01   1.4835930E 00   7.1773022E 02   1.1122703E 01
6.700E 00   2.2504654E 01   1.0822201E 00   1.3419170E 00   9.7003263E-01   1.4979019E 00   7.5382153E 02   1.0569518E 01
6.900E 00   2.3227356E 01   1.0198717E 00   1.3968964E 00   1.0229235E 00   1.5136499E 00   7.8966089E 02   1.0045597E 01
7.100E 00   2.3955048E 01   9.7041088E-01   1.4489374E 00   1.0827227E 00   1.5304127E 00   8.2390137E 02   9.5981045E 00
7.300E 00   2.4609238E 01   9.3227130E-01   1.4963846E 00   1.1461058E 00   1.5472202E 00   8.5456567E 02   9.2400541E 00
7.500E 00   2.5202957E 01   8.9625084E-01   1.5379658E 00   1.2106991E 00   1.5637026E 00   8.8148413E 02   8.9258451E 00
7.700E 00   2.5765030E 01   8.5781240E-01   1.5724220E 00   1.2735920E 00   1.5793886E 00   9.0459473E 02   8.6354189E 00
7.900E 00   2.6304810E 01   8.2190287E-01   1.5994968E 00   1.3323288E 00   1.5938234E 00   9.2389966E 02   8.3823576E 00
8.100E 00   2.6804153E 01   7.9431516E-01   1.6203136E 00   1.3858070E 00   1.6067753E 00   9.3962329E 02   8.1825771E 00
8.300E 00   2.7208496E 01   7.7378207E-01   1.6366587E 00   1.4328203E 00   1.6179247E 00   9.5186841E 02   8.0369673E 00
8.500E 00   2.7552612E 01   7.5424194E-01   1.6488085E 00   1.4732523E 00   1.6274195E 00   9.6146802E 02   7.9110088E 00
8.700E 00   2.7880112E 01   7.3107910E-01   1.6569700E 00   1.5073595E 00   1.6354475E 00   9.6920093E 02   7.7841845E 00
8.900E 00   2.8206711E 01   7.0894217E-01   1.6618166E 00   1.5357656E 00   1.6421556E 00   9.7542261E 02   7.6692629E 00
9.100E 00   2.8510086E 01   6.9379663E-01   1.6645737E 00   1.5591249E 00   1.6476202E 00   9.8019702E 02   7.5855665E 00
9.300E 00   2.8722229E 01   6.6518416E-01   1.6670208E 00   1.5772209E 00   1.6517105E 00   9.8343701E 02   7.5379753E 00
9.500E 00   2.8883636E 01   6.7682856E-01   1.6686544E 00   1.5911465E 00   1.6548367E 00   9.8580396E 02   7.4958706E 00
9.700E 00   2.8966324E 01   6.8052065E-01   1.6702938E 00   1.6014214E 00   1.6570263E 00   9.8702417E 02   7.5002728E 00
9.900E 00   2.8969925E 01   6.8434036E-01   1.6723022E 00   1.6086187E 00   1.6584854E 00   9.8761865E 02   7.5116720E 00
1.010E 01   2.8928238E 01   6.9339997E-01   1.6741590E 00   1.6134844E 00   1.6594181E 00   9.8767725E 02   7.5411148E 00
1.030E 01   2.8805435E 01   7.0749110E-01   1.6766443E 00   1.6162033E 00   1.6597996E 00   9.8714307E 02   7.5959024E 00
1.050E 01   2.8640884E 01   7.2223669E-01   1.6792412E 00   1.6174049E 00   1.6598434E 00   9.8634619E 02   7.6538963E 00
1.070E 01   2.8396042E 01   7.5235182E-01   1.6822948E 00   1.6172543E 00   1.6594782E 00   9.8481128E 02   7.7675304E 00
1.090E 01   2.8065887E 01   7.8427136E-01   1.6861286E 00   1.6159534E 00   1.6587715E 00   9.8288525E 02   7.8953524E 00
1.110E 01   2.7691025E 01   8.2230955E-01   1.6901093E 00   1.6137695E 00   1.6578150E 00   9.8055786E 02   8.0458841E 00
1.130E 01   2.7254913E 01   8.6647755E-01   1.6945086E 00   1.6106758E 00   1.6565590E 00   9.7768164E 02   8.2289658E 00
1.150E 01   2.6784637E 01   9.1461372E-01   1.6989956E 00   1.6067677E 00   1.6550531E 00   9.7433765E 02   8.4315519E 00
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  DYSIMP SIMULATION PROGRAM          POND TEN SUBMODEL RESPONSE                                             PAGE  3  OF RUN  1
 TIME
 Y(12)         Y( 2)          Y( 3)          Y( 6)          Y( 7)          Y( 8)          Y(10)          Y(11)
1.170E 01  2.6241623E 01  9.8380569E-01  1.7034616E 00  1.6019220E 00  1.6531820E 00  9.7000024E 02  8.7186706E 00
1.190E 01  2.5619598E 01  1.0614204E 00  1.7080812E 00  1.5960913E 00  1.6509256E 00  9.6479395E 02  9.0553198E 00
1.210E 01  2.4929825E 01  1.1719275E 00  1.7121048E 00  1.5892563E 00  1.6482420E 00  9.5827637E 02  9.5118628E 00
1.230E 01  2.4061493E 01  1.3201742E 00  1.7155094E 00  1.5814848E 00  1.6450186E 00  9.4998608E 02  1.0184430E 01
1.250E 01  2.3092270E 01  1.5073195E 00  1.7176867E 00  1.5729418E 00  1.6413296E 00  9.4012109E 02  1.1044268E 01
1.270E 01  2.2167984E 01  1.6778851E 00  1.7182913E 00  1.5638685E 00  1.6373701E 00  9.2950049E 02  1.1910647E 01
1.290E 01  2.1319366E 01  1.8901777E 00  1.7161722E 00  1.5542002E 00  1.6330938E 00  9.1744800E 02  1.2971491E 01
1.310E 01  2.0505737E 01  2.1218100E 00  1.7111855E 00  1.5439110E 00  1.6284752E 00  9.0395947E 02  1.4186135E 01
1.330E 01  1.9809169E 01  2.3549109E 00  1.7026510E 00  1.5325670E 00  1.6233797E 00  8.8871680E 02  1.5448687E 01
1.350E 01  1.9150070E 01  2.6412201E 00  1.6893539E 00  1.5198526E 00  1.6176205E 00  8.7080444E 02  1.7029800E 01
1.370E 01  1.8522476E 01  2.9554367E 00  1.6702490E 00  1.5054665E 00  1.6110554E 00  8.4983081E 02  1.8813080E 01
1.390E 01  1.7915878E 01  3.3450556E 00  1.6434412E 00  1.4888811E 00  1.6034050E 00  8.2466162E 02  2.1007523E 01
1.410E 01  1.7320374E 01  3.7656832E 00  1.6066561E 00  1.4694338E 00  1.5943279E 00  7.9422412E 02  2.3485825E 01
1.430E 01  1.6794159E 01  4.1599751E 00  1.5553885E 00  1.4448709E 00  1.5829000E 00  7.5610840E 02  2.5746231E 01
1.450E 01  1.6273651E 01  4.5827522E 00  1.4852848E 00  1.4132137E 00  1.5682325E 00  7.0805518E 02  2.8155975E 01
1.470E 01  1.5786707E 01  4.7925243E 00  1.3967056E 00  1.3732605E 00  1.5501032E 00  6.5178174E 02  2.9413345E 01
1.490E 01  1.5328012E 01  4.9038744E 00  1.2943535E 00  1.3241405E 00  1.5265769E 00  5.9036328E 02  2.9949646E 01
1.510E 01  1.4865914E 01  4.8443317E 00  1.1847353E 00  1.2660303E 00  1.5041809E 00  5.2784497E 02  2.9698883E 01
1.530E 01  1.4461174E 01  4.6401072E 00  1.0872278E 00  1.2062111E 00  1.4806910E 00  4.7528662E 02  2.8630615E 01
1.550E 01  1.4095145E 01  4.4585714E 00  1.0044060E 00  1.1470537E 00  1.4589329E 00  4.3254565E 02  2.7781357E 01
1.570E 01  1.3803738E 01  4.1282110E 00  9.3779874E-01  1.0905190E 00  1.4399290E 00  4.0044434E 02  2.6475525E 01
1.590E 01  1.3604836E 01  3.8570747E 00  8.8743758E-01  1.0379419E 00  1.4241657E 00  3.7819702E 02  2.5410019E 01
1.610E 01  1.3510538E 01  3.3602467E 00  8.5253596E-01  9.9008983E-01  1.4120512E 00  3.6565649E 02  2.3849182E 01
1.630E 01  1.3741686E 01  2.7356386E 00  8.4050983E-01  9.4917476E-01  1.4065075E 00  3.6974072E 02  2.1356873E 01
1.650E 01  1.4224247E 01  2.3211479E 00  8.4692091E-01  9.1461742E-01  1.4058847E 00  3.8589087E 02  1.9544312E 01
1.670E 01  1.4858524E 01  2.0796280E 00  8.6664587E-01  8.8605034E-01  1.4082775E 00  4.0949316E 02  1.8253632E 01
1.690E 01  1.5583385E 01  1.8808889E 00  8.9674240E-01  8.6379117E-01  1.4127131E 00  4.3827979E 02  1.7098251E 01
1.710E 01  1.6382019E 01  1.7254553E 00  9.3514812E-01  8.4844905E-01  1.4187784E 00  4.7096680E 02  1.6042969E 01
1.730E 01  1.7204498E 01  1.6007662E 00  9.7887135E-01  8.4041733E-01  1.4258757E 00  5.0531372E 02  1.5116918E 01
1.750E 01  1.8038818E 01  1.4856148E 00  1.0260878E 00  8.3961952E-01  1.4338923E 00  5.4063232E 02  1.4238344E 01
1.770E 01  1.8874329E 01  1.3849649E 00  1.0755167E 00  8.4577394E-01  1.4427567E 00  5.7641724E 02  1.3432371E 01
1.790E 01  1.9703506E 01  1.2922945E 00  1.1261806E 00  8.5859352E-01  1.4524279E 00  6.1230347E 02  1.2683758E 01
1.810E 01  2.0509018E 01  1.2290907E 00  1.1773043E 00  8.7780166E-01  1.4628210E 00  6.4772998E 02  1.2059920E 01
1.830E 01  2.1212173E 01  1.1896448E 00  1.2311573E 00  9.0425116E-01  1.4741249E 00  6.8318652E 02  1.1576032E 01
1.850E 01  2.1851028E 01  1.1508207E 00  1.2871084E 00  9.3858439E-01  1.4865179E 00  7.1864404E 02  1.1115201E 01
1.870E 01  2.2514404E 01  1.0822334E 00  1.3434544E 00  9.8122126E-01  1.5003576E 00  7.5458374E 02  1.0563552E 01
1.890E 01  2.3235214E 01  1.0198698E 00  1.3981447E 00  1.0320826E 00  1.5156717E 00  7.9028125E 02  1.0040979E 01
1.910E 01  2.3961288E 01  9.7040427E-01  1.4499245E 00  1.0900545E 00  1.5320435E 00  8.2439258E 02  9.5946293E 00
1.930E 01  2.4614059E 01  9.3226641E-01  1.4971466E 00  1.1518631E 00  1.5485106E 00  8.5494531E 02  9.2374878E 00
1.950E 01  2.5206589E 01  8.9625174E-01  1.5385408E 00  1.2151308E 00  1.5647049E 00  8.8177026E 02  8.9239655E 00
1.970E 01  2.5767731E 01  8.5780549E-01  1.5728464E 00  1.2769442E 00  1.5801535E 00  9.0480591E 02  8.6340961E 00
1.990E 01  2.6306793E 01  8.2189459E-01  1.5998039E 00  1.3348293E 00  1.5944004E 00  9.2405249E 02  8.3814325E 00
2.010E 01  2.6805588E 01  7.9431087E-01  1.6205311E 00  1.3876457E 00  1.6072044E 00  9.3973145E 02  8.1819429E 00
2.030E 01  2.7209518E 01  7.7377838E-01  1.6368103E 00  1.4341545E 00  1.6182394E 00  9.5194409E 02  8.0365314E 00
2.050E 01  2.7553314E 01  7.5424159E-01  1.6489124E 00  1.4742069E 00  1.6276464E 00  9.6151978E 02  7.9107141E 00
2.070E 01  2.7880600E 01  7.3108101E-01  1.6570406E 00  1.5080347E 00  1.6356096E 00  9.6923584E 02  7.7839870E 00
2.090E 01  2.8207031E 01  7.0894057E-01  1.6618643E 00  1.5362377E 00  1.6422710E 00  9.7544580E 02  7.6691360E 00
2.110E 01  2.8510300E 01  6.9379634E-01  1.6646051E 00  1.5594530E 00  1.6477013E 00  9.8021240E 02  7.5854816E 00
2.130E 01  2.8722362E 01  6.8518060E-01  1.6670418E 00  1.5774508E 00  1.6517677E 00  9.8344727E 02  7.5379219E 00
2.150E 01  2.8883728E 01  6.7682803E-01  1.6686687E 00  1.5913086E 00  1.6548767E 00  9.8581079E 02  7.4958315E 00
2.170E 01  2.8966400E 01  6.8051666E-01  1.6703033E 00  1.6015368E 00  1.6570559E 00  9.8702905E 02  7.5002480E 00
2.190E 01  2.8969971E 01  6.8433976E-01  1.6723089E 00  1.6087027E 00  1.6585064E 00  9.8762183E 02  7.5116549E 00
2.210E 01  2.8928268E 01  6.9339949E-01  1.6741638E 00  1.6135454E 00  1.6594334E 00  9.8767969E 02  7.5410986E 00
2.230E 01  2.8805466E 01  7.0749038E-01  1.6766481E 00  1.6162500E 00  1.6598120E 00  9.8714478E 02  7.5958920E 00
2.250E 01  2.8640900E 01  7.2223008E-01  1.6792440E 00  1.6174412E 00  1.6598539E 00  9.8634766E 02  7.6538868E 00
2.270E 01  2.8396057E 01  7.5234926E-01  1.6822968E 00  1.6172838E 00  1.6594858E 00  9.8481226E 02  7.7675209E 00
2.290E 01  2.8065918E 01  7.8427100E-01  1.6861296E 00  1.6159773E 00  1.6587782E 00  9.8288623E 02  7.8953409E 00
```
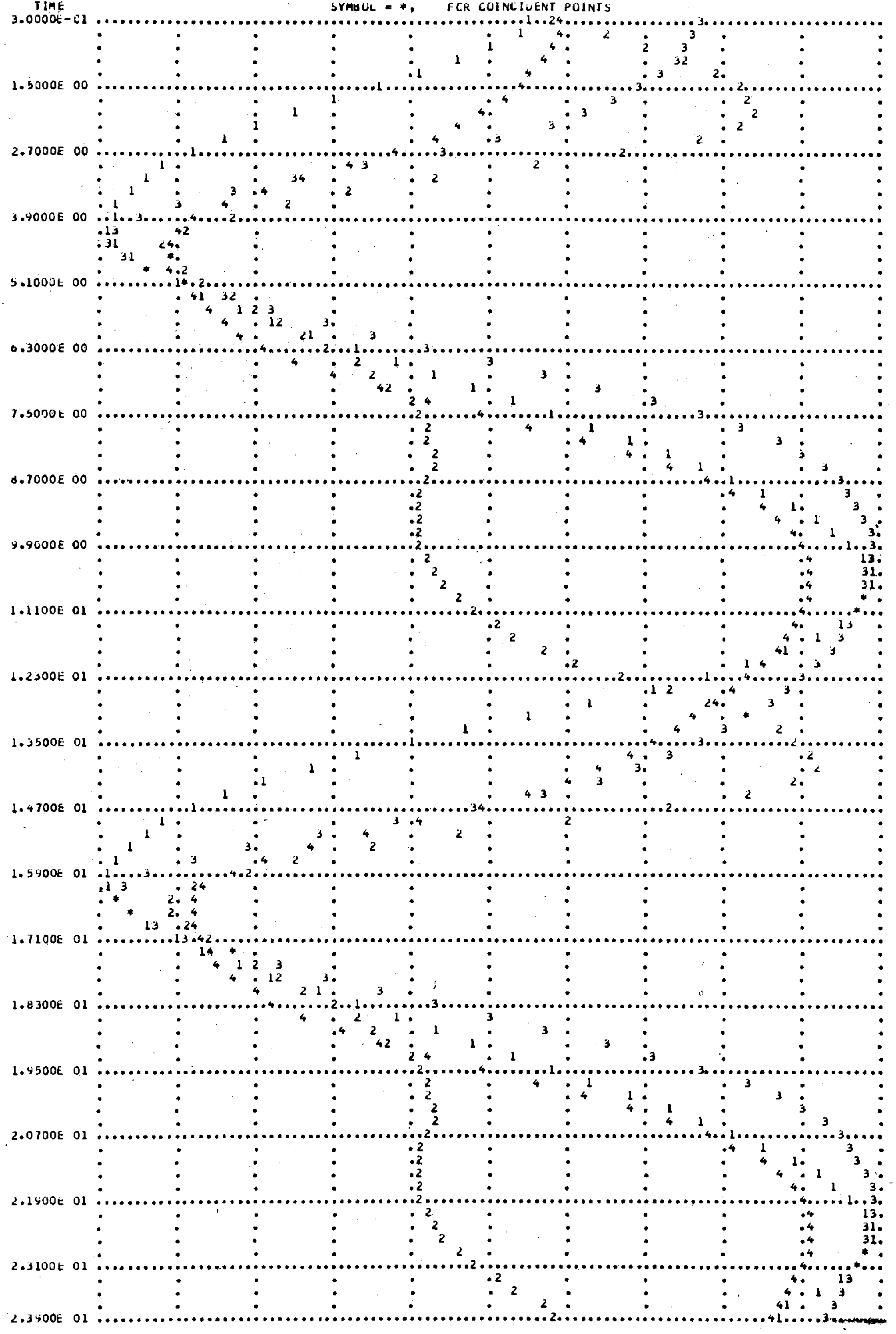

```
  DYSIMP SIMULATION PROGRAM          POND TEN SUBMODEL RESPONSE                                             PAGE  4  OF RUN  1
 TIME
 Y(12)         Y( 2)          Y( 3)          Y( 6)          Y( 7)          Y( 8)          Y(10)          Y(11)
2.310E 01  2.7691040E 01  8.2230365E-01  1.6901102E 00  1.6137905E 00  1.6578207E 00  9.8055884E 02  8.0458689E 00
2.330E 01  2.7254944E 01  8.6646771E-01  1.6945095E 00  1.6106930E 00  1.6565638E 00  9.7768237E 02  8.2289753E 00
2.350E 01  2.6784668E 01  9.1460359E-01  1.6989965E 00  1.6067829E 00  1.6550570E 00  9.7433838E 02  8.4315348E 00
2.370E 01  2.6241669E 01  9.8379529E-01  1.7034626E 00  1.6019354E 00  1.6531858E 00  9.7000098E 02  8.7186565E 00
2.390E 01  2.5619629E 01  1.0614157E 00  1.7080822E 00  1.5961027E 00  1.6509295E 00  9.6479468E 02  9.0553064E 00
```

```
DYSIMP SIMULATION PROGRAM        POND TEN SUBMODEL RESPONSE                                PAGE  5  OF RUN  1
              Y( 1) =  8.605E 00             SYMBOL = 1,    SCALE FACTOR =  8.000E-01             Y( 1) =  1.660E 01
              Y( 4) =  1.684E 01             SYMBOL = 2,    SCALE FACTOR =  4.000E 00             Y( 4) =  5.684E 01
              Y( 5) =  1.555E 00             SYMBOL = 3,    SCALE FACTOR =  3.000E-01             Y( 5) =  4.555E 00
              Y( 9) =  7.091E 00             SYMBOL = 4,    SCALE FACTOR =  4.000E-01             Y( 9) =  1.109E 01
                                             SYMBOL = *,    FOR COINCIDENT POINTS
```



APPENDIX B

POND SERIES SIMULATION RESULTS

The program listing and computer output for the pond series model simulation are presented here. As in Appendix A, the listing includes the DYSIMP user deck and the necessary data. Two simulation runs were required to output all twenty-eight states, since the DYSIMP package allows a maximum of ten printed and ten plotted outputs.

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777
1234567890123456789012345678901234567890123456789012345678901234567890123456789

      DYSIMP USER DECK


      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      READ (NR,2000) M
      DO 2002 I=1,M
      READ(NR,2001) T(I),WT4(I),WT7(I),WT10(I),SOL(I)
      WT4(I)=(WT4(I)-32.0)*(5.0/9.0)
      WT7(I)=(WT7(I)-32.0)*(5.0/9.0)
 2002 WT10(I)=(WT10(I)-32.0)*(5.0/9.0)
      IER=0
      IXVAL=1
      CALL DYSIMP(IXVAL,IER)
 2000 FORMAT(I5)
 2001 FORMAT(5F10.0)
      STOP
      END

      FUNCTION W4(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W4=WT4(M)
      RETURN
    2 W4=WT4(1)
      RETURN
    3 W4=WT4(J-1)+(TIME-T(J-1))*(WT4(J)-WT4(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION W7(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W7=WT7(M)
      RETURN
    2 W7=WT7(1)
      RETURN
    3 W7=WT7(J-1)+(TIME-T(J-1))*(WT7(J)-WT7(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION W10(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W10=WT10(M)
```

```
0000000001111111111222222222233333333334444444444555555555566666666667777777777
1234567890123456789012345678901234567890123456789012345678901234567890123456789
      RETURN
    2 W10=WT10(1)
      RETURN
    3 W10=WT10(J-1)+(TIME-T(J-1))*(WT10(J)-WT10(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION SOL1(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) SOL1=SOL(M)
      RETURN
    2 SOL1=SOL(1)
      RETURN
    3 SOL1=SOL(J-1)+(TIME-T(J-1))*(SOL(J)-SOL(J-1))/(T(J)-T(J-1))
      RETURN
      END

      SUBROUTINE DERFUN
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DIMENSION YINPUT(45),F(45)
      EQUIVALENCE(YINPUT(1),F(1))
      F(1)=(-.15369*Y(1)+.00679*Y(7)+.00906*Y(7)-.01208*Y(1)*Y(4)-12.87)
      F(2)=(-1.75000*Y(2)+.00679*Y(7)-.06568*Y(2)*Y(4)+.13415*Y(7)
     1-112.7)
      F(3)=(-363.76581*Y(3)-7.12668*Y(3)*Y(4)*X(24)+.35681*Y(3)*Y(7)
     1+.15621*Y(3)*Y(5)+.17542*Y(3)*Y(6))
      F(4)=(-21.41437*Y(4)+.06568*Y(2)*Y(4)+7.12668*Y(3)*Y(4)*X(24)
     1+.01208*Y(1)*Y(4)-5.21609*Y(4)*Y(8)-37.76+381.16)*X(21)
      F(5)=(-2.73737*Y(5)-.15621*Y(3)*Y(5)+.00199*Y(4)+.00172*Y(7)
     1+.16605*Y(5)*Y(8)-.329)*X(21)
      F(6)=(-2.21429*Y(6)+.05396*Y(4)-.17542*Y(3)*Y(6)+.13240*Y(6)
     1*Y(8)+.00029*Y(7)-.682)*X(21)
      F(7)=(-.85308*Y(7)+21.24396*Y(4)-.00419*Y(7)*Y(2)-.35681*Y(3)*Y(7)
     1+1.79798*Y(5)+.36713*Y(7)*Y(8)-.00029*Y(7)-.00036*Y(7)*Y(1)
     1+1016.3)*X(21)
      F(8)=(-23.78049*Y(8)-.13240*Y(6)*Y(8)-.16605*Y(5)*Y(8)
     1+5.21609*Y(4)*Y(8)-.36713*Y(7)*Y(8)+1937.554)
      IF (Y(NYP1)-P(5)) 9,2,2
    9 X(2)=.15369*24.92*P(3)
      X(4)=1.75*32.0*P(3)
      X(6)=363.76581*4.3*P(4)
      X(8)=23.78049*4.1*P(4)
    2 F(9)=(-.15385*Y(9)+.00992*Y(16)+.00678*Y(16)-.01842*Y(9)*Y(12)
     1-2.57+X(2)-X(25))
      F(10)=(-1.75185*Y(10)+.00678*Y(16)-.07762*Y(10)*Y(12)+.13368*
     1Y(16)-24.77+X(4)-X(26))
      F(11)=(-201.46714*Y(11)+.05923*Y(11)*Y(15)
     1-14.55779*Y(11)*Y(12)*X(24)
     1+.73050*Y(11)*Y(16)+.35948*Y(11)*Y(14)+.32125*Y(11)*Y(13)+X(6)
     1-X(27))
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

      F(12)=(.01342*Y(9)*Y(12)+14.55779*Y(11)*Y(12)*X(24)+.07662*Y(10)
     1*Y(12)
     1-21.50538*Y(12)-1.93587*Y(12)*Y(17)+85.24+361.16)*X(22)
      F(13)=(.00260*Y(12)-.32125*Y(11)*Y(13)-2.75731*Y(13)+.06187*
     1Y(13)*Y(17)+.00820*Y(16)-.945)*X(22)
      F(14)=(-2.21569*Y(14)+.05597*Y(12)-.35948*Y(11)*Y(14)+.00057*Y(15)
     1+.04991*Y(14)*Y(17)-.75)*X(22)
      F(15)=(-.75122*Y(15)-.05923*Y(11)*Y(15)+.01131*Y(15)*Y(17)
     1+.19620*Y(14)+.114)*X(22)
      F(16)=(-.85316*Y(16)+21.18912*Y(12)+1.80597*Y(13)-.00496*Y(10)
     1*Y(16)-.73050*Y(11)*Y(16)-.00057*Y(16)+.13737*Y(15)*Y(17)
     1-.00056*Y(16)*Y(9)+.10000*Y(15)+231.009)*X(22)
      F(17)=(-23.72727*Y(17)-.01131*Y(15)*Y(17)-.13737*Y(16)*Y(17)
     1+1.93587*Y(12)*Y(17)-.06187*Y(13)*Y(17)-.04991*Y(14)*Y(17)
     1+1095.891+X(8)-X(28))
    4 IF (Y(NYP1)-P(6)) 5,6,6
    5 X(10)=.15385*16.25*P(3)
      X(12)=1.75185*27.0*P(3)
      X(14)=201.46714*2.1*P(4)
      X(16)=23.72727*11.0*P(4)
    6 F(18)=(-.15385*Y(18)-.02308*Y(18)*Y(21)+.00905*Y(27)
     1+.00679*Y(27)+X(10)-X(29))
      F(19)=(-1.74576*Y(19)-.09142*Y(19)*Y(21)+.13360*Y(27)+
     1.00679*Y(27)+X(12)-X(30))
      F(20)=(-105.58462*Y(20)-23.58462*Y(20)*Y(21)*X(24)+.17664*Y(20)
     1*Y(26)+X(14)-X(31)
     1+.09615*Y(20)*Y(25)+1.18101*Y(20)*Y(27)+0.13187*Y(20)*Y(24)
     1+.58046*Y(20)*Y(23)+.51680*Y(20)*Y(22))
      F(21)=(23.58462*Y(20)*Y(21)*X(24)+.09412*Y(19)*Y(21)
     1+.02308*Y(18)*Y(21)
     1-21.33075*Y(21)-2.01500*Y(21)*Y(28)+381.16)*X(23)
      F(22)=(-2.75711*Y(22)-.51680*Y(20)*Y(22)+.30200*Y(21)+.01195
     1*Y(27)+.06442*Y(22)*Y(28))*X(23)
      F(23)=(-2.20859*Y(23)-.58046*Y(20)*Y(23)+.05400*Y(21)+.05175
     1*Y(23)*Y(28)+.00127*Y(27)+.66)*X(23)
      F(24)=(-.79286*Y(24)-.13187*Y(20)*Y(24)+.18088*Y(22)+.25153
     1*Y(23)+.01825*Y(24)*Y(26))*X(23)
      F(25)=(-.75000*Y(25)+.01185*Y(25)*Y(28)+.19018*Y(23)-.09615
     1*Y(20)*Y(25)+.89)*X(23)
      F(26)=(-.64021*Y(26)+.20569*Y(28)+.45000*Y(25)+.40000*Y(24)
     1-.17664*Y(20)*Y(26)+.25153*Y(23)+.77005*Y(22)+1.38)*X(23)
      F(27)=(-.855204*Y(27)-.001267*Y(27)-1.181013*Y(20)*Y(27)
     1-.005816*Y(27)*Y(19)+.114286*Y(24)+.143261*Y(27)*Y(28)
     1+1.801033*Y(22)-.000696*Y(27)*Y(18)+21.22000*Y(21)+.10000
     1*Y(23)+45.06)*X(23)
      F(28)=(-23.709950*Y(28)-.021766*Y(28)*Y(26)-.064416*Y(22)*Y(28)
     1-.143261*Y(27)*Y(28)-.051755*Y(23)*Y(28)-.016249*Y(24)*Y(28)
     1-.011848*Y(25)*Y(28)+2.01500*Y(21)*Y(28)+742.02+X(16)-X(32))
    6 CONTINUE
      DO 1 I=1,NY
      IEQ=NYP2+I
    1 Y(IEQ)=YINPUT(I)
      RETURN
      END
```

80/80 LIST

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890


      SUBROUTINE XVAL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      X(1)=.15369*Y(1)*P(3)
      X(3)=1.75*Y(2)*P(3)
      X(5)=363.76581*Y(3)*P(4)
      X(7)=23.78049*Y(8)*P(4)
      X(9)=.15285*Y(9)*P(3)
      X(11)=1.75185*Y(10)*P(3)
      X(13)=201.46714*Y(11)*P(4)
      X(15)=23.72727*Y(17)*P(4)
      X(17)=W4(Y(NYP1))
      X(18)=W7(Y(NYP1))
      X(19)=W10(Y(NYP1))
      X(20)=SOLI(Y(NYP1))
      X(21)=2.0**(-(18.0810-X(17))/10.0)
      X(22)=2.0**(-(16.5694-X(18))/10.0)
      X(23)=2.0**(-(16.0301-X(19))/10.0)
      X(24)=X(20)/508.7910
      X(25)=.15369*24.92*P(3)
      X(26)=1.75*32.0*P(3)
      X(27)=363.76581*4.3*P(4)
      X(28)=23.78049*4.1*P(4)
      X(29)=.15385*16.25*P(3)
      X(30)=1.75185*27.0*P(3)
      X(31)=201.46714*2.1*P(4)
      X(32)=23.72727*11.0*P(4)
      CALL DELAY
      RETURN
      END

      SUBROUTINE INTDEL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/CDELAY/DELAYV(4000),LABELD(25,4),IDTYPE(25),ND,NDY,NDMAX,
     1IDELAY,TIME(25)
      DO 1 I=1,ND
      J=LABELD(I,1)
      K=LABELD(I,2)
      DO 1 II=J,K
    1 DELAYV(II)=0.0
      RETURN
      END
      SUBROUTINE PARADJ
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      READ(NR,1) P(1)
    1 FORMAT(1F10.0)
      RETURN
      END


          DATA


```

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                                  80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 217      49
 218          0.0       58.0       55.0       55.0      548.0
 219          0.5       46.0       43.5       44.0      475.0
 220          1.0       41.0       37.0       36.0      420.0
 221          1.5       40.0       35.8       34.0      380.0
 222          2.0       41.0       36.0       34.0      345.0
 223          2.5       48.5       44.0       42.0      320.0
 224          3.0       59.0       53.0       50.0      305.0
 225          3.5       56.0       53.0       50.0      300.0
 226          4.0       55.0       53.0       50.0      308.0
 227          4.5       62.5       56.0       53.8      376.0
 228          5.0       65.0       58.5       57.0      430.0
 229          5.5       63.5       59.5       58.2      475.0
 230          6.0       62.0       60.0       60.0      518.0
 231          6.5       68.5       66.0       67.0      540.0
 232          7.0       76.0       75.0       74.0      580.0
 233          7.5       80.0       79.5       79.0      608.0
 234          8.0       82.0       82.0       82.0      640.0
 235          8.5       85.8       84.5       84.5      660.0
 236          9.0       87.0       86.0       86.0      685.0
 237          9.5       85.8       84.0       84.5      695.0
 238         10.0       82.0       81.0       81.0      690.0
 239         10.5       73.0       74.5       73.5      673.0
 240         11.0       68.0       67.0       65.0      640.0
 241         11.5       63.5       60.0       60.0      600.0
 242         12.0       58.0       55.0       55.0      548.0
 243         12.5       46.0       43.5       44.0      475.0
 244         13.0       41.0       37.0       36.0      420.0
 245         13.5       40.0       35.8       34.0      380.0
 246         14.0       41.0       36.0       34.0      345.0
 247         14.5       48.5       44.0       42.0      320.0
 248         15.0       59.0       53.0       50.0      305.0
 249         15.5       56.0       53.0       50.0      300.0
 250         16.0       55.0       53.0       50.0      308.0
 251         16.5       62.5       56.0       53.8      376.0
 252         17.0       65.0       58.5       57.0      430.0
 253         17.5       63.5       59.5       58.2      475.0
 254         18.0       62.0       60.0       60.0      518.0
 255         18.5       68.5       66.0       67.0      540.0
 256         19.0       76.0       75.0       74.0      580.0
 257         19.5       80.0       79.5       79.0      608.0
 258         20.0       82.0       82.0       82.0      640.0
 259         20.5       85.8       84.5       84.5      660.0
 260         21.0       87.0       86.0       86.0      685.0
 261         21.5       85.8       84.0       84.5      695.0
 262         22.0       82.0       81.0       81.0      690.0
 263         22.5       73.0       74.5       73.5      673.0
 264         23.0       68.0       67.0       65.0      640.0
 265         23.5       63.5       60.0       60.0      600.0
 266         24.0       58.0       55.0       55.0      548.0
 267     1 1 1 1 0 0 1 0 0    SERIES POND MODEL RESPONSE
 268      28   32      6 40        0.3       12.3      .0025
 269        24.92       32.0        4.3      35.21        .99         .7     1722.0        4.1
 270        16.25       27.0        2.1      47.43       3.35       1.02        .41     1219.0
```

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                                  80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 271         11.0       13.0      22.97        1.3       40.0       3.87       1.63        1.4
 272          1.6       9.45      884.0      10.55
 273          0.0        0.0        0.3       0.05      0.390      0.480
 274        8
 275       1  2  0      0.090  3  4  0      0.090  5  6  0      0.090  7  8  0      0.090
 276       9 10  0      0.090 11 12  0      0.090 13 14  0      0.090 15 16  0      0.090
 277        3   11   20    8   17   28   24   26
 278        1    9   18    4   12   21
 279
 280
 281
 282
 283
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DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                      PAGE  1  OF RUN  1

ORDER OF SYSTEM      =          28
NUMBER OF X'S        =          32
NUMBER OF PARAMETERS =           6
NUMBER OF DELAYS     =           8
OUTPUT INTERVAL      =          40
INITIAL TIME         =  3.0000E-01
FINAL TIME           =  1.2300E 01
INTEGRATION STEP     =  2.5000E-03

INITIAL Y VALUES

Y( 1) =  2.492000E 01     Y( 2) =  3.200000E 01     Y( 3) =  4.299999E 00     Y( 4) =  3.520999E 01     Y( 5) =  9.899999E-01
Y( 6) =  7.000000E-01     Y( 7) =  1.722000E 03     Y( 8) =  4.099999E 00     Y( 9) =  1.625000E 01     Y(10) =  2.700000E 01
Y(11) =  2.099999E 00     Y(12) =  4.742999E 01     Y(13) =  3.349999E 00     Y(14) =  1.020000E 00     Y(15) =  4.100000E-01
Y(16) =  1.219000E 03     Y(17) =  1.100000E 01     Y(18) =  1.300000E 01     Y(19) =  2.296999E 01     Y(20) =  1.299999E 00
Y(21) =  4.000000E 01     Y(22) =  3.870000E 00     Y(23) =  1.629999E 00     Y(24) =  1.400000E 00     Y(25) =  1.599999E 00
Y(26) =  9.450000E 00     Y(27) =  8.840000E 02     Y(28) =  1.055000E 01

INITIAL X VALUES

X( 1) =  1.148985E 00     X( 2) =  1.148985E 00     X( 3) =  1.679999E 01     X( 4) =  1.679999E 01     X( 5) =  7.820963E 01
X( 6) =  7.820963E 01     X( 7) =  4.874998E 00     X( 8) =  4.874998E 00     X( 9) =  7.451433E-01     X(10) =  7.500182E-01
X(11) =  1.418998E 01     X(12) =  1.418998E 01     X(13) =  2.115404E 01     X(14) =  2.115404E 01     X(15) =  1.304999E 01
X(16) =  1.304999E 01     X(17) =  1.044444E 01     X(18) =  8.944445E 00     X(19) =  9.111113E 00     X(20) =  5.042000E 02
X(21) =  5.890023E-01     X(22) =  5.894759E-01     X(23) =  6.190390E-01     X(24) =  9.909770E-01     X(25) =  1.148985E 00
X(26) =  1.679999E 01     X(27) =  7.820963E 01     X(28) =  4.874998E 00     X(29) =  7.500182E-01     X(30) =  1.418998E 01
X(31) =  2.115404E 01     X(32) =  1.304999E 01

PARAMETER VALUES

P( 1) =  0.0              P( 2) =  0.0              P( 3) =  3.000000E-01     P( 4) =  5.000000E-02     P( 5) =  3.900000E-01
P( 6) =  4.800000E-01

TIME DELAYS

F( 1) =  8.999997E-02     F( 2) =  8.999997E-02     F( 3) =  8.999997E-02     F( 4) =  8.999997E-02     F( 5) =  8.999997E-02
F( 6) =  8.999997E-02     F( 7) =  8.999997E-02     F( 8) =  8.999997E-02
```

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 DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                   PAGE  2  OF RUN  1
 TIME
 Y(29)        Y( 3)           Y(11)           Y(20)           Y( 8)           Y(17)           Y(28)           Y(24)           Y(26)
3.000E-01  4.2999992E 00  2.0999994E 00  1.2999992E 00  4.0999994E 00  1.1000000E 01  1.0549999E 01  1.3999996E 00  9.4499998E 00
4.000E-01  4.6044455E 00  2.2353745E 00  1.4654474E 00  4.1537647E 00  1.1398127E 01  1.0951400E 01  1.3994093E 00  9.4448738E 00
5.000E-01  4.8473778E 00  2.4266300E 00  1.5573587E 00  4.2165489E 00  1.1812529E 01  1.1430431E 01  1.3983879E 00  9.4362202E 00
6.000E-01  5.0064621E 00  2.5855904E 00  1.6034555E 00  4.2696600E 00  1.2153616E 01  1.1887021E 01  1.3971176E 00  9.4257450E 00
7.000E-01  5.1676931E 00  2.7137604E 00  1.6856050E 00  4.3243151E 00  1.2522583E 01  1.2346861E 01  1.3955374E 00  9.4129448E 00
8.000E-01  5.3378687E 00  2.8478136E 00  1.7943277E 00  4.3811760E 00  1.2943007E 01  1.2852115E 01  1.3936539E 00  9.3979387E 00
9.000E-01  5.5180492E 00  3.0100870E 00  1.9152269E 00  4.4405689E 00  1.3405059E 01  1.3424742E 01  1.3914719E 00  9.3808327E 00
1.000E 00  5.7077904E 00  3.1916094E 00  2.0466919E 00  4.5025311E 00  1.3915745E 01  1.4082235E 01  1.3889923E 00  9.3616734E 00
1.100E 00  5.8281384E 00  3.3190622E 00  2.1543970E 00  4.5514507E 00  1.4369665E 01  1.4681735E 01  1.3862715E 00  9.3410969E 00
1.200E 00  5.9557772E 00  3.4706287E 00  2.2715015E 00  4.6014414E 00  1.4823979E 01  1.5296782E 01  1.3832559E 00  9.3185701E 00
1.300E 00  6.0895109E 00  3.6357098E 00  2.3973417E 00  4.6520681E 00  1.5314461E 01  1.5984606E 01  1.3798560E 00  9.2939692E 00
1.400E 00  6.2278070E 00  3.8091164E 00  2.5379477E 00  4.7028236E 00  1.5850998E 01  1.6755371E 01  1.3761129E 00  9.2671947E 00
1.500E 00  6.3682156E 00  3.9971285E 00  2.6958332E 00  4.7531967E 00  1.6435593E 01  1.7622421E 01  1.3719740E 00  9.2381477E 00
1.600E 00  6.4729805E 00  4.1712112E 00  2.8521881E 00  4.7969618E 00  1.7011032E 01  1.8516388E 01  1.3674231E 00  9.2068882E 00
1.700E 00  6.5757303E 00  4.3610058E 00  3.0226936E 00  4.8398638E 00  1.7605743E 01  1.9479828E 01  1.3623867E 00  9.1730232E 00
1.800E 00  6.6747503E 00  4.5650082E 00  3.2123337E 00  4.8811922E 00  1.8241608E 01  2.0556915E 01  1.3568144E 00  9.1363411E 00
1.900E 00  6.7661667E 00  4.7821741E 00  3.4257669E 00  4.9203854E 00  1.8920761E 01  2.1764999E 01  1.3506460E 00  9.0966072E 00
2.000E 00  6.8460169E 00  5.0138330E 00  3.6659880E 00  4.9571161E 00  1.9642410E 01  2.3122665E 01  1.3438158E 00  9.0535583E 00
2.100E 00  6.8268404E 00  5.1768160E 00  3.8640318E 00  4.9800901E 00  2.0229156E 01  2.4356384E 01  1.3361492E 00  9.0066462E 00
2.200E 00  6.8120937E 00  5.3392267E 00  4.0620861E 00  5.0017996E 00  2.0748367E 01  2.5517471E 01  1.3273067E 00  8.9542370E 00
2.300E 00  6.7883663E 00  5.5024033E 00  4.2747564E 00  5.0194530E 00  2.1263763E 01  2.6720795E 01  1.3170862E 00  8.8956099E 00
2.400E 00  6.7373877E 00  5.6619940E 00  4.4927168E 00  5.0334291E 00  2.1760040E 01  2.7968063E 01  1.3052702E 00  8.8301792E 00
2.500E 00  6.6605873E 00  5.8134356E 00  4.7172642E 00  5.0449972E 00  2.2220840E 01  2.9228195E 01  1.2916145E 00  8.7572918E 00
2.600E 00  6.4938955E 00  5.8652191E 00  4.8484945E 00  5.0462608E 00  2.2437836E 01  3.0076828E 01  1.2760620E 00  8.6780777E 00
2.700E 00  6.3511324E 00  5.8854828E 00  4.9388790E 00  5.0473089E 00  2.2519196E 01  3.0569626E 01  1.2585297E 00  8.5930462E 00
2.800E 00  6.2144012E 00  5.8895607E 00  5.0080433E 00  5.0467825E 00  2.2556992E 01  3.0912521E 01  1.2388620E 00  8.5021734E 00
2.900E 00  6.0866165E 00  5.8757820E 00  5.0553780E 00  5.0467367E 00  2.2546432E 01  3.1131012E 01  1.2169151E 00  8.4055300E 00
3.000E 00  5.9823895E 00  5.8426695E 00  5.0800400E 00  5.0479012E 00  2.2492706E 01  3.1221939E 01  1.1925697E 00  8.3033333E 00
3.100E 00  5.8555222E 00  5.7182035E 00  4.9994373E 00  5.0442410E 00  2.2265488E 01  3.0881454E 01  1.1668015E 00  8.2011442E 00
3.200E 00  5.7967091E 00  5.5871181E 00  4.8923521E 00  5.0428963E 00  2.2002289E 01  3.0312881E 01  1.1407576E 00  8.1035213E 00
3.300E 00  5.7624025E 00  5.4677191E 00  4.7882280E 00  5.0423441E 00  2.1786789E 01  2.9771774E 01  1.1146107E 00  8.0103846E 00
3.400E 00  5.7425880E 00  5.3580952E 00  4.6908493E 00  5.0431795E 00  2.1605927E 01  2.9294601E 01  1.0884991E 00  7.9216223E 00
3.500E 00  5.7342463E 00  5.2568197E 00  4.6013803E 00  5.0446949E 00  2.1455460E 01  2.8875793E 01  1.0625467E 00  7.8371944E 00
3.600E 00  5.6543360E 00  5.0749922E 00  4.4343796E 00  5.0397806E 00  2.1209167E 01  2.8238617E 01  1.0371342E 00  7.7593994E 00
3.700E 00  5.6332979E 00  4.9145994E 00  4.2632265E 00  5.0346622E 00  2.0935852E 01  2.7522522E 01  1.0125360E 00  7.6889715E 00
3.800E 00  5.6086483E 00  4.7762222E 00  4.1130962E 00  5.0292797E 00  2.0723709E 01  2.6905289E 01  9.8878986E-01  7.6250696E 00
3.900E 00  5.5925550E 00  4.6594143E 00  3.9833479E 00  5.0251865E 00  2.0544281E 01  2.6389359E 01  9.6591634E-01  7.5670900E 00
4.000E 00  5.5822992E 00  4.5594349E 00  3.8699713E 00  5.0210361E 00  2.0395447E 01  2.5954620E 01  9.4392967E-01  7.5144949E 00
4.100E 00  5.2403488E 00  4.1546726E 00  3.4804316E 00  4.9863796E 00  1.9861221E 01  2.4777863E 01  9.2348796E-01  7.4750881E 00
4.200E 00  5.1464682E 00  3.8081741E 00  3.1118479E 00  4.9494963E 00  1.9149399E 01  2.3327682E 01  9.0477270E-01  7.4493275E 00
4.300E 00  5.0395689E 00  3.5465870E 00  2.8203163E 00  4.9086742E 00  1.8584412E 01  2.2086563E 01  8.8764369E-01  7.4338312E 00
4.400E 00  4.9509325E 00  3.3330603E 00  2.5823984E 00  4.8694572E 00  1.8053589E 01  2.1037598E 01  8.7203091E-01  7.4265633E 00
4.500E 00  4.8779640E 00  3.1503181E 00  2.3827934E 00  4.8281851E 00  1.7553085E 01  2.0108688E 01  8.5791719E-01  7.4259949E 00
4.600E 00  4.8570347E 00  3.0363045E 00  2.2468948E 00  4.7920532E 00  1.7130127E 01  1.9355804E 01  8.4522963E-01  7.4296961E 00
4.700E 00  4.8107128E 00  2.9297600E 00  2.1287022E 00  4.7540932E 00  1.6745743E 01  1.8697937E 01  8.3399552E-01  7.4367933E 00
4.800E 00  4.7543964E 00  2.8282242E 00  2.0202971E 00  4.7144470E 00  1.6349838E 01  1.8066086E 01  8.2429767E-01  7.4471607E 00
4.900E 00  4.6923218E 00  2.7292805E 00  1.9202509E 00  4.6729364E 00  1.5949518E 01  1.7449768E 01  8.1621754E-01  7.4606476E 00
5.000E 00  4.6260643E 00  2.6334181E 00  1.8272982E 00  4.6295347E 00  1.5546402E 01  1.6847412E 01  8.0983800E-01  7.4772034E 00
5.100E 00  4.5822258E 00  2.5631618E 00  1.7556276E 00  4.5895367E 00  1.5178305E 01  1.6308197E 01  8.0520719E-01  7.4960728E 00
5.200E 00  4.5286064E 00  2.4915085E 00  1.6883030E 00  4.5491371E 00  1.4827662E 01  1.5804315E 01  8.0235642E-01  7.5171471E 00
5.300E 00  4.4686193E 00  2.4195185E 00  1.6238022E 00  4.5080385E 00  1.4478234E 01  1.5313760E 01  8.0128014E-01  7.5406561E 00
5.400E 00  4.4044218E 00  2.3481808E 00  1.5616064E 00  4.4661865E 00  1.4131541E 01  1.4836864E 01  8.0195820E-01  7.5667410E 00
5.500E 00  4.3374147E 00  2.2777033E 00  1.5019045E 00  4.4236183E 00  1.3789610E 01  1.4374877E 01  8.0436003E-01  7.5955219E 00
5.600E 00  4.2739992E 00  2.2123728E 00  1.4474211E 00  4.3814659E 00  1.3461077E 01  1.3937131E 01  8.0844575E-01  7.6270552E 00
5.700E 00  4.2087660E 00  2.1481972E 00  1.3954077E 00  4.3390150E 00  1.3142620E 01  1.3518030E 01  8.1418771E-01  7.6615181E 00
5.800E 00  4.1419697E 00  2.0850849E 00  1.3455515E 00  4.2962189E 00  1.2832611E 01  1.3114855E 01  8.2154965E-01  7.6990261E 00
5.900E 00  4.0742369E 00  2.0234728E 00  1.2978067E 00  4.2531157E 00  1.2531530E 01  1.2727862E 01  8.3048594E-01  7.7396669E 00
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  DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                      PAGE  3  OF RUN  1
  TIME
 Y(29)         Y( 3)          Y(11)          Y(20)          Y( 8)          Y(17)          Y(28)          Y(24)          Y(26)
6.000E 00  4.0060759E 00  1.9635353E 00  1.2521601E 00  4.2097921E 00  1.2239904E 01  1.2357334E 01  8.4094214E-01  7.7835026E 00
6.100E 00  3.9913998E 00  1.9384575E 00  1.2312212E 00  4.1759882E 00  1.2018198E 01  1.2071831E 01  8.5299903E-01  7.8304415E 00
6.200E 00  3.9737234E 00  1.9150734E 00  1.2106857E 00  4.1443262E 00  1.1819251E 01  1.1818307E 01  8.6690664E-01  7.8815365E 00
6.300E 00  3.9476185E 00  1.8895216E 00  1.1895275E 00  4.1124249E 00  1.1624558E 01  1.1571918E 01  8.8273793E-01  7.9372215E 00
6.400E 00  3.9221630E 00  1.8642492E 00  1.1690445E 00  4.0802927E 00  1.1433048E 01  1.1331736E 01  9.0053099E-01  7.9977369E 00
6.500E 00  3.8948793E 00  1.8384953E 00  1.1487770E 00  4.0483418E 00  1.1246683E 01  1.1098604E 01  9.2029750E-01  8.0632992E 00
6.600E 00  3.8227444E 00  1.7875652E 00  1.1123009E 00  4.0070820E 00  1.1016395E 01  1.0818480E 01  9.4212013E-01  8.1350660E 00
6.700E 00  3.7618675E 00  1.7388430E 00  1.0777512E 00  3.9632540E 00  1.0773860E 01  1.0532953E 01  9.6600354E-01  8.2133646E 00
6.800E 00  3.6990499E 00  1.6922808E 00  1.0449619E 00  3.9184551E 00  1.0538558E 01  1.0259141E 01  9.9188113E-01  8.2982302E 00
6.900E 00  3.6377954E 00  1.6473799E 00  1.0134001E 00  3.8728476E 00  1.0308772E 01  9.9981232E 00  1.0196543E 00  8.3896790E 00
7.000E 00  3.5774164E 00  1.6038427E 00  9.8317993E-01  3.8265390E 00  1.0086119E 01  9.7501116E 00  1.0491846E 00  8.4876108E 00
7.100E 00  3.5403738E 00  1.5746880E 00  9.6236402E-01  3.7861300E 00  9.8992138E 00  9.5445518E 00  1.0799875E 00  8.5903273E 00
7.200E 00  3.5004988E 00  1.5460157E 00  9.4260991E-01  3.7472115E 00  9.7297583E 00  9.3590221E 00  1.1115389E 00  8.6963129E 00
7.300E 00  3.4598789E 00  1.5176926E 00  9.2307544E-01  3.7094927E 00  9.5701513E 00  9.1858768E 00  1.1435709E 00  8.8050117E 00
7.400E 00  3.4188862E 00  1.4899101E 00  9.0428656E-01  3.6728573E 00  9.4199905E 00  9.0238800E 00  1.1758127E 00  8.9157829E 00
7.500E 00  3.3777151E 00  1.4627123E 00  8.8605642E-01  3.6372414E 00  9.2787886E 00  8.8726444E 00  1.2079867E 00  9.0279388E 00
7.600E 00  3.3296461E 00  1.4323959E 00  8.6592275E-01  3.6008663E 00  9.1386957E 00  8.7238216E 00  1.2396336E 00  9.1402216E 00
7.700E 00  3.2821236E 00  1.4025707E 00  8.4660077E-01  3.5652819E 00  9.0056744E 00  8.5836954E 00  1.2703075E 00  9.2512684E 00
7.800E 00  3.2352524E 00  1.3736620E 00  8.2789099E-01  3.5306120E 00  8.8808308E 00  8.4534950E 00  1.2998505E 00  9.3605556E 00
7.900E 00  3.1889410E 00  1.3455582E 00  8.0978465E-01  3.4968519E 00  8.7635822E 00  8.3324404E 00  1.3281317E 00  9.4676199E 00
8.000E 00  3.1432400E 00  1.3181753E 00  7.9225910E-01  3.4639788E 00  8.6533413E 00  8.2197437E 00  1.3550539E 00  9.5720510E 00
8.100E 00  3.1166592E 00  1.3011971E 00  7.8146303E-01  3.4369946E 00  8.5692129E 00  8.1352367E 00  1.3804064E 00  9.6724815E 00
8.200E 00  3.0889511E 00  1.2848787E 00  7.7077222E-01  3.4119358E 00  8.4956493E 00  8.0616360E 00  1.4040546E 00  9.7680349E 00
8.300E 00  3.0612717E 00  1.2683411E 00  7.6027554E-01  3.3880100E 00  8.4269753E 00  7.9935741E 00  1.4259968E 00  9.8585625E 00
8.400E 00  3.0338259E 00  1.2523785E 00  7.5011533E-01  3.3652010E 00  8.3625231E 00  7.9302235E 00  1.4462547E 00  9.9439983E 00
8.500E 00  3.0065794E 00  1.2365904E 00  7.4015015E-01  3.3433828E 00  8.3020000E 00  7.8710880E 00  1.4648743E 00  1.0024366E 01
8.600E 00  2.9723244E 00  1.2172861E 00  7.2811568E-01  3.3204994E 00  8.2374773E 00  7.8079405E 00  1.4818974E 00  1.0099863E 01
8.700E 00  2.9391651E 00  1.1984949E 00  7.1632928E-01  3.2981596E 00  8.1741800E 00  7.7467518E 00  1.4973860E 00  1.0170638E 01
8.800E 00  2.9063177E 00  1.1799574E 00  7.0478302E-01  3.2764750E 00  8.1139307E 00  7.6888113E 00  1.5114555E 00  1.0236980E 01
8.900E 00  2.8739471E 00  1.1617861E 00  6.9349527E-01  3.2554054E 00  8.0562487E 00  7.6337767E 00  1.5242243E 00  1.0299181E 01
9.000E 00  2.8420391E 00  1.1439400E 00  6.8244106E-01  3.2349119E 00  8.0009775E 00  7.5813961E 00  1.5358057E 00  1.0357520E 01
9.100E 00  2.8302641E 00  1.1368103E 00  6.7773896E-01  3.2208328E 00  7.9679270E 00  7.5521231E 00  1.5460739E 00  1.0410614E 01
9.200E 00  2.8169012E 00  1.1291494E 00  6.7317826E-01  3.2085876E 00  7.9424229E 00  7.5290079E 00  1.5550079E 00  1.0457775E 01
9.300E 00  2.8039608E 00  1.1220045E 00  6.6877878E-01  3.1975317E 00  7.9182339E 00  7.5073366E 00  1.5627842E 00  1.0499699E 01
9.400E 00  2.7911978E 00  1.1149073E 00  6.6438401E-01  3.1873741E 00  7.8955975E 00  7.4869156E 00  1.5695610E 00  1.0537026E 01
9.500E 00  2.7785473E 00  1.1078568E 00  6.6004646E-01  3.1779346E 00  7.8740902E 00  7.4674149E 00  1.5754776E 00  1.0570362E 01
9.600E 00  2.7854185E 00  1.1107931E 00  6.6194010E-01  3.1747313E 00  7.8727827E 00  7.4684868E 00  1.5805044E 00  1.0599004E 01
9.700E 00  2.7905054E 00  1.1141634E 00  6.6380358E-01  3.1732540E 00  7.8774481E 00  7.4744778E 00  1.5846796E 00  1.0622810E 01
9.800E 00  2.7962036E 00  1.1170349E 00  6.6551924E-01  3.1728306E 00  7.8832417E 00  7.4812689E 00  1.5881348E 00  1.0642473E 01
9.900E 00  2.8020077E 00  1.1200886E 00  6.6748011E-01  3.1731768E 00  7.8896141E 00  7.4884253E 00  1.5909834E 00  1.0658600E 01
1.000E 01  2.8079147E 00  1.1234579E 00  6.6952342E-01  3.1741314E 00  7.8965311E 00  7.4959183E 00  1.5933228E 00  1.0671733E 01
1.010E 01  2.8301525E 00  1.1345978E 00  6.7686456E-01  3.1800585E 00  7.9201889E 00  7.5198793E 00  1.5951242E 00  1.0681437E 01
1.020E 01  2.8511696E 00  1.1464090E 00  6.8389469E-01  3.1874542E 00  7.9484568E 00  7.5482874E 00  1.5964155E 00  1.0687753E 01
1.030E 01  2.8728037E 00  1.1585350E 00  6.9132042E-01  3.1955128E 00  7.9776011E 00  7.5773325E 00  1.5972929E 00  1.0691290E 01
1.040E 01  2.8949213E 00  1.1707563E 00  6.9878465E-01  3.2041788E 00  8.0078516E 00  7.6071463E 00  1.5978317E 00  1.0692537E 01
1.050E 01  2.9173651E 00  1.1831923E 00  7.0639837E-01  3.2133083E 00  8.0389442E 00  7.6375389E 00  1.5980949E 00  1.0691912E 01
1.060E 01  2.9626207E 00  1.2085476E 00  7.2125351E-01  3.2293119E 00  8.0943098E 00  7.6926165E 00  1.5980349E 00  1.0688884E 01
1.070E 01  3.0086384E 00  1.2353268E 00  7.3654389E-01  3.2469530E 00  8.1559410E 00  7.7547054E 00  1.5976648E 00  1.0683475E 01
1.080E 01  3.0554295E 00  1.2597380E 00  7.5250387E-01  3.2658157E 00  8.2211962E 00  7.8195801E 00  1.5970355E 00  1.0676048E 01
1.090E 01  3.1033392E 00  1.2858620E 00  7.7013874E-01  3.2857380E 00  8.2900524E 00  7.8861427E 00  1.5961838E 00  1.0666938E 01
1.100E 01  3.1524858E 00  1.3152304E 00  7.8748131E-01  3.3066330E 00  8.3594370E 00  7.9552908E 00  1.5951519E 00  1.0656430E 01
1.110E 01  3.2148418E 00  1.3492861E 00  8.0904251E-01  3.3317595E 00  8.4448843E 00  8.0404549E 00  1.5939054E 00  1.0644217E 01
1.120E 01  3.2783537E 00  1.3855743E 00  8.3178550E-01  3.3583021E 00  8.5366726E 00  8.1315746E 00  1.5924454E 00  1.0630259E 01
1.130E 01  3.3435450E 00  1.4223957E 00  8.5429013E-01  3.3861990E 00  8.6331425E 00  8.2281284E 00  1.5907841E 00  1.0614681E 01
1.140E 01  3.4107418E 00  1.4614763E 00  8.7861770E-01  3.4154186E 00  8.7337151E 00  8.3292646E 00  1.5889359E 00  1.0597615E 01
1.150E 01  3.4802198E 00  1.5019255E 00  9.0405506E-01  3.4459152E 00  8.8393850E 00  8.4355049E 00  1.5869131E 00  1.0579190E 01
1.160E 01  3.5790806E 00  1.5570496E 00  9.3975645E-01  3.4842587E 00  8.9753532E 00  8.5741920E 00  1.5846558E 00  1.0558885E 01
```

```
  DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                      PAGE  4  OF RUN  1
  TIME
 Y(29)         Y( 3)          Y(11)          Y(20)          Y( 8)          Y(17)          Y(28)          Y(24)          Y(26)
1.170E 01  3.6763601E 00  1.6157742E 00  9.7528881E-01  3.5247316E 00  9.1270466E 00  8.7296314E 00  1.5821600E 00  1.0536659E 01
1.180E 01  3.7776289E 00  1.6765041E 00  1.0135145E 00  3.5678043E 00  9.2895613E 00  8.8966637E 00  1.5794325E 00  1.0512607E 01
1.190E 01  3.8853731E 00  1.7399368E 00  1.0542450E 00  3.6129904E 00  9.4628572E 00  9.0757856E 00  1.5764809E 00  1.0486828E 01
1.200E 01  3.9972639E 00  1.8080788E 00  1.0979557E 00  3.6603012E 00  9.6484156E 00  9.2691975E 00  1.5733051E 00  1.0459361E 01
1.210E 01  4.1818447E 00  1.9120235E 00  1.1681385E 00  3.7233782E 00  9.9106283E 00  9.5444469E 00  1.5698509E 00  1.0429724E 01
1.220E 01  4.3533287E 00  2.0268412E 00  1.2399921E 00  3.7925940E 00  1.0216828E 01  9.8724289E 00  1.5661793E 00  1.0398429E 01
1.230E 01  4.5519886E 00  2.1532516E 00  1.3206511E 00  3.8651085E 00  1.0553557E 01  1.0240391E 01  1.5623150E 00  1.0365712E 01
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DYSIMP SIMULATION PROGRAM         SERIES POND MODEL RESPONSE                                              PAGE  1  OF RUN  1

ORDER OF SYSTEM        =          28
NUMBER OF X'S          =          32
NUMBER OF PARAMETERS   =           6
NUMBER OF DELAYS       =           8
OUTPUT INTERVAL        =          40
INITIAL TIME           =  3.0000E-01
FINAL TIME             =  1.2300E 01
INTEGRATION STEP       =  2.5000E-03

INITIAL Y VALUES

Y( 1) =  2.492000E 01     Y( 2) =  3.200000E 01     Y( 3) =  4.299999E 00     Y( 4) =  3.520999E 01     Y( 5) =  9.899999E-01
Y( 6) =  7.000000E-01     Y( 7) =  1.722000E 03     Y( 8) =  4.099999E 00     Y( 9) =  1.625000E 01     Y(10) =  2.700000E 01
Y(11) =  2.099999E 00     Y(12) =  4.742999E 01     Y(13) =  3.349999E 00     Y(14) =  1.020000E 00     Y(15) =  4.100000E-01
Y(16) =  1.219000E 03     Y(17) =  1.100000E 01     Y(18) =  1.300000E 01     Y(19) =  2.296999E 01     Y(20) =  1.299999E 00
Y(21) =  4.000000E 01     Y(22) =  3.870000E 00     Y(23) =  1.629999E 00     Y(24) =  1.400000E 00     Y(25) =  1.599999E 00
Y(26) =  9.450000E 00     Y(27) =  8.840000E 02     Y(28) =  1.055000E 01

INITIAL X VALUES

X( 1) =  1.148985E 00     X( 2) =  1.148985E 00     X( 3) =  1.679999E 01     X( 4) =  1.679999E 01     X( 5) =  7.820963E 01
X( 6) =  7.820963E 01     X( 7) =  4.874998E 00     X( 8) =  4.874998E 00     X( 9) =  7.451433E-01     X(10) =  7.500182E-01
X(11) =  1.418998E 01     X(12) =  1.418998E 01     X(13) =  2.115404E 01     X(14) =  2.115404E 01     X(15) =  1.304999E 01
X(16) =  1.304999E 01     X(17) =  1.044444E 01     X(18) =  8.944445E 00     X(19) =  9.111113E 00     X(20) =  5.042000E 02
X(21) =  5.890023E-01     X(22) =  5.894759E-01     X(23) =  6.190390E-01     X(24) =  9.909770E-01     X(25) =  1.148985E 00
X(26) =  1.679999E 01     X(27) =  7.820963E 01     X(28) =  4.874998E 00     X(29) =  7.500182E-01     X(30) =  1.418998E 01
X(31) =  2.115404E 01     X(32) =  1.304999E 01

PARAMETER VALUES

P( 1) =  0.0              P( 2) =  0.0              P( 3) =  3.000000E-01     P( 4) =  5.000000E-02     P( 5) =  3.900000E-01
P( 6) =  4.800000E-01

TIME DELAYS

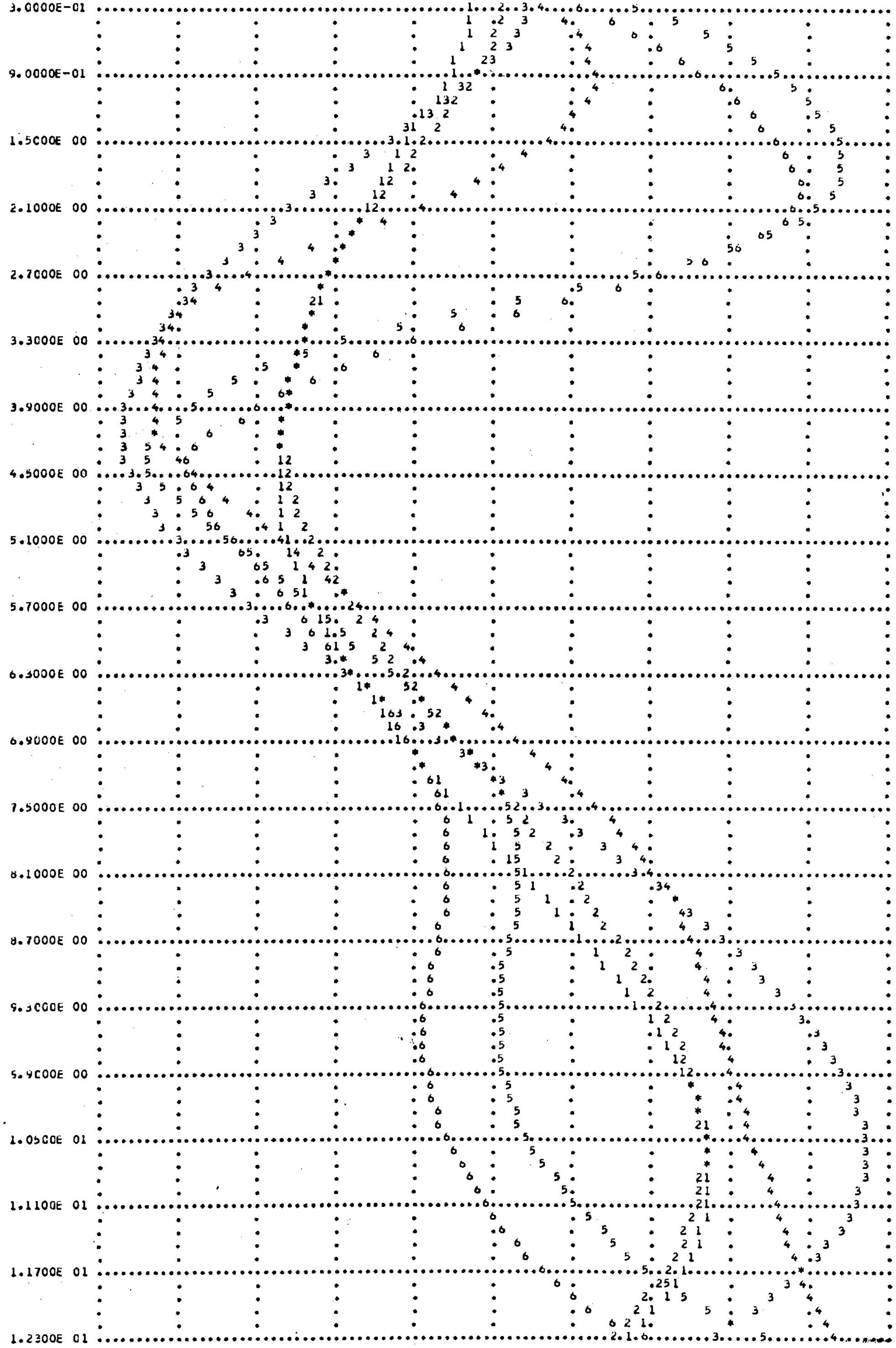
F( 1) =  8.999997E-02     F( 2) =  8.999997E-02     F( 3) =  8.999997E-02     F( 4) =  8.999997E-02     F( 5) =  8.999997E-02
F( 6) =  8.999997E-02     F( 7) =  8.999997E-02     F( 8) =  8.999997E-02
```

```
  DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                          PAGE  2  OF RUN  1
  TIME
Y(29)         Y( 2)           Y(10)           Y(19)           Y(15)           Y(25)           Y( 7)           Y(16)           Y(27)
3.000E-01  3.2000000E 01  2.7000000E 01  2.2969986E 01  4.0999997E-01  1.5999994E 00  1.7220000E 03  1.2190000E 03  8.8400000E 02
4.000E-01  3.1858612E 01  2.6809113E 01  2.2815140E 01  4.0987337E-01  1.5995350E 00  1.7168889E 03  1.2154849E 03  8.8171973E 02
5.000E-01  3.1559799E 01  2.6436218E 01  2.2515533E 01  4.0968484E-01  1.5987720E 00  1.7087173E 03  1.2106340E 03  8.7868066E 02
6.000E-01  3.1169632E 01  2.5975830E 01  2.2130264E 01  4.0948600E-01  1.5978765E 00  1.6989299E 03  1.2056272E 03  8.7575098E 02
7.000E-01  3.0740417E 01  2.5489868E 01  2.1725494E 01  4.0927058E-01  1.5968018E 00  1.6873833E 03  1.1998477E 03  8.7230444E 02
8.000E-01  3.0280930E 01  2.4986313E 01  2.1306107E 01  4.0903360E-01  1.5955572E 00  1.6741443E 03  1.1930791E 03  8.6833789E 02
9.000E-01  2.9797440E 01  2.4470062E 01  2.0874817E 01  4.0877527E-01  1.5941486E 00  1.6592871E 03  1.1853730E 03  8.6384399E 02
1.000E 00  2.9294678E 01  2.3943115E 01  2.0433929E 01  4.0849376E-01  1.5925741E 00  1.6428887E 03  1.1767549E 03  8.5877710E 02
1.100E 00  2.8795624E 01  2.3433823E 01  2.0009476E 01  4.0820277E-01  1.5908918E 00  1.6258047E 03  1.1677109E 03  8.5350122E 02
1.200E 00  2.8321136E 01  2.2965271E 01  1.9617691E 01  4.0789062E-01  1.5890532E 00  1.6076201E 03  1.1577964E 03  8.4768823E 02
1.300E 00  2.7861176E 01  2.2518021E 01  1.9244293E 01  4.0754998E-01  1.5870409E 00  1.5883794E 03  1.1469509E 03  8.4124585E 02
1.400E 00  2.7409378E 01  2.2081253E 01  1.8880722E 01  4.0717173E-01  1.5848398E 00  1.5681333E 03  1.1350703E 03  8.3409937E 02
1.500E 00  2.6961807E 01  2.1649002E 01  1.8521515E 01  4.0674651E-01  1.5824337E 00  1.5469426E 03  1.1220674E 03  8.2617456E 02
1.600E 00  2.6521820E 01  2.1226715E 01  1.8171539E 01  4.0627211E-01  1.5798216E 00  1.5251084E 03  1.1080815E 03  8.1752661E 02
1.700E 00  2.6094009E 01  2.0819168E 01  1.7833603E 01  4.0573555E-01  1.5769606E 00  1.5024531E 03  1.0929041E 03  8.0795020E 02
1.800E 00  2.5673706E 01  2.0417877E 01  1.7501022E 01  4.0512395E-01  1.5738192E 00  1.4790835E 03  1.0764363E 03  7.9731543E 02
1.900E 00  2.5258072E 01  2.0018066E 01  1.7169632E 01  4.0442312E-01  1.5703621E 00  1.4551238E 03  1.0585764E 03  7.8548096E 02
2.000E 00  2.4845551E 01  1.9616898E 01  1.6836685E 01  4.0361792E-01  1.5665474E 00  1.4307139E 03  1.0392246E 03  7.7228833E 02
2.100E 00  2.4444382E 01  1.9230072E 01  1.6516617E 01  4.0269202E-01  1.5623131E 00  1.4063003E 03  1.0184272E 03  7.5770117E 02
2.200E 00  2.4066055E 01  1.8868042E 01  1.6216965E 01  4.0159577E-01  1.5574903E 00  1.3813818E 03  9.9546680E 02  7.4116504E 02
2.300E 00  2.3702713E 01  1.8514877E 01  1.5925241E 01  4.0029043E-01  1.5519810E 00  1.3564316E 03  9.7017993E 02  7.2238599E 02
2.400E 00  2.3349304E 01  1.8161652E 01  1.5632964E 01  3.9873207E-01  1.5456886E 00  1.3318613E 03  9.4247266E 02  7.0116553E 02
2.500E 00  2.3004028E 01  1.7802643E 01  1.5334689E 01  3.9687032E-01  1.5385008E 00  1.3080884E 03  9.1231128E 02  6.7729639E 02
2.600E 00  2.2673325E 01  1.7449814E 01  1.5041430E 01  3.9467829E-01  1.5304794E 00  1.2862466E 03  8.8051392E 02  6.5145605E 02
2.700E 00  2.2369690E 01  1.7112305E 01  1.4760080E 01  3.9210600E-01  1.5216599E 00  1.2666333E 03  8.4742993E 02  6.2410059E 02
2.800E 00  2.2088501E 01  1.6777298E 01  1.4480106E 01  3.8908923E-01  1.5120182E 00  1.2497327E 03  8.1328247E 02  5.9546509E 02
2.900E 00  2.1828156E 01  1.6437317E 01  1.4194714E 01  3.8556415E-01  1.5015345E 00  1.2356096E 03  7.7841724E 02  5.6580273E 02
3.000E 00  2.1588745E 01  1.6087753E 01  1.3899734E 01  3.8146836E-01  1.4902115E 00  1.2241318E 03  7.4325000E 02  5.3542773E 02
3.100E 00  2.1375153E 01  1.5739517E 01  1.3605294E 01  3.7695169E-01  1.4786568E 00  1.2162151E 03  7.1027612E 02  5.0639819E 02
3.200E 00  2.1198563E 01  1.5408215E 01  1.3323305E 01  3.7221330E-01  1.4674635E 00  1.2111899E 03  6.8107178E 02  4.8016970E 02
3.300E 00  2.1051727E 01  1.5091083E 01  1.3051086E 01  3.6728013E-01  1.4566746E 00  1.2078540E 03  6.5525806E 02  4.5660303E 02
3.400E 00  2.0929153E 01  1.4787060E 01  1.2786951E 01  3.6218590E-01  1.4463053E 00  1.2054160E 03  6.3253369E 02  4.3536426E 02
3.500E 00  2.0826157E 01  1.4496233E 01  1.2530162E 01  3.5696524E-01  1.4363689E 00  1.2034944E 03  6.1260205E 02  4.1624048E 02
3.600E 00  2.0743469E 01  1.4230077E 01  1.2291339E 01  3.5170466E-01  1.4271345E 00  1.2028650E 03  5.9613574E 02  3.9979663E 02
3.700E 00  2.0694031E 01  1.4003681E 01  1.2081348E 01  3.4646171E-01  1.4187593E 00  1.2034319E 03  5.8316235E 02  3.8616138E 02
3.800E 00  2.0668304E 01  1.3813228E 01  1.1897148E 01  3.4124756E-01  1.4111786E 00  1.2046506E 03  5.7303662E 02  3.7488989E 02
3.900E 00  2.0662186E 01  1.3655715E 01  1.1736256E 01  3.3608043E-01  1.4043245E 00  1.2061577E 03  5.6531128E 02  3.6561499E 02
4.000E 00  2.0671555E 01  1.3528496E 01  1.1596882E 01  3.3097738E-01  1.3981333E 00  1.2078862E 03  5.5957788E 02  3.5803418E 02
4.100E 00  2.0715866E 01  1.3467654E 01  1.1514433E 01  3.2608992E-01  1.3934708E 00  1.2142429E 03  5.5899097E 02  3.5449902E 02
4.200E 00  2.0868164E 01  1.3531628E 01  1.1530276E 01  3.2145911E-01  1.3906279E 00  1.2256279E 03  5.6452930E 02  3.5548096E 02
4.300E 00  2.1101639E 01  1.3709545E 01  1.1635869E 01  3.1700492E-01  1.3892689E 00  1.2403137E 03  5.7426978E 02  3.6004077E 02
4.400E 00  2.1409576E 01  1.3988872E 01  1.1822250E 01  3.1272209E-01  1.3891325E 00  1.2571609E 03  5.8760229E 02  3.6756201E 02
4.500E 00  2.1784454E 01  1.4358832E 01  1.2082625E 01  3.0861419E-01  1.3900127E 00  1.2759868E 03  6.0386208E 02  3.7758862E 02
4.600E 00  2.2211212E 01  1.4802548E 01  1.2404045E 01  3.0468208E-01  1.3916016E 00  1.2952546E 03  6.2195557E 02  3.8935498E 02
4.700E 00  2.2666641E 01  1.5297511E 01  1.2771670E 01  3.0095589E-01  1.3937359E 00  1.3145671E 03  6.4134155E 02  4.0251733E 02
4.800E 00  2.3146515E 01  1.5836484E 01  1.3180774E 01  2.9748487E-01  1.3963652E 00  1.3342842E 03  6.6200098E 02  4.1696680E 02
4.900E 00  2.3647903E 01  1.6413269E 01  1.3627212E 01  2.9430896E-01  1.3994455E 00  1.3546265E 03  6.8379883E 02  4.3257690E 02
5.000E 00  2.4168900E 01  1.7022156E 01  1.4106779E 01  2.9146403E-01  1.4029427E 00  1.3757217E 03  7.0662256E 02  4.4923389E 02
5.100E 00  2.4701691E 01  1.7651566E 01  1.4609946E 01  2.8898031E-01  1.4067278E 00  1.3967058E 03  7.2988281E 02  4.6647192E 02
5.200E 00  2.5233841E 01  1.8286819E 01  1.5125518E 01  2.8688842E-01  1.4107332E 00  1.4173076E 03  7.5330444E 02  4.8404199E 02
5.300E 00  2.5764618E 01  1.8924622E 01  1.5649729E 01  2.8520274E-01  1.4149580E 00  1.4378015E 03  7.7689209E 02  5.0189355E 02
5.400E 00  2.6294266E 01  1.9562943E 01  1.6179596E 01  2.8392893E-01  1.4193935E 00  1.4583442E 03  8.0060889E 02  5.1995532E 02
5.500E 00  2.6823380E 01  2.0200180E 01  1.6712646E 01  2.8306586E-01  1.4240341E 00  1.4790249E 03  8.2440503E 02  5.3815503E 02
5.600E 00  2.7351089E 01  2.0833374E 01  1.7245514E 01  2.8260523E-01  1.4288673E 00  1.4997625E 03  8.4811084E 02  5.5641699E 02
5.700E 00  2.7875916E 01  2.1459290E 01  1.7775345E 01  2.8253460E-01  1.4338942E 00  1.5205603E 03  8.7163184E 02  5.7471680E 02
5.800E 00  2.8398758E 01  2.2077606E 01  1.8301346E 01  2.8283745E-01  1.4391079E 00  1.5414556E 03  8.9493579E 02  5.9299487E 02
5.900E 00  2.8920395E 01  2.2688385E 01  1.8822845E 01  2.8349429E-01  1.4445000E 00  1.5624617E 03  9.1798169E 02  6.1118921E 02
```

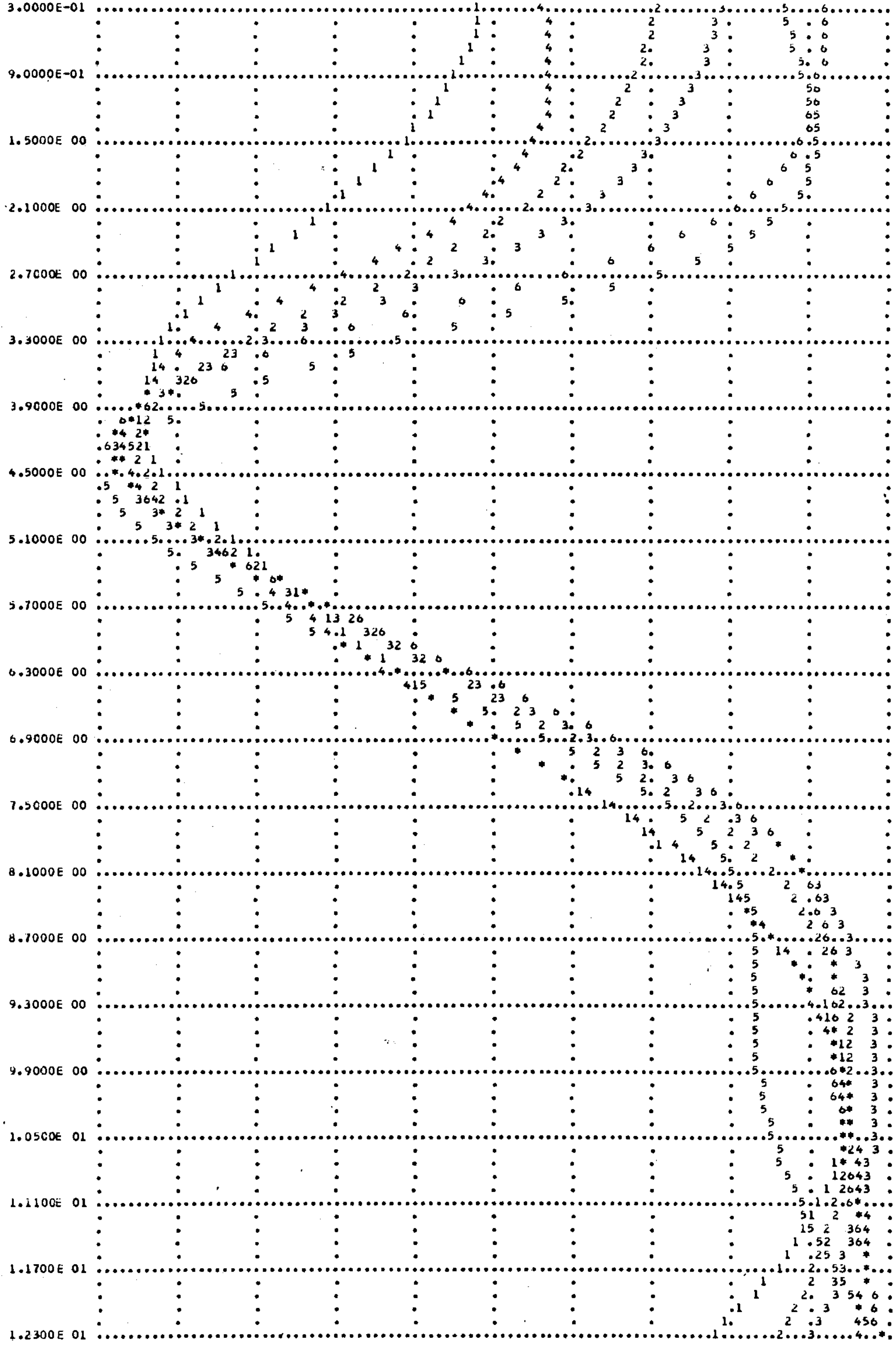
```
  DYSIMP SIMULATION PROGRAM         SERIES POND MODEL RESPONSE                                          PAGE  3  OF RUN  1
  TIME
 Y(29)        Y( 2)          Y(10)          Y(19)          Y(15)           Y(25)          Y( 7)          Y(16)          Y(27)
6.000E 00  2.9441406E 01  2.3291718E 01  1.9339249E 01  2.8448361E-01  1.4500628E 00  1.5835767E 03  9.4072778E 02  6.2923926E 02
6.100E 00  2.9944916E 01  2.3867889E 01  1.9834213E 01  2.8579086E-01  1.4557781E 00  1.6041992E 03  9.6288013E 02  6.4699170E 02
6.200E 00  3.0412094E 01  2.4397568E 01  2.0293976E 01  2.8745264E-01  1.4617338E 00  1.6246099E 03  9.8486938E 02  6.6478735E 02
6.300E 00  3.0851563E 01  2.4891006E 01  2.0725861E 01  2.8949672E-01  1.4679518E 00  1.6449546E 03  1.0067278E 03  6.8262671E 02
6.400E 00  3.1270599E 01  2.5357086E 01  2.1135681E 01  2.9194272E-01  1.4744406E 00  1.6652380E 03  1.0283901E 03  7.0042407E 02
6.500E 00  3.1673920E 01  2.5801666E 01  2.1527557E 01  2.9480296E-01  1.4812012E 00  1.6854526E 03  1.0497915E 03  7.1810596E 02
6.600E 00  3.2083313E 01  2.6249878E 01  2.1920975E 01  2.9813874E-01  1.4883394E 00  1.7068247E 03  1.0717251E 03  7.3599951E 02
6.700E 00  3.2523102E 01  2.6725830E 01  2.2332092E 01  3.0199754E-01  1.4958658E 00  1.7296746E 03  1.0943301E 03  7.5390625E 02
6.800E 00  3.2987793E 01  2.7222763E 01  2.2755219E 01  3.0637074E-01  1.5037441E 00  1.7538066E 03  1.1173123E 03  7.7166797E 02
6.900E 00  3.3473770E 01  2.7734726E 01  2.3185730E 01  3.1124616E-01  1.5119362E 00  1.7790591E 03  1.1405220E 03  7.8916699E 02
7.000E 00  3.3977631E 01  2.8257004E 01  2.3619965E 01  3.1660223E-01  1.5204010E 00  1.8052778E 03  1.1637561E 03  8.0627930E 02
7.100E 00  3.4482330E 01  2.8770294E 01  2.4042953E 01  3.2229817E-01  1.5289574E 00  1.8311624E 03  1.1860217E 03  8.2251538E 02
7.200E 00  3.4969147E 01  2.9256332E 01  2.4442459E 01  3.2818848E-01  1.5374775E 00  1.8561230E 03  1.2069065E 03  8.3776733E 02
7.300E 00  3.5439926E 01  2.9718750E 01  2.4821716E 01  3.3422619E-01  1.5459309E 00  1.8802483E 03  1.2264758E 03  8.5205078E 02
7.400E 00  3.5896423E 01  3.0160950E 01  2.5183365E 01  3.4035385E-01  1.5542803E 00  1.9036067E 03  1.2447549E 03  8.6536279E 02
7.500E 00  3.6340149E 01  3.0585526E 01  2.5529373E 01  3.4650797E-01  1.5624847E 00  1.9262512E 03  1.2617751E 03  8.7770386E 02
7.600E 00  3.6777374E 01  3.0999817E 01  2.5865524E 01  3.5258245E-01  1.5704679E 00  1.9483477E 03  1.2776099E 03  8.8909399E 02
7.700E 00  3.7213318E 01  3.1409348E 01  2.6195831E 01  3.5846609E-01  1.5781422E 00  1.9698647E 03  1.2922051E 03  8.9946509E 02
7.800E 00  3.7646286E 01  3.1812546E 01  2.6519089E 01  3.6410272E-01  1.5854797E 00  1.9908215E 03  1.3056284E 03  9.0887012E 02
7.900E 00  3.8075272E 01  3.2208374E 01  2.6834671E 01  3.6944878E-01  1.5924606E 00  2.0112366E 03  1.3179622E 03  9.1737183E 02
8.000E 00  3.8499756E 01  3.2596527E 01  2.7142410E 01  3.7447125E-01  1.5990686E 00  2.0311257E 03  1.3292874E 03  9.2503394E 02
8.100E 00  3.8903671E 01  3.2960312E 01  2.7429398E 01  3.7913585E-01  1.6052160E 00  2.0498374E 03  1.3392893E 03  9.3167188E 02
8.200E 00  3.9273239E 01  3.3286911E 01  2.7686768E 01  3.8344914E-01  1.6108866E 00  2.0673296E 03  1.3481372E 03  9.3747168E 02
8.300E 00  3.9616684E 01  3.3585541E 01  2.7921494E 01  3.8742769E-01  1.6161108E 00  2.0837639E 03  1.3560383E 03  9.4255542E 02
8.400E 00  3.9939835E 01  3.3863388E 01  2.8138763E 01  3.9107794E-01  1.6209135E 00  2.0992485E 03  1.3631030E 03  9.4700928E 02
8.500E 00  4.0246933E 01  3.4125427E 01  2.8342407E 01  3.9440328E-01  1.6253166E 00  2.1138845E 03  1.3694365E 03  9.5091162E 02
8.600E 00  4.0547974E 01  3.4382278E 01  2.8540710E 01  3.9740139E-01  1.6293554E 00  2.1279746E 03  1.3752720E 03  9.5441455E 02
8.700E 00  4.0850723E 01  3.4641907E 01  2.8739517E 01  4.0006113E-01  1.6330442E 00  2.1415618E 03  1.3806333E 03  9.5751782E 02
8.800E 00  4.1153015E 01  3.4902328E 01  2.8937622E 01  4.0238690E-01  1.6364021E 00  2.1546836E 03  1.3855474E 03  9.6026074E 02
8.900E 00  4.1453629E 01  3.5162170E 01  2.9134277E 01  4.0439254E-01  1.6394520E 00  2.1673752E 03  1.3900667E 03  9.6268848E 02
9.000E 00  4.1751892E 01  3.5420624E 01  2.9329086E 01  4.0609682E-01  1.6422186E 00  2.1796682E 03  1.3942332E 03  9.6483936E 02
9.100E 00  4.2025940E 01  3.5656097E 01  2.9505783E 01  4.0749311E-01  1.6446218E 00  2.1905466E 03  1.3976006E 03  9.6647266E 02
9.200E 00  4.2257645E 01  3.5852020E 01  2.9653214E 01  4.0863281E-01  1.6466713E 00  2.1998926E 03  1.4003362E 03  9.6777954E 02
9.300E 00  4.2458435E 01  3.6019699E 01  2.9779617E 01  4.0958214E-01  1.6484413E 00  2.2080491E 03  1.4026519E 03  9.6886035E 02
9.400E 00  4.2636414E 01  3.6167496E 01  2.9890869E 01  4.1037846E-01  1.6499815E 00  2.2152759E 03  1.4046387E 03  9.6976514E 02
9.500E 00  4.2797455E 01  3.6301239E 01  2.9991211E 01  4.1104531E-01  1.6513290E 00  2.2217693E 03  1.4063745E 03  9.7053394E 02
9.600E 00  4.2923798E 01  3.6403595E 01  3.0067612E 01  4.1158617E-01  1.6524324E 00  2.2267378E 03  1.4074976E 03  9.7094751E 02
9.700E 00  4.3000870E 01  3.6461105E 01  3.0110992E 01  4.1204274E-01  1.6533117E 00  2.2302263E 03  1.4081892E 03  9.7119141E 02
9.800E 00  4.3043167E 01  3.6486954E 01  3.0130981E 01  4.1245431E-01  1.6540222E 00  2.2326011E 03  1.4086248E 03  9.7133643E 02
9.900E 00  4.3060654E 01  3.6491013E 01  3.0134521E 01  4.1283810E-01  1.6546011E 00  2.2341301E 03  1.4088733E 03  9.7140918E 02
1.000E 01  4.3060349E 01  3.6480026E 01  3.0126465E 01  4.1320121E-01  1.6550741E 00  2.2350076E 03  1.4089766E 03  9.7143140E 02
1.010E 01  4.3029205E 01  3.6441071E 01  3.0097137E 01  4.1353244E-01  1.6553974E 00  2.2347175E 03  1.4086504E 03  9.7122974E 02
1.020E 01  4.2956772E 01  3.6364212E 01  3.0039749E 01  4.1384751E-01  1.6555853E 00  2.2333818E 03  1.4080491E 03  9.7093701E 02
1.030E 01  4.2855957E 01  3.6260880E 01  2.9962662E 01  4.1416502E-01  1.6556749E 00  2.2313010E 03  1.4072849E 03  9.7059912E 02
1.040E 01  4.2735474E 01  3.6139450E 01  2.9871704E 01  4.1449058E-01  1.6556892E 00  2.2286621E 03  1.4063962E 03  9.7022827E 02
1.050E 01  4.2601242E 01  3.6005661E 01  2.9771042E 01  4.1482437E-01  1.6556444E 00  2.2256057E 03  1.4054146E 03  9.6983545E 02
1.060E 01  4.2432663E 01  3.5839493E 01  2.9645401E 01  4.1514933E-01  1.6554852E 00  2.2214089E 03  1.4039353E 03  9.6918140E 02
1.070E 01  4.2214035E 01  3.5625687E 01  2.9484238E 01  4.1547829E-01  1.6552210E 00  2.2161223E 03  1.4021829E 03  9.6842920E 02
1.080E 01  4.1961121E 01  3.5378540E 01  2.9298050E 01  4.1582537E-01  1.6548777E 00  2.2099272E 03  1.4002458E 03  9.6760767E 02
1.090E 01  4.1684357E 01  3.5109116E 01  2.9094360E 01  4.1619277E-01  1.6544743E 00  2.2029543E 03  1.3981140E 03  9.6673584E 02
1.100E 01  4.1390656E 01  3.4824783E 01  2.8878098E 01  4.1658038E-01  1.6540232E 00  2.1953040E 03  1.3958633E 03  9.6583057E 02
1.110E 01  4.1073395E 01  3.4518753E 01  2.8644531E 01  4.1697812E-01  1.6534948E 00  2.1866865E 03  1.3932942E 03  9.6474683E 02
1.120E 01  4.0727295E 01  3.4186447E 01  2.8390488E 01  4.1738707E-01  1.6528931E 00  2.1771794E 03  1.3904902E 03  9.6357178E 02
1.130E 01  4.0360916E 01  3.3835938E 01  2.8121735E 01  4.1780847E-01  1.6522255E 00  2.1668640E 03  1.3874934E 03  9.6230249E 02
1.140E 01  3.9979843E 01  3.3473099E 01  2.7842606E 01  4.1824067E-01  1.6514988E 00  2.1558035E 03  1.3843162E 03  9.6093604E 02
1.150E 01  3.9587769E 01  3.3101563E 01  2.7555847E 01  4.1868025E-01  1.6507177E 00  2.1440503E 03  1.3809590E 03  9.5947656E 02
1.160E 01  3.9167603E 01  3.2704025E 01  2.7248108E 01  4.1911608E-01  1.6498356E 00  2.1310422E 03  1.3770852E 03  9.5770068E 02
```

```
  DYSIMP SIMULATION PROGRAM         SERIES POND MODEL RESPONSE                                          PAGE  4  OF RUN.  1
  TIME
 Y(29)        Y( 2)          Y(10)          Y(19)          Y(15)           Y(25)          Y( 7)          Y(16)          Y(27)
1.170E 01  3.8705826E 01  3.2267548E 01  2.6909897E 01  4.1955280E-01  1.6488523E 00  2.1169397E 03  1.3727683E 03  9.5572949E 02
1.180E 01  3.8215775E 01  3.1804504E 01  2.6550369E 01  4.1999495E-01  1.6477766E 00  2.1017766E 03  1.3680659E 03  9.5356494E 02
1.190E 01  3.7705917E 01  3.1323257E 01  2.6175476E 01  4.2044294E-01  1.6466141E 00  2.0856279E 03  1.3629902E 03  9.5121436E 02
1.200E 01  3.7181335E 01  3.0829376E 01  2.5789368E 01  4.2089438E-01  1.6453629E 00  2.0685383E 03  1.3575122E 03  9.4864600E 02
1.210E 01  3.6610764E 01  3.0289246E 01  2.5365494E 01  4.2131042E-01  1.6439571E 00  2.0497231E 03  1.3510496E 03  9.4545581E 02
1.220E 01  3.5967834E 01  2.9678223E 01  2.4885117E 01  4.2167747E-01  1.6424179E 00  2.0297268E 03  1.3439221E 03  9.4187329E 02
1.230E 01  3.5279709E 01  2.9020477E 01  2.4365707E 01  4.2200142E-01  1.6407652E 00  2.0087524E 03  1.3362549E 03  9.3795776E 02
```

```
DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                                    PAGE  5  OF RUN  1
               Y( 1) =  1.551E 01            SYMBOL = 1,    SCALE FACTOR =  2.000E 00               Y( 1) =  3.551E 01
               Y( 9) =  6.019E 00            SYMBOL = 2,    SCALE FACTOR =  2.000E 00               Y( 9) =  2.602E 01
               Y(18) =  8.097E 00            SYMBOL = 3,    SCALE FACTOR =  9.000E-01               Y(18) =  1.710E 01
               Y( 4) =  1.272E 01            SYMBOL = 4,    SCALE FACTOR =  4.000E 00               Y( 4) =  5.272E 01
               Y(12) =  2.019E 01            SYMBOL = 5,    SCALE FACTOR =  4.000E 00               Y(12) =  6.019E 01
               Y(21) =  1.558E 01            SYMBOL = 6,    SCALE FACTOR =  4.000E 00               Y(21) =  5.558E 01
    TIME                                     SYMBCL = *,    FCR COINCIDENT POINTS
```



```
DYSIMP SIMULATION PROGRAM        SERIES POND MODEL RESPONSE                              PAGE  5  OF RUN  1
              Y( 5) =  6.022E-01             SYMBOL = 1,    SCALE FACTOR =  8.000E-02              Y( 5) =  1.402E 00
              Y(13) =  1.232E 00             SYMBOL = 2,    SCALE FACTOR =  3.000E-01              Y(13) =  4.232E 00
              Y(22) =  1.508E 00             SYMBOL = 3,    SCALE FACTOR =  3.000E-01              Y(22) =  4.508E 00
              Y( 6) =  1.928E-01             SYMBOL = 4,    SCALE FACTOR =  9.000E-02              Y( 6) =  1.093E 00
              Y(14) =  3.233E-01             SYMBOL = 5,    SCALE FACTOR =  8.000E-02              Y(14) =  1.123E 00
              Y(23) =  8.055E-01             SYMBOL = 6,    SCALE FACTOR =  9.000E-02              Y(23) =  1.706E 00
   TIME                                      SYMBOL = *,    FOR COINCIDENT POINTS
```



APPENDIX C

CONTROL OPTIMIZATION SIMULATION RESULTS

The program listing and computer output for the control optimization series are presented here. Notice the monitoring option of sampling is incorporated into the user deck for nitrate (or ammonia), fish, and zooplankton. The output first lists the variable parameters, then search trials and corresponding performance index values. The last evaluation returned by the search algorithm is the optimum combination found. Printed and plotted outputs correspond to this parameter combination. Here again, two runs were required to collect all of the pertinent output.

```
                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD


          DYSIMP USER DECK


      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      COMMON/JSAM/JZSAM,JFSAM,JAMSAM
      READ(NR,2004) JVP,JVYI,JVD,JPI,JFID,JCM,JXD,CTOL
      READ(NR,2005) JZSAM,JFSAM,JAMSAM
      READ (NR,2000) M
      DO 2002 I=1,M
      READ(NR,2001) T(I),WT4(I),WT7(I),WT10(I),SOL(I)
      WT4(I)=(WT4(I)-32.0)*(5.0/9.0)
      WT7(I)=(WT7(I)-32.0)*(5.0/9.0)
 2002 WT10(I)=(WT10(I)-32.0)*(5.0/9.0)
      CALL OPTIM(JVP,JVYI,JVD,JPI,JFID,JCM,JXD,CTOL)
 2000 FORMAT(I5)
 2001 FORMAT(5F10.0)
 2004 FORMAT(7I3,F10.5)
 2005 FORMAT(3I3)
      CALL EXIT
      STOP
      END

      FUNCTION W4(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W4=WT4(M)
      RETURN
    2 W4=WT4(1)
      RETURN
    3 W4=WT4(J-1)+(TIME-T(J-1))*(WT4(J)-WT4(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION W7(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W7=WT7(M)
      RETURN
    2 W7=WT7(1)
      RETURN
    3 W7=WT7(J-1)+(TIME-T(J-1))*(WT7(J)-WT7(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION W10(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
```

```
                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) W10=WT10(M)
      RETURN
    2 W10=WT10(1)
      RETURN
    3 W10=WT10(J-1)+(TIME-T(J-1))*(WT10(J)-WT10(J-1))/(T(J)-T(J-1))
      RETURN
      END
      FUNCTION SOLI(TIME)
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DO 1 J=2,M
      IF(TIME.LT.T(1)) GO TO 2
      IF(TIME.GE.T(J-1).AND.TIME.LE.T(J)) GO TO 3
    1 CONTINUE
      IF(TIME.GE.T(M)) SOLI=SOL(M)
      RETURN
    2 SOLI=SOL(1)
      RETURN
    3 SOLI=SOL(J-1)+(TIME-T(J-1))*(SOL(J)-SOL(J-1))/(T(J)-T(J-1))
      RETURN
      END

      SUBROUTINE DERFUN
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NK,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      DIMENSION YINPUT(45),F(45)
      EQUIVALENCE(YINPUT(1),F(1))
      F(1)=(-.15369*Y(1)+.00679*Y(7)+.00906*Y(7)-.01208*Y(1)*Y(4)-12.87)
      F(2)=(-1.75000*Y(2)+.00679*Y(7)-.06568*Y(2)*Y(4)+.13415*Y(7)
     1-112.7)
      F(3)=(-363.76581*Y(3)-7.12668*Y(3)*Y(4)*X(24)+.35661*Y(3)*Y(7)
     1+.15621*Y(3)*Y(5)+.17542*Y(3)*Y(6))
      F(4)=(-21.41437*Y(4)+.06568*Y(2)*Y(4)+7.12668*Y(3)*Y(4)*X(24)
     1+.01208*Y(1)*Y(4)-5.21609*Y(4)*Y(8)-37.76+381.16)*X(21)
      F(5)=(-2.73737*Y(5)-.15621*Y(3)*Y(5)+.00199*Y(4)+.00172*Y(7)
     1+.16605*Y(5)*Y(8)-.329)*X(21)
      F(6)=(-2.21429*Y(6)+.05396*Y(4)-.17542*Y(3)*Y(6)+.13240*Y(6)
     1*Y(8)+.00029*Y(7)-.682)*X(21)
      F(7)=(-.85308*Y(7)+21.24396*Y(4)-.00419*Y(7)*Y(2)-.35661*Y(3)*Y(7)
     1+1.79798*Y(5)+.36713*Y(7)*Y(8)-.00029*Y(7)-.00036*Y(7)*Y(1)
     1+1016.3)*X(21)
      F(8)=(-23.78049*Y(8)-.13240*Y(6)*Y(8)-.16605*Y(5)*Y(8)
     1+5.21609*Y(4)*Y(8)-.36713*Y(7)*Y(8)+1957.554+X(39))
    2 F(9)=(-.15385*Y(9)+.00902*Y(16)+.00678*Y(16)-.01842*Y(9)*Y(12)
     1-2.57+X(2)-X(25))
      F(10)=(-1.75185*Y(10)+.00678*Y(16)-.07762*Y(10)*Y(12)+.13388*
     1Y(16)-24.77+X(4)-X(26))
      F(11)=(-201.46714*Y(11)+.05923*Y(11)*Y(15)
     1-14.55779*Y(11)*Y(12)*X(24)
     1+.73050*Y(11)*Y(16)+.35948*Y(11)*Y(14)+.32125*Y(11)*Y(13)+X(6)
     1-X(27))
      F(12)=(.01842*Y(9)*Y(12)+14.55779*Y(11)*Y(12)*X(24)+.07662*Y(10)
```

80/80 LIST

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0000000001111111111222222222233333333334444444444555555555566666666667777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
     1*Y(12)
     1-21.50538*Y(12)-1.93587*Y(12)*Y(17)+85.24+381.16)*X(22)
      F(13)=(.00200*Y(12)-.32125*Y(11)*Y(13)-2.73731*Y(13)+.06187*
     1Y(13)*Y(17)+.00820*Y(15)-.945)*X(22)
      F(14)=(-2.21569*Y(14)+.05597*Y(12)-.35948*Y(11)*Y(14)+.00057*Y(16)
     1+.04991*Y(14)*Y(17)-.79)*X(22)
      F(15)=(-.75122*Y(15)-.05923*Y(11)*Y(15)+.01131*Y(15)*Y(17)
     1+.19020*Y(14)+.114)*X(22)
      F(16)=(-.85316*Y(16)+21.18912*Y(12)+1.60597*Y(13)-.00496*Y(10)
     1*Y(16)-.73050*Y(11)*Y(16)-.00057*Y(16)+.13737*Y(15)*Y(17)
     1-.00056*Y(16)*Y(9)+.10000*Y(15)+231.009)*X(22)
      F(17)=(-23.72727*Y(17)-.01131*Y(15)*Y(17)-.13737*Y(16)*Y(17)
     1+1.93587*Y(12)*Y(17)-.06167*Y(13)*Y(17)-.04991*Y(14)*Y(17)
     1+1095.891+X(8)-X(28)+X(39))
    6 F(18)=(-.15385*Y(18)-.02308*Y(18)*Y(21)+.00905*Y(27)
     1+.00679*Y(27)+X(10)-X(29))
      F(19)=(-1.74576*Y(19)-.09142*Y(19)*Y(21)+.13360*Y(27)+
     1.00679*Y(27)+X(12)-X(30))
      F(20)=(-105.58462*Y(20)-23.58462*Y(20)*Y(21)*X(24)+.17664*Y(20)
     1*Y(26)+X(14)-X(31)
     1+.09615*Y(20)*Y(25)+1.18101*Y(20)*Y(27)+0.13187*Y(20)*Y(24)
     1+.58046*Y(20)*Y(23)+.51680*Y(20)*Y(22))
      F(21)=(23.58462*Y(20)*Y(21)*X(24)+.09412*Y(19)*Y(21)
     1+.02308*Y(18)*Y(21)
     1-21.33075*Y(21)-2.01500*Y(21)*Y(28)+381.16)*X(23)
      F(22)=(-2.75711*Y(22)-.51680*Y(20)*Y(22)+.00200*Y(21)+.01195
     1*Y(27)+.06442*Y(22)*Y(28))*X(23)
      F(23)=(-2.20859*Y(23)-.58046*Y(20)*Y(23)+.05400*Y(21)+.05175
     1*Y(23)*Y(28)+.00127*Y(27)+.66)*X(23)
      F(24)=(-.79286*Y(24)-.13187*Y(20)*Y(24)+.18088*Y(22)+.25153
     1*Y(23)+.01625*Y(24)*Y(28))*X(23)
      F(25)=(-.75000*Y(25)+.01185*Y(25)*Y(28)+.19018*Y(23)-.09615
     1*Y(20)*Y(25)+.89)*X(23)
      F(26)=(-.64021*Y(26)+.20569*Y(28)+.45000*Y(25)+.40000*Y(24)
     1-.17664*Y(20)*Y(26)+.25153*Y(23)+.77003*Y(22)+1.38)*X(23)
      F(27)=(-.855204*Y(27)-.001267*Y(27)-1.181013*Y(20)*Y(27)
     1-.005616*Y(27)*Y(19)+.114236*Y(24)+.143261*Y(27)*Y(28)
     1+1.801033*Y(22)-.000696*Y(27)*Y(18)+21.22000*Y(21)+.10000
     1*Y(25)+45.06)*X(23)
      F(28)=(-23.709950*Y(28)-.021766*Y(28)*Y(26)-.064416*Y(22)*Y(28)
     1-.143261*Y(27)*Y(28)-.051755*Y(23)*Y(28)-.016249*Y(24)*Y(28)
     1-.011848*Y(25)*Y(28)+2.01500*Y(21)*Y(28)+742.02+X(16)-X(32)+X(39))
      F(29)=X(33)**2+X(35)**2+X(34)**2+X(36)**2+X(37)**2+X(38)**2
      DO 1 I=1,NY
      IEQ=NYP2+1
    1 Y(IEQ)=YINPUT(I)
      Y(1)=OUTLIM(Y(1),0.0,P(17))
      Y(2)=OUTLIM(Y(2),0.0,P(18))
      Y(3)=OUTLIM(Y(3),P(49),P(19))
      Y(4)=OUTLIM(Y(4),0.0,P(20))
      Y(5)=OUTLIM(Y(5),0.0,P(21))
      Y(6)=OUTLIM(Y(6),0.0,P(22))
      Y(7)=OUTLIM(Y(7),0.0,P(23))
      Y(8)=OUTLIM(Y(8),P(50),P(24))
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80/80 LIST

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0000000001111111111222222222233333333334444444444555555555566666666667777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
      Y(9)=OUTLIM(Y(9),0.0,P(25))
      Y(10)=OUTLIM(Y(10),0.0,P(26))
      Y(11)=OUTLIM(Y(11),P(49),P(27))
      Y(12)=OUTLIM(Y(12),0.0,P(28))
      Y(13)=OUTLIM(Y(13),0.0,P(29))
      Y(14)=OUTLIM(Y(14),0.0,P(30))
      Y(15)=OUTLIM(Y(15),0.0,P(31))
      Y(16)=OUTLIM(Y(16),0.0,P(32))
      Y(17)=OUTLIM(Y(17),P(50),P(33))
      Y(18)=OUTLIM(Y(18),0.0,P(34))
      Y(19)=OUTLIM(Y(19),0.0,P(35))
      Y(20)=OUTLIM(Y(20),P(49),P(36))
      Y(21)=OUTLIM(Y(21),0.0,P(37))
      Y(22)=OUTLIM(Y(22),0.0,P(38))
      Y(23)=OUTLIM(Y(23),0.0,P(39))
      Y(24)=OUTLIM(Y(24),0.0,P(40))
      Y(25)=OUTLIM(Y(25),0.0,P(41))
      Y(26)=OUTLIM(Y(26),0.0,P(42))
      Y(27)=OUTLIM(Y(27),0.0,P(43))
      Y(28)=OUTLIM(Y(28),P(50),P(44))
      RETURN
      END

      SUBROUTINE XVAL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/MEAS/T(100),WT4(100),WT7(100),WT10(100),SOL(100),M
      COMMON/JSAM/JZSAM,JFSAM,JAMSAM
      X(1)=.15369*Y(1)*P(3)
      X(3)=1.75*Y(2)*P(3)
      X(5)=363.76581*Y(3)*P(2)
      X(7)=23.78049*Y(8)*P(4)
      X(9)=.15285*Y(9)*P(3)
      X(11)=1.75185*Y(10)*P(3)
      X(13)=201.46714*Y(11)*P(2)
      X(15)=23.72727*Y(17)*P(4)
      X(17)=W4(Y(NYP1))
      X(18)=W7(Y(NYP1))
      X(19)=W10(Y(NYP1))
      X(20)=SOLI(Y(NYP1))
      X(21)=2.0**(-(16.0810-X(17))/10.0)
      X(22)=2.0**(-(16.5694-X(18))/10.0)
      X(23)=2.0**(-(16.0301-X(19))/10.0)
      X(24)=X(20)/506.7910
      X(25)=.15369*24.92*P(3)
      X(26)=1.75*32.0*P(3)
      X(27)=363.76581*4.3*P(2)
      X(28)=23.78049*4.1*P(4)
      X(29)=.15385*16.25*P(3)
      X(30)=1.75185*27.0*P(3)
      X(31)=201.46714*2.1*P(2)
      X(32)=23.72727*11.0*P(4)
      IF(JZSAM.EQ.1) GO TO 1
      X(33)=P(7)*(3.87)/Y(22)
      GO TO 2
```

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                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
    1 CALL SAMPLE(Y(22),X(40),P(45),P(46),1)
      X(33)=P(7)*(3.87)/X(40)
    2 IF(JFSAM.EQ.1) GO TO 3
      X(34)=P(8)*(9.45)/Y(26)
      GO TO 4
    3 CALL SAMPLE(Y(26),X(41),P(45),P(47),2)
      X(34)=P(8)*(9.45)/X(41)
    4 X(35)=P(9)*(1.0-(2.01500*Y(21)+46.61797)/(.021766*Y(26)+
     1.064416*Y(22)+.143261*Y(27)+.051755*Y(23)+.016249*Y(24)+
     1.011848*Y(25)))
      IF(JAMSAM.EQ.1) GO TO 5
      IF(Y(19).LE.P(15)) GO TO 6
      X(36)=P(10)
      GO TO 7
    6 X(36)=0.0
      GO TO 7
    5 CALL SAMPLE(Y(19),X(42),P(45),P(48),3)
      IF(X(42).LE.P(15)) GO TO 8
      X(36)=P(10)
      GO TO 7
    8 X(36)=0.0
    7 X(37)=P(11)*P(12)/.090
      IF(Y(28).GT.P(16)) GO TO 15
      X(39)=P(14)*(P(16)-Y(28))
      X(38)=P(13)*X(39)
      GO TO 16
   15 X(39)=0.0
      X(38)=P(13)*X(39)
   16 CONTINUE
      CALL DELAY
      P(5)=P(45)+P(12)
      IF(Y(NYP1)-P(5)) 17,18,18
   17 X(2)=.15369*24.92*P(3)
      X(4)=1.75*32.0*P(3)
      X(6)=363.76581*4.3*P(2)
      X(8)=23.78049*4.1*P(4)
   18 P(6)=P(45)+2.0*P(12)
      IF(Y(NYP1)-P(6)) 19,20,20
   19 X(10)=.15385*16.25*P(3)
      X(12)=1.75185*27.0*P(3)
      X(14)=201.46714*2.1*P(2)
      X(16)=23.72727*11.0*P(4)
   20 CONTINUE
      RETURN
      END

      SUBROUTINE INTDEL
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      COMMON/CDELAY/DELAYV(4000),LABELD(25,4),IDTYPE(25),ND,NDY,NDMAX,
     1IDELAY,TIME(25)
      DO 1 I=1,ND
      TIME(I)=P(12)
      J=LABELD(I,1)
      K=LABELD(I,2)
```

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                                 80/80 LIST

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890
      DO 1 II=J,K
    1 DELAYV(II)=0.0
      RETURN
      END
      SUBROUTINE PARADJ
      COMMON/ALL/Y(92),X(50),P(50),NY,NYP1,NYP2,NYMAX,NX,NR,NW
      READ(NR,1) P(1)
    1 FORMAT(1F10.0)
      RETURN
      END


              DATA


  2  0  0  1 29  0  1           .4
  0  0  0
   49
         0.0      58.0      55.0      55.0     548.0
         0.5      46.0      43.5      44.0     475.0
         1.0      41.0      37.0      36.0     420.0
         1.5      40.0      35.8      34.0     380.0
         2.0      41.0      36.0      34.0     345.0
         2.5      48.5      44.0      42.0     320.0
         3.0      59.0      53.0      50.0     305.0
         3.5      56.0      53.0      50.0     300.0
         4.0      55.0      53.0      50.0     308.0
         4.5      62.5      56.0      53.8     376.0
         5.0      65.0      58.5      57.0     430.0
         5.5      63.5      59.5      58.2     475.0
         6.0      62.0      60.0      60.0     518.0
         6.5      68.5      66.0      67.0     540.0
         7.0      76.0      75.0      74.0     580.0
         7.5      80.0      79.5      79.0     608.0
         8.0      82.0      82.0      82.0     640.0
         8.5      85.8      84.5      84.5     660.0
         9.0      87.0      86.0      86.0     685.0
         9.5      85.8      84.0      84.5     695.0
        10.0      82.0      81.0      81.0     690.0
        10.5      73.0      74.5      73.5     673.0
        11.0      68.0      67.0      65.0     640.0
        11.5      63.5      60.0      60.0     600.0
        12.0      58.0      55.0      55.0     548.0
        12.5      46.0      43.5      44.0     475.0
        13.0      41.0      37.0      36.0     420.0
        13.5      40.0      35.8      34.0     380.0
        14.0      41.0      36.0      34.0     345.0
        14.5      48.5      44.0      42.0     320.0
        15.0      59.0      53.0      50.0     305.0
        15.5      56.0      53.0      50.0     300.0
        16.0      55.0      53.0      50.0     308.0
        16.5      62.5      56.0      53.8     376.0
        17.0      65.0      58.5      57.0     430.0
        17.5      63.5      59.5      58.2     475.0
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                                     80/80 LIST

       00000000011111111112222222222333333333344444444445555555555666666666677777777778
       12345678901234567890123456789012345678901234567890123456789012345678901234567890
 CARD
  325        16.0      62.0      50.0      60.0     518.0
  326        18.5      68.5      66.0      67.0     540.0
  327        19.0      76.0      75.0      74.0     580.0
  328        19.5      80.0      79.5      79.0     608.0
  329        20.0      82.0      82.0      82.0     640.0
  330        20.5      85.8      84.5      84.5     660.0
  331        21.0      87.0      86.0      86.0     685.0
  332        21.5      85.8      84.0      84.5     695.0
  333        22.0      82.0      81.0      81.0     690.0
  334        22.5      73.0      74.5      73.5     673.0
  335        23.0      68.0      67.0      65.0     640.0
  336        23.5      63.5      60.0      60.0     600.0
  337        24.0      58.0      55.0      55.0     548.0
  338   1 1 1 1 1 0 1 2 0    POND MODEL OPTIMIZATION, TZERO = 6.0
  339     29   42   50   20       6.0      12.0     .0025
  340      21.406    29.433    4.0072    27.791    .86081    .46192    1583.2    4.2105
  341      12.403    22.075    1.9741    32.760    2.3111    .55506    28.348    941.47
  342      12.253    9.5351    16.891    1.2874    26.883    2.5632    1.1394    .82379
  343      1.4428    7.7877    632.83    12.595       0.0
  344         0.0       .05       0.5       1.0     6.090     6.180     400.0     400.0
  345      1000.0      30.0       5.0      .090       .90       0.0      24.0      10.0
  346        32.0      44.0       7.3      50.0       1.5       1.2    2200.0       6.6
  347        22.0      37.0       6.3      61.0       5.3       1.5       .58    1500.0
  348        23.0      18.0      30.0       5.8      53.0       5.6       2.0       1.9
  349        1.92      12.0    1100.0      29.8       6.0       0.0       0.0       0.0
  350         0.0       0.0
  351      8
  352    1  2  0      0.090  3  4  0      0.090  5  6  0      0.090  7  8  0      0.090
  353    9 10  0      0.090 11 12  0      0.090 13 14  0      0.090 15 16  0      0.090
  354
  355
  356
  357
  358     12      .090       1.0
  359     14       0.0     600.0
  360   1 0 0 1 0 1 1 0 0    OPTIMAL CONTROL PARAMETER COMBINATION
  361     29   42   50   20       6.0      12.0     .0025
  362      8
  363    1  2  0      0.090  3  4  0      0.090  5  6  0      0.090  7  8  0      0.090
  364    9 10  0      0.090 11 12  0      0.090 13 14  0      0.090 15 16  0      0.090
  365      3   11   20    8   17   28   24   26
  366      1    9   18    4   12   21
  367
  368
  369
  370
  371
```

```
POND MODEL OPTIMIZATION, TZERO = 6.0

VARIABLE PARAMETER VALUES

P(12) =   8.999997E-02 TO   1.000000E 00
P(14) =   0.0          TO   6.000000E 02

PI =  2.047080E 06     AT


P(12) =   5.450000E-01     P(14) =   3.000000E 02

PI =  1.993078E 06     AT


P(12) =   3.933333E-01     P(14) =   2.000000E 02

PI =  1.997091E 06     AT


P(12) =   6.966665E-01     P(14) =   2.000000E 02

PI =  2.022584E 06     AT


P(12) =   3.933333E-01     P(14) =   4.000000E 02

PI =  1.995593E 06     AT


P(12) =   5.965665E-01     P(14) =   2.000000E 02

PI =  1.990439E 06     AT


P(12) =   1.900999E-01     P(14) =   2.000000E 02

PI =  2.008144E 06     AT


P(12) =   3.933333E-01     P(14) =   3.339998E 02

PI =  1.981780E 06     AT


P(12) =   3.933333E-01     P(14) =   6.599997E 01

PI =  2.011739E 06     AT


P(12) =   3.259258E-01     P(14) =   2.155559E 01

PI =  2.012992E 06     AT


P(12) =   4.607406E-01     P(14) =   2.155556E 01

PI =  1.986393E 06     AT


P(12) =   3.259258E-01     P(14) =   1.104444E 02

PI =  1.987749E 06     AT


P(12) =   4.607406E-01     P(14) =   1.104444E 02

PI =  1.982161E 06     AT


P(12) =   4.382704E-01     P(14) =   6.600000E 01

PI =  1.982840E 06     AT


P(12) =   3.483939E-01     P(14) =   6.600000E 01

PI =  1.983393E 06     AT


P(12) =   3.933333E-01     P(14) =   9.562946E 01

PI =  1.995015E 06     AT


P(12) =   3.933333E-01     P(14) =   3.637024E 01

PI =  1.981780E 06     AT


P(12) =   3.933333E-01     P(14) =   6.599997E 01
```

```
DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                    PAGE  1  OF RUN  1

ORDER OF SYSTEM        =          29
NUMBER OF X'S          =          42
NUMBER OF PARAMETERS   =          50
NUMBER OF DELAYS       =           8
OUTPUT INTERVAL        =          20
INITIAL TIME           =  6.0000E 00
FINAL TIME             =  1.2000E 01
INTEGRATION STEP       =  2.5000E-03

INITIAL Y VALUES

Y( 1) =  2.140599E 01    Y( 2) =  2.943300E 01    Y( 3) =  4.007199E 00    Y( 4) =  2.779099E 01    Y( 5) =  8.608100E-01
Y( 6) =  4.619200E-01    Y( 7) =  1.583200E 03    Y( 8) =  4.210500E 00    Y( 9) =  1.240300E 01    Y(10) =  2.207500E 01
Y(11) =  1.974099E 00    Y(12) =  3.275999E 01    Y(13) =  2.311099E 00    Y(14) =  5.550600E-01    Y(15) =  5.800000E-01
Y(16) =  9.414700E 02    Y(17) =  1.225300E 01    Y(18) =  9.535100E 00    Y(19) =  1.689099E 01    Y(20) =  1.287399E 00
Y(21) =  2.688300E 01    Y(22) =  2.563200E 00    Y(23) =  1.139400E 00    Y(24) =  8.237900E-01    Y(25) =  1.442800E 00
Y(26) =  7.787700E 00    Y(27) =  6.328298E 02    Y(28) =  1.259500E 01    Y(29) =  0.0

INITIAL X VALUES

X( 1) =  1.644942E 00    X( 2) =  1.914976E 00    X( 3) =  2.575386E 01    X( 4) =  2.800000E 01    X( 5) =  7.288405E 01
X( 6) =  7.820958E 01    X( 7) =  1.001277E 02    X( 8) =  9.749997E 01    X( 9) =  9.478989E-01    X(10) =  1.250031E 00
X(11) =  1.933603E 01    X(12) =  2.364996E 01    X(13) =  1.988579E 01    X(14) =  2.115404E 01    X(15) =  2.907300E 02
X(16) =  2.609998E 02    X(17) =  1.666666E 01    X(18) =  1.555555E 01    X(19) =  1.555555E 01    X(20) =  5.180000E 02
X(21) =  9.066177E-01    X(22) =  9.321382E-01    X(23) =  9.676427E-01    X(24) =  1.018100E 00    X(25) =  1.914976E 00
X(26) =  2.800000E 01    X(27) =  7.820958E 01    X(28) =  9.749997E 01    X(29) =  1.250031E 00    X(30) =  2.364996E 01
X(31) =  2.115404E 01    X(32) =  2.609998E 02    X(33) =  6.039324E 02    X(34) =  4.853806E 02    X(35) = -1.065311E 02
X(36) =  0.0             X(37) =  2.185185E 01    X(38) =  0.0             X(39) =  0.0             X(40) =  0.0
X(41) =  0.0             X(42) =  0.0

PARAMETER VALUES

P( 1) =  0.0             P( 2) =  5.000000E-02    P( 3) =  5.000000E-01    P( 4) =  1.000000E 00    P( 5) =  6.393332E 00
P( 6) =  6.786666E 00    P( 7) =  4.000000E 02    P( 8) =  4.000000E 02    P( 9) =  1.000000E 03    P(10) =  3.000000E 01
P(11) =  5.000000E 00    P(12) =  3.933333E-01    P(13) =  9.000000E-01    P(14) =  6.600000E 01    P(15) =  2.400000E 01
P(16) =  1.000000E 01    P(17) =  3.200000E 01    P(18) =  4.400000E 01    P(19) =  7.299999E 00    P(20) =  5.000000E 01
P(21) =  1.500000E 00    P(22) =  1.200000E 00    P(23) =  2.200000E 03    P(24) =  6.599999E 00    P(25) =  2.200000E 01
P(26) =  3.700000E 01    P(27) =  6.299999E 00    P(28) =  6.100000E 01    P(29) =  5.299999E 00    P(30) =  1.500000E 00
P(31) =  5.800000E-01    P(32) =  1.500000E 03    P(33) =  2.300000E 01    P(34) =  1.800000E 01    P(35) =  3.000000E 01
P(36) =  5.799999E 00    P(37) =  5.300000E 01    P(38) =  5.599999E 00    P(39) =  2.000000E 00    P(40) =  1.900000E 00
P(41) =  1.919999E 00    P(42) =  1.200000E 01    P(43) =  1.100000E 03    P(44) =  2.979999E 01    P(45) =  6.000000E 00
P(46) =  0.0             P(47) =  0.0             P(48) =  0.0             P(49) =  0.0             P(50) =  0.0

TIME DELAYS

F( 1) =  3.933333E-01    F( 2) =  3.933333E-01    F( 3) =  3.933333E-01    F( 4) =  3.933333E-01    F( 5) =  3.933333E-01
F( 6) =  3.933333E-01    F( 7) =  3.933333E-01    F( 8) =  3.933333E-01
```

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 DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                          PAGE  2  OF RUN  1
 TIME
 Y(30)         Y( 3)           Y(11)           Y(20)           Y( 8)           Y(17)           Y(28)           Y(24)           Y(26)
6.000E 00  4.0071993E 00  1.9740992E 00  1.2873993E 00  4.2104998E 00  1.2252999E 01  1.2594999E 01  8.2378995E-01  7.7876997E 00
6.050E 00  4.0123911E 00  1.9643307E 00  1.2585592E 00  4.1924458E 00  1.2154150E 01  1.2170891E 01  8.3005577E-01  7.8091354E 00
6.100E 00  3.9896688E 00  1.9539385E 00  1.2425718E 00  4.1763792E 00  1.2055255E 01  1.2033571E 01  8.3678651E-01  7.8313961E 00
6.150E 00  3.9830341E 00  1.9429197E 00  1.2261620E 00  4.1611652E 00  1.1956555E 01  1.1913276E 01  8.4401596E-01  7.8550081E 00
6.200E 00  3.9734230E 00  1.9310465E 00  1.2143269E 00  4.1445293E 00  1.1858766E 01  1.1791410E 01  8.5174865E-01  7.8799782E 00
6.250E 00  3.9590292E 00  1.9184055E 00  1.2052507E 00  4.1285400E 00  1.1762092E 01  1.1670036E 01  8.5998410E-01  7.9062643E 00
6.300E 00  3.9474573E 00  1.9052067E 00  1.1945486E 00  4.1126842E 00  1.1666518E 01  1.1551992E 01  8.6872542E-01  7.9338884E 00
6.350E 00  3.9353600E 00  1.8917284E 00  1.1830931E 00  4.0965576E 00  1.1571924E 01  1.1435729E 01  8.7797612E-01  7.9628992E 00
6.400E 00  3.9218950E 00  1.8505926E 00  1.1729860E 00  4.0804977E 00  1.1477818E 01  1.1320128E 01  8.8773447E-01  7.9932957E 00
6.450E 00  3.9083605E 00  1.8278437E 00  1.1629038E 00  4.0645208E 00  1.1347632E 01  1.1206482E 01  8.9799660E-01  8.0250750E 00
6.500E 00  3.8947277E 00  1.8266678E 00  1.1526175E 00  4.0485249E 00  1.1237490E 01  1.1094669E 01  9.0875886E-01  8.0582561E 00
6.550E 00  3.8542385E 00  1.8160276E 00  1.1339273E 00  4.0279875E 00  1.1114204E 01  1.0963403E 01  9.2004472E-01  8.0931625E 00
6.600E 00  3.8226185E 00  1.7932844E 00  1.1165905E 00  4.0072403E 00  1.0994573E 01  1.0821280E 01  9.3185633E-01  8.1298304E 00
6.650E 00  3.7928705E 00  1.7628412E 00  1.0999174E 00  3.9855433E 00  1.0872838E 01  1.0681812E 01  9.4417894E-01  8.1681719E 00
6.700E 00  3.7617760E 00  1.7349977E 00  1.0829029E 00  3.9633923E 00  1.0749413E 01  1.0545171E 01  9.5700741E-01  8.2082348E 00
6.750E 00  3.7301893E 00  1.7128716E 00  1.0668583E 00  3.9410696E 00  1.0625352E 01  1.0411038E 01  9.7032887E-01  8.2499981E 00
6.800E 00  3.6989794E 00  1.6900139E 00  1.0304098E 00  3.9185724E 00  1.0504617E 01  1.0215278E 01  9.8415917E-01  8.2937603E 00
6.850E 00  3.6682129E 00  1.6655684E 00  1.0275717E 00  3.8958654E 00  1.0385974E 01  9.9948940E 00  9.9838078E-01  8.3381987E 00
6.900E 00  3.6470594E 00  1.6486578E 00  1.0036783E 00  3.8848381E 00  1.0316471E 01  9.9001865E 00  1.0130510E 00  8.3844824E 00
6.950E 00  3.6239033E 00  1.6327581E 00  9.9581462E-01  3.8726034E 00  1.0252357E 01  9.8174829E 00  1.0281296E 00  8.4324760E 00
7.000E 00  3.6001282E 00  1.6166887E 00  9.8398864E-01  3.8585367E 00  1.0185259E 01  9.7414570E 00  1.0436325E 00  8.4825382E 00
7.050E 00  3.5879955E 00  1.6075039E 00  9.7642863E-01  3.8458881E 00  1.0124076E 01  9.6772165E 00  1.0594378E 00  8.5339966E 00
7.100E 00  3.5743074E 00  1.5965357E 00  9.6912676E-01  3.8331623E 00  1.0066607E 01  9.6135225E 00  1.0754595E 00  8.5866404E 00
7.150E 00  3.5598011E 00  1.5862827E 00  9.6140158E-01  3.8202801E 00  1.0009765E 01  9.5528040E 00  1.0916672E 00  8.6403418E 00
7.200E 00  3.5448198E 00  1.5756063E 00  9.5394272E-01  3.8073959E 00  9.9541922E 00  9.4929371E 00  1.1080389E 00  8.6950607E 00
7.250E 00  3.5294476E 00  1.5650778E 00  9.4655228E-01  3.7944965E 00  9.8986721E 00  9.4342842E 00  1.1245461E 00  8.7507038E 00
7.300E 00  3.5137835E 00  1.5543146E 00  9.3918490E-01  3.7815924E 00  9.8443317E 00  9.3764477E 00  1.1411648E 00  8.8072090E 00
7.350E 00  3.4978495E 00  1.5437670E 00  9.3182456E-01  3.7686787E 00  9.7905464E 00  9.3196316E 00  1.1578684E 00  8.8644905E 00
7.400E 00  3.4816589E 00  1.5329704E 00  9.2454755E-01  3.7557507E 00  9.7377768E 00  9.2637587E 00  1.1746349E 00  8.9224758E 00
7.450E 00  3.4652424E 00  1.5223528E 00  9.1727626E-01  3.7428055E 00  9.6857195E 00  9.2089205E 00  1.1914368E 00  8.9810877E 00
7.500E 00  3.4486227E 00  1.5116320E 00  9.1008437E-01  3.7298479E 00  9.6345367E 00  9.1550732E 00  1.2082500E 00  9.0402479E 00
7.550E 00  3.4284763E 00  1.4987783E 00  9.0168297E-01  3.7162724E 00  9.5818567E 00  9.0999928E 00  1.2250023E 00  9.0997572E 00
7.600E 00  3.4081602E 00  1.4867277E 00  8.9351475E-01  3.7026701E 00  9.5293779E 00  9.0456305E 00  1.2416058E 00  9.1593266E 00
7.650E 00  3.3878794E 00  1.4741840E 00  8.8546395E-01  3.6890640E 00  9.4777365E 00  8.9918537E 00  1.2580462E 00  9.2188950E 00
7.700E 00  3.3676224E 00  1.4618692E 00  8.7737989E-01  3.6754255E 00  9.4271345E 00  8.9392719E 00  1.2743063E 00  9.2783957E 00
7.750E 00  3.3473434E 00  1.4497137E 00  8.6942822E-01  3.6617823E 00  9.3774147E 00  8.8877935E 00  1.2903719E 00  9.3377695E 00
7.800E 00  3.3270159E 00  1.4375076E 00  8.6152565E-01  3.6481304E 00  9.3286591E 00  8.8374949E 00  1.3062305E 00  9.3969612E 00
7.850E 00  3.3066387E 00  1.4253988E 00  8.5368538E-01  3.6344748E 00  9.2808161E 00  8.7883635E 00  1.3218679E 00  9.4559164E 00
7.900E 00  3.2862320E 00  1.4133797E 00  8.4593439E-01  3.6208258E 00  9.2338533E 00  8.7403545E 00  1.3372726E 00  9.5145807E 00
7.950E 00  3.2658205E 00  1.4014282E 00  8.3825505E-01  3.6071901E 00  9.1877756E 00  8.6934605E 00  1.3524361E 00  9.5729036E 00
8.000E 00  3.2454062E 00  1.3895559E 00  8.3064663E-01  3.5935764E 00  9.1425819E 00  8.6476593E 00  1.3673468E 00  9.6308384E 00
8.050E 00  3.2339993E 00  1.3832722E 00  8.2602108E-01  3.5817013E 00  9.1049881E 00  8.6092796E 00  1.3819523E 00  9.6880131E 00
8.100E 00  3.2228851E 00  1.3757305E 00  8.2131070E-01  3.5702705E 00  9.0697441E 00  8.5731106E 00  1.3962193E 00  9.7442350E 00
8.150E 00  3.2105722E 00  1.3683653E 00  8.1656349E-01  3.5589972E 00  9.0365610E 00  8.5394764E 00  1.4101391E 00  9.7994652E 00
8.200E 00  3.1979532E 00  1.3611507E 00  8.1197858E-01  3.5478363E 00  9.0040083E 00  8.5069618E 00  1.4237070E 00  9.8536730E 00
8.250E 00  3.1854753E 00  1.3540297E 00  8.0742180E-01  3.5368338E 00  8.9720917E 00  8.4755507E 00  1.4369183E 00  9.9068327E 00
8.300E 00  3.1729631E 00  1.3468981E 00  8.0285180E-01  3.5260382E 00  8.9410744E 00  8.4450865E 00  1.4497681E 00  9.9589148E 00
8.350E 00  3.1603708E 00  1.3397369E 00  7.9829693E-01  3.5154276E 00  8.9109573E 00  8.4155235E 00  1.4622526E 00  1.0009897E 01
8.400E 00  3.1477566E 00  1.3326178E 00  7.9377747E-01  3.5049887E 00  8.8816338E 00  8.3868322E 00  1.4743710E 00  1.0059765E 01
8.450E 00  3.1351118E 00  1.3255281E 00  7.8928989E-01  3.4947214E 00  8.8530626E 00  8.3589706E 00  1.4861231E 00  1.0108505E 01
8.500E 00  3.1224451E 00  1.3184557E 00  7.8482610E-01  3.4846172E 00  8.8252201E 00  8.3319035E 00  1.4975080E 00  1.0156111E 01
8.550E 00  3.1060801E 00  1.3094339E 00  7.7932519E-01  3.4740114E 00  8.7953796E 00  8.3031549E 00  1.5085239E 00  1.0202614E 01
8.600E 00  3.0899696E 00  1.3006535E 00  7.7384526E-01  3.4633293E 00  8.7657843E 00  8.2747345E 00  1.5191593E 00  1.0247981E 01
8.650E 00  3.0742598E 00  1.2919703E 00  7.6840371E-01  3.4528809E 00  8.7363911E 00  8.2464876E 00  1.5294228E 00  1.0292231E 01
8.700E 00  3.0583906E 00  1.2833748E 00  7.6259351E-01  3.4425564E 00  8.7076740E 00  8.2188578E 00  1.5393257E 00  1.0335384E 01
8.750E 00  3.0426502E 00  1.2747908E 00  7.5762463E-01  3.4323330E 00  8.6795654E 00  8.1918335E 00  1.5488768E 00  1.0377463E 01
8.800E 00  3.0269432E 00  1.2662621E 00  7.5230008E-01  3.4222240E 00  8.6519785E 00  8.1654491E 00  1.5580864E 00  1.0418490E 01
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 DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                        PAGE  3  OF RUN  1
 TIME
 Y(30)         Y( 3)           Y(11)           Y(20)           Y( 8)           Y(17)           Y(28)           Y(24)           Y(26)
8.850E 00  3.0113106E 00  1.2577734E 00  7.4702495E-01  3.4122171E 00  8.6249332E 00  8.1396675E 00  1.5669661E 00  1.0458489E 01
8.900E 00  2.9957294E 00  1.2493372E 00  7.4179578E-01  3.4023180E 00  8.5983944E 00  8.1144581E 00  1.5755262E 00  1.0497486E 01
8.950E 00  2.9802313E 00  1.2409601E 00  7.3661190E-01  3.3925190E 00  8.5723543E 00  8.0898066E 00  1.5837774E 00  1.0535502E 01
9.000E 00  2.9648094E 00  1.2326422E 00  7.3146904E-01  3.3828259E 00  8.5467873E 00  8.0656891E 00  1.5917301E 00  1.0572564E 01
9.050E 00  2.9598961E 00  1.2295876E 00  7.2921580E-01  3.3752508E 00  8.5292721E 00  8.0487814E 00  1.5993147E 00  1.0608155E 01
9.100E 00  2.9534769E 00  1.2262812E 00  7.2709787E-01  3.3687096E 00  8.5134783E 00  8.0335865E 00  1.6064854E 00  1.0641970E 01
9.150E 00  2.9469185E 00  1.2228479E 00  7.2499001E-01  3.3621283E 00  8.4995022E 00  8.0204372E 00  1.6132631E 00  1.0674091E 01
9.200E 00  2.9406595E 00  1.2194042E 00  7.2288471E-01  3.3559637E 00  8.4858122E 00  8.0080309E 00  1.6196699E 00  1.0704606E 01
9.250E 00  2.9342403E 00  1.2159243E 00  7.2078121E-01  3.3500748E 00  8.4727907E 00  7.9962587E 00  1.6257248E 00  1.0733598E 01
9.300E 00  2.9279404E 00  1.2124481E 00  7.1869272E-01  3.3444662E 00  8.4603405E 00  7.9849081E 00  1.6314478E 00  1.0761147E 01
9.350E 00  2.9216290E 00  1.2090616E 00  7.1663111E-01  3.3391075E 00  8.4483576E 00  7.9739609E 00  1.6368561E 00  1.0787329E 01
9.400E 00  2.9153528E 00  1.2057333E 00  7.1459407E-01  3.3339682E 00  8.4367838E 00  7.9633894E 00  1.6419668E 00  1.0812220E 01
9.450E 00  2.9091091E 00  1.2024374E 00  7.1257091E-01  3.3290272E 00  8.4255819E 00  7.9531527E 00  1.6467972E 00  1.0835890E 01
9.500E 00  2.9028816E 00  1.1991453E 00  7.1055841E-01  3.3242645E 00  8.4147282E 00  7.9432240E 00  1.6513634E 00  1.0858411E 01
9.550E 00  2.9069157E 00  1.2012491E 00  7.1135938E-01  3.3216400E 00  8.4114237E 00  7.9400673E 00  1.6556263E 00  1.0879435E 01
9.600E 00  2.9095860E 00  1.2027655E 00  7.1221477E-01  3.3200521E 00  8.4095316E 00  7.9383192E 00  1.6595736E 00  1.0898835E 01
9.650E 00  2.9119101E 00  1.2038794E 00  7.1305096E-01  3.3184357E 00  8.4094925E 00  7.9383430E 00  1.6632252E 00  1.0916713E 01
9.700E 00  2.9147892E 00  1.2051210E 00  7.1397805E-01  3.3172150E 00  8.4095821E 00  7.9388437E 00  1.6666012E 00  1.0933167E 01
9.750E 00  2.9174185E 00  1.2066154E 00  7.1497673E-01  3.3162889E 00  8.4100552E 00  7.9397306E 00  1.6697187E 00  1.0948298E 01
9.800E 00  2.9201937E 00  1.2081976E 00  7.1598089E-01  3.3156118E 00  8.4108372E 00  7.9408598E 00  1.6725960E 00  1.0962191E 01
9.850E 00  2.9230013E 00  1.2097769E 00  7.1694481E-01  3.3151712E 00  8.4119091E 00  7.9422569E 00  1.6752491E 00  1.0974934E 01
9.900E 00  2.9258385E 00  1.2112617E 00  7.1789289E-01  3.3149300E 00  8.4133568E 00  7.9438982E 00  1.6776934E 00  1.0986607E 01
9.950E 00  2.9287043E 00  1.2127838E 00  7.1885365E-01  3.3148689E 00  8.4150896E 00  7.9457388E 00  1.6799421E 00  1.0997286E 01
1.000E 01  2.9316044E 00  1.2143888E 00  7.1984160E-01  3.3149681E 00  8.4170198E 00  7.9477425E 00  1.6820107E 00  1.1007044E 01
1.005E 01  2.9427128E 00  1.2208519E 00  7.2331351E-01  3.3168192E 00  8.4248848E 00  7.9552269E 00  1.6838684E 00  1.1015626E 01
1.010E 01  2.9538040E 00  1.2258511E 00  7.2673470E-01  3.3194113E 00  8.4341898E 00  7.9637852E 00  1.6855078E 00  1.1022983E 01
1.015E 01  2.9636965E 00  1.2310772E 00  7.3002529E-01  3.3221130E 00  8.4452076E 00  7.9738541E 00  1.6869478E 00  1.1029212E 01
1.020E 01  2.9740429E 00  1.2370911E 00  7.3357725E-01  3.3249664E 00  8.4557543E 00  7.9842110E 00  1.6882067E 00  1.1034414E 01
1.025E 01  2.9847212E 00  1.2425423E 00  7.3703223E-01  3.3280354E 00  8.4666805E 00  7.9949245E 00  1.6892996E 00  1.1038686E 01
1.030E 01  2.9954281E 00  1.2482252E 00  7.4032664E-01  3.3312979E 00  8.4781914E 00  8.0060453E 00  1.6902390E 00  1.1042097E 01
1.035E 01  3.0061617E 00  1.2542553E 00  7.4392545E-01  3.3347349E 00  8.4896936E 00  8.0172911E 00  1.6910391E 00  1.1044725E 01
1.040E 01  3.0170002E 00  1.2597980E 00  7.4752915E-01  3.3383074E 00  8.5017452E 00  8.0286875E 00  1.6917124E 00  1.1046646E 01
1.045E 01  3.0279503E 00  1.2659245E 00  7.5106573E-01  3.3419971E 00  8.5138350E 00  8.0403671E 00  1.6922684E 00  1.1047915E 01
1.050E 01  3.0389833E 00  1.2717133E 00  7.5473386E-01  3.3458052E 00  8.5262260E 00  8.0521622E 00  1.6927176E 00  1.1048592E 01
1.055E 01  3.0609512E 00  1.2853985E 00  7.6282841E-01  3.3522253E 00  8.5465746E 00  8.0714397E 00  1.6930313E 00  1.1048419E 01
1.060E 01  3.0837641E 00  1.2947187E 00  7.6923281E-01  3.3589687E 00  8.5706882E 00  8.0926905E 00  1.6932163E 00  1.1047416E 01
1.065E 01  3.1064453E 00  1.3093309E 00  7.7621001E-01  3.3660040E 00  8.5938120E 00  8.1166267E 00  1.6932764E 00  1.1045605E 01
1.070E 01  3.1289358E 00  1.3188639E 00  7.8425413E-01  3.3734417E 00  8.6202555E 00  8.1399078E 00  1.6932287E 00  1.1043113E 01
1.075E 01  3.1515465E 00  1.3330126E 00  7.9083174E-01  3.3810167E 00  8.6443281E 00  8.1652632E 00  1.6930752E 00  1.1039934E 01
1.080E 01  3.1742840E 00  1.3438606E 00  7.9923671E-01  3.3889675E 00  8.6715317E 00  8.1897078E 00  1.6928282E 00  1.1036174E 01
1.085E 01  3.1973610E 00  1.3572416E 00  8.0632162E-01  3.3970470E 00  8.6970272E 00  8.2158766E 00  1.6924896E 00  1.1031828E 01
1.090E 01  3.2206907E 00  1.3700399E 00  8.1452155E-01  3.4054298E 00  8.7246456E 00  8.2414608E 00  1.6920719E 00  1.1026990E 01
1.095E 01  3.2443724E 00  1.3822489E 00  8.2251453E-01  3.4139833E 00  8.7521267E 00  8.2683525E 00  1.6915741E 00  1.1021648E 01
1.100E 01  3.2683563E 00  1.3965797E 00  8.3018762E-01  3.4227409E 00  8.7797699E 00  8.2952938E 00  1.6910086E 00  1.1015891E 01
1.105E 01  3.2982216E 00  1.4124765E 00  8.4156328E-01  3.4330778E 00  8.8129320E 00  8.3261223E 00  1.6903572E 00  1.1009555E 01
1.110E 01  3.3264779E 00  1.4296255E 00  8.5026699E-01  3.4434948E 00  8.8469076E 00  8.3596954E 00  1.6896191E 00  1.1002621E 01
1.115E 01  3.3589287E 00  1.4456767E 00  8.6141557E-01  3.4543047E 00  8.8827286E 00  8.3931656E 00  1.6888008E 00  1.0995143E 01
1.120E 01  3.3898230E 00  1.4629774E 00  8.7138897E-01  3.4652624E 00  8.9186010E 00  8.4289513E 00  1.6879005E 00  1.0987098E 01
1.125E 01  3.4210749E 00  1.4804163E 00  8.8190198E-01  3.4765463E 00  8.9554834E 00  8.4644651E 00  1.6869259E 00  1.0978563E 01
1.130E 01  3.4527464E 00  1.4975615E 00  8.9338487E-01  3.4880924E 00  8.9934425E 00  8.5012970E 00  1.6858749E 00  1.0969504E 01
1.135E 01  3.4848871E 00  1.5155535E 00  9.0348095E-01  3.4998131E 00  9.0315504E 00  8.5391102E 00  1.6847525E 00  1.0959981E 01
1.140E 01  3.5174122E 00  1.5339394E 00  9.1546363E-01  3.5118666E 00  9.0707884E 00  8.5770702E 00  1.6835604E 00  1.0949997E 01
1.145E 01  3.5504379E 00  1.5524311E 00  9.2669839E-01  3.5240726E 00  9.1108398E 00  8.6166315E 00  1.6822996E 00  1.0939558E 01
1.150E 01  3.5839167E 00  1.5711660E 00  9.3809408E-01  3.5365143E 00  9.1515770E 00  8.6566648E 00  1.6809740E 00  1.0928707E 01
1.155E 01  3.6307001E 00  1.5963287E 00  9.5507008E-01  3.5519075E 00  9.2017536E 00  8.7047272E 00  1.6795597E 00  1.0917227E 01
1.160E 01  3.6775303E 00  1.6240788E 00  9.7085267E-01  3.5672541E 00  9.2540874E 00  8.7572184E 00  1.6780539E 00  1.0905096E 01
1.165E 01  3.7242069E 00  1.6502409E 00  9.8607188E-01  3.5827570E 00  9.3099909E 00  8.8120413E 00  1.6764660E 00  1.0892402E 01
```

```
 DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                        PAGE  4  OF RUN  1
 TIME
 Y(30)         Y( 3)           Y(11)           Y(20)           Y( 8)           Y(17)           Y(28)           Y(24)           Y(26)
1.170E 01  3.7709703E 00  1.6758604E 00  1.0037222E 00  3.5986910E 00  9.3678741E 00  8.8685055E 00  1.6747932E 00  1.0879114E 01
1.175E 01  3.8182392E 00  1.7024355E 00  1.0197067E 00  3.6148548E 00  9.4263210E 00  8.9277706E 00  1.6730375E 00  1.0865260E 01
1.180E 01  3.8663330E 00  1.7305346E 00  1.0369234E 00  3.6314783E 00  9.4859390E 00  8.9877501E 00  1.6712027E 00  1.0850873E 01
1.185E 01  3.9155769E 00  1.7596960E 00  1.0558453E 00  3.6484842E 00  9.5474539E 00  9.0495214E 00  1.6692867E 00  1.0835932E 01
1.190E 01  3.9661112E 00  1.7894287E 00  1.0739555E 00  3.6656704E 00  9.6106853E 00  9.1139383E 00  1.6672916E 00  1.0820457E 01
1.195E 01  4.0177479E 00  1.8195295E 00  1.0923948E 00  3.6830997E 00  9.6757441E 00  9.1800032E 00  1.6652184E 00  1.0804473E 01
1.200E 01  4.0702515E 00  1.8501310E 00  1.1120739E 00  3.7007933E 00  9.7427816E 00  9.2478828E 00  1.6630678E 00  1.0787982E 01
```

```
DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                    PAGE  1  OF RUN  1

ORDER OF SYSTEM       =          29
NUMBER OF X'S         =          42
NUMBER OF PARAMETERS  =          50
NUMBER OF DELAYS      =           8
OUTPUT INTERVAL       =          20
INITIAL TIME          =  6.0000E 00
FINAL TIME            =  1.2000E 01
INTEGRATION STEP      =  2.5000E-03

INITIAL Y VALUES

Y( 1) =  2.140599E 01     Y( 2) =  2.943300E 01     Y( 3) =  4.007199E 00     Y( 4) =  2.779099E 01     Y( 5) =  8.608100E-01
Y( 6) =  4.619200E-01     Y( 7) =  1.583200E 03     Y( 8) =  4.210500E 00     Y( 9) =  1.240300E 01     Y(10) =  2.207500E 01
Y(11) =  1.974099E 00     Y(12) =  3.275999E 01     Y(13) =  2.311099E 00     Y(14) =  5.550600E-01     Y(15) =  5.800000E-01
Y(16) =  9.414700E 02     Y(17) =  1.225300E 01     Y(18) =  9.535100E 00     Y(19) =  1.689099E 01     Y(20) =  1.287399E 00
Y(21) =  2.688300E 01     Y(22) =  2.563200E 00     Y(23) =  1.139400E 00     Y(24) =  8.237900E-01     Y(25) =  1.442800E 00
Y(26) =  7.787700E 00     Y(27) =  6.328298E 02     Y(28) =  1.259500E 01     Y(29) =  0.0

INITIAL X VALUES

X( 1) =  1.644942E 00     X( 2) =  1.914976E 00     X( 3) =  2.575386E 01     X( 4) =  2.800000E 01     X( 5) =  7.288405E 01
X( 6) =  7.820958E 01     X( 7) =  1.001277E 02     X( 8) =  9.749997E 01     X( 9) =  9.478989E-01     X(10) =  1.250031E 00
X(11) =  1.933603E 01     X(12) =  2.364996E 01     X(13) =  1.988579E 01     X(14) =  2.115404E 01     X(15) =  2.907300E 02
X(16) =  2.609998E 02     X(17) =  1.666666E 01     X(18) =  1.555555E 01     X(19) =  1.555555E 01     X(20) =  5.180000E 02
X(21) =  9.066177E-01     X(22) =  9.321382E-01     X(23) =  9.676427E-01     X(24) =  1.018100E 00     X(25) =  1.914976E 00
X(26) =  2.800000E 01     X(27) =  7.820958E 01     X(28) =  9.749997E 01     X(29) =  1.250031E 00     X(30) =  2.364996E 01
X(31) =  2.115404E 01     X(32) =  2.609998E 02     X(33) =  6.039324E 02     X(34) =  4.853806E 02     X(35) = -1.065311E 02
X(36) =  0.0              X(37) =  2.185185E 01     X(38) =  0.0              X(39) =  0.0              X(40) =  0.0
X(41) =  0.0              X(42) =  0.0

PARAMETER VALUES

P( 1) =  0.0              P( 2) =  5.000000E-02     P( 3) =  5.000000E-01     P( 4) =  1.000000E 00     P( 5) =  6.393332E 00
P( 6) =  6.786666E 00     P( 7) =  4.000000E 02     P( 8) =  4.000000E 02     P( 9) =  1.000000E 03     P(10) =  3.000000E 01
P(11) =  5.000000E 00     P(12) =  3.933333E-01     P(13) =  9.000000E-01     P(14) =  6.600000E 01     P(15) =  2.400000E 01
P(16) =  1.000000E 01     P(17) =  3.200000E 01     P(18) =  4.400000E 01     P(19) =  7.299999E 00     P(20) =  5.000000E 01
P(21) =  1.500000E 00     P(22) =  1.200000E 00     P(23) =  2.200000E 03     P(24) =  6.599999E 00     P(25) =  2.200000E 01
P(26) =  3.700000E 01     P(27) =  6.299999E 00     P(28) =  6.100000E 01     P(29) =  5.299999E 00     P(30) =  1.500000E 00
P(31) =  5.800000E-01     P(32) =  1.500000E 03     P(33) =  2.300000E 01     P(34) =  1.800000E 01     P(35) =  3.000000E 01
P(36) =  5.799999E 00     P(37) =  5.300000E 01     P(38) =  5.599999E 00     P(39) =  2.000000E 00     P(40) =  1.900000E 00
P(41) =  1.919999E 00     P(42) =  1.200000E 01     P(43) =  1.100000E 03     P(44) =  2.979999E 01     P(45) =  6.000000E 00
P(46) =  0.0              P(47) =  0.0              P(48) =  0.0              P(49) =  0.0              P(50) =  0.0

TIME DELAYS

F( 1) =  3.933333E-01     F( 2) =  3.933333E-01     F( 3) =  3.933333E-01     F( 4) =  3.933333E-01     F( 5) =  3.933333E-01
F( 6) =  3.933333E-01     F( 7) =  3.933333E-01     F( 8) =  3.933333E-01
```

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 DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                    PAGE  2  OF RUN  1
  TIME
 Y(30)         Y( 2)           Y(10)           Y(19)           Y(15)           Y(25)           Y( 7)           Y(16)           Y(27)
6.000E 00  2.9432999E 01  2.2074997E 01  1.6890991E 01  5.7999998E-01  1.4427996E 00  1.5832000E 03  9.4146997E 02  6.3282983E 02
6.050E 00  2.9691513E 01  2.2662674E 01  1.7711502E 01  5.6299710E-01  1.4457331E 00  1.5935933E 03  9.5255347E 02  6.4174365E 02
6.100E 00  2.9937622E 01  2.3174164E 01  1.8408661E 01  5.5406368E-01  1.4487228E 00  1.6038875E 03  9.6364209E 02  6.5051685E 02
6.150E 00  3.0175827E 01  2.3623032E 01  1.9003723E 01  5.4534107E-01  1.4518023E 00  1.6140920E 03  9.7471997E 02  6.5933569E 02
6.200E 00  3.0400036E 01  2.4020538E 01  1.9515335E 01  5.3683871E-01  1.4549704E 00  1.6243430E 03  9.8577612E 02  6.6818213E 02
6.250E 00  3.0629089E 01  2.4375931E 01  1.9958527E 01  5.2856588E-01  1.4582176E 00  1.6345464E 03  9.9680249E 02  6.7701855E 02
6.300E 00  3.0846451E 01  2.4696838E 01  2.0345459E 01  5.2053148E-01  1.4615459E 00  1.6447185E 03  1.0077932E 03  6.8584570E 02
6.350E 00  3.1058655E 01  2.4989487E 01  2.0686417E 01  5.1274383E-01  1.4649572E 00  1.6548857E 03  1.0187424E 03  6.9467505E 02
6.400E 00  3.1266281E 01  2.5254654E 01  2.0989899E 01  5.0521302E-01  1.4684477E 00  1.6650342E 03  1.0296973E 03  7.0349023E 02
6.450E 00  3.1470001E 01  2.5486511E 01  2.1262711E 01  4.9795097E-01  1.4720144E 00  1.6751626E 03  1.0405969E 03  7.1227661E 02
6.500E 00  3.1670288E 01  2.5716766E 01  2.1510406E 01  4.9094647E-01  1.4756584E 00  1.6852759E 03  1.0512966E 03  7.2103320E 02
6.550E 00  3.1870956E 01  2.5948990E 01  2.1741501E 01  4.8417991E-01  1.4794102E 00  1.6957974E 03  1.0620664E 03  7.2989648E 02
6.600E 00  3.2080261E 01  2.6188370E 01  2.1964493E 01  4.7762376E-01  1.4832716E 00  1.7066726E 03  1.0729736E 03  7.3882056E 02
6.650E 00  3.2297058E 01  2.6434967E 01  2.2180939E 01  4.7129393E-01  1.4872293E 00  1.7179333E 03  1.0840679E 03  7.4773853E 02
6.700E 00  3.2520538E 01  2.6688354E 01  2.2391998E 01  4.6520036E-01  1.4912834E 00  1.7295439E 03  1.0953540E 03  7.5666431E 02
6.750E 00  3.2750198E 01  2.6947906E 01  2.2598770E 01  4.5935184E-01  1.4954262E 00  1.7414712E 03  1.1066843E 03  7.6556763E 02
6.800E 00  3.2985611E 01  2.7212250E 01  2.2800735E 01  4.5375824E-01  1.4996824E 00  1.7536951E 03  1.1180522E 03  7.7460645E 02
6.850E 00  3.3226349E 01  2.7480591E 01  2.3009781E 01  4.4843060E-01  1.5039349E 00  1.7661990E 03  1.1294724E 03  7.8289795E 02
6.900E 00  3.3472672E 01  2.7752945E 01  2.3223450E 01  4.4338053E-01  1.5082741E 00  1.7790583E 03  1.1410002E 03  7.9125513E 02
6.950E 00  3.3723541E 01  2.8028397E 01  2.3443222E 01  4.3862015E-01  1.5126753E 00  1.7923462E 03  1.1527432E 03  7.9948560E 02
7.000E 00  3.3978958E 01  2.8306290E 01  2.3666550E 01  4.3415576E-01  1.5171661E 00  1.8060044E 03  1.1646511E 03  8.0784717E 02
7.050E 00  3.4235794E 01  2.8582825E 01  2.3890015E 01  4.3002170E-01  1.5216808E 00  1.8196470E 03  1.1764834E 03  8.1605688E 02
7.100E 00  3.4488724E 01  2.8853149E 01  2.4109802E 01  4.2624861E-01  1.5262022E 00  1.8331619E 03  1.1880923E 03  8.2417798E 02
7.150E 00  3.4738037E 01  2.9117676E 01  2.4326050E 01  4.2282903E-01  1.5307207E 00  1.8465566E 03  1.1995332E 03  8.3217578E 02
7.200E 00  3.4984009E 01  2.9376846E 01  2.4538571E 01  4.1975206E-01  1.5352364E 00  1.8598359E 03  1.2107690E 03  8.4006665E 02
7.250E 00  3.5226852E 01  2.9631149E 01  2.4748627E 01  4.1700798E-01  1.5397444E 00  1.8730066E 03  1.2218262E 03  8.4783398E 02
7.300E 00  3.5466797E 01  2.9880966E 01  2.4955139E 01  4.1458452E-01  1.5442400E 00  1.8860730E 03  1.2326816E 03  8.5548169E 02
7.350E 00  3.5704010E 01  3.0126663E 01  2.5158615E 01  4.1246969E-01  1.5487194E 00  1.8990398E 03  1.2433430E 03  8.6299731E 02
7.400E 00  3.5938675E 01  3.0368484E 01  2.5359161E 01  4.1065043E-01  1.5531788E 00  1.9119094E 03  1.2538018E 03  8.7038013E 02
7.450E 00  3.6170959E 01  3.0606705E 01  2.5556885E 01  4.0911341E-01  1.5576134E 00  1.9246843E 03  1.2640571E 03  8.7762329E 02
7.500E 00  3.6401001E 01  3.0841507E 01  2.5751877E 01  4.0784478E-01  1.5620184E 00  1.9373657E 03  1.2741062E 03  8.8472290E 02
7.550E 00  3.6630066E 01  3.1074417E 01  2.5945282E 01  4.0683562E-01  1.5663843E 00  1.9500056E 03  1.2839695E 03  8.9168945E 02
7.600E 00  3.6859787E 01  3.1307068E 01  2.6138275E 01  4.0607113E-01  1.5706892E 00  1.9625684E 03  1.2935996E 03  8.9848096E 02
7.650E 00  3.7089859E 01  3.1539108E 01  2.6330536E 01  4.0553087E-01  1.5749321E 00  1.9750513E 03  1.3030015E 03  9.0509839E 02
7.700E 00  3.7319592E 01  3.1770355E 01  2.6521835E 01  4.0519506E-01  1.5791092E 00  1.9874521E 03  1.3121665E 03  9.1153833E 02
7.750E 00  3.7549927E 01  3.2000565E 01  2.6712051E 01  4.0504533E-01  1.5832167E 00  1.9997693E 03  1.3211025E 03  9.1780054E 02
7.800E 00  3.7779510E 01  3.2229538E 01  2.6901031E 01  4.0506428E-01  1.5872536E 00  2.0120000E 03  1.3298106E 03  9.2388721E 02
7.850E 00  3.8008591E 01  3.2457153E 01  2.7088669E 01  4.0523559E-01  1.5912180E 00  2.0241428E 03  1.3382930E 03  9.2979810E 02
7.900E 00  3.8237030E 01  3.2683319E 01  2.7274872E 01  4.0554363E-01  1.5951061E 00  2.0361948E 03  1.3465527E 03  9.3553516E 02
7.950E 00  3.8464752E 01  3.2907959E 01  2.7459595E 01  4.0597403E-01  1.5989180E 00  2.0481538E 03  1.3545923E 03  9.4109985E 02
8.000E 00  3.8691666E 01  3.3131012E 01  2.7642776E 01  4.0651304E-01  1.6026525E 00  2.0600171E 03  1.3624148E 03  9.4649365E 02
8.050E 00  3.8913895E 01  3.3348221E 01  2.7820999E 01  4.0714234E-01  1.6062794E 00  2.0715488E 03  1.3698545E 03  9.5160522E 02
8.100E 00  3.9126373E 01  3.3554779E 01  2.7990784E 01  4.0785295E-01  1.6097937E 00  2.0827473E 03  1.3769686E 03  9.5647217E 02
8.150E 00  3.9330246E 01  3.3751892E 01  2.8153152E 01  4.0863746E-01  1.6131983E 00  2.0936460E 03  1.3837581E 03  9.6110986E 02
8.200E 00  3.9526657E 01  3.3940689E 01  2.8308899E 01  4.0948927E-01  1.6164980E 00  2.1042625E 03  1.3902603E 03  9.6553467E 02
8.250E 00  3.9716537E 01  3.4122223E 01  2.8458664E 01  4.1040051E-01  1.6196957E 00  2.1146045E 03  1.3964883E 03  9.6975928E 02
8.300E 00  3.9900635E 01  3.4297333E 01  2.8603058E 01  4.1136283E-01  1.6227932E 00  2.1246829E 03  1.4024524E 03  9.7379150E 02
8.350E 00  4.0079590E 01  3.4466797E 01  2.8742615E 01  4.1236806E-01  1.6257925E 00  2.1345100E 03  1.4081653E 03  9.7763989E 02
8.400E 00  4.0253967E 01  3.4631241E 01  2.8877823E 01  4.1340804E-01  1.6286945E 00  2.1440969E 03  1.4136394E 03  9.8131323E 02
8.450E 00  4.0424240E 01  3.4791245E 01  2.9009094E 01  4.1447484E-01  1.6315031E 00  2.1534529E 03  1.4188867E 03  9.8481934E 02
8.500E 00  4.0590790E 01  3.4947250E 01  2.9136810E 01  4.1556102E-01  1.6342173E 00  2.1625879E 03  1.4239180E 03  9.8816650E 02
8.550E 00  4.0755676E 01  3.5101563E 01  2.9262787E 01  4.1665965E-01  1.6368456E 00  2.1715867E 03  1.4288054E 03  9.9140039E 02
8.600E 00  4.0921356E 01  3.5256470E 01  2.9388733E 01  4.1776043E-01  1.6393852E 00  2.1804402E 03  1.4335286E 03  9.9450806E 02
8.650E 00  4.1087418E 01  3.5411758E 01  2.9514465E 01  4.1885531E-01  1.6418381E 00  2.1891370E 03  1.4380969E 03  9.9749170E 02
8.700E 00  4.1253448E 01  3.5567184E 01  2.9639816E 01  4.1993737E-01  1.6442041E 00  2.1976892E 03  1.4425088E 03  1.0003545E 03
8.750E 00  4.1419266E 01  3.5722504E 01  2.9764740E 01  4.2100090E-01  1.6464863E 00  2.2000000E 03  1.4467732E 03  1.0031003E 03
8.800E 00  4.1584641E 01  3.5877548E 01  2.9889145E 01  4.2204142E-01  1.6486845E 00  2.2000000E 03  1.4508955E 03  1.0057351E 03
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 DYSIMP SIMULATICN PROGRAM        CPTIMAL CCNTROL PARAMETER COMBINATION                        PAGE  3  GF RUN  1
 TIME
Y(30)        Y( 2)          Y(10)          Y(19)          Y(15)          Y(25)          Y( 7)          Y(16)          Y(27)
8.850E 00  4.1749435E 01  3.6032181E 01  3.0000000E 01  4.2305511E-01  1.6508026E 00  2.2000000E 03  1.4548811E 03  1.0082632E 03
8.900E 00  4.1913544E 01  3.6186310E 01  3.C000000E 01  4.2403901E-01  1.6528416E 00  2.2000000E 03  1.4587361E 03  1.0106897E 03
8.950E 00  4.2076904E 01  3.6339844E 01  3.0000000E 01  4.2499077E-01  1.6548061E 00  2.2000000E 03  1.4624651E 03  1.0130193E 03
9.C00E 0C  4.2239456E 01  3.6492737E 01  3.0000000E 01  4.2590851E-01  1.6566963E 00  2.2000000E 03  1.4660735E 03  1.0152561E 03
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9.100E 00  4.2538803E 01  3.6773376E 01  3.0000000E 01  4.2760146E-01  1.6601419E 00  2.2000000E 03  1.4723423E 03  1.0191030E 03
9.150E 00  4.2670578E 01  3.6896698E 01  3.0000000E 01  4.2838275E-01  1.6617012E 00  2.2000000E 03  1.4750886E 03  1.0207820E 03
9.200E 00  4.2792725E 01  3.7000000E 01  3.0000000E 01  4.2912859E-01  1.6631660E 00  2.2000000E 03  1.4776331E 03  1.0223303E 03
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9.550E 00  4.3464218E 01  3.7C00000E 01  3.0000000E 01  4.3349814E-01  1.6713161E 00  2.2000000E 03  1.4909890E 03  1.0304346E 03
9.600E 00  4.3526108E 01  3.7000000E 01  3.0000000E 01  4.3400061E-01  1.6721792E 00  2.2000000E 03  1.4921846E 03  1.0311467E 03
9.650E C0  4.3574890E 01  3.7000000E 01  3.0000000E 01  4.3447846E-01  1.6729650E 00  2.2000000E 03  1.4931936E 03  1.0317559E 03
9.700E 00  4.3612717E 01  3.7000000E 01  3.0000000E 01  4.3493682E-01  1.6736851E 00  2.2000000E 03  1.4940598E 03  1.0322805E 03
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9.900E 00  4.3684753E 01  3.7000000E 01  3.0000000E 01  4.3661726E-01  1.6760149E 00  2.2000000E 03  1.4963660E 03  1.0337505E 03
9.950E 00  4.3688568E 01  3.7000000E 01  3.0000000E 01  4.3700349E-01  1.6764841E 00  2.2000000E 03  1.4967205E 03  1.0339946E 03
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1.010E 01  4.3658569E 01  3.7000000E 01  3.0000000E 01  4.3806481E-01  1.6776009E 00  2.2000000E 03  1.4970269E 03  1.0342698E 03
1.C15E 01  4.3626038E 01  3.7000000E 01  3.0000000E 01  4.3838412E-01  1.6778641E 00  2.2000000E 03  1.4968306E 03  1.0341995E 03
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1.035E 01  4.3420029E 01  3.7000000E 01  3.0000000E 01  4.3956333E-01  1.6785288E 00  2.2000000E 03  1.4952295E 03  1.0334646E 03
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1.050E 01  4.3215942E 01  3.7000000E 01  3.0000000E 01  4.4036859E-01  1.6787224E 00  2.2000000E 03  1.4933831E 03  1.0325784E 03
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1.065E 01  4.2930145E 01  3.7000000E 01  3.0000000E 01  4.4108474E-01  1.6785860E 00  2.2000000E 03  1.4903225E 03  1.0309758E 03
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1.075E 01  4.2680862E 01  3.6781631E 01  3.0000000E 01  4.4153273E-01  1.6783266E 00  2.2000000E 03  1.4877532E 03  1.0296431E 03
1.080E 01  4.2544449E 01  3.6642334E 01  3.0000000E 01  4.4175279E-01  1.6781588E 00  2.2000000E 03  1.4863342E 03  1.0289224E 03
1.C85E 01  4.2401932E 01  3.6497025E 01  3.0000000E 01  4.4197190E-01  1.6779661E 00  2.2000000E 03  1.4848674E 03  1.0281528E 03
1.090E 01  4.2254318E 01  3.6346344E 01  3.0000000E 01  4.4218880E-01  1.6777534E 00  2.2000000E 03  1.4833054E 03  1.0273665E 03
1.095E 01  4.2102386E 01  3.6191238E 01  3.0000000E 01  4.4240487E-01  1.6775208E 00  2.2000000E 03  1.4817075E 03  1.0265344E 03
1.100E 01  4.1946793E 01  3.6032669E 01  3.0000000E 01  4.4261891E-01  1.6772709E 00  2.2000000E 03  1.4800354E 03  1.0256909E 03
1.105E 01  4.1785172E 01  3.5867859E 01  2.9939682E 01  4.4282877E-01  1.6769924E 00  2.2000000E 03  1.4782346E 03  1.0247546E 03
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1.115E 01  4.1436401E 01  3.5513885E 01  2.9663010E 01  4.4323844E-01  1.6763535E 00  2.2000000E 03  1.4743394E 03  1.0227239E 03
1.120E 01  4.1252106E 01  3.5327271E 01  2.9515915E 01  4.4343978E-01  1.6759949E 00  2.2000000E 03  1.4722727E 03  1.0216252E 03
1.125E 01  4.1062637E 01  3.5135605E 01  2.9364227E 01  4.4363886E-01  1.6756163E 00  2.2000000E 03  1.4701233E 03  1.0204988E 03
1.130E 01  4.0868805E 01  3.4939697E 01  2.9208664E 01  4.4383603E-01  1.6752138E 00  2.2000000E 03  1.4679060E 03  1.0193105E 03
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1.150E 01  4.0061081E 01  3.4126556E 01  2.8557327E 01  4.4460142E-01  1.6734018E 00  2.2000000E 03  1.4583562E 03  1.0141506E 03
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1.160E 01  3.9621826E 01  3.3686447E 01  2.8202927E 01  4.4495702E-01  1.6723280E 00  2.2000000E 03  1.4528037E 03  1.0110537E 03
1.165E 01  3.9384949E 01  3.3449585E 01  2.8012405E 01  4.4512743E-01  1.6717424E 00  2.1945137E 03  1.4497910E 03  1.0093911E 03
```
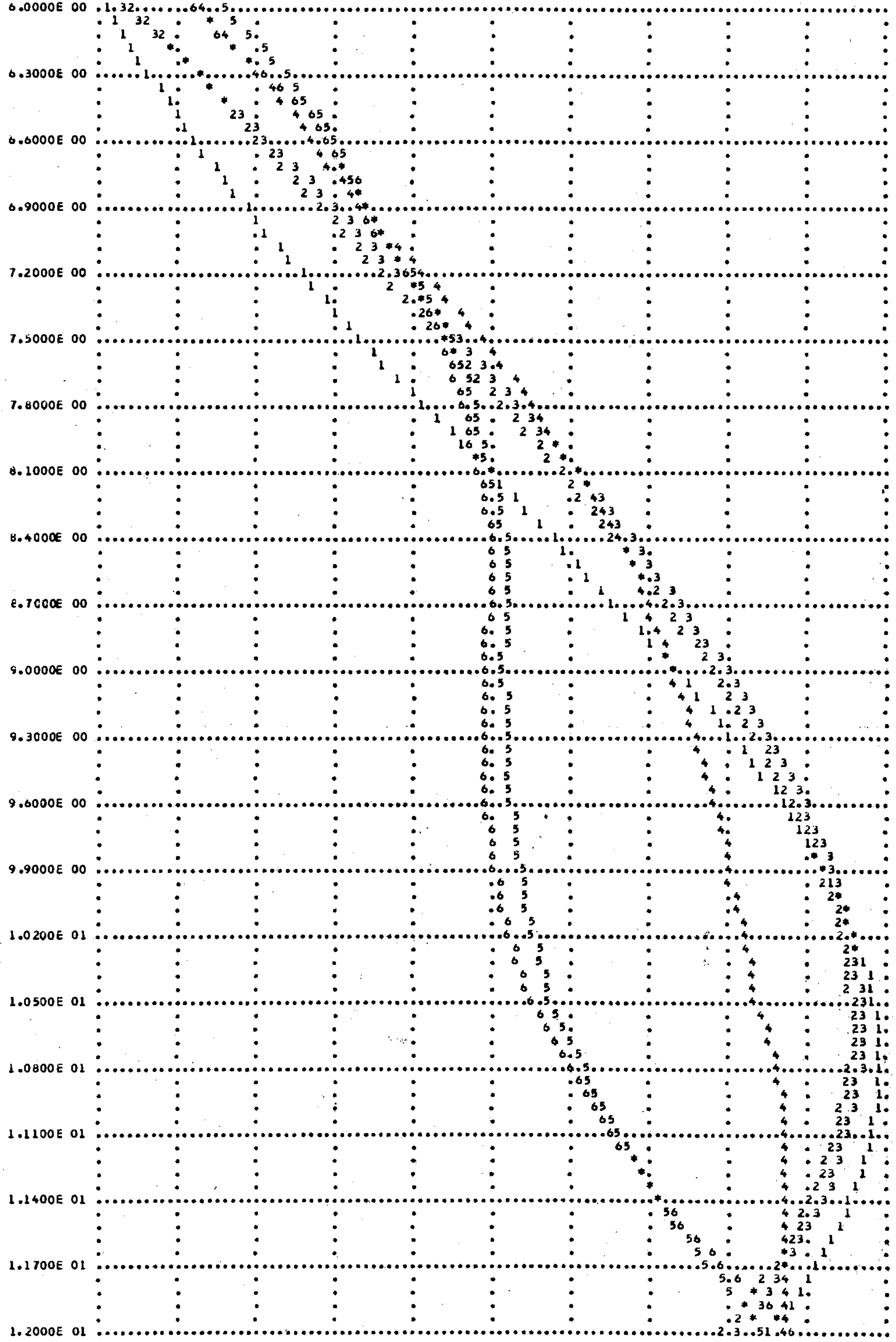

```
 DYSIMP SIMULATICN PROGRAM        CPTIMAL CCNTROL PARAMETER COMBINATION                        PAGE  4  OF RUN  1
 TIME
Y(30)        Y( 2)          Y(10)          Y(19)          Y(15)          Y(25)          Y( 7)          Y(16)          Y(27)
1.170E 01  3.9139343E 01  3.3204025E 01  2.7815125E 01  4.4529444E-01  1.6711245E 00  2.1862075E 03  1.4466462E 03  1.0076411E 03
1.175E 01  3.8686551E 01  3.2951416E 01  2.7611725E 01  4.4545847E-01  1.6704769E 00  2.1776021E 03  1.4433738E 03  1.0058157E 03
1.180E 01  3.8627808E 01  3.2692993E 01  2.7403366E 01  4.4561952E-01  1.6698008E 00  2.1687053E 03  1.4399678E 03  1.0039250E 03
1.185E 01  3.8364120E 01  3.2429688E 01  2.7190811E 01  4.4577748E-01  1.6690950E 00  2.1595278E 03  1.4364258E 03  1.0019475E 03
1.190E 01  3.8096268E 01  3.2162247E 01  2.6974442E 01  4.4593221E-01  1.6683607E 00  2.1500781E 03  1.4327483E 03  9.9988916E 02
1.195E C1  3.7824814E 01  3.1891327E 01  2.6754898E 01  4.4608343E-01  1.6675987E 00  2.1403635E 03  1.4289355E 03  9.9775830E 02
1.200E 01  3.7550247E 01  3.1617477E 01  2.6532715E 01  4.4623083E-01  1.6668081E 00  2.1303909E 03  1.4249883E 03  9.9554663E 02
```

```
DYSIMP SIMULATICN PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                  PAGE  5  OF RUN  1
                 Y( 1) =  2.131E 01           SYMBOL = 1,    SCALE FACTCR =  1.000E 00          Y( 1) =  3.131E 01
                 Y( 9) =  1.197E 01           SYMBOL = 2,    SCALE FACTOR =  1.000E 00          Y( 9) =  2.197E 01
                 Y(18) =  9.284E 00           SYMBOL = 3,    SCALE FACTOR =  8.000E-01          Y(18) =  1.728E 01
                 Y( 4) =  2.390E 01           SYMBOL = 4,    SCALE FACTOR =  3.000E 00          Y( 4) =  5.390E 01
                 Y(12) =  2.809E 01           SYMBOL = 5,    SCALE FACTOR =  3.000E 00          Y(12) =  5.809E 01
                 Y(21) =  2.455E 01           SYMBOL = 6,    SCALE FACTOR =  2.000E 00          Y(21) =  4.455E 01
   TIME                                       SYMBOL = *,    FOR COINCIDENT POINTS
```



```
DYSIMP SIMULATION PROGRAM        OPTIMAL CONTROL PARAMETER COMBINATION                          PAGE  5  OF RUN  1
                Y( 5) =  8.399E-01            SYMBOL = 1,   SCALE FACTOR =  6.000E-02             Y( 5) =  1.440E 00
                Y(13) =  1.844E 00            SYMBOL = 2,   SCALE FACTOR =  3.000E-01             Y(13) =  4.844E 00
                Y(22) =  2.155E 00            SYMBOL = 3,   SCALE FACTOR =  3.000E-01             Y(22) =  5.155E 00
                Y( 6) =  4.539E-01            SYMBOL = 4,   SCALE FACTOR =  7.000E-02             Y( 6) =  1.154E 00
                Y(14) =  5.183E-01            SYMBOL = 5,   SCALE FACTOR =  7.000E-02             Y(14) =  1.218E 00
                Y(23) =  1.102E 00            SYMBOL = 6,   SCALE FACTOR =  7.000E-02             Y(23) =  1.802E 00
        TIME                                  SYMBOL = *,   FOR COINCIDENT POINTS
     6.0000E 00 .4.1.*........3.2....................................................................................
                .  4 1 56 .    3 2  .         .         .         .         .         .         .         .         .
                .   4 1  56      3 2.         .         .         .         .         .         .         .         .
                .     4 1 .5 6     32         .         .         .         .         .         .         .         .
                .      4 1.  5 6    .32       .         .         .         .         .         .         .         .
     6.3000E 00 .........4.1...5..6....*.............................................................................
                .         .41     5 6   32    .         .         .         .         .         .         .         .
                .         .  41     5  6  *   .         .         .         .         .         .         .         .
                .         .   41    . 5  6  * .         .         .         .         .         .         .         .
                .         .     41  .   5   623         .         .         .         .         .         .         .
     6.6000E 00 ..................41......5...623....................................................................
                .         .         *       5 .  *3     .         .         .         .         .         .         .
                .         .         . *       5   2*    .         .         .         .         .         .         .
                .         .         .   *     . 5   236 .         .         .         .         .         .         .
                .         .         .    *    .    5 2 36         .         .         .         .         .         .
     6.9000E 00 ...........................*.........5.2.36..........................................................
                .         .         .        *.        5.2 3 6    .         .         .         .         .         .
                .         .         .         .*        .5 2 3 6  .         .         .         .         .         .
                .         .         .         .  *      .  52 3  6.         .         .         .         .         .
                .         .         .         .    *    .    52 3 .6        .         .         .         .         .
     7.2000E 00 .....................................*.........52.3..6...............................................
                .         .         .         .        *.       52. 3  6    .         .         .         .         .
                .         .         .         .         .*        52 3   6  .         .         .         .         .
                .         .         .         .         .  14     . *  3   6.         .         .         .         .
                .         .         .         .         .    14   .   * 3   6         .         .         .         .
     7.5000E 00 ...............................................14......25.3...6......................................
                .         .         .         .         .        14      253.   6     .         .         .         .
                .         .         .         .         .         14      25.3    6   .         .         .         .
                .         .         .         .         .         . 14      253    6  .         .         .         .
                .         .         .         .         .         .   14     .25 3    6.         .         .         .
     7.8000E 00 ........................................................14....25.3....6..............................
                .         .         .         .         .         .       14.    253  .6        .         .         .
                .         .         .         .         .         .         *     253 . 6       .         .         .
                .         .         .         .         .         .         .14   25 3.   6     .         .         .
                .         .         .         .         .         .         .  14  25 3    6    .         .         .
     8.1000E 00 .................................................................*..25.3....6........................
                .         .         .         .         .         .         .     14 25 3    6  .         .         .
                .         .         .         .         .         .         .       * 25 3    6 .         .         .
                .         .         .         .         .         .         .         *25 3    6.         .         .
                .         .         .         .         .         .         .         .1*5 3    6         .         .
     8.4000E 00 .........................................................................*5.3....6...................
                .         .         .         .         .         .         .         .   *  3  . 6       .         .
                .         .         .         .         .         .         .         .    **3  .  6      .         .
                .         .         .         .         .         .         .         .    25*3 .  6      .         .
                .         .         .         .         .         .         .         .     * *3.   6     .         .
     8.7000E 00 .............................................................................*.*1...6................
                .         .         .         .         .         .         .         .      *  3*   6    .         .
                .         .         .         .         .         .         .         .       * .3*  6    .         .
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                .         .         .         .         .         .         .         .       52. 3  416  .         .
     9.0000E 00 ..............................................................................5.2.3.4.16.............
                .         .         .         .         .         .         .         .        52  3 4 *  .         .
                .         .         .         .         .         .         .         .        5.2 3  461 .         .
                .         .         .         .         .         .         .         .        5.2  3  461.         .
                .         .         .         .         .         .         .         .        5. 2 3   * 1         .
     9.3000E 00 ................................................................................5.2.3...64.1.........
                .         .         .         .         .         .         .         .         5  2 3  6 4 1       .
                .         .         .         .         .         .         .         .         5  2 3   64 1       .
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     9.6000E 00 .................................................................................5..2.3..6..4.1......
                .         .         .         .         .         .         .         .         .5  2 3  6.  4 1    .
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                .         .         .         .         .         .         .         .         .5  2 3   6   4 1   .
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     9.9000E 00 ..................................................................................5.2.3...6....41....
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                .         .         .         .         .         .         .         .         .  52 3   6      41 .
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                .         .         .         .         .         .         .         .         .  52 3   .6    14  .
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                .         .         .         .         .         .         .         .         .   * 3   .6    14  .
                .         .         .         .         .         .         .         .         .   * 3   .6    14  .
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     1.2000E 01 ............................................................................213................*.4...
```

2

VITA

Gregory Dean Martin

Candidate for the Degree of

Master of Science

Thesis: OPTIMAL CONTROL OF AN OIL REFINERY WASTE TREATMENT FACILITY: A TOTAL ECOSYSTEM APPROACH

Major Field: Mechanical Engineering

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, January 21, 1949, the son of Mr. and Mrs. Howard B. Martin.

Education: Graduated from Northeast High School, Oklahoma City, Oklahoma in May, 1967; received the Bachelor of Science degree, with a major in Mechanical Engineering, from Oklahoma State University, Stillwater, Oklahoma, in January, 1972; completed the requirements for the degree of Master of Science in May, 1973.

Professional Experience: Special Technical Student, Western Electric Company, Summer, 1971; Process Engineer, Whirlpool Corporation, Summer, 1972; Project Assistant on research project at Oklahoma State University (NSF-Center for Systems Science) 1972 to date.

Professional Organizations: Member of National Society of Professional Engineers, Oklahoma Society of Professional Engineers (ET-2502), American Society of Mechanical Engineers, American Institute of Aeronautics and Astronautics, Pi Tau Sigma, and Sigma Tau.