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MIXED INTEGER PROGRAMMING MODELS FOR WATER RESOURCES MANAGEMENT

by
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ABSTRACT

A regional water quality control model is developed by linking a steady-state water quality simulation model with an optimization model. The water quality simulation model can be applied to complex river systems with both point and nonpoint loads using multiple interdependent pollution parameters described by either linear or nonlinear equations. Twelve water quality parameters can be modeled simultaneously: four nonconservative constituents (or conservative constituents if the decay rate is set equal to zero); coliform bacteria (MPN); phosphorus; biochemical oxygen demand (BOD); ammonia (NH_3); nitrate (NO_3); dissolved oxygen (DO); temperature (°C); and algae. The water quality model is used to generate constraint equations for the optimization model. The optimization model is formulated as an integer programming problem in which the integer decision variables are wastewater treatment levels or diffuse source management practices to be determined for each load. The model considers the addition or upgrading of wastewater treatment with structural and nonstructural schemes for both point and diffuse pollution sources. A least cost solution is found subject to water quality standards at surveillance points. Additional constraints can include uniform and zoned uniform treatment. Low flow augmentation and bypass piping can be considered with slight water quality simulation model modification. A simulation model-optimization model iteration procedure is used to find an optimum solution.

The regional water quality model is applied to two problems, a hypothetical problem and the Jordan River in Utah. The hypothetical problem consists of four pollution discharge points, at which seven possible treatment levels are available for six quality constituents: phosphorus; biochemical oxygen demand; ammonia; nitrate; dissolved oxygen; and algae. Water quality standards for three constituents are imposed at five surveillance points along the river. The portion of the Jordan River examined consists of seven pollution discharge points, at which seven treatment levels are available for the same six quality constituents as in the hypothetical problem. Water quality standards for two constituents are imposed at three surveillance points. The cost minimization problem for the Jordan River (1975 flows) required tertiary sand filters at all point loads at an increase from current costs of $1,795,881 per year to meet stream water quality standards.

To assist in gaining familiarity with the linked simulation-optimization model, several sensitivity studies are performed. The sensitivity of the optimal solution to two model input parameters is investigated. These parameters are the water quality equation coefficients and the water quality stream standards. Substantial reductions in treatment costs were possible by making minor changes in some of the input parameters. In the hypothetical problem, 10 percent increase in the ammonia decay rate or a 15 percent increase in the maximum specific algae growth rate would result in a 16 percent reduction in the minimum system treatment cost. A 10 percent relaxation of the stream standards at all surveillance points would result in a 54 percent reduction in the minimum system treatment costs. The optimal solution's sensitivity to changes in headwater and point discharge flow is also investigated. The optimal treatment scheme for the projected 1995 flows on the Jordan River was the same as for the 1975 flows. The increase from current costs for the 1995 flows was $2,407,092 per year.

CHAPTER I

INTRODUCTION

Background

To effectively manage the water and related land resources of a river basin so as to provide adequate water of a quality required to sustain towns and cities, economic and agricultural production, and recreational and environmental uses, a tool is needed which will select treatment technologies for pollution sources (point and diffuse) to meet stream quality requirements. In order to determine the optimal combinations of technologies, a model that 1) predicts the stream quality at various control points given treatment combinations and pollutant discharges from activities within a river basin, and 2) finds the minimum cost combination for treatment of point and diffuse pollution sources which will satisfy water quality standards for various beneficial water uses is necessary. The first problem suggests the use of a simulation model, to predict stream qualities given the treatments and residual loadings as solved by an optimization model. The second problem implies least cost optimization approach with stream quality constraints which depend on the flow conditions and stream characteristics. The overall approach indicated is a linking of a stream water quality simulation model with a treatment cost minimization model in order to combine their capabilities in analyzing the total waste load allocation problem. Hughes et al. (1976) showed that integer and mixed integer programming models were practical for solving problems of this structure.

A conceptual structure of the river basin water quality control problem is shown in Figure 1-1. Level I is where policy is formulated and final decisions are made on plan implementation. On Level II, technical decision-makers put together management alternatives which satisfy the numerous and diverse policy constraints determined at Level I. Level III consists of a number of management tools (computer programs) which assist the technical decision-maker in reaching an optimal plan or a series of "good" alternatives which satisfy policy constraints.

Objective

The overall objective of this study is to investigate and evaluate the applicability of a regional water quality control model which links an optimization model proposed by Bishop and Grenney (1976) to a nonlinear stream simulation model. To achieve this objective the optimization model is modified so that it can be used with a nonlinear simulation model and the stream simulation model is modified so that it can represent nonlinear systems and so that it can be easily linked to the optimization model. The linked models are then applied to two river basins for testing and evaluation. Convergence criteria for the optimal solution are investigated and an evaluation is made of the sensitivity of the optimal solution to various model input parameters.

Summary of Contents

A detailed description of the stream simulation model is presented in Chapter II. Sections on river system layout, program procedure,

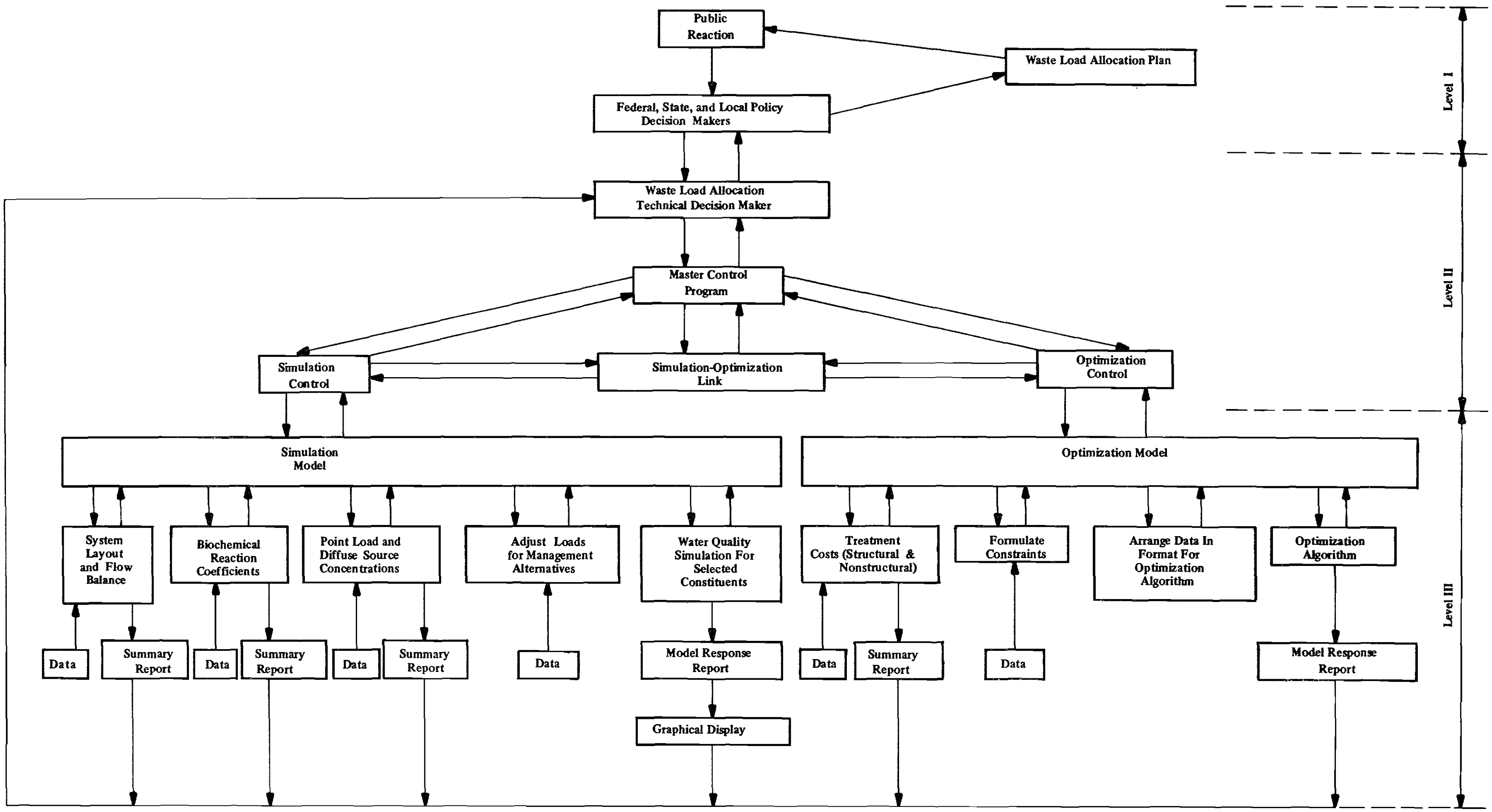

Figure 1-1. Example of a possible flow of information for obtaining optimal basin wide management.

water balance equations, water quality equations, and solution technique are included.

Chapter III is divided into two parts. The first part is a review of the applications of mathematical programming to regional water quality control, and the second part is devoted to the theoretical development of the optimization model used in this study.

Application of the linked simulation-optimization model is described in Chapter IV. The model is first applied to a hypothetical problem and the sensitivity of the optimal solution to several input parameters is shown. The results of the model application to the Jordan River in Utah are then presented. Sections on optimal solution convergence and computational aspects are also included.

The differences between the regional water quality control model and the water supply model described by Hughes et al. (1977) is discussed in Chapter V. Also included is a discussion on linking the regional water quality model with the water supply model.

A summary of the research accomplished in this study is contained in Chapter VI. In addition, several conclusions and recommendations for further work are made.

Subroutine descriptions and flow charts, data input formats, and a program listing for the stream simulation model (SSAM) are shown in Appendices A, B, and C, respectively. Subroutine descriptions and flow chart, data input formats, and program listing for the simulation-optimization linking program (HELPSU) is shown in Appendices D, E, and F, respectively. Appendix G contains an example computer printout of the model application.

CHAPTER II

DESCRIPTION OF THE STREAM SIMULATION MODEL

The Stream Simulation and Assessment Model (SSAM) was chosen as the mathematical model for this study. The model has been successfully applied to six river basins in the Intermountain West. The program was written in Burroughs-B6700/B7700 FORTRAN (comparable to FORTRAN IV, Level H). Subroutine descriptions and flow charts, data input formats, and program listing are provided in Appendices A, B, and C, respectively. The model, SSAM, can be applied to a river system with diffuse surface inflow, groundwater inflow (or outflow) and any reasonable number of tributaries (including second-order tributaries), point loads and point diversions.

River System Layout

Eight types of points may be used to describe the river system. These eight point types are described below:

HEADWATER (H) -- The upstream boundaries of the system which mark the beginning of the first reach in each branch of the river system.

REACH (R) -- A section of river channel having uniform physical characteristics.

JUNCTION (J) -- The confluence of two branches of the river system. Junctions mark the beginning of a new reach for the downstream channel.

POINT LOAD (L) -- Point loads discharging into the river.

POINT DIVERSION (D) -- Point diversions from the river.

CHECK POINT (C) -- An additional point along the river
where calculated output is desired.

EVAPORATION (E) -- A reach where evaporation is significant.

TERMINAL POINT (T) -- The last point in the river system.

Figure 2-1 shows a river system having three headwaters, two junctions, eight reaches (including a reach where evaporation is significant), two point loads, and three check points. Lateral inflows from surface water (Q_S) and groundwater (Q_G) are shown along reach number four.

All model calculations are conducted in metric units. A user option is available, however, that will allow English units for input or output.

Program Procedure

The program examines the system layout input data and assigns a "calculation point" (numbered in sequence from the first headwater) to each type of point in the input. A user option is available to have the program automatically assign additional calculation points at specified intervals within reaches. The segment of channel between two calculation points is defined as an "element." An element is a subsection of a reach. As a general procedure, the model starts at the first headwater in the system and proceeds downstream considering each calculation point in sequence. Changes in flow and water quality which occur during passage through an element are modeled by a system of differential equations. Conditions resulting at the end of one element

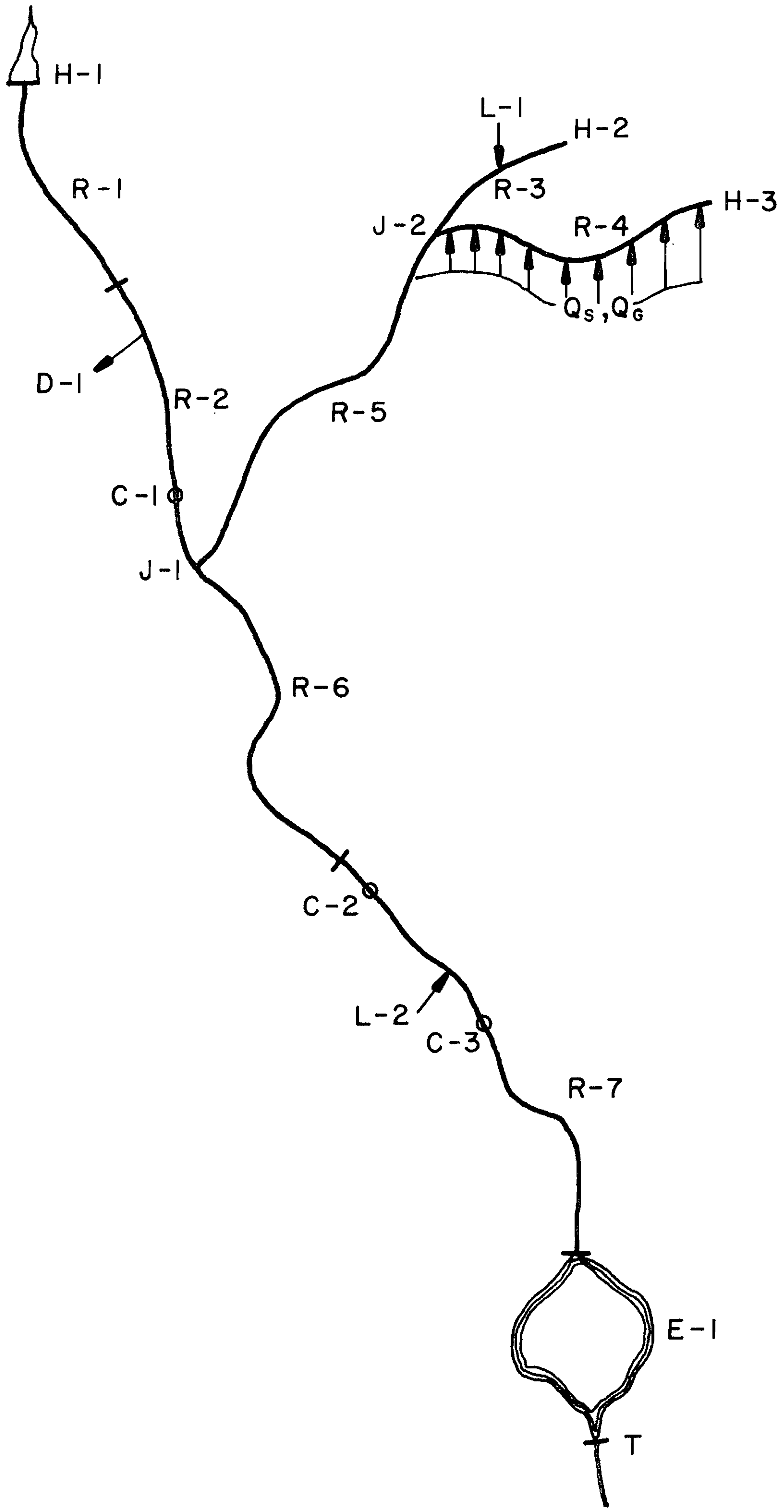

Figure 2-1. Example of a river system layout for the water quality simulation model.

are used to calculate the boundary conditions at the beginning of the next downstream element.

The program was developed to operate through three distinct steps: 1) system layout and flow balance, 2) point and diffuse loadings on the system by selected water quality constituents, and 3) simulation of the water quality constituents. A user option is available to stop the program at the end of any step so that a basin can be modeled a step at a time. The differential equations for step 1 are solved independently from the differential equations representing the water quality constituents (steps 2 and 3). The model starts with a headwater flow and proceeds downstream conducting a flow balance by adding (or subtracting as appropriate) lateral surface flow, lateral subsurface flow, point load flows, and diversion flows. When a junction is encountered, the model jumps to the tributary headwater and proceeds down the tributary in the same way. When the confluence with the main stream is reached, the flows from the two branches are summed and the model continues to conduct a flow balance down the main stream. In addition to calculating flows, the model determines the average velocity, cross-sectional area, and hydraulic radius of each element. A summary of the system layout, flow, and stream characteristics is printed out to provide an easy means for checking the input data and to provide a concise display of the important features of the river system.

The second step in the model is the reading of water quality data. The model automatically reads the appropriate data for the constituents being modeled during any particular run. A summary of the water quality data and the coefficients (after temperature adjustment, if appropriate) is printed out to provide an easy means for checking the input data and to provide a concise display of the constituent loadings on the system.

The third step in the program is the prediction of constituent concentration distributions along the river for the specified flow and loading patterns. Basically, the model simulates the reactions and interactions among constituents occurring in a control volume (C.V.) of water as it travels downstream at a velocity $\overline{V}$. It is assumed that mixing with adjacent C.V.'s (dispersion) is negligible. Mass can be added to the C.V. by lateral inflow and by leaching from the bottom. Oxygen can enter the C.V. by diffusion across the air-water interface and by the photosynthetic oxygen production of benthic and planktonic algae. These reactions and mass transport phenomena are represented in the model by a system of differential equations.

In the prediction step, as in the case of the flow balance step, the model starts at the first headwater, where water quality constituent concentrations are known. These concentrations provide the boundary conditions for the system of equations. Then the concentrations that will occur in the C.V. when it reaches the next cownstream calculation point are predicted. A mass balance is conducted on the C.V. at this point to account for mass added by point loads or for the mixing of two branches at a junction. The concentrations occurring in the C.V. just below this calculation point become new boundary conditions for the differential equations. Then the equations are solved to predict the concentrations which will occur in the C.V. by the time it reaches the next downstream calculation point. The model proceeds downstream, element by element, in this manner. The model then applies user specified treatment levels to selected point and diffuse loads. The treatment levels are applied one at a time to each specified load and the river quality is determined for the entire river system.

Flow Balance Equations

Flow is assumed to be steady (invariant with time) for the entire system. Calculation points are designated at each point load and point diversion and the flows are added to (or subtracted from) the main stream flow as they are encountered by the model. When the groundwater flow is positive (i.e., flows into the main stream) the flow in an element can be represented by the following equation:

$$\frac{dQ}{d\tau} = Q_S\overline{V} + Q_G\overline{V} \tag{2.1}$$

in which

Q = main stream flow (m^3/sec)

τ = travel time (sec)

$\overline{V}$ = average velocity in the main stream (m/sec)

Q_S = lateral surface flow (m^3/sec/m)

Q_G = lateral subsurface flow (m^3/sec/m)

The solution to Equation 2.1 is:

$$Q = Q_o + (Q_S + Q_G)\ \Delta x \tag{2.2}$$

and

$$\Delta x = \overline{V}\Delta\tau \tag{2.3}$$

in which

Q_o = flow at the start of the element (m^3/sec)

Q = flow at the end of the element (m^3/sec)

Δx = length of the element (m)

$\Delta \tau$ = travel time through the element (sec)

The average flow in the element ($\overline{Q}$) is:

$$\overline{Q} = \frac{Q + Q_o}{2} \tag{2.4}$$

When the stream is recharging the groundwater (i.e., groundwater flow is negative), it is convenient to assume that the recharge rate varies with the flow in the stream so that the flow in an element can be represented by the following equation:

$$\frac{dQ}{d\tau} = Q_S\overline{V} - K_G\overline{V}Q \tag{2.5}$$

in which

K_G = the fraction of main stream flow lost per meter

The solution to Equation 2.5 is:

$$Q = \frac{Q_S}{K_G} + \left(Q_o - \frac{Q_S}{K_G}\right) e^{-K_G \Delta x} \tag{2.6}$$

It can be shown that the average flow in the element is:

$$\overline{Q} = \left[\frac{Q_S}{\Delta x K_G{}^2} - \frac{Q_o}{\Delta x K_G}\right] \left[e^{-K_G \Delta x} - 1.0\right] + \frac{Q_S}{K_G} \tag{2.7}$$

The average velocity ($\overline{V}$) in an element is calculated by the equation:

$$\overline{V} = \beta_1 \overline{Q}^{\beta_2} \tag{2.8}$$

in which

β_1 and β_2 = empirical coefficients for a stream reach

Two options are available to the user for calculating the average hydraulic radius ($\overline{R}$) of an element which is used in the water quality equations. One option is based on Mannings equation expressed as follows:

$$\overline{R} = \left[\frac{n\ \overline{V}}{S^{1/2}} \right]^{1.5} \tag{2.9}$$

in which

S = average slope of a stream reach

n = Mannings coefficient for the reach

The other option is based on an empirical relationship between the hydraulic radius and the average cross-sectional area of the flow ($\overline{A}$):

$$\overline{R} = \beta_3 \overline{A}^{\beta_4} \tag{2.10}$$

and

$$\overline{A} = \frac{\overline{Q}}{\overline{V}} \tag{2.11}$$

in which

β_3 and β_4 = empirical coefficients for a stream reach

Water Quality Equations

The water quality equations are based upon a one-dimensional channel transport equation that can be expressed as follows:

$$\frac{\partial\ (AX)}{\partial t} = \frac{\partial}{\partial x} (AD\ \frac{\partial X}{\partial x}) - \frac{\partial\ (VAX)}{\partial\ x} + S \tag{2.12}$$

in which

X = constituent concentration (mg/1)
t = time (sec)
x = distance along the channel (m)
A = cross-sectional area (m^2)
D = longitudinal dispersion coefficient (m^2/sec)
V = average velocity over the cross-section (m/sec)
S = other sources or sinks (mg/l/sec)

Equation 2.12 represents the change with time of the mass in some differential element (Figure 2-2). The first term on the right-hand side of the equation is the dispersion term and represents the transport of material due to nonuniform velocity gradients in the river profile. The second term represents the downstream advection of the material.

According to Grenney et al. (1976) many stream simulation models assume dispersion and can be neglected. If the longitudinal dispersion is assumed negligible, the flow is assumed nonuniform (inflow allowed), sources and sinks are assumed to be from the lateral surface and groundwater flow and the streambed, and noting that $Q = VA$, Equation 2.12 becomes:

$$\frac{\partial AX}{\partial t} = \bar{C} \frac{\partial Q}{\partial x} - Q \frac{\partial X}{\partial x} + Q_S X_S + Q_G X_G + \frac{LA}{R} \qquad (2.13)$$

in which

Q = river flow (m^3/sec)
Q_S = lateral surface inflow (m^3/sec/m)
Q_G = lateral groundwater inflow (m^3/sec/m)
L = benthic leaching rate (mg/m^2/sec)

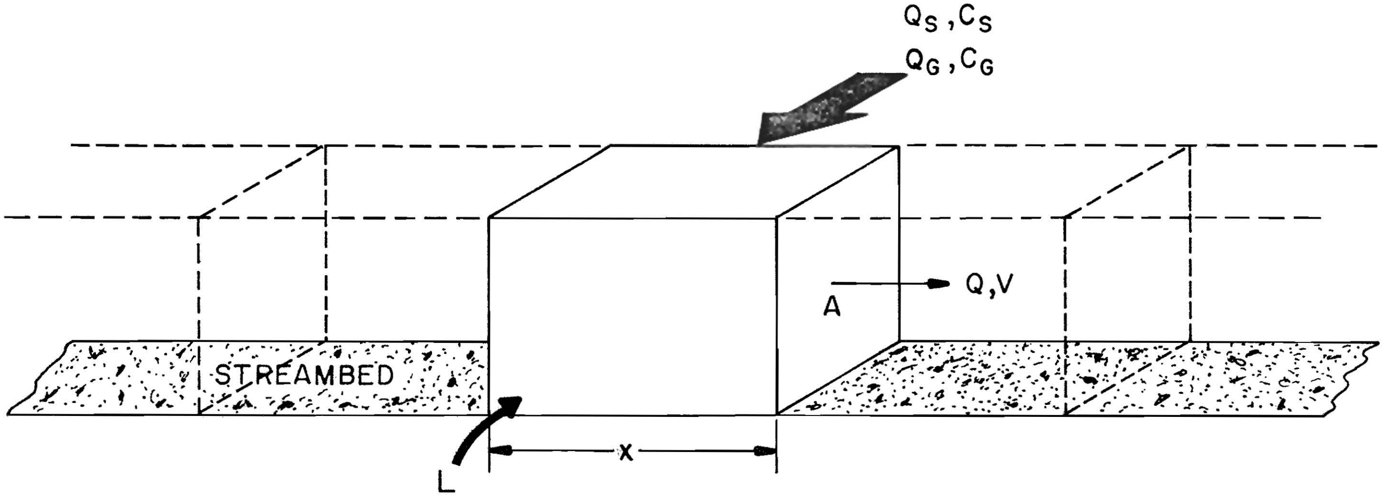

Figure 2-2. Model conceptualization of a stream element.

R = hydraulic radius (m)

X_S = constituent concentration in lateral surface inflow (mg/l)

X_G = constituent concentration in lateral groundwater inflow (mg/l)

If steady-state is assumed:

$$\frac{\partial AX}{\partial t} = 0$$

Equation 2.13 can be simplified to:

$$\frac{dX}{dx} = \frac{-X}{Q}\frac{dQ}{dx} + \frac{Q_S X_S}{Q} + \frac{Q_G X_G}{Q} + \frac{LA}{RQ} \tag{2.14}$$

Since

$$\frac{dQ}{dx} = Q_S + Q_G$$

and

$$dx = \overline{V}\, d\tau$$

letting

$$Q = \overline{X}A$$

in a reach where

$\overline{V}$ = average reach velocity

then

$$\frac{dX}{d\tau} = \frac{-X\ (Q_S + Q_G)}{A} + \frac{Q_S X_S + Q_G X_G}{A} + \frac{L}{R}$$

or

$$\frac{dX}{d\tau} = \frac{Q_S\ (X_S - X) + Q_G\ (X_G - X)}{A} + \frac{L}{R} \tag{2.15}$$

in which

τ = travel time (sec)

When Equation 2.15 is applied to a nonconservative constituent and to a reach with average cross-sectional area $\bar{A}$ and average hydraulic radius $\bar{R}$, it becomes:

$$\frac{dX}{d\tau} = \alpha + \frac{L}{\bar{R}} + \frac{Q_S\ (X_S - X) + Q_G\ (X_G - X)}{\bar{A}} \qquad (2.16)$$

in which

α = rate of loss or gain of the constituent due to biological reactions, physical removal or phase transfers (mg/l/sec)

For simplicity, the last two terms in Equation 2.16 can be expressed as:

$$S = \frac{L}{\bar{R}} + \frac{(S_S + S_G)}{\bar{A}} \qquad (2.17)$$

in which

$$S_S = \begin{cases} Q_S\ (X_S - X) & : \text{(Flow into reach; } Q_S \text{ positive)} \\ 0 & : \text{(Flow out of reach; } Q_S \text{ negative)} \end{cases}$$

$$S_G = \begin{cases} Q_G\ (X_G - X) & : \text{(Flow into reach; } Q_G \text{ positive)} \\ 0 & : \text{(Flow out of reach; } Q_G \text{ negative)} \end{cases}$$

so Equation 2-16 becomes:

$$\frac{dX}{d\tau} = \alpha + S \qquad (2.18)$$

The water quality model, SSAM, can simulate twelve water quality parameters simultaneously: four nonconservative constituents (or conservative constituents if the decay rate is set equal to zero); coliform bacteria (MPN); phosphorus (P); biochemical oxygen demand (BOD); ammonia (NH_3); nitrate (NO_3); dissolved oxygen (DO); temperature (°C); and algae. The form of the equation for each constituent is identical to Equation 2.18. These equations are summarized in Table 2-1 and are described below. It should be remembered that $\dot{X}_i$ represents the

Table 2-1. Equations used in exact and numeric solution model.

Description	CODE	ICODE	Equation
Nonconservative	NC01	1	
Exact and Numeric			$\dot{X}_1 = -\beta_{1,1}X_1 + S_1$
Nonconservative	NC02	2	
Exact and Numeric			$\dot{X}_2 = -\beta_{2,1}X_2 + S_2$
Nonconservative	NC03	3	
Exact and Numeric			$\dot{X}_3 = -\beta_{3,1}X_3 + \beta_{3,2}\beta_{2,1}X_2 + S_3$
Nonconservative	NC04	4	
Exact and Numeric			$\dot{X}_4 = -\beta_{4,1}X_4 + \beta_{4,2}\beta_{2,1}X_2 + \beta_{4,3}\beta_{3,1}X_3 + S_4$
Coliform	COLI	5	
Exact and Numeric			$\dot{X}_5 = -\beta_{5,1}X_5 + S_5$
Phosphorus	PHOS	6	
Exact			$\dot{X}_6 = -\beta_{6,1}X_6 + S_6$
Numeric			$\dot{X}_6 = -\beta_{6,1}X_6 - \beta_{6,2}\mu X_{12} + S_7$
Biochemical Oxygen Demand	CBOD	7	
Exact			$\dot{X}_7 = -\beta_{7,1}X_7 - \beta_{7,2}X_7 + S_7$
Numeric			$\dot{X}_7 = -\beta_{7,1}X_7 - \beta_{7,2}X_7 + \beta_{7,3}\beta_{12,2}X_{12} + S_7$
Ammonia	NH3N	8	
Exact			$\dot{X}_8 = -\beta_{8,1}X_8 - \beta_{8,2}X_8 + \beta_{8,3}\beta_{7,1}X_7 + S_8$
Numeric			$\dot{X}_8 = -\beta_{8,1}X_8 - \beta_{8,2}X_8 + \beta_{8,3}\beta_{7,1}X_7 - \beta_{8,4}\left(\frac{\beta_{8,5}X_8}{\beta_{8,5}X_8 + X_9}\right)\mu X_{12} + S_8$

Table 2-1. Continued.

Description	CODE	ICODE	Equation
Nitrate	NO3N	9	
Exact			$\dot{X}_9 = -\beta_{9,1}X_9 + \beta_{8,1}X_8 + S_9$
Numeric			$\dot{X}_9 = -\beta_{9,1}X_9 + \beta_{8,1}X_8 - \beta_{9,2}\left(1 - \frac{\beta_{8,5}}{\beta_{8,5}X_8 + X_9}\right)\mu X_{12} + S_9$
Dissolved Oxygen	DOXY	10	
Exact			$\dot{X}_{10} = \beta_{10,1}(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\beta_{8,1}X_8$ $-\beta_{10,4}X_{10}/\overline{R} + S_{10}$
Numeric			$\dot{X}_{10} = \beta_{10,1}(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\beta_{8,1}X_8$ $-\beta_{10,4}X_{10}/\overline{R} + \beta_{10,5}X_{12} + S_{10}$
Temperature	TEMP	11	
Exact and Numeric			$\dot{X}_{11} = \beta_{11,1}(\beta_{11,2} - X_{11}) + S_{11}$
Algae	ALGP	12	
Numeric			$\dot{X}_{12} = \mu X_{12} - \beta_{12,2}X_{12} + S_{12}$

NOTE: $\dot{X}_i$ represents the time derivative of the variable

$$S_i = L_i/\overline{R} + (S_{si} + S_{Gi})/\overline{A} \qquad \mu = \beta_{12,1}\left(\frac{X_6}{\beta_{6,3} + X_6}\right)\left(\frac{\beta_{9,3}X_8 + \beta_{8,6}X_9}{\beta_{9,3}\beta_{8,6} + \beta_{9,3}X_8 + \beta_{8,6}X_9}\right)$$

$$S_{si} = \begin{cases} Q_s\,(X_{si} - X_i) & \text{(flow into reach; } Q_s \text{ positive)} \\ 0 & \text{(flow out of reach; } Q_s \text{ negative)} \end{cases}$$

$$S_{Gi} = \begin{cases} Q_G\,(X_{Gi} - X_i) & \text{(flow into reach; } Q_G \text{ positive)} \\ 0 & \text{(flow out of reach; } Q_G \text{ negative)} \end{cases}$$

derivative of X_i, the concentration of the ith water quality constituent, with respect to travel time (τ) and not standard time (t). In Table 2-1, $B_{i,j}$ refers to the jth coefficient for the ith water quality constituent. S_i refers to sources or sinks of the ith constituent from lateral inflow as defined in Equation 2.17. The definition of the coefficients used in the water quality equations are listed in Table 2-2.

In the original version of SSAM the only solution technique available for the water quality equations was an exact solution algorithm which required linear differential equations. To allow for nonlinear quality equations a user option was added to allow for a numerical solution technique. For this reason, some of the quality constituents have equations that vary with the solution technique. When using the exact solution technique, linear first-order kinetics are assumed for all quality constituents. When using the numerical solution technique, the equations for phosphorus, biochemical oxygen demand, ammonia, nitrate, and dissolved oxygen are changed to link them with the nonlinear growth of algae.

NCO1 and NCO2 (nonconservative)

Exact and numeric solution. The rate of change in concentration is influenced by first-order decay and by mass input and from lateral inflow and leaching from bottom deposits.

$$\frac{dX_1}{d\tau} = -\beta_{1,1}X_1 + S_1 \tag{2.19}$$

Table 2-2. Definition of model coefficients grouped by water quality parameter.

Parameter	Coefficient		Description	Coefficient Needed For	
	Symbol	Units		Exact	Numeric
NCO1	$\beta_{1,1}$	per day	First order decay rate	X	X
NCO2	$\beta_{2,1}$	per day	First order decay rate	X	X
NCO3	$\beta_{3,1}$	per day	First order decay rate	X	X
	$\beta_{3,2}$	mg NCO3/mg NCO2	Stoichiometric ratio	X	X
NCO4	$\beta_{4,1}$	per day	First order decay rate	X	X
	$\beta_{4,2}$	mg NCO4/mg NCO2	Stoichiometric ratio	X	X
	$\beta_{4,3}$	mg NCO4/mg NCO3	Stoichiometric ratio	X	X
COLI	$\beta_{5,1}$	per day	First order decay rate	X	X
PHOS	$\beta_{6,1}$	per day	First order removal rate	X	X
	$\beta_{6,2}$	mg PHOS/mg ALGP	Yield coefficient		X
	$\beta_{6,3}$	mg/l	Half saturation coefficient		X
CBOD	$\beta_{7,1}$	per day	First order oxidation rate	X	X
	$\beta_{7,2}$	per day	First order removal rate	X	X
	$\beta_{7,3}$	mg CBOD/mg dead ALGP	Ratio of CBOD to dead ALGP		X
NH3N	$\beta_{8,1}$	per day	First order oxidation rate (Nitrification)	X	X
	$\beta_{8,2}$	per day	First order removal rate	X	X

Table 2-2. Continued.

Parameter	Coefficient		Description	Coefficient Needed For	
	Symbol	Units		Exact	Numeric
	$\beta_{8,3}$	mg NH3N/mg CBOD	Stoichiometric ratio	X	X
	$\beta_{8,4}$	mg NH3N/mg ALGP	Yield coefficient		X
	$\beta_{8,5}$	Dimensionless	Weighting coefficient to indicate preference of algae for NH3N over NO3N		X
	$\beta_{8,6}$	mg/l	Half saturation coefficient		X
NO3N	$\beta_{9,1}$	per day	First order removal rate	X	X
	$\beta_{9,2}$	mg NO3N/mg ALGP	Yield coefficient		X
	$\beta_{9,3}$	mg/l	Half saturation coefficient		X
DOXY	$\beta_{10,1}$	per day	Reaeration rate (if this is left blank the model will calculate the reaeration rate using the equation $\beta_{10,1} = 5.58\ V^{0.607}/H^{1.689}$ V = Velocity (m/sec) H = Depth (m)	X	X
	$\beta_{10,2}$	mg/l	Dissolved oxygen saturation at 20°C	X	X
	$\beta_{10,2}$	m	OPTIONAL: The model will calculate the DO saturation for each reach if "C" is assigned -1.0 and $\beta_{10,2}$ is the elevation of each reach in meters	X	X

Exact solution.

$$\frac{dX_{10}}{d\tau} = \beta_{10,1}\,(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\,\beta_{8,1}X_8 - \beta_{10,4}X_{10}/\bar{R} + S_{10} \qquad (2.31)$$

Numerical solution.

$$\frac{dX_{10}}{d\tau} = \beta_{10,1}\,(\beta_{10,2} - X_{10}) - \beta_{7,1}X_7 + \beta_{10,3} - 4.33\,\beta_{8,1}X_8 - \beta_{10,4}X_{10}/\bar{R} + \beta_{10,5}X_{12} + S_{10} \qquad (2.32)$$

With both solution techniques, coefficients are adjusted as follows:

$$\beta_{10,2_{T,E}} = [24.8 - 0.4259\,T_f + 0.003734\,T_f^{\,2} - 0.00001328\,T_f^{\,3}]\left\{\text{EXP}\left[\frac{0.03419\,E}{288.0 - 0.006496\,E}\right]\right\}$$ (Bishop and Grenney, 1977)

where,

T = temperature (°C)

T_f = temperature (°F)

E = elevation (M)

$\beta_{10,2_{T,E}}$ = dissolved oxygen saturation at temperature T, and elevation E

TEMP (temperature)

Exact and numeric solution. The rate of change is influenced by heat transfer from the air, the temperature of lateral inflow, and solar radiation entering the water.

$$\frac{dX_{11}}{d\tau} = \beta_{11,1}\,(\beta_{11,2} - X_{11}) + S_{11} \qquad (2.33)$$

ALGP (algae)

Numeric solution. The rate of change in concentration is influenced by the algal growth rate, the first-order decay (death) rate, and mass added from lateral inflow.

$$\frac{dX_{12}}{d\tau} = \mu X_{12} - \beta_{12,2} X_{12} + S_{12} \tag{2.34a}$$

in which

μ = algae growth rate

$$\mu = \beta_{12,1} \left(\frac{X_6}{\beta_{6,3} + X_6}\right) \left(\frac{\beta_{9,3} X_8 + \beta_{8,6} X_9}{\beta_{9,3}\beta_{8,6} + \beta_{9,3} X_8 + \beta_{8,6} X_9}\right) \tag{2.34b}$$

Equation 2.34b is a combination of ideas put forth by Chen (1970), Porcella et al. (1970), and Bowles (1977). Chen and Porcella proposed multiplying together a Michaelis-Menton saturation kinetics term for each constituent utilized by algae. This model can be summarized by:

$$\mu = \hat{\mu} \prod_{i=1}^{n} \left(\frac{X_i}{K_{s_i} + X_i}\right) \tag{2.35}$$

in which

$\hat{\mu}$ = maximum specific growth rate of algae (per day)

X_i = concentration of the ith constituent linked with algae (mg/l)

K_{s_i} = half saturation coefficient for the ith constituent linked with algae (mg/l)

n = number of constituents utilized by algae

Π = product operator, i.e., $\prod_{i=1}^{n} z_i = (z_1)(z_2)(z_3)\ldots(z_n)$

Bowles, in linking ammonia and nitrate with algae in the Jordan River proposed a modified form of saturation kinetics that includes the preferential uptake of the ammonia form of nitrogen over the nitrate form by algae. This model can be represented by:

$$\mu = \beta_{12,1} \left(\frac{\beta_{9,3}X_8 + \beta_{8,6}X_9}{\beta_{9,3}\beta_{8,6} + \beta_{9,3}X_8 + \beta_{8,6}X_9}\right) \qquad (2.36)$$

In the stream simulation and assessment model, three constituents are linked with algae, phosphorus, ammonia, and nitrate. Multiplying the conventional Michaelis-Menton kinetics term for phosphorus by the modified saturation kinetics term for ammonia and nitrate (Equation 2.36) produces Equations 2.34b, the algae growth rate term used in SSAM.

A user may choose not to model all three constituents linked to algae due to a lack of data or a decision that algae growth is not a function of a particular constituent. When any of the three constituents is not modeled, the program assumes that algae growth is not a function of that constituent and therefore, Equation 2.34a, for algae growth rate is adjusted to remove the dependence on that constituent. For example, when incorporating Equation 2.36 into SSAM, and ammonia is not modeled, X_8 is set equal to zero and $\beta_{8,6}$ is set equal to one so that Equation 2.36 reduces to:

$$\mu = \beta_{12,1} \left(\frac{X_9}{\beta_{9,3} + X_9}\right) \qquad (2.37)$$

If nitrate is not modeled, X_9 is set equal to zero and $\beta_{9,3}$ is set equal to one so that Equation 2.36 reduces to:

$$\mu = \beta_{12,1} \left(\frac{X_8}{\beta_{8,6} + X_8}\right) \qquad (2.38)$$

Thus, in each of these limiting cases, Equation 2.36 reduces to the conventional Michaelis-Menton model and Equation 2.34b reduces to the Chen and Porcella model. If both ammonia and nitrate are not modeled, the term

$$\left(\frac{\beta_{9,3}X_8 + \beta_{8,6}X_9}{\beta_{9,3}\beta_{8,6} + \beta_{9,3}X_8 + \beta_{8,6}X_9}\right)$$

in Equation 2.34b is set equal to one. If phosphorus is not modeled, the term

$$\left(\frac{X_6}{\beta_{6,3} + X_6}\right)$$

in Equation 2.34b is set equal to one.

Several of the water quality equation coefficients are temperature adjusted by the following equation:

$$\beta_T = \beta_{20}\theta^{T - 20} \qquad (2.39)$$

in which

β_T = coefficient at temperature T

β_{20} = coefficient at $20°_C$

T = stream temperature (°C)

θ = 1.047 for $\beta_{5,1}$, $\beta_{7,1}$, $\beta_{8,1}$, $\beta_{12,1}$, and $\beta_{12,2}$ (Bishop and Grenney, 1977)
1.0159 for $\beta_{10,1}$ (Bishop and Grenney, 1977)

Solution Technique

One of the purposes of this research was to modify SSAM by the addition of a numerical solution technique that could be used in lieu of the existing exact solution technique. The exact solution has the advantages of being computationally fast and accurate, but is restricted to linear differential equations. The numerical solution has the advantages of 1) allowing the use of nonlinear equations and 2) reasonable accuracy, although it is significantly slower, and therefore more costly than the exact solution technique.

Exact Solution Technique

The exact solution technique used in this study was developed by Grenney (1977). The purpose of this algorithm is to construct the closed solution for a system of linear ordinary differential equations with constant coefficients which can be solved in sequence.

All of the solution forms which could possibly be encountered for this type of system have been grouped into the five categories shown in Table 2-3. For a particular left-hand side (column 2) and a particular term on the right-hand side (colume 3), solutions are shown in columns 4-7 depending on the values of the coefficients. The solution for each of the differential equations can be expressed in the general form:

$$X_i = \sum_{j=1}^{n_i} \beta_{i,j} t^{k_{i,j}} e^{\xi_{i,j} t} \qquad (2.40)$$

where i identifies the dependent variable X, n_i is the number of terms in the solution, and β, k, and ξ are coefficients.

The algorithm operates on one equation at a time in sequence. The first equation in the system is expressed in the form $\dot{X}_1 + G_{1,1}X_1 = G_{1,2}$ where the dot over X_1 indicates the time derivative and values for the G's are constant coefficients. The appropriate solution is taken

Table 2-3. Solutions for term by term integration of model equations.

Category Number	Differential Equation		Solution Depending on Values of the Coefficients			
	Left hand side	Right hand term	$\beta_1 = 0,\ \xi_2 \neq 0$	$\beta_1 + \xi_2 \neq 0$ $\beta_1 \neq 0,\ \xi_2 \neq 0$	$\beta_1 \neq 0,\ \xi_2 \neq 0$ $\beta_1 + \xi_2 = 0$	$\xi_2 = 0$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	$\frac{dX}{dt} + \beta_1 X$	$+ \beta_2 +$	$\beta_2 t + C_I$	$\frac{\beta_2}{\beta_1} + C_I e^{-\beta_1 t}$	Not Applicable	Not Applicable
2	$\frac{dX}{dt} + \beta_1 X$	$+ \beta_2 t^k +$	$\frac{\beta_2}{k+1} t^{k+1} + C_I$	$\beta_2 f_{(t)} + C_I e^{-\beta_1 t}$	Not Applicable	Not Applicable
3	$\frac{dX}{dt} + \beta_1 X$	$+ \beta_2 e^{\xi_2 t} +$	$\frac{\beta_2}{\xi_2} e^{\xi_2 t} + C_I$	$\frac{\beta_2}{\xi_2 + \beta_1} e^{\xi_2 t} + C_I e^{-\beta_1 t}$	$\beta_2 t e^{-\beta_1 t} + C_I e^{-\beta_1 t}$	Go to Category #1
4	$\frac{dX}{dt} + \beta_1 X$	$+ \beta_2 t^k e^{\xi_2 t} +$	$\frac{\beta_2}{\xi_2} e^{\xi 2 t} f_{(t)} + C_I$	$\frac{\beta_2}{\xi_2 + \beta_1} e^{\xi_2 t} f_{(t)} + C_I e^{-\beta_1 t}$	$\frac{\beta_2}{k + 1} t^{k+1} e^{-\beta_1 t} + C_I e^{-\beta_1 t}$	Go to Category #2
5	$\frac{dX}{dt} + \beta_1 X$	0	C_I	$C_I e^{-\beta_1 t}$	Not Applicable	Not Applicable

a) C_I is a constant of integration which incorporates the initial conditions of the system.

b) $f_{(t)} = \overset{k+1}{\underset{m=1}{}} \frac{k!\, t^{(m-1)} (-1)^{(k+m-1)}}{(m-1)!\, \beta_1^{(k+2-m)}}$

from Table 2-3 and values of β, k, and ξ are calculated and stored for each term in the solution. The solution to the first equation is then substituted into the second equation resulting in the expression:

$$\dot{X}_2 + G_{2,1}X_2 = G_{2,2}\left(\sum_{j=1}^{n_1} \beta_{1,j} t^{k_{1,j}} e^{\xi_{1,j} t}\right) + G_{2,3} \tag{2.41}$$

This equation is then solved by superimposing the solution (as shown in Table 2-3) for each term on the right-hand side. Thus, each equation is operated on in sequence, first involving the substitution of appropriate preceding solutions and then conducting a term by term integration.

The algorithm is basically one of accounting for all of the terms in a particular differential equation, identifying its form, and selecting the appropriate solution from a table. If a term becomes zero, it is dropped from the equation and eliminated from future calculations. Once a closed solution is constructed by the algorithm, it can be used to calculate values for the dependent variables at future times. This type of approach is much more efficient than using a numerical technique and avoids distortions which may be significant in numerical approximations.

Numerical Solution Technique

Runge-Kutta algorithm

A fourth-order Runge-Kutta algorithm with Kutta's coefficients was chosen to integrate the system of up to twelve simultaneous first-order differential equations. A Runge-Kutta algorithm has been used by many researchers to obtain solutions to ordinary differential equations in water quality mass balance models. Pence et al. (1968) modeling BOD and DO in the Delaware estuary used a fourth-order Runge-Kutta algorithm. PIONEER-I, a Battelle Pacific Northwest Laboratories (1974) water quality program uses a fourth-order Runge-Kutta numerical solution algorithm. Bowles (1977) in applying estimation theory to water quality modeling, used a fourth-order algorithm while Di Toro et al. (1970) used a second-order algorithm in a dynamic phytoplankton model.

The fourth-order Runge-Kutta algorithm for n simultaneous equations can be expressed as follows:

$$X_i^{t+h} = X_i^t + 1/6\ (K_{1,i} + 2K_{2,i} + 2K_{3,i} + K_{4,i}) \qquad (2.42a)$$

in which

$$K_{1,i} = (h)\ f\ (X_1^t, \ldots, X_n^t) \qquad (2.42b)$$

$$K_{2,i} = (h)\ f\ (X_1^t + \frac{K_{1,1}}{2}, X_2^t + \frac{K_{1,2}}{2}, \ldots, X_n^t + \frac{K_{1,n}}{2}) \qquad (2.42c)$$

$$K_{3,i} = (h)\ f\ (X_1^t + \frac{K_{2,1}}{2}, X_2^t + \frac{K_{2,2}}{2}, \ldots, X_n^t + \frac{K_{2,n}}{2}) \qquad (2.42d)$$

$$K_{4,i} = (h)\ f\ (X_1^t + K_{3,1}, X_2^t + K_{3,2}, \ldots, X_n^t + K_{3,n}) \qquad (2.42e)$$

in which

X_i^t = concentration of the ith constituent at time t (mg/1)

X_i^{t+h} = concentration of the ith constituent at time t + h (mg/1)

h = integration step size (sec)

n = number of constituents modeled

Step size selection

Numerical methods for solving differential equations produce solutions which only approximate the exact solution. The difference between the exact solution and the numerical solution at any step is known as the total (or local) error for that step. According to James et al. (1967), the total error at any step results from per-step roundoff error, per-step truncation error, and errors present from a previous step. A roundoff error is introduced in a given step by performing the arithmetic operations of that step with numeric values having a limited number of significant digits. A truncation error is introduced in a given step by approximating the solution of the mathematical problem.

The total error in a numerical integration process depends on the step size (h) used and therefore, care must be taken in step size selection. If h is too small, the number of steps to complete the integration becomes large, with the result that computation time and roundoff errors increase. If h is too large, a large per-step truncation error will result. The step size choice is further complicated when the rate of change of the function with time varies greatly. For example, consider the time variation of the concentration of a nutrient under the influence of algae uptake as shown in Figure 2-3. A step size that yields a satisfactory numerical solution in Sections A and C of Figure 2-3 would be too large for Section B. Mar (1976) proposed abandoning the classical Michaelis-Menton model as applied to phytoplankton kinetics partly because it can cause negative substrate concentrations in models using numerical difference techniques. The finite difference modeling

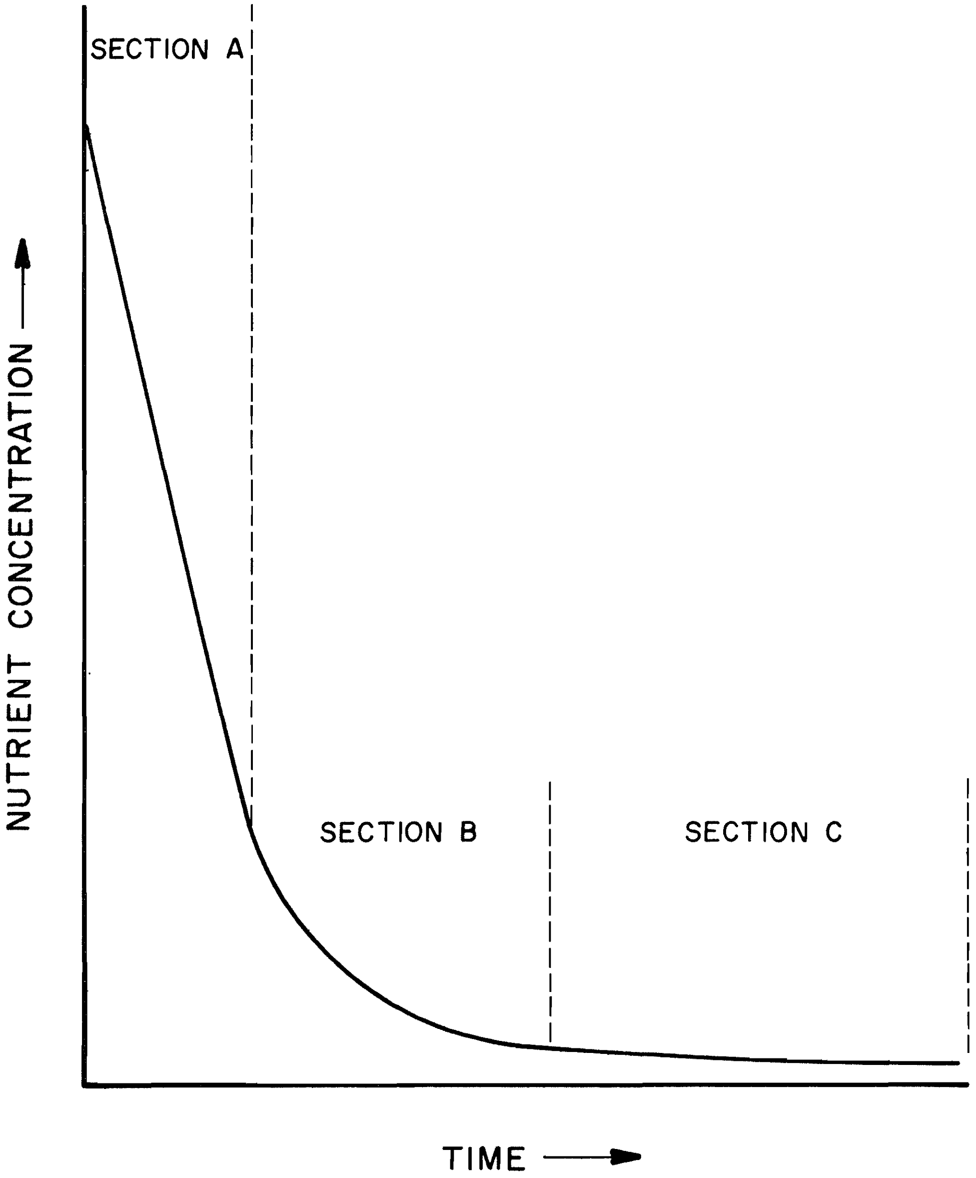

Figure 2-3. Hypothetical nutrient uptake by algae.

approximations cannot round the corner in section B (Figure 2-3) unless the integration step size is chosen small enough.

One method of choosing a suitable step size is based on a halving and doubling procedure. It is assumed that the per-step truncation errors have the form Kh^{m+1} with K constant, and that the per-step truncation error dominates the change in the total error for each step. An estimate of the per-step truncation error can be made by integrating between two points X_n and X_{n+1}, using two step sizes h_1 and h_2 with corresponding solutions $y_{n+1,1}$ and $y_{n+1,2}$. If h_2 is chosen to be one-half h, the per-step truncation error (e_t) of the larger step can be shown to be equal to 16/15 of the difference between $y_{n+1,2}$ and $y_{n+1,2}$ (Carnahan et al. 1969), or:

$$e_t = \frac{16}{15} (y_{n+1,2} - y_{n+1,1}) \tag{2.43}$$

Equation 2.43 also provides an estimate of the change in total error in a step since the truncation error was assumed to be the major contributor to the total error. By choosing a maximum allowable e_t, a suitable step size can be found for each integration interval. Although this halving and doubling procedure works well, the total number of calculations is approximately three times the number required using just one step size (Carnahan et al. 1969). A modified form of Equation 2.43 was used by Pence et al. (1969) to choose an appropriate step size. They used an equation of the form:

$$e_t = y_{n+1,2} - y_{n+1,1} \tag{2.44}$$

Bowles (1977) use the Courant condition (Stone and Brian, 1963) to choose a step size. The Courant condition is:

$$F = \frac{V\Delta t}{\Delta x} \leq 1 \qquad (2.45)$$

in which

V = average cross-section stream velocity (m/sec)
Δt = computational time interval (sec)
Δx = computational space interval (m)

Bowles assured that F would equal one by setting $\Delta x = V\Delta t$, choosing a Δt and then slightly adjusting the location of calculation points to the nearest Δx. Although Bowles experienced no difficulties with stability, it will be shown later that extremely inaccurate results can be experienced even with $F < 1$.

Merson (1957) suggested a variation of the fourth-order Runge-Kutta method which provides for step size control. The Merson process uses the equation:

$$X^{t+h} = X^t + \frac{1}{6} hf\ (X^t) + \frac{2}{3} hf\ (K_3) + \frac{1}{6} hf\ (K_4) \qquad (2.46a)$$

in which

$$K_1 = X^t + \frac{1}{3} hf\ (X^t) \qquad (2.46b)$$

$$K_2 = X^t + \frac{1}{6} hf\ (X^t) + \frac{1}{6} hf\ (K_1) \qquad (2.46c)$$

$$K_3 = X^t + \frac{1}{8} hf\ (X^t) + \frac{3}{8} hf\ (K_2) \qquad (2.46d)$$

$$K_4 = X^t + \frac{1}{2} hf\ (X^t) - \frac{3}{2} hf\ (K_2) + 2hf\ (K_3) \qquad (2.46e)$$

Close inspection of Equations 2.46a through 2.46e reveals the necessity of evaluating the derivative one time more than required in the Runge-Kutta algorithm listed in Equations 2.42a through 2.42e.

This additional computation is used to determine the local truncation error. If the step size is small enough so that the function f(X) can be represented by the linear approximation

$$f\ (X) = AX + B$$

Merson showed that a good estimate of the error in X^{t+h} is $\frac{1}{5}$ $(K_4 - X^{t+h})$. The step size can now be chosen to keep the error within some specified range. Fox (1962) showed that this technique may overestimate the error when applied to nonlinear equations.

The water quality models used by Di Toro et al. (1970) and Battelle Pacific Northwest Laboratories (1974) do not internally control the integration step size. Di Toro's model apparently uses a constant step size selected by the user. Battelle's model uses one-tenth the reach travel time as the step size. The step size could be varied by the user by choosing appropriate reach lengths.

Another method of step size control was proposed by Collatz (1960). This method will be developed in detail below. Let,

$$\dot{y} = f\ (x,y)$$

where $\dot{y}$ is the derivative of y. At some step n, let the error be ϕ_n, so:

$$\phi_n = f\ (x_n,\ y_n) - f\ [x_n,\ y\ (x_n)] \tag{2.47}$$

From the mean value theorem it can be shown that (Kreyszig, 1972)

$$f\ (x_n,\ y_n) - f\ [x_n,\ y\ (x_n)] = f_y\ (x_n,\ \tilde{y})\ \eta_n \tag{2.48a}$$

in which

$$y_n \leq \tilde{y} \leq y\ (x_n) \tag{2.48b}$$

and

$$\eta_n = \text{the error in } y_n$$

$$\eta_n = y_n - y\ (X_n) \tag{2.48c}$$

Assume that the error in the derivative, $\dot{y}$, denoted ϕ_n effects the y_{n+1} approximation linearly in the step size h. Hence, the contribution of ϕ_n to the error of y_{n+1} is:

$$h\phi_n = hf_y\ (x_n, \tilde{y})\ \eta_n \tag{2.49}$$

Rearranging yields:

$$\frac{h\phi_n}{\eta_n} = hf_y\ (x_n, \tilde{y}) \tag{2.50}$$

Let

$$Z = \frac{h\phi_n}{\eta_n} = h\ \left(\frac{\text{Derivative error in } (n + 1)^{\text{th}} \text{ step}}{\text{Accumulated Total Error}}\right)$$

Therefore

$$Z = h\ \left(\frac{\text{Error in } y_{n+1} - \text{Error in } y_n}{\text{Error in } y_n}\right) \tag{2.51}$$

If Z is much greater than zero, the total error is growing very rapidly. This suggests a means of determining an appropriate step size. If Z is kept within a certain interval the step size would be large enough to prevent excessive rounding errors and small enough to prevent a large truncation error. Reported values for Z range from $0.05 \leq Z \leq 0.2$ (Kreyszig, 1972) to "a few hundredths" (Collatz, 1960). Since,

$$Z = hf_y\ (x_n, \tilde{y}) \tag{2.52}$$

A means of choosing a step size is possible by placing a close upper bound K on $|f_y|$ in the region of interest and to choose h such that:

$$Z = hK$$

is within the range previous discussed. Since K is a close upper bound on $|f_y|$:

$$Z = hK \approx h|f_y| \tag{2.53}$$

From the definition of f_y:

$$Z \approx h \left| \frac{f\ (x,\ y^*) - f\ (x,\ y^{**})}{y^* - y^{**}} \right| \tag{2.54}$$

Let

$$x = x_n + \frac{1}{2} h$$

$$y^* = y_n + \frac{1}{2} K_{2,n}$$

$$y^{**} = y_n + \frac{1}{2} K_{1,n}$$

$$f\ (x,\ y^*) = f\ (x_n + \frac{1}{2} h,\ y_n + \frac{1}{2} K_{2,n}) = \frac{K_{3,n}}{h}$$

$$f\ (x,\ y^{**}) = f\ (x_n + \frac{1}{2} h,\ y_n + \frac{1}{2} K_{1,n}) = \frac{K_{2,n}}{h}$$

where $K_{1,n}$, $K_{2,n}$, and $K_{3,n}$ are coefficients used in the Runge-Kutta algorithm (Equations 2.42a through 2.42e).

Solving for Z yields:

$$Z \approx 2 \left| \frac{K_{3,n} - K_{2,n}}{K_{2,n} - K_{1,n}} \right| \tag{2.55}$$

Equation 2.55 can be simplified to:

$$Z = \left| \frac{K_{3,n} - K_{2,n}}{K_{2,n} - K_{1,n}} \right| \tag{2.56}$$

which is the form of Collatz's (1960) rule of thumb for the step size.

A provision can now be made to leave h unchanged if Z is between some specified limits, to double h if Z is less than the lower limit, or to halve h if Z is greater than the upper limit. Although this criteria for choosing a step size is very qualitative, it has the advantage of adding little extra computation.

In applying Equation 2.56 to SSAM, the limits for Z are supplied by the user as is a maximum step size and a maximum number of iterations (reductions of h by 50 percent) to find a small enough step size. If in a particular step, Z is greater than the specified upper limit and upon reducing the step size h by 50 percent, Z is less than the specified lower limit, the smaller step size is chosen and the integration continues.

In some instances when successive values of the concentration of a constituent were near zero and varied little, a small step size was chosen. To prevent this from happening, the step size was not reduced if the difference between successive constituent concentrations was less than the variable ERRMAX, whose value is supplied by the user.

Tests on the step size algorithms

To test the effectiveness of Equation 2.56 in controlling the step size, SSAM was applied to a simple hypothetical stream comprised of a 200 km (124 mile) stream reach with a calculation point every 10 km (6.2 miles). The physical characteristics of the stream are shown in Table 2-4. Two quality constituents were modeled: phosphorus; and algae as chlorophyll a. The stream loading and model coefficients are shown in Table 2-5. The model was run both with and without the step size control. When running with the step size control the range for Z was set at $0.02 \leq Z \leq 0.14$. The maximum step size was 167 minutes and the variable ERRMAX was set equal to 0.004. Without the step size control the step size was kept constant throughout the stream. Several runs were made with constant step sizes ranging from 167 minutes (from Equation 2.45, F = 1.0) to 21.0 minutes (F = .126). Figure 2-4 shows that with all the step sizes the model successfully predicted

Table 2-4. Stream physical characteristics.

Flow	5.0 m^3/sec[a]
Velocity	1.0 m/sec[b]
Depth	2.0 m[c]
Area	5.0 m^2 [d]
Temperature	20°C[e]

[a] 1 m^3/sec = 35.31 ft^3/sec

[b] 1 m/sec = 3.281 ft/sec

[c] 1 m = 3.281 ft

[d] 1 m^2 = 10.76 ft^2

[e] $°C = \frac{5\ (°F - 32)}{9}$

Table 2-5. Loading and model coefficients.

Water Quality Constituent	Coefficient	Description	Value Used
Phosphorus	$\beta_{6,1}$	Removal rate	0.0
	$\beta_{6,2}$	Yield coefficient	1.0 mg PHOS/mg ALGP
	$\beta_{6,3}$	Half saturation coef.	0.001 mg/l
Algae	$\beta_{12,1}$	Maximum growth rate	2.0/day
	$\beta_{12,2}$	Death rate	0.005/day

NOTE: Headwater loading: 0.1 mg/l PHOS, 0.007 mg/l ALGP.

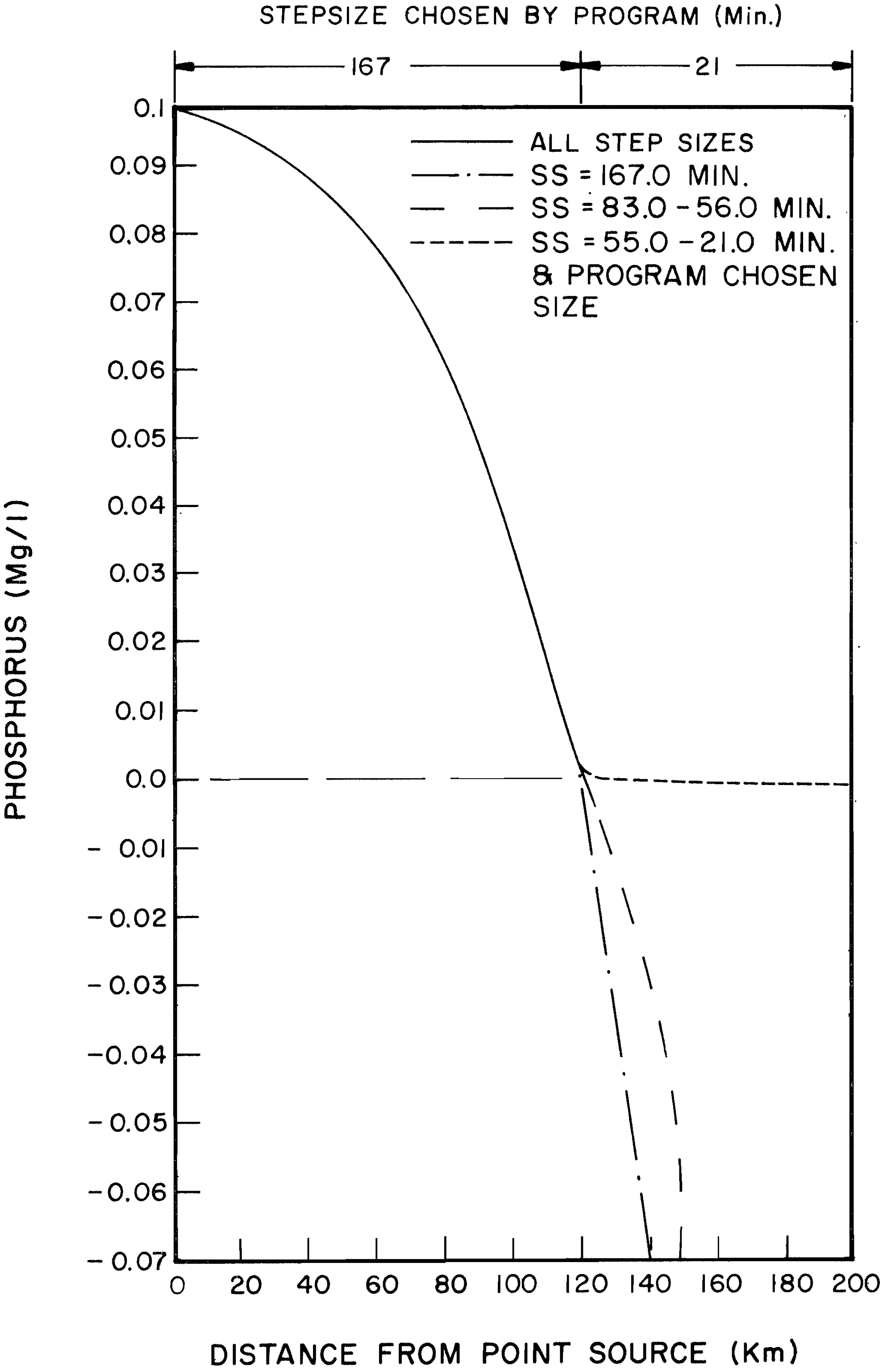

Figure 2-4. Comparison of single step size with program chosen step size.

the concentration of phosphorus up to 120 km. The rate of change in phosphorus concentration between 120 and 130 km was very high and for step sizes greater than 55 minutes (F = .33). The model did not reproduce the sharp bend and instead predicted negative concentrations for the remainder of the stream. Only at a step size less than or equal to 55 minutes was the model able to successfully predict the concentration of phosphorus beyond 120 km. The model successfully predicted the concentration of phosphorus beyond 120 km using the step size control procedure. The procedure chose the maximum allowable step size (the travel time between calculation points, 167 minutes) for the first 120 km and 21 minutes for the remainder of the stream.

Because all the step sizes produced acceptable results up to 120 km, a step size smaller than the travel time (167 minutes) between calculation points is computationally wasteful. Using the step size program, the model simulated the large rate change of phosphorus concentration between 120 and 130 km without the inefficiency of a small step size from zero to 120 km.

Equation 2.56 tendency to choose a small step size even when the rate of change in the function is small was exhibited in his example. From 130 to 200 km the model stayed with a 21 minute step size. Judging from the results with the 56 minute constant step size, the 21 minute size was smaller than necessary. Some other means of controlling the step size in regions where the slope approaches zero would improve this step length control scheme.

Equation 2.56 was used in conjunction with SSAM in several more complex river systems, including the Jordan River in Utah. In all cases, no problems with stability or excessive computation time were experienced.

Because Equation 2.56 successfully controls the integration step size in water quality applications with a minimum amount of extra computation, it is judged to be a viable alternative to the half and doubling procedure used by Pence (1968). Bowles' use of the Courant condition for controlling the step size proved totally unsatisfactory in the example. The largest value of F from Equation 2.45 that provided a step size small enough for successful integration was 0.33 (55 minutes). The models by Di Toro and Battelle that are without internal step size control would usually result in the user choosing a relatively short step size resulting in a larger amount of computation time and rounding errors than necessary.

CHAPTER III

OPTIMIZATION MODEL

Review of Applications of Mathematical Programming to Regional Water Quality Control

Numerous mathematical programming and optimization techniques have been used in regional water quality control models. Mathematical programming can allow the planner to consider combinations of alternative pollution abatement techniques for a variety of water quality parameters.

Fan et al. (1971) found an optimal waste discharge policy along a stream based on minimizing the total cost of maintaining a certain water quality in the stream on a regional basis. A steady-state dispersion model was employed to predict the BOD and DO concentration in the stream and a sequential minimization technique, employing a discrete search, was used to find the least cost solution given specified water quality goals.

A nonlinear programming model formulated as a geometric programming problem was used by McNamara (1976) to find a least cost solution for the upper Hudson River. The model permitted the simultaneous consideration of waste treatment processes, bypass piping, flow regulation and artificial aeration to meet the water quality goal of a specified minimum dissolved oxygen deficit. A linear model was used to predict first stage BOD concentrations in the stream.

Marsden et al. (1973) and Loehman et al. (1974) used nonlinear optimization techniques to find a least cost pollution abatement program for the West Fork White River in Indiana. Streeter-Phelps equations were used to model BOD and DO. Treatment schemes considered by Loehman et al. included nonuniform treatment levels at waste treatment plants, treatment in regional plants, flow augmentation, and bypass piping. Marsden et al. considered these schemes and added cooling towers. Loehman's model considered the effect of cost allocation and pricing mechanisms on the optimal solution.

Kerri (1966) used a linear programming optimization model to find a least cost solution for the Willamette River in Oregon. Kerri's model found the treatment plant efficiencies required to provide a minimum DO concentration in the river as predicted by the Streeter-Phelps equation. Bayer (1972) formulated a nonlinear programming model to select the optimal scale of construction for a set of structures for regional water quality control. These structures included wastewater treatment plants, storage dams, and reservoirs. Constraints specified for the system were maximum BOD concentration, minimum DO concentrations, and minimum mainstream and tributary flows. The BOD, DO model was based on a second-order reaction. The model was applied to Willamette River using only the DO constraint. Arbabi and Elzina (1975) used a linear approach to meet system water quality standards for DO at minimum cost on the Willamette River. Using properties of the dissolved oxygen sag equation, they constructed relations of DO concentrations as linear functions of BOD loading. Written as linear inequalities, these become the constraint sets in a linear programming problem to minimize the sum of the treatment costs over all plants in the system.

Several models have been applied to the Delaware estuary. Thomann and Sobel (1964) formulated a linear programming model used with an estuary simulation model to find a least cost solution for the upgrading of treatment facilities in the estuary subject to DO constraints. To link the simulation model with the optimization model a transfer matrix was used. The transfer matrix indicates the pollutant diffusing and transporting effect of one section of the estuary on the water quality in other sections of the estuary. Therefore, it represents the response in pollutant levels in one section to a unit discharge of material in another section. Using Thomanns transfer matrix, Liebman and Marks (1968) found a least cost solution subject to constraints requiring zones of uniform treatment in the estuary. Liebman and Marks structured the problem as a integer program and used a Balas implicit enumeration algorithm to find the optimal solution. Graves et al. (1972) used a combination of linear feedback and control system and nonlinear programming to find a least cost pollution abatement scheme for the estuary. The linear feedback and control system included a linear estuary model for BOD and DO using Thomann's transfer matrix. The mathematical model allowed for the possibilities of at-source treatment, regional treatment plants, and bypass piping.

Gourishankar and Lawson (1975) used a multi-cost system optimization to determine the least cost of water pollution controls subject to several water quality performance criteria. The control measures included controlled discharge of industrial wastes and artificial aeration. Performance criteria were chosen to reflect the costs of waste treatment, water treatment, or polluted water to the environment. The model predicted the concentration of BOD and DO by using first-order decay equations.

Haimes (1971, 1972) and Haimes et al. (1972) applied a multi-level approach to develop a general mathematical model to represent a system of treatment plants discharging effluent into a river. The water quality could be represented by several variables such as BOD, DO, pH, conductivity, temperature, nitrate, phosphate, and algae. Costs are minimized among charges for treatment at individual treatment plants or a regional plant, or an effluent charge for direct discharge of various quantities of effluent. The overall system cost is minimized by a second level controller, which imposes the effluent charge.

Hyden et al. (1975) used dynamic nonlinear optimization to solve a serial use-damage problem where a party imposes damages through reduced water quality to another party. The problem was structured as a basin-wide cost minimization subject to the water reaching each user being at a quality treatable by conventional means. The model can consider several dynamic conditions including increased user demand, new users, and variable stream flow.

Water quality management models have primarily included only one stream quality parameter, DO, and have minimized treatment costs in terms of removal of only one constituent, BOD. The optimization model described here is similar to the model proposed by Bishop and Grenney (1976), incorporates multiple interdependent pollution parameters described by either linear or nonlinear equations. Full advantage is taken of the capabilities of complex river water quality simulation models in generating constraints for the optimization model. The model considers the addition or upgrading of waste treatment with structural and nonstructural schemes for both point and diffuse pollution sources. Structural treatment schemes include a conventional waste treatment plant where the process is closely regulated and physically controlled and where some mechanical means of treatment is used. Nonstructural treatment implies the use of land use or waste discharge controls as in a buffer zone or green belt between a farm and a stream. The model can consider uniform treatment, zoned uniform treatment, and least cost treatment. Low flow augmentation and bypass piping can also be considered with slight river simulation model modification.

Theoretical Development of the Optimization Model

The essential components of the optimization model are shown in Figure 3-1. The components consist of a series of loads (either point or diffuse) receiving some sort of treatment (either structural or nonstructural) and a series of surveillance points where pollution concentration limitations are enforced. The following variables and relationships are defined for use in the model formulation.

k = Surveillance point index = $1,2,\ldots,K$

n = Treatment level index = $1,2,\ldots,N$

ℓ = Load index = $1,2,\ldots,L$

c = Water quality constituent index = $1,2,\ldots,C$

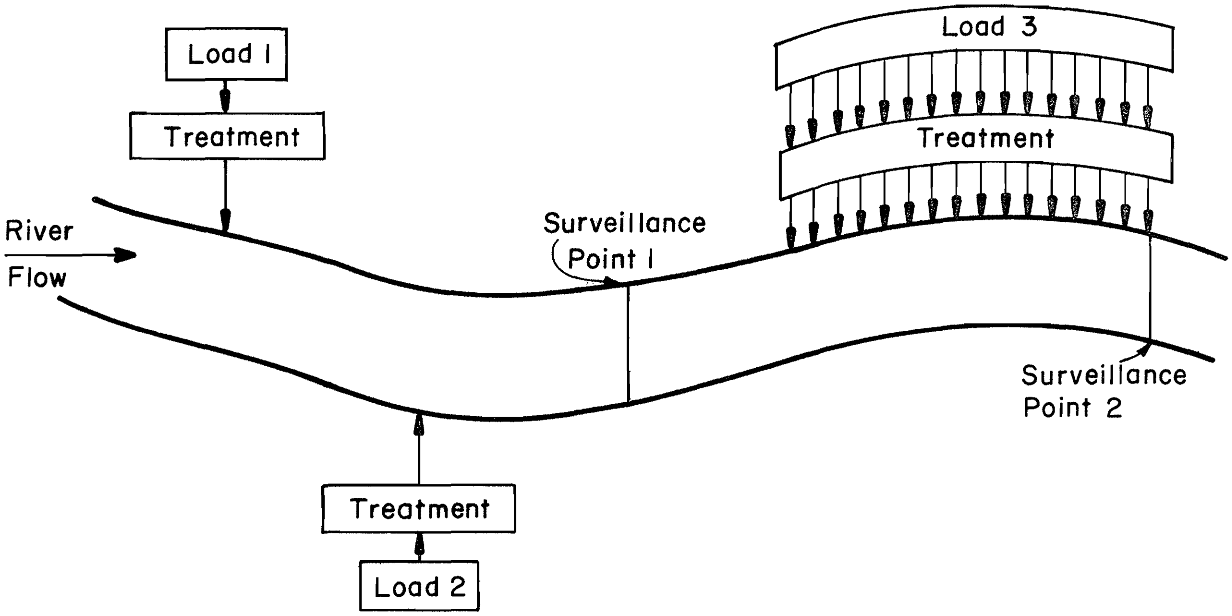

Figure 3-1. Schematic representation of stream quality management problem.

$B_k = (b_c)_k$ = A vector of pollution concentration limitations (stream standards) for c constituents, at each surveillance point, k.

$T_\ell = (t_n)_\ell$ = An integer vector ($t_n = 1$ or 0) indicating which treatment level, n, is provided: $t_n = 0$ if level not provided, $t_n = 1$ if level is provided.

$Y^o_k = (y^o_c)_k$ = vector of concentrations for c constituents, at each surveillance point, k, resulting from existing stream loading.

$Y_{\ell,k} = (y_{c,n})_{\ell,k}$ = Matrix of constituent, c, concentrations occurring at surveillance point, k, for treatment level n, being applied at load ℓ and existing treatment at the remainder of the loads. That is it represents the concentrations resulting at k if only load ℓ was given additional treatment.

$Y'_k = (y'_c)_k$ = Vector of concentrations for each constituent, c, at each surveillance point, k, resulting from the optimal loading scheme determined by the model.

Treatment level may be a structural or nonstructural technique which will achieve certain predictable results in terms of reduction of each quality constituent. Treatment levels become the decision variable implying the need for an integer programming approach to the problem since treatment levels are usually applied as discrete levels. A treatment level may have a different percentage constituent removal at each load.

Assuming that the concentration of each constituent must be less than the stream standard at each surveillance point:

$$Y'_k \leq B_k \qquad k = 1,2,\ldots,K \tag{3.1}$$

For a linear system,

$$Y'_k = Y^o_k - \sum_{\ell=1}^{L} [Y^o_k - Y_{\ell,k}\, T_\ell] \tag{3.2}$$

Therefore, substituting for Y'_k, Equation 3.1 becomes:

$$Y^o_k - \sum_{\ell=1}^{L} [Y^o_k - Y_{\ell,k} T_\ell] \leq B_k \qquad k = 1,2,\ldots,K \tag{3.3}$$

Now define:

$D_{\ell,k} = (d_{c,n})_{\ell,k}$ = A matrix representing the change from the existing concentration of constituent c at surveillance point k when treatment level n is applied at load ℓ.

Therefore, from the definition of D:

$$D_{\ell,k}T_\ell = Y^o_k - Y_{\ell,k}T_\ell \tag{3.4}$$

Substituting Equation 3.4 into Equation 3.3 and rearranging yields:

$$\sum_{\ell=1}^{L} D_{\ell,k}T_\ell \geq Y^o_k - B_k \qquad k = 1,2,\ldots,K \tag{3.5}$$

Finally, define

$C_\ell = (c_n)_\ell$ = A vector of treatment costs for treatment level n at load ℓ.

Nonlinearities in cost functions are accounted for since a specific cost is associated with each treatment scheme and load.

An integer programming problem to minimize the cost of regional treatment can now be structured as follows:

$$\text{Minimize total cost} = \sum_{\ell=1}^{L} C^T_\ell T_\ell \tag{3.6}$$

Subject to the set of constraints:

1. Water quality stream standards.

$$\sum_{\ell=1}^{L} D_{\ell,k}T_\ell \geq Y^o_k - B_k \qquad k = 1,2,\ldots K \tag{3.7}$$

2. Integer solution for treatment levels and only one treatment level per load.

$$\sum_{n=1}^{N} (t_n)_\ell = 1 \qquad \ell = 1,2,\ldots,L \tag{3.8}$$

and $t_n = 0$ or 1 for all values of n.

If a stream standard for a particular constituent is a minimum stream standard (i.e., DO) the inequality in Equation 3.7 becomes a "less than or equal to" sign.

If uniform or zoned uniform treatment are required, additional constraints should be added to force the treatment levels for specified loads to be equal. For example, suppose that two zones of uniform treatment are created in a river basin with six loads. Zone 1 is to include loads 1, 2, 4, and 6 and Zone 2 is to include loads 3 and 5. These two zones of uniform treatment could be assured in the optimal solution by adding the following constraints: $T_1 = T_2$, $T_2 = T_4$, $T_4 = T_6$, and $T_3 = T_5$. The problem can easily be structured for uniform treatment since it is a one zone, zoned uniform treatment problem. In this example, uniform treatment could be assured in the optimal solution by adding the following constraints: $T_1 = T_2$, $T_2 = T_3$, $T_3 = T_4$, $T_4 = T_5$, and $T_5 = T_6$.

Equations 3.6 through 3.8 were formulated so that the optimization model and the simulation model are linked by a single parameter, the "D" matrices. The D matrix in Equation 3.7 is conveniently generated by the stream simulation model using the following procedure:

1. Calculate Y^o_k from existing loading.
2. Apply the first treatment level at the first load and calculated $Y_{\ell,k}$.

3. Calculate the "D" matrices where:

$$D_{\ell,k} = Y^{o}_{k}Z^{T} - Y_{\ell,k}$$

when vector Z is defined as follows: $Z = (z_\ell)$, a vector with each element equal to 1.0. More simply, each element in $D_{\ell,k}$ is calculated as follows:

$$d_{c,n,\ell,k} = y^{o}_{c,k} - y_{c,n,\ell,k}$$

4. Repeat steps 2 and 3 for each treatment level.
5. Repeat steps 2, 3 and 4 for each load.

Because the development of the stream standard constraint equation was based on a linear system, Equation 3.7 is not strictly valid if the quality relationships in the water quality simulation model are nonlinear. For nonlinear equations, an iterative technique between the simulation model and the optimization model is required. The iteration procedure is an attempt to have a D matrix that truly represents the effect of the treatment levels on the stream when the quality constituent concentrations are at the level produced by the global optimum solution. Therefore, the iteration exit criterion is that the load allocations used to obtain the D matrix coefficients be the same as the actual loading under the optimum treatment scheme. Referring to Figure 3-2, the iteration is begun by generating the D matrix with the simulation model, running the optimization model, and producing an initial optimal solution. If a system of linear differential equations was used in the simulation model, the initial solution is a global optimum. If nonlinear equations were used, the simulation model must be run again. To arrive at a new D matrix and solution, the

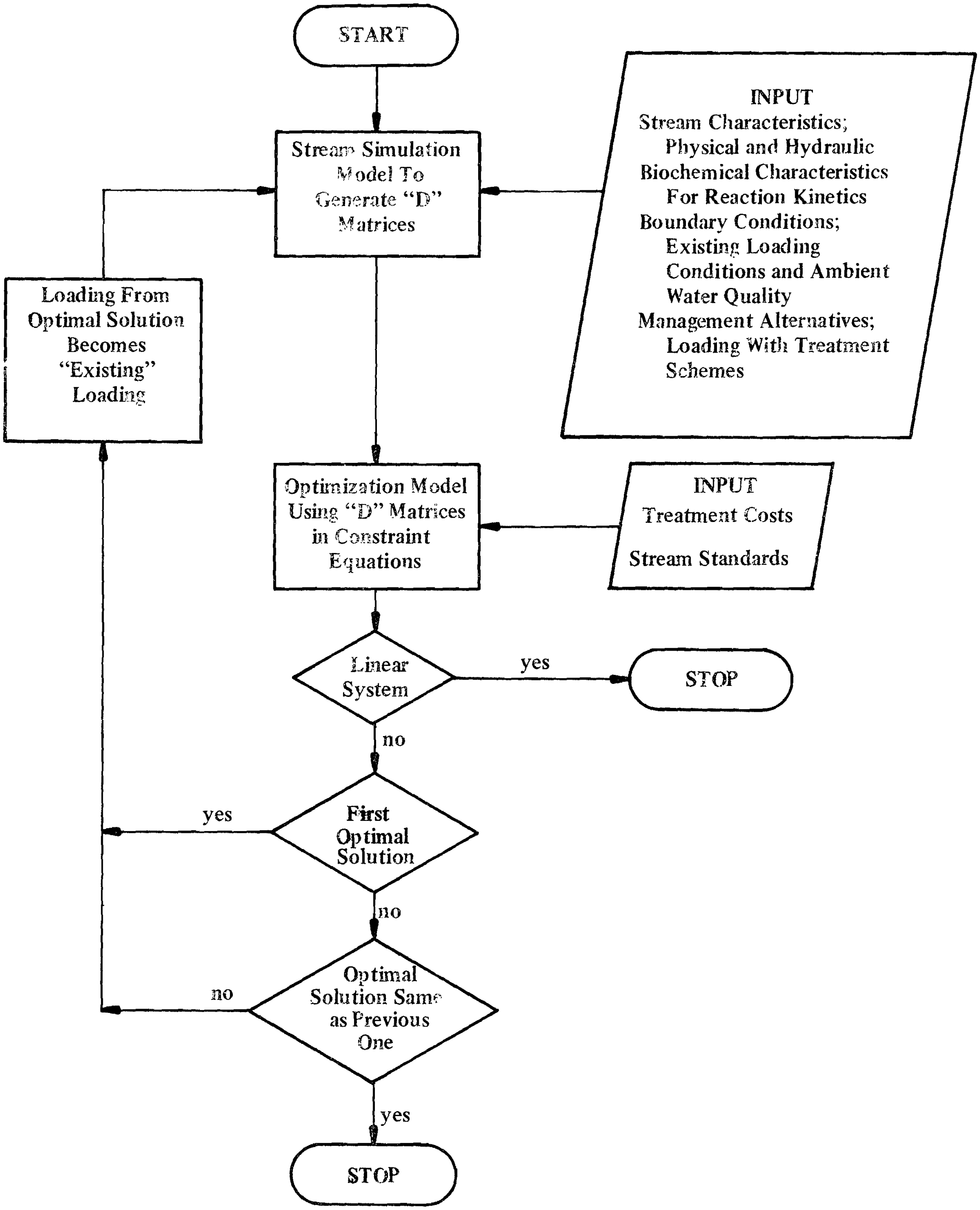

Figure 3-2. Flow chart of the simulation and optimization model iteration process.

previous solution is used as the "existing" loading. A new D matrix is generated, the optimization program run again and a new optimal solution is obtained. When two successive solutions are equivalent, the solution is assumed to be the optimum and the iteration ends.

The optimization model presented here is basically the same as the model presented by Bishop and Grenney (1976) but has been extended so that it may be applied to nonlinear systems. Extending the model required incorporation of the simulation-optimization model iteration procedure previously discussed and a redefining of the D matrices. In Bishop and Grenney the elements of the D matrices linked an incremental change in water quality at a load to a resulting incremental change in stream water quality at a surveillance point. The elements of the D matrices were determined by decreasing the loading of a particular quality constituent by a unit amount at a point load and noting the change in concentration of all constituents at each surveillance point. The elements of the D matrices in the model presented herein link a reduction in a load due to the application of a treatment level at a point load to the change in concentration of all constituents at the surveillance points. Treatment levels were applied instead of varying individual constituents in order to develop quality responses at the surveillance points that more closely match the responses at the optimal loading scheme produced by the optimization model. In a nonlinear system, when generating the D matrices, the closer the concentrations of constituents at any point are to the concentrations produced by the optimal loading scheme, the more realistic the responses (and therefore, the D matrices) and fewer simulation-optimization model iterations should be required.

Although the optimization model can be used to consider discrete levels of low flow augmentation and bypass piping, the simulation model used (SSAM) is presently unable to generate the D matrix if the flow from each load varies with treatment level. A slight modification of the simulation model to allow variable flow from loads would greatly extend the application of the combined models.

The optimization model was solved by the mixed integer linear programming algorithm MXINT contained in the TEMPO mathematical programming package available from Burroughs Corporation (1975). Hughes et al. (1976) found this algorithm to be the best of four algorithms tested on a similar regional water quality control model. A description of the MXINT algorithm is contained in Hughes et al. (1976).

A computer program (HELPSU) was written to simplify the linkage between the simulation and optimization models. This program reads in the matrices necessary for the objective and constraint equations (Equations 3.6 through 3.8). The objective function and constraint equations are generated and stored on a disk computer storage device in the format by MXINT. Subroutine descriptions and flow charts, data input formats, and program listing for HELPSU are shown in Appendices D, E, and F respectively.

CHAPTER IV

LINKED SIMULATION-OPTIMIZATION MODEL APPLICATION

The coupled simulation-optimization model was applied to a hypothetical problem and the Jordan River in Utah. Although the optimization modeling technique developed in the previous chapter is designed to include the control of diffuse sources, no diffuse source control was considered in either application.

Six water quality constituents were modeled in each application: 1) phosphorus, 2) biochemical oxygen demand, 3) ammonia, 4) nitrate, 5) dissolved oxygen, and 6) algae. Seven wastewater treatment levels were considered. A description and cost function in 1974 dollars for each treatment level is shown in Table 4-1, where the design flow, Q, is expressed in millions of gallons per day. In each application the treatment costs were adjusted from 1974 dollars to 1977 dollars by an inflation factor of 25 percent. Secondary treatment was assumed to currently exist at all point loads. The index identification used in both applications is shown in Table 4-2.

Model Application to Hypothetical Problem

Problem description

Figure 4-1 is a diagram of the river system used in this hypothetical problem. It consists of a main river and a major tributary, four point loads, five surveillance points, and six river reaches. The data in Tables 4-3 through 4-7 provide the necessary information for the

Table 4-1. Cost functions for treatment levels.

Treatment Level	Description of Process	Cost Functions, in dollars		Reference
		Capital Cost, K	Operation and Maintenance (OM)	
I	Secondary treatment (now provided)	----	----	----
II	Nitrification	$K = 26{,}400Q^{0.870}$	$OM = 6{,}200Q^{0.940}$	Klemetson and Grenney (1975)
III	Chemical precipitation of phosphorus in secondary system	$K + OM = 5{,}380 + 41{,}200Q + 4{,}620Q^{0.594}$		Porcella and Bishop (1975)
IV	Tertiary precipitation of phosphorus	$K + OM = 5{,}380 + 41{,}400Q + 4{,}620Q^{0.594} + 15{,}200Q^{0.865}$		Porcella and Bishop (1975)
V	Tertiary sand filter	$K = 14{,}320Q^{0.660}$	$OM = 47{,}000Q^{0.636}$	Klemetson and Grenney (1975)
VI	Nitrification and tertiary precipitation of phosphorus	Sum of II and IV		
VII	Reverse osmosis and aeration	$K + OM = 99{,}700\,(2.87 - \log Q)Q$		Porcella and Bishop (1975)

Table 4-2. Index identification.

Index Identification

Index	Description
c	Index on water quality constituents c = 1,2,...,C
n	Index on treatment levels n = 1,2,...,N
ℓ	Index on loads ℓ = 1,2,...,L
k	Index on surveillance points k = 1,2,...,K

Water Quality Constituents

Index c	Description
1	Phosphorus; total in hypothetical problem, ortho in Jordan River (mg/l)
2	Biochemical oxygen demand (ultimate) (mg/l)
3	Ammonia (as nitrogen) (mg/l)
4	Nitrate (as nitrogen) (mg/l)
5	Dissolved oxygen (mg/l)
6	Algae (as chlorophyll "A") (mg/l)

Treatment Levels

Index n	Description
1	No additional treatment (i.e., remain at secondary)
2	Ammonia removal; nitrification
3	Phosphorus removal; chemical precipitation in secondary
4	Phosphorus removal; tertiary precipitation
5	BOD and SS removal; tertiary sand filter
6	Ammonia and phosphorus removal; nitrification plus tertiary phosphorus precipitation
7	Reverse osmosis and aeration

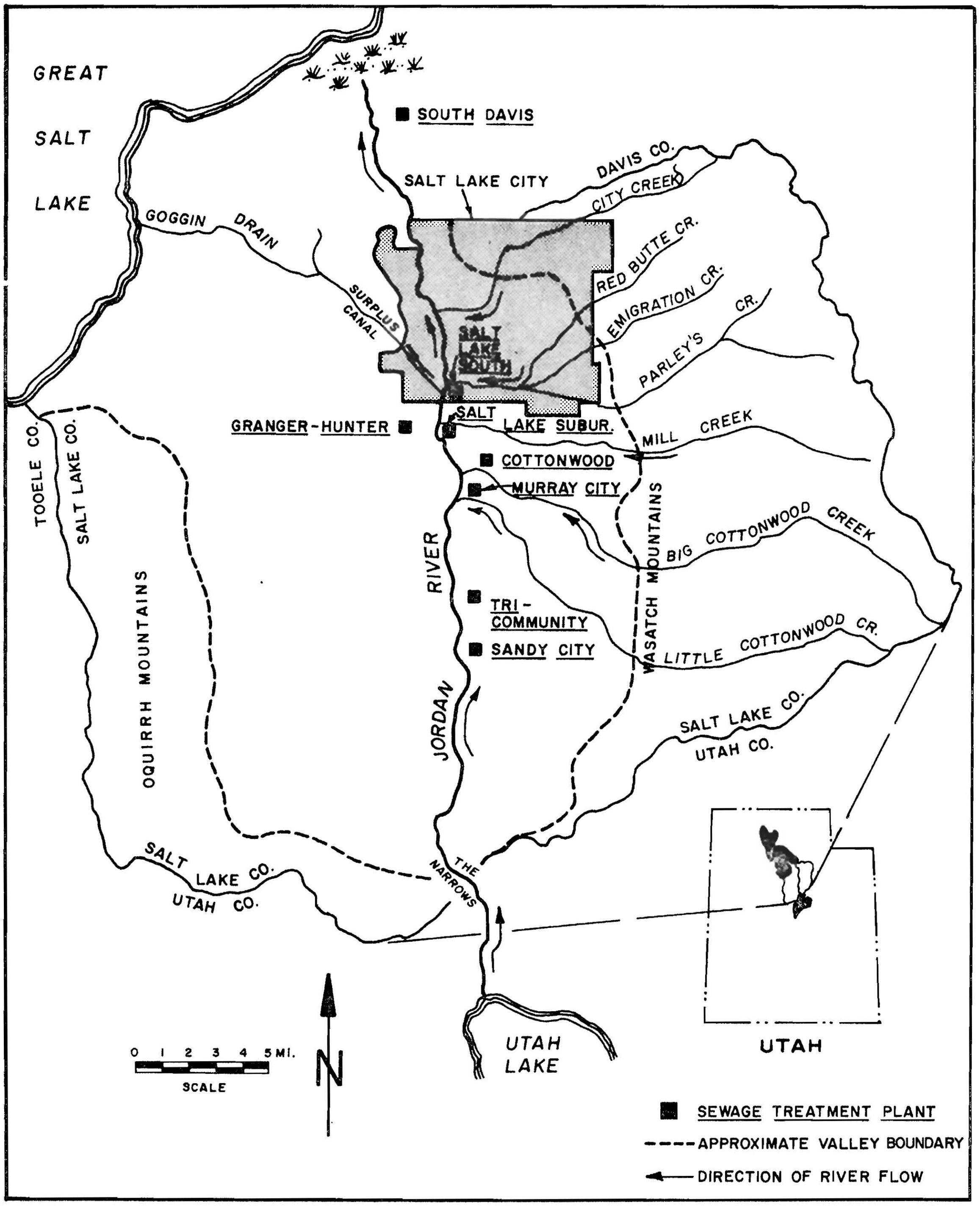

Figure 4-5. Jordan River Valley.

are of interest in this study pass through a valley area which is flanked by the Traverse Mountains to the south, the Wasatch Mountains to the east and the Oquirrh Mountains to the west. River flows are supplemented by many tributaries entering from the east, groundwater flows entering from springs and seeps, and irrigation return flow. Eight municipal wastewater treatment plants (WTP) and numerous urban stormwater drains, with perennial flow, also discharge into the lower 40 miles of the river.

Dixon et al. (1975) identified three major land use diversions along the river:

1. Upper agricultural reaches -- mainly agricultural pasture land and small communities south of Salt Lake City.
2. Industrial and urban areas -- within and adjacent to Salt Lake City.
3. Lower agricultural reaches -- north of Salt Lake City.

The river is important in that it provides: 1) water for municipal and industrial use, 2) irrigation water in a valley already importing water, 3) essential water for water fowl management areas, 4) a convenient storm and wastewater drainage system for the Jordan River Valley, and 5) a potential recreation resource (Dixon et al. 1975).

Tables 4-18 through 4-22 provide the necessary information for the system simulation model to generate the D matrices. The Jordan River was divided into 14 reaches with the uniform characteristics shown in Table 4-18. The location and flow associated with the headwater, point loads, diversions, and surveillance points are shown in

Table 4-18. Physical characteristics of river reaches.

Reach	Location (miles)[c]	Lateral[a] Surface Flow (ft^3/sec/mile)[d]	Lateral[a] Ground Flow (ft^3/sec/mile)[d]	Velocity[b] Coef. θ_1	Velocity[b] Exp. θ_2	Hydraulic[b] Rad. Coef. θ_3	Hydraulic[b] Rad. Exp. θ_4	Temperature (°C)[e]
1	40.8	8.0	3.0	.310	.120	.206	.568	20
2	36.0	8.0	3.0	.310	.150	.201	.588	20
3	34.2	8.0	3.0	.310	.150	.201	.568	20
4	32.1	8.6	3.0	.310	.140	.202	.581	20
5	30.0	11.0	18.0	.300	.333	.031	.792	20
6	27.9	11.0	18.0	.520	.345	.058	.766	20
7	26.5	11.0	18.0	.450	.347	.053	.795	20
8	25.0	6.0	6.0	.450	.347	.053	.795	20
9	22.8	6.0	6.0	.740	.228	.235	.400	20
10	21.4	6.0	6.0	.400	.301	.109	.688	20
11	18.1	6.0	6.0	.157	.384	.021	.843	20
12	16.7	1.0	0.1	.009	1.000	2.200	0.0	20
13	15.0	1.0	0.0	.009	1.000	2.200	0.0	20
14	12.0	1.0	0.0	.009	1.000	2.200	0.0	20

[a] Source: Salt Lake County Council of Governments (1977a)

[b] Source: Salt Lake County Council of Governments (1977a) (Reaches 1-4), Dixon et al. (1975) (Reaches 5-11), Salt Lake County Council of Governments (1977a) (Reaches 12-14)

[c] 1 mile = 1.61 km

[d] 1 ft^3/sec/mile = 1.056 m^3/min/km

[e] $^{\circ}C = \frac{5\ (^{\circ}F - 32)}{9}$

Table 4-19. Headwaters, point loads, diversions and surveillance points.

Description	Location (miles)[a]	Flow (f^3/sec)[b]
Jordan River headwater	40.8	15.0
Galenda Canal	37.2	-8.0
Beckstead Ditch	34.2	-4.0
North Jordan Canal	30.0	-96.0
Sandy WTP ($\ell = 1$)	28.9	5.0
Tri-Community WTP ($\ell = 2$)	26.5	10.0
Surveillance Point ($k = 1$)	26.0	
Little Cottonwood Ck	22.8	10.0
Brighton Canal	22.2	-30.0
Murray WTP ($\ell = 3$)	22.0	6.0
Big Cottonwood Ck	21.4	45.0
Cottonwood WTP ($\ell = 4$)	21.4	13.0
Granger Hunter WTP ($\ell = 5$)	18.7	12.0
Salt Lake Sub WTP ($\ell = 6$)	18.3	21.0
Surveillance Point ($k = 2$)	18.1	
Milk Ck	18.1	15.0
Surplus Canal	16.7	-225.0
South Salt Lake WTP ($\ell = 7$)	16.2	7.0
Parley, Emmigration and Red Butte Cks.	15.0	18.0
City Ck.	12.4	6.0
Surveillance Point ($k = 3$)	12.0	
South Davis WTP	5.9	3.0

[a] 1 mile = 1.61 km

[b] 1 ft^3/sec = 1.70 m^3/min

Source: Bowles (1977)

Table 4-20. River system water quality characterization.

Description	Ortho-Phosphorus[a] (mg/l)	Ult. Biochemical Oxygen Demand[a] (mg/l)	Ammonia[a] (mg/l)	Nitrate[a] (mg/l)	Dissolved Oxygen[a] (mg/l)	Algae CHL "A"[b] (mg/l)
Headwater	0.1	3.0	0.0	0.3	13.5	0.06
Reaches 1-4, Lateral Surface Inflow	0.4	8.7	0.0	2.0	7.3	0.0
Reaches 1-4, Lateral Ground Inflow	0.0	0.1	0.0	1.9	0.0	0.0
Reaches 5-7, Lateral Surface Inflow	1.4	9.5	0.0	2.0	7.3	0.0
Reaches 5-7, Lateral Ground Inflow	0.0	0.1	0.0	2.1	0.0	0.0
Reaches 8-14, Lateral Surface Inflow	1.4	8.7[c]	0.0	2.0	7.6	0.0
Reaches 8-14, Lateral Ground Inflow	0.0	0.1	0.0	2.2	0.0	0.0
Sandy WTP	7.08	101.	22.1	0.19	3.95	0.0
Tri-Community WTP	8.84	74.5	15.7	1.13	3.95	0.0
Little Cottonwood Ck.	0.09	9.01	0.0	0.59	7.00	0.0
Murray WTP	7.45	83.2	13.4	4.45	3.95	0.0
Big Cottonwood Ck.	0.0	2.48	0.0	1.07	7.90	0.0
Cottonwood WTP	9.06	48.2	18.7	2.64	6.00	0.0
Granger WTP	11.2	88.8	5.62	0.91	6.00	0.0
Salt Lake Sub WTP	9.79	54.2	5.62	4.04	6.00	0.0
Mill Creek	0.01	2.10	0.0	1.98	7.90	0.0
South Salt Lake WTP	4.16	50.8	3.81	4.95	6.00	0.0
Parley, Emmigration and Red Butte Creeks	0.05	4.20	0.0	1.26	7.00	0.0
City Creek	0.09	1.67	0.0	1.51	7.90	0.0
South Davis WTP	5.19	47.7	13.7	1.92	3.95	0.0

[a] Source: Salt Lake County Council of Governments (1977a)

[b] Source: Dixon et al. (1975)

[c] For reach 13 = 148 mg/l (Bowles, 1977)

Table 4-21. Effluent discharge quality after treatment as specified levels.

Load (ℓ)	Quality Parameter	Effluent Concentration for Treatment Levels (mg/l)						
		I	II	III	IV	V	VI	VII
1	PO_4	7.1	5.0	0.7	0.1	4.3	0.1	0.0
	BOD	101.0	80.8	50.5	20.2	20.2	20.2	6.1
	NH_3-N	22.1	4.4	15.5	15.5	15.5	3.3	1.1
	NO_3-N	0.2	0.2	0.2	0.2	0.2	0.2	0.0
	DO	4.0	4.0	4.0	4.0	4.0	4.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	PO_4	8.8	6.2	0.9	0.2	5.3	0.2	0.0
	BOD	74.5	59.6	37.3	14.9	14.9	14.9	4.5
	NH_3-N	15.7	3.1	11.0	11.0	11.0	2.4	0.8
	NO_3-N	1.1	1.1	1.1	1.1	1.1	1.1	0.2
	DO	4.0	4.0	4.0	4.0	4.0	4.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	PO_4	7.5	5.2	0.8	0.2	4.5	0.2	0.0
	BOD	83.2	66.6	41.6	16.6	16.6	16.6	5.0
	NH_3-N	13.4	2.7	9.4	9.4	9.4	2.0	0.7
	NO_3-N	4.5	4.5	4.5	4.5	4.5	4.5	0.7
	DO	4.0	4.0	4.0	4.0	4.0	4.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	PO_4	9.1	6.3	0.9	0.2	5.4	0.2	0.0
	BOD	48.2	38.6	24.1	9.6	9.6	9.6	2.9
	NH_3-N	18.7	3.7	13.1	13.1	13.1	2.8	0.9
	NO_3-N	2.6	2.6	2.6	2.6	2.6	2.6	0.4
	DO	6.0	6.0	6.0	6.0	6.0	6.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	PO_4	11.2	7.8	1.1	0.2	6.7	0.2	0.0
	BOD	88.8	71.0	44.4	17.8	17.8	17.8	5.3
	NH_3-N	5.6	1.1	3.9	3.9	3.9	0.8	0.3
	NO_3-N	0.9	0.9	0.9	0.9	0.9	0.9	0.1
	DO	6.0	6.0	6.0	6.0	6.0	6.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	PO_4	9.8	6.9	1.1	0.2	5.9	0.2	0.0
	BOD	54.2	43.4	27.1	10.8	10.8	10.8	3.2
	NH_3-N	5.6	1.1	3.9	3.9	3.9	0.8	0.3
	NO_3-N	4.0	4.0	4.0	4.0	4.0	4.0	0.6
	DO	6.0	6.0	6.0	6.0	6.0	6.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4-21. Continued.

Load (ℓ)	Quality Parameter	Effluent Concentration for Treatment Levels (mg/l)						
		I	II	III	IV	V	VI	VII
7	PO_4	4.2	2.9	0.4	8.1	2.5	0.1	0.0
	BOD	50.8	40.6	25.4	10.2	10.2	10.2	3.1
	NH_3-N	3.8	0.8	2.7	2.7	2.7	0.6	0.2
	NO_3-N	5.0	5.0	5.0	5.0	5.0	5.0	0.7
	DO	6.0	6.0	6.0	6.0	6.0	6.0	7.7
	Algae	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4-22. Model coefficients used for Jordan River.

Constituent	Code	Coefficient		Description	Value	Comments	Reference
		Symbol	Units				
Ortho-Phosphate	PHOS	$\beta_{6,1}$	per day	First order removal rate	0.0	All reaches	Dixon et al. (1975)
		$\beta_{6,2}$	mg PHOS/mg ALGP	Yield coefficient	1.0	All reaches	Dixon et al. (1975)
		$\beta_{6,3}$	mg/l	Half saturation coefficient	0.1	All reaches	Dixon et al. (1975)
Biochemical Oxygen Demand	CBOD	$\beta_{7,1}$	per day	First order oxidation rate	0.7	All reaches	Bowles (1977)
		$\beta_{7,2}$	per day	First order removal rate	0.0	All reaches	
		$\beta_{7,3}$	mg CBOD/mg dead ALGP	Ratio of CBOD to dead ALGP	0.3	All reaches	
Ammonia	NH3N	$\beta_{8,1}$	per day	First order oxidation rate (Nitrification)	0.3	All reaches	Bowles (1977)
		$\beta_{8,2}$	per day	First order removal rate	0.0	All reaches	
		$\beta_{8,3}$	mg NH3N/mg CBOD	Stoichiometric ratio	0.0	All reaches	
		$\beta_{8,4}$	mg NH3N/mg ALGP	Yield coefficient	10.0	All reaches	Dixon et al. (1975)
		$\beta_{8,5}$	Dimensionless	Weighting coefficient to indicate preference of algae for NH3N over NO3N	2.0	All reaches	Bowles (1977)
		$\beta_{8,6}$	mg/l	Half saturation coefficient	0.008	All reaches	Bowles (1977)
Nitrate	NO3N	$\beta_{9,1}$	per day	First order removal rate	0.0	All reaches	
		$\beta_{9,2}$	mg NO3N/mg ALGP	Yield coefficient	10.0	All reaches	Dixon et al. (1975)
		$\beta_{9,3}$	mg/l	Half saturation coefficient	0.015	All reaches	Bowles (1977)
Dissolved Oxygen	DOXY	$\beta_{10,1}$	per day	Reaeration rate		Calculated by Program	
		$\beta_{10,2}$	mg/l	Dissolved oxygen saturation	7.713	All reaches	
		$\beta_{10,3}$	(mg/l)/day	Net oxygen production by phytoplankton	0.0	All reaches	
		$\beta_{10,4}$	$(g/m^2/day)/(mg\ O_2/l)$	Benthic uptake of oxygen	0.0	Reaches 1-4	Dixon et al. (1975)
					0.030	Reach 5	Dixon et al. (1975)
					0.038	Reach 6	Dixon et al. (1975)
					0.044	Reach 7	Dixon et al. (1975)
					0.050	Reach 8	Dixon et al. (1975)
					0.058	Reach 9	Dixon et al. (1975)
					0.066	Reach 10	Dixon et al. (1975)
					0.078	Reach 11	Dixon et al. (1975)
					1.30	Reaches 12-14	Bowles (1977)
		$\beta_{10,5}$	$(mg\ O_2/day)mg\ ALGP$	Algae O_2 production	180.0	All reaches	Grenney (1975)
Algae	ALGP	$\beta_{12,1}$	per day	Maximum specific growth rate	2.0	Reaches 1-11	Bowles (1977)
					1.5	Reaches 12-14	Bowles (1977)
		$\beta_{12,2}$	per day	Algae death rate	0.04	All reaches	Bowles (1977)

Table 4-19. Table 4-20 shows the existing loading from point and diffuse sources and the water quality boundary conditions and Table 4-21 gives the effluent discharge quality from each point load after treatment at a specified level. The water quality equation coefficients are shown in Table 4-22.

The initial quality constituent concentrations in the river at the surveillance points generated by the model are shown in Table 4-23 and the water quality stream standards are shown in Table 4-24. Note that the BOD standard is exceeded at all surveillance points and the DO standard is exceeded at the third surveillance point. Total cost per year for each treatment level at each point load, in thousands of 1977 dollars is shown in Table 4-25.

Results from optimization model

As with the hypothetical problem, the solution from the first simulation-optimization model iteration was found to be the optimum solution. Table 4-26 shows that treatment level V (tertiary sand filter) is required at all loads to meet stream water quality standards at a increase from current costs of $1,795,881 per year. The excess stream capacities at the optimal solution are shown in Table 4-27.

To determine whether the optimal treatment scheme would be able to handle increased loads from expected growth in the Jordan River Valley, the simulation-optimization model was run with the projected 1995 point load flows shown in Table 4-28. The 1995 flows were based on a 58 percent increase from the 1974 typical summer flows (Table 4-19) projected by Salt Lake County Council of Governments (1977b).

Table 4-23. Initial river conditions at surveillance points: Y_k^o.

Quality Parameter	Initial Concentrations at Surveillance Points k (mg/l)		
	Y_1^o	Y_2^o	Y_3^o
PO_4	1.21	2.13	1.80
BOD	11.04	14.92	14.03
NH_3-N	1.67	2.05	1.53
NO_3-N	1.79	1.99	2.12
DO	6.25	6.22	5.26
Algae	0.015	0.009	0.010

Table 4-24. Water quality stream standards: B_k.

Quality Parameter	Standard	Stream Standard at Surveillance Point, k (mg/l)		
		B_1	B_2	B_3
PO_4	$(y_1)_k \leq \infty$ at each k (no standard)	∞	∞	∞
BOD	$(y_2)_k \leq 5.0$ at each k	5.0	5.0	5.0
NH_3-N	$(y_3)_k \leq \infty$ at each k (no standard)	∞	∞	∞
NO_3-N	$(y_4)_k \leq \infty$ at each k (no standard)	∞	∞	∞
DO	$(y_5)_k \geq 5.5$ at each k	5.5	5.5	5.5
Algae	$(y_6)_k \leq \infty$ at each k (no standard)	∞	∞	∞

Table 4-25. Cost per year in thousands of 1977 dollars (capital recovery factor = 0.08) for each treatment level at each load.

Load (ℓ)	Flow Q (ℓ) (mgd)	Treatment Level (n)						
		I	II	III	IV	V	VI	VII
1	3.23	0	115	185	238	163	353	951
2	6.46	0	212	357	454	254	666	1659
3	3.88	0	135	219	282	183	417	1103
4	8.40	0	268	460	582	300	849	2037
5	7.76	0	249	426	539	285	789	1914
6	13.6	0	409	733	918	409	1127	2940
7	4.52	0	155	254	325	202	480	1249

Table 4-26. Optimal solution for Jordan River.

Parameter	Load (ℓ)						
	1	2	3	4	5	6	7
Treatment Level (n)	V	V	V	V	V	V	V
Cost in thousands of 1977 dollars per year	163	254	183	300	285	409	202

Table 4-27. Excess stream capacities at optimal solution.

Water Quality Constituent	Excess Stream Capacities at Surveillance Point, k (mg/l)		
	1	2	3
PO_4	0.0	0.0	0.0
BOD	2.16	1.71	0.31
NH_3-N	0.0	0.0	0.0
NO_3-N	0.0	0.0	0.0
DO	0.84	1.11	0.39
Algae	0.0	0.0	0.0

Table 4-28. 1995 projected flow from point discharges.

Description	Location (miles)[a]	Flow (ft^3/sec)[b]
Sandy WTP (ℓ = 1)	28.9	7.89
Tri-Community WTP (ℓ = 2)	26.5	15.78
Murray WTP (ℓ = 3)	22.0	9.47
Cottonwood WTP (ℓ = 4)	21.4	20.52
Granger Hunter WTP (ℓ = 5)	18.7	18.94
Salt Lake Sub. WTP (ℓ = 6)	18.3	33.15
South Salt Lake WTP (ℓ = 7)	16.2	11.05

[a] 1 mile = 1.61 km

[b] 1 ft^3/sec = 0.0283 m^3/sec

For the purposes of this study the increase was assumed to be uniform over all point loads. It was determined that the optimal treatment scheme for the 1995 flows was the same as for the 1975 flows (Table 4-26). The increase from current treatment costs for the 1995 flows was $2,407,092 per year.

Optimal Solution Convergence

In both the hypothetical problem and the Jordan River application, the solution converged to an optimum after one simulation-optimization model iteration. When changing the BOD equation to a second-order decay equation in the hypothetical problem, the solution converged after only two iterations. This would tend to indicate that with most applications, convergence of the optimal solution does not appear to be a problem.

Computational Aspects

All model runs were made on the Burroughs 6700 computer located on the Utah State University campus. One iteration of the simulation-optimization model for the hypothetical problem required 183 seconds central processor time for the simulation model and 15 seconds central processor time for the optimization model at a total cost of $30. The Jordan River application required 333 seconds central processor time for the simulation model and 16 seconds central processor time for the optimization model at a total cost of $46.

CHAPTER V

WATER SUPPLY COMPONENT OF RESEARCH PROGRAM

Scope

This research program included integer programming optimization models for both water quality and water supply planning problems. The water quality simulation and optimization model is reported in detail in this report. The water supply optimization model (WASOPT) is described in a separate publication (Hughes et al. 1977). This chapter, however, will: 1) give a very brief description of the structure and capability of the water supply model and 2) discuss the potential for combined use of both models.

Description of WASOPT

The water supply model is a mixed integer programming (MIP) model which is quite general. It can be applied to problem scopes ranging from an individual municipal system to regional problems with many separate (but potentially connectable) systems. It also considers operational as well as capital investment optimization. The method is, however, limited to planning source related facilities such as treatment plants, wells, springs, wholesale purchases, and transmission lines as opposed to the distribution system. Distrubition systems can normally be planned essentially independently of the facilities upstream from equalizing reservoirs.

The thrust of the planning method is not hydraulic optimization (which is a relatively simple component of the source related facility problem) but rather economic comparison (least cost objective function) of types of facilities with widely varying degrees of capital intensity.

The structure is basically a transportation problem which requires zonal demands to be satisfied by flow from existing or potential wells, springs, treatment plants, or wholesalers. Interzonal transfers of water are accomplished by existing or proposed conduits connecting the zones. If such facilities as desalting plants or recycling of municipal sewage plants are to be considered as alternatives, they can be included as treatment plants simply by making appropriate adjustments in cost coefficients (however, in applications where recycling is an important quantitative factor, other modifications to the model would be desirable as discussed below).

A MIP model structure was chosen to enable the separation of capital investment costs (integer variables) and operation and maintenance (O&M) costs (continuous variables). The integer variables allow the build/no build option of discrete sizes for proposed facilities which more closely duplicates the actual alternative planning situation. The continuous variables provide for the continuous function (cost/unit) associated with O&M costs and allow use factors to vary independently of fixed costs.

The objective function is structured to provide for the least annual cost at a desired level of service. The general structure provides for modeling from one to four seasons and a peak day. Peak day constraints were added because normally the level of capital investment required to satisfy the peak season demand is not adequate to satisfy the peak day demand during an average year and, therefore, would clearly be inadequate for peak day demand in an unusually high demand and/or low supply day.

The simplified form of the model is as follows:

$$\text{Minimize total annual cost} = C_1 I + C_2 X$$

in which

I = vector of integer variables (discrete size of type of potential new facility)

X = vector of continuous seasonal and peak variables (level of use of existing or proposed facilities)

C_1, C_2 = fixed ($) and variable ($/MG) cost coefficients, respectively

Subject to the following seasonal and peak day constraints:

$X \geq d$ = (supply to each zone $\geq$ demand for each season)

$X \leq b$ = (flow from each existing production facility $\leq$ its capacity)

$X \leq AI$ = (flow from each new facility $\leq$ its capacity)

$X \geq lbI$ = (minimum contract purchases)

I = number of units built

A = capacity of each single unit

The standard model has been tested on several real world planning problems varying in scope from a single system with several service zones to a regional problem with 23 separate systems. The latter model included 278 constraints and 258 variables, 54 of which were integer variables. Computational effort and computer costs for large problems using three different MIP algorithm/computer system combinations have been described by Hughes et al. (1975).

Model Generator

The key to use of this methodology by planners who have little knowledge of mathematical programming is the capability for internal generation of the mathematical model in MIP form by the computer.

Planning engineers who have had experience with developing mathematical programming optimization models for complex water resource problems realize the manual effort required to define the hundreds of variables, to structure the constraints, and to calculate all of the numerical coefficients represents a difficult task. This effort is not only very time consuming, but inevitably results in numeric, if not solution output that contains inconsistencies (thereby also increasing computer costs). WASOPT, however, totally avoids manual construction of such models for municipal water supply planning problems. The procedure involves the use of: 1) a model generating program called GAMMA which is available as an addition to the Burrough TEMPO mathematical programming package on B6700 computer systems (very similar software is becoming available on other computers); 2) a series of subroutines which obtain problem input data from the user via a series of questions and instructive statements in interactive mode; and 3) a series of computer control statements which link the subroutines, the data generator, and the mathematical programming or modeling expertise from the user.

In addition to generating models GAMMA also has a report writing capability. This feature is also used within WASOPT to produce solution output in a form and language that is specifically designed for the water supply problem and is, therefore, a great improvement over normal TEMPO output.

Combined Use of the Water Quality and Water Supply Models

Collectively, the water quality water and supply models developed by this research program can optimize the entire scope of least cost planning problems related to municipal supply and waste treatment of regional water resources. The recommended mode of application of these models in comprehensive water resource studies is that of a manual interface as opposed to total combination into one super model. This recommendation is based upon reasons described below.

The water supply and waste treatment problems have obvious interactions: 1) outflow from the supply system becomes inflow to the treatment system; and 2) the reverse is true if recycling is considered. On the other hand the division between the two systems represents a natural point for decomposing the total planning problem. One of the important limitations of integer programming models is the exponential increase in computational effort as the number of variables increases. Clearly, for other than relatively small problems it is desirable to decompose the problem and therefore a totally integrated form of combined planning model appears not to be cost effective.

Short of total combination into a model in which both supply and waste treatment inequalities are solved simultaneously, however, a mode of use in which the two models are linked in series may be desirable. It is possible currently to operate in this mode by manually relating the input and outputs of the two models.

possible treatment levels are available for six quality constituents. Water quality standards for three constituents are imposed at five surveillance points along the river. The portion of the Jordan River examined consists of seven pollution discharge points, at which seven treatment levels are available to remove six quality constituents. Water quality standards for two constituents are imposed at three surveillance points. The cost minimization problem for the Jordan River (1975 flows) required tertiary sand filters at all point loads at an increase from current costs of $1,795,881 per year to meet stream water quality standards.

To assist in gaining familiarity with the linked simulation-optimization model, several sensitivity studies are performed. The sensitivity of the optimal solution to two model input parameters is investigated. These parameters are the water quality equation coefficients and the water quality stream standards. In the hypothetical problem, a 10 percent increase in the ammonia decay rate or a 15 percent increase in the maximum specific algae growth rate would result in a 16 percent reduction in the minimum system treatment cost. A 10 percent relaxation of the stream standards at all surveillance points would result in a 54 percent reduction in the minimum system treatment costs. The sensitivity of the optimal solution to changes in headwater and point discharge flow is also investigated. The optimal treatment scheme for the projected 1995 flows on the Jordan River was the same as the 1975 flows. The minimum treatment costs for the 1995 flows was $2,407,092 per year.

The regional water quality model and the water supply model are both formulated as integer programming problems but are nevertheless different types of models. In order to develop optimal plans for both the waste treatment and the water supply activities of a region, both models should be used and could be linked in terms of output of one representing input for the other (for example, where water recycling is considered). At the present time, the two models are interfaced manually thereby taking advantage of natural decomposition of the overall problem.

Conclusions

The following conclusions have been developed from results and experience gained during this study:

1. Computation time and solution results indicate the regional water quality control model developed herein is a viable tool in river basin water quality management. To reach the optimal solution in the Jordan River application only 333 seconds process time for the simulation model and 16 seconds process time for the optimization model was required.
2. The solution converged rapidly to an optimum with a nonlinear system. It appears that only one simulation-optimization model iteration is required for most applications.
3. A sensitivity analysis on changes in the optimal solution with changes in the water quality equation coefficients and stream standards may reveal substantial monetary savings with minor changes in the coefficients or slight

relaxation of the stream standards. For example, in the hypothetical problem, a 10 percent relaxation of the stream standards at all surveillance points would result in a 54 percent reduction in the minimum system treatment costs.

4. The regional water quality control model is useful in examining the impact of alternative futures on the cost of wastewater treatment in a river basin.

Recommendations

The following recommendations for further work are based on experience gained during this study:

1. The water quality simulation model (SSAM), should be modified so that variable flows for point and diffuse loads can be considered. This would allow the optimization model to consider low flow augmentation and bypass piping as treatment alternatives.
2. A general economic model should be interfaced with the regional water quality control model. Some features of the economic model might include a program to generate waste discharge fees for wastewater dischargers who choose not to participate in a regional water quality control plan, and a program to generate a tax or fee structure for users of the regional water quality control facilities.

3. The theoretical problems associated with convergence and optimality of a programming problem linked to a non-linear simulation model should be studied.
4. Use random differential equations to model the water quality parameters and develop solution techniques for these equations so that confidence intervals on the solution are possible.

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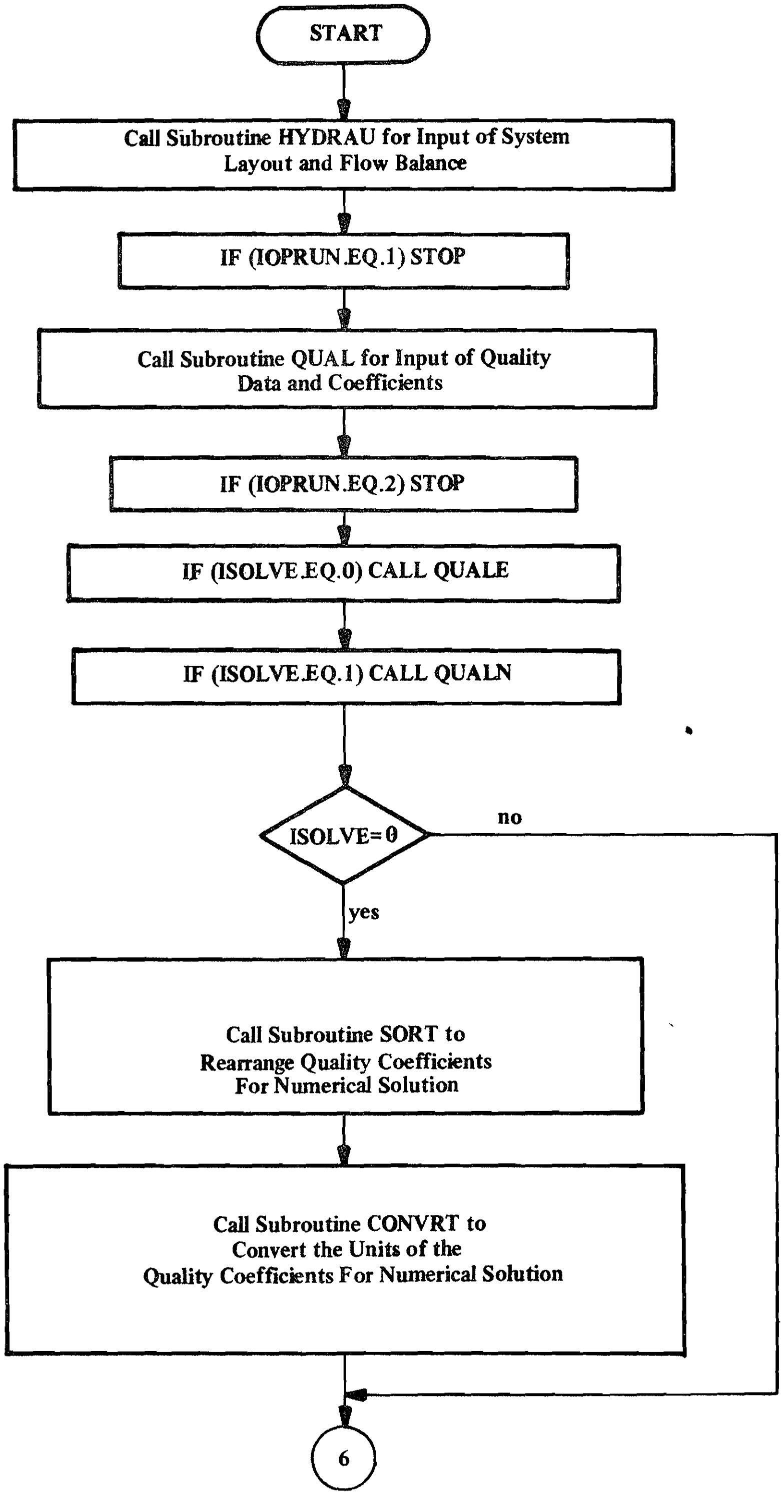
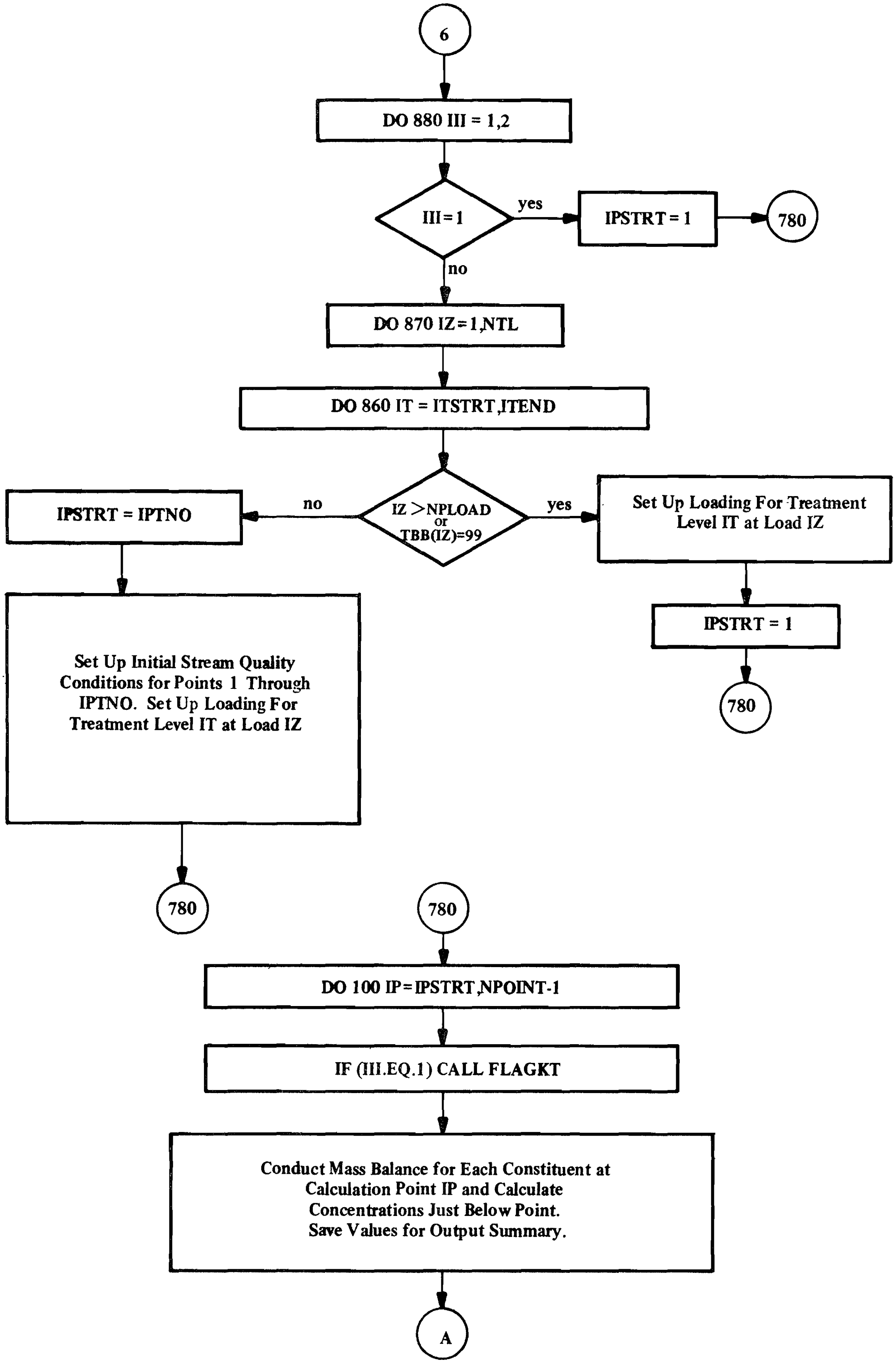
APPENDICES

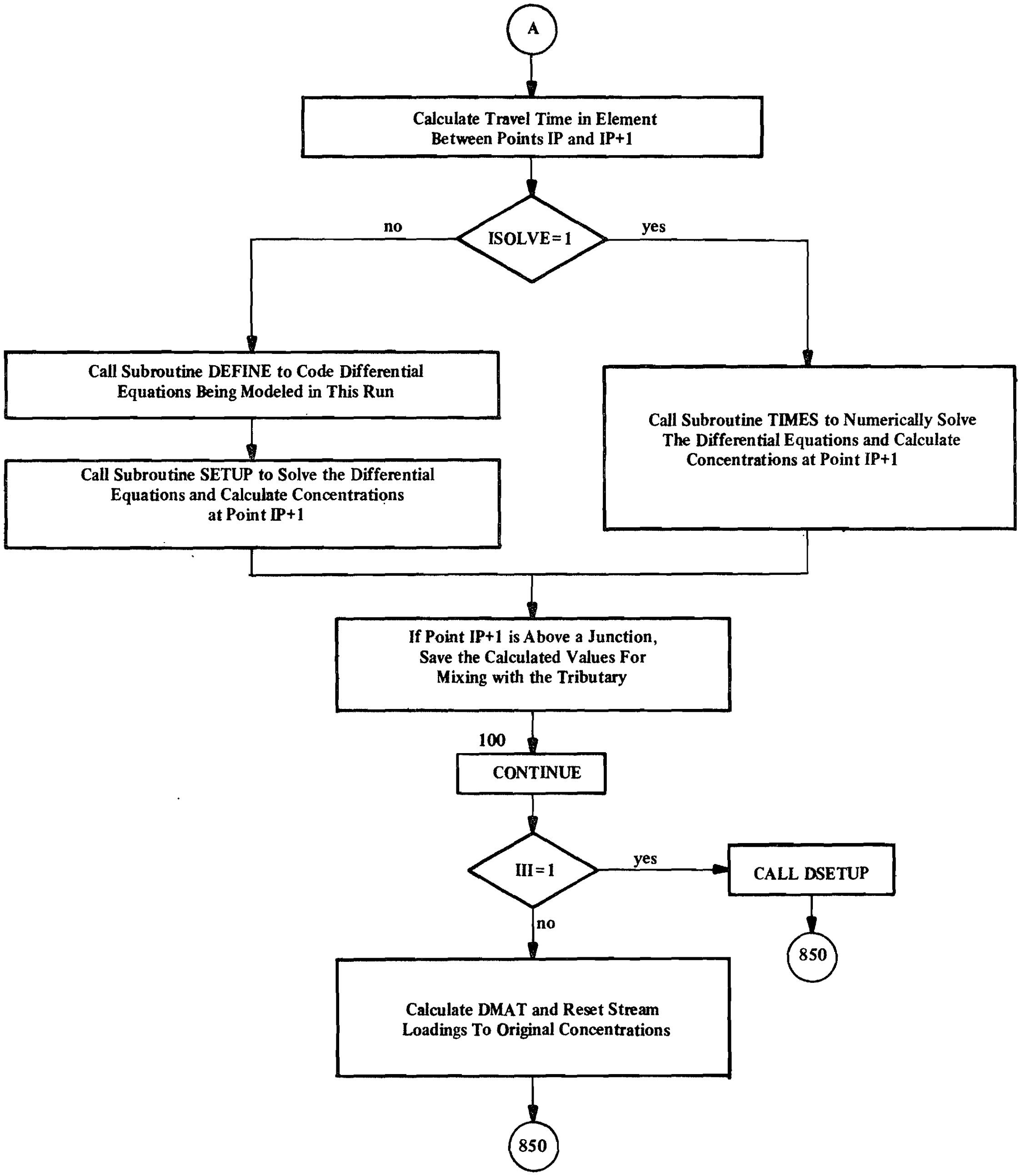
NHDW	Number of headwaters
NLOAD	Number of point loads
NDIRV	Number of point diversions
IC	Code number of constituent
NPLOAD	Number of point loads to be considered
NDLOAD	Number of diffuse loads to be considered
NTL	Sum of NPLOAD and NDLOAD ≤ 30
NTLPL	Number of treatment levels for point loads
NTLDL	Number of treatment levels for diffuse loads
NTTL	Sum of NTLPL and NTLDL ≤ 15
NK	Number of surveillance points ≤ 10
IZ	Load index
IT	Treatment level index
IK	Surveillance point index
ZDSAVE(IC,IP)	Array of initial stream conditions (mg/l)
LP(IZ)	Array of point load numbers
LD1(IZ)	Beginning reach numbers for diffuse load
LD2(IZ)	Ending reach numbers for diffuse loads
LPPTNO(IZ)	River point numbers for point loads
ILP	Point load index
ILD	Diffuse load reach index
ZLDMAT(IC,IT,ILP)	Concentration of constituent IC with treatment level IT at point load ILP (mg/l)
CSDMAT(IC,IT,ILD)	Concentration of constituent IC with treatment level IT from the diffuse load at reach ILD (mg/l)
ZLSAVE(IC,ILP)	Vector of concentration added by a point load (mg/l)
CSSAVE(IC,ILD)	Vector of concentration added by a diffuse load (mg/l)

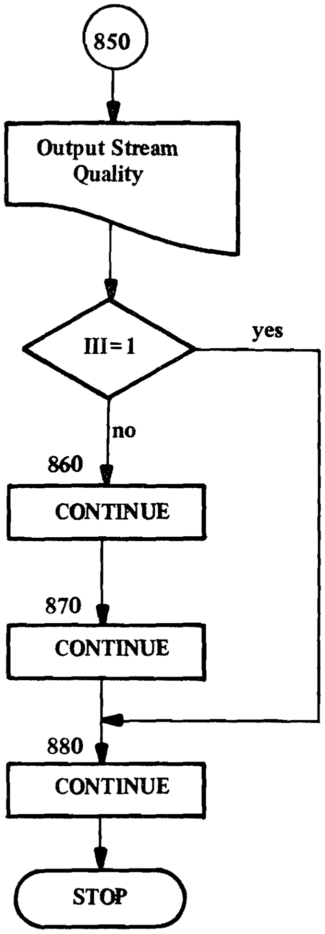
KID(IK)	Point numbers of surveillance points
DMAT(IC,IT,IZ,IK)	Change in constituent IC at surveillance point IK with treatment level IT on load IZ
TBB(IZ)	If point load IZ is not on the main river branch, TBB(IZ) = 99
IPTNO	Calculation point number for point load IZ

Subroutine CONTRL




6
DO 880 III = 1,2
III=1
yes
IPSTRT = 1
780
no
DO 870 IZ=1,NTL
DO 860 IT = ITSTRT,ITEND
IPSTRT = IPTNO
no
IZ >NPLOAD or TBB(IZ)=99
yes
Set Up Loading For Treatment Level IT at Load IZ
IPSTRT = 1
780
Set Up Initial Stream Quality Conditions for Points 1 Through IPTNO. Set Up Loading For Treatment Level IT at Load IZ
780
780
DO 100 IP=IPSTRT,NPOINT-1
IF (III.EQ.1) CALL FLAGKT
Conduct Mass Balance for Each Constituent at Calculation Point IP and Calculate Concentrations Just Below Point. Save Values for Output Summary.
A


A
Calculate Travel Time in Element Between Points IP and IP+1
ISOLVE=1
no
yes
Call Subroutine DEFINE to Code Differential Equations Being Modeled in This Run
Call Subroutine SETUP to Solve the Differential Equations and Calculate Concentrations at Point IP+1
Call Subroutine TIMES to Numerically Solve The Differential Equations and Calculate Concentrations at Point IP+1
If Point IP+1 is Above a Junction, Save the Calculated Values For Mixing with the Tributary
100
CONTINUE
III=1
yes
CALL DSETUP
850
no
Calculate DMAT and Reset Stream Loadings To Original Concentrations
850


850
Output Stream Quality
III=1
yes
no
860
CONTINUE
870
CONTINUE
880
CONTINUE
STOP

SUBROUTINE HYDRAU

Purpose

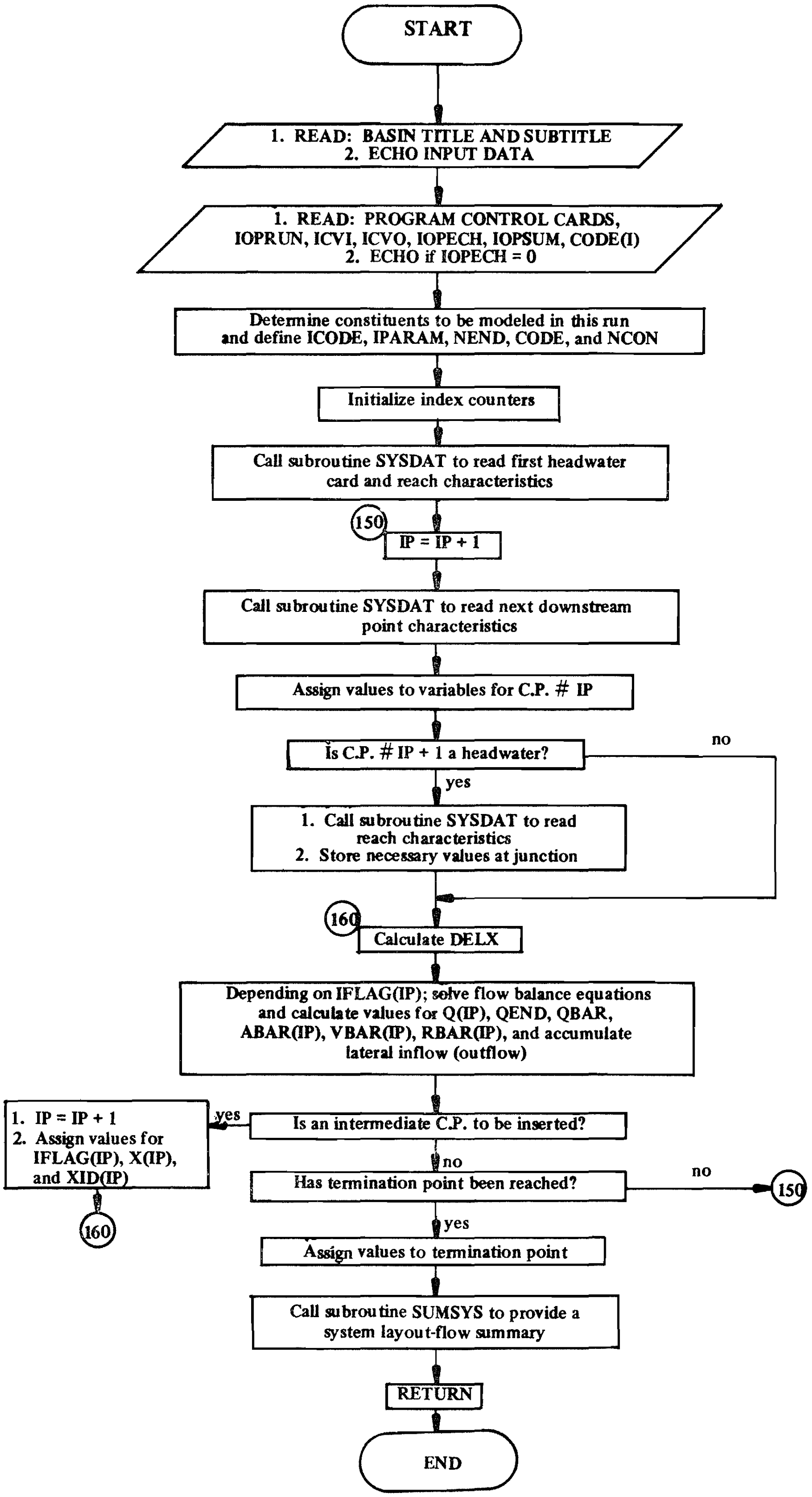
1. Read in data for the system layout, flow, and reach hydraulic characteristics.
2. Echo input data at user's option (IOPECH).
3. Determine the number and type of constituents to be modeled.
4. Layout the system of calculation points.
5. Calculate and store the flow, cross-sectional area, hydraulic radius, and velocity for each element.
6. Write a system layout-flow summary at user's option.

Variable Name	Variable Description
IOPECH	= 0 echo input data = 1 do not echo input data
IOPSUM	= 0 write summary for both hydraulics and quality = 1 write summary for hydraulics only = 2 write summary for quality only
IOPRAD	= 0 calculate hydraulic radius using Manning's equation = 1 calculate hydraulic radius using $R = \beta_3 A^{\beta_4}$
IOPRUN	= 1 execute program through HYDRAU = 2 execute program through QUAL = 3 execute entire program
ICONV	= 0 input is in metric units = 1 input is in English units
ICODE(IEQ)	Vector of code numbers (in sequence of constituents being modeled
IEQ	Sequence number of differential equation
IPARAM(IC)	The sequence number of constituent IC in the current run = 0: constituent number IC is not being modeled

IC	Code number of constituent
CODE(IEQ)	Alpha numeric code for constituent
NEND	Number of constituents on the control card
NCON	Number of constituents to be modeled (excludes TEMP)
IP	Index of calculation point (C.P.)
NPOINT	Number of C.P.'s in the system
NREACH	Number of reaches in the system
NHDW	Number of headwaters in the system
NLOAD	Number of point loads in the system
NDIRV	Number of point diversions in the system
X(IP)	River distance to calculate point IP (km)
IFLAG(IP)	Flag associated with C.P. #IP
	= 1 (H) headwater
	= 2 (R) head of reach other than a headwater or a junction
	= 3 (L) point load
	= 4 (D) point diversion
	= 5 (J) just downstream from a junction
	= 6 (C) check point
	= 7 intermediate C.P. (write output)
	= 8 intermediate C.P. (suppress output)
	= 9 (T) termination point
XID(IP)	Four character identification code for C.P. #IP
Q(IP)	Flow just downstream from C.P. #IP (cms)
QEND	Flow just upstream from C.P. #IP + 1 (cms)
XRUN	River distance to check if an intermediate calculation point should be inserted (km)

VBAR(IP)	Average velocity between C.P. #IP and C.P. #IP + 1 (mps)
ABAR(IP)	Average cross-sectional area between C.P. #IP and C.P. #IP + 1 (m^2)
RBAR(IP)	Average hydraulic radius between C.P. #IP and C.P. #IP + 1 (m)
COEF(1,LID2,LID1)	Accumulated lateral surface flow for a reach (cms)
COEF(2,LID2,LID1)	Accumulated lateral ground flow for a reach (cms)
QL(IL)	Flow for point load IL (cms)
QD(ID)	Flow for point diversion ID (cms)
DELX	Distance between C.P. #IP and C.P. #IP + 1 (m)
TITLE(I)	Basin title
SUBTL(I)	Basin subtitle
ZL(IS,I)	Dummy matrix used for temporary storage of input data
	I = 1: Flag
	I = 2: River distance
	I = 3: Alpha numeric identification code
	I = 4 to 8: Alpha numeric identification code
	I = 11: Input flow (headwater, point load, point diversion) (cms)
	I = 12: Lateral surface inflow (cms/km)
	I = 13: Lateral ground inflow (mms/km)
	I = 14: Reach slope
	I = 15: Reach Manning coefficient
	I = 16: Reach β_1
	I = 17: Reach β_2
	I = 18: Reach β_3
	I = 19: Reach β_4
	I = 20: IOPRAD
COEF(K,IID2,IID1)	Matrix used for temporary storage of alpha numeric identification (K = 4 to 8)

Subroutine HYDRAU



SUBROUTINE SYSDAT

Purpose: To read system input data for subroutine HYDRAU and convert English units to metric.

Variable Name	Variable Description
ICONV	= 0 input is in metric units = 1 input is in English units
IE	Index identifying data at the downstream end of the element
IS	Index identifying data at the upstream end of the element
ZL(1,I)	Type code
ZL(2,I)	River distance
ZL(3,I)	Alpha numeric identification code
ZL(4,I)-ZL(8,I)	Alpha numeric description
ZL(9,I)	Output code
ZL(10,I)	Incremental length
ZL(11,I)	Flow
ZL(12,I)	Lateral surface flow
ZL(13,I)	Lateral subsurface flow
ZL(14,I)	Slope
ZL(15,I)	Mannings n
ZL(16,I)	Coefficient converting flow to velocity
ZL(17,I)	Exponent converting flow to velocity
ZL(18,I)	Coefficient converting area to hydraulic radius
ZL(19,I)	Exponent converting area to hydraulic radius
ZL(20,I)	IOPRAD: = 0 use Mannings equation = 1 use empirical equation

SUBROUTINE SUMSYS

Purpose: To provide an output summary of:

1. System layout, flow balance, and the calculated hydraulic parameters
2. System loading patterns

Variables used in this subroutine are the same as those used in Subroutines HYDRAU and QUAL.

SUBROUTINE QUALI

Purpose

1. Read in data for water quality characteristics: headwater, lateral inflow, point load concentrations, and reach coefficients.
2. Echo input data at user's option (IOPECH).
3. Assign input data to proper variables.
4. Write a water quality summary at user's option.

Variable Name	Variable Description
C(K)	Matrix for temporary storage of coefficient values
CG(IEQ,IR)	Concentration in lateral groundwater flow (mg/l)
CHW(IH,IEQ)	Concentration in headwater (mg/l)
COEF(IEQ,J,IR)	Coefficient for differential equation IEQ, term J, and reach IR
CS(IEQ,IR)	Concentration in lateral surface flow (mg/l)
CTEMP(IT,IR)	Temperature for reach IR
IC	Code number of water quality constituent
IEQ	Sequence number of differential equation
IH	Headwater index
IL	Point load index
IR	Reach index
NCO(IC)	Number of coefficients to be read in for constituent IC
NHDW	Number of headwaters
NLOAD	Number of point loads
NPOINT	Number of calculation points in the system
NREACH	Number of reaches

ZD(K,I)	Matrix for temporary storage of data
ZD(L1,I)	Matrix used for temporary storage of input variables
ZL(IEQ,IL)	Concentration in point load (mg/l)

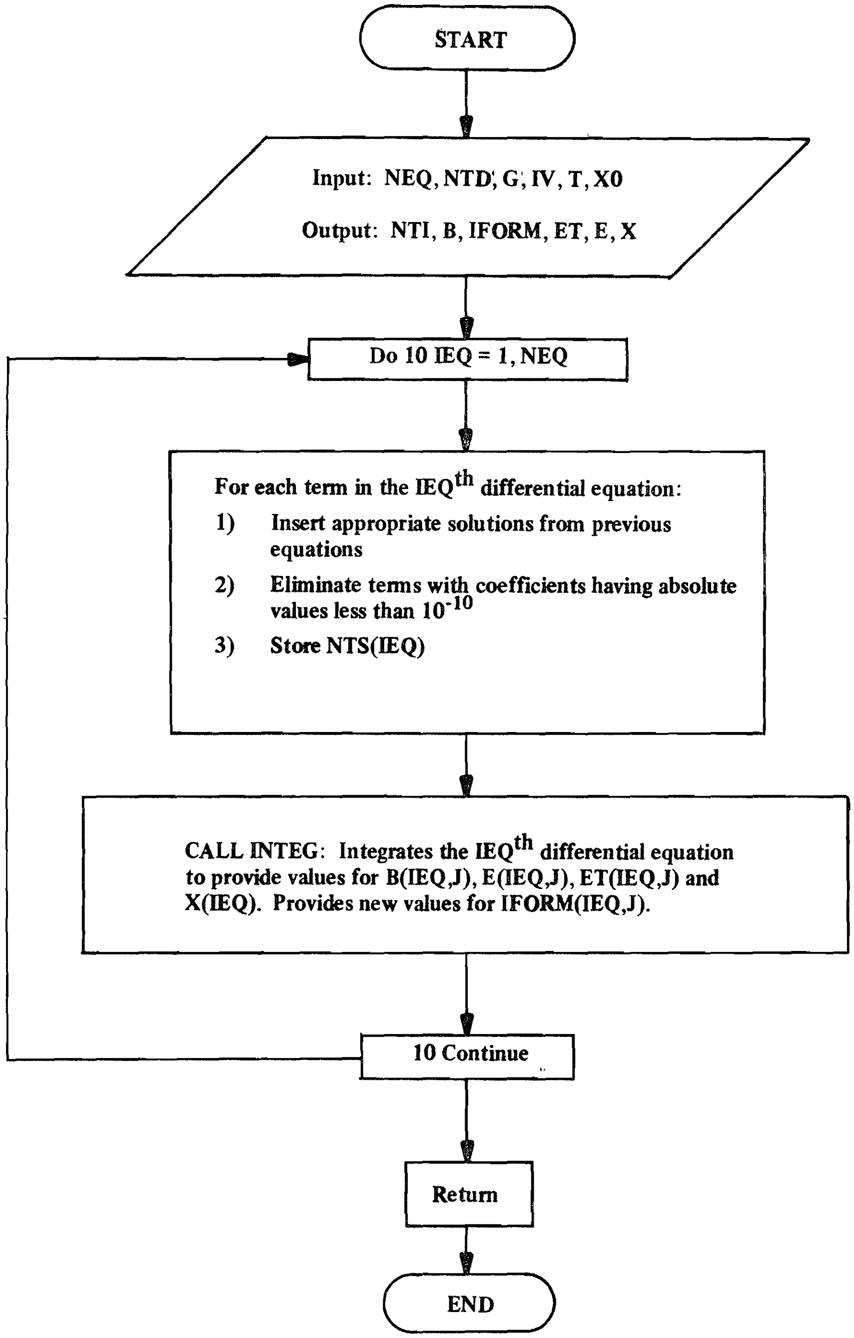
SUBROUTINE SETUP

Purpose: To set up the ordinary differential equations to be solved by Subroutine INTEG.

Variable Name	Variable Description
NEQ	Number of different equations in the system
NTD(IEQ)	Number of terms in the IEQth differential equation; excluding the derivative
G(IEQ,J)	Value of the coefficient for the Jth term of the IEQth differential equation
IV(IEQ,J)	Index of the dependent variable associated with Jth term of the IEQth differential equation
T	Travel time in the first reach of stream
XO(IEQ)	Initial value of the IEQth dependent variable at the upstream boundary of the reach
NTI(IEQ)	Number of terms in the solution equation to the IEQth differential equation
B(IEQ,J)	Value of the coefficient for the Jth term of the IEQth solution equation
IFORM(IEQ,J)	Category number for the Jth term in the IEQth solution equation
E(IEQ,J)	Value of the exponent on "e" for the Jth term of the IEQth solution equation
ET(IEQ,J)	Value of the exponent on "t" for the Jth term of the IEQth solution equation
X(IEQ)	Value of the dependent variable in the IEQth equation at time "T" given the initial condition "XO(IEQ)"
IEQ	The equations in the system are numbered in order. IEQ is the index identifying a particular equation. IEQ ranges between 1 and NEQ. The IEQth solution equation is the closed solution for the IEQth differential equation

NTS(IEQ)	Number of terms in the IEQth differential equation after inserting appropriate solutions from previous equations
B(IEQ,M)	Value of the coefficient for the Mth term of the IEQth differential equation after the insertion of the solutions for appropriate preceding equations. B(IEQ,1) is the coefficient on the left-hand-side of the equation
E(IEQ,M) and ET(IEQ,M)	Values of the exponents for the Mth term of the IEQth differential equation after insertion of the solutions for appropriate preceding equations
INFORM(IEQ,M)	Category number for the Mth term of the IEQth differential equation

Subroutine SETUP



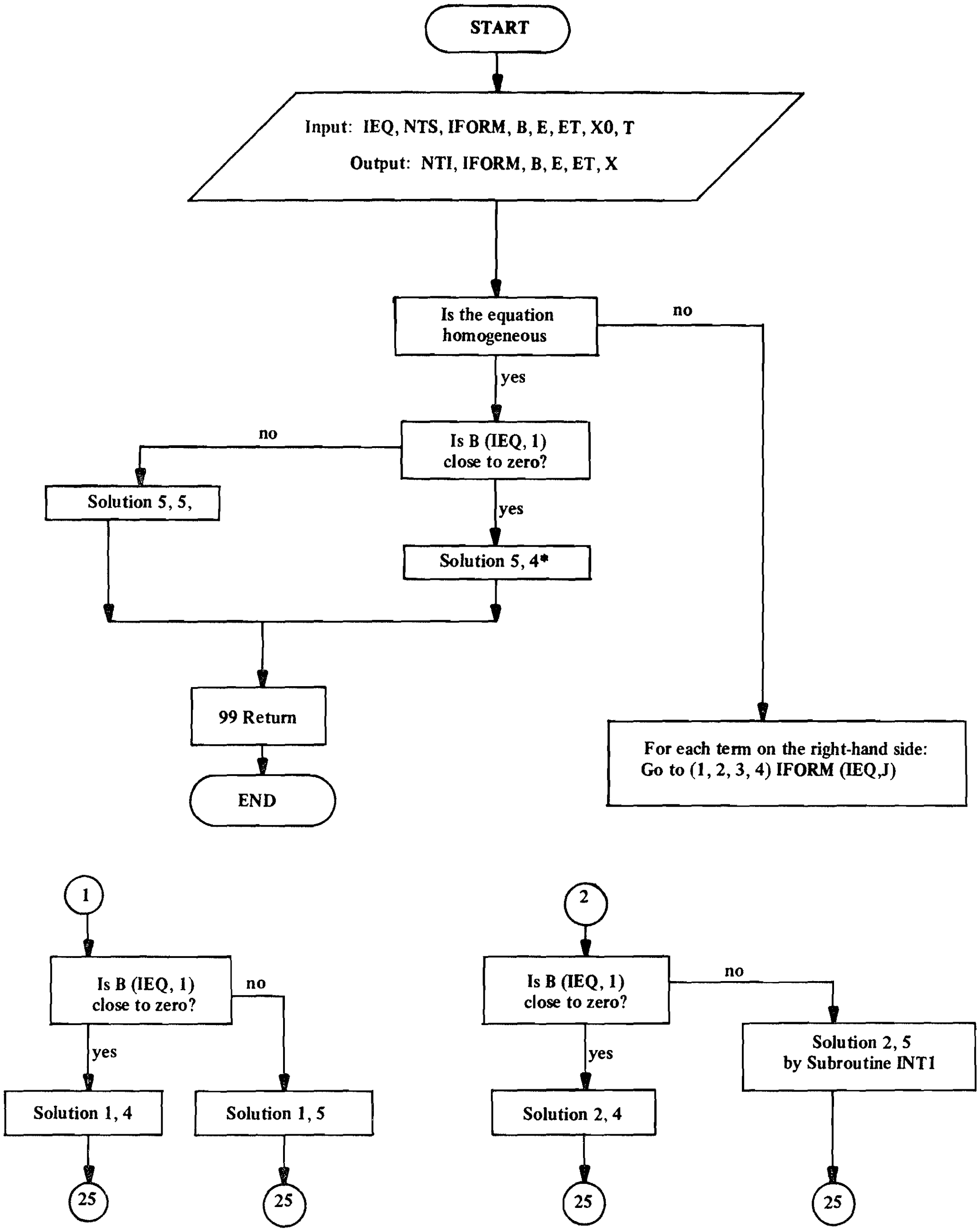
SUBROUTINE INTEG

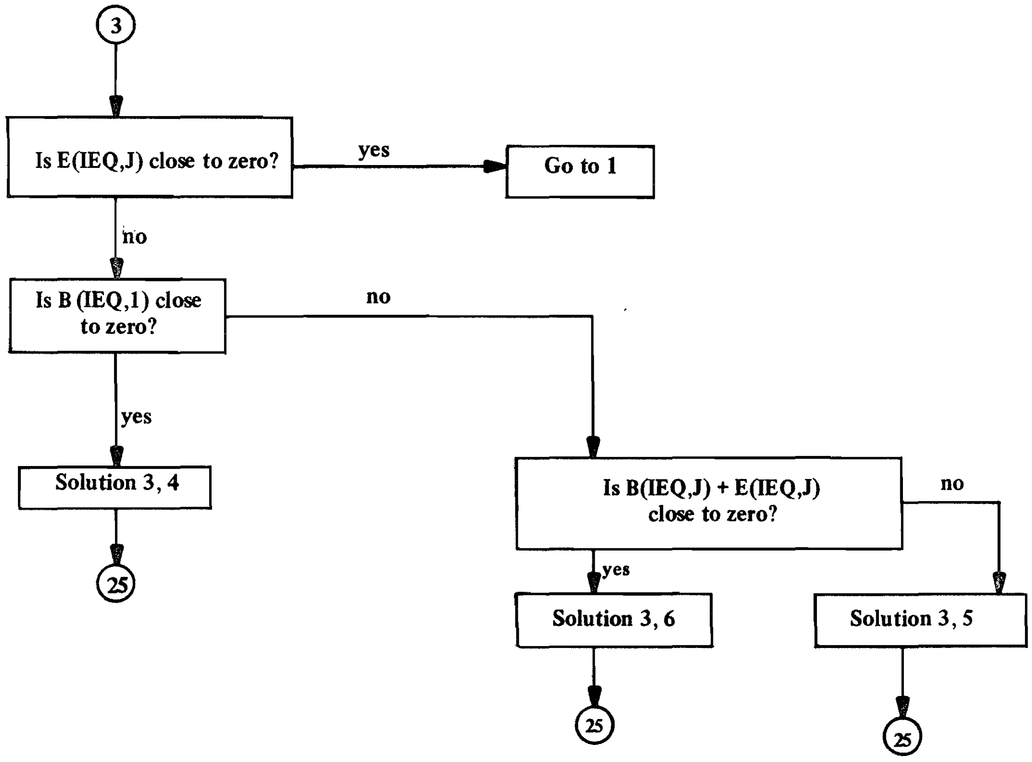
Purpose: To perform the term by term integration of the differential equation provided by Subroutine SETUP.

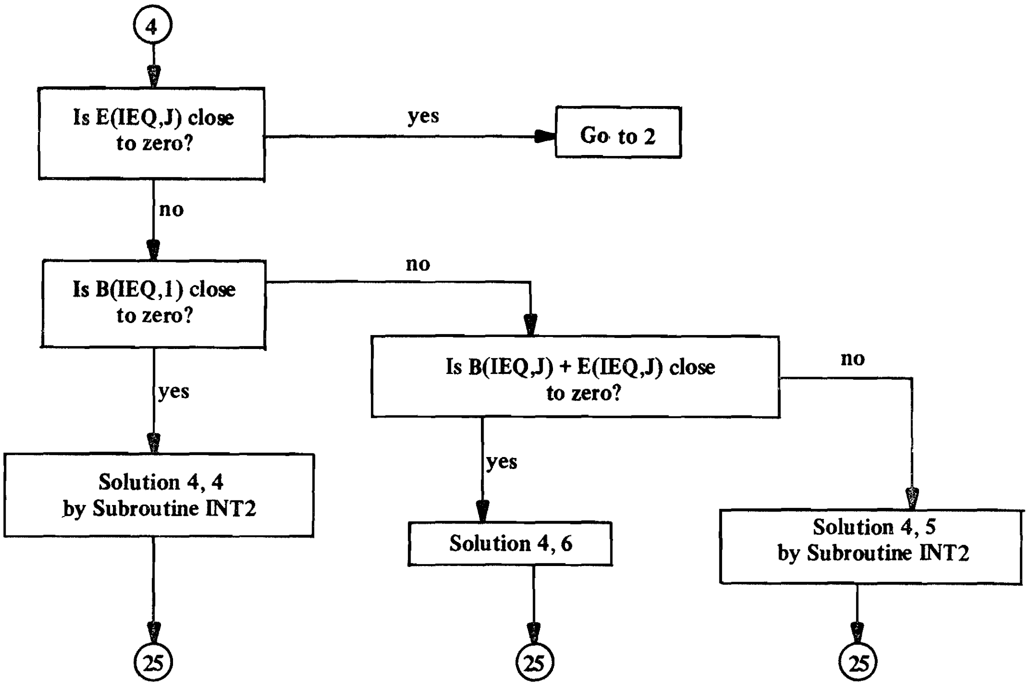
Variable Name	Variable Description
IEQ	Identification number of differential equation to be integrated
NTS(IEQ)	Number of terms in the IEQth differential equation; excluding the derivative
IFROM(IEQ,J)	Category number for the Jth term of the IEQth equation
B(IEQ,J)	Value of the coefficient for the Jth term of the IEQth differential equation before integration; B(IEQ,1) is the coefficient on the left-hand-side of the equation
E(IEQ,J)	Value of the exponent on "e" for the Jth term of the IEQth differential equation before integration
ET(IEQ,J)	Value of the exponent on "t" for the Jth term of the IEQth differential equation before integration
XO(IEQ)	Initial condition for the IEQth differential equation
T	Travel time in reach
NTI(IEQ)	Number of terms in the IEQth solution equation
IFORM(IEQ,J)	Category number of the Jth term in the IEQth solution equation
B(IEQ,J)	Value of the coefficient for the Jth term of the IEQth solution equation
E(IEQ,J)	Value of the exponent of "e" for Jth term of the IEQth solution equation
ET(IEQ,J)	Value of the exponent on "t" for Jth term of the IEQth solution equation

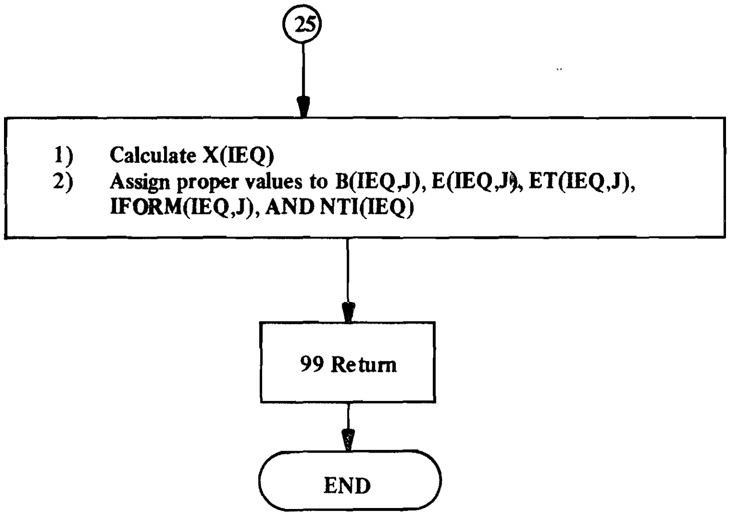
ET(IEQ,J)	Value of the exponent on "t" for Jth term of IEQth solution equation
X(IEQ)	Value of the dependent variable in the IEQth equation at time "T" given the initial condition "XO(IEQ);" Note: In this calculation, zero to the zero power is equal to 1.0
EPS	Coefficients having an absolute value less than EPS are considered equal to zero (EPS = 10^{-10})
ISUM	Counter to keep track of the terms in the solution equation
XSUM	Partial solution for X(IEQ)
CI	Constant of integration
BX(ISUM)	Value of the coefficient for the ISUMth term of the solution equation
IFROMX(ISUM)	Category number of the ISUMth term in the solution equation
EX(ISUM)	Value of the exponent on "e" for the ISUMth of the solution equation
ETX(ISUM)	Value of the exponent on "t" for the ISUMth term of the solution equation

Subroutine INTEG

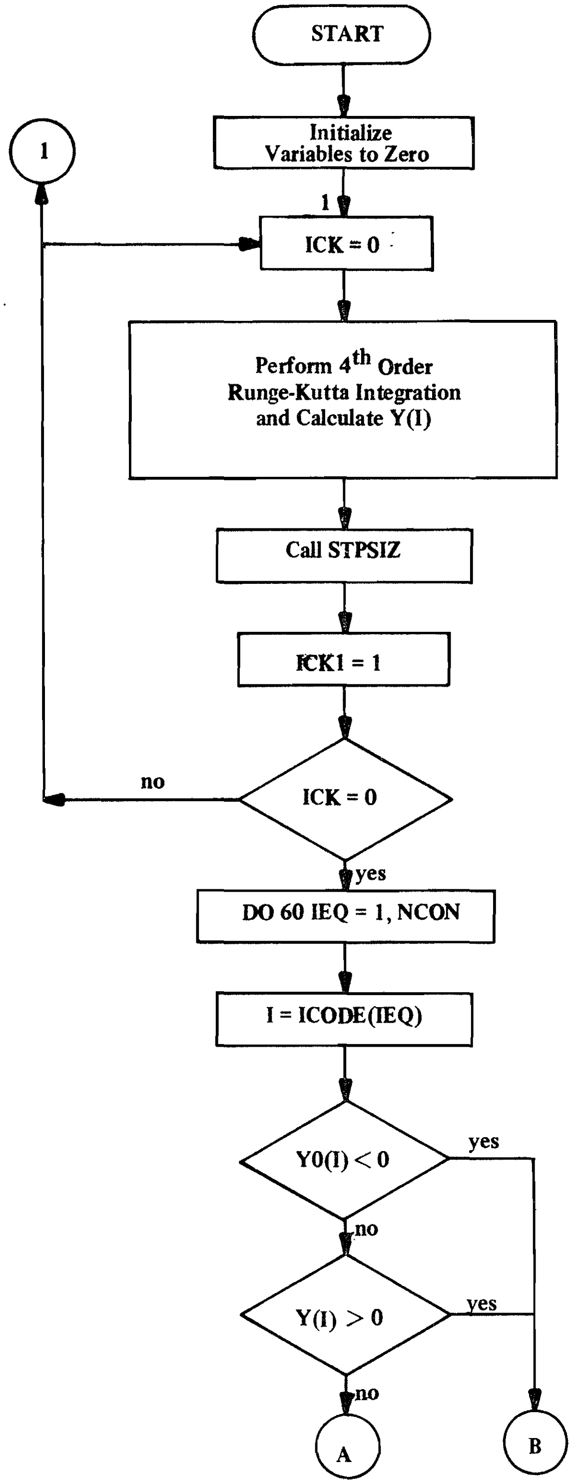


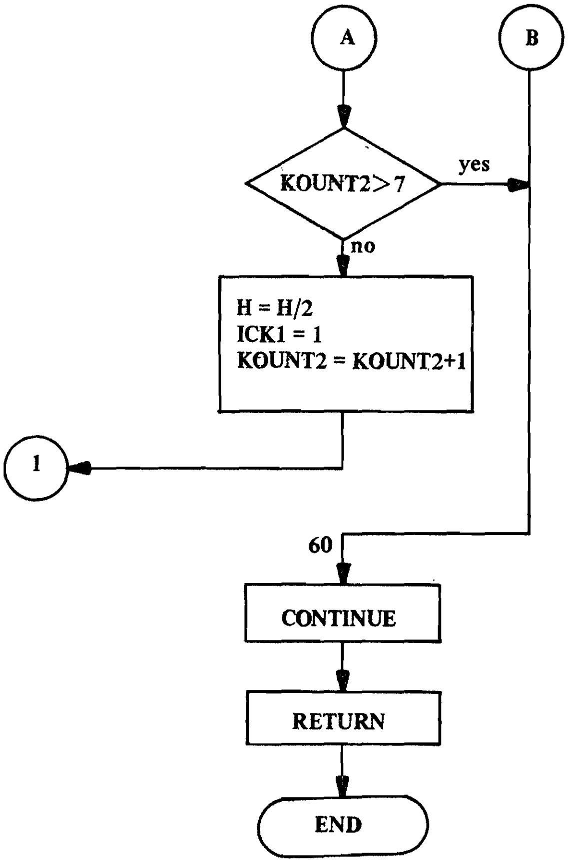

3
Is E(IEQ,J) close to zero?
yes
Go to 1
no
Is B (IEQ,1) close to zero?
no
yes
Solution 3, 4
25
Is B(IEQ,J) + E(IEQ,J) close to zero?
no
yes
Solution 3, 6
Solution 3, 5
25
25


4
Is E(IEQ,J) close to zero?
yes
Go to 2
no
Is B(IEQ,1) close to zero?
no
yes
Is B(IEQ,J) + E(IEQ,J) close to zero?
no
yes
Solution 4, 4 by Subroutine INT2
Solution 4, 6
Solution 4, 5 by Subroutine INT2
25
25
25


25
1) Calculate X(IEQ)
2) Assign proper values to B(IEQ,J), E(IEQ,J), ET(IEQ,J), IFORM(IEQ,J), AND NTI(IEQ)
99 Return
END

Subroutine RUNGE



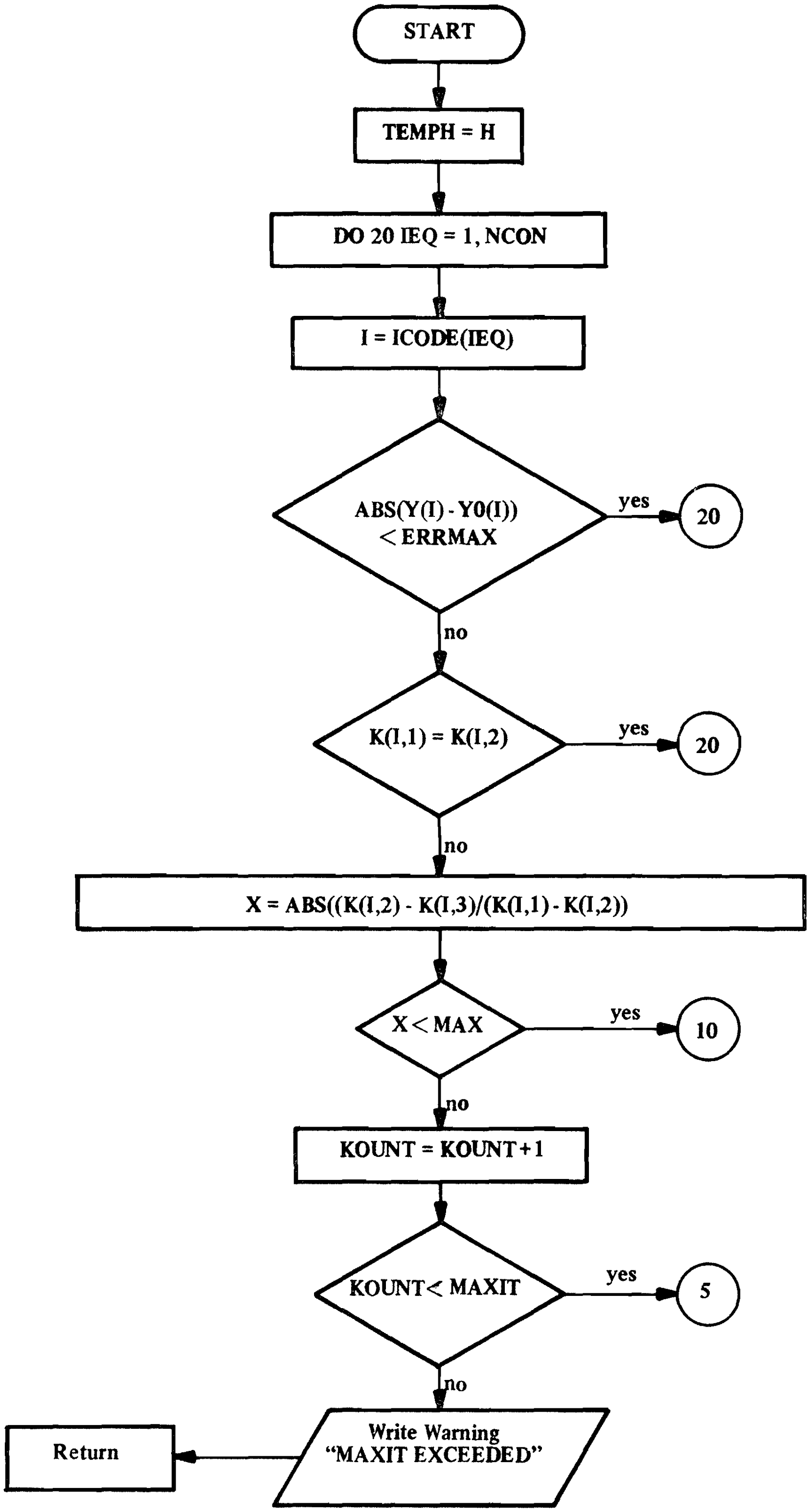

A
B
KOUNT2>7
yes
no
H = H/2
ICK1 = 1
KOUNT2 = KOUNT2+1
1
60
CONTINUE
RETURN
END

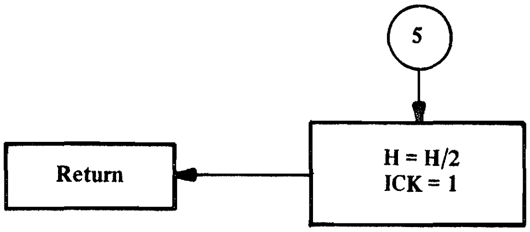
SUBROUTINE STPSIZ

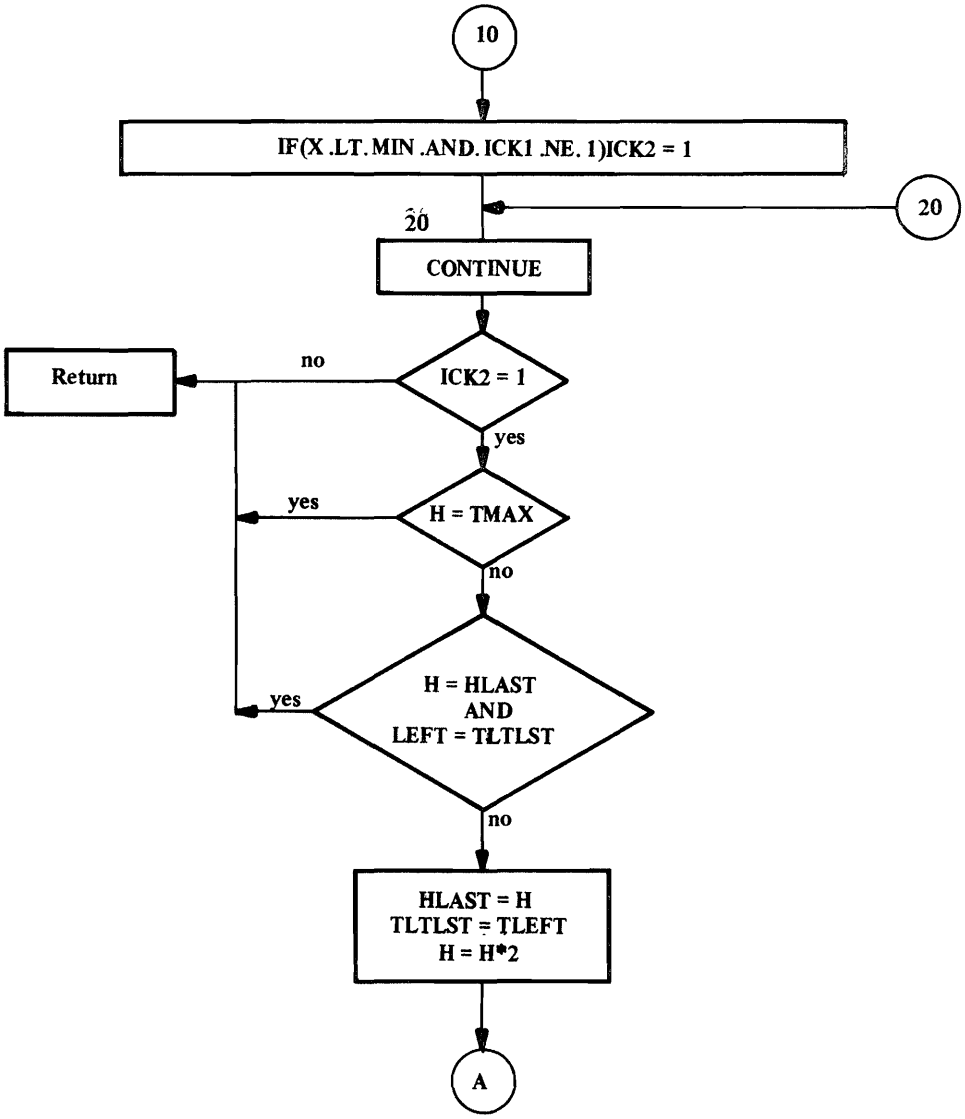
Purpose: To find an optimal step size for the numerical integration.

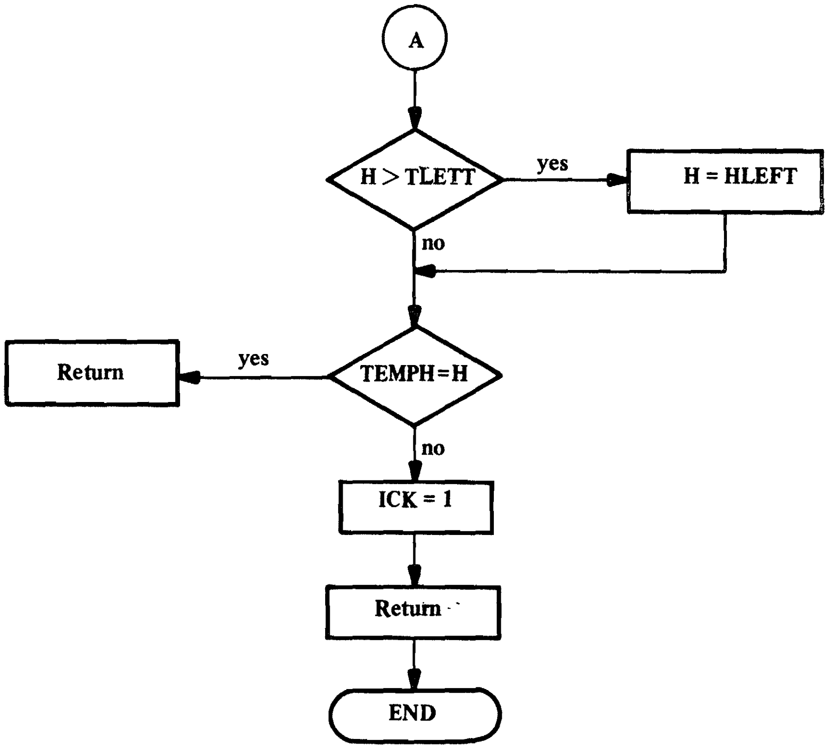
Variable Name	Variable Description
I	Constituent index
Y0(I)	Concentration of the Ith constituent at the beginning of the time step (mg/l)
Y(I)	Concentration of the Ith constituent at the end of the time step (mg/l)
ERRMAX	If the absolute value of the difference between Y0(I) and Y(I) is less than ERRMAX, the step size test will be ignored
MIN	Minimum value of the step size test before the time step doubled
MAX	Maximum value of the step size test before the time step is halved
X	Value of the step size test
MAXIT	Maximum number of iterations to find a small enough step size to satisfy the step size test
H	The step size (sec)
TEMPH	The step size when entering the subroutine (sec)
ICK	If ICK = 1, a step size change has occurred
TMAX	The total amount integration time to be used
HLAST	The step size on the previous pass through the subroutine RUNGE
TLEFT	The amount of integration time remaining to be used
TLTLST	The amount of integration time remaining to be used on the previous pass through the subroutine RUNGE

Subroutine STPSIZ




5
H = H/2
ICK = 1
Return


10
IF(X .LT. MIN .AND. ICK1 .NE. 1)ICK2 = 1
20
20
CONTINUE
ICK2 = 1
no
Return
yes
H = TMAX
yes
no
H = HLAST
AND
LEFT = TLTLST
yes
no
HLAST = H
TLTLST = TLEFT
H = H*2
A


A
H > TLETT
yes
H = HLEFT
no
Return
yes
TEMPH = H
no
ICK = 1
Return
END

SUBROUTINE DSETUP

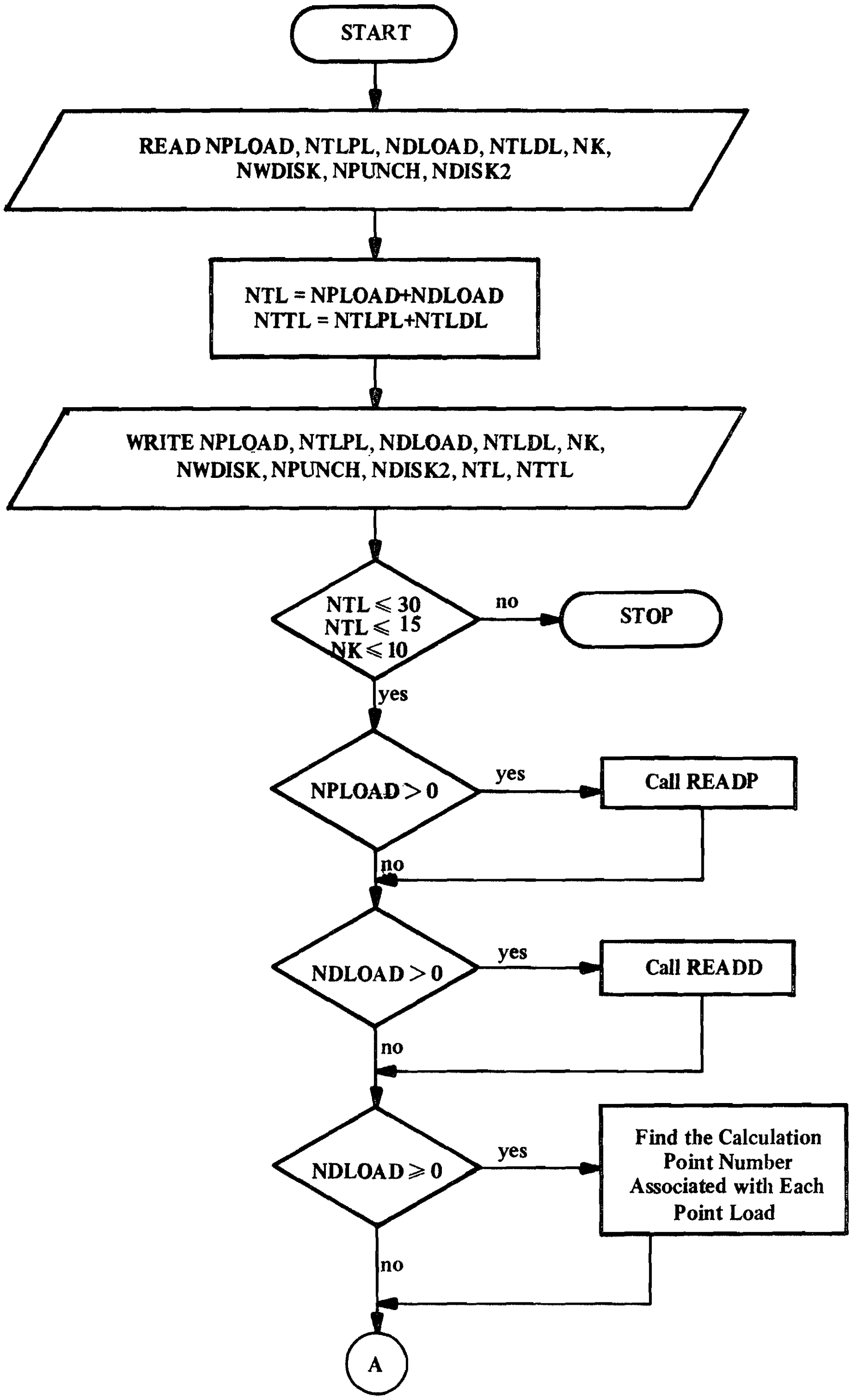
Purpose

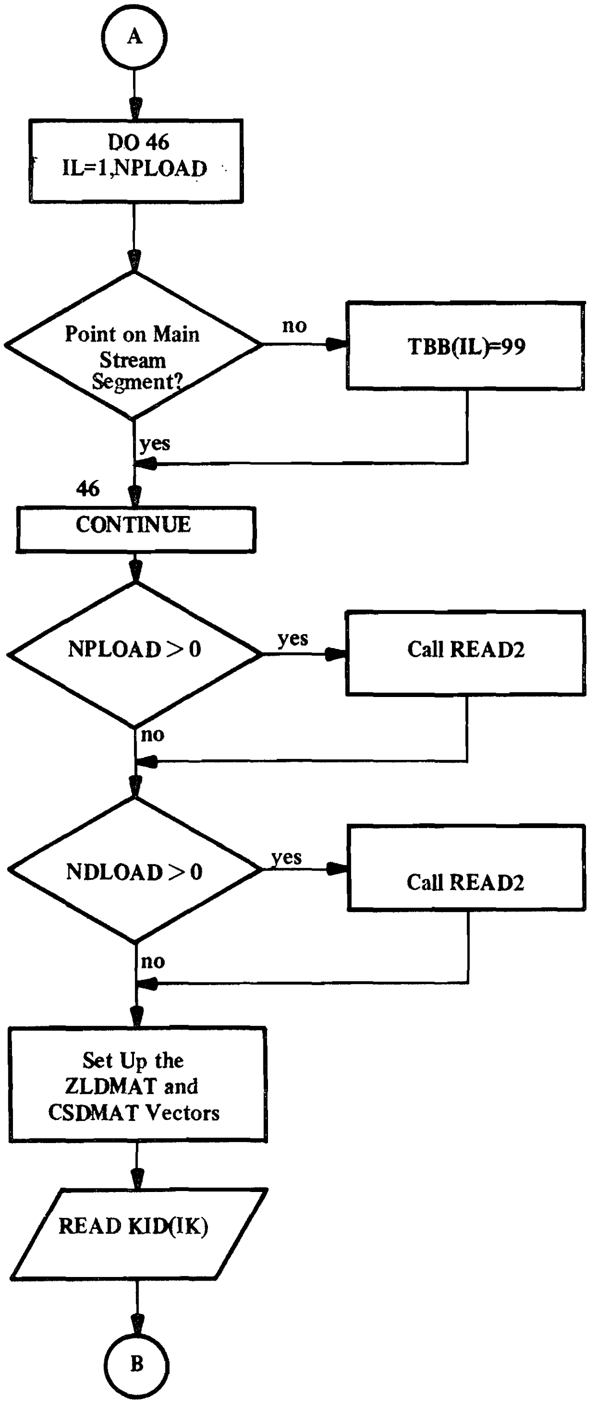
1. Read in data needed to generate D matrix.
2. Save initial stream conditions, point loads, and diffuse loads.
3. Set up loading matrix for point and diffuse loads with treatment.
4. Write out initial conditions file to disk.

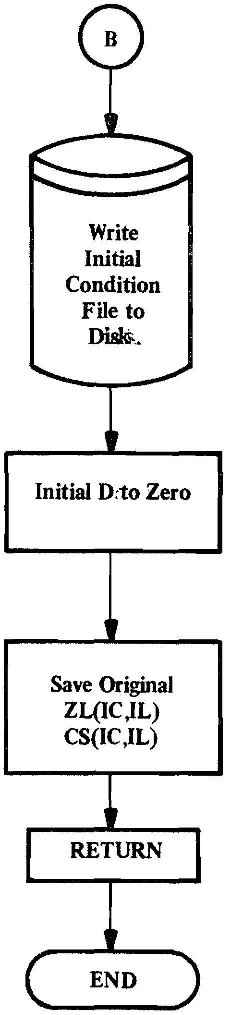
Variable Name	Variable Description
NPLOAD	Number of point loads to be considered
NDLOAD	Number of diffuse loads to be considered
NTL	Sum of NPLOAD and NDLOAD ≤ 30
NTLPL	Number of treatment levels for point loads
NTLDL	Number of treatment levels for diffuse loads
NTTL	Sum of NTLPL and NTLDL ≤ 15
NK	Number of surveillance points ≤ 10
IL	Load index
IT	Treatment level index
IK	Surveillance point index
ZDSAVE(IC,IP)	Array of initial stream conditions (mg/l)
LP(IL)	Array of point load numbers
LD1(IL)	Beginning reach numbers for diffuse loads
LD2(IL)	Ending reach numbers for diffuse loads
LPPTNO(IL)	River point numbers for point loads
ZLSAVE(IC,IL)	Vector of concentration added by a point load (mg/l)

CSSAVE(IC,IL)	Vector of concentration added by a diffuse load (mg/l)
KID(IK)	Point numbers of surveillance points
DMAT(IC,IT,IL,IK)	Change in constituent IC at surveillance point IK with treatment level IT on load IL
TBB(IL)	If point load IL is not on the main river branch TBB(IZ) = 99
IPTNO	Calculation point number of point load IL
ILP	Point load index
ILD	Diffuse load reach index
ZLDMAT(IC,IT,ILP)	Concentration of constituent IC with treatment level IT at point load ILP
CSDMAT(IC,IT,ILD)	Concentration of constituent IC with treatment level IT from the diffuse load at reach ILD

Subroutine DSETUP




A
DO 46
IL=1,NPLOAD
Point on Main Stream Segment?
no
TBB(IL)=99
yes
46
CONTINUE
NPLOAD > 0
yes
Call READ2
no
NDLOAD > 0
yes
Call READ2
no
Set Up the ZLDMAT and CSDMAT Vectors
READ KID(IK)
B


B
Write Initial Condition File to Disk.
Initial D to Zero
Save Original ZL(IC,IL) CS(IC,IL)
RETURN
END

SUBROUTINES READP AND READD

Purpose: To read in the point load numbers (Subroutine READP) and diffuse load reach numbers (Subroutine READD) to be considered in generating the D matrix.

Variables used in these subroutines are the same as those used in Subroutine DSETUP.

SUBROUTINE READ2

Purpose: To read in concentration of the quality constituents with treatment at the point and diffuse loads used in generating the D matrix.

Variables used in this subroutine are the same as those used in Subroutine DSETUP.

Appendix B

DATA INPUT FORMATS FOR THE STREAM SIMULATION AND ASSESSMENT MODEL (SSAM)

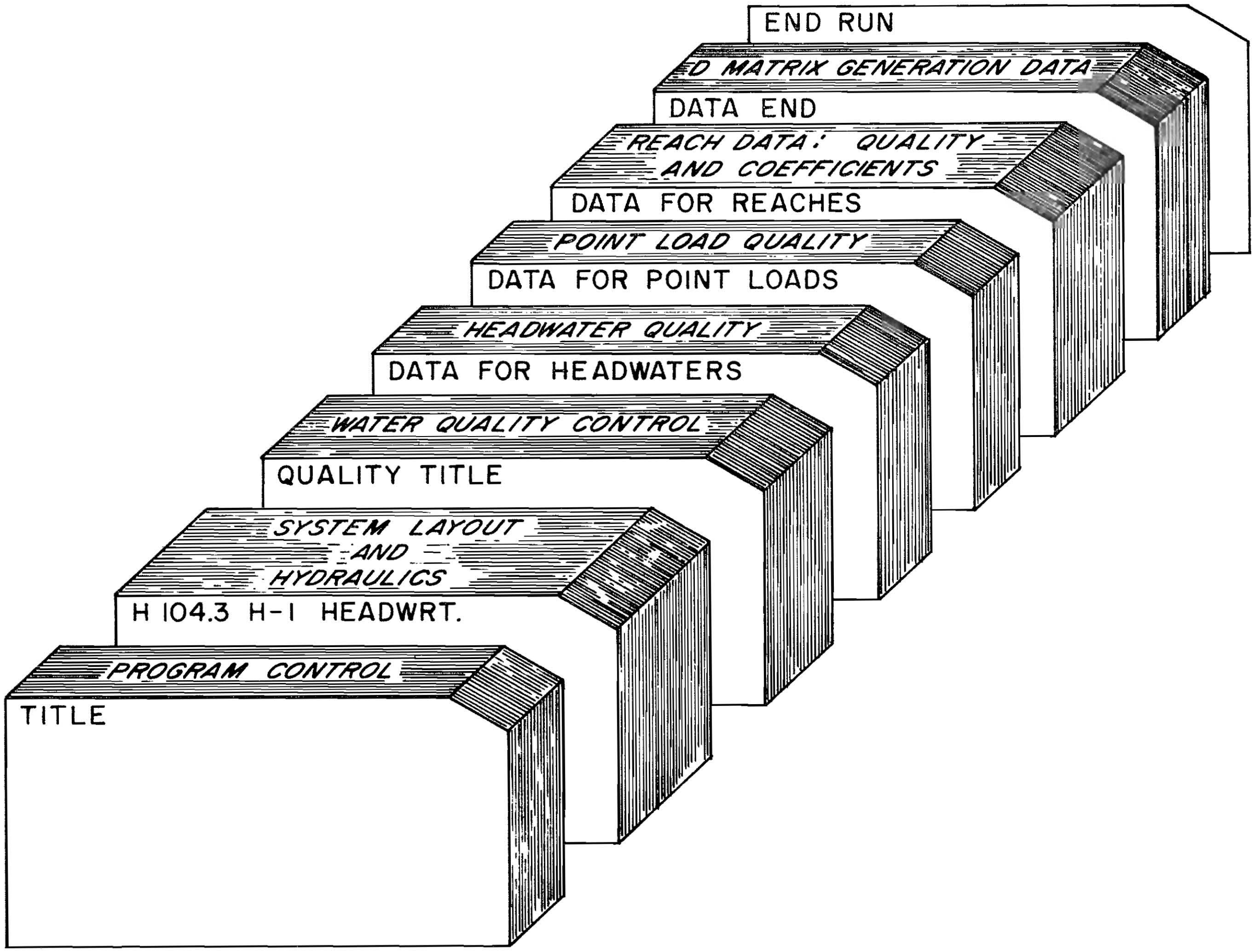


Figure B-1. Typical data deck setup for SSAM.

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
Program Control	1	1-80	20A4	TITLE (I)	Title of run
	2	1-80	20A4	SUBTL (I)	Subtitle of run
	3	1-2	I2	IOPRUN	Run option = 1: thru flow balance = 2: thru water quality coefficients = 3: complete run
	3	3-4	I2	ICVI	Metric conversion for input data = blank: all input is metric = 1: all input is English
	3	5-6	I2	ICVO	English conversion for output = blank: all output will be metric = 1: all output will be English
	3	7-8	I2	IOPECH	Echo input data = blank: echo input = 1: do not echo input data
	3	9-10	I2	IOPSUM	Summary option = blank: write summary for both hydraulics and quality = write summary for hydraulics only = write summary for quality only
	3	11-12	I2	IOPWRT	Output option = blank: write responses when calculated = 1: sort output by stream segment
	3	14	I1	IOPGW	Groundwater outflow option = blank; QG is modeled like QS = 1: QG is modeled as a fraction of stream flow

System Layout and Hydraulics: input formats are shown in Table B-1.

IFLAG
H = Headwater (considered the start of a new reach)
R = start of a new reach
J = junction: just downstream from a tributary junction (considered as the start of a new reach)
L = point load
D = point diversion
C = check point (output desired at this point)
B = branch point: just upstream from a tributary junction
E = reach in which evaporation is significant (considered as the start of a new reach)
T = terminal downstream point in the system

X = upstream distance to the point (miles or kilometers)

XID = point identification code

Description = point description

Column 31 = S: suppresses output for computer generated points

DX = Maximum downstream element length; if the next downstream point is a greater distance away intermediate points will be generated.

Q = for H or L: flow for headwater or point load (ft^3/sec or m^3/sec)
= for E: evaporation (ft^3/sec/mile or m^3/sec/kilometer)

QS = lateral surface inflow (+) or outflow (-) (ft^3/sec/mile or m^3/sec/kilometer)

QG = lateral groundwater inflow (+) or outflow (-) (ft^3/sec/mile or m^3/sec/kilometer)
= for IOPFLO = 1: outflow (-) (fraction of mainstream flow/mile or per kilometer)

S = average slope of stream bed (dimensionless)

n = Manning's coefficient

CQV = Θ_1 in the equation $V = \Theta_1 Q^{\Theta_2}$

EQV = Θ_2 in the equation $V = \Theta_1 Q^{\Theta_2}$

CAR = Θ_3 in the equation $R = \Theta_3 A^{\Theta_4}$

EAR = Θ_4 in the equation $R = \Theta_3 A^{\Theta_4}$

IOPRAD = E: use equations above to calculate hydraulic radius
= ƀ: use Manning's equation to calculate hydraulic radius

Table B-1. Input format for system layout and hydraulics.

	Type of Point	Distance to Point (miles or km)	Abbreviated Identification Symbol	Point Identification Description	If = S, Suppress Output for Computer Generated Calculation Points	Maximum Downstream Element Length (miles or km)	Point Flow & Evap. (cfs or cms) (cfs/mile or cms/km)	Lateral Surface Inflow Downstream Reach (cfs/mile or cms/km)	Lateral Groundwater Inflow Downstream Reach (cfs/mile or cms/km)	Slope of Downstream Reach	Manning's Coefficient for Downstream Reach	Flow to Velocity Coefficient Downstream Reach	Flow to Velocity Exponent, Downstream Reach	Area to Hydraulic Radius Coefficient Downstream Reach	Area to Hydraulic Radius Exponent Downstream Reach	Flow to Hydraulic Radius Option. E = Empirical, ₿ = Mannings
Symbol	IFLAG	X	XID	Descript.		DX	Q	QS	QG	S	n	CQV	EQV	CAR	EAR	IOPRAD
Format	A1	F7.0	A4	A2, 4A4	A1	F3.0	F5.0	F5.0	F5.0	F5.5	F5.5	F5.0	F5.0	F5.0	F5.0	A1
Beginning Column	1	2	9	13	31	32	35	40	45	50	55	60	65	70	75	80
Headwater	H	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Reach	R	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Junction	J	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Point Load	L	*	*	*			*									
Point Diversion	D	*	*	*			*									
Check Point	C	*	*	*												
Branch Point	B	*	*	*												
Evaporation	E	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Terminal	T	*	*	*												

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
Water Quality Control	1	1-60	A3,14A4,A1		WATER QUALITY TITLE
	2	1-2	I2	ITEMPO	Temperature option = blank: do not read in constant temperature for each reach = 1: read constant temperature for each reach
	2	3-4	I2	ISOLVE	Solution technique option = blank: exact = 1: numerical
	2	5-14	F10.0	DTMAX	Maximum time step for numerical solution (minutes)
	2	15-24	F10.0	MIN	Minimum value for the step size test (suggested value = 0.02 to 0.05)
	2	25-34	F10.0	MAX	Maximum value for the step size test (suggested value = 0.1 to 0.15)
	2	35-38	I4	MAXIT	Maximum number of iterations allowed to find optimal step size
	2	39-47	E9.3	ERRMAX	Stepsize test is ignored if $ABS(Y_t - Y_{t+\Delta t}) < ERRMAX$
	3	2-5	A4	CODE (1)	Symbol for water quality parameters to be modeled this run
	3	7-10	A4	CODE (2)	Symbol for water quality parameters to be modeled this run

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	3	12-15	A4	CODE (3)	Symbol for water quality parameters to be modeled this run
	:	:	:	:	:
	3	57-60	A4	CODE (12)	Symbol for water quality parameters to be modeled this run
	4	4-7	A4	CODE (1)	Symbol for water quality parameter
	4	8-80	13A4,A1		Description of water quality parameter
	5	4-7	A4	CODE (2)	Symbol for next water quality parameter
	5	8-80	13A4,A1		Description of next water quality parameter
	.	.	.		
	.	.	.		
	15	4-7	13A4,A1	CODE (12)	Symbol for last water quality parameter
	15	8-80	A4		Description of last water quality parameter
Headwater Quality	1	1-19	A4		"DATA FOR HEADWATERS"
	2	11-14	A4	CODE (1)	Symbol for water quality code
	2	17-20	A4	CODE (2)	Symbol for water quality code
	2	23-26	A4	CODE (3)	Symbol for water quality code
		:		:	:
		77-80	A4	CODE (12)	Symbol for water quality code
	3	1-4	A4		Headwater identification

Note: Cards of the type 4-15 are needed only for those parameters being modeled in the current run.

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	3	9-14	F6.0		Concentration for constituent CODE (1) at Headwater 1 (mg/1)
	3	15-20	F6.0		Concentration for constituent CODE (2) at Headwater 1 (mg/1)
	3	21-26	F6.0		Concentration for constituent CODE (3) at Headwater 1 (mg/1)
		⋮	⋮		⋮
	3	75-80	F6.0		Concentration for constituent CODE (12) at Headwater 1 (mg/1)
	4				Repeat one card for each Headwater as described for card 3
Point Load Quality	1	1-20			"DATA FOR POINT LOADS"
	2				Same formats as for headwaters. If there are no point loads, omit this section
	↓				
	4				
Reach Data: Quality and Coefficients	1	1-16			"DATA FOR REACHES"
	2*	1-20			"CONSTANT TEMPERATURE"
	3*	11-17	F7.0		Temperature for Reach 1 (°C)
		18-24	F7.0		Temperature for Reach 2 (°C)
		⋮	⋮		⋮
		74-80	F7.0		Temperature for Reach 10 (°C) (use as many cards like 3 as necessary to include all Reaches)

*NOTE: Include cards only if ITEMPO = 1

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	4	1-4			Identification code of constituent
		6-26	A4		"DIFFUSE CONCENTRATIONS"
		30-39	F10.0	C	Coefficient: constant for all reaches and associated with constituent (if the identification code is "DOXY" and C = - 1.0, the reaeration rate is calculated)
	5	1-7			"SURFACE"
		11-17	F7.0		Concentration in lateral surface inflow for Reach 1 (mg/l)
		18-24	F7.0		Concentration in lateral surface inflow for Reach 2 (mg/l)
		⋮	⋮		⋮
		74-80	F7.0		Concentration in lateral surface inflow for Reach 10 (mg/l) (use as many cards like 5 as necessary to include all reaches)
	6	1-7			"GROUND"
		11-17	F7.0		Concentration in lateral subsurface inflow for Reach 1 (mg/l)
		18-24	F7.0		Concentration in lateral subsurface inflow for Reach 2 (mg/l)
		⋮	⋮		⋮
		74-80	F7.0		Concentration in lateral subsurface inflow for Reach 10 (mg/l) (use as many cards like 6 as necessary to include all Reaches)

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	7	1-10			"LEACH RATE"
		11-17	F7.0		Leaching rate for Reach 1 (g/m^2/day)
		18-24	F7.0		Leaching rate for Reach 2 (g/m^2/day)
		⋮	⋮		
		74-80	F7.0		Leaching rate for Reach 10 (g/m^2/day) (use as many cards like 5 as necessary to include all Reaches)
	8	1-10	2A4,A2		"BETA 1,1"
		11-17	F7.0		Value of first coefficient for first constituent, Reach 1
		18-24	F7.0		Value of first coefficient for first constituent, Reach 2
		⋮	⋮		⋮
		74-80	F7.0		Value of first coefficient for first constituent, Reach 10
					(use as many cards like 8 as necessary to include all Reaches)
	9	1-10			"BETA 1,2"
					(use as many cards like 7 as necessary to include all coefficients)
					(use as many cards like 4 through 9 as necessary to include all constituents)

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
D Matrix Generation	1	1-7			"DATAEND"
	2	1-3	I3	NPLOAD	Number of point loads to be considered
		4-6	I3	NTLPL	Number of treatment levels for point loads (existing treatment should be considered as a level)
		7-9	I3	NDLOAD	Number of diffuse loads to be considered (NPLOAD + NDLOAD must be less than 31)
		10-12	I3	NTLDL	Number of treatment levels for diffuse loads (existing treatment should be considered as a level) (NTLPL + NTLDL must be less than 16)
		13-15	I3	NK	Number of surveillance points (maximum of 10)
		16-18	I3	NWDISK	Write file for D matrix (disk)
		19-21	I3	NPUNCH	Write file for D matrix (punched cards)
		22-24	I3	NDISK2	Write file for initial condition (disk)
	3	1-4	I4	LP(1)	Point load number for the first point load to be considered (this is not the program generated point number, but a number between one and the number of point loads in the hydraulic and quality portions of the program)

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
		5-8	I4	LP(2)	Point load number for the second point load to be considered
		⋮			
		77-80	I4	LP(20)	Point load number for the twentieth point load to be considered (if NPLOAD ≥ 20, use another card like 3 to include all point loads)
	4	1-4	I4	LD1(1)	Reach number that marks the beginning of diffuse load 1
		5-8	I4	LD2(1)	Reach number that marks the end of diffuse load 1
		9-12	I4	LD1(2)	Reach number that marks the beginning of diffuse load 2
		13-16	I4	LD2(2)	Reach number that marks the end of diffuse load 2
		⋮			
		73-76	I4	LD1(10)	Reach number that marks the beginning of diffuse load 10
		77-80	I4	LD2(10)	Reach number that marks the end of diffuse load 10 (use as many cards like 3 as necessary to include all diffuse loads)
	5	11-14	A4	ZCODE(1)	Symbol for water quality code
		17-20	A4	ZCODE(2)	Symbol for water quality code

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
		23-26	A4	ZCODE(3)	Symbol for water quality code
		⋮			
		77-80	A4	ZCODE(12)	Symbol for water quality code
	6	9-14	F6.0	RED(1,1,1)	Concentration for constituent CODE (1), treatment level 1, point load 1 (mg/l)
		15-20	F6.0	RED(2,1,1)	Concentration for constituent CODE(2), treatment level 1, point load 1 (mg/l)
		21-26	F6.0	RED(3,1,1)	Concentration for constituent CODE(3), treatment level 1, point load 1 (mg/l)
		⋮			
		75-80	F6.0	RED(12,1,1)	Concentration for constituent CODE(12), treatment level 1, point load 1 (mg/l)
	7	9-14	F6.0	RED(1,1,2)	Concentration for constituent CODE(1), treatment level 1, point load 2 (mg/l)
		15-20	F6.0	RED(2,1,2)	Concentration for constituent CODE(2), treatment level 1, point load 2 (mg/l)
		⋮			
		75-80	F6.0	RED(12,1,2)	Concentration for constituent CODE(12), treatment level 1, point load 2 (mg/l)
	8				Repeat card 7 for each remaining point load
	9				Repeat cards 6-8 for each treatment level
	10				Repeat cards 5-9 for diffuse loads

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	11	1-4	I4	KID(1)	Point number of surveillance point 1 (the point number is the program generated point number)
		5-8	I4	KID(2)	Point number of surveillance point 2
		9-12	I4	KID(3)	Point number of surveillance point 3
		⋮			
		37-40	I4	KID(10)	Point number of surveillance point 10
	12	1-6			"ENDRUN" this terminates the run

NOTE: Do not include cards 3, 5, 6, 7, 8, and 9 if NPLOAD = 0

Do not include cards 4 and 10 if NDLOAD = 0

Appendix C

PROGRAM LISTING FOR THE
STREAM SIMULATION AND ASSESSMENT MODEL (SSAM)

```
C*    SSAM  D MATRIX VERSION
C*                  STREAM SIMULATICN AND ASSESSMENT MODEL  (SSAM)
C*
C*
$ SET AUTOBIND
$ BIND PL360 FROM UTILITY/=
FILE  5=FILE5
FILE  6=FILE6
FILE  7=FILE7
FILE  20(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="DMATRIX")
FILE  21(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="INITCON")
FILE  22(KIND=DISK,MAXRECSIZE=22,BLCCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="INITCON2")
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *,IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,10C),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,5C),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      COMMON /DMAT1/NPOINT,IOPECH,TBB(30),NPLOAD,NTLPL,NDLOAD,NTLDL,NTL,
     *             NTTL,NK,NWDISK,NPUNCH,ZDSAVE(12,500),LP(30),
     *             LD1(30),LD2(30),LPPTNO(30),REDPL(12,15,30),
     *             REDDL(12,15,30),ZLSAVE(12,150),CSSAVE(12,100),
     *             KID(10),NDISK2
      DIMENSION TBL(14),TBL1(10)
      DATA NCOE/1,1,2,3,1,1,2,3,1,4,2,0/
      DATA NCONU/1,1,2,3,1,3,3,6,3,5,2,2/
      DATA TBL/4HNC01,4HNC02,4HNC03,4HNC04,4HCOLI,4HPHOS,4HCBOD
     *       ,4HNH3N,4HNO3N,4HDOXY,4HTEMP,4HALGP,4H    ,3HDAT/
      DATA TBL1/1HH,1HR,1HJ,1HL,1HD,1HC,1HB,1HE,1HT,1HS/
C*                  NR IS THE READ CEVICE AND NW IS THE WRITE DEVICE
      NR=5
      NW=6
C*                  NPTL IS THE NPOINT LIMIT, NRLM THE NO. OF REACH
C*                  LIMIT, NLDL THE MAX. NO. OF LOAPS ALSO THE MAX. NO.
C*                  OF DIVERSIONS, NITL THE MAX, NO. OF TERMS ALLOWED.
      NPTL=500
      NRLM=100
      NLDL=150
      NITL=50
      MAXHD=15
      MAXBR=14
      NCOEFL=7
   10 CALL CONTRL(TBL,TBL1)
      GOTO 10
      END
      SUBROUTINE CONTRL(TBL,TBL1)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *,IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      COMMON/S/ NSEG(15),ISST(15,15),ISED(15,15),IRR(15,15),IJJ(15,15)
     *          ,ILL(15,15)
```

```
      COMMON /DMAT1/NPOINT,IOPECH,TBB(30),NPLOAD,NTLPL,NDLOAD,NTLDL,NTL,
     *           NTTL,NK,NWDISK,NPUNCH,ZDSAVE(12,500),LP(30),
     *           LD1(30),LD2(30),LPPTNO(30),REDPL(12,15,30),
     *           REDDL(12,15,30),ZLSAVE(12,150),CSSAVE(12,100),
     *           KID(10),NDISK2
      COMMON /DMAT2/D(12,16,30,10)
      COMMON /DMAT3/ZLDMAT(12,15,15C),CSDMAT(12,15,100)
      DIMENSION NFLAG(7,500),ZSAVE(12,150)
      DIMENSION TBL1(10),TBL(14)
      DIMENSION ZB(15,12),IJCO(15)
      REAL MIN,MAX
    1 CALL HYDRAU(IOPRUN,NPOINT,ICVI,ICVO,IOPECH,IOPSUM,TBL,TBL1,IOPWRT)
    2 IF(IOPRUN.EQ.1) STOP
      CALL QUALI(NPOINT,IOPECH,IOPSUM,IOPRUN,IOPWRT,TBL,ITEMOP,
     *          DTMAX,MIN,MAX,MAXIT)
      IF(ISOLVE.EQ.0)
     *CALL QUALE(NPOINT,IOPSUM,TBL,IOPWRT)
      IF(ISOLVE.NE.0)
     *CALL QUALN
      IF(IOPSUM.EQ.0.OR.IOPSUM.EQ.2)
     *CALL SUMQUA(NPOINT,TBL,IOPWRT)
      IF(IOPRUN.EQ.2) STOP
      IF(ISOLVE.NE.1)GO TO 5
      CALL SORT(NCON,NREACH,CS,CG,COEF,ICODE)
      CALL CONVRT(NREACH,COEF,IPARAM,NW)
    5 DO 6 I=1,12
      ZO(I)=0.
6     CONTINUE
      NSTOP=NPOINT-1
      DO 880 III=1,2
      IF(III.EQ.1)GO TO 770
      DO 870 IZ=1,NTL
      ITSTRT=1
      IF(IZ.GT.NPLOAD)ITSTRT=NTLPL+1
      ITEND=NTLPL
      IF(IZ.GT.NPLOAD)ITEND=NTTL
      DO 860 IT=ITSTRT,ITEND
      IF(IZ.GT.NPLOAD.OR.TBB(IZ).EQ.99.)GO TO 720
      IPTNO=LPPTNO(IZ)
      IW=NFLAG(1,IPTNO)
      ID=NFLAG(2,IPTNO)
      IL=NFLAG(3,IPTNO)
      IH=NFLAG(4,IPTNO)
      IR=NFLAG(5,IPTNO)
      IJ=NFLAG(6,IPTNO)
      IB=NFLAG(7,IPTNO)
C*
C*    SET UP INITIAL STREAM CONDITION
C*
      IPSTRT=IPTNO
      DO 710 IC=1,NCON
      DO 705 ILZ=1,IPSTRT
      ZD(IC,ILZ)=ZDSAVE(IC,ILZ)
705   CONTINUE
      Z(IC)=ZSAVE(IC,IPTNO-1)
710   CONTINUE
720   CONTINUE
C*
C*    SET UP NEW STREAM LOADING
C*
      IF(IZ.GT.NPLOAD)GO TO 740
```

```
      ILP=LP(IZ)
      DO 730 IC=1,NCON
      ZL(IC,ILP)=ZLDMAT(IC,IT,ILP)
  730 CONTINUE
      IF(TBB(IZ).EQ.99)GO TO 770
      GO TO 780
  740 CONTINUE
      IT1=IT-NTLPL
      ILD=IZ-NPLOAD
      ILDST=LD1(ILD)
      ILDEND=LD2(ILD)
      DO 760 IC=1,NCON
      DO 750 ILD=ILDST,ILDEND
      IEQ=IC
      IF(ISOLVE.EQ.1)IEQ=ICODE(IC)
      CS(IEQ,ILD)=CSDMAT(IEQ,IT1,ILD)
  750 CONTINUE
  760 CONTINUE
  770 CONTINUE
      IPSTRT=1
      IW=0
      IH=0
      ID=0
      IL=0
      IR=0
      IJ=0
      IB=0
  780 CONTINUE
      IPP=0
      DO 100 IP=IPSTRT,NSTOP
      IF(III.EQ.1)CALL FLAGKT(IP,IW,ID,IL,IH,IR,IJ,IB,NFLAG)
      IF(IPP.EQ.0) GO TO 300
      IPP=0
      GO TO 100
  300 IFL=IFLAG(IP)
      GOTO(101,102,105,103,104,106,108,102,108,107,107),IFL
C*
C*                                   HEADWATER
C*
  101 IH=IH+1
      IR=IR+1
      DO 110 IEQ=1,NCON
      ZO(IEQ)=CHW(IH,IEQ)
      ZD(IEQ,IP)=ZO(IEQ)
  110 CONTINUE
      GO TO 200
C*
C*                                   HEAD OF REACH
C*
  102 IR=IR+1
      DO 115 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)
      ZD(IEQ,IP)=ZO(IEQ)
  115 CONTINUE
      GO TO 200
C*
C*                                   POINT LOAD
C*
  103 IL=IL+1
      DO 120 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)+(ZL(IEQ,IL)-Z(IEQ))*QL(IL)/Q(IP)
```

```
      ZO(IEQ,IP)=ZO(IEQ)
  120 CONTINUE
      GO TO 200
C*
C*                                 POINT DIVERSION
C*
  104 ID=ID+1
      DO 125 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)
      ZO(IEQ,IP)=ZO(IEQ)
  125 CONTINUE
      GO TO 200
C*
C*                                 JUST BELOW A JUNCTION
C*
  105 IR=IR+1
      K=IJCO(IB)
      DO 130 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)+(ZB(IB,IEQ)-Z(IEQ))*Q(K)/Q(IP)
      ZO(IEQ,IP)=ZO(IEQ)
  130 CONTINUE
      IB=IB-1
      GO TO 200
C*
C*                                 CALC POINT
C*
  107 DO 140 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)
      ZO(IEQ,IP)=ZO(IEQ)
  140 CONTINUE
      GOTO 200
C*
C*                                 CHECK POINT
C*
  106 DO 135 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)
      ZO(IEQ,IP)=ZO(IEQ)
  135 CONTINUE
C*
C*                                 DEFINE THE EQUATIONS, WRITE OUTPUT,
C*                                 AND SOLVE FOR MASS AT THE NEXT
C*                                 DOWNSTREAM POINT.
C*
  200 IPP1=IP+1
      TIME=(X(IP)-X(IPP1))*1000./VBAR(IP)
      IF(IFL.NE.9.AND.IOPWRT.EQ.0) CALL WRPT(1,IP,IW,ICVO)
      IF(ISOLVE.EQ.1) GO TO 400
      CALL DEFINE (IR,IP)
      CALL SETUP(NCON,NTO,NTI,G,IV,E,TIME,ZO,IFORM,E,ET,Z,NITL)
      GO TO 450
  400 IDENOM=1
      IF(TIME.GT.DTMAX) IDENOM=IFIX(TIME/DTMAX+1.0)
      H=TIME/FLOAT(IDENOM)
      IF(TIME.LT.10.)GO TO 417
      IF(H.LE.0.)WRITE(NW,910)H,TIME
910   FORMAT(//,2X,'***** ERROR *****  H = ',E9.3,2X,'TIME = ',E9.3)
  410 DO 420 II=1,IDENOM
      CALL TIMES(ZO,Z,H,MIN,MAX,MAXIT,IP,IR,NCON,ICODE,IPARAM,NW)
      IF(II.EQ.IDENOM) GO TO 420
      DO 415 IEQ=1,NCON
  415 ZO(IEQ)=Z(IEQ)
```

```
      GO TO 420
  417 DO 418 IEQ=1,NCON
  418 Z(IEQ)=ZO(IEQ)
  420 CONTINUE
 450  IF(III.GT.1)GO TO 451
      DO 451 IC=1,NCON
      ZSAVE(IC,IP)=Z(IC)
 451  CONTINUE
      IF(IFLAG(IPP1).NE.7) GO TO 100
      IPP=1
      IB=IB+1
      IJCO(IB)=IPP1
      DO 203 IEQ=1,NCON
      ZB(IB,IEQ)=Z(IEQ)
      ZD(IEQ,IPP1)=Z(IEQ)
  203 CONTINUE
      IF(IFL.NE.9.AND.IOPWRT.EQ.0) CALL WRPT(1,IPP1,IW,ICVO)
  100 CONTINUE
      DO 145 IEQ=1,NCON
      ZO(IEQ)=Z(IEQ)
      ZD(IEQ,NPOINT)=ZO(IEQ)
  145 CONTINUE
      IF(III.EQ.1)CALL DSETUP(TBL)
      IF(III.EQ.1)GO TO 850
C*
C*    CALCULATE D AND RESET STREAM LOADING
C*
      DO 800 IK=1,NK
      KK=KID(IK)
      DO 790 IC=1,NCON
      D(IC,IT,IZ,IK)=ZDSAVE(IC,KK)-ZD(IC,KK)
 790  CONTINUE
 800  CONTINUE
      IF(IZ.GT.NPLOAD)GO TO 820
      ILP=LP(IZ)
      DO 810 IC=1,NCON
      ZL(IC,ILP)=ZLSAVE(IC,ILP)
 810  CONTINUE
      GO TO 850
 820  CONTINUE
      DO 840 IC=1,NCON
      IEQ=IC
      IF(ISOLVE.EQ.1)IEQ=ICODE(IC)
      DO 830 ILD=ILDST,ILDEND
      CS(IEQ,ILD)=CSSAVE(IEQ,ILD)
 830  CONTINUE
 840  CONTINUE
 850  CONTINUE
      IF(IOPWRT.EQ.0) GO TO 513
      CALL TITL(TITLE,SUBTL,NW)
      ILD=IZ-NPLOAD
      IF(III.EQ.2.AND.IZ.LE.NPLOAD)WRITE(NW,2000)IZ,IT
 2000 FORMAT(/,1X,'POINT LOAD ',I2,3X,'TREATMENT LEVEL ',I2,//)
      IF(III.EQ.2.AND.IZ.GT.NPLOAD)WRITE(NW,2010)ILD,IT
 2010 FORMAT(/,1X,'DIFFUSE LOAD ',I2,3X,'TREATMENT LEVEL ',I2,//)
      WRITE(NW,551)(CODE(II),II=1,NCON)
  551 FORMAT(5H0 PNT,2X,8HDISTANCE,2X,4H ID ,11(6X,A4))
      DO 512 IH=1,NHDW
      N1=NSEG(IH)
      DO 514 I=1,N1
      N2=ISST(IH,I)
```

```
      N3=ISED(IH,I)
      IR=IRR(IH,I)
      DO 516 IP=N2,N3
      IF(ICVO.GT.0) X(IP)=X(IP)*.62137119
      IFL=IFLAG(IP)
      GOTO(560,561,561,520,520,520,520,561,520,516,520),IFL
  560 IR=IR+1
      WRITE(NW,570) IR,IH
  570 FORMAT(1H0 // 1H0,'REACH#',I3,4X,'HEADWATER',I3)
      GOTO 520
  561 IR=IR+1
      WRITE(NW,571) IR
  571 FORMAT(1H0,'REACH#',I3)
      WRITE(NW,553)IP,X(IP),XID(IP),(ZD(K,IP),K=1,NCON)
  553 FORMAT(1H ,I4,F10.2,2X,A4,11F10.3)
      GOTO 516
  520 WRITE(NW,552) IP,X(IP),XID(IP),(ZD(K,IP),K=1,NCON)
  552 FORMAT(1H0,I4,F10.2,2X,A4,11F10.3)
  516 CONTINUE
  514 CONTINUE
  512 CONTINUE
      GO TO 515
  513 CALL WRPT(1,NPOINT,IW,ICVO)
515   CONTINUE
      IF(ICVO.EQ.0)GO TO 856
      DO 854 IP=1,NPOINT
      X(IP)=X(IP)/.62137119
854   CONTINUE
856   CONTINUE
      IF(III.EQ.1)GO TO 880
860   CONTINUE
870   CONTINUE
880   CONTINUE
      CALL WTDMAT(D,NW,NWDISK,NPUNCH,NK,NTTL,NTL,NPLOAD,NCON,CODE)
      CALL PLOTT
      STOP
  108 WRITE(6,601) IP,IFL
  601 FORMAT(1H /// 1H ,72HERROR IN SUBROUTINE CONTRL,  MAY BE CP TYPE,
     *STOP AT STATEMENT 108, IP=  ,I3,3X, 4HIFL=,I3)
      STOP
      END
      SUBROUTINE HYDRAU(IOPRUN,NPOINT,ICVI,ICVO,IOPECH,IOPSUM,TBL,TBL1,
     *IOPWRT)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *, QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *, ICODE(12),CODE(12),IPARAM(12),CHM(15,12),Z0(12),Z(12),NTI(12)
     *, IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *, NEND,NREACH,NHDW,NLOAD,NCIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *, COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *, NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      DIMENSION TBL(14),TBL1(10),IJCO(15)
      COMMON/S/ NSEG(15),ISST(15,15),ISED(15,15),IRR(15,15),IJJ(15,15)
     *          ,ILL(15,15)
      DATA DATA1,END/3HICP,4HENDR/
C*     READ TITLE AND SUBTITLE CARDS
    1 READ(NR,202) (TITLE(I),I=1,20)
      IF(TITLE(1).EQ.'ENDJ') STOP
      READ(NR,202) (SUBTL(I),I=1,20)
  202 FORMAT(20A4)
      CALL TITL(TITLE,SUBTL,NW)
```

```
      READ(NR,203)IOPRUN,ICVI,ICVO,IOPECH,IOPSUM,IOPWRT
     *    ,IOPGW
  203 FORMAT(7I2)
      WRITE(NW,204)IOPRUN,ICVI,ICVO,IOPECH,IOPSUM,IOPWRT,IOPGW
  204 FORMAT(9H0IOPRUN =I2,5X6HICVI =I2,5X6HICVO =I2,5X8HIOPECH =I2,
     *5X,8HIOPSUM =,I2,5X,8HIOPWRT =,I2,5X,'IOPGW=',I2)
C*(TBL1)  H  R  J  L  D  C  B  E  T  S
C*        1  2  3  4  5  6  7  8  9 10
      IF(IOPECH.NE.1) WRITE(NW,600)
  600 FORMAT(1H0,4HCARD,1X,8HDISTANCE,1X,20HMNEMONIC DESCRIPTION,1X,5HPRO
     *INT,1X,5HDELTA,3X,4HFLOW,3X,7HLATERAL,2X,7HLATERAL,3X,5HSLOPE,3X,7
     *HMANNING,4X,3HVEL,6X,3HVEL,5X,4HHYDR,5X,4HHYDR,3X,4HHYDR/1H ,4HCOD
     *E,32X,4HCODE,16X,7HSURFACE,2X,6HGROUND,14X,3H N ,5X,4HCOEF,6X,3HEX
     *P,6X,4HCOEF,5X,3HEXP,4X,3HOPT/1H ,58X,4HFLOW,4X,4HFLOW/)
      GOTO 11
   10 DELX=(X(IP)-XEND)*1000.
      IFP1=ZL(IE,1)+0.1
      IP=0
      IH=0
      IR=0
      IJ=0
      IL=0
      ID=0
      IB=0
      IBB=0
      ITERM=0
      IS=1
      IE=2
      IID1=0
      IID2=1
  400 CALL SYSDAT(IS,ICVI,IOPECH,TBL1,ZL,NR,NW,IOPGW)
  150 IP=IP+1
      IF(IP.LE.NPTL) GO TO 152
      WRITE(6,250)
  250 FORMAT(46H THE NUMBER OF CALCULATION POINTS EXCEEDS NPTL)
      STOP
  152 CALL SYSDAT(IE,ICVI,IOPECH,TBL1,ZL,NR,NW,IOPGW)
      X(IP)=ZL(IS,2)
      IFLAG(IP)=ZL(IS,1)+0.1
      IFL=IFLAG(IP)
      IF(IFL.LE.3.OR.IFL.EQ.8)XINC=ZL(IS,10)
      XEND=ZL(IE,2)
      XID(IP)=ZL(IS,3)
      IID1=IID1+1
      IF(IID1.LE.NRLM) GOTO 15
      IID1=1
      IID2=IID2+1
   15 DO 20 K=4,8
   20 COEF(K,IID2,IID1)=ZL(IS,K)
  160 IF(XINC.LT..01) GOTO 10
      XRUN=X(IP)-XINC*1.10
      IF(XRUN.LT.XEND) GOTO 10
      DELX=XINC*1000.
      IF(IFP1.EQ.9) ITERM=1
      XRUN=-1000.
   11 IF(DELX.GE.0.0) GO TO 12
      WRITE( 6,205) XID(IP),IP,X(IP),DELX
  205 FORMAT(1H0,'CHECK FOR INCREASING MILEAGE IN THE DOWNSTREAM'
     *       ,' DIRECTION NEAR ',A4 / 1H ,'IP =',I4,5X,'X(IP) ='
     *       ,F12.3,' KM',5X,'DELX =',E11.3,' M')
      STOP
```

```
   12 IFL=IFLAG(IP)
      GO TO (101,102,103,104,105,106,107,102,108,106,106),IFL
  101 IH=IH+1
      IR=IR+1
      Q(IP)=ZL(IS,11)
      GO TO 110
  102 IR=IR+1
      Q(IP)=QEND
      GO TO 114
  103 IR=IR+1
      K=IJCO(IB)
      Q(IP)=QEND+Q(K)
      IB=IB-1
      XTEST=ABS(X(IP)-X(K))/X(IP)
      IF(XTEST.LT.0.1) GOTO 114
      WRITE(NW,260) XID(IP),X(IP),X(K)
  250 FORMAT(1H0,'AT ',A4,',  RIVER MILES AT JUNCTION,',F8.2
     *       ,'  DO NOT MATCH BRANCH,',F8.2)
      IOPRUN=1
      GO TO 114
  110 IF(IH.LE.MAXHO) GO TO 114
      WRITE(6,251)
  251 FORMAT(51H THE MAXIMUM NUMBER OF HEADWATERS HAS BEEN EXCEEDED)
      STOP
  114 IF(IR.LE.NRLM) GO TO 115
      WRITE(NW,252)
  252 FORMAT(48H THE MAXIMUM NUMBER OF REACHES HAS BEEN EXCEEDED)
      STOP
  115 QS(IR)=ZL(IS,12)*0.001
      QG(IR)=ZL(IS,13)*.001
      IF(IFL.EQ.8) GOTO 702
      QEVAP(IR)=0.0
      GOTO 704
  702 QEVAP(IR) = ZL(IS,11)*0.001
  704 CONTINUE
      IFLICP=ZL(IS,9)+0.1
      SLOPE=ZL(IS,14)
      CHAN=ZL(IS,15)
      CQV=ZL(IS,16)
      EQV=ZL(IS,17)
      CAR=ZL(IS,18)
      EAR=ZL(IS,19)
      IOPRAD=ZL(IS,20)+0.1
      LID2=IID2
      LID1=IID1
      COEF(1,LID2,LID1)=0.
      COEF(2,LID2,LID1)=0.
      COEF(10,LID2,LID1)=0.
      IF(IR-1.NE.0) RAVEV(IR-1)=RAVEV(IR-1)/XNPPR
      IF(IR-1.NE.0) RAVED(IR-1)=RAVED(IR-1)/XNPPR
      XNPPR=0.0
      RAVEV(IR)=0.0
      RAVED(IR)=0.0
      GO TO 120
  104 IL=IL+1
      IF(IL.LE.NLDL) GO TO 116
      WRITE(NW,253)
  253 FORMAT(46H THE MAXIMUM NUMBER OF LOADS HAS BEEN EXCEEDED)
      STOP
  116 QL(IL)=ZL(IS,11)
      Q(IP)=QEND+ZL(IS,11)
```

```
      COEF(3,IID2,IID1)=ZL(IS,11)
      GO TO 120
  105 ID=ID+1
      IF(ID.LE.NLOL) GO TO 117
      WRITE(NW,254)
  254 FORMAT(51H THE MAXIMUM NUMBER OF DIVERSIONS HAS BEEN EXCEEDED)
      STOP
  117 QD(ID)=ZL(IS,11)
      Q(IP)=QEND-ZL(IS,11)
      COEF(3,IID2,IID1)=ZL(IS,11)
      GO TO 120
  106 Q(IP)=QEND
      GO TO 120
  107 WRITE(6,256)
  256 FORMAT(61H COMPUTED GO TO HAS SENCED A BRANCH POINT, IT SHOULD NOT
     * HAVE)
      STOP
  120 IF(QG(IR).LT.0.0.AND.IOPGW.EQ.1)GOTO 200
      COEF(1,LID2,LID1)=QS(IR)*DELX+COEF(1,LID2,LID1)
      COEF(2,LID2,LID1)=QG(IR)*DELX+COEF(2,LID2,LID1)
      COEF(10,LID2,LID1)=-QEVAP(IR)*DELX+COEF(10,LID2,LID1)
      QEND=Q(IP)+(QS(IR)+QG(IR)-QEVAP(IR))*DELX
      QBAR=(Q(IP)+QEND)*.5
      GO TO 125
  200 QG(IR)=QG(IR)/100.
      FAC=EXP(QG(IR)*DELX)
      QEND=Q(IP)*FAC+(1.0-FAC)*(QS(IR)-QEVAP(IR))/(-QG(IR))
      IF(DELX.GT.0.0) GOTO 530
      QBAR=Q(IP)
      GOTO 532
  530 QBAR=(Q(IP)*(FAC-1.0)+(QS(IR)-QEVAP(IR))*((FAC-1.0)/QG(IR)
     *      -DELX))/(DELX*QG(IR))
  532 COEF(1,LID2,LID1)=QS(IR)*DELX+COEF(1,LID2,LID1)
      COEF(2,LID2,LID1)=QEND-Q(IP)-QS(IR)*DELX+COEF(2,LID2,LID1)
  125 IF(Q(IP).GT.0.0) GO TO 126
  534 WRITE(NW,127) IP,X(IP),Q(IP),QBAR
  127 FORMAT(1H0,'FLOW IS LE 0.0, IP=',I4,5X,'X(IP)=',F11.3,5X,'Q(IP)='
     *      ,E11.3,5X,'QBAR=',E11.3)
      IOPRUN=1
      Q(IP)=1.0E-6
      QBAR=1.0E-6
  126 IF(QBAR.LE.0.0)GOTO 534
      VBAR(IP)=CQV*QBAR**EQV
      IF(VBAR(IP))25,25,26
   25 ABAR(IP)=0.
      IOPRUN=1
      WRITE(NW,210) IP,XID(IP),VBAR(IP)
  210 FORMAT(1H0,'ERROR: VBAR(IP) LE 0.  IP=',I4,5X,A4,5X,'VBAR(IP)='
     *      ,E11.3)
      GOTO 27
   26 ABAR(IP)=QBAR/VBAR(IP)
   27 COEF(9,IID2,IID1)=SLOPE
      IF(IOPRAD.EQ.1) GO TO 130
      IF(SLOPE.GT.0.0)GOTO 536
      WRITE(NW,538)SLOPE
  538 FORMAT(1H0,'ERROR: SLOPE =',E12.3)
      RBAR(IP)=1.0E8
      IOPRUN=1
      GOTO 136
  536 RBAR(IP)=(CMAN*VBAR(IP)/SQRT(SLOPE))**1.5
      GO TO 136
```

```
130 RBAR(IP)=CAR*ABAR(IP)**EAR
136 XNPPR=XNPPR+DELX
    RAVEV(IR)=RAVEV(IR)+VBAR(IP)*DELX
    RAVED(IR)=RAVED(IR)+RBAR(IP)*DELX
    IF(XRUN.GT.XEND) GOTO 140
    IF(ITERM.EQ.1) GO TO 108
320 IDUM=IE
    IE=IS
    IS=IDUM
    IF(IFIX(ZL(IS,1)+0.1).NE.7) GO TO 150
    IP=IP+1
    IFLAG(IP)=ZL(IS,1)+0.1
    X(IP)=ZL(IS,2)
    XID(IP)=ZL(IS,3)
    IID1=IID1+1
    IF(IID1.LE.NRLM) GO TO 122
    IID1=1
    IID2=IID2+1
122 DO 121 K=4,8
121 COEF(K,IID2,IID1)=ZL(IS,K)
    IB=IB+1
    IBB=IBB+1
    IF(IBB.LE.MAXBR) GO TO 118
    WRITE(NW,255)
255 FORMAT(49H THE MAXIMUM NUMBER OF BRANCHES HAS BEEN EXCEEDED)
    STOP
118 Q(IP)=QEND
    IJCO(IB)=IP
    GO TO 400
140 IP=IP+1
    IFLAG(IP)=IFLICP
    X(IP)=X(IP-1)-DELX*.001
    XID(IP)=DATA1
    IID1=IID1+1
    IF(IID1.LE.NRLM) GOTO 160
    IID1=1
    IID2=IID2+1
141 GO TO 160
108 IP=IP+1
    IF(IP.LE.NPTL) GO TO 119
    WRITE(NW,250)
119 CONTINUE
    IFLAG(IP)=9
    X(IP)=ZL(IE,2)
    XID(IP)=ZL(IE,3)
    IID1=IID1+1
    IF(IID1.LE.NRLM) GOTO 112
    IID1=1
    IID2=IID2+1
112 DO 113 K=4,8
113 COEF(K,IID2,IID1)=ZL(IE,K)
    Q(IP)=QEND
    VBAR(IP)=VBAR(IP-1)
    RBAR(IP)=RBAR(IP-1)
    ABAR(IP)=ABAR(IP-1)
    RAVEV(IR)=RAVEV(IR)/XNPPR
    RAVED(IR)=RAVED(IR)/XNPPR
    NPOINT=IP
    NREACH=IR
    NHDW=IH
    NLOAD=IL
```

```
  203 FORMAT(1H ,12X,10F11.3)
  304 CONTINUE
      RETURN
      END
      SUBROUTINE QUALE(NPOINT,IOPSUM,TBL,IOPWRT)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),Z0(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      DIMENSION TBL(14)
C*                    ADJUST COEF. FOR TEMP, CALCULATE DOSAT
      DO 1 IR=1,NREACH
      F1=1.047**(CTEMP(IR)-20.)
      DO 2 IEQ=1,NCON
      IC=ICODE(IEQ)
      GOTO(2,2,2,2,4,2,10,10,2,11,2,2),IC
    4 COEF(IEQ,1,IR)=COEF(IEQ,1,IR)*F1
      GOTO 2
   10 COEF(IEQ,1,IR)=COEF(IEQ,1,IR)*F1
      GOTO 2
   11 IF(CX(IEQ).GE.-1.0E-11) GOTO 12
      TF=CTEMP(IR)*1.8+32.
      DOS=24.89-0.4259*TF+0.003734*TF*TF-0.00001328*TF*TF*TF
      COEF(IEQ,2,IR)=DOS*EXP(-(.03418*COEF(IEQ,2,IR))
     *                /(288.-.006496*COEF(IEQ,2,IR)))
   12 IF(COEF(IEQ,1,IR).GT.0.000001) GOTO 14
      XX1=RAVEV(IR)**0.607
      XX2=RAVED(IR)**1.689
      COEF(IEQ,1,IR)=5.58*XX1/XX2
   14 COEF(IEQ,1,IR)=COEF(IEQ,1,IR)*(1.0159**(CTEMP(IR)-20.))
    2 CONTINUE
    1 CONTINUE
   20 CONTINUE
      RETURN
      END
      SUBROUTINE SUMQUA(NPOINT,TBL,IOPWRT)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),Z0(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      DIMENSION TBL(14)
      COMMON/S/ NSEG(15),ISST(15,15),ISED(15,15),IRR(15,15),IJJ(15,15)
     *           ,ILL(15,15)
  500 CALL TITL(TITLE,SUBTL,NW)
      IH=0
      NSTP=NEND
      WRITE(NW,100)(CODE(K),K=1,NCON)
  100 FORMAT(///1H ,17H CONSTITUENTS... ,11(A4,6X),A4)
      NHD=NHDW
      IF(IOPWRT.EQ.0) NHD=1
      DO 30 IHH=1,NHD
      N1=NSEG(IHH)
      IF(IOPWRT.EQ.0) N1=1
```

```
      DO 20 III=1,N1
      N2=ISST(IHH,III)
      N3=ISED(IHH,III)
      IR= IRR(IHH,III)
      IL= ILL(IHH,III)
      IF(IOPWRT.GT.0) GO TO 1
      N2=1
      N3=NPOINT
      IR=0
      IL=0
    1 DO 10 IP=N2,N3
      IFL=IFLAG(IP)
      GO TO(200,201,202,203,10,10,10,204,10,10,10),IFL
  200 IH=IH+1
      IR=IR+1
      WRITE(NW,370)IR
  370 FORMAT(1H0 / 1H0,'REACH#',I4)
      WRITE(NW,108) XID(IP),(CHW(IH,K),K=1,NCON)
  108 FORMAT(1H ,'HEAD ',1X,A4,1X,12F10.3)
      GO TO 5
  201 IR=IR+1
      WRITE(NW,372) IR
  372 FORMAT(1H0,'REACH#',I4)
      WRITE(NW,102) XID(IP)
  102 FORMAT(1H  ,'REACH',1X,A4)
      GO TO 5
  202 IR=IR+1
      WRITE(NW,372) IR
      WRITE(NW,103) XID(IP)
  103 FORMAT(1H  ,'JUNCT',1X,A4)
      GO TO 5
  203 IL=IL+1
      WRITE(NW,104) XID(IP),(ZL(K,IL),K=1,NCON)
  104 FORMAT(1H ,' LOAD',1X,A4,1X,12F10.3)
      GO TO 10
  204 IR=IR+1
      WRITE(NW,372) IR
      WRITE(NW,360) XID(IP)
  360 FORMAT(1H  ,'EVAP ',1X,A4)
    5 WRITE(NW,304) CTEMP(IR)
  304 FORMAT(1H ,1X,'TEMP=',F5.1)
      WRITE(NW,105)(CS(K,IR),K=1,NCON)
  105 FORMAT(1H ,' CS      =',2X,12F10.3)
      WRITE(NW,106)(CG(K,IR),K=1,NCON)
  106 FORMAT(1H ,' CG      =',2X,12F10.3)
      WRITE(NW,306) (COEF(K,7,IR),K=1,NCON)
  306 FORMAT(1H ,' L RATE =',2X,12F10.3)
   10 CONTINUE
   20 CONTINUE
   30 CONTINUE
      WRITE(NW,107)
  107 FORMAT(///1H ,20X,52HSUMMARY OF COEFFICIENTS FOR THE VARIOUS CONST
     *ITUENTS)
      DO 40 I=1,NCON
      WRITE(NW,42) CODE(I)
   42 FORMAT(1H / 1H ,'COEFFICIENTS FOR ',A4)
      IC=ICODE(I)
      IF(ISOLVE.EQ.0) LOOPS=NCOE(IC)
      IF(ISOLVE.NE.0) LOOPS=NCONU(IC)
      DO 44 J=1,LOOPS
      IF(NREACH-10) 335,335,340
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335 WRITE(NW,402) IC,J,(COEF(I,J,IR),IR=1,NREACH)
402 FORMAT(1H0,'BETA',I2,',',I2,' = ',10F11.3)
    GOTO 44
340 WRITE(NW,402) IC,J,(COEF(I,J,IR),IR=1,10)
    NNSTOP=NREACH-1
    DO 350 KK=10,NNSTOP,10
    KS=KK+1
    KE=KK+10
    IF(NREACH-KK.LT.10)KE=NREACH
    WRITE(NW,403) (COEF(I,J,IR),IR=KS,KE)
403 FORMAT(1H ,12X,10F11.3)
350 CONTINUE
 44 CONTINUE
 40 CONTINUE
    RETURN
    END
    SUBROUTINE DEFINE(IR,IP)
    COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
   *,IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
   *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
   *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
   *,IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
   *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
   *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
   *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
    DO 2 I=1,NCON
    IF(QS(IR)) 4,4,6
  4 SIS=0.0
    SJS=0.0
    GO TO 8
  6 SIS=QS(IR)*CS(I,IR)
    SJS=QS(IR)
  8 IF(QG(IR))10,10,12
 10 SIG=0.0
    SJG=0.0
    GO TO 14
 12 SIG=QG(IR)*CG(I,IR)
    SJG=QG(IR)
 14 SI=(SIS+SIG)/ABAR(IP)+COEF(I,7,IR)/86400./RBAR(IP)
    SJ=(SJS+SJG-QEVAP(IR))/ABAR(IP)
    IC=ICODE(I)
    GO TO (101,101,103,103,101,101,107,108,109,110,111,101),IC
101 G(I,1)=COEF(I,1,IR)/86400.+SJ
    G(I,2)=SI
    IV(I,2)=0
    NTD(I)=2
    GO TO 2
103 G(I,1)=COEF(I,1,IR)/86400.+SJ
    G(I,2)=SI
    IV(I,2)=0
    NTD(I)=2
    J=3
    K=IPARAM(2)
    IF(K.LE.0) GOTO 202
    G(I,J)=COEF(I,2,IR)*COEF(K,1,IR)/86400.
    IV(I,J)=K
    NTD(I)=J
    J=J+1
202 IF(IC.NE.4) GOTO 2
    K=IPARAM(3)
    IF(K.LE.0) GOTO 2
```

```
    1 IF(ABS(B(IEQ,1)).LT.EPS) GO TO 100
      ISUM=ISUM+1
      BX(ISUM)=B(IEQ,J)/B(IEQ,1)
      IFORMX(ISUM)=1
      EX(ISUM)=0.0
      ETX(ISUM)=0.0
      XSUM=XSUM+BX(ISUM)
      CI=CI-BX(ISUM)
      GO TO 25
  100 ISUM=ISUM+1
      BX(ISUM)=B(IEQ,J)
      IFORMX(ISUM)=2
      EX(ISUM)=0.0
      ETX(ISUM)=1.0
      XSUM=XSUM+BX(ISUM)*T
      GO TO 25
    2 IF(ABS(B(IEQ,1)).LT.EPS) GO TO 140
      CALL INT1(IEQ,J,B,E,ET,ISUM,BX,EX,ETX,X0,X,XSUM,CI,IFORMX,T,NITL)
      GO TO 25
  140 ISUM=ISUM+1
      ETX(ISUM)=ET(IEQ,J)+1.
      BX(ISUM)=B(IEQ,J)/ETX(ISUM)
      EX(ISUM)=0.0
      IFORMX(ISUM)=2
      XSUM=XSUM+BX(ISUM)*(T**ETX(ISUM))
      GO TO 25
    3 IF(ABS(E(IEQ,J)).LT.EPS) GO TC 1
      IF(ABS(B(IEQ,1)).LT.EPS) GO TO 110
      IF(ABS(B(IEQ,1)+E(IEQ,J)).LT.EPS) GO TO 115
      ISUM=ISUM+1
      BX(ISUM)=B(IEQ,J)/(E(IEQ,J)+B(IEQ,1))
      IFORMX(ISUM)=3
      EX(ISUM)=E(IEQ,J)
      ETX(ISUM)=0.0
      XSUM=XSUM+BX(ISUM)*EXP(EX(ISUM)*T)
      CI=CI-BX(ISUM)
      GO TO 25
  110 ISUM=ISUM+1
      BX(ISUM)=B(IEQ,J)/E(IEQ,J)
      EX(ISUM)=E(IEQ,J)
      ETX(ISUM)=0.0
      IFORMX(ISUM)=3
      XSUM=XSUM+BX(ISUM)*EXP(EX(ISUM)*T)
      CI=CI-BX(ISUM)
      GO TO 25
  115 ISUM=ISUM+1
      BX(ISUM)=B(IEQ,J)
      EX(ISUM)=-B(IEQ,1)
      ETX(ISUM)=1.0
      IFORMX(ISUM)=4
      XSUM=XSUM+BX(ISUM)*T*EXP(EX(ISUM)*T)
      GO TO 25
    4 IF(ABS(E(IEQ,J)).LT.EPS) GO TO 2
      IF(ABS(B(IEQ,1)).LT.EPS) GO TO 150
      IF(ABS(B(IEQ,1)+E(IEQ,J)).LT.EPS) GO TO 155
      CONST=E(IEQ,J)+B(IEQ,1)
      CALL INT2(IEQ,J,B,E,ET,ISUM,BX,EX,ETX,X0,X,XSUM,CI,CONST,IFORMX,T,
     *NITL)
      GO TO 25
  155 ISUM=ISUM+1
      EX(ISUM)=-B(IEQ,1)
```

```
      ETX(ISUM)=ET(IEQ,J)+1.
      BX(ISUM)=B(IEQ,J)/ETX(ISUM)
      IFORMX(ISUM)=4
      XSUM=XSUM+BX(ISUM)*(T**ETX(ISUM))*EXP(EX (ISUM)*T)
      GO TO 25
  150 CONST=E(IEQ,J)
      CALL INT2(IEQ,J,B,E,ET,ISUM,BX,EX,ETX,X0,X,XSUM,CI,CONST,IFORMX,T,
     *NITL)
   25 CONTINUE
      IF(ABS(B(IEQ,1)).LT.EPS) GO TO 160
      ISUM=ISUM+1
      BX(ISUM)=CI
      EX(ISUM)=-B(IEQ,1)
      ETX(ISUM)=0.0
      IFORMX(ISUM)=3
      X(IEQ)=XSUM+BX(ISUM)*EXP(EX(ISUM)*T)
      GO TO 165
  160 ISUM=ISUM+1
      BX(ISUM)=CI
      EX(ISUM)=0.0
      ETX(ISUM)=0.0
      IFORMX(ISUM)=1
      X(IEQ)=XSUM+CI
  165 DO 170 J=1,ISUM
      B(IEQ,J)=BX(J)
      E(IEQ,J)=EX(J)
      ET(IEQ,J)=ETX(J)
      IFORM(IEQ,J)=IFORMX(J)
  170 CONTINUE
      NTI(IEQ)=ISUM
   99 RETURN
      END
      SUBROUTINE INT1(IEQ,J,B,E,ET,ISUM,BX,EX,ETX,X0,X,XSUM,CI,IFORMX,T,
     *NITL)
      DIMENSION B(12,50),E(12,50),ET(12,50),BX(50),EX(50),ETX(50),X0(12)
     *,X(12),IFORMX(50)
C*
      IEND=ET(IEQ,J)+0.001
      ISUM=ISUM+1
      ETX(ISUM)=ET(IEQ,J)
      EX(ISUM)=0.0
      IFORMX(ISUM)=2
      BX(ISUM)=1.0/B(IEQ,1)
      XSUM=XSUM+BX(ISUM)*(T**ETX(ISUM))*B(IEQ,J)
      DO 10 I=1,IEND
      ISUM=ISUM+1
      IF(ISUM.GE.NITL-1) CALL ISUMER(ISUM,2)
      ETX(ISUM)=IEND-I
      EX(ISUM)=0.0
      BX(ISUM)=-(ETX(ISUM)+1.0)*BX(ISUM-1)/B(IEQ,1)
      IFORMX(ISUM)=2
      TCAL=T**ETX(ISUM)
      IF(ABS(ETX(ISUM)).LT.1.E-10) TCAL=1.
      XSUM=XSUM+BX(ISUM)*TCAL*B(IEQ,J)
      BX(ISUM-1)=BX(ISUM-1)*B(IEQ,J)
   10 CONTINUE
      IFORMX(ISUM)=1
      BX(ISUM)=BX(ISUM)*B(IEQ,J)
      CI=CI-BX(ISUM)
      RETURN
      END
```

```
      SUBROUTINE INT2(IEQ,J,B,E,ET,ISUM,BX,EX,ETX,X0,X,XSUM,CI,CONST
     *,IFORMX,T,NITL)
      DIMENSION B(12,50),E(12,50),ET(12,50),BX(50),EX(50),ETX(50),X0(12)
     *,X(12),IFORMX(50)
C*
      IEND=ET(IEQ,J)+0.001
      ISUM=ISUM+1
      ETX(ISUM)=ET(IEQ,J)
      EX(ISUM)=E(IEQ,J)
      BX(ISUM)=1.0/CONST
      IFORMX(ISUM)=4
      XSUM=XSUM+BX(ISUM)*(T**ETX(ISUM))*EXP(EX(ISUM)*T) *B(IEQ,J)
      DO 10 I=1,IEND
      ISUM=ISUM+1
      IF(ISUM.GE.NITL-1) CALL ISUMER(ISUM,3)
      ETX(ISUM)=IEND-I
      EX(ISUM)=E(IEQ,J)
      BX(ISUM)=-(ETX(ISUM)+1.0)*BX(ISUM-1)/CONST
      IFORMX(ISUM)=4
      TCAL=T**ETX(ISUM)
      IF(ABS(ETX(ISUM)).LT.1.E-10) TCAL=1.
      XSUM=XSUM+BX(ISUM)*TCAL*B(IEQ,J)*EXP(EX(ISUM)*T)
      BX(ISUM-1)=BX(ISUM-1)*B(IEQ,J)
   10 CONTINUE
      IFORMX(ISUM)=3
      BX(ISUM)=BX(ISUM)*B(IEQ,J)
      CI=CI-BX(ISUM)
      RETURN
      END
      SUBROUTINE ISUMER(ISUM,J)
      DIMENSION S(3)
      DATA S(1),S(2),S(3)/4HINTG,4HINT1,4HINT2/
      WRITE(6,100) ISUM,S(J)
  100 FORMAT(1X22HITERATION ERROR-ISUM =I5,16H  IN SUBROUTINE A4)
      STOP
      END
      SUBROUTINE CALC(NEQ,NTI,B,E,ET,T,X)
      DIMENSION NTI(12),B(12,50),E(12,50),ET(12,50),X(12)
      DO 1 IEQ=1,NEQ
      XSUM=0.0
      NF=NTI(IEQ)
      DO 2 J=1,NF
      IF(T.GT.0.00001) GO TO 3
      IF(ABS(ET(IEQ,J)).GT.0.00001) GO TO 3
      XSUM=XSUM+B(IEQ,J)
      GO TO 2
    3 XSUM=XSUM+B(IEQ,J)*(T**ET(IEQ,J))*EXP(T*E(IEQ,J))
    2 CONTINUE
      X(IEQ)=XSUM
    1 CONTINUE
      RETURN
      END
      SUBROUTINE TITL(T,S,NW)
      DIMENSION T(1),S(1)
      WRITE(NW,100)(T(I),I=1,20)
  100 FORMAT(1H120A4)
      WRITE(NW,101)(S(I),I=1,20)
  101 FORMAT(1X20A4)
      RETURN
      END
      SUBROUTINE SAVE(Z0,C,I,J)
```

```
      DIMENSION ZD(12,1),C(1)
      ZD(I,J)=C(I)
      RETURN
      END
      SUBROUTINE WRPT(L,IP,IW,ICVC)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *, QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *, ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *, IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *, NEND,NREACH,NHOW,NLOAD,NDIRV,NPTL,NRLM,NLOL,NITL,ZD(12,500)
     *, COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *, NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      IF(IW.NE.0) GO TO 10
      IW=1
      CALL TITL(TITLE,SUBTL,NW)
      WRITE(NW,101)(CODE(I),I=1,NCON)
  101 FORMAT(5H0 PNT2X8HDISTANCE2X4H ID 11(6XA4)/21X11(6XA4))
   10 WRITE(NW,100)IP,X(IP),XID(IP),(ZD(K,IP),K=1,NCON)
  100 FORMAT(1H0I4,F10.2,2XA4,11F10.3/21X11F10.3)
      RETURN
      END
      SUBROUTINE PLOTT
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *, QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *, ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *, IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *, NEND,NREACH,NHOW,NLOAD,NDIRV,NPTL,NRLM,NLOL,NITL,ZD(12,500)
     *, COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *, NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      COMMON/S/ NSEG(15),ISST(15,15),ISED(15,15),IRR(15,15),IJJ(15,15)
     *          ,ILL(15,15)
      DIMENSION A(1045),XLABEL(12),YLABEL(12)
      EQUIVALENCE(A(1),CS(1,1))
      DO 30 K=1,1045
      A(K)='     '
   30 CONTINUE
      DO 4 K=1,12
      CX(K)='      '
      XLABEL(K)='      '
      YLABEL(K)='      '
    4 CONTINUE
      NOSG=0
      READ(NR,102) Q(1),Q(2),NOSG,IOPLT
  102 FORMAT(A4,A2,2I2)
      WRITE(NW,104) Q(1),Q(2),NOSG,IOPLT
  104 FORMAT(1H0 // 1H0,A4,A2,5X,'PLOTS FOLLOW FOR',I3
     *       ,' SEGMENTS',5X,'IOPLT =',I2)
      IF(Q(1).NE.'PLOT') STOP
      DO 2 IS=1,NOSG
      READ (NR,106)(CX(K),K=4,9),(XLABEL(K),K=3,6),NHD,NPLT,XMIN,XMAX
  106 FORMAT(6A6,4A6,2I3,2F7.2)
      IF(IOPLT.EQ.1)
     *WRITE(NW,108) (CX(K),K=4,9),(XLABEL(K),K=3,6),NHD,NPLT,XMIN,XMAX
  108 FORMAT(1H0//1H0,6A6,2X,4A6,2X,'HW #=',I2,3X,'NO. OF.PLOTS='
     *       ,I2,3X,'XMIN=',F10.2,3X,'XMAX=',F10.2)
      DO 8 IPL=1,NPLT
      READ(NR,110) CCD,(YLABEL(K),K=3,10),YMIN,YMAX,NP,LOG
  110 FORMAT(A4,8A6,2F7.2,I3,1X,I4)
      IF(IOPLT.EQ.1)
```

```
     *WRITE(NW,112) CCD,(YLABEL(K),K=3,10),YMIN,YMAX,NP,LOG
  112 FORMAT(1H0//1H0,A4,2X,8A6,2X,'YMIN=',F10.2,3X,'YMAX='
     *       ,F10.2,3X,'NO. OF POINTS =',I3,3X,'SCALE CODE=',I4)
      IF(NP.EQ.0) GOTO 12
      READ(NR,114) (RBAR(K),ABAR(K),K=1,NP)
  114 FORMAT(10F8.0)
      IF(IOPLT.EQ.1)
     *WRITE(NW,116) (RBAR(K),ABAR(K),K=1,NP)
  116 FORMAT(1H ,10F12.3)
   12 NSYM=-92-LOG
      IF(NP.EQ.0)NSYM=92+LOG
      N1=NSEG(NHD)
      IY=0
      DO 24 III=1,NCON
      IF(CCD.NE.CODE(III))GOTO 24
      IEQ=III
      GOTO 40
   24 CONTINUE
      WRITE(NW,118) CCD
  118 FORMAT(1H0,'SORRY, ',A4,' WAS NOT MODELED IN THIS RUN.')
      GOTO 8
   40 DO 22 II=1,N1
      N2=ISST(NHD,II)
      N3=ISED(NHD,II)
      DO 22 IP=N2,N3
      IY=IY+1
      Q(IY)=X(IP)
      VBAR(IY)=ZD(IEQ,IP)
   22 CONTINUE
   26 CONTINUE
      XL=XMAX
      XS=XMIN
      YL=YMAX
      YS=YMIN
      DO 28 I=2,IY
      IF(XL.LT.Q(I))XL=Q(I)
      IF(XS.GT.Q(I))XS=Q(I)
      IF(YL.LT.VBAR(I))YL=VBAR(I)
      IF(YS.GT.VBAR(I))YS=VBAR(I)
   28 CONTINUE
      IF(NP.EQ.0) GOTO 42
      DO 18 I=1,NP
      IF(XL.LT.ABAR(I))XL=ABAR(I)
      IF(XS.GT.ABAR(I))XS=ABAR(I)
      IF(YL.LT.RBAR(I))YL=RBAR(I)
      IF(YS.GT.RBAR(I))YS=RBAR(I)
   18 CONTINUE
   42 CALL PL360(IY,A,Q,XS,XL,XLABEL,VBAR
     *       ,YS,YL,YLABEL,CX,NSYM)
      IF(NP.EQ.0) GOTO 52
      NSYM=240+LOG
      CALL PL360(NP,A,ABAR,XS,XL,XLABEL,RBAR
     *       ,YS,YL,YLABEL,CX,NSYM)
   52 WRITE(NW,124) (TITLE(K),K=1,20)
      WRITE(NW,124) (SUBTL(K),K=1,20)
  124 FORMAT(1H ,20A4)
      WRITE(NW,122)
  122 FORMAT(1H ,'NOTE: O INDICATES OBSERVED DATA AND * INDICATES'
     *       ,' CALCULATED VALUES.')
    8 CONTINUE
    2 CONTINUE
```

```
      RETURN
      END
      SUBROUTINE QUALN
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *, IFLAG(50C),NR,NW,TITLE(2C),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,10C),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,5C),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
C*                     ADJUST COEF. 6OR TEMP, CALCULATE DOSAT & REAERATION
      DO 160 IR=1,NREACH
      F1=1.047**(CTEMP(IR)-20.)
      DO 150 IEQ=1,NCON
      IC=ICODE(IEQ)
      GO TO (150,150,150,150, 70,15C,70,70,150,100,150,70),IC
   70 COEF(IEQ,1,IR)=COEF(IEQ,1,IR)*F1
      IF(IC.EQ.12)COEF(IEQ,2,IR)=COEF(IEQ,2,IR)*F1
      GO TO 150
  100 IF(CX(IEQ).GE.-1.0E-11) GCTC 110
      TF=CTEMP(IR)*1.8+32.
      DOS=24.89-0.4259*TF+0.003734*TF*TF-0.00001328*TF*TF*TF
      COEF(IEQ,2,IR)=DOS*EXP(-(.03418*COEF(IEQ,2,IR))
     *                 /(288.-.006496*COEF(IEQ,2,IR)))
  110 IF(COEF(IEQ,1,IR).GT.0.00C001) GOTO 120
      XX1=RAVEV(IR)**0.607
      XX2=RAVED(IR)**1.689
      COEF(IEQ,1,IR)=5.58*XX1/XX2
  120 COEF(IEQ,1,IR)=COEF(IEQ,1,IR)*(1.0159**(CTEMP(IR)-20.))
      GO TO 150
  150 CONTINUE
  160 CONTINUE
      RETURN
      END
      SUBROUTINE SORT(NCON,NREACH,CS,CG,COEF,ICODE)
      DIMENSION CS(12,100),CG(12,10C),COEF(12,7,100),ICODE(12)
      DIMENSION TCS(12,100),TCG(12,100),TCOEF(12,7,100)
      DO 20 IEQ=1,NCON
      DO 20 K=1,NREACH
      DO 10 N=1,7
      TCOEF(IEQ,N,K)=COEF(IEQ,N,K)
      COEF(IEQ,N,K)=0.
10    CONTINUE
      TCS(IEQ,K)=CS(IEQ,K)
      TCG(IEQ,K)=CG(IEQ,K)
      CS(IEQ,K)=0.
      CG(IEQ,K)=0.
20    CONTINUE
      DO 25 I=NCON,12
      DO 25 K=1,NREACH
      DO 23 N=1,7
      COEF(I,N,K)=0.
23    CONTINUE
      CS(I,K)=0.
      CG(I,K)=0.
25    CONTINUE
      DO 40 I=1,NCON
      DO 40 K=1,NREACH
      IEQ=ICODE(I)
      DO 30 N=1,7
```

```
      COEF(IEQ,N,K)=TCOEF(I,N,K)
30    CONTINUE
      CS(IEQ,K)=TCS(I,K)
      CG(IEQ,K)=TCG(I,K)
40    CONTINUE
      RETURN
      END
      SUBROUTINE CONVRT(NREACH,COEF,IPARAM,NW)
      DIMENSION COEF(12,7,100),IPARAM(12)
      X=86400.
      DO 20 K=1,NREACH
      DO 10 I=1,10
      COEF(I,1,K)=COEF(I,1,K)/X
      COEF(I,7,K)=COEF(I,7,K)/X
10    CONTINUE
      COEF(7,2,K)=COEF(7,2,K)/X
      COEF(8,2,K)=COEF(8,2,K)/X
      COEF(10,3,K)=COEF(10,3,K)/X
      COEF(10,4,K)=COEF(10,4,K)/X
      COEF(10,5,K)=COEF(10,5,K)/X
      COEF(12,1,K)=COEF(12,1,K)/X
      COEF(12,2,K)=COEF(12,2,K)/X
      COEF(12,7,K)=COEF(12,7,K)/X
20    CONTINUE
C*
C*    THIS SECTION SETS BETA 8,6 = 1 IF NH3 IS NOT BEING MODELED AND
C*    BETA 9,3 = 1 IF NO3 IS NOT BEING MODELED
C*
      IF(IPARAM(8).GT.0)GO TO 40
      DO 30 K=1,NREACH
      COEF(8,6,K)=1.
30    CONTINUE
40    CONTINUE
      IF(IPARAM(9).GT.0)RETURN
      DO 50 K=1,NREACH
      COEF(9,3,K)=1.
50    CONTINUE
      RETURN
      END
      SUBROUTINE TIMES(YO,Y,H,MIN,MAX,MAXIT,IP,IR,NCON,ICODE,IPARAM,NW)
      REAL MIN,MAX
      DIMENSION YO(12),Y(12),ICODE(12),IPARAM(12)
      TUSED=0.
      TMAX=H
      TLEFT=H
      CALL SORTIN(YO,NCON,ICODE)
10    CONTINUE
      CALL RUNGE(YO,Y,H,TMAX,TLEFT,MIN,MAX,MAXIT,IP,IR,NCON,ICODE,
     *          IPARAM,NW)
      TUSED=TUSED+H
      TLEFT=TMAX-TUSED
      IF(ABS(TLEFT).GT.1.E-6)GO TO 20
      CALL SORTOT(YO,Y,NCON,ICODE,IFARAM)
      H=TMAX
      RETURN
20    IF(H.GT.TLEFT)H=TLEFT
      DO 30 IEQ=1,NCON
      I=ICODE(IEQ)
      YO(I)=Y(I)
30    CONTINUE
      GO TO 10
```

```
      END
      SUBROUTINE SORTIN(YO,NCON,ICODE)
      DIMENSION YO(12),ICODE(12)
      DIMENSION TYO(12)
      DO 10 I=1,12
      TYO(I)=0.
10    CONTINUE
      DO 20 IEQ=1,NCON
      I=ICODE(IEQ)
      TYO(I)=YO(IEQ)
20    CONTINUE
      DO 30 I=1,12
      YO(I)=TYO(I)
30    CONTINUE
      RETURN
      END
      SUBROUTINE SORTOT(YO,Y,NCON,ICODE,IPARAM)
      DIMENSION YO(12),Y(12),ICODE(12),IPARAM(12)
      DIMENSION TYO(12),TY(12)
      DO 10 I=1,12
      TYO(I)=0.
      TY(I)=0.
10    CONTINUE
      DO 20 IEQ=1,NCON
      I=ICODE(IEQ)
      TYO(I)=YO(I)
      TY(I)=Y(I)
20    CONTINUE
      DO 30 I=1,12
      IEQ=IPARAM(I)
      IF(IEQ.LE.0)GO TO 30
      YO(IEQ)=TYO(I)
      Y(IEQ)=TY(I)
30    CONTINUE
      RETURN
      END
      SUBROUTINE RUNGE(YO,Y,H,TMAX,TLEFT,MIN,MAX,MAXIT,IP,IR,NCON,ICODE,
     *                  IPARAM,NN)
      REAL MIN,MAX,K
      DIMENSION YO(12),Y(12),ICODE(12),IPARAM(12)
      DIMENSION DY(12),K(12,4)
      ICK1=0
      KOUNT=0
      KOUNT2=0
      TLTLST=0.
      HLAST=0.
1     ICK=0
      DO 10 IEQ=1,NCON
      I=ICODE(IEQ)
      Y(I)=YO(I)
10    CONTINUE
      CALL DRV(Y,DY,IP,IR)
      DO 20 IEQ=1,NCON
      I=ICODE(IEQ)
      K(I,1)=H*DY(I)
      Y(I)=YO(I)+K(I,1)/2.
20    CONTINUE
      CALL DRV(Y,DY,IP,IR)
      DO 30 IEQ=1,NCON
      I=ICODE(IEQ)
      K(I,2)=H*DY(I)
```

```
      Y(I)=YO(I)+K(I,2)/2.
30    CONTINUE
      CALL DRV(Y,DY,IP,IR)
      DO 40 IEQ=1,NCON
      I=ICODE(IEQ)
      K(I,3)=H*DY(I)
      Y(I)=YO(I)+K(I,3)
40    CONTINUE
      CALL DRV(Y,DY,IP,IR)
      DO 50 IEQ=1,NCON
      I=ICODE(IEQ)
      K(I,4)=H*DY(I)
      Y(I)=YO(I)+(K(I,1)+2.*K(I,2)+2.*K(I,3)+K(I,4))/6.
50    CONTINUE
      CALL STPSIZ(H,TMAX,TLEFT,MIN,MAX,MAXIT,NCON,ICODE,NW,K,KOUNT,ICK,
     *            YO,Y,ICK1,KOUNT2,HLAST,TLTLST)
      ICK1=0
      IF(ICK.NE.0)GO TO 1
      DO 60 IEQ=1,NCON
      I=ICODE(IEQ)
      IF(YO(I).LE.0.)GO TO 60
      IF(Y(I).GE.0.) GO TO 60
      IF(KOUNT2.GT.7)GO TO 60
      H=H/2.
      ICK1=1
      KOUNT2=KOUNT2+1
      GO TO 1
60    CONTINUE
      RETURN
      END
      SUBROUTINE DRV(Y,DY,IP,IR)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *,IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,5C),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(10C),RAVED(100),ISOLVE
      DIMENSION Y(12),DY(12)
      DIMENSION S(12)
      CALL SIEQ(Y,IR,IP,NCON,ICODE,QS,QG,CS,CG,COEF,ABAR,RBAR,S)
      CALL TERMS(Y,IR,NCON,IPARAM,COEF,TERM1,TERM2,TERM3,TERM4)
      DO 13 IEQ=1,NCON
      I=ICODE(IEQ)
      GO TO(1,2,3,4,5,6,7,8,9,1C,11,12),I
1     DY(I)=-COEF(1,1,IR)*Y(1)+S(1)
      GO TO 13
2     DY(I)=-COEF(2,1,IR)*Y(2)+S(2)
      GO TO 13
3     DY(I)=-COEF(3,1,IR)*Y(3)+COEF(3,2,IR)*COEF(2,1,IR)*Y(2)+S(3)
      GO TO 13
4     DY(I)=-COEF(4,1,IR)*Y(4)+COEF(4,2,IR)*COEF(2,1,IR)*Y(2)
     *      +COEF(4,3,IR)*COEF(3,1,IR)*Y(3)+S(4)
      GO TO 13
5     DY(I)=-COEF(5,1,IR)*Y(5)+S(5)
      GO TO 13
6     DY(I)=-COEF(6,1,IR)*Y(6)-COEF(6,2,IR)*TERM2*TERM3*TERM4+S(6)
      GO TO 13
7     DY(I)=-COEF(7,1,IR)*Y(7)-COEF(7,2,IR)*Y(7)
     *      +COEF(7,3,IR)*COEF(12,2,IR)*X(12)+S(7)
```

```
      GO TO 13
8     DY(I)=-COEF(8,1,IR)*Y(8)-COEF(8,2,IR)*Y(8)
     *       +COEF(8,3,IR)*COEF(7,1,IR)*Y(7)
     *       -COEF(8,4,IR)*TERM1*TERM2*TERM3*TERM4+S(8)
      GO TO 13
9     DY(I)=-COEF(9,1,IR)*Y(9)+COEF(8,1,IR)*Y(8)
     *       -COEF(9,2,IR)*(1.-TERM1)*TERM2*TERM3*TERM4+S(9)
      GO TO 13
10    DY(I)= COEF(10,1,IR)*(COEF(10,2,IR)-Y(10))-COEF(7,1,IR)*Y(7)
     *       +COEF(10,3,IR)-4.33*COEF(8,1,IR)*Y(8)
     *       -COEF(10,4,IR)*Y(10)/RBAR(IP)+COEF(10,5,IR)*Y(12)+S(10)
      GO TO 13
11    DY(I)=COEF(11,1,IR)*(COEF(11,2,IR)-Y(11))+S(11)
      GO TO 13
12    DY(I)= TERM2*TERM3*TERM4-COEF(12,2,IR)*Y(12)+S(12)
13    CONTINUE
      RETURN
      END
      SUBROUTINE STPSIZ(H,TMAX,TLEFT,MIN,MAX,MAXIT,NCON,ICODE,NW,K,
     *                  KOUNT,ICK,YC,Y,ICK1,KOUNT2,HLAST,TLTLST)
      COMMON /STPSIZ/ ERRMAX
      REAL MIN,MAX,K
      DIMENSION ICODE(12),K(12,4),YC(12),Y(12)
      TEMPH=H
      DO 20 IEQ=1,NCON
      I=ICODE(IEQ)
      IF(ABS(Y(I)-YO(I)).LT.ERRMAX)GO TO 20
      IF((K(I,1)-K(I,2)).EQ.0.)GO TO 20
      X=ABS((K(I,2)-K(I,3))/(K(I,1)-K(I,2)))
      IF(X.LT.MAX)GO TO 10
      KOUNT=KOUNT+1
      IF(KOUNT.LE.MAXIT)GO TO 5
      WRITE(NW,1000)MAXIT,H
100)  FORMAT(/,10X,"*** WARNING THE NUMBER OF ITERATIONS TO FIND A ",
     *        "SMALL ENOUGH STEP SIZE IS GREATER THAN MAXIT (MAXIT = ",
     *        I4,' H = ',E9.3,')')
      RETURN
5     H=H/2.
      ICK=1
      RETURN
10    IF(X.LT.MIN.AND.ICK1.NE.1)ICK2=1
20    CONTINUE
      IF(ICK2.EQ.1)GO TO 30
      RETURN
30    IF(ABS(H-TMAX).GT.1.E-6)GO TO 40
      RETURN
40    CONTINUE
      IF(H.EQ.HLAST.AND.TLEFT.EQ.TLTLST)RETURN
      HLAST=H
      TLTLST=TLEFT
      H=H*2.
      IF(H.GT.TLEFT)H=TLEFT
      IF(ABS(TEMPH-H).LT.1.0E-6)RETURN
      ICK=1
      RETURN
      END
      SUBROUTINE SIEQ(Y,IR,IP,NCON,ICODE,QS,QG,CS,CG,COEF,ABAR,RBAR,S)
      DIMENSION Y(12),ICODE(12),QS(100),QG(100),CS(12,100),CG(12,100),
     *          COEF(12,7,100),ABAR(500),RBAR(500),S(12)
      IF(QS(IR).GT.1.0E-6.OR.QG(IR).GT.1.0E-6)GO TO 20
      DO 10 I=1,12
```

```
      S(I)=COEF(I,7,IR)/RBAR(IP)
10    CONTINUE
      RETURN
20    CONTINUE
      DO 70 IEQ=1,NCON
      I=ICODE(IEQ)
      IF(QS(IR).GT.1.0E-6)GO TO 30
      SS=0.
      GO TO 40
30    SS=QS(IR)*(CS(I,IR)-Y(I))
40    CONTINUE
      IF(QG(IR).GT.1.0E-6)GO TO 50
      SG=0.
      GO TO 60
50    SG=QG(IR)*(CG(I,IR)-Y(I))
60    CONTINUE
      S(I)=COEF(I,7,IR)/RBAR(IP)+(SS+SG)/ABAR(IP)
70    CONTINUE
      RETURN
      END
      SUBROUTINE TERMS(Y,IR,NCON,IPARAM,COEF,TERM1,TERM2,TERM3,TERM4)
      DIMENSION Y(12),IPARAM(12),COEF(12,7,100)
C*
C*    IF ALGP NOT BEING MODELED TERM1,2,3,4 = 0.
C*
      IF(IPARAM(12).GT.0)GO TO 10
      TERM1=0.
      TERM2=0.
      TERM3=0.
      TERM4=0.
      RETURN
10    TERM4=COEF(12,1,IR)*Y(12)
C*
C*    IF EITHER NO3 OR NH3 ARE NOT BEING MODELED TERM1=1
C*
      IF(IPARAM(8).GT.0.AND.IPARAM(9).GT.0)GO TO 20
      TERM1=1.
      GO TO 30
20    TERM1=COEF(8,5,IR)*Y(8)/(COEF(8,5,IR)*Y(8)+Y(9))
30    CONTINUE
C*
C*    IF PO4 NOT BEING MODELED TERM2=1
C*
      IF(IPARAM(6).GT.0)GO TO 40
      TERM2=1.
      GO TO 50
40    TERM2=Y(6)/(COEF(6,3,IR)+Y(6))
50    CONTINUE
C*
C*    TERM3=(KNO3*NH3+KNH3*NO3)/(KNO3*KNH3+KNO3*NH3+KNH3*NO3)
C*    IF BOTH NO3 AND NH3 ARE NOT BEING MODELED TERM3=1
C*    IF NO3 IS NOT BEING MODELED TERM3=NH3/(KNH3+NH3) WHICH REQUIRES
C*    KNO3=1.  THIS WAS DONE IN SUBROUTINE CONVRT.
C*    IF NH3 IS NOT BEING MODELED TERM3=NO3/(KNO3+NO3) WHICH REQUIRES
C*    KNH3=1.  THIS WAS ALSO DONE IN SUBROUTINE CONVRT.
C*
      IF(IPARAM(8).GT.0.OR.IPARAM(9).GT.0)GO TO 60
      TERM3=1
      RETURN
60    TERM3=(COEF(9,3,IR)*Y(8)+COEF(8,6,IR)*Y(9))/
     *      (COEF(8,6,IR)*COEF(9,3,IR)+COEF(9,3,IR)*Y(8)+COEF(8,6,IR)*
```

```
     *      Y(9))
      RETURN
      END
      SUBROUTINE FLAGKT(IP,IW,ID,IL,IH,IR,IJ,IB,NFLAG)
      DIMENSION NFLAG(7,500)
      NFLAG(1,IP)=IW
      NFLAG(2,IP)=ID
      NFLAG(3,IP)=IL
      NFLAG(4,IP)=IH
      NFLAG(5,IP)=IR
      NFLAG(6,IP)=IJ
      NFLAG(7,IP)=IB
      RETURN
      END
      SUBROUTINE DSETUP(TBL)
      COMMON Q(500),X(500),XID(500),ABAR(500),RBAR(500),VBAR(500)
     *,IFLAG(500),NR,NW,TITLE(20),SUBTL(20),ZL(12,150),QL(150),QD(150)
     *,QS(100),QG(100),CS(12,100),CG(12,100),G(12,10),IV(12,10),NTD(12)
     *,ICODE(12),CODE(12),IPARAM(12),CHW(15,12),ZO(12),Z(12),NTI(12)
     *,IFORM(12,50),B(12,50),E(12,50),ET(12,50),C(12),ZJUNC(12),NCON
     *,NEND,NREACH,NHDW,NLOAD,NDIRV,NPTL,NRLM,NLDL,NITL,ZD(12,500)
     *,COEF(12,7,100),MAXHD,MAXBR,NCOE(12),NCONU(12),CX(12),CTEMP(100)
     *,NCOEFL,QEVAP(100),RAVEV(100),RAVED(100),ISOLVE
      COMMON /DMAT1/NPOINT,IOPECH,TBB(30),NPLOAD,NTLPL,NDLOAD,NTLDL,NTL,
     *              NTTL,NK,NWDISK,NPUNCH,ZDSAVE(12,500),LP(30),
     *              LD1(30),LD2(30),LPPTNO(30),REDPL(12,15,30),
     *              REDDL(12,15,30),ZLSAVE(12,150),CSSAVE(12,100),
     *              KID(10),NDISK2
      COMMON /DMAT2/D(12,16,30,10)
      COMMON /DMAT3/ZLDMAT(12,15,150),CSDMAT(12,15,100)
      COMMON/S/ NSEG(15),ISST(15,15),ISED(15,15),IRR(15,15),IJJ(15,15)
     *          ,ILL(15,15)
      DIMENSION TBL(14)
      READ(NR,1000)NPLOAD,NTLPL,NDLOAD,NTLDL,NK,NWDISK,NPUNCH,NDISK2
1000  FORMAT(8I3)
      NTL=NPLOAD+NDLOAD
      NTTL=NTLPL+NTLDL
      IF(IOPECH.NE.1)WRITE(NW,2000)NPLOAD,NTLPL,NDLOAD,NTLDL,NK,NWDISK,
     *                              NPUNCH,NDISK2,NTL,NTTL
2000  FORMAT(1H1,//,1X,'D MATRIX INPUT DATA',/,2X,'NPLOAD = ',I3,3X,
     *       'NTLPL = ',I3,3X,'NDLOAD = ',I3,3X,'NTLDL = ',I3,3X,'NK = '
     *       ,I3,3X,'NWDISK = ',I3,3X,'NPUNCH = ',I3,3X,'NDISK2 = ',I2,/
     *       /,2X,'THE TOTAL NUMBER OF LOADS TO BE CONSIDERED = ',I2,3X,
     *       'THE TOTAL NUMBER OF TREATMENT LEVELS = ',I3,//)
      IF(NTL.LE.30.AND.NTTL.LE.15.AND.NK.LE.10)GO TO 10
      WRITE(NW,2010)
2010  FORMAT(1X,'INPUT LIMITS HAVE BEEN EXCEEDED',/,5X,'LIMITS ARE',4X,
     *       'NTL = 30',/,20X,'NK = 10',/,20X,'TOTAL NUMBER OF ',
     *       'TREATMENT LEVELS = 15')
      STOP
10    CONTINUE
C*
C*    ENTER INITIAL STREAM CONDITIONS
C*
      DO 20 I=1,NCON
      DO 20 J=1,NPOINT
      ZDSAVE(I,J)=ZO(I,J)
20    CONTINUE
C*
C*    READ IN POINT AND SURFACE DIFFUSE LOAD NUMBERS TO BE CONSIDERED
C*
```

```
      IF(NPLOAD.GT.0)CALL READP(LP,NPLOAD,NR,NW,IOPECH)
      IF(NDLOAD.GT.0)CALL READD( LD1,LD2,NDLOAD,NR,NW,IOPECH)
C*
C*    FIND THE POINT NUMBER ASSOCIATED WITH EACH POINT LOAD
      IF(NPLOAD.LE.0) GO TO 40
      KOUNT1=1
      KOUNT2=0
      DO 30 I=1,NPOINT
      IF(IFLAG(I).NE.4)GO TO 30
      KOUNT2=KOUNT2+1
      IF(LP(KOUNT1).NE.KOUNT2)GO TO 30
      LPPTNO(KOUNT1)=I
      KOUNT1=KOUNT1+1
30    CONTINUE
40    CONTINUE
C*
C*    FIND OUT WHICH LOADS ARE NOT ON MAIN STREAM
C*
      N1=NSEG(1)
      DO 46 IL=1,NPLOAD
      DO 44 KI=1,N1
      N2=ISST(1,KI)
      N3=ISED(1,KI)
      IF(LPPTNO(IL).GE.N2.AND.LPPTNO(IL).LE.N3)GO TO 46
44    CONTINUE
      TBB(IL)=99.
46    CONTINUE
C*
C*    READ IN LOADS WITH TREATMENT
C*
      IF(NPLOAD.GT.0)CALL READ2(REDPL,NTLPL,CODE,ICODE,TBL,NCON,NR,NW,
     *                           ICPECH,1,ISOLVE,NPLOAD)
      IF(NDLOAD.GT.0)CALL READ2(REDDL,NTLDL,CODE,ICODE,TBL,NCON,NR,NW,
     *                           IOPECH,2,ISOLVE,NDLOAD)
C*
C*    CALCULATE NEW LOADING MATRIX
      IF(NPLOAD.LE.0)GOTO 70
      DO 70 IL=1,NPLOAD
      ILP=LP(IL)
      DO 60 IT=1,NTLPL
      DO 50 IC=1,NCON
      ZLDMAT(IC,IT,ILP)=REDPL(IC,IT,IL)
50    CONTINUE
60    CONTINUE
70    CONTINUE
      IF(NDLOAD.LE.0)GO TO 110
      DO 110 IL=1,NDLOAD
      ILDST=LD1(IL)
      ILDEND=LD2(IL)
      DO 100 IT=1,NTLDL
      DO 90 IC=1,NCON
      IEQ=IC
      IF(ISOLVE.EQ.1)IEQ=ICODE(IC)
      DO 80 ILD=ILDST,ILDEND
      CSDMAT(IEQ,IT,ILD)=REDDL(IEQ,IT,IL)
80    CONTINUE
90    CONTINUE
100   CONTINUE
110   CONTINUE
C*
C*    READ IN POINT NUMBERS OF SURVEILANCE POINTS
```

```
C*
      READ(NR,1010)(KID(IK),IK=1,NK)
1010  FORMAT(20I4)
      IF(IOPECH.NE.1)WRITE(NW,2020)(KID(IK),IK=1,NK)
2020  FORMAT(//,1X,'POINT NUMBERS OF SURVEILLANCE POINTS',/,20(2X,I3))
C*
C*    WRITE OUT INITIAL CONDITICN FILE
C*
      DO 115 IK=1,NK
      KI=KID(IK)
      WRITE(NDISK2,2030)KI,(ZDSAVE(IC,KI),IC=1,NCON)
2030  FORMAT(I2,3X,12F10.3)
115   CONTINUE
      LOCK NDISK2
C*
C*    INITILIZE D TO ZERO
      DO 120 IK=1,NK
      DO 120 IL=1,NTL
      DO 120 IT=1,NTTL
      DO 120 IC=1,NCON
      D(IC,IT,IL,IK)=0.
120   CONTINUE
C*
C*    SAVE ORIGIONAL ZL AND CS
      DO 150 IC=1,NCON
      IEQ=IC
      IF(ISOLVE.EQ.1)IEQ=ICODE(IC)
      DO 130 IL=1,100
      CSSAVE(IEQ,IL)=CS(IEQ,IL)
      ZLSAVE(IC,IL)=ZL(IC,IL)
130   CONTINUE
      DO 140 IL=101,150
      ZLSAVE(IC,IL)=ZL(IC,IL)
140   CONTINUE
150   CONTINUE
      RETURN
      END
      SUBROUTINE READP(LP,N,NR,NW,IOPECH)
      DIMENSION LP(30)
      IF(IOPECH.NE.1)WRITE(NW,2000)
2000  FORMAT(///,1X,'POINT LOAD NUMBERS TO BE CONSIDERED',/)
      ISTRT=1
10    ISTOP=ISTRT+19
      IF(ISTOP.GT.N)ISTOP=N
      READ(NR,1000)(LP(I),I=ISTRT,ISTOP)
1000  FORMAT(20I4)
      IF(IOPECH.NE.1)WRITE(NW,2010)(LP(I),I=ISTRT,ISTOP)
2010  FORMAT(20(3X,I3))
      ISTRT=ISTOP+1
      IF(ISTRT.LE.N)GO TO 10
      DO 20 I=2,N
      IF(LP(I).LE.LP(I-1))GO TO 30
20    CONTINUE
      RETURN
30    WRITE(NW,2020)I
2020  FORMAT(//,10X,'ERROR, CHECK FOR DECREASING POINT LOAD NUMBERS AT',
     *       ' LOAD NUMBER ',I3)
      STOP
      END
      SUBROUTINE READD(LD1,LD2,N,NR,NW,IOPECH)
      DIMENSION LD1(30),LD2(30)
```

```
      IF(IOPECH.NE.1)WRITE(NW,2000)
2000  FORMAT(///,1X,'RANGE OF REACHES ASSOCIATED WITH DIFFUSE SURFACE ',
     *       'LOADS',/)
      ISTRT=1
10    ISTOP=ISTRT+9
      IF(ISTOP.GT.N)ISTOP=N
      READ(NR,1000)(LD1(I),LD2(I),I=ISTRT,ISTOP)
1000  FORMAT(20I4)
      IF(IOPECH.NE.1)WRITE(NW,2010)(LD1(I),LD2(I),I=ISTRT,ISTOP)
2010  FORMAT(3X,10(I3,'-',I3,3X))
      ISTRT=ISTOP+1
      IF(ISTRT.LE.N)GO TO 10
      IF(LD1(1).GT.LD2(1))GO TO 30
      IF(N.EQ.1)GO TO 20
      DO 20 I=2,N
      IF(LD1(I).GT.LD2(I).OR.LD1(I).LT.LD2(I-1))GO TO 30
20    CONTINUE
      RETURN
30    CONTINUE
      WRITE(NW,2020)I
2020  FORMAT(//,10X,'ERROR, CHECK FOR DECREASING REACH NUMBERS OR ',
     *       'OVERLAPPING REACH GROUPS AT GROUP NUMBER ',I3)
      STOP
      END
      SUBROUTINE READ2(RED,N,CODE,ICODE,TBL,NCON,NR,NW,IOPECH,IOP,
     *                 ISOLVE,NL)
      DIMENSION RED(12,15,30),CODE(12),ICODE(12),TBL(14),ZCODE(12),
     *          IDXQ(12),TEMRED(12)
      IF(IOPECH.EQ.1)GO TO 20
      IF(IOP.EQ.2)GO TO 10
      WRITE(NW,2000)
2000  FORMAT(//,1X,'POINT LOADS WITH TREATMENT'/)
      GO TO 20
10    WRITE(NW,2010)
2010  FORMAT(//,1X,'DIFFUSE LOADS WITH TREATMENT',/)
20    CONTINUE
      READ(NR,1000)(ZCODE(I),I=1,12)
1000  FORMAT(8X,12(2X,A4))
      IF(IOPECH.NE.1)WRITE(NW,2020)(ZCODE(I),I=1,12)
2020  FORMAT(10X,12(6X,A4))
      IEND=0
      DO 30 I=1,12
      IF(ZCODE(I).EQ.TBL(13))GO TO 40
      IEND=IEND+1
30    CONTINUE
40    CONTINUE
      IF(IEND.EQ.NCON)GO TO 60
50    WRITE(NW,2030)(ZCODE(I),I=1,IEND)
2030  FORMAT(//,1X,'ERROR IN CONSTITUENT CODE',5X,12(2X,A4))
      STOP
60    CONTINUE
      DO 80 I=1,NCON
      DO 70 J=1,NCON
      IF(ZCODE(J).NE.CODE(I))GO TO 70
      IDXQ(I)=J
      GO TO 80
70    CONTINUE
      GO TO 50
80    CONTINUE
      DO 110 IT=1,N
      DO 100 IL=1,NL
```

```
      READ(NR,1010)(TEMRED(J),J=1,NCON)
1010  FORMAT(8X,12F6.0)
      IF(IOPECH.NE.1)WRITE(NW,2040)IT,IL,(TEMRED(J),J=1,NCON)
2040  FORMAT(1X,'TL ',I2,1X,'LOAD ',I2,1X,11(F5.1,5X),F5.1)
      DO 90 I=1,NCON
      J=IDXQ(I)
      IC=I
      IF(IOP.EQ.2.AND.ISOLVE.EQ.1)IC=ICODE(I)
      RED(IC,IT,IL)=TEMRED(J)
90    CONTINUE
100   CONTINUE
110   CONTINUE
      RETURN
      END
      SUBROUTINE WTOMAT(D,NW,NWDISK,NPUNCH,NK,NTTL,NTL,NPLOAD,NCON,CODE)
      DIMENSION D(12,16,30,10),CODE(12)
      WRITE(NW,2000)
2000  FORMAT(1H1,//)
      WRITE(NWDISK,2005)NK,NTTL,NTL,NCON
2005  FORMAT(4I3)
      DO 60 IK=1,NK
      DO 50 IT=1,NTTL
      WRITE(NW,2010)IK,IT,(CODE(I),I=1,NCON)
2010  FORMAT(//,1X,'CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE ',
     *       'POINT ',I2,' TREATMENT LEVEL ',I2,//,3X,'LOAD',5X,
     *       11(A4,6X),A4)
      DO 40 IL=1,NTL
      ILL=IL
      IF(ILL.GT.NPLOAD)ILL=IL-NPLOAD
      IF(ILL.NE.IL)GO TO 10
      WRITE(NW,2020)ILL,(D(IC,IT,IL,IK),IC=1,NCON)
2020  FORMAT(/,1X,'PT. ',I3,1X,11(F7.3,3X),F7.3)
      GO TO 20
10    WRITE(NW,2030)ILL,(D(IC,IT,IL,IK),IC=1,NCON)
2030  FORMAT(/,1X,'DIF. ',I2,1X,11(F7.3,3X),F7.3)
20    ICEND=NCON
      IF(ICEND.GT.11)ICEND=11
      WRITE(NPUNCH,2040)ILL,(D(IC,IT,IL,IK),IC=1,ICEND)
2040  FORMAT(I3,11F7.3)
      IF(ICEND.EQ.NCON)GO TO 30
      WRITE(NPUNCH,2040)ILL,(D(IC,IT,IL,IK),IC=12,NCON)
30    WRITE(NWDISK,2050)ILL,(D(IC,IT,IL,IK),IC=1,NCON)
2050  FORMAT(I3,12(2X,F7.3))
40    CONTINUE
50    CONTINUE
60    CONTINUE
      LOCK NWDISK
      RETURN
      END
```

Appendix D

SUBROUTINE DESCRIPTIONS AND FLOW CHART FOR THE SIMULATION-OPTIMIZATION MODEL LINKING PROGRAM (HELPSU)

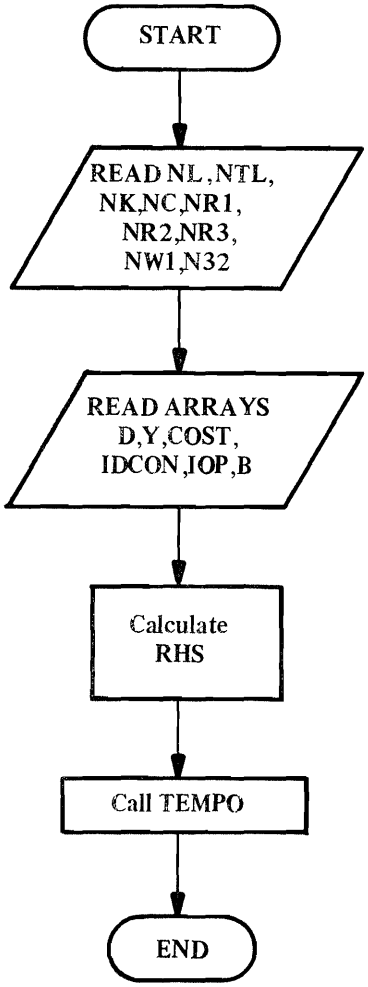
SUBROUTINE MAIN

Purpose: To read in input files and calculate right hand side of constraint equations.

Variable Name	Variable Description
NL	Number of loads to be considered (point and diffuse) ≤ 30
NTL	Number of treatment levels ≤ 15
NK	Number of surveillance points ≤ 10
NC	Number of quality constituents for which there are stream standards ≤ 12
NR1	Read file for D matrix
NR2	Read file for initial conditions matrix
NR3	Read file for cost matrix
NW1	Write file for TEMPO input data
NW2	If NW2 > 0, input data will be echoed on file NW2
IK	Surveillance point index
IT	Treatment level index
IL	Load index
IC	Constituent index
D(IC,IT,IL,IK)	The change from the initial condition of constituent IC at surveillance point IK with treatment level IT on load IL
Y(IC,IK)	Initial condition of constituent IC at surveillance point IK
COST(IT,IL)	Cost of treatment level IT at load IL
IDCON(IC)	Sequence number (from program SSAM) of the ICth constituent to have a stream standard

IOP(IC)	If IOP(IC) = 0, the concentration of constituent IDCON(IC) must be less than the stream standard If IOP(IC) = 1, the concentration of constituent IDCON(IC) must be greater than the stream standard
B(IC,IK)	Stream standard for constituent IC at surveillance point IK
RHS(IC,IK)	Right hand size of the constraint equation for constituent IC, surveillance point IK

Subroutine MAIN



SUBROUTINE TEMPO

Purpose: To write out the objective function and the constraint equations in the format used by the integer programming algorithm.

Variables used in this subroutine are the same as those used in Subroutine MAIN.

Appendix E

DATA INPUT FORMATS FOR THE SIMULATION-OPTIMIZATION MODEL LINKING PROGRAM (HELPSU)

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
Control	1	1-3	I3	NL	Number of loads to be considered (point + diffuse) (MAX = 30)
		4-6	I3	NTL	Number of treatment levels to be considered (MAX = 15)
		7-9	I3	NK	Number of surveillance points (MAX = 10)
		10-12	I3	NC	Number of quality constituents for which there are stream standards
		13-15	I3	NR1	Read file for D matrix (this file has been stored on disk by SSAM)
		16-18	I3	NR2	Read file for initial condition matrix (this file has been stored on disk by SSAM)
		19-21	I3	NR3	Read file for cost matrix (can be read from disk or cards)
		22-24	I3	NW1	Write file for TEMPO input data (disk)
		25-27	I3	NW2	If NW2 > 0, input data will be echoed on file NW2
Input Cost Matrix (not needed if cost read from disk)	1	1-10	F10.0	COST(1,1)	Cost of treatment level 1 at load 1
		11-20	F10.0	COST(2,1)	Cost of treatment level 2 at load 1
		21-30	F10.0	COST(3,1)	Cost of treatment level 3 at load 1
		⋮			
		71-80	F10.0	COST(10,1)	Cost of treatment level 10 at load 1 If the number of treatment levels is > 10, use another card like 1 for the remainder of treatment levels

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
	2				Repeat card 1 for each load
Stream Standards	1	1-2	I2	IDCON(1)	Constituent number (from SSAM) of the first constituent that has a stream standard (will be a number between one and the number of constituents modeled in SSAM)
		3-4	I2	IOP(1)	If IOP = 0, the concentration of IDCON(1) must be less than the stream standard If IOP = 1, the concentration of IDCON(1) must be greater than the stream standard
		5-6	I2	IDCON(2)	Constituent number of the second constituent that has a stream standard
		7-8	I2	IOP(2)	If IOP = 0, the concentration of IDCON(2) must be less than the stream standard If IOP = 1, the concentration of IDCON(2) must be greater than the stream standard
		⋮			
		45-46	I2	IDCON(12)	The constituent number of the twelfth constituent to have a stream standard
		47-48	I2	IOP(12)	
	2	1-6	F6.0	B(1,1)	Stream standard for constituent 1, surveillance point 1 (mg/l)

Data Segment	Card No. in Data Segment	Column	Format	Symbol	Description
		7-12	F6.0	B(2,1)	Stream standard for constituent 2, surveillance point 2 (mg/l)
		⋮			
		67-72	F6.0	B(12,1)	Stream standard for constituent 2, surveillance point 2 (mg/l)
	3				Repeat card 2 for each surveillance point

Appendix F

PROGRAM LISTING FOR THE SIMULATION-OPTIMIZATION MODEL LINKING PROGRAM (HELPSU)

```
FILE  5=FILE5
FILE  6=FILE6
FILE  20(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="DMATRIX")
FILE  21(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="INITCCN")
FILE  22(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="COST")
FILE  23(KIND=DISK,MAXRECSIZE=22,BLOCKSIZE=220,AREAS=1000,AREASIZE=10
     *  ,SAVEFACTOR=99,TITLE="TEMPO")
      COMMON D(12,16,30,10),B(12,10),Y(12,10),COST(16,30),RHS(12,10),
     *         IDCON(12),IOP(12),NL,NTL,NK,NC,NR1,NR2,NR3,NW1,NW2
      NR=5
      NW=6
      READ(NR,1000)NL,NTL,NK,NC,NR1,NR2,NR3,NW1,NW2
1000  FORMAT(9I3)
      WRITE(NW,2000)NL,NTL,NK,NC,NR1,NR2,NR3,NW1,NW2
2000  FORMAT(///,1X,'NL = ',I2,3X,'NTL = ',I2,3X,'NK = ',I2,3X,'NC = ',
     *         I2,3X,'NR1 = ',I2,3X,'NR2 = ',I2,3X,'NR3 = ',I2,3X,
     *         'NW1 = ',I2,3X,'NW2 = ',I2,///)
C*
C*    READ IN INPUT FILES
C*
      READ(NR1,1005)N1,N2,N3,N4
1005  FORMAT(4I3)
      IF(NW2.NE.0)WRITE(NW2,2010)
2010  FORMAT(10X,'D MATRIX',/)
      DO 30 IK=1,N1
      DO 20 IT=1,N2
      DO 10 IL=1,N3
      READ(NR1,1010)(D(IC,IT,IL,IK),IC=1,N4)
1010  FORMAT(3X,12(2X,F7.3))
      IF(NW2.NE.0)WRITE(NW2,1010)(D(IC,IT,IL,IK),IC=1,N4)
10    CONTINUE
20    CONTINUE
30    CONTINUE
      IF(NW2.NE.0)WRITE(NW2,2020)
2020  FORMAT(//,10X,'INIT. CONC.',/)
      DO 40 IK=1,NK
      READ(NR2,1020)(Y(IC,IK),IC=1,N4)
1020  FORMAT(5X,12F10.3)
      IF(NW2.NE.0)WRITE(NW2,1020)(Y(IC,IK),IC=1,N4)
40    CONTINUE
      IF(NW2.NE.0)WRITE(NW2,2030)
2030  FORMAT(//,10X,'COST')
      DO 50 IL=1,NL
      READ(NR3,1030)(COST(IT,IL),IT=1,NTL)
1030  FORMAT(10F10.0)
      IF(NW2.NE.0)WRITE(NW2,2040)(COST(IT,IL),IT=1,NTL)
2040  FORMAT(1X,10F10.0)
50    CONTINUE
C*
C*    READ IN STREAM STANDARDS (CONSTITUENT, TYPE, AND AMOUNT)
C*
      READ(NR,1040)(IDCON(IC),IOP(IC),IC=1,NC)
1040  FORMAT(24I2)
      IF(NW2.NE.0)WRITE(NW2,2050)(IDCON(IC),IOP(IC),IC=1,NC)
2050  FORMAT(//,10X,'IDCON AND IOP ',//,24(3X,I2))
      IF(NW2.NE.0)WRITE(NW2,2060)
2060  FORMAT(//,10X,'B MATRIX',/)
      DO 60 IK=1,NK
```

```
      READ(NR,1050)(B(IC,IK),IC=1,NC)
1050  FORMAT(12F6.0)
      IF(NW2.NE.0)WRITE(NW2,2070)(B(IC,IK),IC=1,NC)
2070  FORMAT(1X,12F10.1)
60    CONTINUE
C*
C*    CALCULATE RHS
C*
      DO 80 IC=1,NC
      ICC=IDCON(IC)
      DO 70 IK=1,NK
      RHS(IC,IK)=Y(ICC,IK)-B(IC,IK)
70    CONTINUE
80    CONTINUE
      CALL TEMPO
      END
      SUBROUTINE TEMPO
      COMMON D(12,16,30,10),B(12,10),Y(12,10),COST(16,30),RHS(12,10),
     *        IDCON(12),IOP(12),NL,NTL,NK,NC,NR1,NR2,NR3,NW1,NW2
      WRITE(NW1,2000)
2000  FORMAT('NAME',10X,'WLA',/,'ROWS',/,1X,'N',2X,'COST')
      DO 20 IC=1,NC
      CALL OUT(IC,IC1,IC2)
      DO 10 IK=1,NK
      CALL OUT(IK,IK1,IK2)
      IF(IOP(IC).EQ.1)GO TO 5
      WRITE(NW1,2010)IK1,IK2,IC1,IC2
2010  FORMAT(1X,'G',2X,'RK',2I1,'C',2I1)
      GO TO 10
5     WRITE(NW1,2020)IK1,IK2,IC1,IC2
2020  FORMAT(1X,'L',2X,'RK',2I1,'C',2I1)
10    CONTINUE
20    CONTINUE
      DO 30 IL=1,NL
      CALL OUT(IL,IL1,IL2)
      WRITE(NW1,2030)IL1,IL2
2030  FORMAT(1X,'E',2X,'ROWL',2I1)
30    CONTINUE
      WRITE(NW1,2040)
2040  FORMAT('COLUMNS',/,4X,'BEGINT',4X,8H'MARKER',17X,8H'BIVORG')
      DO 70 IL=1,NL
      CALL OUT(IL,IL1,IL2)
      DO 60 IT=1,NTL
      CALL OUT(IT,IT1,IT2)
      WRITE(NW1,2050)IT1,IT2,IL1,IL2,COST(IT,IL)
2050  FORMAT(4X,'T',4I1,5X,'COST',6X,F12.3)
      DO 50 IC=1,NC
      ICC=IDCON(IC)
      CALL OUT(IC,IC1,IC2)
      DO 40 IK=1,NK
      CALL OUT(IK,IK1,IK2)
      WRITE(NW1,2060)IT1,IT2,IL1,IL2,IK1,IK2,IC1,IC2,D(ICC,IT,IL,IK)
2060  FORMAT(4X,'T',4I1,5X,'RK',2I1,'C',2I1,3X,F12.3)
40    CONTINUE
50    CONTINUE
      WRITE(NW1,2070)IT1,IT2,IL1,IL2,IL1,IL2
2070  FORMAT(4X,'T',4I1,5X,'ROWL',2I1,11X,'1.0')
60    CONTINUE
70    CONTINUE
      WRITE(NW1,2080)
2080  FORMAT(4X,'ENDINT',4X,8H'MARKER',17X,8H'BIVEND',/,'RHS')
```

```
      DO 90 IC=1,NC
      CALL OUT(IC,IC1,IC2)
      DO 80 IK=1,NK
      CALL CUT(IK,IK1,IK2)
      WRITE(NW1,2090)IK1,IK2,IC1,IC2,RHS(IC,IK)
2090  FORMAT(4X,'ZRHS',6X,'RK',2I1,'C',2I1,3X,F12.3)
80    CONTINUE
90    CONTINUE
      DO 100 IL=1,NL
      CALL OUT(IL,IL1,IL2)
      WRITE(NW1,2100)IL1,IL2
2100  FORMAT(4X,'ZRHS',6X,'ROWL',2I1,11X,'1.0')
100   CONTINUE
      WRITE(NW1,2110)
2110  FORMAT('ENDATA')
      LOCK NW1
      RETURN
      END
      SUBROUTINE OUT(I,I1,I2)
      I1=I/10
      I2=I-I1*10
      RETURN
      END
```

Appendix G

SAMPLE OF LINKED SIMULATION-OPTIMIZATION MODEL OUTPUT

The linked simulation-optimization model is comprised of three computer programs, SSAM, HELPSU, and MXINT. SSAM is the stream simulation model that generates the D matrices used in the optimization model. The program HELPSU sets up the optimization problem so that it can be solved by the mixed integer linear programming algorithm, MXINT. This appendix includes the output from the application of the linked simulation-optimization model to the hypothetical problem described in Chapter IV. The output is divided into three parts: 1) Sample Output from SSAM, 2) Sample Output from HELPSU, and 3) Sample Output from MXINT.

SAMPLE OUTPUT FROM SSAM

```
WASTE LOAD ALLOCATION
SAMPLE PROPLEM

IOPRUN = 3     ICVI = 0     ICVO = C     IOPECH = 0     IOPSUM = 0     IOPWRT = 1     IOPGW= 0

CARD DISTANCE MNEMONIC DESCRIPTION PRINT DELTA   FLOW   LATERAL  LATERAL   SLOPE   MANNING   VEL     VEL    HYDR    HYDR   HYDR
CODE                               CODE                 SURFACE  GROUND               N      COEF    EXP    COEF    EXP    OPT
                                                          FLOW    FLOW


  H   200.00  H-1 HEADWATER 1             0.00    5.00    0.02     0.00   0.0000   0.0000   0.0900  0.6000  0.5332  0.6000  E

  L   200.00  L-1 WWTP 1                  0.00    0.83    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  C   200.00  C-1 SURVEILLANCE PT.1       0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  B   170.00  B-1 BRANCH                  0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  H   220.00  H-2 HEADWATER 2             0.00    1.67    0.00     0.00   0.0000   0.0000   0.2360  0.6000  0.4867  0.6000  E

  L   220.00  L-2 WWTP 2                  0.00    0.33    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  C   220.00  C-2 SURVEILLANCE PT.2       0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  J   170.00  J-1 JUNCTION                0.00    0.00    0.02     0.00   0.0000   0.0000   0.0631  0.6000  0.5429  0.6000  E

  C   170.00  C-3 SURVEILLANCE PT.3       0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  R   130.00  R-4 REACH 4                 0.00    0.00    0.01     0.00   0.0000   0.0000   0.0490  0.6000  0.5353  0.6000  E

  L   130.00  L-3 WWTP 3                  0.00    1.17    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  R   110.00  R-5 REACH 5                 0.00    0.00    0.00     0.00   0.0000   0.0000   0.0487  0.6000  0.5510  0.6000  E

  C   110.00  C-4 SURVEILLANCE PT.4       0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  R    90.00  R-6 REACH 6                 0.00    0.00    0.00     0.00   0.0000   0.0000   0.0455  0.6000  0.5401  0.6000  E

  L    90.00  L-4 WWTP 4                  0.00    1.17    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  C    70.00  C-5 SURVEILLANCE PT.5       0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000

  T    70.00  T-1 END                     0.00    0.00    0.00     0.00   0.0000   0.0000   0.0000  0.0000  0.0000  0.0000
```

```
WASTE LOAD ALLOCATION
SAMPLE PROPLEM

                        SUMMARY OF SYSTEM FLOW LAYOUT

                                                           LATERAL   LATERAL     MAIN-     MAIN-    MAIN-    MAIN-    MAIN-     AVE.    AVE.
PT. F.  ID    IDENTIFICATION      DISTANCE    INPUT    SURFACE   GROUND      STREAM    STREAM   STREAM   STREAM   STREAM    REACH   REACH
       CODE                                   FLOW     FLOW      FLOW        FLOW      VEL.     AREA     H. RAD.  SLOPE     VEL.    H.RAD.
                                    (KM)      (CMS)     (CMS)     (CMS)      (CMS)     (MPS)    (SQM)     (M)               (MPS)    (M)


REACH   1     HEADWATER  1                                                                                                  0.266    3.488
  1 1  H-1   HEADWATER 1         200.00     5.0000   0.5010    0.0000      5.0000    0.236    21.15     3.33   0.00000
  2 4  L-1   WWTP 1              200.00     0.8330                         5.8330    0.259    22.50     3.45   0.00000
  3 6  C-1   SURVEILLANCE PT.1   200.00                                    5.8330    0.266    22.88     3.49   0.00000
  4 7  B-1   BRANCH              170.00                                    6.3340

REACH   3     JUNCTION  1                                                                                                   0.233    4.806
  8 3  J-1   JUNCTION            170.00              0.6680    0.0000      8.4990    0.228    37.30     4.76   0.00000
  9 6  C-3   SURVEILLANCE PT.3   170.00                                    8.4990    0.233    37.88     4.81   0.00000

REACH   4                                                                                                                   0.200    5.738
 10 2  R-4   REACH 4             130.00              0.1660    0.0000      9.1670    0.185    49.51     5.56   0.00000
 11 4  L-3   WWTP 3              130.00     1.1670                        10.3340    0.200    52.11     5.74   0.00000

REACH   5                                                                                                                   0.200    5.944
 12 2  R-5   REACH 5             110.00              0.0660    0.0000     10.5000    0.200    52.60     5.94   0.00000
 13 6  C-4   SURVEILLANCE PT.4   110.00                                   10.5000    0.200    52.66     5.94   0.00000

REACH   6                                                                                                                   0.200    6.232
 14 2  R-6   REACH 6              90.00              0.0660    0.0000     10.5660    0.187    56.44     6.07   0.00000
 15 4  L-4   WWTP 4               90.00     1.1670                        11.7330    0.200    58.92     6.23   0.00000
 16 6  C-5   SURVEILLANCE PT.5    70.00                                   11.7990    0.200    58.98     6.24   0.00000
 17 9  T-1   END                  70.00                                   11.7990


REACH   2     HEADWATER  2                                                                                                  0.366    1.380
  5 1  H-2   HEADWATER 2         220.00     1.6670   0.1650    0.0000      1.6670    0.321     5.20     1.31   0.00000
  6 4  L-2   WWTP 2              220.00     0.3330                         2.0000    0.358     5.59     1.37   0.00000
  7 6  C-2   SURVEILLANCE PT.2   220.00                                    2.0000    0.366     5.68     1.38   0.00000
NPOINT =  17     NREACH =  6     NHWD =  2     NLOAD =  4     NOIRV =  0
```

```
WASTE LOAD ALLOCATION
SAMPLE PROPLEM


          STREAM SIMULATION AND ASSESSMENT MODEL, SSAM


WASTE LOAD ALLOCATION  SAMPLE PROBLEM

ITEROP =  1     ISOLVE =  1     DTMAX = 300.00     MIN =    0.02     MAX =    0.10     MAXIT =   20     ERRMAX =  .100E-05

 6 CONSTITUENTS WILL BE MODELED IN THIS RUN
     PHOS  CBOD  NH3N  NO3N  DOXY  ALGP

   PHOS PHOSPHORUS (MG/L)

   CBOD BIOCHEMICAL OXYGEN DEMAND, ULTIMATE (MG/L)

   NH3N AMMONIA (MG-N/L)

   NO3N NITRATE (MG-N/L)

   DOXY DISSOLVED OXYGEN (MG/L)

   ALGP ALGAE, FLOATING (MG-CLA/L)


DATA FOR HEADWATERS

                 PHOS       CBOD       NH3N       NO3N       DOXY       ALGP

H-1             0.000      2.000      1.000      0.200      9.100      0.007

H-2             0.000      1.000      1.000      0.200     10.200      0.007


DATA FOR POINT LOADS

                 PHOS       CBOD       NH3N       NO3N       DOXY       ALGP

L-1            20.000     30.000     25.000      9.000      0.000      0.000

L-2            15.000     20.000     25.000      8.000      0.000      0.000

L-3            20.000     25.000     20.000     10.000      0.000      0.000

L-4            15.000     30.000     15.000     11.000      0.000      0.000


DATA FOR REACHES
```

```
CONSTANT TEMPERATURE
WATER TEMP          9.000       7.000      10.000      11.000      12.000      12.000


PHOS DIFFUSE CONCENTRATION           0.000

L. SURFACE =        0.005       0.000       0.800       0.010       0.010       0.050

L. GROUND  =        0.000       0.000       0.000       0.000       0.000       0.000

LEACH RATE =        0.000       0.000       0.000       0.000       0.000       0.000

BETA  6, 1          0.000       0.000       0.000       0.000       0.000       0.000

BETA  6, 2          1.000       1.000       1.000       1.000       1.000       1.000

BETA  6, 3          0.025       0.025       0.025       0.025       0.025       0.025


CBOD DIFFUSE CONCENTRATION           0.000

L. SURFACE =        0.000       0.000       1.500       0.900       0.500       0.800

L. GROUND  =        0.000       0.000       0.000       0.000       0.000       0.000

LEACH RATE =        0.000       0.000       0.020       0.040       0.100       0.100

BETA  7, 1          0.410       0.454       0.507       0.484       0.462       0.462

BETA  7, 2          0.000       0.000       0.000       0.000       0.000       0.000

BETA  7, 3          0.300       0.300       0.300       0.300       0.300       0.300


NH3N DIFFUSE CONCENTRATION           0.000

L. SURFACE =        0.500       0.000       0.300       1.200       0.400       1.000

L. GROUND  =        0.000       0.000       0.000       0.000       0.000       0.000

LEACH RATE =        0.000       0.000       0.010       0.030       0.080       0.080

BETA  8, 1          0.500       0.545       0.522       0.529       0.505       0.505

BETA  8, 2          0.000       0.000       0.000       0.000       0.000       0.000

BETA  8, 3          0.000       0.000       0.000       0.000       0.000       0.000

BETA  8, 4         10.000      10.000      10.000      10.000      10.000      10.000

BETA  8, 5          2.000       2.000       2.000       2.000       2.000       2.000

BETA  8, 6          0.050       0.050       0.050       0.050       0.050       0.050


NO3N DIFFUSE CONCENTRATION           0.000

L. SURFACE =        1.000       1.000       1.000       1.300       1.400       1.400
```

```
L. GROUND  =        0.000      0.000      0.000      0.000      0.000      0.000

LEACH RATE =        0.000      0.000      0.000      0.000      0.000      0.000

BETA  9, 1          0.000      0.000      0.000      0.000      0.000      0.000

BETA  9, 2         10.000     10.000     10.000     10.000     10.000     10.000

BETA  9, 3          0.100      0.100      0.100      0.100      0.100      0.100


DOXY DIFFUSE CONCENTRATION       -1.000

L. SURFACE =        8.100      9.700      8.200      8.200      8.600      9.100

L. GROUND  =        0.000      0.000      0.000      0.000      0.000      0.000

LEACH RATE =        0.000      0.000      0.000      0.000      0.000      0.000

BETA10, 1           0.000      0.000      0.000      0.000      0.000      0.000

BETA10, 2        1000.000   1000.000    900.000    885.000    875.000    865.000

BETA10, 3           0.000      0.000      0.000      0.000      0.000      0.000

BETA10, 4           0.000      0.000      0.020      0.060      0.060      0.060

BETA10, 5         105.000    105.000    105.000    150.000    105.000    105.000


ALGP DIFFUSE CONCENTRATION        0.000

L. SURFACE =        0.000      0.000      0.000      0.000      0.000      0.000

L. GROUND  =        0.000      0.000      0.000      0.000      0.000      0.000

LEACH RATE =        0.000      0.000      0.000      0.000      0.000      0.000

BETA12, 1           0.700      0.700      0.700      0.800      0.800      0.800

BETA12, 2           0.005      0.005      0.005      0.005      0.005      0.005
```

```
WASTE LOAD ALLOCATION
SAMPLE PROBLEM


 CONSTITUENTS... PHOS       CBOD       NH3N       NO3N       DOXY       ALGP


REACH#    1
HEAD   H-1      0.000      2.000      1.000      0.200      9.100      0.007
 TEMP=  9.0
 CS     =       0.005      0.000      0.500      1.000      8.100      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.000      0.000      0.000      0.000      0.000
 LOAD  L-1     20.000     30.000     25.000      9.000      0.000      0.000

REACH#    3
JUNCT  J-1
 TEMP= 10.0
 CS     =       0.800      1.500      0.300      1.000      8.200      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.020      0.010      0.000      0.000      0.000

REACH#    4
REACH  R-4
 TEMP= 11.0
 CS     =       0.010      0.900      1.200      1.300      8.200      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.040      0.030      0.000      0.000      0.000
 LOAD  L-3     20.000     25.000     20.000     10.000      0.000      0.000

REACH#    5
REACH  R-5
 TEMP= 12.0
 CS     =       0.010      0.500      0.400      1.400      8.600      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.100      0.080      0.000      0.000      0.000

REACH#    6
REACH  R-6
 TEMP= 12.0
 CS     =       0.050      0.800      1.000      1.400      9.100      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.100      0.080      0.000      0.000      0.000
 LOAD  L-4     15.000     30.000     15.000     11.000      0.000      0.000



REACH#    2
HEAD   H-2      0.000      1.000      1.000      0.200     10.200      0.007
 TEMP=  7.0
 CS     =       0.000      0.000      0.000      1.000      9.700      0.000
 CG     =       0.000      0.000      0.000      0.000      0.000      0.000
 L RATE =       0.000      0.000      0.000      0.000      0.000      0.000
 LOAD  L-2     15.000     20.000     25.000      8.000      0.000      0.000
```

SUMMARY OF COEFFICIENTS FOR THE VARIOUS CONSTITUENTS

```
COEFFICIENTS FOR PHOS
BETA  6, 1 =       0.000      0.000      0.000      0.000      0.000      0.000
BETA  6, 2 =       1.000      1.000      1.000      1.000      1.000      1.000
BETA  6, 3 =       0.025      0.025      0.025      0.025      0.025      0.025
COEFFICIENTS FOR CBOD
BETA  7, 1 =       0.247      0.250      0.320      0.320      0.320      0.320
BETA  7, 2 =       0.000      0.000      0.000      0.000      0.000      0.000
BETA  7, 3 =       0.300      0.300      0.300      0.300      0.300      0.300
COEFFICIENTS FOR NH3N
BETA  8, 1 =       0.302      0.300      0.330      0.350      0.350      0.350
BETA  8, 2 =       0.000      0.000      0.000      0.000      0.000      0.000
BETA  8, 3 =       0.000      0.000      0.000      0.000      0.000      0.000
BETA  8, 4 =      10.000     10.000     10.000     10.000     10.000     10.000
BETA  8, 5 =       2.000      2.000      2.000      2.000      2.000      2.000
BETA  8, 6 =       0.050      0.050      0.050      0.050      0.050      0.050
COEFFICIENTS FOR NO3N
BETA  9, 1 =       0.000      0.000      0.000      0.000      0.000      0.000
BETA  9, 2 =      10.000     10.000     10.000     10.000     10.000     10.000
BETA  9, 3 =       0.100      0.100      0.100      0.100      0.100      0.100
COEFFICIENTS FOR DOXY
BETA10, 1 =        0.255      1.434      0.139      0.095      0.091      0.084
BETA10, 2 =       10.229     10.756     10.106      9.884      9.664      9.676
BETA10, 3 =        0.000      0.000      0.000      0.000      0.000      0.000
BETA10, 4 =        0.000      0.000      0.020      0.060      0.060      0.060
BETA10, 5 =      105.000    105.000    105.000    150.000    105.000    105.000
COEFFICIENTS FOR ALGP
BETA12, 1 =        0.422      0.385      0.442      0.529      0.554      0.554
BETA12, 2 =        0.003      0.003      0.003      0.003      0.003      0.003
```

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D MATRIX INPUT DATA
 NPLOAD =    4    NTLPL =    7    NDLOAD =    0    NTLDL =    0    NK =    5    NWDISK =  20    NPUNCH =    7    NDISK2 = 21

 THE TOTAL NUMBER OF LOADS TO BE CONSIDERED =  4   THE TOTAL NUMBER OF TREATMENT LEVELS =   7



POINT LOAD NUMBERS TO BE CONSIDERED

    1      2      3      4


POINT LOADS WITH TREATMENT

                  PHOS        CBOD        NH3N        NO3N        COXY        ALGP
TL  1 LOAD  1   20.0        30.0        25.0         9.0         0.0         0.0
TL  1 LOAD  2   15.0        20.0        25.0         8.0         0.0         0.0
TL  1 LOAD  3   20.0        25.0        20.0        10.0         0.0         0.0
TL  1 LOAD  4   15.0        30.0        15.0        11.0         0.0         0.0
TL  2 LOAD  1   15.0        25.0         5.0         9.0         0.1         0.0
TL  2 LOAD  2   10.0        15.0         5.0         8.0         0.0         0.0
TL  2 LOAD  3   15.0        20.0         3.0        10.0         0.2         0.0
TL  2 LOAD  4   10.0        25.0         3.0        11.0         0.1         0.0
TL  3 LOAD  1    2.0        20.0        20.0         9.0         0.1         0.0
TL  3 LOAD  2    2.0        10.0        20.0         8.0         0.0         0.0
TL  3 LOAD  3    2.0        15.0        10.0        10.0         0.2         0.0
TL  3 LOAD  4    2.0        10.0        10.0        11.0         0.1         0.0
TL  4 LOAD  1    0.5         5.0        20.0         9.0         0.1         0.0
TL  4 LOAD  2    0.3         5.0        20.0         8.0         0.0         0.0
TL  4 LOAD  3    0.5         5.0        10.0        10.0         0.2         0.0
TL  4 LOAD  4    0.3         5.0        10.0        11.0         0.1         0.0
TL  5 LOAD  1   10.0         5.0        20.0         9.0         0.1         0.0
TL  5 LOAD  2    8.0         5.0        20.0         8.0         0.0         0.0
TL  5 LOAD  3   10.0         5.0        10.0        10.0         0.2         0.0
TL  5 LOAD  4   10.0         5.0        10.0        11.0         0.1         0.0
TL  6 LOAD  1    0.5         5.0         4.0         9.0         0.1         0.0
TL  6 LOAD  2    0.3         5.0         4.0         8.0         0.0         0.0
TL  6 LOAD  3    0.5         5.0         2.0        10.0         0.2         0.0
TL  6 LOAD  4    0.3         5.0         2.0        11.0         0.1         0.0
TL  7 LOAD  1    0.0         0.0         0.0         0.0        10.1         0.0
TL  7 LOAD  2    0.0         0.0         0.0         0.0        10.7         0.0
TL  7 LOAD  3    0.0         0.0         0.0         0.0        10.2         0.0
TL  7 LOAD  4    0.0         0.0         0.0         0.0        10.1         0.0

POINT NUMBERS OF SURVEILLANCE POINTS
   3     7     9    13    16
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

 PNT  DISTANCE    ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#   1     HEADWATER  1

    1    200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

    2    200.00   L-1      2.856      5.999      4.427      1.457      7.800      0.006

    3    200.00   C-1      2.856      5.999      4.427      1.457      7.800      0.006

    4    170.00   B-1      2.627      4.106      2.758      2.740      3.200      0.009

REACH#   3
    8    170.00   J-1      2.544      3.750      2.781      2.853      4.381      0.010

    9    170.00   C-3      2.544      3.750      2.781      2.853      4.381      0.010

REACH#   4
   10    130.00   R-4      2.405      2.076      1.313      3.890      2.459      0.021

   11    130.00   L-3      4.392      4.665      3.424      4.580      2.181      0.018

REACH#   5
   12    110.00   R-5      4.308      3.292      2.204      5.569      1.233      0.033

   13    110.00   C-4      4.308      3.292      2.204      5.569      1.233      0.033

REACH#   6
   14     90.00   R-6      4.253      2.388      1.388      6.076      3.464      0.061

   15     90.00   L-4      5.321      5.135      2.742      6.566      3.119      0.055

   16     70.00   C-5      5.244      3.653      1.683      7.118      7.454      0.103

   17     70.00   T-1      5.244      3.653      1.683      7.118      7.454      0.103



REACH#   2     HEADWATER  2

    5    220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

    6    220.00   L-2      2.498      4.164      4.596      1.499      8.502      0.006

    7    220.00   C-2      2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1   TREATMENT LEVEL  1


 PNT   DISTANCE    ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

   1    200.00    H-1       0.000      2.000      1.000      0.200      9.100      0.007

   2    200.00    L-1       2.856      5.999      4.427      1.457      7.800      0.006

   3    200.00    C-1       2.856      5.999      4.427      1.457      7.800      0.006

   4    170.00    B-1       2.627      4.106      2.758      2.740      3.200      0.009

REACH#  3
   8    170.00    J-1       2.544      3.750      2.781      2.853      4.381      0.010

   9    170.00    C-3       2.544      3.750      2.781      2.853      4.381      0.010

REACH#  4
  10    130.00    R-4       2.405      2.076      1.313      3.890      2.459      0.021

  11    130.00    L-3       4.392      4.665      3.424      4.580      2.181      0.018

REACH#  5
  12    110.00    R-5       4.308      3.292      2.204      5.569      1.233      0.033

  13    110.00    C-4       4.308      3.292      2.204      5.569      1.233      0.033

REACH#  6
  14     90.00    R-6       4.253      2.388      1.388      6.076      3.464      0.061

  15     90.00    L-4       5.321      5.135      2.742      6.566      3.119      0.055

  16     70.00    C-5       5.244      3.653      1.683      7.118      7.454      0.103

  17     70.00    T-1       5.244      3.653      1.683      7.118      7.454      0.103



REACH#  2    HEADWATER  2

   5    220.00    H-2       0.000      1.000      1.000      0.200     10.200      0.007

   6    220.00    L-2       2.498      4.164      4.596      1.499      8.502      0.006

   7    220.00    C-2       2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1   TREATMENT LEVEL  2


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1      2.142     5.285     1.571     1.457     7.815     0.006

   3    200.00   C-1      2.142     5.285     1.571     1.457     7.815     0.006

   4    170.00   B-1      1.969     3.630     0.990     1.879     6.475     0.009

REACH#  3
   8    170.00   J-1      2.054     3.395     1.463     2.211     6.822     0.009

   9    170.00   C-3      2.054     3.395     1.463     2.211     6.822     0.009

REACH#  4
  10    130.00   R-4      1.951     1.902     0.686     2.702     6.434     0.020

  11    130.00   L-3      3.989     4.510     2.867     3.526     5.707     0.018

REACH#  5
  12    110.00   R-5      3.912     3.187     1.838     4.353     5.023     0.032

  13    110.00   C-4      3.912     3.187     1.838     4.353     5.023     0.032

REACH#  6
  14     90.00   R-6      3.859     2.316     1.144     4.755     7.243     0.060

  15     90.00   L-4      4.968     5.070     2.523     5.376     6.523     0.054

  16     70.00   C-5      4.893     3.609     1.531     5.878    10.641     0.101

  17     70.00   T-1      4.893     3.609     1.531     5.878    10.641     0.101



REACH#  2    HEADWATER  2

   5    220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

POINT LOAD  1   TREATMENT LEVEL  3


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGF



REACH#  1    HEADWATER  1

    1    200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

    2    200.00   L-1      0.286     4.571     3.713     1.457     7.815     0.006

    3    200.00   C-1      0.286     4.571     3.713     1.457     7.815     0.006

    4    170.00   B-1      0.260     3.154     2.317     2.527     4.274     0.009

REACH#  3
    8    170.00   J-1      0.780     3.040     2.452     2.694     5.181     0.009

    9    170.00   C-3      0.780     3.040     2.452     2.694     5.181     0.009

REACH#  4
   10    130.00   R-4      0.771     1.728     1.159     3.600     3.713     0.020

   11    130.00   L-3      2.942     4.356     3.287     4.322     3.294     0.017

REACH#  5
   12    110.00   R-5      2.882     3.082     2.117     5.276     2.265     0.031

   13    110.00   C-4      2.882     3.082     2.117     5.276     2.266     0.031

REACH#  6
   14     90.00   R-6      2.837     2.244     1.335     5.768     4.278     0.058

   15     90.00   L-4      4.046     5.005     2.694     6.288     3.852     0.052

   16     70.00   C-5      3.978     3.564     1.657     6.846     7.732     0.097

   17     70.00   T-1      3.978     3.564     1.657     6.846     7.732     0.097



REACH#  2    HEADWATER  2

    5    220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

    6    220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

    7    220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1   TREATMENT LEVEL  4


 PN   DISTANCE   ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

   2    200.00   L-1      0.071      2.428      3.713      1.457      7.815      0.006

   3    200.00   C-1      0.071      2.428      3.713      1.457      7.815      0.006

   4    170.00   B-1      0.063      1.726      2.323      2.530      4.683      0.008

REACH#  3
   8    170.00   J-1      0.634      1.976      2.456      2.697      5.486      0.009

   9    170.00   C-3      0.634      1.976      2.456      2.697      5.486      0.009

REACH#  4
  10    130.00   R-4      0.636      1.205      1.164      3.609      4.130      0.018

  11    130.00   L-3      2.822      3.892      3.291      4.331      3.664      0.016

REACH#  5
  12    110.00   R-5      2.765      2.768      2.125      5.292      2.417      0.029

  13    110.00   C-4      2.765      2.768      2.125      5.292      2.417      0.029

REACH#  6
  14     90.00   R-6      2.723      2.028      1.346      5.801      4.107      0.054

  15     90.00   L-4      3.944      4.810      2.704      6.318      3.699      0.048

  16     70.00   C-5      3.880      3.431      1.675      6.903      6.989      0.090

  17     70.00   T-1      3.880      3.431      1.675      6.903      6.989      0.090



REACH#  2    HEADWATER  2

   5    220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

   6    220.00   L-2      2.498      4.164      4.596      1.499      8.502      0.006

   7    220.00   C-2      2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1   TREATMENT LEVEL  5


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1     HEADWATER  1

   1    200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1      1.428     2.428     3.713     1.457     7.815     0.006

   3    200.00   C-1      1.428     2.428     3.713     1.457     7.815     0.006

   4    170.00   B-1      1.312     1.726     2.315     2.526     4.752     0.009

REACH#  3
   8    170.00   J-1      1.564     1.976     2.451     2.693     5.538     0.009

   9    170.00   C-3      1.564     1.976     2.451     2.693     5.538     0.009

REACH#  4
  10    130.00   R-4      1.497     1.205     1.156     3.594     4.451     0.020

  11    130.00   L-3      3.586     3.892     3.284     4.318     3.949     0.018

REACH#  5
  12    110.00   R-5      3.515     2.768     2.113     5.267     3.132     0.033

  13    110.00   C-4      3.515     2.768     2.113     5.267     3.132     0.033

REACH#  6
  14     90.00   R-6      3.465     2.028     1.329     5.749     5.351     0.060

  15     90.00   L-4      4.612     4.810     2.688     6.272     4.819     0.054

  16     70.00   C-5      4.539     3.431     1.647     6.814     9.021     0.101

  17     70.00   T-1      4.539     3.431     1.647     6.814     9.021     0.101


REACH#  2     HEADWATER  2

   5    220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2      2.498     4.164     4.596     1.499     8.502     0.006

   7    220.00   C-2      2.498     4.164     4.596     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1   TREATMENT LEVEL  6


 PNT  DISTANCE   ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

    1   200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

    2   200.00   L-1      0.071      2.428      1.428      1.457      7.815      0.006

    3   200.00   C-1      0.071      2.428      1.428      1.457      7.815      0.006

    4   170.00   B-1      0.064      1.726      0.907      1.842      7.174      0.003

REACH#  3
    8   170.00   J-1      0.634      1.976      1.402      2.184      7.343      0.009

    9   170.00   C-3      0.634      1.976      1.402      2.184      7.343      0.009

REACH#  4
   10   130.00   R-4      0.636      1.205      0.662      2.659      7.146      0.018

   11   130.00   L-3      2.823      3.892      2.846      3.488      6.339      0.016

REACH#  5
   12   110.00   R-5      2.765      2.768      1.832      4.319      5.304      0.029

   13   110.00   C-4      2.765      2.768      1.832      4.319      5.304      0.029

REACH#  6
   14    90.00   R-6      2.723      2.028      1.151      4.742      7.002      0.053

   15    90.00   L-4      3.944      4.810      2.528      5.364      6.305      0.048

   16    70.00   C-5      3.881      3.431      1.553      5.907      9.461      0.089

   17    70.00   T-1      3.881      3.431      1.553      5.907      9.461      0.089



REACH#  2    HEADWATER  2

    5   220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

    6   220.00   L-2      2.498      4.164      4.996      1.499      8.502      0.006

    7   220.00   C-2      2.498      4.164      4.996      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  1    TREATMENT LEVEL   7


 PN    DISTANCE    ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1     HEADWATER  1

   1    200.00    H-1      0.000      2.000      1.000      0.200      9.100      0.007

   2    200.00    L-1      0.000      1.714      0.857      0.171      9.243      0.006

   3    200.00    C-1      0.000      1.714      0.857      0.171      9.243      0.006

   4    170.00    B-1      0.000      1.250      0.565      0.501      8.732      0.006

REACH#  3
   8    170.00    J-1      0.587      1.621      1.147      1.184      8.504      0.007

   9    170.00    C-3      0.587      1.621      1.147      1.184      8.504      0.007

REACH#  4
  10    130.00    R-4      0.595      1.031      0.542      1.640      7.977      0.014

  11    130.00    L-3      2.786      3.738      2.740      2.584      7.076      0.012

REACH#  5
  12    110.00    R-5      2.732      2.663      1.771      3.416      5.285      0.022

  13    110.00    C-4      2.732      2.663      1.771      3.416      5.285      0.022

REACH#  6
  14     90.00    R-6      2.697      1.956      1.122      3.872      6.007      0.040

  15     90.00    L-4      3.920      4.745      2.503      4.581      5.410      0.036

  16     70.00    C-5      3.867      3.386      1.561      5.195      6.871      0.068

  17     70.00    T-1      3.867      3.386      1.561      5.195      6.871      0.068



REACH#  2     HEADWATER  2

   5    220.00    H-2      0.000      1.000      1.000      0.200     10.200      0.007

   6    220.00    L-2      2.498      4.164      4.596      1.499      8.502      0.006

   7    220.00    C-2      2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  2   TREATMENT LEVEL  1


 PNT  DISTANCE   ID      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1     0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1     2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1     2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1     2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1     2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00   C-3     2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00   R-4     2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00   L-3     4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12    110.00   R-5     4.308     3.292     2.204     5.569     1.233     0.033

  13    110.00   C-4     4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14     90.00   R-6     4.253     2.388     1.388     6.076     3.464     0.061

  15     90.00   L-4     5.321     5.135     2.742     6.566     3.119     0.055

  16     70.00   C-5     5.244     3.653     1.683     7.118     7.454     0.103

  17     70.00   T-1     5.244     3.653     1.683     7.118     7.454     0.103



REACH#  2    HEADWATER  2

   5    220.00   H-2     0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2     2.498     4.164     4.596     1.499     8.502     0.006

   7    220.00   C-2     2.498     4.164     4.596     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  2   TREATMENT LEVEL  2


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1     0.000     2.000     1.000     0.200     9.100     0.007

   2   200.00   L-1     2.856     5.999     4.427     1.457     7.800     0.006

   3   200.00   C-1     2.856     5.999     4.427     1.457     7.800     0.006

   4   170.00   B-1     2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8   170.00   J-1     2.348     3.618     2.294     2.556     4.869     0.009

   9   170.00   C-3     2.348     3.618     2.294     2.556     4.869     0.009

REACH#  4
  10   130.00   R-4     2.224     2.011     1.081     3.397     3.639     0.021

  11   130.00   L-3     4.231     4.607     3.217     4.142     3.228     0.018

REACH#  5
  12   110.00   R-5     4.150     3.253     2.068     5.072     2.412     0.033

  13   110.00   C-4     4.150     3.253     2.068     5.072     2.412     0.033

REACH#  6
  14    90.00   R-6     4.095     2.362     1.298     5.541     4.667     0.061

  15    90.00   L-4     5.180     5.111     2.660     6.084     4.203     0.055

  16    70.00   C-5     5.103     3.637     1.626     6.618     8.479     0.102

  17    70.00   T-1     5.103     3.637     1.626     6.618     8.479     0.102



REACH#  2    HEADWATER  2

   5   220.00   H-2     0.000     1.000     1.000     0.200    10.200     0.007

   6   220.00   L-2     1.665     3.331     1.666     1.499     8.502     0.006

   7   220.00   C-2     1.665     3.331     1.666     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  2   TREATMENT LEVEL  3


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1       0.000     2.000     1.000     0.200     9.100     0.007

   2   200.00   L-1       2.856     5.999     4.427     1.457     7.800     0.006

   3   200.00   C-1       2.856     5.999     4.427     1.457     7.800     0.006

   4   170.00   B-1       2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8   170.00   J-1       2.035     3.486     2.659     2.780     4.541     0.009

   9   170.00   C-3       2.035     3.486     2.659     2.780     4.541     0.009

REACH#  4
  10   130.00   R-4       1.933     1.946     1.256     3.768     2.839     0.020

  11   130.00   L-3       3.974     4.550     3.373     4.472     2.518     0.018

REACH#  5
  12   110.00   R-5       3.896     3.214     2.171     5.447     1.575     0.032

  13   110.00   C-4       3.896     3.214     2.171     5.447     1.575     0.032

REACH#  6
  14    90.00   R-6       3.844     2.335     1.368     5.947     3.763     0.060

  15    90.00   L-4       4.953     5.086     2.723     6.450     3.389     0.054

  16    70.00   C-5       4.878     3.620     1.672     7.002     7.614     0.101

  17    70.00   T-1       4.878     3.620     1.672     7.002     7.614     0.101



REACH#  2    HEADWATER  2

   5   220.00   H-2       0.000     1.000     1.000     0.200    10.200     0.007

   6   220.00   L-2       0.333     2.499     4.164     1.499     8.502     0.006

   7   220.00   C-2       0.333     2.499     4.164     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

POINT LOAD  2   TREATMENT LEVEL  4


 PNT   DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1     200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2     200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3     200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4     170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8     170.00   J-1      1.969     3.354     2.662     2.781     4.549     0.009

   9     170.00   C-3      1.969     3.354     2.662     2.781     4.549     0.009

REACH#  4
  10     130.00   R-4      1.872     1.881     1.259     3.773     2.789     0.020

  11     130.00   L-3      3.919     4.492     3.375     4.476     2.474     0.017

REACH#  5
  12     110.00   R-5      3.843     3.175     2.175     5.456     1.391     0.031

  13     110.00   C-4      3.843     3.175     2.175     5.456     1.391     0.031

REACH#  6
  14      90.00   R-6      3.792     2.308     1.374     5.965     3.401     0.058

  15      90.00   L-4      4.907     5.062     2.729     6.466     3.063     0.052

  16      70.00   C-5      4.834     3.604     1.681     7.033     6.976     0.097

  17      70.00   T-1      4.834     3.604     1.681     7.033     6.976     0.097



REACH#  2    HEADWATER  2

   5     220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6     220.00   L-2      0.050     1.666     4.164     1.499     8.502     0.006

   7     220.00   C-2      0.050     1.666     4.164     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  2   TREATMENT LEVEL  5


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1     0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1     2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1     2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1     2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1     2.270     3.354     2.659     2.779     4.568     0.010

   9    170.00   C-3     2.270     3.354     2.659     2.779     4.568     0.010

REACH#  4
  10    130.00   R-4     2.151     1.881     1.255     3.767     2.931     0.021

  11    130.00   L-3     4.167     4.492     3.372     4.471     2.600     0.018

REACH#  5
  12    110.00   R-5     4.086     3.175     2.170     5.445     1.702     0.033

  13    110.00   C-4     4.086     3.175     2.170     5.445     1.702     0.033

REACH#  6
  14     90.00   R-6     4.032     2.308     1.366     5.943     3.939     0.061

  15     90.00   L-4     5.123     5.062     2.722     6.446     3.547     0.055

  16     70.00   C-5     5.046     3.604     1.669     6.994     7.851     0.102

  17     70.00   T-1     5.046     3.604     1.669     6.994     7.851     0.102



REACH#  2    HEADWATER  2

   5    220.00   H-2     0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2     1.332     1.666     4.164     1.499     8.502     0.006

   7    220.00   C-2     1.332     1.666     4.164     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  2   TREATMENT LEVEL  6


 PNT   DISTANCE    ID         PHOS        CBOD        NH3N        NO3N        DOXY        ALGF



REACH#  1     HEADWATER  1

    1    200.00    H-1       0.000       2.000       1.000       0.200       9.100       0.007

    2    200.00    L-1       2.856       5.999       4.427       1.457       7.800       0.006

    3    200.00    C-1       2.856       5.999       4.427       1.457       7.800       0.006

    4    170.00    B-1       2.627       4.106       2.758       2.740       3.200       0.009

REACH#  3
    8    170.00    J-1       1.969       3.354       2.272       2.544       4.921       0.009

    9    170.00    C-3       1.969       3.354       2.272       2.544       4.921       0.009

REACH#  4
   10    130.00    R-4       1.872       1.881       1.072       3.379       3.685       0.020

   11    130.00    L-3       3.920       4.492       3.210       4.127       3.269       0.017

REACH#  5
   12    110.00    R-5       3.844       3.175       2.066       5.058       2.292       0.031

   13    110.00    C-4       3.844       3.175       2.066       5.058       2.292       0.031

REACH#  6
   14     90.00    R-6       3.793       2.308       1.301       5.536       4.328       0.058

   15     90.00    L-4       4.907       5.062       2.663       6.079       3.898       0.052

   16     70.00    C-5       4.835       3.604       1.635       6.631       7.781       0.097

   17     70.00    T-1       4.835       3.604       1.635       6.631       7.781       0.097



REACH#  2     HEADWATER  2

    5    220.00    H-2       0.000       1.000       1.000       0.200      10.200       0.007

    6    220.00    L-2       0.050       1.666       1.500       1.499       8.502       0.006

    7    220.00    C-2       0.050       1.666       1.500       1.499       8.502       0.006
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

POINT LOAD  2   TREATMENT LEVEL  7


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2   200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3   200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4   170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8   170.00   J-1      1.958     3.222     2.177     2.175     5.052     0.008

   9   170.00   C-3      1.958     3.222     2.177     2.175     5.052     0.008

REACH#  4
  10   130.00   R-4      1.863     1.817     1.028     3.002     3.805     0.018

  11   130.00   L-3      3.911     4.435     3.170     3.792     3.375     0.016

REACH#  5
  12   110.00   R-5      3.836     3.136     2.043     4.724     2.172     0.029

  13   110.00   C-4      3.836     3.136     2.043     4.724     2.172     0.029

REACH#  6
  14    90.00   R-6      3.787     2.281     1.289     5.212     3.899     0.054

  15    90.00   L-4      4.903     5.038     2.653     5.788     3.512     0.048

  16    70.00   C-5      4.833     3.587     1.635     6.363     6.840     0.090

  17    70.00   T-1      4.833     3.587     1.635     6.363     6.840     0.090



REACH#  2    HEADWATER  2

   5   220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6   220.00   L-2      0.000     0.834     0.834     0.167    10.283     0.006

   7   220.00   C-2      0.000     0.834     0.834     0.167    10.283     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  1


 PNT   DISTANCE   ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1       0.000      2.000      1.000      0.200      9.100      0.007

   2    200.00   L-1       2.856      5.999      4.427      1.457      7.800      0.006

   3    200.00   C-1       2.856      5.999      4.427      1.457      7.800      0.006

   4    170.00   B-1       2.627      4.106      2.758      2.740      3.200      0.009

REACH#  3
   8    170.00   J-1       2.544      3.750      2.781      2.853      4.381      0.010

   9    170.00   C-3       2.544      3.750      2.781      2.853      4.381      0.010

REACH#  4
  10    130.00   R-4       2.405      2.076      1.313      3.890      2.459      0.021

  11    130.00   L-3       4.392      4.665      3.424      4.580      2.181      0.018

REACH#  5
  12    110.00   R-5       4.308      3.292      2.204      5.569      1.233      0.033

  13    110.00   C-4       4.308      3.292      2.204      5.569      1.233      0.033

REACH#  6
  14     90.00   R-6       4.253      2.388      1.388      6.076      3.464      0.061

  15     90.00   L-4       5.321      5.135      2.742      6.566      3.119      0.055

  16     70.00   C-5       5.244      3.653      1.683      7.118      7.454      0.103

  17     70.00   T-1       5.244      3.653      1.683      7.118      7.454      0.103



REACH#  2    HEADWATER  2

   5    220.00   H-2       0.000      1.000      1.000      0.200     10.200      0.007

   6    220.00   L-2       2.498      4.164      4.596      1.499      8.502      0.006

   7    220.00   C-2       2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  2


 PNT  DISTANCE    ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

    1    200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

    2    200.00   L-1      2.856      5.999      4.427      1.457      7.800      0.006

    3    200.00   C-1      2.856      5.999      4.427      1.457      7.800      0.006

    4    170.00   B-1      2.627      4.106      2.758      2.740      3.200      0.009

REACH#  3
    8    170.00   J-1      2.544      3.750      2.781      2.853      4.381      0.010

    9    170.00   C-3      2.544      3.750      2.781      2.853      4.381      0.010

REACH#  4
   10    130.00   R-4      2.405      2.076      1.313      3.890      2.459      0.021

   11    130.00   L-3      3.828      4.100      1.504      4.580      2.204      0.018

REACH#  5
   12    110.00   R-5      3.752      2.909      0.967      4.918      3.942      0.033

   13    110.00   C-4      3.752      2.909      0.967      4.918      3.942      0.033

REACH#  6
   14     90.00   R-6      3.701      2.125      0.601      4.990      7.580      0.061

   15     90.00   L-4      4.825      4.898      2.033      5.587      6.826      0.055

   16     70.00   C-5      4.750      3.491      1.227      5.901     11.712      0.102

   17     70.00   T-1      4.750      3.491      1.227      5.901     11.712      0.102



REACH#  2    HEADWATER  2

    5    220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

    6    220.00   L-2      2.498      4.164      4.596      1.499      8.502      0.006

    7    220.00   C-2      2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  3


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2   200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3   200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4   170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8   170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

   9   170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10   130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

  11   130.00   L-3      2.360     3.535     2.294     4.580     2.204     0.018

REACH#  5
  12   110.00   R-5      2.308     2.525     1.475     5.188     3.059     0.033

  13   110.00   C-4      2.308     2.525     1.475     5.188     3.059     0.033

REACH#  6
  14    90.00   R-6      2.265     1.862     0.922     5.443     6.231     0.061

  15    90.00   L-4      3.532     4.661     2.322     5.996     5.611     0.055

  16    70.00   C-5      3.464     3.328     1.413     6.410    10.287     0.102

  17    70.00   T-1      3.464     3.328     1.413     6.410    10.287     0.102



REACH#  2    HEADWATER  2

   5   220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6   220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7   220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

POINT LOAD  3   TREATMENT LEVEL  4


 PNT  DISTANCE    ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1       0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1       2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1       2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1       2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1       2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00   C-3       2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00   R-4       2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00   L-3       2.190     2.406     2.294     4.580     2.204     0.018

REACH#  5
  12    110.00   R-5       2.141     1.758     1.475     5.188     3.380     0.033

  13    110.00   C-4       2.141     1.758     1.475     5.188     3.380     0.033

REACH#  6
  14     90.00   R-6       2.099     1.335     0.922     5.444     6.733     0.061

  15     90.00   L-4       3.382     4.186     2.322     5.996     6.063     0.055

  16     70.00   C-5       3.316     3.003     1.414     6.411    10.818     0.102

  17     70.00   T-1       3.316     3.003     1.414     6.411    10.818     0.102



REACH#  2    HEADWATER  2

   5    220.00   H-2       0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2       2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00   C-2       2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  5


 PNT  DISTANCE   ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

   2   200.00   L-1      2.856      5.999      4.427      1.457      7.800      0.006

   3   200.00   C-1      2.856      5.999      4.427      1.457      7.800      0.006

   4   170.00   B-1      2.627      4.106      2.758      2.740      3.200      0.009

REACH#  3
   8   170.00   J-1      2.544      3.750      2.781      2.853      4.381      0.010

   9   170.00   C-3      2.544      3.750      2.781      2.853      4.381      0.010

REACH#  4
  10   130.00   R-4      2.405      2.076      1.313      3.890      2.459      0.021

  11   130.00   L-3      3.263      2.406      2.294      4.580      2.204      0.018

REACH#  5
  12   110.00   R-5      3.197      1.758      1.474      5.188      3.386      0.033

  13   110.00   C-4      3.197      1.758      1.474      5.188      3.386      0.033

REACH#  6
  14    90.00   R-6      3.148      1.335      0.922      5.442      6.757      0.061

  15    90.00   L-4      4.327      4.186      2.322      5.994      6.085      0.055

  16    70.00   C-5      4.255      3.003      1.412      6.406     10.885      0.102

  17    70.00   T-1      4.255      3.003      1.412      6.406     10.885      0.102



REACH#  2    HEADWATER  2

   5   220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

   6   220.00   L-2      2.498      4.164      4.996      1.499      8.502      0.006

   7   220.00   C-2      2.498      4.164      4.996      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  6


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

    1   200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

    2   200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

    3   200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

    4   170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
    8   170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

    9   170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
   10   130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

   11   130.00   L-3      2.190     2.406     1.391     4.580     2.204     0.018

REACH#  5
   12   110.00   R-5      2.141     1.758     0.895     4.880     4.568     0.033

   13   110.00   C-4      2.141     1.758     0.895     4.880     4.568     0.033

REACH#  6
   14    90.00   R-6      2.100     1.335     0.557     4.927     8.533     0.060

   15    90.00   L-4      3.383     4.186     1.993     5.531     7.684     0.054

   16    70.00   C-5      3.317     3.003     1.202     5.835    12.672     0.101

   17    70.00   T-1      3.317     3.003     1.202     5.835    12.672     0.101



REACH#  2    HEADWATER  2

    5   220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

    6   220.00   L-2      2.498     4.164     4.596     1.499     8.502     0.006

    7   220.00   C-2      2.498     4.164     4.596     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  3   TREATMENT LEVEL  7


 PNT  DISTANCE   ID        PHOS       CBOD       NH3N       NO3N       DOXY       ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1      0.000      2.000      1.000      0.200      9.100      0.007

   2    200.00   L-1      2.856      5.999      4.427      1.457      7.800      0.006

   3    200.00   C-1      2.856      5.999      4.427      1.457      7.800      0.006

   4    170.00   B-1      2.627      4.106      2.758      2.740      3.200      0.009

REACH#  3
   8    170.00   J-1      2.544      3.750      2.781      2.853      4.381      0.010

   9    170.00   C-3      2.544      3.750      2.781      2.853      4.381      0.010

REACH#  4
  10    130.00   R-4      2.405      2.076      1.313      3.890      2.459      0.021

  11    130.00   L-3      2.134      1.841      1.165      3.450      3.333      0.018

REACH#  5
  12    110.00   R-5      2.085      1.374      0.744      3.697      6.009      0.033

  13    110.00   C-4      2.085      1.374      0.744      3.697      6.009      0.033

REACH#  6
  14     90.00   R-6      2.045      1.072      0.454      3.708     10.102      0.060

  15     90.00   L-4      3.333      3.949      1.901      4.434      9.097      0.054

  16     70.00   C-5      3.268      2.840      1.128      4.729     14.084      0.100

  17     70.00   T-1      3.268      2.840      1.128      4.729     14.084      0.100



REACH#  2    HEADWATER  2

   5    220.00   H-2      0.000      1.000      1.000      0.200     10.200      0.007

   6    220.00   L-2      2.498      4.164      4.596      1.499      8.502      0.006

   7    220.00   C-2      2.498      4.164      4.596      1.499      8.502      0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  1


 PNT  DISTANCE    ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00    H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00    L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00    C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00    B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00    J-1      2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00    C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00    R-4      2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00    L-3      4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12    110.00    R-5      4.308     3.292     2.204     5.569     1.233     0.033

  13    110.00    C-4      4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14     90.00    R-6      4.253     2.388     1.388     6.076     3.464     0.061

  15     90.00    L-4      5.321     5.135     2.742     6.566     3.119     0.055

  16     70.00    C-5      5.244     3.653     1.683     7.118     7.454     0.103

  17     70.00    T-1      5.244     3.653     1.683     7.118     7.454     0.103



REACH#  2    HEADWATER  2

   5    220.00    H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00    L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00    C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  2


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1     HEADWATER  1

   1    200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00   L-3      4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12    110.00   R-5      4.308     3.292     2.204     5.569     1.233     0.033

  13    110.00   C-4      4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14     90.00   R-6      4.253     2.388     1.388     6.076     3.464     0.061

  15     90.00   L-4      4.824     4.637     1.549     6.566     3.129     0.055

  16     70.00   C-5      4.749     3.312     0.939     6.677     9.177     0.103

  17     70.00   T-1      4.749     3.312     0.939     6.677     9.177     0.103



REACH#  2     HEADWATER  2

   5    220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  3


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

    1   200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

    2   200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

    3   200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

    4   170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
    8   170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

    9   170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
   10   130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

   11   130.00   L-3      4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
   12   110.00   R-5      4.308     3.292     2.204     5.569     1.233     0.033

   13   110.00   C-4      4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
   14    90.00   R-6      4.253     2.388     1.388     6.076     3.464     0.061

   15    90.00   L-4      4.028     3.145     2.245     6.566     3.129     0.055

   16    70.00   C-5      3.958     2.288     1.371     6.937     8.694     0.103

   17    70.00   T-1      3.958     2.288     1.371     6.937     8.694     0.103



REACH#  2    HEADWATER  2

    5   220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

    6   220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

    7   220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  4


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1     0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1     2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1     2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1     2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1     2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00   C-3     2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00   R-4     2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00   L-3     4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12    110.00   R-5     4.308     3.292     2.204     5.569     1.233     0.033

  13    110.00   C-4     4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14     90.00   R-6     4.253     2.388     1.388     6.076     3.464     0.061

  15     90.00   L-4     3.859     2.648     2.245     6.566     3.129     0.055

  16     70.00   C-5     3.790     1.947     1.371     6.937     8.838     0.103

  17     70.00   T-1     3.790     1.947     1.371     6.937     8.838     0.103


REACH#  2    HEADWATER  2

   5    220.00   H-2     0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2     2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00   C-2     2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  5


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1    200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2    200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3    200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4    170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8    170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

   9    170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10    130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

  11    130.00   L-3      4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12    110.00   R-5      4.308     3.292     2.204     5.569     1.233     0.033

  13    110.00   C-4      4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14     90.00   R-6      4.253     2.388     1.388     6.076     3.464     0.061

  15     90.00   L-4      4.824     2.648     2.245     6.566     3.129     0.055

  16     70.00   C-5      4.749     1.947     1.371     6.936     8.842     0.103

  17     70.00   T-1      4.749     1.947     1.371     6.936     8.842     0.103



REACH#  2    HEADWATER  2

   5    220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6    220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7    220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROPLEM

POINT LOAD  4   TREATMENT LEVEL  6


 PNT  DISTANCE   ID       PHOS      CBOD      NH3N      NO3N      DOXY      ALGP



REACH#  1    HEADWATER  1

   1   200.00   H-1      0.000     2.000     1.000     0.200     9.100     0.007

   2   200.00   L-1      2.856     5.999     4.427     1.457     7.800     0.006

   3   200.00   C-1      2.856     5.999     4.427     1.457     7.800     0.006

   4   170.00   B-1      2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
   8   170.00   J-1      2.544     3.750     2.781     2.853     4.381     0.010

   9   170.00   C-3      2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
  10   130.00   R-4      2.405     2.076     1.313     3.890     2.459     0.021

  11   130.00   L-3      4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
  12   110.00   R-5      4.308     3.292     2.204     5.569     1.233     0.033

  13   110.00   C-4      4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
  14    90.00   R-6      4.253     2.388     1.388     6.076     3.464     0.061

  15    90.00   L-4      3.859     2.648     1.449     6.566     3.129     0.055

  16    70.00   C-5      3.790     1.947     0.878     6.640     9.882     0.103

  17    70.00   T-1      3.790     1.947     0.878     6.640     9.882     0.103



REACH#  2    HEADWATER  2

   5   220.00   H-2      0.000     1.000     1.000     0.200    10.200     0.007

   6   220.00   L-2      2.498     4.164     4.996     1.499     8.502     0.006

   7   220.00   C-2      2.498     4.164     4.996     1.499     8.502     0.006
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WASTE LOAD ALLOCATION
SAMPLE PROBLEM

POINT LOAD  4   TREATMENT LEVEL  7


 PNT  DISTANCE   ID        PHOS      CBOD      NH3N      NO3N      DOXY      ALGF



REACH#  1    HEADWATER  1

    1    200.00   H-1     0.000     2.000     1.000     0.200     9.100     0.007

    2    200.00   L-1     2.856     5.999     4.427     1.457     7.800     0.006

    3    200.00   C-1     2.856     5.999     4.427     1.457     7.800     0.006

    4    170.00   B-1     2.627     4.106     2.758     2.740     3.200     0.009

REACH#  3
    8    170.00   J-1     2.544     3.750     2.781     2.853     4.381     0.010

    9    170.00   C-3     2.544     3.750     2.781     2.853     4.381     0.010

REACH#  4
   10    130.00   R-4     2.405     2.076     1.313     3.890     2.459     0.021

   11    130.00   L-3     4.392     4.665     3.424     4.580     2.181     0.018

REACH#  5
   12    110.00   R-5     4.308     3.292     2.204     5.569     1.233     0.033

   13    110.00   C-4     4.308     3.292     2.204     5.569     1.233     0.033

REACH#  6
   14     90.00   R-6     4.253     2.388     1.388     6.076     3.464     0.061

   15     90.00   L-4     3.830     2.151     1.250     5.472     4.124     0.055

   16     70.00   C-5     3.760     1.606     0.744     5.489    11.178     0.102

   17     70.00   T-1     3.760     1.606     0.744     5.489    11.178     0.102



REACH#  2    HEADWATER  2

    5    220.00   H-2     0.000     1.000     1.000     0.200    10.200     0.007

    6    220.00   L-2     2.498     4.164     4.596     1.499     8.502     0.006

    7    220.00   C-2     2.498     4.164     4.596     1.499     8.502     0.006
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CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  1

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.  1   0.000     0.000     0.000     0.000     0.000     0.000

PT.  2   0.000     0.000     0.000     0.000     0.000     0.000

PT.  3   0.000     0.000     0.000     0.000     0.000     0.000

PT.  4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  2

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.  1   0.714     0.714     2.856     0.000    -0.014     0.000

PT.  2   0.000     0.000     0.000     0.000     0.000     0.000

PT.  3   0.000     0.000     0.000     0.000     0.000     0.000

PT.  4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  3

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.  1   2.571     1.428     0.714     0.000    -0.014     0.000

PT.  2   0.000     0.000     0.000     0.000     0.000     0.000

PT.  3   0.000     0.000     0.000     0.000     0.000     0.000

PT.  4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  4

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.  1   2.785     3.570     0.714     0.000    -0.014     0.000

PT.  2   0.000     0.000     0.000     0.000     0.000     0.000

PT.  3   0.000     0.000     0.000     0.000     0.000     0.000

PT.  4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  5

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
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PT.   1   1.428     3.570     0.714     0.000     -0.014     0.000
PT.   2   0.000     0.000     0.000     0.000      0.000     0.000
PT.   3   0.000     0.000     0.000     0.000      0.000     0.000
PT.   4   0.000     0.000     0.000     0.000      0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  6
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1   2.785     3.570     2.959     0.000     -0.014     0.000
PT.   2   0.000     0.000     0.000     0.000      0.000     0.000
PT.   3   0.000     0.000     0.000     0.000      0.000     0.000
PT.   4   0.000     0.000     0.000     0.000      0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  1 TREATMENT LEVEL  7
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1   2.856     4.284     3.570     1.285     -1.442     0.000
PT.   2   0.000     0.000     0.000     0.000      0.000     0.000
PT.   3   0.000     0.000     0.000     0.000      0.000     0.000
PT.   4   0.000     0.000     0.000     0.000      0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  1
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1   0.000     0.000     0.000     0.000      0.000     0.000
PT.   2   0.000     0.000     0.000     0.000      0.000     0.000
PT.   3   0.000     0.000     0.000     0.000      0.000     0.000
PT.   4   0.000     0.000     0.000     0.000      0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  2
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1   0.000     0.000     0.000     0.000      0.000     0.000
PT.   2   0.833     0.833     3.330     0.000      0.000     0.000
PT.   3   0.000     0.000     0.000     0.000      0.000     0.000
PT.   4   0.000     0.000     0.000     0.000      0.000     0.000
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CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  3
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.000     0.000     0.000     0.000     0.000     0.000
PT.   2    2.165     1.665     0.833     0.000     0.000     0.000
PT.   3    0.000     0.000     0.000     0.000     0.000     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  4
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.000     0.000     0.000     0.000     0.000     0.000
PT.   2    2.448     2.498     0.833     0.000     0.000     0.000
PT.   3    0.000     0.000     0.000     0.000     0.000     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  5
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.000     0.000     0.000     0.000     0.000     0.000
PT.   2    1.166     2.498     0.833     0.000     0.000     0.000
PT.   3    0.000     0.000     0.000     0.000     0.000     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  6
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.000     0.000     0.000     0.000     0.000     0.000
PT.   2    2.448     2.498     3.457     0.000     0.000     0.000
PT.   3    0.000     0.000     0.000     0.000     0.000     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  2 TREATMENT LEVEL  7
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.000     0.000     0.000     0.000     0.000     0.000
PT.   2    2.498     3.330     4.163     1.332    -1.782     0.000
PT.   3    0.000     0.000     0.000     0.000     0.000     0.000
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PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  1

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.000     0.000     0.000     0.000     0.000     0.000

PT.   2   0.000     0.000     0.000     0.000     0.000     0.000

PT.   3   0.000     0.000     0.000     0.000     0.000     0.000

PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  2

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.490     0.355     1.318     0.642    -2.441     0.000

PT.   2   0.196     0.132     0.486     0.297    -0.487     0.000

PT.   3   0.000     0.000     0.000     0.000     0.000     0.000

PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  3

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   1.764     0.710     0.328     0.159    -0.800     0.000

PT.   2   0.509     0.264     0.121     0.074    -0.160     0.000

PT.   3   0.000     0.000     0.000     0.000     0.000     0.000

PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  4

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   1.910     1.774     0.324     0.156    -1.105     0.001

PT.   2   0.576     0.396     0.119     0.072    -0.168     0.000

PT.   3   0.000     0.000     0.000     0.000     0.000     0.000

PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  5

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.980     1.774     0.330     0.160    -1.156     0.000
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PT.   2  0.274     0.396     0.122     0.074    -0.186     0.000

PT.   3  0.000     0.000     0.000     0.000     0.000     0.000

PT.   4  0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  6

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1  1.910     1.774     1.379     0.670    -2.962     0.001

PT.   2  0.576     0.396     0.509     0.310    -0.539     0.000

PT.   3  0.000     0.000     0.000     0.000     0.000     0.000

PT.   4  0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  3 TREATMENT LEVEL  7

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1  1.957     2.129     1.634     1.669    -4.122     0.003

PT.   2  0.587     0.528     0.603     0.679    -0.670     0.001

PT.   3  0.000     0.000     0.000     0.000     0.000     0.000

PT.   4  0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  1

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1  0.000     0.000     0.000     0.000     0.000     0.000

PT.   2  0.000     0.000     0.000     0.000     0.000     0.000

PT.   3  0.000     0.000     0.000     0.000     0.000     0.000

PT.   4  0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  2

  LOAD     PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1  0.396     0.105     0.366     1.215    -3.790     0.001

PT.   2  0.158     0.039     0.136     0.496    -1.179     0.000

PT.   3  0.556     0.384     1.237     0.651    -2.709     0.000

PT.   4  0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  3
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  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    1.426     0.210     0.087     0.293    -1.033     0.002
PT.   2    0.412     0.078     0.033     0.122    -0.342     0.000
PT.   3    2.000     0.767     0.730     0.380    -1.826     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  4
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    1.543     0.525     0.079     0.277    -1.184     0.004
PT.   2    0.465     0.117     0.029     0.113    -0.158     0.002
PT.   3    2.167     1.534     0.730     0.380    -2.147     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  5
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    0.793     0.525     0.051     0.302    -1.899     0.000
PT.   2    0.222     0.117     0.034     0.124    -0.469     0.000
PT.   3    1.111     1.534     0.730     0.381    -2.153     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  6
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    1.543     0.525     0.373     1.250    -4.071     0.004
PT.   2    0.464     0.117     0.138     0.510    -1.059     0.002
PT.   3    2.167     1.534     1.309     0.689    -3.335     0.000
PT.   4    0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  4 TREATMENT LEVEL  7
  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP
PT.   1    1.576     0.630     0.433     2.152    -4.052     0.011
PT.   2    0.472     0.156     0.161     0.845    -0.939     0.004
PT.   3    2.223     1.918     1.460     1.871    -4.777     0.000
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PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  1

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.000     0.000     0.000     0.000     0.000     0.000

PT.   2   0.000     0.000     0.000     0.000     0.000     0.000

PT.   3   0.000     0.000     0.000     0.000     0.000     0.000

PT.   4   0.000     0.000     0.000     0.000     0.000     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  2

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.351     0.045     0.152     1.239    -3.187     0.002

PT.   2   0.140     0.017     0.057     0.500    -1.025     0.001

PT.   3   0.494     0.163     0.456     1.216    -4.258     0.001

PT.   4   0.494     0.341     0.744     0.441    -1.723     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  3

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   1.265     0.089     0.026     0.272    -0.278     0.006

PT.   2   0.366     0.033     0.011     0.116    -0.160     0.001

PT.   3   1.779     0.325     0.270     0.708    -2.833     0.001

PT.   4   1.286     1.365     0.312     0.181    -1.240     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  4

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   1.364     0.223     0.008     0.215     0.465     0.013

PT.   2   0.410     0.050     0.002     0.085     0.478     0.005

PT.   3   1.927     0.651     0.269     0.707    -3.364     0.001

PT.   4   1.454     1.707     0.312     0.181    -1.383     0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  5

  LOAD      PHOS      CBOD      NH3N      NO3N      DOXY      ALGP

PT.   1   0.705     0.223     0.036     0.303    -1.566     0.001
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PT.   2   0.197    0.050    0.014    0.123   -0.397    0.000

PT.   3   0.988    0.651    0.271    0.711   -3.431    0.001

PT.   4   0.494    1.707    0.312    0.181   -1.388    0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  6

  LOAD     PHOS     CBOD     NH3N     NO3N     DOXY      ALGP

PT.   1   1.363    0.223    0.130    1.211   -2.007    0.014

PT.   2   0.409    0.050    0.048    0.487   -0.326    0.006

PT.   3   1.927    0.651    0.481    1.283   -5.218    0.002

PT.   4   1.454    1.707    0.805    0.478   -2.427    0.000

CHANGE IN CONSTITUENTS FROM LOADS AT SURVEILLANCE POINT  5 TREATMENT LEVEL  7

  LOAD     PHOS     CBOD     NH3N     NO3N     DOXY      ALGP

PT.   1   1.377    0.267    0.122    1.923    0.583    0.035

PT.   2   0.410    0.066    0.048    0.755    0.614    0.013

PT.   3   1.976    0.813    0.555    2.388   -6.629    0.002

PT.   4   1.483    2.048    0.939    1.629   -3.724    0.000


ENDRUN     PLOTS FOLLOW FOR  C SEGMENTS     IOPLT = 0
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SAMPLE OUTPUT FROM HELPSU

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NL =  4   NTL =  7   NK =  5   NC =  3   NR1 = 20   NR2 = 21   NR3 = 22   NW1 = 23   NW2 =  6


     D MATRIX

   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.714     0.714     2.856     0.000    -0.014     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.571     1.428     0.714     0.000    -0.014     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.785     3.570     0.714     0.000    -0.014     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   1.428     3.570     0.714     0.000    -0.014     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.785     3.570     2.999     0.000    -0.014     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.856     4.284     3.570     1.285    -1.442     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.833     0.833     3.330     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.165     1.665     0.833     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.448     2.498     0.833     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   1.166     2.498     0.833     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
   2.448     2.498     3.497     0.000     0.000     0.000
   0.000     0.000     0.000     0.000     0.000     0.000
```

```
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
2.498     3.330     4.163     1.332     -1.782     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.490     0.355     1.318     0.642     -2.441     0.000
0.196     0.132     0.486     0.297     -0.487     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.764     0.710     0.328     0.159     -0.800     0.000
0.509     0.264     0.121     0.074     -0.160     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.910     1.774     0.324     0.156     -1.105     0.001
0.576     0.396     0.119     0.072     -0.168     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.980     1.774     0.330     0.160     -1.156     0.000
0.274     0.396     0.122     0.074     -0.186     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.910     1.774     1.379     0.670     -2.962     0.001
0.576     0.396     0.509     0.310     -0.539     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.957     2.129     1.634     1.669     -4.122     0.003
0.587     0.528     0.603     0.679     -0.670     0.001
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.396     0.105     0.366     1.215     -3.790     0.001
0.158     0.039     0.136     0.496     -1.179     0.000
0.556     0.384     1.237     0.651     -2.709     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.426     0.210     0.087     0.293     -1.033     0.002
0.412     0.078     0.033     0.122     -0.342     0.000
2.000     0.767     0.730     0.380     -1.826     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.543     0.525     0.079     0.277     -1.184     0.004
0.465     0.117     0.029     0.113     -0.158     0.002
2.167     1.534     0.730     0.380     -2.147     0.000
0.000     0.000     0.000     0.000      0.000     0.000
0.793     0.525     0.091     0.302     -1.899     0.000
0.222     0.117     0.034     0.124     -0.469     0.000
1.111     1.534     0.730     0.381     -2.153     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.543     0.525     0.373     1.250     -4.071     0.004
0.464     0.117     0.138     0.510     -1.059     0.002
2.167     1.534     1.309     0.689     -3.335     0.000
0.000     0.000     0.000     0.000      0.000     0.000
1.576     0.630     0.433     2.152     -4.052     0.011
0.472     0.156     0.161     0.845     -0.939     0.004
2.223     1.918     1.460     1.871     -4.777     0.000
0.000     0.000     0.000     0.000      0.000     0.000
```

```
0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000
0.000     0.000     0.000     0.000     0.000     0.000
0.351     0.045     0.152     1.239    -3.187     0.002
0.140     0.017     0.057     0.500    -1.025     0.001
0.494     0.163     0.456     1.216    -4.258     0.001
0.494     0.341     0.744     0.441    -1.723     0.000
1.265     0.089     0.026     0.272    -0.278     0.006
0.366     0.033     0.011     0.116    -0.160     0.001
1.779     0.325     0.270     0.708    -2.833     0.001
1.286     1.365     0.312     0.181    -1.240     0.000
1.364     0.223     0.008     0.215     0.465     0.013
0.410     0.050     0.002     0.085     0.478     0.005
1.927     0.651     0.269     0.707    -3.364     0.001
1.454     1.707     0.312     0.181    -1.383     0.000
0.705     0.223     0.036     0.303    -1.566     0.001
0.197     0.050     0.014     0.123    -0.397     0.000
0.988     0.651     0.271     0.711    -3.431     0.001
0.494     1.707     0.312     0.181    -1.388     0.000
1.363     0.223     0.130     1.211    -2.007     0.014
0.409     0.050     0.048     0.487    -0.326     0.006
1.927     0.651     0.481     1.283    -5.218     0.002
1.454     1.707     0.805     0.478    -2.427     0.000
1.377     0.267     0.122     1.923     0.583     0.035
0.410     0.066     0.048     0.755     0.614     0.013
1.976     0.813     0.555     2.388    -6.629     0.002
1.483     2.048     0.939     1.629    -3.724     0.000


   INIT. CONC.

   2.856      5.999      4.427      1.457      7.800      0.006
   2.498      4.164      4.996      1.499      8.502      0.006
   2.544      3.750      2.781      2.853      4.381      0.010
   4.308      3.292      2.204      5.569      1.233      0.033
   5.244      3.653      1.683      7.118      7.454      0.103


   COST
  0.    550996.  1018425.  1265766.   507181.  1816762.  3767873.
  0.    244825.   417389.   559103.   281669.   773928.  1884058.
  0.    742321.  1417170.  1748365.   629459.  2490687.  4790604.
  0.    742321.  1417170.  1748365.   629459.  2490687.  4790604.


   IDCON AND IOP

2    0    3    0    5    1


   B MATRIX

  5.0       99.0       6.5
  5.0       99.0       6.5
  5.0        1.0       6.5
  5.0        1.0       6.5
  5.0        1.0       6.5
```

SAMPLE OUTPUT FROM MXINT

```
*************************************************************************************************************************************

                                              B 6 7 0 0 / 7 7 0 0   T E M P O

                                                  VERSION : 27.500.000

                                                  RELEASED: MARCH 76

                                                  DATE    : 08/11/77

                                                  TIME    : 11:38:41

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

          ZNAME="S.P.3"                                                             0000
          ZDATA="WLA"                                                               0001
          INPUT                                                                     0002
          BCDOUT                                                                    0003
          SETUP(MIN)                                                                0004
          ZOBJ="COST"                                                               0005
          ZRHS="ZRHS"                                                               0006
          PRIMAL                                                                    0007
          ZTOLIN=.0001                                                              0008
          MXINT(SUMMARY)                                                            0009
          OUTPUT                                                                    0010
          PICTURE                                                                   0011
          EXIT                                                                      0012
```

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B6700/7700 TEMPO
VERSION: 27.500.000


INPUT     TIME--PROCESSOR =     0.02    ELAPSED =     0.02


ZNAME = S.P.3

1-ROW SECTION.

2-COLUMNS SECTION.

3-RHS SECTION.
    ZRHS
OLD ENTRY S.P.3    DELETED ON ZPROF (OR ZSOLF)
NEW ENTRY S.P.3    ENTERED ON ZPROF (OR ZSOLF)

PROBLEM STATISTICS:     20 ROWS,           48 VARIABLES.
                 265 ELEMENTS, DENSITY =     27.60417 PERCENT.
THESE STATISTICS INCLUDE ONE SLACK VARIABLE FOR EACH ROW.

NUMBER OF INTEGER VARIABLES =           28

           0 MINOR ERRORS,            0 MAJOR ERRORS.


BCDOUT    TIME--PROCESSOR =     0.06    ELAPSED =     0.20

NAME          WLA
ROWS
 N  COST
 G  RK01C01
 G  RK02C01
 G  RK03C01
 G  RK04C01
 G  RK05C01
 G  RK01C02
 G  RK02C02
 G  RK03C02
 G  RK04C02
 G  RK05C02
 L  RK01C03
 L  RK02C03
 L  RK03C03
 L  RK04C03
 L  RK05C03
 E  ROWL01
 E  ROWL02
 E  ROWL03
 E  ROWL04
COLUMNS
    BEGINT    'MARKER'                 'BIVORG'
    T0101     ROWL01           1.00000
    T0201     COST         5.50996E 05   RK01C01        0.71400
    T0201     RK03C01          0.35500   RK04C01        0.10500
```

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B6700/7700 TEMPO                                                S.P.3
VERSION: 27.500.000

    T0201      RK05C01        0.04500    RK01C02          2.85600
    T0201      RK03C02        1.31800    RK04C02          0.36600
    T0201      RK05C02        0.15200    RK01C03         -0.01400
    T0201      RK03C03       -2.44100    RK04C03         -3.79000
    T0201      RK05C03       -3.18700    ROWL01           1.00000
    T0301      COST       1.01842E 06    RK01C01          1.42800
    T0301      RK03C01        0.71000    RK04C01          0.21000
    T0301      RK05C01        0.08900    RK01C02          0.71400
    T0301      RK03C02        0.32800    RK04C02          0.08700
    T0301      RK05C02        0.02600    RK01C03         -0.01400
    T0301      RK03C03       -0.80000    RK04C03         -1.03300
    T0301      RK05C03       -0.27800    ROWL01           1.00000
    T0401      COST       1.26577E 06    RK01C01          3.57000
    T0401      RK03C01        1.77400    RK04C01          0.52500
    T0401      RK05C01        0.22300    RK01C02          0.71400
    T0401      RK03C02        0.32400    RK04C02          0.07900
    T0401      RK05C02        0.08000    RK01C03         -0.01400
    T0401      RK03C03       -1.10500    RK04C03         -1.18400
    T0401      RK05C03        0.46500    ROWL01           1.00000
    T0501      COST       5.07181E 05    RK01C01          3.57000
    T0501      RK03C01        1.77400    RK04C01          0.52500
    T0501      RK05C01        0.22300    RK01C02          0.71400
    T0501      RK03C02        0.33000    RK04C02          0.09100
    T0501      RK05C02        0.03600    RK01C03         -0.01400
    T0501      RK03C03       -1.15600    RK04C03         -1.89900
    T0501      RK05C03       -1.56600    ROWL01           1.00000
    T0601      COST       1.81676E 06    RK01C01          3.57000
    T0601      RK03C01        1.77400    RK04C01          0.52500
    T0601      RK05C01        0.22300    RK01C02          2.99900
    T0601      RK03C02        1.37900    RK04C02          0.37300
    T0601      RK05C02        0.13000    RK01C03         -0.01400
    T0601      RK03C03       -2.96200    RK04C03         -4.07100
    T0601      RK05C03       -2.00700    ROWL01           1.00000
    T0701      COST       3.76787E 06    RK01C01          4.28400
    T0701      RK03C01        2.12900    RK04C01          0.63000
    T0701      RK05C01        0.26700    RK01C02          3.57000
    T0701      RK03C02        1.63400    RK04C02          0.43300
    T0701      RK05C02        0.12200    RK01C03         -1.44200
    T0701      RK03C03       -4.12200    RK04C03         -4.05200
    T0701      RK05C03        0.58300    ROWL01           1.00000
    T0102      ROWL02         1.00000
    T0202      COST       2.44825E 05    RK02C01          0.83300
    T0202      RK03C01        0.13200    RK04C01          0.03900
    T0202      RK05C01        0.01700    RK02C02          3.33000
    T0202      RK03C02        0.48600    RK04C02          0.13600
    T0202      RK05C02        0.05700    RK03C03         -0.48700
    T0202      RK04C03       -1.17900    RK05C03         -1.02500
    T0202      ROWL02         1.00000
    T0302      COST       4.17389E 05    RK02C01          1.66500
    T0302      RK03C01        0.26400    RK04C01          0.07800
```

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B6700/7700 TEMPO                                          S.P.3
VERSION: 27.500.000

    T0302       RK05C01          0.03300     RK02C02           0.83300
    T0302       RK03C02          0.12100     RK04C02           0.03300
    T0302       RK05C02          0.01100     RK03C03          -0.16000
    T0302       RK04C03         -0.34200     RK05C03          -0.16000
    T0302       ROWL02           1.00000
    T0402       COST         5.29103E 05     RK02C01           2.49800
    T0402       RK03C01          0.39600     RK04C01           0.11700
    T0402       RK05C01          0.05000     RK02C02           0.83300
    T0402       RK03C02          0.11900     RK04C02           0.02900
    T0402       RK05C02          0.00200     RK03C03          -0.16800
    T0402       RK04C03         -0.15800     RK05C03           0.47800
    T0402       ROWL02           1.00000
    T0502       COST         2.81669E 05     RK02C01           2.49800
    T0502       RK03C01          0.39600     RK04C01           0.11700
    T0502       RK05C01          0.05000     RK02C02           0.83300
    T0502       RK03C02          0.12200     RK04C02           0.03400
    T0502       RK05C02          0.01400     RK03C03          -0.18600
    T0502       RK04C03         -0.46900     RK05C03          -0.39700
    T0502       ROWL02           1.00000
    T0602       COST         7.73928E 05     RK02C01           2.49800
    T0602       RK03C01          0.39600     RK04C01           0.11700
    T0602       RK05C01          0.05000     RK02C02           3.49700
    T0602       RK03C02          0.50900     RK04C02           0.13800
    T0602       RK05C02          0.04800     RK03C03          -0.53900
    T0602       RK04C03         -1.05900     RK05C03          -0.32600
    T0602       ROWL02           1.00000
    T0702       COST         1.88406E 06     RK02C01           3.33000
    T0702       RK03C01          0.52800     RK04C01           0.15600
    T0702       RK05C01          0.06600     RK02C02           4.16300
    T0702       RK03C02          0.60300     RK04C02           0.16100
    T0702       RK05C02          0.04800     RK02C03          -1.78200
    T0702       RK03C03         -0.67000     RK04C03          -0.93900
    T0702       RK05C03          0.61400     ROWL02            1.00000
    T0103       ROWL03           1.00000
    T0203       COST         7.42321E 05     RK04C01           0.38400
    T0203       RK05C01          0.16300     RK04C02           1.23700
    T0203       RK05C02          0.45600     RK04C03          -2.70900
    T0203       RK05C03         -4.25800     ROWL03            1.00000
    T0303       COST         1.41717E 06     RK04C01           0.76700
    T0303       RK05C01          0.32500     RK04C02           0.73000
    T0303       RK05C02          0.27000     RK04C03          -1.82600
    T0303       RK05C03         -2.83300     ROWL03            1.00000
    T0403       COST         1.74837E 06     RK04C01           1.53400
    T0403       RK05C01          0.65100     RK04C02           0.73000
    T0403       RK05C02          0.26900     RK04C03          -2.14700
    T0403       RK05C03         -3.36400     ROWL03            1.00000
    T0503       COST         6.29459E 05     RK04C01           1.53400
    T0503       RK05C01          0.65100     RK04C02           0.73000
    T0503       RK05C02          0.27100     RK04C03          -2.15300
    T0503       RK05C03         -3.43100     ROWL03            1.00000
```

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B6700/7700 TEMPO                                                  S.P.3
VERSION: 27.500.000

    T0603      COST        2.49069E 06   RK04C01          1.53400
    T0603      RK05C01         0.65100   RK04C02          1.30900
    T0603      RK05C02         0.48100   RK04C03         -3.33500
    T0603      RK05C03        -5.21800   ROWL03           1.00000
    T0703      COST        4.79060E 06   RK04C01          1.91800
    T0703      RK05C01         0.81300   RK04C02          1.46000
    T0703      RK05C02         0.55500   RK04C03         -4.77700
    T0703      RK05C03        -6.62900   ROWL03           1.00000
    T0104      ROWL04          1.00000
    T0204      COST        7.42321E 05   RK05C01          0.34100
    T0204      RK05C02         0.74400   RK05C03         -1.72300
    T0204      ROWL04          1.00000
    T0304      COST        1.41717E 06   RK05C01          1.36500
    T0304      RK05C02         0.31200   RK05C03         -1.24000
    T0304      ROWL04          1.00000
    T0404      COST        1.74837E 06   RK05C01          1.70700
    T0404      RK05C02         0.31200   RK05C03         -1.38300
    T0404      ROWL04          1.00000
    T0504      COST        6.29459E 05   RK05C01          1.70700
    T0504      RK05C02         0.31200   RK05C03         -1.38800
    T0504      ROWL04          1.00000
    T0604      COST        2.49069E 06   RK05C01          1.70700
    T0604      RK05C02         0.80500   RK05C03         -2.42700
    T0604      ROWL04          1.00000
    T0704      COST        4.79060E 06   RK05C01          2.04800
    T0704      RK05C02         0.93900   RK05C03         -3.72400
    T0704      ROWL04          1.00000
    ENDINT     'MARKER'                  'BIVEND'
RHS
    ZRHS       RK01C01         0.99900   RK02C01         -0.83600
    ZRHS       RK03C01        -1.25000   RK04C01         -1.70800
    ZRHS       RK05C01        -1.34700   RK01C02        -94.57300
    ZRHS       RK02C02       -94.00400   RK03C02          1.78100
    ZRHS       RK04C02         1.20400   RK05C02          0.68300
    ZRHS       RK01C03         1.30000   RK02C03          2.00200
    ZRHS       RK03C03        -2.11900   RK04C03         -5.26700
    ZRHS       RK05C03         0.95400   ROWL01           1.00000
    ZRHS       ROWL02          1.00000   ROWL03           1.00000
    ZRHS       ROWL04          1.00000
ENDATA

SETUP     TIME--PROCESSOR =      0.09   ELAPSED =      0.27
```

```
B6700/7700 TEMPO                                              S.P.3
VERSION: 27.500.000

PROBLEM STATISTICS
              NUMBER       FREE      FIXED   BOUNDED    NORMAL
  ROWS   :        20          1          4         0        15
  COLUMNS:        28          0          0        28         0

MATRIX IN CORE : MEMORY ALLOCATION =     602 WORDS.
INVERSE: MEMORY ALLOCATION =   3120 WORDS. RECORD LENGTH =   1560 WORDS.

NUMBER OF INTEGER VARIABLES =           28

PRIMAL     TIME--PROCESSOR =     0.10    ELAPSED =      0.34

          ZOBJ = COST          ZRHS = ZRHS

PRESOL     TIME--PROCESSOR =     0.10    ELAPSED =      0.35

PROBLEM MODIFIED TO :

              NUMBER       FREE      FIXED   BOUNDED    NORMAL
  ROWS   :        12          1          4         0         7
  COLUMNS:        28          0          0        28         0
  NUMBER OF ELEMENTS =     177.  DENSITY EXCLUDING ROWS = 47.41  PERCENT.


CRASH      TIME--PROCESSOR =     0.12    ELAPSED =      0.45


INVERT     TIME--PROCESSOR =     0.12    ELAPSED =      0.45

CURRENT INVERSE :                ETA RECORDS =     1. ETA VECTORS =     0. ELEMENTS =       0.
CURRENT BASIS   : EQUALITY =    4.     SLACKS =     7. STRUCTURALS =     0. ELEMENTS =       7.

     AT START
        NUMBER OF INFEAS =    10
        SUM OF INFEAS    =      -16.05300

PASSII     TIME--PROCESSOR =     0.12    ELAPSED =      0.46


     AFTER PASSII
        NUMBER OF INFEAS =     1
        SUM OF INFEAS    =        -0.70257

     COMPLETED
```

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B6700/7700 TEMPO                                      S.P.3
VERSION: 27.500.000

PRIMAL    TIME--PROCESSOR =     0.12    ELAPSED =     0.48

          ZOBJ = COST         ZRHS = ZRHS
 ITERATION   NUMBER     SUM OF     NUMBER     REDUCED       PIVOT   VECTOR    VECTOR      FUNCTION
TYPE NUMBER  INFEAS     INFEAS     NEG DJ      COST         INDEX    OUT        IN         VALUE
P 6       9       1       -0.5622       7       -0.74401        2        2         6     2.10696E 06
  3      10       0          .          7       -0.60300       10       56        62     3.99102E 06

SOLUTION FEASIBLE


INVERT    TIME--PROCESSOR =     0.12    ELAPSED =     0.52

CURRENT INVERSE :                 ETA RECORDS =    1. ETA VECTORS =    14. ELEMENTS =     55.
CURRENT BASIS   : EQUALITY =    0.     SLACKS =    6. STRUCTURALS =     5. ELEMENTS =     42.
NEW INVERSE     : FORWARD  TRIANGULAR VECTORS =    3.                      ELEMENTS =     21.
                  NUCLEUS VECTORS             =    2. TRANSFORMED =     1. ELEMENTS =     41.

PRIMAL    TIME--PROCESSOR =     0.13    ELAPSED =     0.55

          ZOBJ = COST         ZRHS = ZRHS
 ITERATION   NUMBER     SUM OF     NUMBER     REDUCED       PIVOT   VECTOR    VECTOR      FUNCTION
TYPE NUMBER  INFEAS     INFEAS     NEG DJ      COST         INDEX    OUT        IN         VALUE
P 6      11       0          .         12   -1.63923E 06        3        3        57     3.41927E 06
P 3      12       0          .          3   -1.42301E 07        3       57U       54     2.39158E 06
  1      13       0          .          3  -761718.62653        9       52        53     2.37046E 06
P 3      14       0          .          3   -1.13127E 06       10       62        56     2.37046E 06
P 3      15       0          .          3  -742321.00000        5        5        70     1.65089E 06
  1      16       0          .          3  -287350.06451        4        4        63     1.52827E 06

CREATE    TIME--PROCESSOR =     0.13    ELAPSED =     0.59

  PROBLEM RESTORED.

INVERT    TIME--PROCESSOR =     0.15    ELAPSED =     0.70

CURRENT INVERSE :                 ETA RECORDS =    1. ETA VECTORS =    16. ELEMENTS =      0.
CURRENT BASIS   : EQUALITY =    0.     SLACKS =   11. STRUCTURALS =     8. ELEMENTS =     69.
NEW INVERSE     : FORWARD  TRIANGULAR VECTORS =    1.                      ELEMENTS =      7.
                  NUCLEUS VECTORS             =    3. TRANSFORMED =     2. ELEMENTS =     52.
                  BACKWARD TRIANGULAR VECTORS =    4.                      ELEMENTS =     67.

PRIMAL    TIME--PROCESSOR =     0.15    ELAPSED =     0.73
```

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B6700/7700 TEMPO                                               S.P.3
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          ZOBJ = COST          ZRHS = ZRHS

EXIT CONDITION: OPTIMAL SOLUTION.

                    FUNCTION VALUE =     1528266.21418

MXINT     TIME--PROCESSOR =     0.15   ELAPSED =     0.75
```

```
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        M X I N T    B R A N C H  &  B O U N D
      I N I T I A L   I N T E G E R   S U M M A R Y
       NAME       NUMBER   RANGE   LOW-BOUND    ACTIVITY
   1. T0101         49       1            0       .
   2. T0201         50       1            0     0.900210
   3. T0301         51       1            0       .
   4. T0401         52       1            0       .
   5. T0501         53       1            0     0.027728
   6. T0601         54       1            0     0.072061
   7. T0701         55       1            0       .
   8. T0102         56       1            0       .
   9. T0202         57       1            0     1.000000
  10. T0302         58       1            0       .
  11. T0402         59       1            0       .
  12. T0502         60       1            0       .
  13. T0602         61       1            0       .
  14. T0702         62       1            0       .
  15. T0103         63       1            0     0.426741
  16. T0203         64       1            0     0.573259
  17. T0303         65       1            0       .
  18. T0403         66       1            0       .
  19. T0503         67       1            0       .
  20. T0603         68       1            0       .
  21. T0703         69       1            0       .
  22. T0104         70       1            0     0.707801
  23. T0204         71       1            0     0.292199
  24. T0304         72       1            0       .
  25. T0404         73       1            0       .
  26. T0504         74       1            0       .
  27. T0604         75       1            0       .
  28. T0704         76       1            0       .
                S E T   S U M M A R Y
ROWL01   (E)      49     50     51     52     53     54
                  55
ROWL02   (E)      56     57     58     59     60     61
                  62
ROWL03   (E)      63     64     65     66     67     68
                  69
ROWL04   (E)      70     71     72     73     74     75
                  76
 NODE DROPPED - INFEASIBLE
 NODE **      1** RELOADED    OBJECTIVE =  1528266.2142
 NODE **      3** RELOADED    OBJECTIVE =  2620426.4954
 NODE DROPPED - INFEASIBLE
 NODE **      4** RELOADED    OBJECTIVE =  2741052.9369
 NODE **      5** RELOADED    OBJECTIVE =  2741052.9369
 NODE DROPPED - INFEASIBLE
 NODE **      7** RELOADED    OBJECTIVE =  3209839.2944
 NODE DROPPED - INFEASIBLE
 NODE **      9** RELOADED    OBJECTIVE =  3278189.5679
```

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B6700/7700 TEMPO                                                    S.P.3
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          I N T E G E R   S O L U T I O N

 NODE **   9  **  OPTIMIZED     INTEGER NODE
 FIRST INTEGER SOLUTION     OBJECTIVE =  3320505.0000
 CUTOFF NOW AT  3.32E 06     POSTPONE AT  2.87E 06
     A C T I V E   I N T E G E R   V A R I A B L E S
      NAME       NUMBER  ACTIVITY
   6. T0601          54      1.00
   9. T0202          57      1.00
  19. T0503          67      1.00
  26. T0504          74      1.00
 EXIT MXINT ON INTEGER SOLUTION DEMAND


MXINT      TIME--PROCESSOR =      0.21    ELAPSED =      1.30

 ** RETURN TO MXINT FROM DEMAND EXIT **
 NO REMAINING VALID NODES
 E N D    B R A N C H  &  B O U N D

OUTPUT     TIME--PROCESSOR =      0.21    ELAPSED =      1.32
```

```
                                                                    S.P.3
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          O U T P U T

            PROBLEM IDENTIFICATION
              PROBLEM     NAME   =      S.P.3

              FUNCTIONAL NAME   =      COST
              RESTRAINT  NAME   =      ZRHS

            SOLUTION STATUS     =     OPTIMAL
            ITERATION NUMBER    =          43
            FUNCTIONAL VALUE    =     3320505.00000
```

```
B6700/7700 TEMPO                                  S.P.3
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          ROWS SECTION

      NUMBER    NAME     STATUS     ACTIVITY       SLACK ACTIVITY    LOWER LIMIT     UPPER LIMIT     DUAL ACTIVITY

           1   COST        BS     3320505.00000   -3320505.00000     NONE            NONE                1.00000
           2   RK01C01     BS           3.57000         -2.57100          0.99900    NONE                 .
           3   RK02C01     BS           0.83300         -1.66900         -0.83600    NONE                 .
           4   RK03C01     BS           1.90600         -3.15600         -1.25000    NONE                 .
           5   RK04C01     BS           2.09800         -3.80600         -1.70800    NONE                 .
           6   RK05C01     BS           2.59800         -3.94500         -1.34700    NONE                 .
           7   RK01C02     BS           2.99900        -97.57200        -94.57300    NONE                 .
           8   RK02C02     BS           3.33000        -97.33400        -94.00400    NONE                 .
           9   RK03C02     BS           1.86500         -0.08400          1.78100    NONE                 .
          10   RK04C02     BS           1.23900         -0.03500          1.20400    NONE                 .
          11   RK05C02     BS           0.77000         -0.08700          0.68300    NONE                 .
          12   RK01C03     BS          -0.01400          1.31400     NONE                1.30000        .
          13   RK02C03     BS            .               2.00200     NONE                2.00200        .
          14   RK03C03     BS          -3.44900          1.33000     NONE               -2.11900        .
          15   RK04C03     BS          -7.40300          2.13600     NONE               -5.26700        .
          16   RK05C03     BS          -7.85100          8.80500     NONE                0.95400        .
          17   ROWL01      EQ           1.00000           .               1.00000        1.00000   -1816762.00000
          18   ROWL02      EQ           1.00000           .               1.00000        1.00000    -244825.00000
          19   ROWL03      EQ           1.00000           .               1.00000        1.00000    -629459.00000
          20   ROWL04      EQ           1.00000           .               1.00000        1.00000    -629459.00000
```

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B6700/7700 TEMPO                                  S.P.3
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            COLUMNS SECTION

NUMBER   NAME    STATUS   ACTIVITY     INPUT COST      LOWER LIMIT   UPPER LIMIT   REDUCED COST

    49  T0101     IV         .              .               .          1.00000   -1816762.00000
    50  T0201     IV         .        550996.00000          .          1.00000   -1265766.00000
    51  T0301     IV         .       1018425.00000          .          1.00000    -798337.00000
    52  T0401     IV         .       1265766.00000          .          1.00000    -550996.00000
    53  T0501     IV         .        507181.00000          .          1.00000   -1309581.00000
    54  T0601     IV      1.00000    1816762.00000          .          1.00000          .
    55  T0701     IV         .       3767873.00000          .          1.00000    1951111.00000
    56  T0102     IV         .              .               .          1.00000    -244825.00000
    57  T0202     IV      1.00000     244825.00000          .          1.00000          .
    58  T0302     IV         .        417389.00000          .          1.00000     172564.00000
    59  T0402     IV         .        529103.00000          .          1.00000     284278.00000
    60  T0502     IV         .        281669.00000          .          1.00000      36844.00000
    61  T0602     IV         .        773928.00000          .          1.00000     529103.00000
    62  T0702     IV         .       1884058.00000          .          1.00000    1639233.00000
    63  T0103     IV         .              .               .          1.00000    -629459.00000
    64  T0203     IV         .        742321.00000          .          1.00000     112862.00000
    65  T0303     IV         .       1417170.00000          .          1.00000     787711.00000
    66  T0403     IV         .       1748365.00000          .          1.00000    1118906.00000
    67  T0503     IV      1.00000     629459.00000          .          1.00000          .
    68  T0603     IV         .       2490687.00000          .          1.00000    1861228.00000
    69  T0703     IV         .       4790604.00000          .          1.00000    4161145.00000
    70  T0104     IV         .              .               .          1.00000    -629459.00000
    71  T0204     IV         .        742321.00000          .          1.00000     112862.00000
    72  T0304     IV         .       1417170.00000          .          1.00000     787711.00000
    73  T0404     IV         .       1748365.00000          .          1.00000    1118906.00000
    74  T0504     IV      1.00000     629459.00000          .          1.00000          .
    75  T0604     IV         .       2490687.00000          .          1.00000    1861228.00000
    76  T0704     IV         .       4790604.00000          .          1.00000    4161145.00000
```

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B6700/7700 TEMPO                                     S.P.3
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     PART   1  OF   1
     PAGE    1
                        T T T T T T T T T T T T T T T T T T T T T T T T T T T T Z      R  S
                        0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 R      A  C
                        1 2 3 4 5 6 7 1 2 3 4 5 6 7 1 2 3 4 5 6 7 1 2 3 4 5 6 7 H      N  A
                        0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 S      G  L
                        1 1 1 1 1 1 1 2 2 2 2 2 2 2 3 3 3 3 3 3 3 4 4 4 4 4 4 4        E  E


                SCALE
          UPPER BOUND   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
          LOWER BOUND
                 TYPE
          COST      N     F G G F G G   F F F F F G   F G G F G G   F G G F G G              COST
          RK01C01   G     T A A A A A                                           T            RK01C01
          RK02C01   G                   T A A A A A                            -T            RK02C01
          RK03C01   G     T T A A A A   T T T T T T                            -A            RK03C01
          RK04C01   G     T T T T T T   U U T T T T   T T A A A A              -A            RK04C01
          RK05C01   G     U U T T T T   U U U U U U   T T T T T T   T A A A A A-A            RK05C01
          RK01C02   G     A T T T A A                                          -B            RK01C02
          RK02C02   G                   A T T T A A                            -B            RK02C02
          RK03C02   G     A T T T A A   T T T T T T                             A            RK03C02
          RK04C02   G     T U U U T T   T U U U T T   A T T T A A               A            RK04C02
          RK05C02   G     T U V U T T   U U V U U U   T T T T T T   T T T T T T T            RK05C02
          RK01C03   L    -U-U-U-U-U-A                                           A            RK01C03
          RK02C03   L                            -A                             A            RK02C03
          RK03C03   L    -A-T-A-A-A-A  -T-T-T-T-T-T                            -A            RK03C03
          RK04C03   L    -A-A-A-A-A-A  -A-T-T-T-A-T  -A-A-A-A-A-A              -A            RK04C03
          RK05C03   L    -A-T T-A-A T  -A-T T-T-T T  -A-A-A-A-A-A  -A-A-A-A-A-A T            RK05C03
          ROWL01    E   1 1 1 1 1 1 1                                           1            ROWL01
          ROWL02    E                 1 1 1 1 1 1 1                             1            ROWL02
          ROWL03    E                               1 1 1 1 1 1 1               1            ROWL03
          ROWL04    E                                             1 1 1 1 1 1 1 1            ROWL04
```

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B6700/7700 TEMPO                                          S.P.3
VERSION: 27.500.000


                              SUMMARY OF MATRIX
       SYMBOL                     RANGE                           COUNT INCL RHS
         Z                  LESS THAN              .000001            0
         Y              .000001 THRU               .000009            0
         X              .000010 THRU               .000099            0
         W              .000100 THRU               .000999            0
         V              .001000 THRU               .009999            2
         U              .010000 THRU               .099999           28
         T              .100000 THRU               .999999           95
         1             1.000000 THRU              1.000000           32
         A             1.000001 THRU             10.000000           81
         B            10.000001 THRU            100.000000            2
         C           100.000001 THRU          1,000.000000            0
         D         1,000.000001 THRU         10,000.000000            0
         E        10,000.000001 THRU        100,000.000000            0
         F       100,000.000001 THRU      1,000,000.000000           11
         G             GREATER THAN       1,000,000.000000           13

               MINIMUM  =     -94.573000     MAXIMUM  = 4790604.000000

PERMANENT SYSTEM FILE DIRECTORIES

PROBLEMS ON ZPROF

  ZNAME        DATE      NO ROWS    NO COLS    NO RECS

S.P.3        08/11/77        20         28          1


BASES ON ZPROF

 ZBASNM        DATE         ZNAME        NO RECS


TOTAL   RECORDS =     12
WASTED RECORDS =     11

ENDRUN    TIME--PROCESSOR =      0.24     ELAPSED =      1.52
```