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COMPUTER PROGRAM DOCUMENTATION

for the

STREAM QUALITY MODEL

QUAL-II

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FOREWORD

QUAL-II/SEMCOG version was developed by Water Resources Engineers for the Southeast Michigan Council of Governments (SEMCOG) under Section 208 of PL 92-500. It represents a substantial improvement over previous versions of the model and is being made available through the Center for Water Quality Modeling as a service to interested users with the permission of SEMCOG. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

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I. INTRODUCTION

QUAL-II is a comprehensive and versatile stream water quality model. It can simulate up to 13 water quality constituents in any combination desired by the user. Constituents which can be simulated are:

1. Dissolved Oxygen
2. Biochemical Oxygen Demand
3. Temperature
4. Algae as Chlorophyll <u>a</u>
5. Ammonia as N
6. Nitrite as N
7. Nitrate as N
8. Dissolved Orthophosphate as P
9. Coliforms
10. Arbitrary Nonconservative Constituent
11. Three Conservative Constituents

The model is applicable to dendritic streams which are well mixed. It assumes that the major transport mechanisms, advection and dispersion, are significant only along the main direction of flow (longitudinal axis of the stream or canal). It allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow. It also has the capability to compute required dilution flows for flow augmentation to meet any prespecified dissolved oxygen level.

Hydraulically QUAL-II is limited to the simulation of time periods during which the stream flows in the river basin are essentially constant. Input waste loads must also be held constant over time. QUAL-II can be operated as a steady-state model or a dynamic model. Dynamic operation makes it possible to study water quality (primarily dissolved oxygen and temperature) as it is affected by diurnal variations in meteorological data. The basic theory and mechanics behind the development of QUAL-II are described in this Program Documentation Manual which is intended to supplement the User's Manual.

QUAL-II can be very helpful as a water quality planning tool. It can be used to study the impact of waste loads (magnitude, quality and location) on in-stream water quality. It could also be used in conjunction with a field sampling program to identify the magnitude and quality characteristics of nonpoint source waste loads. By operating the model dynamically, diurnal dissolved oxygen variations due to algae growth and respiration can be studied. Dynamic operation also makes it possible to trace the water quality impact of a slug loading, such as a spill, or of seasonal or periodic discharges.

HISTORY AND ACKNOWLEDGMENTS

QUAL-II/SEMCOG VERSION is a new release of QUAL-II which was developed by Water Resources Engineers, Inc. It includes modifications and refinements made in the model since its original development in 1972 and is intended to supersede all prior releases of the computer program. The significant differences between this program and earlier releases are:

1. Option of English or Metric units on input data.
2. Option for English or Metric output--choice is independent of input units.
3. Option to specify channel hydraulic properties in terms of trapezoidal channels or stage-discharge and velocity discharge curves.
4. Option to use Tsivoglou's computational method for stream reaeration.
5. Improved output display routines.
6. Improved steady-state temperature computation routines.

QUAL-II is an extension of the stream water quality model QUAL-I developed in 1970 by F. D. Masch and Associates and the Texas Water Development Board (1971)* and the Texas Water Development Board (1970).

*See List of References at the end of Section V.

The computer code was written by W. A. White. In 1972, WRE under contract to the U.S. Environmental Protection Agency, modified and extended QUAL-I to produce the first version of QUAL-II. Over the next three years, several different versions of the model evolved in response to specific client needs. In March of 1976, the Southeast Michigan Council of Governments (SEMCOG) contracted with WRE to make further modifications and to combine the best features of the existing versions of QUAL-II into a single model. QUAL-II/SEMCOG VERSION is that Model.

PROTOTYPE REPRESENTATION

QUAL-II permits any branching, one-dimensional stream system to be simulated. The first step involved in approximating the prototype is to subdivide the stream system into reaches, which are stretches of stream that have uniform hydraulic characteristics. Each reach is then divided into computational elements of equal length so that all computational elements in all reaches are the same length. Thus, all reaches must consist of an integer number of computational elements.

In total, there are seven different types of computational elements; these are:

1. Headwater element
2. Standard element
3. Element just upstream from a junction
4. Junction element
5. Last element in system
6. Input element
7. Withdrawal element

Headwater elements begin every tributary as well as the main river system, and as such, they must always be the first element in a reach. A standard element is one that does not qualify as one of the remaining six element types. Since incremental inflow is permitted in all element types, the only input permitted in a standard element is incremental inflow. A type

3 element is used to designate an element on the mainstem that is just upstream from a junction element (type 4) which is an element that has a simulated tributary entering it. Element type 5 identifies the last computational element in the river system; there should be only one element type 5. Element types 6 and 7 represent elements which have inputs (waste loads and unsimulated tributaries) and water withdrawals, respectively. River reaches, which are aggregates of computational elements, are the basis of most data input. Hydraulic data, reaction rate coefficients, initial conditions, and incremental runoff data are constant for all computational elements within a reach.

MODEL LIMITATIONS

QUAL-II has been developed to be a relatively general program; however, certain dimensional limitations have been imposed upon it during program development. These limitations are as follows:

Reaches: a maximum of 75

Computational elements: no more than 20 per reach or 500 in total

Headwater elements: a maximum of 15

Junction elements: a maximum of 15

Input and withdrawal elements: a maximum of 90 in total

MODEL STRUCTURE AND SUBROUTINES

QUAL-II is structured as one main program, QUAL2, supported by 23 different subroutines. Figure I-1 graphically illustrates the functional relationships between the main program and the 23 subroutines. The original version of QUAL was structured to permit the addition of parameters easily through addition of subroutines. This basic concept, which proved to be an extremely valuable one, was maintained in the extension

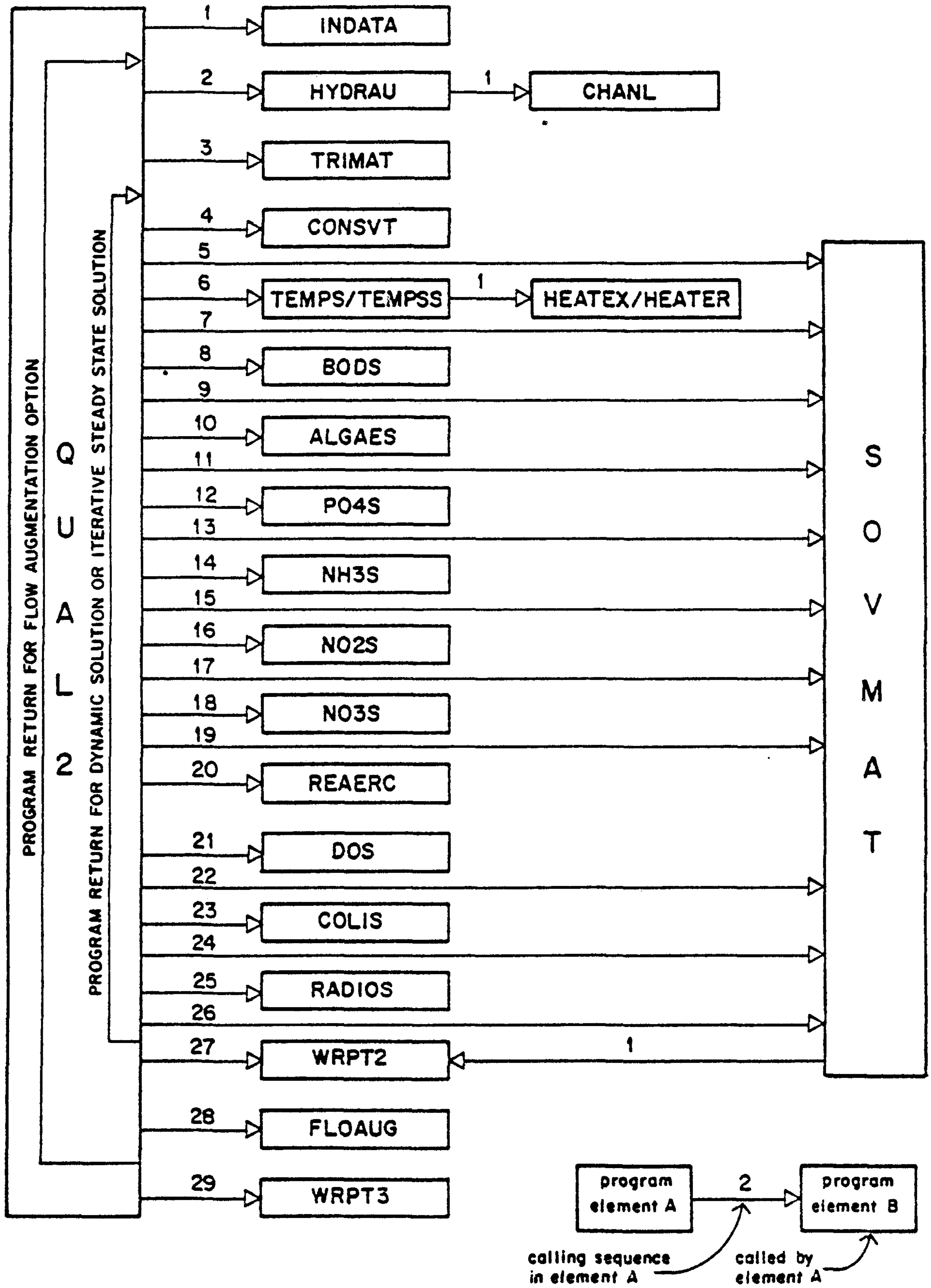

FIGURE I-1
GENERAL STRUCTURE OF QUAL-II

of the original version to QUAL-II. Thus, if it becomes desirable at some later time to add new parameters or modify existing parameter relationships, the changes can be made with a minimum of model restructuring.

PROGRAM LANGUAGE AND OPERATING REQUIREMENTS

QUAL-II is written in FORTRAN IV and is compatible with the UNIVAC 1108, CDC 6400, and IBM 360 and 370 computer systems. The SEMCOG version of QUAL-II requires an average of 51,000 words of core storage. QUAL-II uses the system's 80 column card reader as the only input device and the system's line printer as the only output device.

TYPICAL EXECUTION TIMES

Execution time on any particular computer system is nearly linearly related to:

1. The number of water quality parameters simulated,
2. The number of computational elements in the system, and
3. The number of time steps simulated when the dynamic simulation option is used.

Approximate execution times for a UNIVAC and IBM computer are shown below.

Computer	Execution Time: Steady-State Simulation*	Execution Time: Dynamic Simulation**
UNIVAC 1108	0.02	0.01
IBM 360/40	0.15	0.05

* Seconds/water quality parameter/computational element
**Seconds/water quality parameter/computational element/time step

JOB CONTROL CONSIDERATIONS

If the system's normal FORTRAN input device unit is not unit 5 or the output unit is not unit 6, then the variables "NI" and "NJ" in the subroutine INDATA should be changed to reflect the system's I/O unit identifiers.

II. GENERAL MODEL FORMULATION

INTRODUCTION

The primary objective of any stream water quality model development is to produce a tool which has the capability for simulating the behavior of the hydrologic and water quality components of a stream system. The development of this tool to simulate prototype behavior by application of a mathematical model on a digital computer proceeds through three general phases (Water Resources Engineers, Inc. (1967)):

1. Conceptual representation
2. Functional representation
3. Computational representation.

Conceptual representation involves a graphic idealization of the prototype by description of the geometric properties that are to be modeled and by identification of boundary conditions and interrelationships between various parts of the prototype. Usually, this process entails discretizing the prototype into "elements" of a size compatible with the objectives that the model must serve, defining these elements according to some simple geometric rules, and designating the mode by which they are connected, either physically or functionally, as integral parts of the whole. A part of this conceptual structuring is the designation of those boundary conditions that will be considered in the simulation.

Functional representation entails formulation of the physical features, processes, and boundary conditions into sets of algebraic equations. It involves precise definition of each variable and its relationship to all other parameters that characterize the model or its input-cutput relationships.

Computational representation is the process whereby the functional model is translated into the mathematical forms and computational procedures required for solution of the problem over the desired time and space continuum. It is concerned with development of a specific solution technique that can be accommodated by the computer and with codification of the technique in computer language.

In the remainder of this section the Conceptual Representation of QUAL-II will be described together with its general Functional Representation for mass transport, hydraulic characteristics, and longitudinal dispersion. Section III will discuss specific constituent reactions and interactions. Section IV will develop the Functional Representation of stream temperature as simulated in QUAL-II.

CONCEPTUAL REPRESENTATION

Figure II-1 shows a stream reach n which has been subdivided into a number of subreaches or *computational elements* each of length Δx. For each of these computational elements, the hydrologic balance shown can be written in terms of flows into the upstream element (Q_{i-1}), external sources or withdrawals (Q_{x_i}), and the outflow (Q_i) through the downstream face of the element. Similarly, a materials balance for any constituent C can be written for the element. In the materials balance, we consider both transport ($Q \cdot C$) and dispersion ($A \frac{D_L}{\Delta x} \frac{\partial C}{\partial x}$) as the movers of mass along the stream axis. Mass can be added to the system via wasteloads ($Q_x C_x$) and added or removed via internal sources or sinks (S_i) such as benthic sources and biological transformation. Each computational element is considered to be completely mixed.

Thus the stream can be conceptualized as a string of completely mixed reactors--computational elements--which are linked sequentially to one another via the mechanisms of transport and dispersion. Sequential

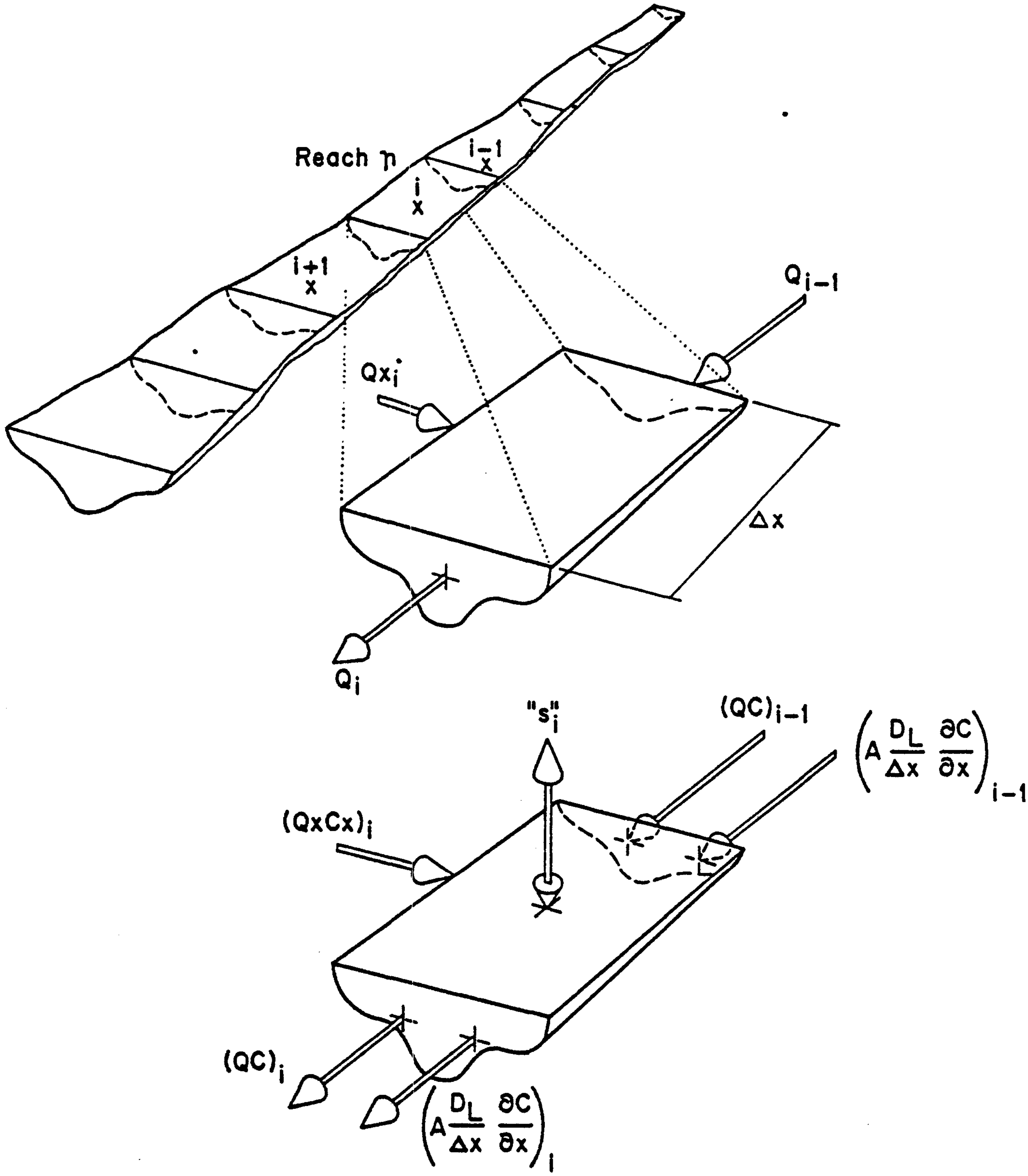

FIGURE II-1

DISCRETIZED STREAM SYSTEM
After Water Resources Engineers, Inc. (1967)

groups of these reactors can be defined as *reaches* in which the computational elements have the same hydrogeometric properties--stream slope, channel cross section, roughness, etc.--and biological rate constants--BOD decay rate, benthos source rates, algae settling rates, etc.--so that the stream shown at the left of Figure II-2 can be conceptually represented by grouping of reaches and computational elements shown on the lower right of the figure.

FUNCTIONAL REPRESENTATION

Mass Transport Equation

The basic equation solved by QUAL-II is the advection-dispersion mass transport equation, which is numerically integrated over time for each water quality constituent. This equation includes the effects of advection, dispersion, dilution, constituent reactions and interactions, and sources and sinks. For any constituent, C, this equation can be written as:

$$\frac{\partial M}{\partial t} = \frac{\partial (A_x D_L \frac{\partial C}{\partial x})}{\partial x} dx - \frac{\partial (A_x \bar{u} C)}{\partial x} dx + (A_x dx) \frac{dC}{dt} + s \qquad \text{II-1}$$

where

M = mass (M)

x = distance (L)

t = time (T)

C = concentration (M/L^3)

A_x = cross-sectional area (L^2)

D_L = dispersion coefficient (L^2/T)

$\bar{u}$ = mean velocity (L/T)

s = external source or sinks (M/T)

Since M = VC, we can write

$$\frac{\partial M}{\partial t} = \frac{\partial (VC)}{\partial t} = V \frac{\partial C}{\partial t} + C \frac{\partial V}{\partial t} \qquad \text{II-2a}$$

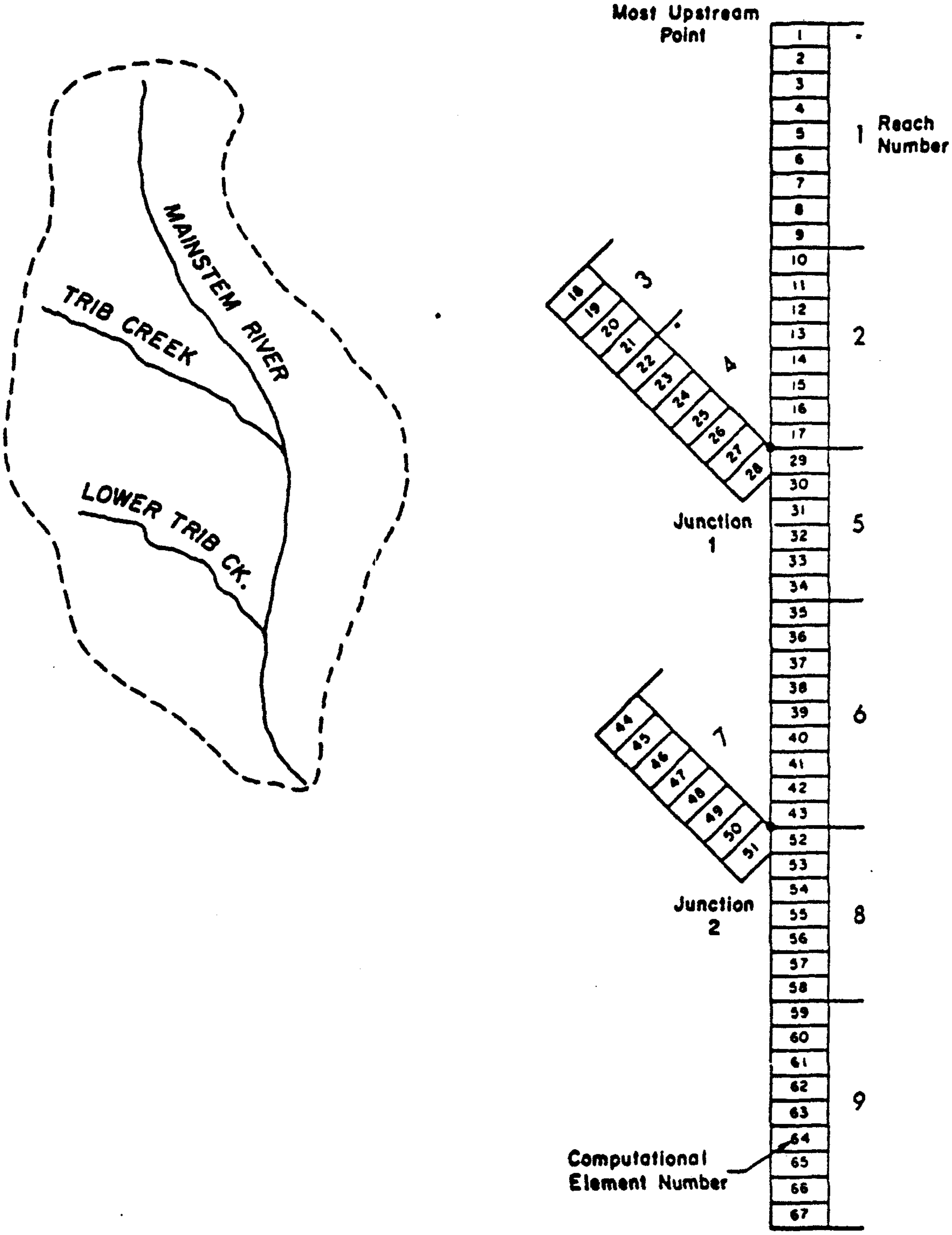

FIGURE II-2

STREAM NETWORK OF COMPUTATIONAL ELEMENTS AND REACHES

where

$$V = A_x\, dx = \text{Incremental volume } (L^3)$$

If we assume that the flow in the stream is steady, i.e. $\partial Q/\partial t = 0$, then the term $\partial V/\partial t = 0$ and equation II-2a becomes

$$\frac{\partial M}{\partial t} = V \frac{\partial C}{\partial t} \qquad \text{II-2b}$$

Combining equations II-1 and II-2b and rearranging,

$$\frac{\partial C}{\partial t} = \frac{\partial (A_x D_L \frac{\partial C}{\partial x})}{A_x \partial x} - \frac{\partial (A_x\, \bar{u}\, C)}{A_x \partial x} + \frac{dC}{dt} + \frac{s}{V} \qquad \text{II-3}$$

The terms on the right-hand side of the equation represent, respectively, dispersion, advection, constituent changes, external sources/sinks, and dilution. The $\frac{dC}{dt}$ term refers only to constituent changes such as growth and decay, and should not be confused with the term $\frac{\partial C}{\partial t}$, the local concentration gradient. The latter term includes the effect of constituent changes as well as dispersion, advection, sources/sinks, and dilutions.

Under steady-state conditions, the local derivative becomes equal to zero; in other words:

$$\frac{\partial C}{\partial t} = 0 \qquad \text{II-4}$$

Changes that occur to individual constituents or particles independent of advection, dispersion and waste inputs are defined by the term:

$$\frac{dC}{dt} = \text{individual constituents changes} \qquad \text{II-5}$$

These changes include the physical, chemical, and biological reactions and interactions that occur in the stream. Examples of these changes are reaeration, algal respiration and photosynthesis, and coliform die-off.

HYDRAULIC CHARACTERISTICS

QUAL-II assumes that the stream hydraulic regime is steady-state; i.e. $\partial Q/\partial t = 0$, therefore, the hydrologic balance for a computational element can be written simply as (see Figure II-1):

$$\left(\frac{\partial Q}{\partial x}\right)_i = (Q_x)_i \qquad \text{II-6}$$

where $(Q_x)_i$ is the sum of the external inflows and/or withdrawal to that element.

Once equation II-6 has been solved for Q, the other hydraulic characteristics of the stream segments can be determined by equations of the form:

$$\bar{u} = aQ^b \qquad \text{II-7}$$

$$A_x = Q/\bar{u} \qquad \text{II-8}$$

and

$$d = \alpha Q^\beta \qquad \text{II-9}$$

where a, b, α and β are constants, and d is the stream depth. These constants usually can be determined from stage-discharge rating curves.

Alternatively, if the cross-sectional properties of the stream segment are available as a function of the depth d, $\bar{u}$ can be obtained as a function of discharge by the trial and error solution of Mannings equation:

$$Q = \frac{1.486}{n} A_x R_x^{2/3} S_e^{1/2} \qquad \text{II-10}$$

where

A_x = cross-sectional area of the channel or canal in square feet,

R_x = mean effective hydraulic radius (area divided by wetted perimeter) feet,

n = Manning roughness factor (usual range 0.010 to 0.10)

S_e = slope of the energy grade line, unitless,

Q = discharge in cubic feet per second.

The value for $\bar{u}$ is then determined from equation II-8.

LONGITUDINAL DISPERSION

Dispersion is basically a convective transport mechanism. The term "dispersion" is generally used for transport associated with spatially-averaged velocity variation, as opposed to "diffusion" which is reserved for transport that is associated primarily with time-averaged velocity fluctuations.

Taylor (1954) was able to derive a predictive equation for the longitudinal dispersion coefficient, D_L, in long straight pipes, as

$$D_L = 10\ r_o\ u^*,\ ft^2/sec. \qquad \text{II-11}$$

where r_o is the pipe radius and u^* is the average shear velocity defined as

$$u^* = \sqrt{\tau_0/\rho},\ ft/sec. \qquad \text{II-12}$$

where

τ_0 = boundary shear stress, lb/ft^2, and
ρ = mass fluid density, $lb\text{-}sec^2/ft^4$

Some investigators have attempted to apply Taylor's expression to streamflow. However, such applications can be highly approximate, because of the difference between the geometry or velocity distributions in streamflow and those in a pipe.

Elder (1959) assumed that only the vertical velocity gradient was important in streamflow and developed an expression analogous to Taylor's expression but with a coefficient equal to 5.93:

$$D_L = 5.93\ du^* \qquad \text{II-13}$$

where d is the mean depth in feet of the stream.

Other investigators have derived similar expressions for D_L and found it to be extremely sensitive to lateral velocity profiles. Elder's expression, however, seems adequate in one-dimensional situations where the channel is not too wide. For very wide channels, Fisher (1964) has shown that half-width rather than depth is the dominant scale and therefore is important to the definition of the longitudinal dispersion coefficient. Equations II-11 and II-13 can be written in terms of the Manning Equation and other variables characteristic of stream channels.

As an example, for steady-state open-channel flow:

$$u^* = C\sqrt{RS_e} \qquad \text{II-14}$$

where

C = Chezy's coefficient
R = the hydraulic radius
S_e = the slope of the energy grade line

Chezy's coefficient is given by:

$$C = \frac{R^{1/6}}{n} \qquad \text{II-15}$$

where n is the Manning roughness coefficient tabulated for different types of channels in Table II-1.

S_e, the slope of the energy gradient, is given by

$$S_e = \left(\frac{\bar{u}\, n}{1.486\, R^{2/3}}\right)^2 \qquad \text{II-16}$$

where $\bar{u}$ is the mean velocity. Substituting equations II-14, II-15 and II-16 into equation II-13 and letting $R = d$ for a wide channel yields the expression

$$D_L = 22.6\, n\, \bar{u}\, d^{0.833} \qquad \text{II-17}$$

TABLE II-1

VALUES OF MANNING'S "n" ROUGHNESS COEFFICIENT
After Henderson (1966)

Artificial Channels	n
Glass, plastic, machined metal	0.010
Dressed timber, joints flush	0.011
Sawn timber, joints uneven	0.014
Cement plaster	0.011
Concrete, steel troweled	0.012
Concrete, timber forms, unfinished	0.014
Untreated gunite	0.015-0.017
Brickwork or dressed masonry	0.014
Rubble set in cement	0.017
Earth, smooth, no weeds	0.020
Earth, some stones, and weeds	0.025

Natural River Channels	n
Clean and straight	0.025-0.030
Winding with pools and shoals	0.033-0.040
Very weedy, winding and overgrown	0.075-0.150
Clean straight alluvial channels	$0.031\ d^{1/6}$ (d = D-75 size in ft. = diameter that 75 percent of particles are smaller than

where

D_L = longitudinal dispersion coefficient, $ft^2/sec.$

n = Manning's roughness coefficient

$\bar{u}$ = mean velocity, ft/sec.

d = mean depth, ft.

Typical values for dispersion coefficients are given in Table II-2.

TABLE II-2

TYPICAL VALUES OF DISPERSION COEFFICIENTS
After Gloyna (1967)

System Classification	D_L, $ft^2/sec.$
Flumes and small streams	3×10^{-2} – 3
Large rivers	3 – 3×10^{2}
Estuaries	3×10^{2} – 6×10^{3}

III. CONSTITUENT REACTIONS AND INTERRELATIONSHIPS

GENERAL CONSIDERATIONS

One of the most important considerations in determining the waste-assimilative capacity of a stream is its ability to maintain an adequate dissolved oxygen concentration. Dissolved oxygen concentrations in streams are controlled by atmospheric reaeration, photosynthesis, plant and animal respiration, benthal demand, biochemical oxygen demand, nitrification, salinity, and temperature, among other factors.

The most accurate oxygen balance would consider all significant factors. The QUAL-II includes the major interactions of the nutrient cycles, algae production, benthic oxygen demand, carbonaceous oxygen uptake, atmospheric aeration and their effect on the behavior of dissolved oxygen. Figure III-1 illustrates the conceptualization of these interactions. It should be noted that the arrows on the figure indicate the direction of normal system progression in a moderately polluted environment; the directions may be reversed in some circumstances for some constituents. For example, under conditions of oxygen supersaturation, which might occur as a result of algal photosynthesis, oxygen might be driven from solution, opposite to the indicated direction of the flow path.

Coliforms and the arbitrary nonconservative constituent are modeled as nonconservative decaying constituents, and do not interact with other constituents. The conservative constituents, of course, neither decay nor interact in any way with other constituents.

The mathematical relationships that describe the individual reactions and interactions are presented in the following paragraphs.

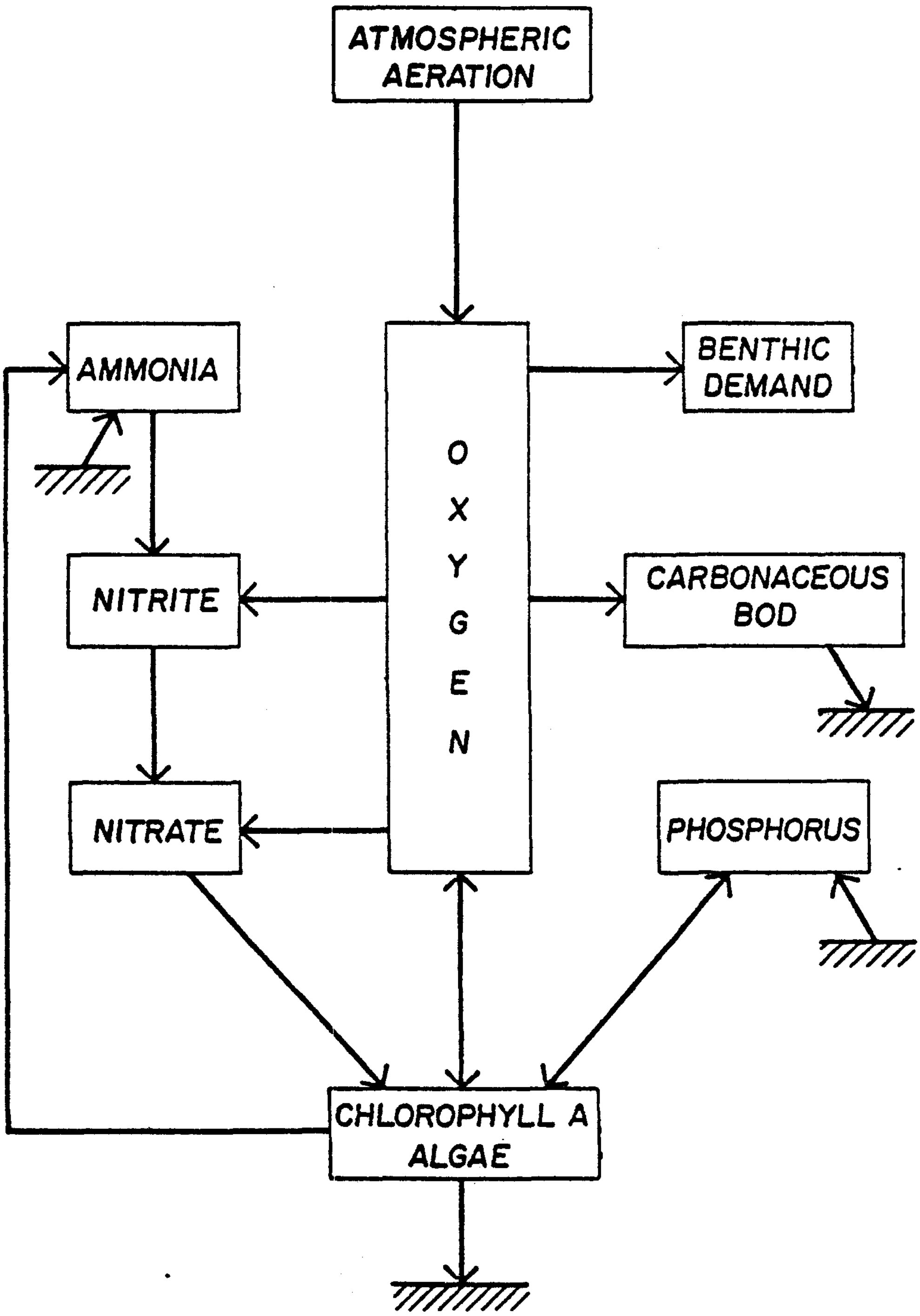

FIGURE III-1
MAJOR CONSTITUENT INTERACTIONS

Chlorophyll a (Phytoplanktonic Algae)

Chlorophyll a is considered to be directly proportional to the concentration of phytoplanktonic algal biomass. For the purposes of this model algal biomass is converted to chlorophyll a by the simple relationship:

$$\text{Chl } \underline{a} = \alpha_0 A \qquad \text{III-1}$$

where

Chl a = chlorophyll a concentration
A = algal biomass concentration
α_0 = a conversion factor

The differential equation that governs the growth and production of algae (chlorophyll a) is formulated according to the following relationship:

$$\frac{dA}{dt} = \mu A - \rho A - \frac{\sigma_1}{d} A \qquad \text{III-2}$$

where

A = algal biomass concentration
t = time
μ = the local specific growth rate of algae as defined below, which is temperature dependent
ρ = the local respiration rate of algae, which is temperature dependent
σ_1 = the local settling rate for algae
d = average depth

Now, the local specific growth rate of algae is known to be coupled to availability of required nutrients and light. The standard formulation for the local specific growth rate takes the form:

$$\mu = \mu_{max} \frac{N_3}{N_3 + K_N} \cdot \frac{P}{P + K_P} \cdot \frac{1}{\lambda d} \ln \frac{K_L + L}{K_L + Le^{-\lambda d}} \qquad \text{III-3}$$

where

μ_{max} = the maximum specific growth rate

N_3 = the local concentration of nitrate nitrogen

P = the local concentration of orthophosphate

L = the local intensity of light

λ = the light extinction coefficient ($L_d = Le^{-\lambda d}$)

K_N, K_P, K_L = empirical half-saturation constants (temperature dependent)

It should be noted that equation III-3 couples algal production to the available nutrient supply, and thus algae and chlorophyll a can be expected to vary in time and space as nutrients are added. If either nitrogen or phosphorus or both are not simulated, it is assumed that they will not limit the growth of algae. It should also be noted that equation III-3 includes light intensity, as input to the model. Finally, the growth and respiration constants are temperature dependent and are formulated, along with all other temperature dependent system variables, according to the procedure explained in a later paragraph of this section.

Nitrogen Cycle

The nitrogen cycle in QUAL-II contains three components as shown in Figure III-1. The differential equations governing transformation of nitrogen from one form to another are given below.

Ammonia Nitrogen

$$\frac{dN_1}{dt} = \alpha_1 \rho A - \beta_1 N_1 + \sigma_3/A_x \qquad \text{III-4}$$

where

N_1 = the concentration of ammonia nitrogen as nitrogen

β_1 = rate constant for the biological oxidation of ammonia nitrogen, temperature dependent

α_1 = the fraction of respired algal biomass which is resolubilized as ammonia nitrogen by bacterial action

σ_3 = the benthos source rate for ammonia nitrogen

A_x = average cross-sectional area

and other terms are as previously defined.

Nitrite Nitrogen

$$\frac{dN_2}{dt} = \beta_1 N_1 - \beta_2 N_2 \qquad \text{III-5}$$

where

N_2 = the concentration of nitrite nitrogen as nitrogen

β_2 = rate constant for the oxidation of nitrite nitrogen, temperature dependent

and other terms are as previously defined.

Nitrate Nitrogen

$$\frac{dN_3}{dt} = \beta_2 N_2 - \alpha_1 \mu A \qquad \text{III-6}$$

Note the coupling that exists between the conversion of nitrate and the production of algae to close the loop indicated in Figure III-1.

Phosphorus Cycle

The formulation of the phosphorus cycle is less complex than the nitrogen cycle because the model considers only the interaction of phosphorus and algae plus a sink term. Correspondingly, the differential equation describing the distribution can be written as:

$$\frac{dP}{dt} = \alpha_2 \rho A - \alpha_2 \mu A + \sigma_2/A_x \qquad \text{III-7}$$

where

P = the concentration of orthophosphate as phosphorus

α_2 = the fraction of algal biomass that is phosphorus

σ_2 = the benthos source rate for phosphorus

and all other terms are as previously defined.

Carbonaceous BOD

The rate of change of carbonaceous BOD is formulated as a first order reaction according to the formula:

$$\frac{dL}{dt} = -K_1 L - K_3 L \qquad \text{III-8}$$

where

L = the concentration of carbonaceous BOD

K_1 = the rate of decay of carbonaceous BOD (temperature dependent)

K_3 = the rate of loss of carbonaceous BOD due to settling

Note that while the change in BOD is expressed by equation III-8, the oxygen demand exerted as a result of the change is only K_1L. The BOD which settles becomes a benthic oxygen demand.

Dissolved Oxygen

The differential equation that describes the rate of change of oxygen in the model is written in the form:

$$\frac{dO}{dt} = K_2(O^* - O) + (\alpha_3\mu - \alpha_4\rho) A - K_1 L - K_4/A_x - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2 \qquad \text{III-9}$$

where

O = the concentration of dissolved oxygen

O^* = the saturation concentration of dissolved oxygen at the local temperature and pressure

α_3 = the rate of oxygen production per unit of algae (photosynthesis)

α_4 = the rate of oxygen uptake per unit of algae respired

α_5 = the rate of oxygen uptake per unit of ammonia oxidation

α_6 = the rate of oxygen uptake per unit of nitrite nitrogen oxidation

K_2 = the aeration rate in accordance with the Fickian diffusion analogy

K_4 = constant benthic uptake rate

The saturation concentration of dissolved oxygen is computed at standard pressure (29.92 in. of Hg) by the equation:

$$O^* = 24.89 - 0.426\ T + 0.00373\ T^2 - 0.0000133\ T^3 \qquad \text{III-10}$$

where

T = temperature of water in °F.

According to the American Public Health Association, Inc. (1965), O* can be corrected for a given barometric pressure other than standard pressure by the equation:

$$O^* = O^* \frac{P_a - e_s}{29.92 - e_s} \qquad \text{III-11}$$

where

P_a = barometric pressure, in. of Hg

e_s = saturated water vapor pressure at the temperature of the water surface, in. of Hg

and for elevation less than 3,000 feet by

$$O^* = O^* \frac{P_a}{29.92} \qquad \text{III-12}$$

For water temperatures above 60°F, the American Public Health Association, Inc. (1965) indicates that the solubility of oxygen in water decreases by approximately 0.008 mg/l per 100 mg/l of chloride present. QUAL-II does not correct O* for either pressure or chlorides.

Numerous equations have been developed to compute reaeration coefficients (K_2) based on stream geometry and characteristics. Those which have been selected as options are discussed below.

Churchill, Elmore, and Buckingham (1962)

This investigation was based on probably the most extensive and accurate measurements of stream reaeration available and produced the following expression for K_2 at 20°C (68°F):

$$K_2^{20} = 5.026\ \bar{u}^{0.969}\ d^{-1.673} \times 2.31 \qquad \text{III-13}$$

where

$\bar{u}$ = average velocity in the stream, ft/sec.

d = average depth of the stream, ft

K_2 = reaeration coefficient, 1/day

O'Connor and Dobbins (1958)

These investigators proposed equations based on the turbulent characteristics of a stream as follows:

For streams displaying low velocities and isotropic conditions

$$K_2^{20} = \frac{(D_m\ \bar{u})^{0.5}}{d^{1.5}} \qquad \text{III-14}$$

For streams displaying high velocities and nonisotropic conditions

$$K_2^{20} = \frac{480\ D_m^{0.5}\ S_o^{0.25}}{d^{1.25}} \times 2.31 \qquad \text{III-15}$$

where

S_o = slope of the streambed

d = mean stream depth, ft.

$\bar{u}$ = mean velocity, ft/day

K_2 = reaeration coefficient, 1/day

and where D_m is the molecular diffusion coefficient (ft²/day) which can be computed by

$$D_m = 1.91 \times 10^3 (1.037)^{T-20} \qquad \text{III-16}$$

Isotropic conditions are satisfied when Chezy's coefficient is greater than 17, and nonisotropic for values less than 17. O'Conner and Dobbins (1958) have shown that equation III-14 is generally applicable for most cases, and is the equation used in the program for this option.

Owens, Edwards, and Gibbs (1964)

For streams with a velocity variation range from 0.1 to 5.0 ft/sec. and depths from 0.4 to 11.0 ft:

$$K_2^{20} = 9.4\, \bar{u}^{0.67} / d^{1.85} \times 2.31 \qquad \text{III-17}$$

where

$\bar{u}$ = mean velocity, ft/sec.

d = mean depth, ft.

K_2 = reaeration coefficient, 1/day

Thackston and Krenkel (1966)

This investigation included several rivers in the Tennessee Valley Authority system and resulted in the following equation for K_2 at 20°C:

$$K_2^{20} = 10.8\, (1 + F^{0.5})\, \frac{u^*}{d} \times 2.31 \qquad \text{III-18}$$

where F is the Froude number which can be computed by

$$F = \frac{u^*}{\sqrt{g\ d}} \qquad \text{III-19}$$

and u* is the shear velocity, ft/sec., which can be computed by

$$u^* = \sqrt{d\ S_e\ g} = \frac{\overline{u}\ n\ \sqrt{g}}{1.49\ d^{1.167}} \qquad \text{III-20}$$

where

- d = mean depth, ft.
- g = acceleration of gravity, ft/sec²
- S_e = slope of the energy gradient
- $\overline{u}$ = mean velocity (ft/sec)
- n = Manning's coefficient

Langbien and Durum (1967)

$$K_2^{20} = 3.3\ \overline{u}/d^{1.33} \times 2.31 \qquad \text{III-21}$$

where

- $\overline{u}$ = mean velocity, ft/sec.
- d = mean depth, ft.
- K_2 = reaeration coefficient, 1/day

Tsivoglou and Wallace (1972)

This approach postulates that the reaeration coefficient for a reach is proportional to the change in elevation of the water surface in the reach and inversely proportional to the flow time through the reach.

$$K_2^{20} = K\ (\frac{\Delta h}{t_f}) \qquad \text{III-22}$$

where

- K = constant of proportionality, ft^{-1}
- Δh = change in water surface elevation in reach, ft.
- t_f = flow time within reach, hours

Assuming uniform flow,

$$\Delta h = S_e \, \Delta x \qquad \text{III-2}$$

where

S_e = slope of the energy gradient, ft/ft

Δx = reach length, ft.

The time of passage through a reach is:

$$t_f = \frac{\Delta x}{\bar{u}} \qquad \text{III-24}$$

where

$\bar{u}$ = mean velocity in reach, ft/sec.

Thus, equation III-22 can be rewritten as

$$K_2^{20} = 3600 \; K \; S_e \; \bar{u} \qquad \text{III-25}$$

where the constant 3600 converts velocity to units of ft/hr.

The energy gradient may be input directly as noted in the User's Manual. If it is not specified, S_e is estimated from the Manning equation:

$$S_e = \frac{\bar{u}^2 \; n^2}{(1.49)^2 \; d^{4/3}} \qquad \text{III-26}$$

where

d = mean depth, ft.

n = Manning's coefficient

The constant K should be treated as a variable and determined empirically. A value of 0.0524--English units--for K was derived from data collection in five rivers in the Southeastern United States.

Coliforms

The differential equation that describes the die-off of coliforms in the stream is:

$$\frac{dE}{dt} = - K_5 E \qquad \text{III-27}$$

where

E = the concentration of coliforms

K_5 = coliform die-off rate

Arbitrary Nonconservative Constituent

The differential equation that describes the decay of the arbitrary nonconservative constituent is:

$$\frac{dR}{dt} = -K_6 R$$

where

R = the concentration of the nonconservative constituent

K_6 = decay rate for the constituent

SUMMARY OF MATHEMATICAL RELATIONSHIPS

Table III-1 summarizes the complete set of equations solved by QUAL-II with the exception of the temperature relationships. The equations that describe the temperature routing as well as the associated relationships for all the heat budget terms are described in the next chapter. The equations presented in Table III-1 include the effects of dispersion, advection, constituent reactions and interactions, and a source term. Section V of this documentation describes how QUAL-II is structured to solve these equations.

SUMMARY OF DIFFERENTIAL EQUATIONS TO BE SOLVED BY QUAL-II
(except temperature)

Conservative mineral (c)

$$\frac{\partial c}{\partial t} = \frac{\partial (A_x D_L \frac{\partial c}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u c)}{A_x \partial x} + \frac{S_c}{A_x dx}$$

Algae (A)

$$\frac{\partial A}{\partial t} = \frac{\partial (A_x D_L \frac{\partial A}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u A)}{A_x \partial x} + \frac{S_A}{A_x dx} + (\mu - \rho - \frac{\sigma_1}{}) A$$

Ammonia nitrogen (N_1)

$$\frac{\partial N_1}{\partial t} = \frac{\partial (A_x D_L \frac{\partial N_1}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u N_1)}{A_x \partial x} + \frac{S_{N_1}}{A_x dx} + (\alpha_1 \rho A - \beta_1 N_1 + \frac{\sigma_3}{A_x})$$

Nitrite nitrogen (N_2)

$$\frac{\partial N_2}{\partial t} = \frac{\partial (A_x D_L \frac{\partial N_2}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u N_2)}{A_x \partial x} + \frac{S_{N_2}}{A_x dx} + (\beta_1 N_1 - \beta_2 N_2)$$

Nitrate nitrogen (N_3)

$$\frac{\partial N_3}{\partial t} = \frac{\partial (A_x D_L \frac{\partial N_3}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u N_3)}{A_x \partial x} + \frac{S_{N_3}}{A_x dx} + (\beta_2 N_2 - \alpha_1 \mu A)$$

Dissolved Orthophosphate (P)

$$\frac{\partial P}{\partial t} = \frac{\partial (A_x D_L \frac{\partial P}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u P)}{A_x \partial x} + \frac{S_P}{A_x dx} + (\alpha_2 (\rho - \mu) A - \frac{\sigma_2}{A_x})$$

Biochemical oxygen demand (L)

$$\frac{\partial L}{\partial t} = \frac{\partial (A_x D_L \frac{\partial L}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u L)}{A_x \partial x} + \frac{S_L}{A_x dx} - (K_1 + K_3) L$$

Dissolved oxygen (ϕ)

$$\frac{\partial \phi}{\partial t} = \frac{\partial (A_x D_L \frac{\partial \phi}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u \phi)}{A_x \partial x} + \frac{S_\phi}{A_x dx} + [K_2 (\phi^* - \phi) + (\alpha_3 \mu - \alpha_4 \rho) A - K_1 L - \frac{K_4}{A_x} - \alpha_5 \beta_1 N_1 - \alpha_6 \beta_2 N_2]$$

Coliform (F)

$$\frac{\partial F}{\partial t} = \frac{\partial (A_x D_L \frac{\partial F}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u F)}{A_x \partial x} - \frac{S_F}{A_x dx} - K_5 F$$

Arbitrary Nonconservative (R)

$$\frac{\partial R}{\partial t} = \frac{\partial (A_x D_L \frac{\partial R}{\partial x})}{A_x \partial x} - \frac{\partial (A_x u R)}{A_x \partial x} - \frac{S_R}{A_x dx} - K_6 R$$

REACTION RATES AND PHYSICAL CONSTANTS

The chemical and biological reactions that are simulated by QUAL-II are represented by a complex set of equations that contain many system parameters: some are constants, some are spatially variable, and some are temperature dependent. Table III-2 lists these system parameters and gives the usual range of values, units, types of variation, and reliability of the range for each parameter. Kramer (1970) and Chen and Orlob (1972) give detailed discussions of the basic sources of data, ranges and reliabilities of each of these parameters. Final selection of the values for many of these system parameters should be made during model calibration and verification.

TEMPERATURE DEPENDENCE

All rate constants and other factors (except the saturation concentration of oxygen) that are known to be temperature dependent are formulated according to the relationship:

$$X_T = X_T^{20} \quad \theta^{(T-20)} \qquad \text{III-28}$$

where

X_T = the value of the variable at the local temperature, T(°C)

X_T^{20} = the value of the variable at 20°C

θ = an empirical constant for each temperature dependent system variable
= 1.0159 for K_2
= 1.047 for all others

TABLE III-2

INPUT PARAMETERS FOR QUAL-II

INPUT PARAMETER NAME IN EQU.	NAME IN QUAL	DESCRIPTION	UNITS	RANGE OF VALUES	VARIABLE BY REACH	TEMPERATURE DEPENDENT	RELIABILITY
•	ALPHAØ	Ratio of chlorophyll a to algae biomass	$\frac{\mu g\ Chl\text{-}A}{mg\ A}$	50-100	Yes	No	Fair
1	ALPHA1	Fraction of algae biomass which is N	$\frac{mg\ N}{mg\ A}$	0.08-0.09	No	No	Good
2	ALPHA2	Fraction of algae biomass which is P	$\frac{mg\ P}{mg\ A}$	0.012-0.015	No	No	Good
3	ALPHA3	O_2 production per unit of algae growth	$\frac{mg\ O}{mg\ A}$	1.4-1.8	No	No	Good
4	ALPHA4	O_2 uptake per unit of algae respired	$\frac{mg\ O}{mg\ A}$	1.6-2.3	No	No	Fair
5	ALPHA5	O_2 uptake per unit of NH_3 oxidation	$\frac{mg\ O}{mg\ N}$	3.0-4.0	No	No	Good
6	ALPHA6	O_2 uptake per unit of NO_2 oxidation	$\frac{mg\ O}{mg\ N}$	1.0-1.14	No	No	Good
max	GRØMAX	Maximum specific growth rate of algae	$\frac{1}{day}$	1.0-3.0	No	Yes	Good
	RESPRT	Algae respiration rate	$\frac{1}{day}$	0.05-0.5	No	Yes	Fair
1	CKNH3	Rate constant for biological oxidation of $NH_3 \rightarrow NO_2$	$\frac{1}{day}$	0.1-0.5	Yes	Yes	Fair
2	CKNØ2	Rate constant for biological oxidation of $NO_2 \rightarrow NO_3$	$\frac{1}{day}$	0.5-2.0	Yes	Yes	Fair
1	ALGSET	Local settling rate for algae	$\frac{ft}{day}$	0.5-6.0	Yes	No	Fair
2	SPHØS	Benthos source rate for phosphorus	$\frac{mg\ P}{day\text{-}ft}$	*	Yes	No	Poor
3	SNH3	Benthos source rate for NH	$\frac{mg\ N}{day\text{-}ft}$	*	Yes	No	Poor
1	CK1	Carbonaceous BOD decay rate	$\frac{1}{day}$	0.1-2.0	Yes	Yes	Poor
2	CK2	Reaeration rate	$\frac{1}{day}$	0.0-100	Yes	Yes	Good
3	CK3	Carbonaceous BOD sink rate	$\frac{1}{day}$	-0.36-0.36	Yes	No	Poor
	CK4	Benthos source rate for BOD	$\frac{mg}{day\text{-}ft}$	*	Yes	No	Poor
	CK5	Coliform die-off rate	$\frac{1}{day}$	0.5-4.0	Yes	Yes	Fair
	CK6	Arbitrary nonconservative decay rate	$\frac{1}{day}$	*	Yes	Yes	*
	CKN	Nitrogen half-saturation constant for algae growth	$\frac{mg}{\ell}$	0.2-0.4	No	No	Fair to Good
	CKP	Phosphorus half-saturation constant for algae growth	$\frac{mg}{\ell}$	0.03-0.05	No	No	Fair to Good
	CKL	Light half-saturation constant for algae growth	$\frac{Langleys}{min.}$	.03	No	No	Good

*ghly variable

IV. FUNCTIONAL REPRESENTATION OF TEMPERATURE

THE BASIC TEMPERATURE EQUATION

The basic mass transport equation for QUAL-II was given in Section II as (see equation II-3):

$$\frac{\partial C}{\partial t} = \frac{\partial (A_x D_L \frac{\partial C}{\partial x})}{A_x \, \partial x} - \frac{\partial (A_x \, \bar{u} \, C)}{A_x \, \partial x} + \frac{dC}{dt} + \frac{s}{V} \qquad \text{IV-1}$$

In temperature modeling, C is taken as the concentration of heat (HL^{-3}) which can be equated to temperature through the relationship:

$$C = \rho \, c \, (T - T_0) \qquad \text{IV-2}$$

where

- ρ = the density of water ($M \, L^{-3}$)
- c = the heat capacity of water ($HM^{-1} \, D^{-1}$)
- T = the water temperature
- T_0 = an arbitrary base temperature
- D = degrees

The parameters ρ and c can be considered constant for practical purposes. Also, internal heat generation, $\frac{dC}{dt}$, which results from viscous dissipation of energy and boundary friction, is generally so small as to be negligible. Thus setting $\frac{dC}{dt} = 0$ in equation IV-1 and substituting equation IV-2 for C gives us (after some simplification):

$$\frac{\partial T}{\partial t} = \frac{\partial (A_x D_L \frac{\partial T}{\partial x})}{A_x \, \partial x} - \frac{\partial (A_x \, \bar{u} \, T)}{A_x \, \partial x} + \frac{1}{\rho c} \frac{s}{V} \qquad \text{IV-3}$$

The source term s/V, which has units of $HL^{-3}T,^{-1}$ accounts for all heat transferred across the system boundaries, i.e. heat transferred across the air-water interface and heat conducted across mud-water interface.

Heat transfer across the mud-water interface is generally insignificant; hence, s/V takes on the identify of the net rate of heat input, per unit volume of stream, through the air-water interface.

It is most convenient to represent the interfacial heat transfer rate as a flux H_N having units of $(HL^{-2}T^{-1})$. For a stream element of length dx and mean surface width W, H_N is related to s/V as follows.

The total rate of heat input across the air-water interface is H_N dx W. This heat is distributed uniformly throughout the underlying volume of $\bar{A}_x$ dx, where $\bar{A}x$ is the mean cross-sectional area of the element, thus the rate of heat gain per unit volume of water, s/V, is computed as:

$$\frac{s}{V} = \frac{s}{\bar{A}_x\, dx} = \frac{H_N\,(Wdx)}{\bar{A}_x\, dx} = \frac{H_N}{d} \qquad \text{IV-4}$$

where $d = \bar{A}_x/W$ is the hydraulic depth of the stream. Substituting equation IV-4 into equation IV-3 gives the generalized form of the temperature equation as:

$$\frac{\partial T}{\partial t} = \frac{\partial(A_x D_L \frac{\partial T}{\partial x})}{A_x\, \partial x} - \frac{\partial(A_x\, \bar{u}\, T)}{A_x\, \partial x} + \frac{H_N}{\rho c d} \qquad \text{IV-5}$$

DEFINITION OF H_N

Heat is transferred across the air-water interface of a surface water body by three difference processes: radiation exchange, evaporation, and conduction. The individual heat terms associated with these processes are shown in Figure IV-1 and are defined in Table IV-1 along with the typical ranges of their magnitudes in northern latitudes.

The expression that results from the summation of these various energy fluxes is:

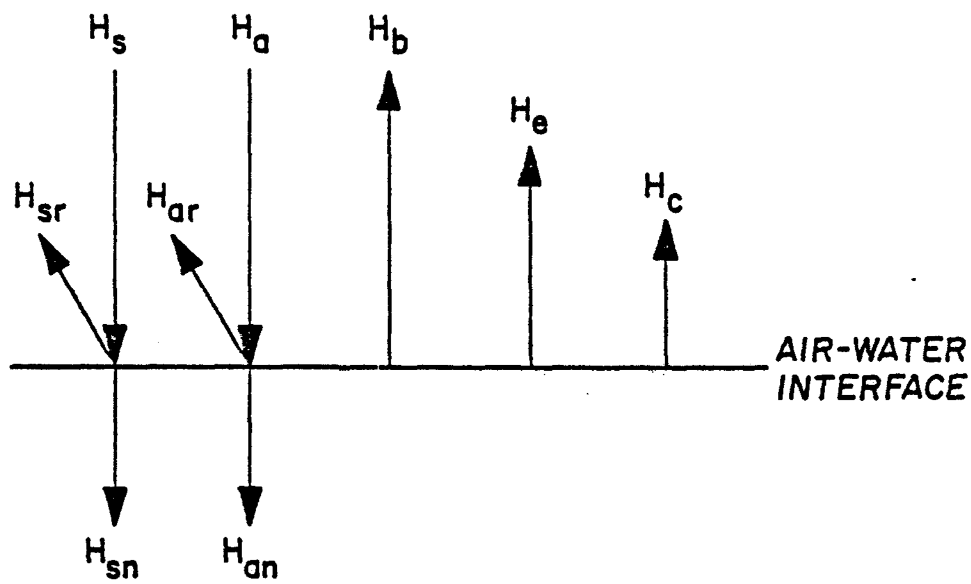

FIGURE IV-1

HEAT TRANSFER TERMS ASSOCIATED WITH
INTERFACIAL HEAT TRANSFER

TABLE IV-1

DEFINITION OF HEAT TRANSFER TERMS
ILLUSTRATED IN FIGURE 1

	Heat Term	Units	Magnitude (BTU ft^{-2} day^{-1})
H_s	= total incoming solar or short-wave radiation	$HL^{-2}T^{-1}$	400-2800
H_{sr}	= reflected short-wave radiation	$HL^{-2}T^{-1}$	40-200
H_a	= total incoming atmospheric radiation	$HL^{-2}T^{-1}$	2400-3200
H_{ar}	= reflected atmospheric radiation	$HL^{-2}T^{-1}$	70-120
H_b	= back radiation from the water surface	$HL^{-2}T^{-1}$	2400-3600
H_e	= heat loss by evaporation	$HL^{-2}T^{-1}$	150-3000
H_c	= heat loss by conduction to atmosphere	$HL^{-2}T^{-1}$	-320 to +400

$$H_N = H_{sn} + H_{an} - (H_b \pm H_c + H_e) \qquad \text{IV-6}$$

where

H_N = net energy flux passing the air-water interface, Btu/ft²-day

H_{sn} = net short-wave solar radiation flux passing through the interface after losses due to absorption and scattering in the atmosphere and by reflection at the interface, Btu/ft²-day

H_{an} = net long-wave atmospheric radiation flux passing through the interface after reflection, Btu/ft²-day

H_b = outgoing long-wave back radiation flux, Btu/ft²-day

H_c = convective energy flux passing back and forth between the interface and the atmosphere, Btu/ft²-day

H_e = energy loss by evaporation, Btu/ft²-day

These mechanisms by which heat is exchanged between the water surface and the atmosphere are fairly well understood and are adequately documented in the literature by Edinger and Geyer (1965). The functional representation of these terms has been defined by Water Resources Engineers, Inc. (1967). The formulations reported here were extracted from that more detailed work by Frank D. Masch and Associates and the Texas Water Development Board (1971).

NET SHORT-WAVE SOLAR RADIATION

The net incoming solar radiation is short-wave radiation which passes directly from the sun to the earth's surface. Its magnitude depends on: the altitude of the sun, which varies daily as well as seasonally for a fixed location on the earth; the dampening effect of scattering and absorption in the atmosphere due to cloud cover; and the reflection from the water surface.

The net amount of solar radiation which reaches the surface of the earth may be represented functionally on an hourly basis as:

$$H_{sn} = \underbrace{H_o}_{(i)}\underbrace{a_t}_{(ii)}\underbrace{(1 - R_s)}_{(iii)}\underbrace{(1 - 0.65C_L^2)}_{(iv)} \qquad \text{IV-7}$$

where

H_{sn} = net short-wave solar radiation flux, Btu/ft²-hour

H_o = amount of radiation flux reaching the earth's atmosphere, Btu/ft²-hour

a_t = atmospheric transmission term

R_s = Albedo or reflection coefficient

C_L = cloudiness as a fraction of sky covered

It is appropriate for purposes of the discussion here to identify and treat separately the four components in equation IV-7 as (i) extra-terrestrial solar radiation, (ii) radiation scattering and absorption, (iii) reflectivity, and (iv) cloudiness.

Extraterrestrial Radiation

The short-wave solar radiation flux that strikes the earth's outer atmosphere over a given period of time is given by Water Resources Engineers, Inc. (1967) as:

$$H_o = \frac{H_{sc}}{r^2}\{\sin\frac{\pi\phi}{180}\sin\delta\,(t_e - t_b) + \frac{12}{\pi}\cos\frac{\pi\phi}{180}\cos\delta\,[\sin(\frac{\pi t_e}{12}) - \sin(\frac{\pi t_b}{12})]\}\,\Gamma \qquad \text{IV-8}$$

where

H_{sc} = solar constant = 438.0 Btu/ft²-hour

r = normalized radius of the earth's orbit

ϕ = latitude of the site, degrees

δ = declination of the sun, degrees

t_b, t_e = hour angles corresponding to the beginning and end, respectively, of any time interval between sunrise and sunset

Γ = a correction factor for diurnal exposure to radiation flux.

Several parameters in equation IV-8 requiring further definition are described by Water Resources Engineers, Inc. (1967).

Relative Earth-Sun Distance

$$r = 1.0 + 0.17 \cos \left[\frac{2\pi}{365}(186\text{-}Dy)\right] \qquad \text{IV-9}$$

where Dy is the number of the day of the year (beginning January 1).

Declination

$$\delta = \frac{23.45}{180}\pi \cos \left[\frac{2\pi}{365}(173\text{-}Dy)\right] \qquad \text{IV-10}$$

Hour Angles

$$t_b = ST_b - \Delta t_s + ET - 12 \qquad \text{IV-11}$$

and

$$t_e = ST_e - \Delta t_s + ET - 12 \qquad \text{IV-12}$$

where ST_b, ST_e are the standard times at the beginning and end of the time interval selected.

ET = an expression for time from a solar ephemeris which represents the difference in hours between "true solar time" and that computed on the basis of a year average. It is given for each day of the year, Dy, by

$$ET = 0.000121 - 0.12319 \sin \left[\frac{2\pi}{365}(Dy\text{-}1) - 0.0714\right]$$

$$- 0.16549 \sin \left[\frac{4\pi}{365}(Dy\text{-}1) + 0.3088\right] \qquad \text{IV-13}$$

Δt_s = difference between standard and local civil time in hours as determined from

$$\Delta t_s = \frac{\varepsilon}{15}(L_{sm} - L_{lm}) \qquad \text{IV-14}$$

where

ε = -1 for west longitude

ε = +1 for east longitude

L_{sm} = longitude of standard meridian, degrees

L_{lm} = longitude of local meridian, degrees

Diurnal Exposure

$$\Gamma = 1 \text{ when } ST_r \leq ST_b \text{ or } ST_e \leq ST_s \qquad \text{IV-15}$$

$$\Gamma = 0 \text{ when } ST_s \leq ST_b \text{ or } ST_e \leq ST_r \qquad \text{IV-16}$$

where ST_r and ST_s are the standard times of sunrise and sunset, respectively, as determined from:

$$ST_r = 12 - \frac{12}{\pi} \text{ arc cos } [\tan (\frac{\pi\phi}{180}) \tan \delta] + \Delta t_s \qquad \text{IV-17}$$

and

$$ST_s = 24 - ST_r + 2\Delta t_s \qquad \text{IV-18}$$

Radiation Scattering and Absorption

The atmospheric transmission term, a_t, is given by Water Resources Engineers, Inc. (1967) as:

$$a_t = \frac{a'' + 0.5 (1 - a' - d)}{1 - 0.5 R_s(1 - a' + d)} \qquad \text{IV-19}$$

in which a" is the mean atmospheric transmission coefficient after scattering and absorption given by:

$$a'' = \exp \{- [0.465 + 0.0408 P_{wc}] [0.179 + 0.421 \exp (-0.721 \theta_{am})] \theta_{am}\} \qquad \text{IV-20}$$

where θ_{am} is the optical air mass given by the expression:

$$\theta_{am} = \frac{\exp(-Z/2532)}{\sin\alpha + 0.15\left(\frac{180\alpha}{\pi} + 3.885\right)^{-1.253}} \qquad \text{IV-21}$$

in which

Z = elevation of the site in feet

α = sun's altitude in radians given by

$$\alpha = \text{arc sin}\left[\sin\frac{\pi\phi}{180}\sin\delta + \cos\frac{\pi\phi}{180}\cos\delta\cos\frac{\pi t}{12}\right] \qquad \text{IV-22}$$

in which t is the hour angle, described by an equation similar to equations IV-11 and IV-12.

P_{wc} in equation IV-20 is the mean daily precipitable water content in the atmosphere, given by the expression

$$P_{wc} = 0.00614 \exp(0.0489 T_d) \qquad \text{IV-23}$$

where T_d is the dewpoint in °F, which can be obtained from the expression:

$$T_d = \ln[(e_a + 0.0837)/0.1001]/0.03 \qquad \text{IV-24}$$

where e_a is the water vapor pressure of the air.

The mean atmospheric coefficient, a', can also be represented by an equation of the form of equation IV-20 as:

$$a' = \exp\{-[0.465 + 0.0408 P_{wc}][0.129 + 0.171\exp(-0.880\,\theta_{am})]\,\theta_{am}\} \qquad \text{IV-25}$$

Dust attenuation of the solar radiation flux, which is represented in equation IV-19 by the quantity d, varies with optical air mass, season of the year, and geographic location. Water Resources Engineers, Inc. (1967) gives a range of 0-0.13 for several locations.

Cloudiness

The dampening effect on the solar radiation flux is given by Water Resources Engineers, Inc. (1967) as

$$C_s = 1.0 - 0.65\, C_L^2 \qquad \text{IV-26}$$

where C_L is the decimal fraction of the sky covered. Water Resources Engineers, Inc. (1967) reports that equation IV-26 gives satisfactory results except for heavy overcast conditions, i.e. when C_L approaches 1.0.

Reflectivity

The reflection coefficient, R_s, can be approximately computed as a function of the solar altitude, α, by Anderson's (1954) empirical formula:

$$R_s = A\alpha^B \qquad \text{IV-27}$$

where α is in degrees, and A and B are functions of cloudiness, C_L. Values for A and B given by Anderson (1954) are shown in Table IV-2.

TABLE IV-2

EMPIRICAL COEFFICIENTS FOR DETERMINING R_s
After Anderson (1954)

Cloudiness C_L	0 Clear		0.1 - 0.5 Scattered		0.6 - 0.9 Broken		1.0 Overcast	
Coefficients	A	B	A	B	A	B	A	B
	1.18	-0.77	2.20	-0.97	0.95	-0.75	0.35	-0.45

LONG-WAVE ATMOSPHERIC RADIATION

The long-wave radiation emitted by the atmosphere varies directly with the moisture content of the atmosphere. Although it is primarily dependent on air temperature and humidity, it can also be affected by ozone, carbon dioxide, and possibly other materials in the atmosphere. Anderson (1954) indicated that the amount of atmospheric radiation is also significantly affected by cloud height. The amount of long-wave atmospheric radiation that is reflected is approximately a constant fraction of the incoming radiation. Anderson (1954) found this fraction to be approximately 0.03.

The net atmospheric radiation flux can be expressed as:

$$H_{an} = [2.89 \times 10^{-6}]\, \sigma\, (T_a + 460)^6\, (1.0 + 0.17C_L^2)\, (1 - R_L) \qquad \text{IV-28}$$

where

H_{an} = net long-wave atmospheric radiation flux, Btu/ft²/hour

σ = Stefan-Boltzman constant, 1.73×10^{-9} Btu/ft²/hour/°Rankine^4

T_a = air temperature at a level 6 feet above the water surface, °F

R_L = reflectivity of the water surface for atmospheric radiation = 0.03

WATER SURFACE BACK RADIATION

The third source of radiation transfer through the air-water interface is long-wave back radiation from the water surface, H_b, which represents a loss of heat from the water. It can be seen from Table IV-1 that back radiation accounts for a substantial portion of the heat loss from a body of water. This loss is expressed by the Stefan-Boltzman Fourth Power Radiation Law for a blackbody as:

$$H_b = 0.97\,\sigma\,(T_s + 460)^4 \qquad \text{IV-29}$$

where

H_b = water surface back radiation flux, Btu/ft²/hour

T_s = water surface temperature, °F

Equation IV-29 can be linearized over a given temperature range as:

$$H_b = \alpha_2 + \beta_2\,T_s \qquad \text{IV-30}$$

where

α_2, β_2 = constants defined over the range

In the steady-state temperature solution, this linearized version of the back radiation equation is used to allow the temperature dependent terms to be separated out of the equation. Sets of α_2, β_2 are specified for 21 5°F temperature intervals between 35°F and 135°F. For dynamic simulations the heat flux term calculations are based on the temperature at the beginning of the time step.

EVAPORATION

A water body also loses heat to the atmosphere by evaporation. Each pound of water that leaves as water vapor carries its latent heat of vaporization (approximately 1050 BTU at 60°F) plus its sensible heat. Therefore, evaporation also represents a significant loss of heat.

This heat loss can be expressed as:

$$H_e = \gamma\,H_L E + H_v \qquad \text{IV-31}$$

where

γ = specific weight of the water being evaporated, lb/ft³

H_L = latent heat of vaporization, Btu/lb, given by

H_L = 1084 - 0.5 T_s

E = evaporation rate, ft/hour

H_v = sensible heat loss Btu/ft²/hour

The evaporation rate, E, is most often expressed as

$$E = (a + bW)(e_s - e_a) \qquad \text{IV-32}$$

where

a,b = constants

W = wind speed, in mph, measured 6 feet above the water surface

e_s = saturation vapor pressure of the air, in. of Hg, at the temperature of the water surface, as given by

$$e_s = 0.1001 \exp(0.03\,T_s) - 0.0837 \qquad \text{IV-33}$$

and

e_a = water vapor pressure, in. of Hg, at a height of 6 feet above the water surface, given as

$$e_a = e_{wb} - 0.000367\,P_a\,(T_a - T_{wb})\left(1.0 + \frac{T_{wb} - 32}{1571}\right) \qquad \text{IV-34}$$

where

e_{wb} = saturation vapor pressure, in. of Hg, at the wet bulb temperature from the expression

$$e_{wb} = 0.1001 \exp(0.03\,T_{wb}) - 0.0837 \qquad \text{IV-35}$$

P_a = local barometric pressure, in. of Hg

T_{wb} = wet bulb temperature, °F

The literature contains a wide range of values for the evaporation constants a and b. Roesner (1969) reports that a good average value of a would be 6.8×10^{-4} ft/hour-in. of Hg, while b would best be represented by 2.7×10^{-4} ft/hour-in. of Hg.-mph.

To linearize the variation of evaporation rate with surface water temperature T_s, equation IV-34 is approximated over 5°F intervals as:

$$e_s = \alpha_1 + \beta_1 T_s \qquad \text{IV-36}$$

Sets of α_1, β_1 are specified for 21 5°F intervals between 35°F and 135°F. The linearized evaporation expression is used in the steady-state temperature solution.

The sensible evaporative heat loss can be expressed simply as:

$$H_V = c \gamma E (T_s - T_o) \qquad \text{IV-37}$$

where

c = heat capacity of water = 1 Btu/lb/°F

T_o = reference temperature, °F

Sensible heat loss is very small compared to the other heat loss components in the energy budget and thus is not included in the QUAL-II temperature computation.

CONDUCTION

Heat that is transferred between the water and the atmosphere due to a temperature difference between the two phases is normally called conduction. Using the fact that transfer by conduction is a function of the same variables as evaporation, it is possible to arrive at a proportionality between heat conduction and heat loss by evaporation. This proportionality, known as Bowen's ratio, is expressed as:

$$B = \frac{H_c}{H_e} = C_B \left[\frac{T_s - T_a}{e_s - e_a}\right] \frac{P_a}{29.92} \qquad \text{IV-38}$$

where C_B is a coefficient ≅ 0.01.

By using Bowen's ratio, the rate of heat loss to the atmosphere by heat conduction, H_c, can be defined as:

$$H_c = \gamma H_L (a + bW) \left(0.01 \frac{P_a}{29.92}\right) (T_s - T_a) \qquad \text{IV-39}$$

For practical purposes, the ratio (P_a/29.92) can be taken as unity.

V. COMPUTATIONAL REPRESENTATION

PROTOTYPE REPRESENTATION

To expand upon the basic conceptual representation presented in Section II, QUAL-II permits any branching, one-dimensional stream system to be simulated. The first step involved in approximating the prototype is to subdivide the stream system into <u>reaches</u>, which are stretches of stream that have uniform hydraulic characteristics. Each reach is then divided into computational elements of equal length so that all computational elements in all reaches are the same length. Thus, all reaches must consist of an integer number of computational elements.

In total, there are seven different types of computational elements; these are:

1. Headwater element
2. Standard element
3. Element just upstream from a junction
4. Junction element
5. Last element in system
6. Input element
7. Withdrawal element

Headwater elements begin every tributary as well as the main river system, and as such, they must always be the first element in a reach. A standard element is one that does not qualify as one of the remaining six element types. Since incremental inflow is permitted in all element types, the only input permitted in a standard element is incremental inflow. A type 3 element is used to designate an element on the mainstem that is just upstream from a junction element (type 4) which is an element that has a simulated tributary entering it. Element type 5 identifies the last computational element in the river system; there should be only one element type 5. Element types 6 and 7 represent elements which have inputs (waste loads and unsimulated tributaries) and water withdrawals, respectively.

River reaches, which are aggregates of computational elements, are the basis of most data input. Hydraulic data, reaction rate coefficients, initial conditions, and incremental runoff data are constant for all computational elements within a reach.

MODEL LIMITATIONS

QUAL-II has been developed to be a relatively general program; however, certain dimensional limitations have been imposed upon it during program development. These limitations are as follows:

Reaches: a maximum of 75

Computational elements: no more than 20 per reach
or 500 in total

Headwater elements: a maximum of 15

Junction elements: a maximum of 15

Input and withdrawal elements: a maximum of 90 in total

QUAL-II can be used to simulate any combination of the following parameters or groups of parameters:

1. Conservative minerals (up to three at a time)
2. Temperature
3. BOD
4. Chlorophyll a
5. Dissolved orthophosphate as phosphorus
6. Ammonia, nitrite and nitrate as nitrogen
7. Dissolved oxygen
8. Coliforms
9. An arbitrary nonconservative constituent

All parameters can be simulated under either steady-state or dynamic conditions. If either phosphorus or the nitrogen cycle are not being simulated, the model presumes they will not limit algal growth.

NUMERIC SOLUTION TECHNIQUE

At each time step and for each constituent, equation II-3 can be written I times, once for each of the I computational elements in the network. Since it is not possible to obtain analytical solutions to these equations under most prototype situations, a finite difference method is used, more specifically, the classical implicit backward difference method (see Smith, 1966).

The general basis of a finite difference scheme is to find the value of a variable (e.g., constituent concentration) as a function of space at a time step n+1 when its spatial distribution at the n^{th} time step is known. Time step zero corresponds to the initial condition. Backward difference or implicit schemes are characterized by the fact that all spatial derivatives ($\partial/\partial x$) are approximated in difference form at time step n+1.

Formulation of the Finite Difference Scheme

The finite difference scheme is formulated by considering the constituent concentration, C, at four points in the mnemonic scheme as shown in Figure V-1.

Three points are required at time n+1 to approximate the spatial derivatives. The temporal derivative is approximated at distance step i.

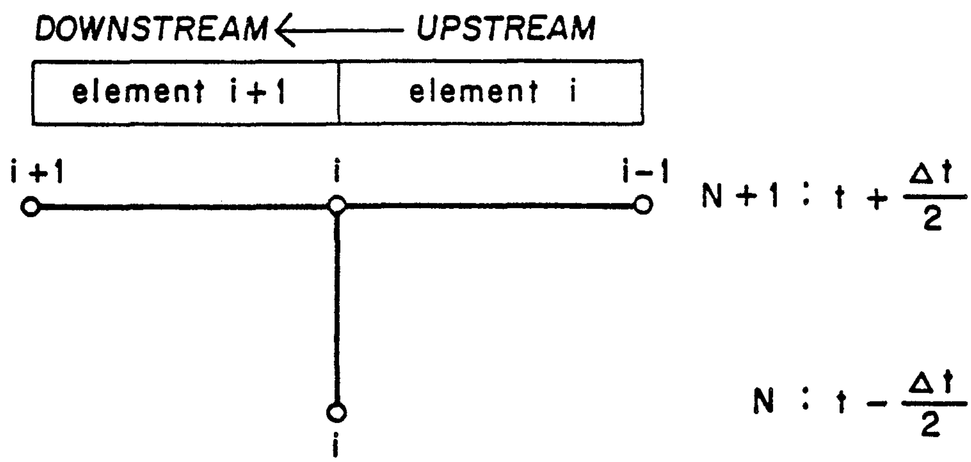

FIGURE V-1
CLASSICAL IMPLICIT NODAL SCHEME

Equation II-3 can be written in finite difference form in two steps. First, the advection and diffusion terms are differentiated once with respect to x giving:

$$\frac{\partial C_i}{\partial t} = \frac{\left(AD_L \frac{\partial C}{\partial x}\right)_i - \left(AD_L \frac{\partial C}{\partial x}\right)_{i-1}}{V_i} - \frac{(A\,\bar{u}\,C)_i - (A\,\bar{u}\,C)_{i-1}}{V_i}$$

$$+ \frac{dC_i}{dt} + \frac{s_i}{V_i} \qquad \text{V-1}$$

where

$$V_i = A_i\,\Delta x_i$$

Secondly, expressing the spatial derivative of the diffusion terms in finite difference and thence the time derivative of C in finite difference, there results:

$$\frac{C_i^{n+1} - C_i^{n}}{\Delta t} = \left\{ \frac{[(AD_L)_i]\,C_{i+1}^{n+1} - [(AD_L)_i]\,C_i^{n+1}}{V_i\,\Delta x_i} - \frac{[(AD_L)_{i-1}]\,C_i^{n+1} - [(AD_L)_{i-1}]\,C_{i-1}^{n+1}}{V_i\,\Delta x_i} \right\}$$

$$- \left\{ \frac{Q_i\,C_i^{n+1} - Q_{i-1}\,C_{i-1}^{n+1}}{V_i} \right\} + r_i\,C_i^{n+1} + p_i + \frac{s_i}{V_i} \qquad \text{V-2}$$

In equation V-2, the term dC/dt is expressed as:

$$\frac{dC_i}{dt} = r_i\,C_i^{n+1} + p_i$$

where

r_i = rate constant

p_i = internal constituent sources and sinks (e.g. nutrient loss from algal growth, benthos sources, etc.)

Note that the $\frac{dC}{dt}$ for every constituent modeled by QUAL-II can be expressed in this form (see Table III-1 and equation IV-5).

If equation V-2 is rearranged in terms of the coefficients of C_{i-1}^{n+1}, C_i^{n+1}, and C_{i-1}^{n+1}, we obtain the equation:

$$a_i \, C_{i-1}^{n+1} + b_i \, C_i^{n+1} + c_i \, C_{i+1}^{n+1} = Z_i \qquad \text{V-3}$$

where

$$a_i = - \left[(AD_L)_{i-1} \frac{\Delta t}{V_i \, \Delta x_i} + \frac{Q_{i-1} \, \Delta t}{V_i} \right]$$

$$b_i = 1.0 + [(AD_L)_i + (AD_L)_{i-1}] \frac{\Delta t}{V_i \, \Delta x_i} + Q_i \frac{\Delta t}{V_i} - r_i \, \Delta t$$

$$c_i = - \left[(AD_L)_i \frac{\Delta t}{V_i \, \Delta x_i} \right]$$

$$Z_i = C_i^n + \frac{s_i \, \Delta t}{V_i} + p_i \, \Delta t$$

The values of a_i, b_i, c_i, and Z_i are all known at time n, while the C_i^{n+1} terms are the unknowns at time step n+1.

In the case of a junction element with a tributary upstream element, the basic equation becomes:

$$a_i \, C_{i-1}^{n+1} + b_i \, C_i^{n+1} + c_i \, C_{i+1}^{n+1} + d_j \, C_j^{n+1} = Z_i \qquad \text{V-4}$$

where

$$d_j = - [(AD)_j \frac{\Delta t}{V_i \, \Delta x_i} + \frac{Q_j \, \Delta t}{V_i}]$$

j = the element upstream of junction element i

C_j^{n+1} = concentration of constituent in element j at time n+1

It can be seen that the d_j term is analogous to the a_i term. Both terms account for mass inputs from upstream due to dispersion and advection.

Under steady-state conditions, $\frac{\partial C_i}{\partial t} = 0$ in equation V-1. Working through the finite difference approximations and rearranging terms as before, the steady-state version of equation V-3 is derived:

$$a_i \, C_{i-1}^{n+1} + b_i \, C_i^{n+1} + c_i \, C_{i+1}^{n+1} = Z_i \qquad \text{V-5}$$

where

$$a_i = -[\frac{(AD_L)_{i-1}}{V_i \Delta x_i} + \frac{Q_{i-1}}{V_i}]$$

$$b_i = [\frac{(AD_L)_i}{V_i \Delta x_i} + \frac{(AD_L)_{i-1}}{V_i \Delta x_i} + \frac{Q_i}{V_i} - r_i]$$

$$c_i = [\frac{(AD_L)_i}{V_i \Delta x_i}]$$

$$Z_i = \frac{A_i}{V_i} + p_i$$

Note that equation V-5 is the same as equation V-3, with the following changes:

- Δt equals 1.0
- the constant 1.0 in b_i = 0.0
- the initial concentration C_i^n in Z_i = 0.0

Method of Solution

Equations V-3 and V-5 each represent a set of simultaneous linear equations whose solution provides the values of C_i^{n+1} for all i's. Expressed in matrix form this set of equations appears as:

$$
\begin{bmatrix}
b_1 & c_1 & & & & & & \\
a_2 & b_2 & c_2 & & & & & \\
 & a_3 & b_3 & c_3 & & & & \\
 & & \cdot & \cdot & \cdot & & & \\
 & & & a_i & b_i & c_i & & \\
 & & & & \cdot & \cdot & \cdot & \\
 & & & & & a_{I-1} & b_{I-1} & c_{I-1} \\
 & & & & & & a_I & b_I
\end{bmatrix}
\times
\begin{bmatrix}
C_1^{n+1} \\ C_2^{n+1} \\ C_3^{n+1} \\ \vdots \\ C_i^{n+1} \\ \vdots \\ C_{I-1}^{n+1} \\ C_I^{n+1}
\end{bmatrix}
=
\begin{bmatrix}
Z_1 \\ Z_2 \\ Z_3 \\ \vdots \\ Z_i \\ \vdots \\ Z_{I-1} \\ Z_I
\end{bmatrix}
\qquad \text{V-6}
$$

The left matrix is a tri-diagonal matrix. An efficient method that readily lends itself to a computer solution of such a set of equations is as follows:

1) Divide through the first equation in V-6 by b_1 to obtain:

$$
C_1^{n+1} + W_1 \, C_2^{n+1} = G_1 \qquad \text{V-7}
$$

where

$$
W_1 = c_1/b_1 \text{ and } G_1 = Z_1/b_1.
$$

2) Combine the expression for b_i (see V-3) and the second equation in V-6 to eliminate a_2 and the result is:

$$
C_2^{n+1} + W_2 \, C_3^{n+1} = G_2 \qquad \text{V-8}
$$

where

$$
W_2 = \frac{c_2}{b_2 - a_2 W_1} \quad \text{and} \quad G_2 = \frac{Z_2 - a_2 G_1}{b_2 - a_2 W_1}
$$

3) Combine equation V-8 and the third equation in V-6 to eliminate a_3 and the result is:

$$C_3^{n+1} + W_3 C_4^{n+1} = G_3 \qquad \text{V-9}$$

where

$$W_3 = \frac{c_3}{b_3 - a_3 W_2} \quad \text{and} \quad G_3 = \frac{Z_3 - a_3 G_2}{b_3 - a_3 W_2}$$

4) Proceed through the equations, eliminating a_i and storing the values of W_i and G_i given by:

$$W_i = \frac{c_i}{b_i - a_i W_{i-1}}, \; i = 2, 3, \ldots, I \qquad \text{V-10}$$

and

$$G_i = \frac{Z_i - a_i G_{i-1}}{b_i - a_i W_{i-1}}, \; i = 2, 3, \ldots, I \qquad \text{V-11}$$

5) The last equation is solved for C_I^{n+1} by

$$C_I^{n+1} = G_I \qquad \text{V-12}$$

6) Solve for $C_{i-1}^{n+1}, C_{i-2}^{n+1}, \ldots, C_1^{n+1}$ by back substitution.

$$C_i^{n+1} = G_i - W_i C_{i+1}^{n+1}, \; i = I-1, I-2, \ldots, 1 \qquad \text{V-13}$$

Boundary Conditions

Upstream

In most situations of interest, transport is unidirectional in nature, i.e., there is no significant transport upstream. Therefore, the concentration at some point just upstream from the upper end of the stream reach of interest can be used as the boundary condition. Hence, Z_1 in equation V-3 is taken as:

$$Z_1 = C_1^{\,n} + \frac{s\,\Delta t}{V_1} + p_i\,\Delta t - a_1\,C_o^{n+1} \qquad \text{V-14}$$

where C_o^{n+1} is the boundary condition (headwater concentration).

Downstream

For the boundary condition at the downstream end of the system it is possible to assume a fictitious boundary condition at a point only slightly downstream from the lower end of the reach of interest. This is possible because the magnitudes of D_L and $\bar{u}$ in virtually all situations of interest are such that the downstream boundary condition has very little effect on the water upstream. Then, one can let

$$C_{I+1}^{n+1} = C_I^{n+1} \qquad \text{V-15}$$

where C_{I+1}^{n+1} is the concentration just downstream from the end of the system.

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VI. COMPUTER PROGRAM DESCRIPTION

MODEL STRUCTURE AND SUBROUTINES

QUAL-II is structured as one main program, QUAL2, supported by 23 different subroutines. Figure VI-1 graphically illustrates the functional relationships between the main program and its subroutines. The original version of QUAL, as programmed by William A. White, was structured to permit the addition of parameters easily through addition of subroutines. This basic concept, which proved to be an extremely valuable one, was maintained in the extension of the original version to QUAL-II. Thus, if it becomes desirable at some later time to add new parameters or modify existing parameter relationships, the changes can be made with a minimum of model restructuring.

This section describes the main program QUAL2, and its 23 subroutines. Each program description contains: (1) a brief written description of what the program does, including mathematical relationships; (2) a program flow chart; and (3) a program listing. Section VII contains definitions of all program variables in COMMON storage.

MAIN PROGRAM QUAL2

QUAL2 is the main program of QUAL-II; it calls most of the subroutines, computes some miscellaneous constants, sets up the initial conditions, performs the convergence checks when a steady-state problem is being solved, and controls the printing of the output reports. The only subroutines not called by the main program are HEATEX, HEATER, and CHANL, which are called by Subroutines TEMPS, TEMPSS, and HYDRAU, respectively.

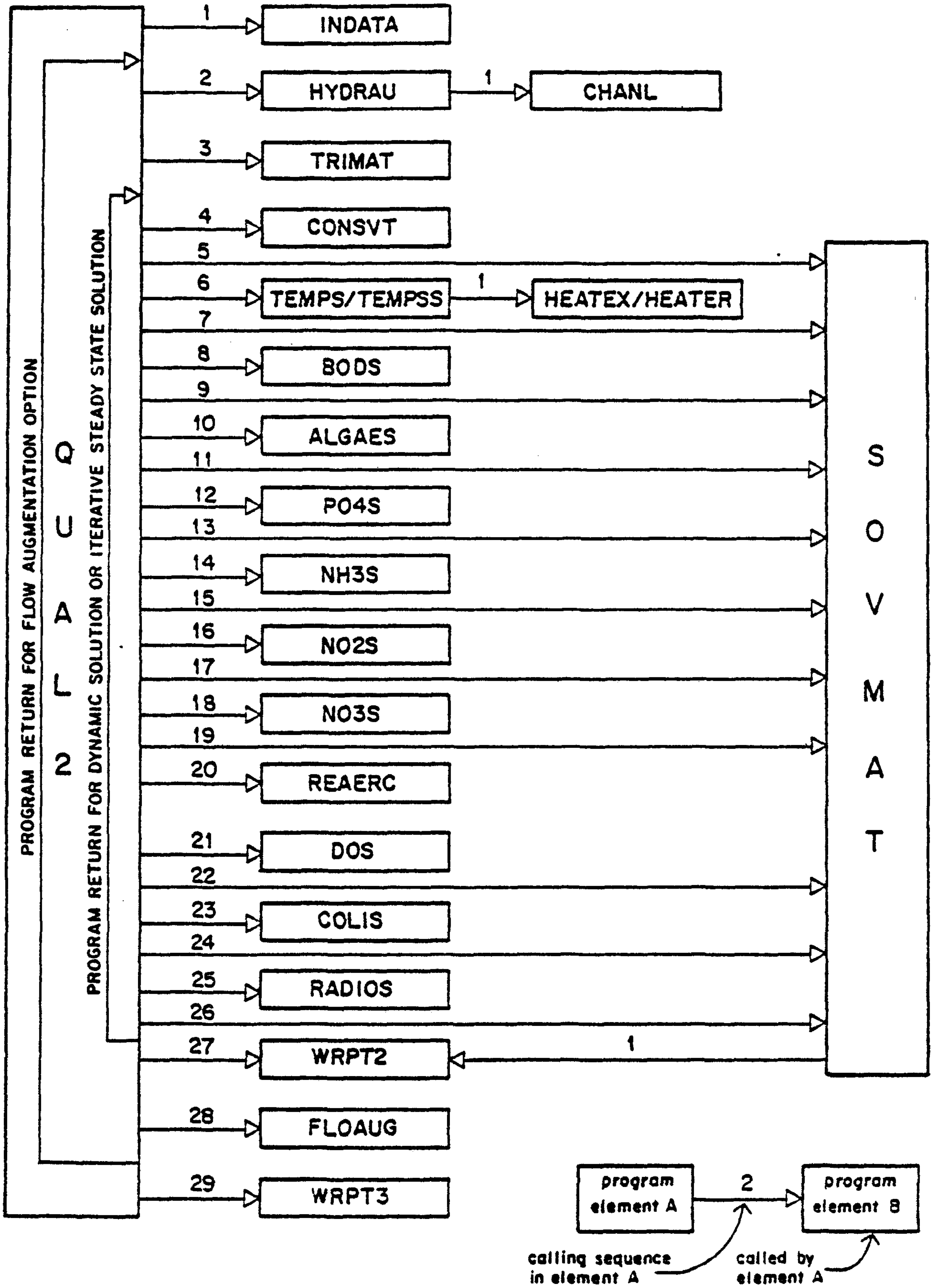

FIGURE VI-1

GENERAL STRUCTURE OF QUAL-II

After QUAL2 calls INDATA, which reads in the input data, and computes some miscellaneous constants, it sets up the initial conditions for each computational element. Initial conditions for each reach are read in and used to define the initial conditions for all computational elements within a reach. QUAL2 then calls the subroutines necessary to simulate the water quality parameters specified on the title cards.

The input Title Data Cards (see User's Manual) prescribe which water quality parameters QUAL-II will simulate. Whenever a Title Data Card indicates a parameter is to be simulated, the program assigns a positive integer to an internal variable (MODOPT) that indicates which model options are to be used. The correspondence between internal model options and parameters is as follows.

Model Option	Parameter(s) to be Simulated
MODOPT (1)	Conservative Constituents
MODOPT (2)	Temperature
MODOPT (3)	Biochemical Oxygen Demand
MODOPT (4)	Chlorophyll a
MODOPT (5)	Dissolved Orthophosphate as P
MODOPT (6)	Ammonia, Nitrite and Nitrate (as N)
MODOPT (7)	Dissolved Oxygen
MODOPT (8)	Coliforms

Any combination of the above options will work. However, it should be noted that if chlorophyll a is to be simulated when either phosphorus or the nitrogen cycle or both are not to be simulated, the program assumes they will not limit algae growth.

When temperature is to be simulated under steady-state conditions, QUAL2 uses an iterative numerical scheme to converge on a solution. The procedure is as follows:

1. Using the known values of temperature in each element (initial conditions or values from previous iteration step 2), select the linear constants for the appropriate 5°F temperature range to be substituted into equations IV-30 and IV-36, then compute the heat flux terms.

2. Compute a new steady-state temperature in each element.

3. For each element, check whether the newly computed temperatures: 1) lie in the same 5°F linear range as the old temperatures which were used to compute the heat flux terms, and 2) lie between 35°F and 135°F.

4. If the above conditions are satisfied in all elements, the problem is considered solved. If one or more elements have not converged, repeat steps 1, 2, and 3 using the newly calculated temperatures to compute the heat flux terms. If convergence is not achieved after 10 iterations, terminate execution of the program.

When chlorophyll a is to be simulated under steady-state conditions, QUAL2 uses an iterative numerical scheme to converge on a solution. Basically the procedure works as follows:

1. Calculate an algae growth rate based on the initial conditions for the first iteration.

2. Compute the resulting phosphorus and nitrate concentrations.

3. Recompute the growth rate based on the newly computed phosphorus and nitrate levels.

4. Compare the previous and newly computed growth rates.

5. If all growth rates have not changed by at least 0.05 per day, the problem is considered solved. If the growth rate change in any one computational element exceeds 0.05 per day, steps 2 through 5 are repeated.

Upon completion of the stream quality computations, QUAL2 selectively reports the results and execution is terminated.

The flow chart for QUAL2 is illustrated in Figure VI-2 and is followed by the program listing. All program variables contained in COMMON are described in Section VII.

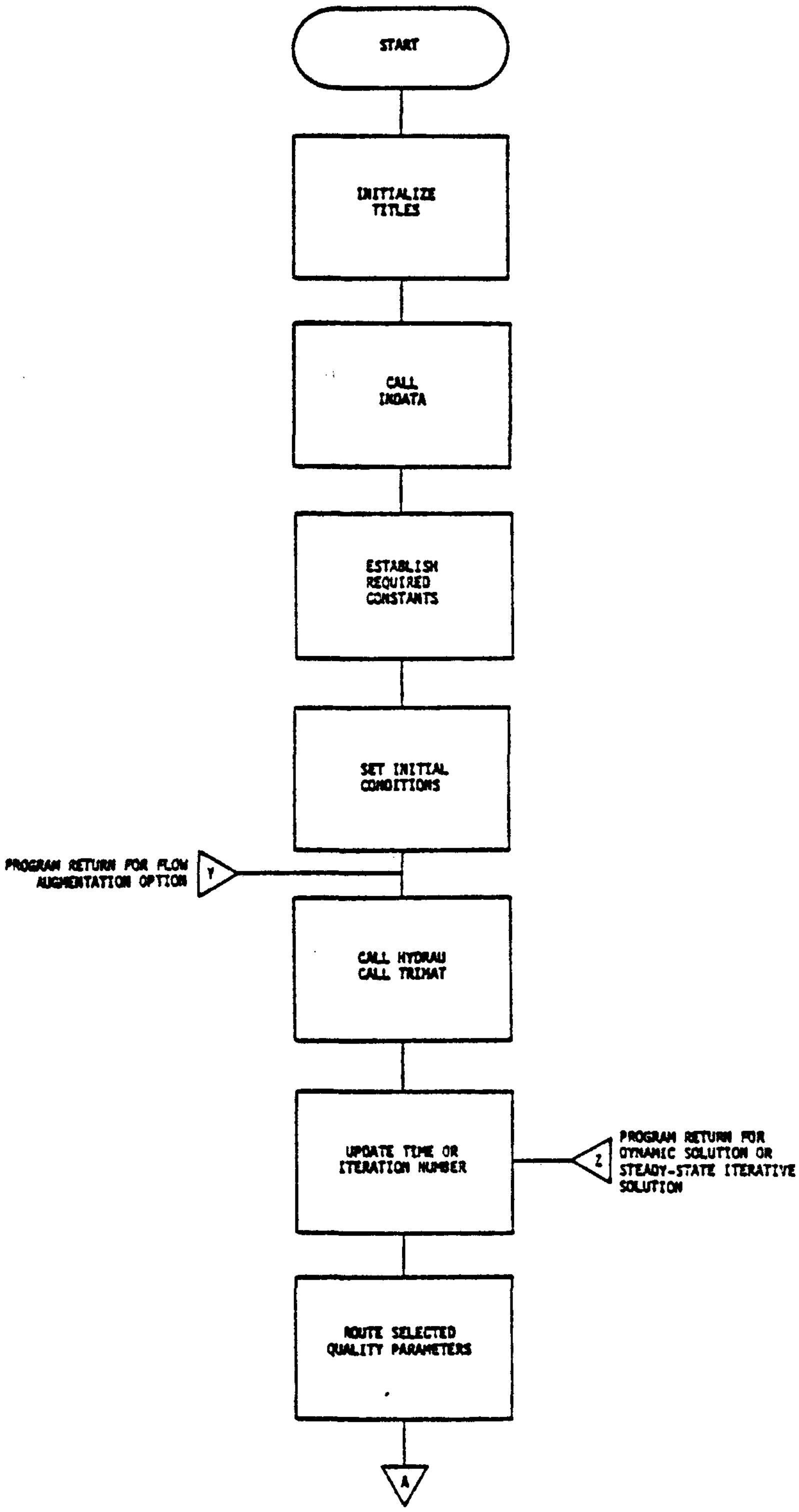

FIGURE VI-2. FLOW CHART FOR MAIN PROGRAM QUAL2

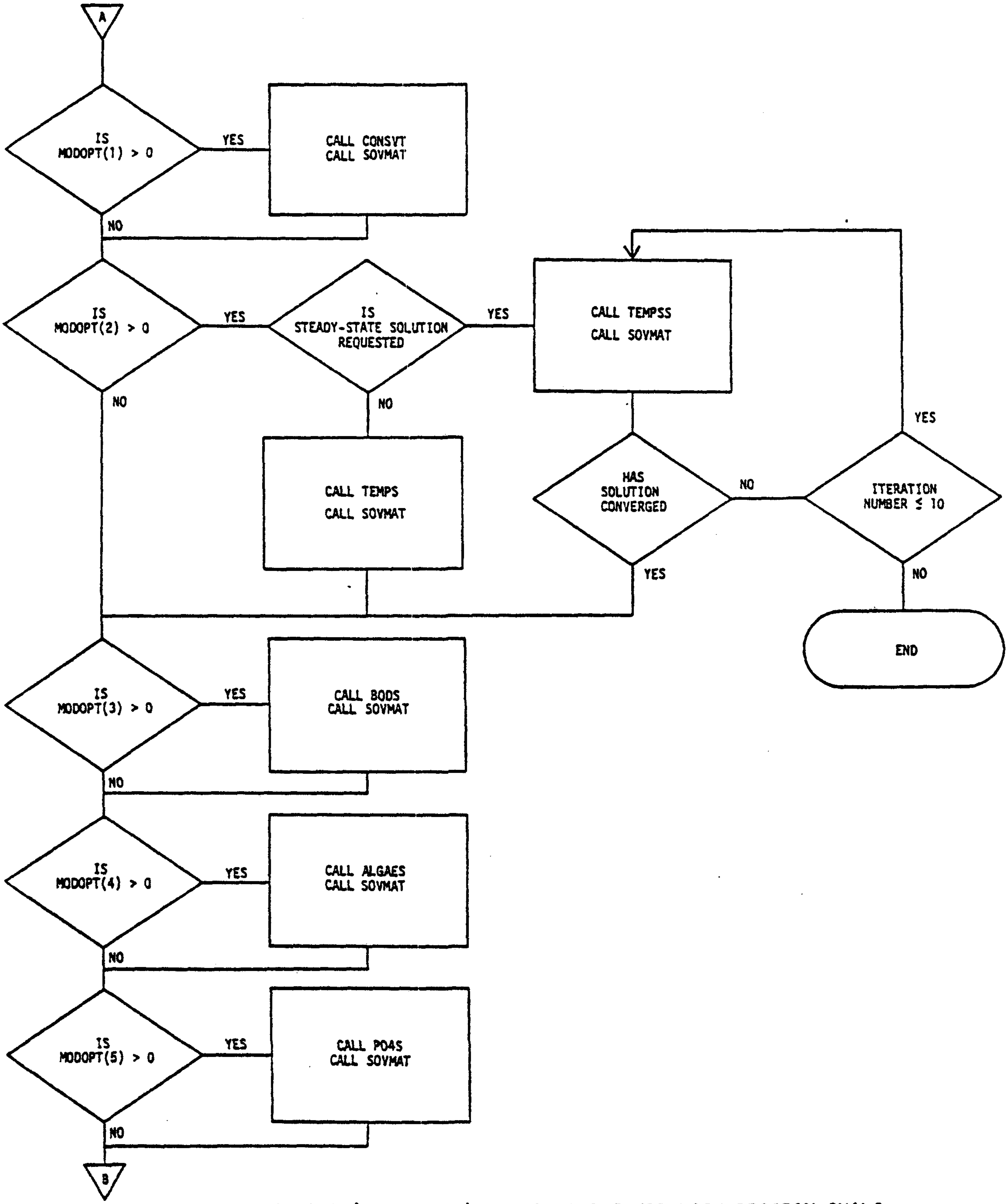

FIGURE VI-2 (Continued). FLOW CHART FOR MAIN PROGRAM QUAL2

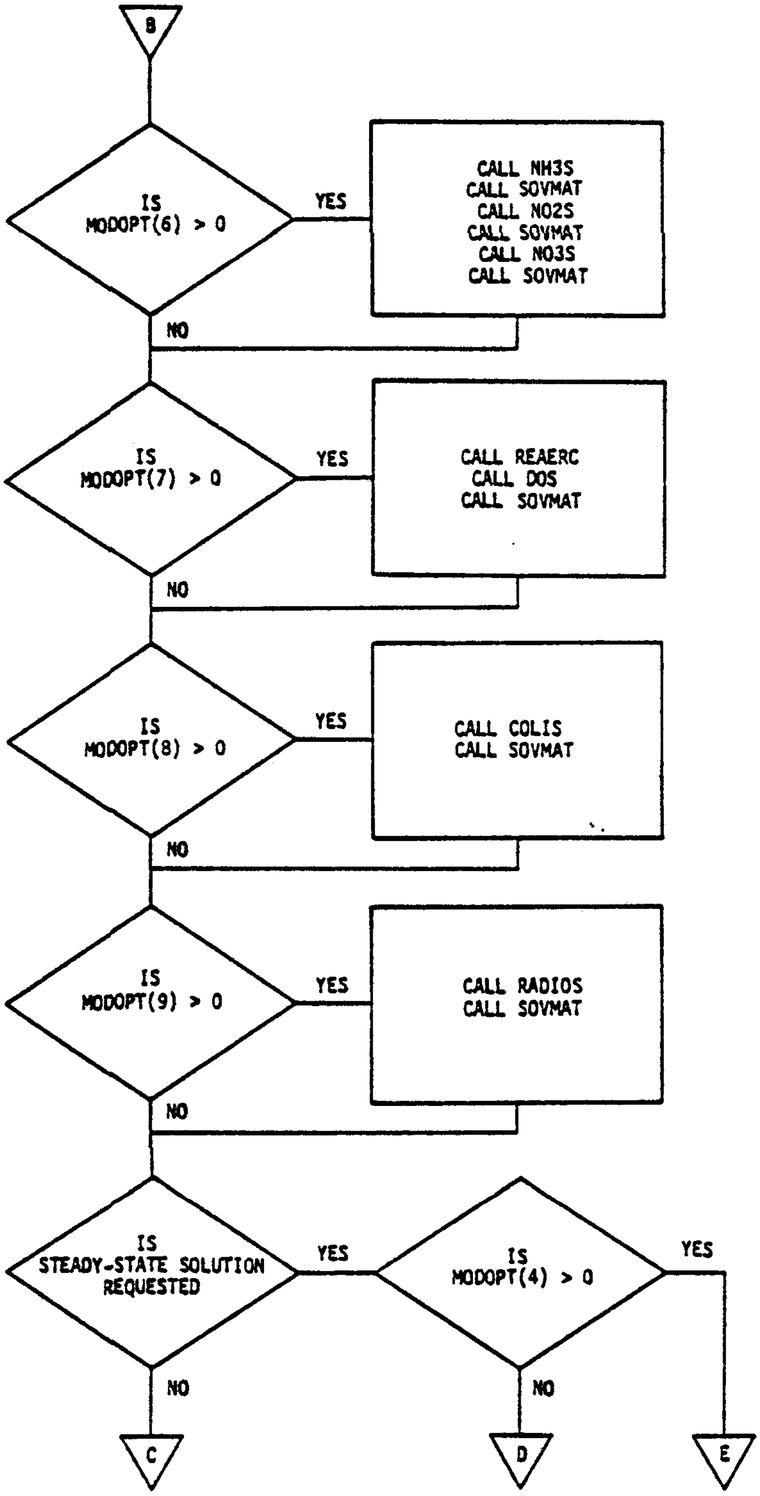

FIGURE VI-2 (Continued). FLOW CHART FOR MAIN PROGRAM QUAL2

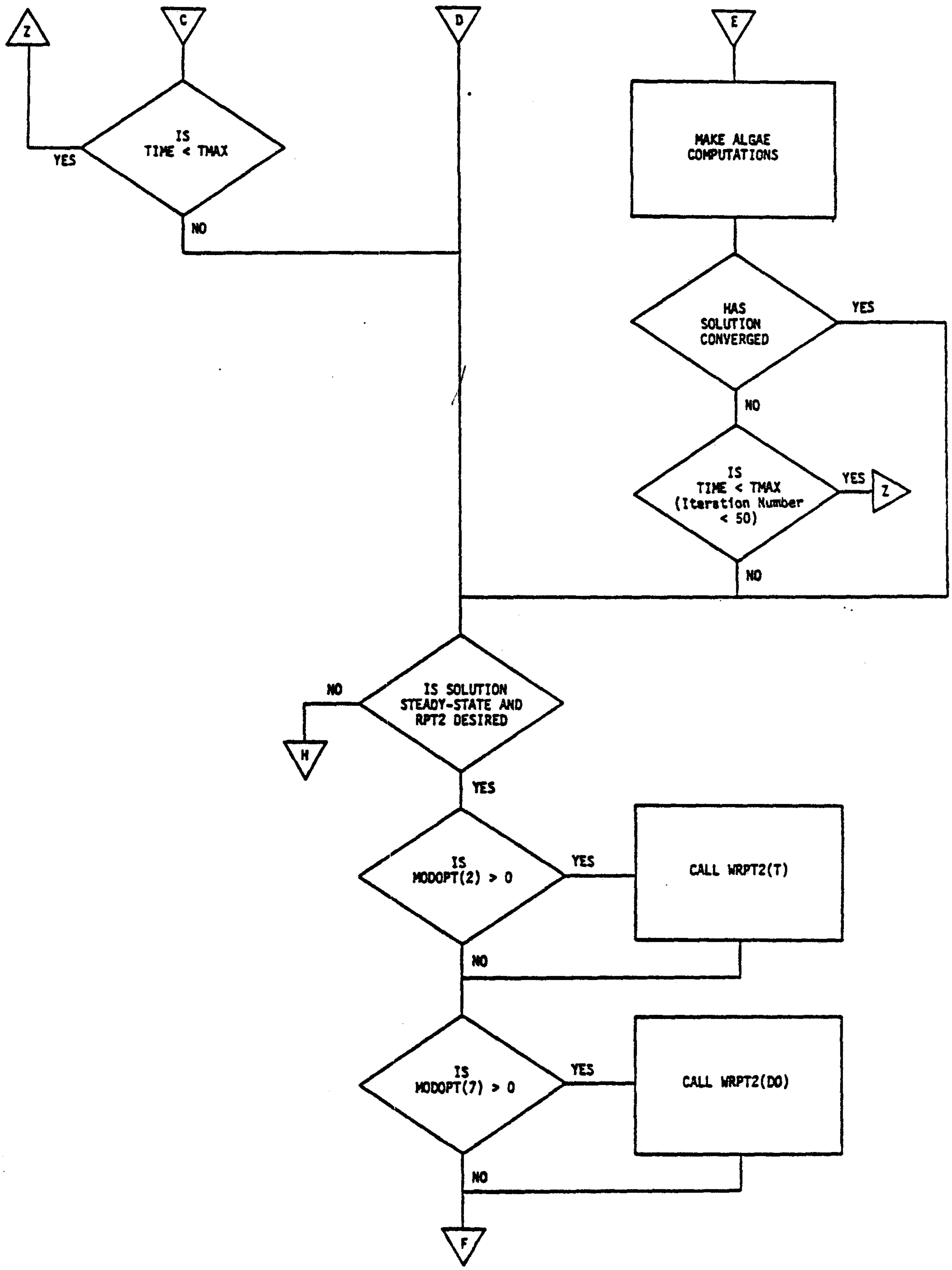

FIGURE VI-2 (Continued). FLOW CHART FOR MAIN PROGRAM QUAL2

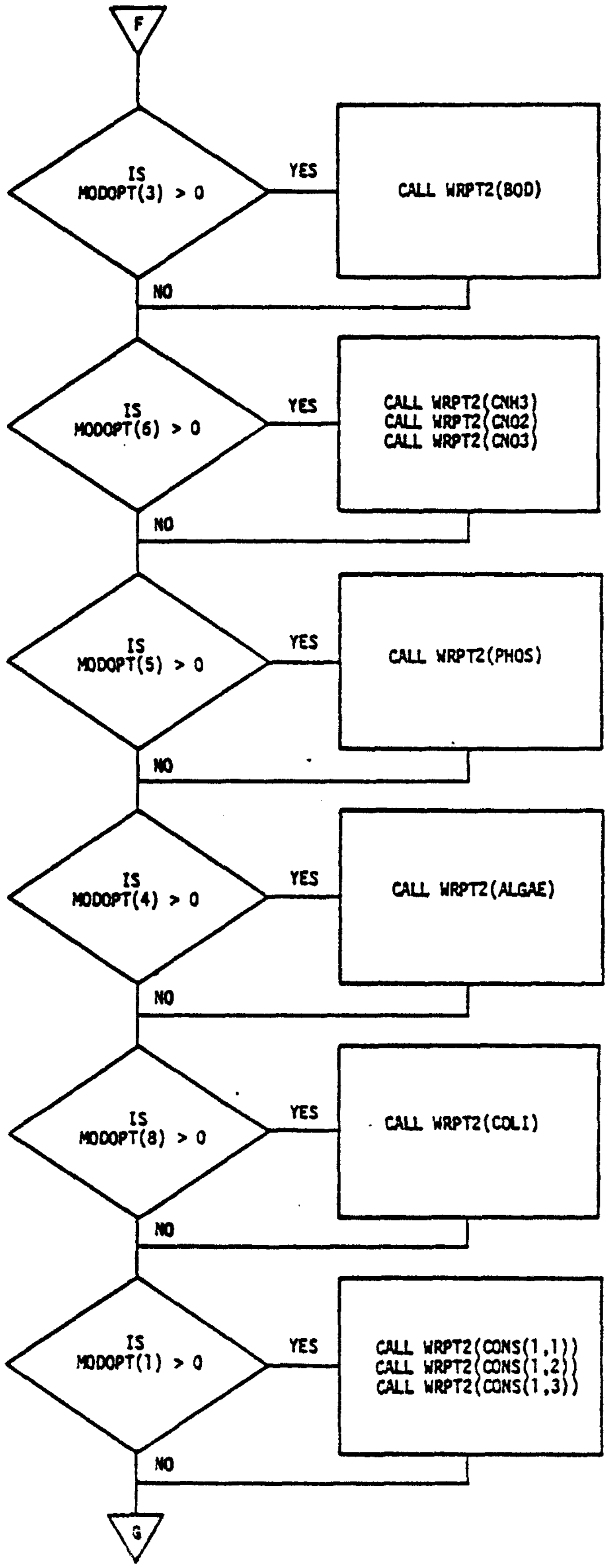

FIGURE VI-2 (Continued). FLOW CHART FOR MAIN PROGRAM QUAL2

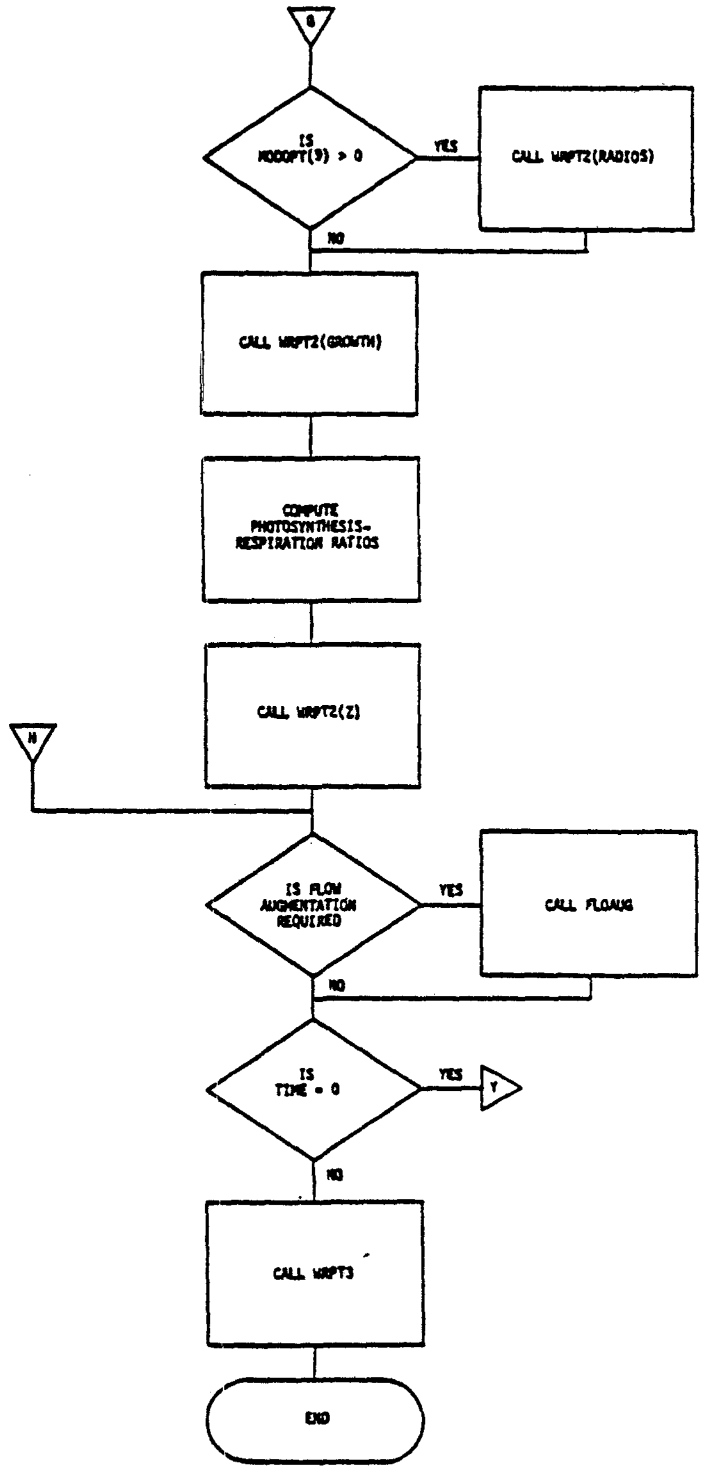

FIGURE VI-2 (Continued). FLOW CHART FOR MAIN PROGRAM QUAL2

```
C         PROGRAM QUAL-2
C
C                              QUAL-2 IS A SET OF INTERRELATED STREAM
C                               QUALITY ROUTING MODELS. IT HAS THE
C                               CAPABILITY TO ROUTE TEMP.,BOD/DO,
C                               NITROGEN SERIES, PHOSPHATE, ALAGE,
C                               COLIFORMS, RADIO NUCLIDE, AND
C                               UP TO THREE CONSERVATIVE MINERALS
C                               THROUGH A FULLY-MIXED STREAM SYSTEM.
C                               THESE PARAMETERS CAN BE ROUTED ON AN
C                               INDIVIDUAL BASIS OR SIMULTANEOUSLY IN
C                               SUCH A COMBINATION AS THE USER MAY
C                               DESIRE. QUAL-1 ALSO HAS THE CAPABILITY
C                               TO COMPUTE THE FLOW AUGMENTATION REQED.
C                               TO MEET PRESELECTED MINIMUM DO LEVELS.
C                               HYDRAULICS ARE CONSIDERED STEADY-STATE.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/SSTATE/ X(500),ISS
      COMMON/SSTEMP/JT(500),SOLRCH(75),CLDRCH(75),PATRCH(75),TDBRCH(75),
     *TWBRCH(75),WINRCH(75)
C
C
      COMMON/RADION/ CK6(75),RADNIT(75),RADNI(75),HWRADN(15),WSRADN(90),
     *              RADIO(500)
C
C + + + + + + + + + + FEB. 1980 REVISIONS
      COMMON/OUTPUT/IRPT1
      COMMON/AUG/IAUGIT
C + + + + + + + + + +
C
C + + + + + + + + + + REV PER 3-20-80 NOTES
C     COMMON/METER/ METRIC,METOUT
C + + + + + + + + + +
C + + ******* COMMENTED OUT PER TOM BARNWELL
C
C
      DIMENSION TJ1(500)
      DIMENSION TITL19(15),TITL20(15)
      REAL K1,K2,LAT,LLM,LSM,JUNCID
      DATA TITL19            /4H ALG,4HAE G,4HROWT,4HH RA,4HTES ,4HIN
```

```
     *P,4HER D,4HAY A,4HRE  ,4H    ,4H    ,4H    ,4H    ,4H    ,4H    /
      DATA TITL20            /4H PHO,4HTOSY,4HNTHE,4HSIS-,4HRESP,4HIRA
     *T,4HION ,4HRATI,4HOS A,4HRE  ,4H    ,4H    ,4H    ,4H    ,4H    /
C
C
C                                         STEP 1-0
C                                         INITIALIZE CERTAIN PARAMETERS
      DO 10 J=6,20
      I=J-5
      TITLE(19,J)=TITL19(I)
      TITLE(20,J)=TITL20(I)
   10 CONTINUE
C
C                                         STEP 2-0
C                                         READ IN TITLES
C
C                                         STEP 3-0
C                                         READ IN ALL DATA REQUIRED FOR OP
C                                         OF THE MODELS.
C
C                                         STEP 4-0
C                                         IF THE CORRECT NO. OF DATA CARDS
C                                         NOT BEEN READ IN, THE PROGRAM WI
C                                         TERMINATE.
C
      CALL INDATA(ILIST,IRPT1,IAUGOP,TMAX,NCELLS)
C                                         STEP 5-0
C                                         ESTABLISH REQUIRED CONSTANTS.
C
      DELX=DELX*5280.0
      IF (ISS) 901,901,900
  900 D1LT = 1.0/24.0
      D2LT = 1.0
      DELT = 3600.0
      IF (PTIME.LE.0.) PTIME=TMAX
      GO TO 902
  901 D1LT = DELT/24.0
      D2LT=DELT
      DELT=DELT*3600.0
      TMAX=TMAX-0.01
  902 CONTINUE
      DTODX2=DELT/(DELX*DELX)
      DT2ODX=2.0*DELT/DELX
C
C                                         STEP 6-0
C                                         SET INITIAL CONDITIONS.
C
C + + + + + + FEB 1980 REVISIONS
C + + + + + + NO. 2
C                                         CONVERSION OF CKL TO LANGLEYS/HR
      CKL=CKL*60.
C                                         CONVERSION TO BTU/SQ.FT./HR
C                                         THE FOLLOWING COMPUTES THE
C                                         AVERAGE LIGHT INTENSITY FOR
C                                         STEADY-STATE COMPUTATION
C + + + + + + + FEB 1980 REVISIONS NO. 3
C
      IF(MODOPT(2).GT.0.0.AND.ISS.LE.0) CKL=CKL*3.685
C
C + + + + + + +
      IF (ISS.LE.0) GO TO 110
      FUNCT=0.0
      IF (SONET.LT.1.0E-4) GO TO 51
      NDLH=14
      DLH=FLOAT(NDLH)
      SOAVE=SONET/DLH
      DO 50 M=1,NDLH
      FM=M
```

```
      TOT=SOAVE*(1.0-COS(6.28*FM/DLH))
   50 FUNCT=FUNCT+(TOT/(CKL+TOT))
   51 CONTINUE
      FUNCT=FUNCT/24.
      SONNEN=CKL*FUNCT/(1.-FUNCT)
  110 CONTINUE
C
C + + + + + + + FEB 1980 REVISIONS NO. 4
      IAUGIT=0
  998 CALL HYDRAU
      CALL TRIMAT
C
C + + + + + + +
      DO 915 I=1,NREACH
      NCELR=NCELRH(I)
      DO 915 J=1,NCELR
      IOR=ICLORD(I,J)
      T(IOR)=TINIT(I)
C + + + FOLLOWING STATEMENT DELETED TO AVOID DOUBLE CONVERSIONS
C        PER LETTER OF 23 SEPT 1980.
C     IF(METRIC.GT.0)T(IOR)=1.8*T(IOR)+32.0
C + + +
      DO(IOR)=DOINIT(I)
      BOD(IOR)=BOINIT(I)
      CONS(IOR,1)=COINIT(I,1)
      CONS(IOR,2)=COINIT(I,2)
      CONS(IOR,3)=COINIT(I,3)
      ALGAE(IOR)=ALGIT(I)
      PHOS(IOR)=PHOSIT(I)
      CNH3(IOR)=CNH3IT(I)
      CNO2(IOR)=CNO2IT(I)
      CNO3(IOR)=CNO3IT(I)
      COLI(IOR)=COLIIT(I)
      RADIO(IOR)=RADNIT(I)
      IF(MODOPT(4).EQ.0)  GO TO 915
      TC=0.556*(T(IOR)-68.0)
      EXPT=EXP(-EXCOEF(I)*DEPTH(IOR))
      TLOG=ALOG((CKL+SONNEN)/(CKL+SONNEN*EXPT))
      GROWTH(IOR)=GROMAX*TLOG/(EXCOEF(I)*DEPTH(IOR))
      GROWTH(IOR)=GROWTH(IOR)*1.047**TC
  915 CONTINUE
      DO 922 NWS=1,NWASTE
      EFLBOD=1.0-TRFACT(NWS)
      WSBOD(NWS)=EFLBOD*WSBOD(NWS)
  922 CONTINUE
C
C                                        STEP 7-0
C                                        BEGIN COMPUTATIONS AND OPERATE U
C                                        STEADY-STATE CONDITIONS ARE REAC
C                                        WHICH IS THE TIME (TMAX) REQUIRE
C                                        WATER PARTICLE AT THE UPPERMOST
C                                        IN THE SYSTEM TO REACH THE END O
C                                        THE SYSTEM.
C
C                                        STEP 7-1
C                                        CALL SUBROUTINES TO PERFORM HYDR
C                                        BALANCE ON SYSTEM AND ESTABLISH
C                                        COEFFICIENT MATRIX.
C
      NITER=0
      ITER=0
  999 TIME=TIME+D2LT
      TPRINT=TPRINT+D2LT
C
C                                        STEP 7-2
C                                        ROUTE SELECTED QUALITY PARAMETER
C
C                                        MODOPT(1)   CONSERVATIVE
C                                        MODOPT(2)   TEMPERATURE
C                                        MODOPT(3)   BOD
```

```
C                                                   MODOPT(4)   CHLOROPHYLL A
C                                                   MODOPT(5)   PHOSPHOROUS
C                                                   MODOPT(6)   NH3,NO2,NO3
C                                                   MODOPT(7)   OXYGEN
C                                                   MODOPT(8)   COLIFORMS
C                                                   MODOPT(9)   NON-CONSERVATIVE
C
      IF (MODOPT(1).EQ.0) GO TO 702
  701 NT=3
      DO 777 NC=1,NCS
      CALL CONSVT
      CALL SOVMAT
      NT=NI+1
      DO 808 I=1,NCELLS
      CONS(I,NC)=Z(I)
  808 CONTINUE
  777 CONTINUE
C
  702 IF (MODOPT(2).EQ.0) GO TO 703
      NT=6
      IF (ISS.GT.0.) GO TO 7702
      CALL TEMPS
      CALL SOVMAT
      DO 800 I=1,NCELLS
      T(I)=Z(I)
  800 CONTINUE
      GO TO 703
C
 7702 IF (NITER.GT.0) GO TO 703
 7703 DO 7706 I=1,NCELLS
      TJ1(I)=(T(I)-35.)/5.
 7706 CONTINUE
      CALL TEMPSS(NITER)
      CALL SOVMAT
      MM=0
      DO 7704 I=1,NCELLS
      T(I)=Z(I)
      TJ=(T(I)-35.)/5.
      M=TJ+1
      IF (JT(I).EQ.M.AND.M.GT.0.AND.M.LE.21) GO TO 7704
      IF (JT(I).NE.M.AND.ABS(TJ-TJ1(I)).LE.0.10) GO TO 7704
      MM=MM+1
 7704 CONTINUE
      NITER=NITER+1
      WRITE (6,7705) MM,NITER
 7705 FORMAT (15X,9H*** MM= ,I5,13H *** NITER = I5)
      IF (NITER.GT.10) CALL EXIT
      IF (MM.GT.0) GO TO 7703
  703 IF (MODOPT(3).EQ.0) GO TO 704
      NT = 7
      CALL BODS
      CALL SOVMAT
      DO 802 I=1,NCELLS
      BOD(I)=Z(I)
  802 CONTINUE
C
  704 IF (MODOPT(4).EQ.0) GO TO 705
      NT = 8
      CALL ALGAES
      CALL SOVMAT
      DO 804 I=1,NCELLS
      ALGAE(I) = Z(I)
      IF (ALGAE(I).GT.50.) ALGAE(I)=50.
      IF (ALGAE(I).LE.0.0) ALGAE(I)=0.00001
  804 CONTINUE
C
  705 IF (MODOPT(5).EQ.0) GO TO 706
      NT = 9
      CALL PO4S
      CALL SOVMAT
```

```
      DO 805 I=1,NCELLS
      PHOS(I) = Z(I)
  805 CONTINUE
C
  706 IF (MODOPT(6).EQ.0) GO TO 707
      NT = 10
      CALL NH3S
      CALL SOVMAT
      DO 806 I=1,NCELLS
      CNH3(I) = Z(I)
  806 CONTINUE
      NT = 11
      CALL NO2S
      CALL SOVMAT
      DO 816 I=1,NCELLS
      CNO2(I) = Z(I)
  816 CONTINUE
      NT = 12
      CALL NO3S
      CALL SOVMAT
      DO 826 I=1,NCELLS
      CNO3(I) = Z(I)
  826 CONTINUE
C
  707 IF (MODOPT(7).EQ.0) GO TO 708
      NT = 13
      CALL REAERC
      CALL DOS
      CALL SOVMAT
      DO 803 I=1,NCELLS
      DO(I)=Z(I)
  803 CONTINUE
  708 IF (MODOPT(8).EQ.0) GO TO 799
      NT = 14
      CALL COLIS
      CALL SOVMAT
      DO 807 I=1,NCELLS
      COLI(I) = Z(I)
  807 CONTINUE
  799 CONTINUE
      IF(MODOPT(9).EQ.0) GO TO 7999
      NT=15
      CALL RADIOS
      CALL SOVMAT
      DO 809 I=1,NCELLS
      RADIO(I)=Z(1)
  809 CONTINUE
 7999 CONTINUE
      IF (TPRINT.LT.PTIME) GO TO 997
      TPRINT=0.0
  997 CONTINUE
C
C                                              STEP 7-3
C                                              IF STEADY-STATE CONDITION HAS NO
C                                              REACHED, CONTINUE ROUTING.
C
      IF(ISS) 9996,9996,9990
 9990 IF (MODOPT(4)) 1001,1001,9992
 9992 NUM = 0
      ITER = ITER + 1
      WRITE (NJ,7779) ITER
 7779 FORMAT (12H ITERATION  ,I5)
      DO 9994 JJ=1,NREACH
      NCELR=NCELRH(JJ)
      DO 9994 KK=1,NCELR
      I=ICLORD(JJ,KK)
      TC=0.556*(T(I)-68.0)
      EXPT=EXP(-EXCOEF(JJ)*DEPTH(I))
      TLOG=ALOG((CKL+SONNEN)/(CKL+SONNEN*EXPT))
      XGROA=GROMAX*TLOG/(EXCOEF(JJ)*DEPTH(I))
```

```
      XGROW=XGROW*1.047**TC
      TT = DELX/(VEL(I)*86400.)
      TGROW = XGROW
      IF (MODOPT(5).EQ.0) GO TO 9820
      DGDP = -1.0/(ALPHA2*ALGAE(I)*TT)
      XA = DGDP
      XB = GROWTH(I)+(CKP+PHOS(I))*DGDP-XGROW
      XC = GROWTH(I)*(CKP+PHOS(I))-XGROW*PHOS(I)
      ROOT = SQRT(XB*XB-4.0*XA*XC)
      DPHOS=-0.5*XB/XA + 0.5*ROOT/ABS(XA)
      PHOS(I) = PHOS(I)+DPHOS
      IF (PHOS(I).LT.0.0) PHOS(I) = 0.0
      TGROW = XGROW*PHOS(I)/(CKP+PHOS(I))
 9820 IF (MODOPT(6).EQ.0) GO TO 9840
      DGDN = -1.0/(ALPHA1*ALGAE(I)*TT)
      XA = DGDN
      XB = GROWTH(I)+(CKN+CNO3(I))*DGDN-XGROW
      XC = GROWTH(I)*(CKN+CNO3(I))-XGROW*CNO3(I)
      ROOT = SQRT(XB*XB-4.0*XA*XC)
      DCNO3=-0.5*XB/XA + 0.5*ROOT/ABS(XA)
      CNO3(I) = CNO3(I) + DCNO3
      IF (CNO3(I).LT.0.0) CNO3(I) = 0.0
      TGROW = TGROW*CNO3(I)/(CKN+CNO3(I))
 9840 CONTINUE
      DG = TGROW - GROWTH(I)
      IF (ABS(DG).LT.0.05) GO TO 8994
      NUM = NUM + 1
 8994 GROWTH(I) = GROWTH(I) + 0.7*DG
 9994 CONTINUE
      WRITE (NJ,7780) NUM
 7780 FORMAT (30H GROWTH RATE NON CONVERGENT IN,I4,9H ELEMENTS)
      IF (NUM) 1001,1001,9996
 9996 IF (TIME.LT.TMAX) GO TO 999
 1001 CONTINUE
      IF(ISS.LE.0.OR.IRPT1.LE.0) GO TO 9998
      IF (MODOPT(2)) 1011,1011,1002
 1002 NT=6
      CALL WRPT2(T)
 1011 CONTINUE
      IF (MODOPT(7)) 1021,1021,1012
 1012 NT=13
      CALL WRPT2(DO)
 1021 CONTINUE
      IF (MODOPT(3)) 1031,1031,1022
 1022 NT=7
      CALL WRPT2(BOD)
 1031 CONTINUE
      IF (MODOPT(6)) 1041,1041,1032
 1032 NT=10
      CALL WRPT2(CNH3)
      NT=11
      CALL WRPT2 (CNO2)
      NT=12
      CALL WRPT2 (CNO3)
 1041 CONTINUE
      IF (MODOPT(5)) 1051,1051,1042
 1042 NT=9
      CALL WRPT2 (PHOS)
 1051 CONTINUE
      IF (MODOPT(4)) 1061,1061,1052
 1052 NT=8
      CALL WRPT2 (ALGAE)
 1061 CONTINUE
      IF (MODOPT(8)) 1071,1071,1062
 1062 NT=14
      CALL WRPT2 (COLI)
 1071 CONTINUE
      IF (MODOPT(1)) 1081,1081,1072
 1072 NT=3
      DO 1075 NC=1,NCS
```

```
      CALL WRPT2 (CONS(1,NC))
 1075 NT=NT+1
 1081 CONTINUE
      IF (MODOPT(9)) 1091,1091,1082
 1082 NT=15
      CALL WRPT2 (RADIO)
 1091 CONTINUE
      IF (MODOPT(4).EQ.0) GO TO 9965
C
      NT=19
      IF(IRPT1.EQ.1)CALL WRPT2 (GROWTH)
C
      XTEMP = ALPHA3/ALPHA4
      DO 9960 I=1,NCELLS
      Z(I) = XTEMP*GROWTH(I)/RESPRR(I)
 9960 CONTINUE
      NT = 20
      IF(IRPT1.EQ.1)CALL WRPT2(Z)
 9965 CONTINUE
 9998 CONTINUE
C
C                                             STEP 8-0
C
C                                             IF FLOW AUGMENTATION IS DESIRED,
C                                             HOW MUCH IS REQUIRED, AUGMENT TH
C                                             NECESSARY HEADWATER FLOWS AND ST
C                                             ROUTING AGAIN AT TIME = ZERO.
C
      IF (IAUGOP.EQ.0) GO TO 9999
C
C + + + + + + + FEB 1980 REVISIONS NO. 5
      IAUGIT=1
C + + + + + + + +
C
      CALL FLOAUG
      IF (TIME.EQ.0.0) GO TO 998
 9999 CONTINUE
      CALL WRPT3
      STOP
      END
```

SUBROUTINE ALGAES*

Subroutine ALGAES completes the setup of the equations necessary to calculate algal biomass concentrations in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations. In addition, solar radiation is read at three hour intervals if a dynamic simulation is being performed.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computation element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i - (\mu_i - \rho - \sigma_{1_i}/D)\Delta t$
7. Withdrawal	$b_i = x_i - (\mu_i - \rho - \sigma_{1_i}/D)\Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The growth rate, μ_i, is computed according to Equation II-6 as

$$\mu_i = \mu_{max} \left(\frac{N_3}{N_3 + K_N}\right)_i \left(\frac{P}{P + K_P}\right)_i \frac{1}{\lambda_i D_i} \ln \frac{K_L + L}{K_L + Le^{-\lambda_i D_i}}$$

For dynamic simulation, nitrate (N_3) and phosphorus (P) values from the previous time period are used to calculate the growth rate; for steady-state simulation, values from the previous iteration are used.

If, under the program options, algal concentrations are being simulated and either nitrate or phosphorus or both are not being simulated, the program assumes that the parameter or parameters not simulated are not limiting. For example, if both nitrate and phosphorus are not being simulated the growth rate would be computed as

$$\mu_i = \hat{\mu} \frac{1}{\lambda_i D_i} \ln \frac{K_L + L}{K_L + Le^{-\lambda_i D_i}}$$

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = A_i^* + q_i'A_i' \frac{\Delta t}{V_i} - a_iA_h$
6. Waste Input	$S_i = A_i^* + q_i'A_i' \frac{\Delta t}{V_i} + q_wA_w \frac{\Delta t}{V_i}$
All Others	$S_i = A_i^* + q_i'A_i' \frac{\Delta t}{V_i}$

For steady-state simulation, the only difference is that the value from the previous time step, A_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-3 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

*All symbols used are defined at the end of this section of the Documentation Report.

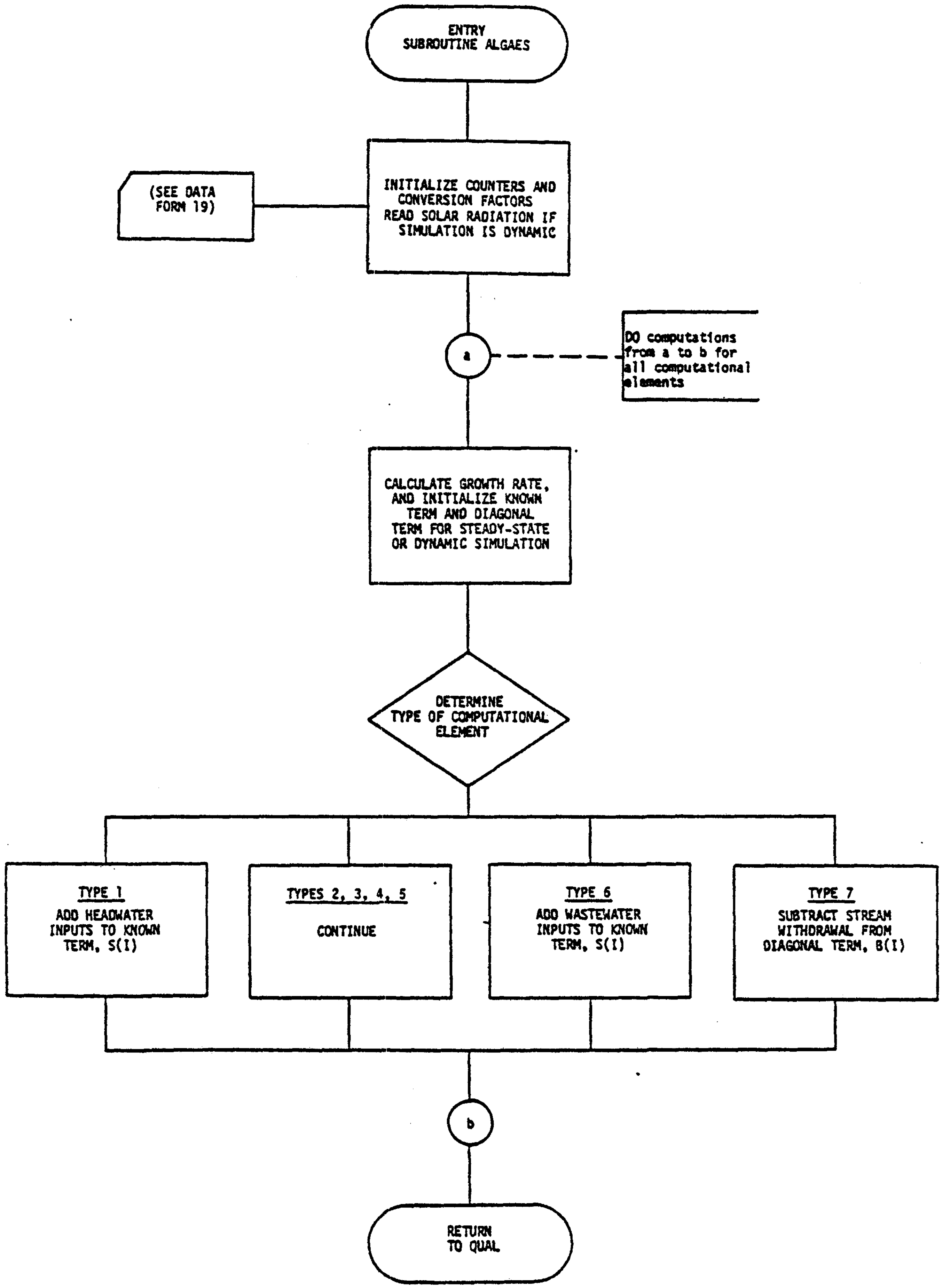

FIGURE VI-3. FLOW CHART FOR SUBROUTINE ALGAES

```
      SUBROUTINE ALGAES
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
      COMMON/SSTATE/X(500),ISS
C
C                               INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                                              READ SOLAR RADIATION DATA IF REQD
C
      IF(ISS .GT. 0 .OR. MODOPT(2) .GT. 0) GO TO 20
      IF(TRLCD) 10,10,15
   10 READ(NI,11) SONET
   11 FORMAT(30X,F10.0)
      TRLCD=3.0
   15 TRLCD=TRLCD-D2LT
   20 CONTINUE
C
C                               LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
```

```
      ALGIJ = QI(I)/CNCELR*ALGI(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                                   COMPUTE ALGAE GROWTH RATES
C
      TC = 0.556*(T(IOR)-68.0)
      RESPRR(IOR)=RESPRT*1.047**TC
      ALSINK=ALGSET(I)/DEPTH(IOR)
      IF (ISS.GT.0) GO TO 52
      EXPT=EXP(-EXCOEF(I)*DEPTH(IOR))
      TLOG=ALOG((CKL+SONET )/(CKL+SONET *EXPT))
      GROWTH(IOR)=GROMAX*TLOG/(EXCOEF(I)*DEPTH(IOR))
      GROWTH(IOR)=GROWTH(IOR)*1.047**TC
      IF (MODOPT(5).EQ.0) GO TO 50
      GROWTH(IOR) = GROWTH(IOR)*PHOS(IOR)/(CKP+PHOS(IOR))
   50 IF (MODOPT(6).EQ.0) GO TO 52
      GROWTH(IOR) = GROWTH(IOR)*CNO3(IOR)/(CKN+CNO3(IOR))
   52 CONTINUE
C
C                                   INITIALIZE DIAGONAL AND KNOWN TERMS
C
      REACT=GROWTH(IOR)-RESPRR(IOR)-ALSINK
      B(IOR)=X(IOR)-REACT*DILT
      S(IOR)=ALGAE(IOR)
      IF(ISS.GT.1) S(IOR)=0.0
      S(IOR) = S(IOR)+ALGIJ*DTOVCL(IOR)
C
C                                   MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      IFL=IFLAG(I,J)
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR) = S(IOR) - A(IOR)*HWALG(NHW)
      GO TO 100
  103 NWS=NWS+1
      S(IOR) = S(IOR) + WSFLOW(NWS)*WSALG(NWS)*DTOVCL(IOR)
      GO TO 100
  104 NWS=NWS+1
      B(IOR) = B(IOR) - WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE BODS*

Subroutine BODS completes the setup of the equations necessary to calculate BOD levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + (K_1 + K_3)\Delta t$
7. Withdrawal	$b_i = x_i + (K_1 + K_3)\Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = L_i^* + q_i' L_i' \frac{\Delta t}{V_i} - a_i L_h$
6. Waste Input	$S_i = L_i^* + q_i' L_i' \frac{\Delta t}{V_i} + q_w L_w \frac{\Delta t}{V_i}$
All Others	$S_i = L_i^* + q_i' L_i' \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, L_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-4 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

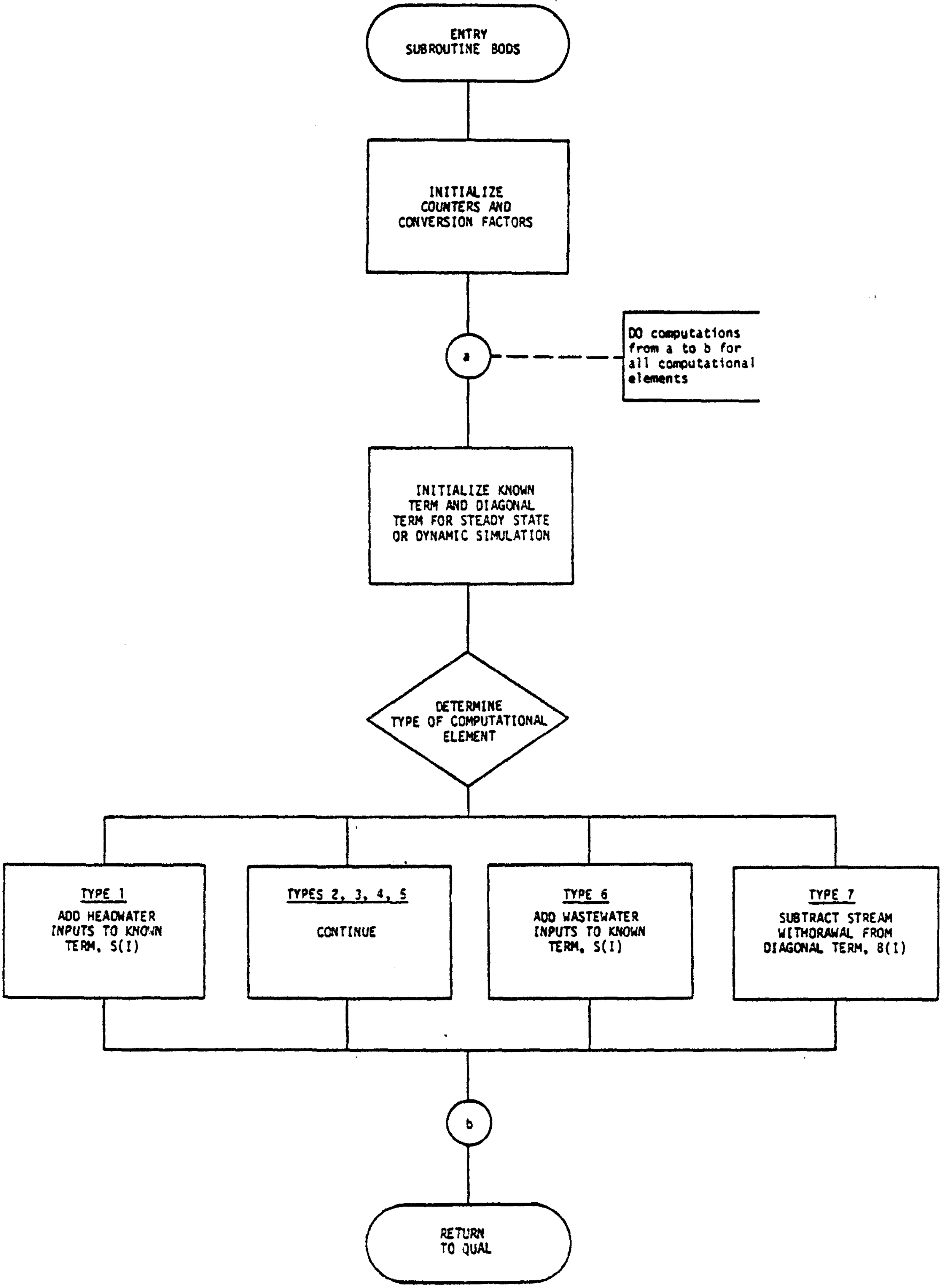

FIGURE VI-4. FLOW CHART FOR SUBROUTINE BODS

```
      SUBROUTINE BODS
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2DDX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/SSTATE/X(500),ISS
      REAL K1,K3
C
C                             INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                             LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      BODIJ=QI(I)/CNCELR*BODI(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                             INITIALIZE DIAGONAL AND KNOWN TERMS
C
      TC=0.556*(T(IOR)-68.0)
      K1(IOR)=CK1(I)*1.047**TC
      K3=CK3(I)
      REACT=D1LT*(K1(IOR)+K3)
      B(IOR)=X(IOR)+REACT
      S(IOR)=BOD(IOR)
      IF(ISS.GT.1) S(IOR)=0.0
      S(IOR)=S(IOR)+BODIJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                             MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWBOD(NHW)
      GO TO 100
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSBOD(NWS)*DTOVCL(IOR)
      GO TO 100
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE CHANL

Subroutine CHANL is called by subroutine HYDRAU to compute the velocity and depth in each computational element given the flow in that element. One of two techniques as explained in Section II, Hydraulic Characteristics, is used depending on input specifications. The first involves the use of discharge coefficients and exponents to compute the velocity and depth while the second computes these values from the geometric properties of the stream reach.

The subroutine flow chart is illustrated in Figure VI-5 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

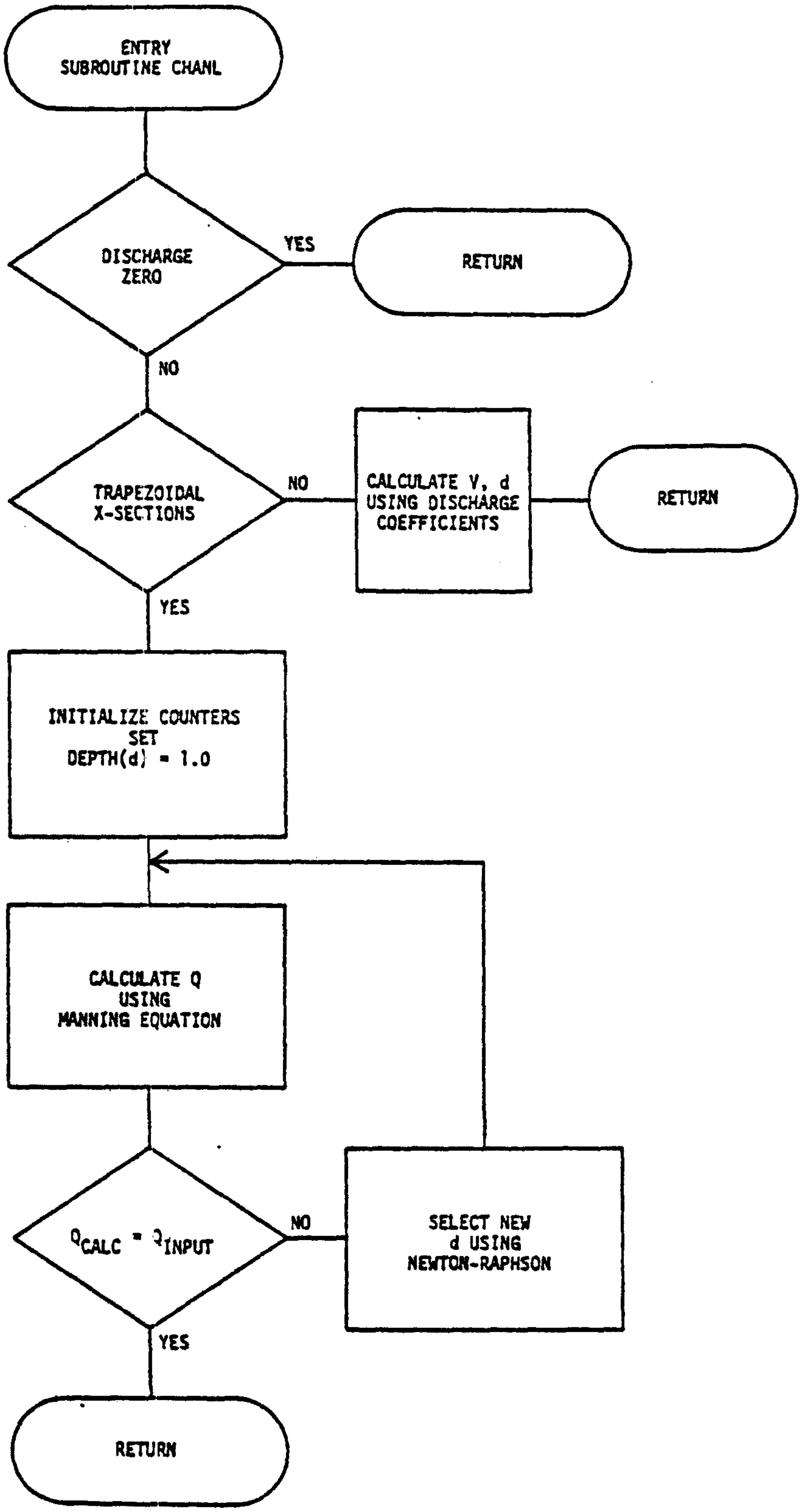

FIGURE VI-5. FLOW CHART FOR SUBROUTINE CHANL

```
      SUBROUTINE CHANL(J,Q,VELO,DPTH)
C
C
C                 THIS SUBROUTINE RETURNS VELOCITY AND DEPTH
C                 USING  THE NEWTON RAPHSON TECHNIQUE WHEN
C                 TRAP-CHANNEL DATA IS INPUT OR
C                 ALPHA'S AND BETA'S OTHERWISE
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *      TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *      ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *      CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *      EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *      QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *      JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *      HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *      WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *      A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *      FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *      HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *      DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *      NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *      LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *      ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *      CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *      ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *      SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *      ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *      COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *      CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *      CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *      WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *      HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *      MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/CDATA/SS1(75),SS2(75),WIDTH(75),SLOPE(75),ITRAP
C
      IF(Q.NE.0.)GO TO 340
      VELO=0.
      DPTH=0
      RETURN
  340 CONTINUE
C
C
      IF(ITRAP.EQ.1)GO TO 350
      VELO=COEFQV(J)*Q**EXPOQV(J)
      DPTH=COEFQH(J)*Q**EXPOQH(J)
      RETURN
  350 CONTINUE
```

```
C
C
      DEL=1.
      DELD=1.
      CONST=1.486/CMANN(J)*SQRT(SLOPE(J))
      DO 360 I=1,30
      AREA=0.5*(SS1(J)+SS2(J))*DEL**2+WIDTH(J)*DEL
      DAREA=(SS1(J)+SS2(J))*DEL+WIDTH(J)
      WETPER=SQRT(SS1(J)**2+1)*DEL+SQRT(SS2(J)**2+1)*DEL+WIDTH(J)
      DWETP=(SQRT(SS1(J)**2+1))+(SQRT(SS2(J)**2+1))
      FLW=CONST*((AREA**1.66667)/(WETPER**0.66667))
      F=FLW-Q
      DF=CONST*(((1.66667*AREA**0.6667*DAREA)*(WETPER**0.66667))
     1   -((AREA**1.66667)*0.66667*(WETPER**(-0.33333))*DWETP))/
     2   (WETPER**1.33333)
      DEL=DELD-F/DF
      IF(ABS(F).LT.0.001*Q) GO TO 380
  360 DELD=DEL
      WRITE(6,1111)
 1111 FORMAT(1H ,32HTHERE IS NO CONVERGENCE IN CHANL)
      RETURN
  380 CONTINUE
      DPTH=DEL
      VELO=Q/AREA
      RETURN
      END
```

SUBROUTINE COLIS*

Subroutine COLIS completes the setup of the equations necessary to calculate coliform levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + K_5 \Delta t$
7. Withdrawal	$b_i = x_i + K_5 \Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = E_i^* + q_i' E_i' \frac{\Delta t}{V_i} - a_i E_h$
6. Waste Input	$S_i = E_i^* + q_i' E_i' \frac{\Delta t}{V_i} + q_w E_w \frac{\Delta t}{V_i}$
All Others	$S_i = E_i^* + q_i' E_i' \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, E_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-6 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

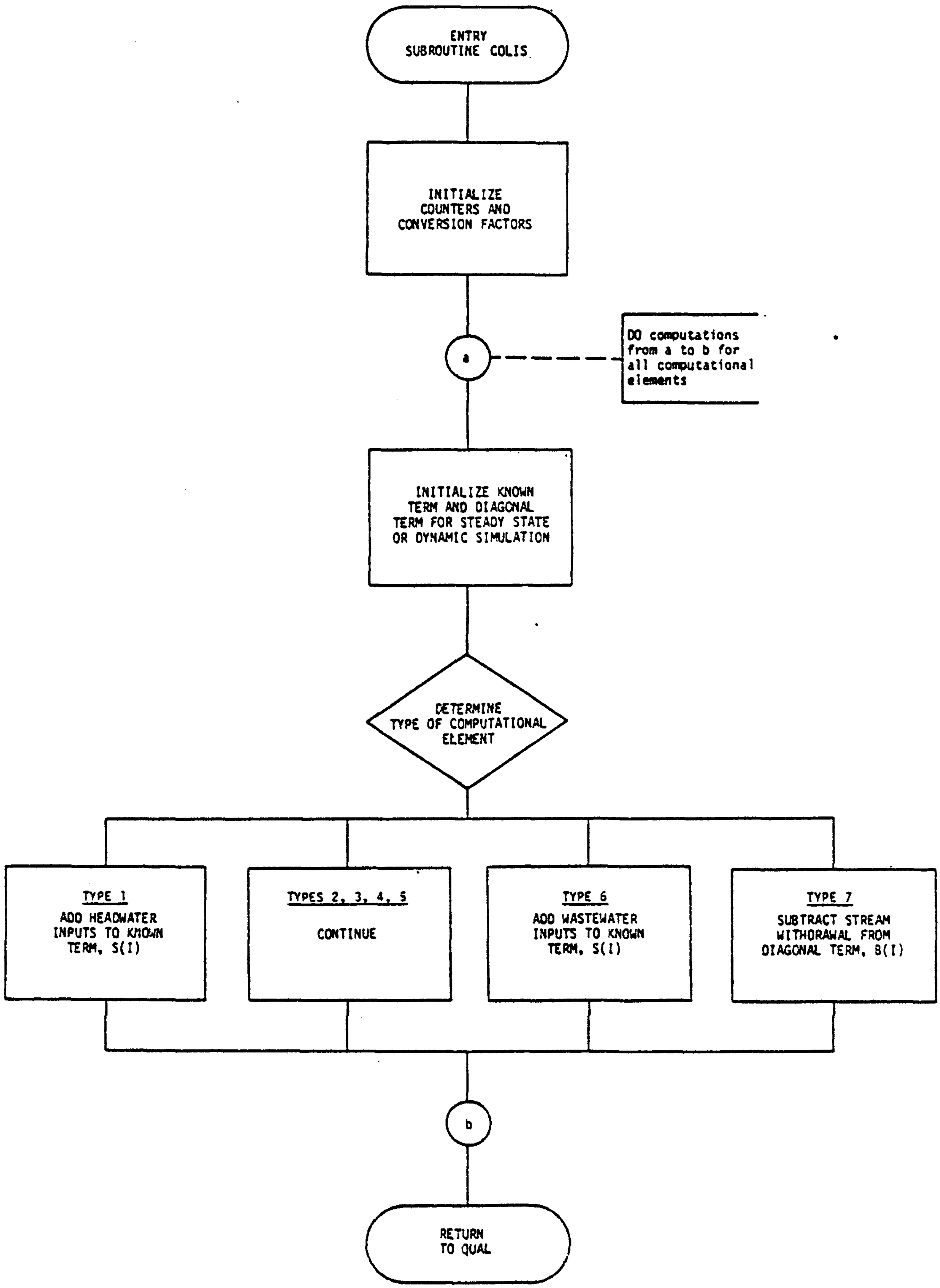

FIGURE VI-6. FLOW CHART FOR SUBROUTINE COLIS

```
      SUBROUTINE COLIS
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/SSTATE/X(500),ISS
      REAL K5
C
C                                INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                                LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      COLIJ=QI(I)/CNCELR*COLIR(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                                INITIALIZE DIAGONAL AND KNOWN TERMS
C
      TC=0.556*(T(IOR)-68.0)
```

```
      KS=CK5(I)*1.047**TC
      REACT=D1LT*KS
      B(IOR)=X(IOR)+REACT
      S(IOR)=COLI(IOR)
      IF (ISS.GT.0) S(IOR)=0.0
      S(IOR)=S(IOR)+COLIJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                                          MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWCOLI(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSCOLI(NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE CONSVT*

Subroutine CONSVT completes the setup of the equations necessary to calculate concentrations of a conservative constituent level in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i$
7. Withdrawal	$b_i = x_i - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = C_i^* + q_i' C_i' \frac{\Delta t}{V_i} - a_i C_h$
6. Waste Input	$S_i = C_i^* + q_i' C_i' \frac{\Delta t}{V_i} + q_w C_w \frac{\Delta t}{V_i}$
All Others	$S_i = C_i^* + q_i' C_i' \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, C_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-7 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

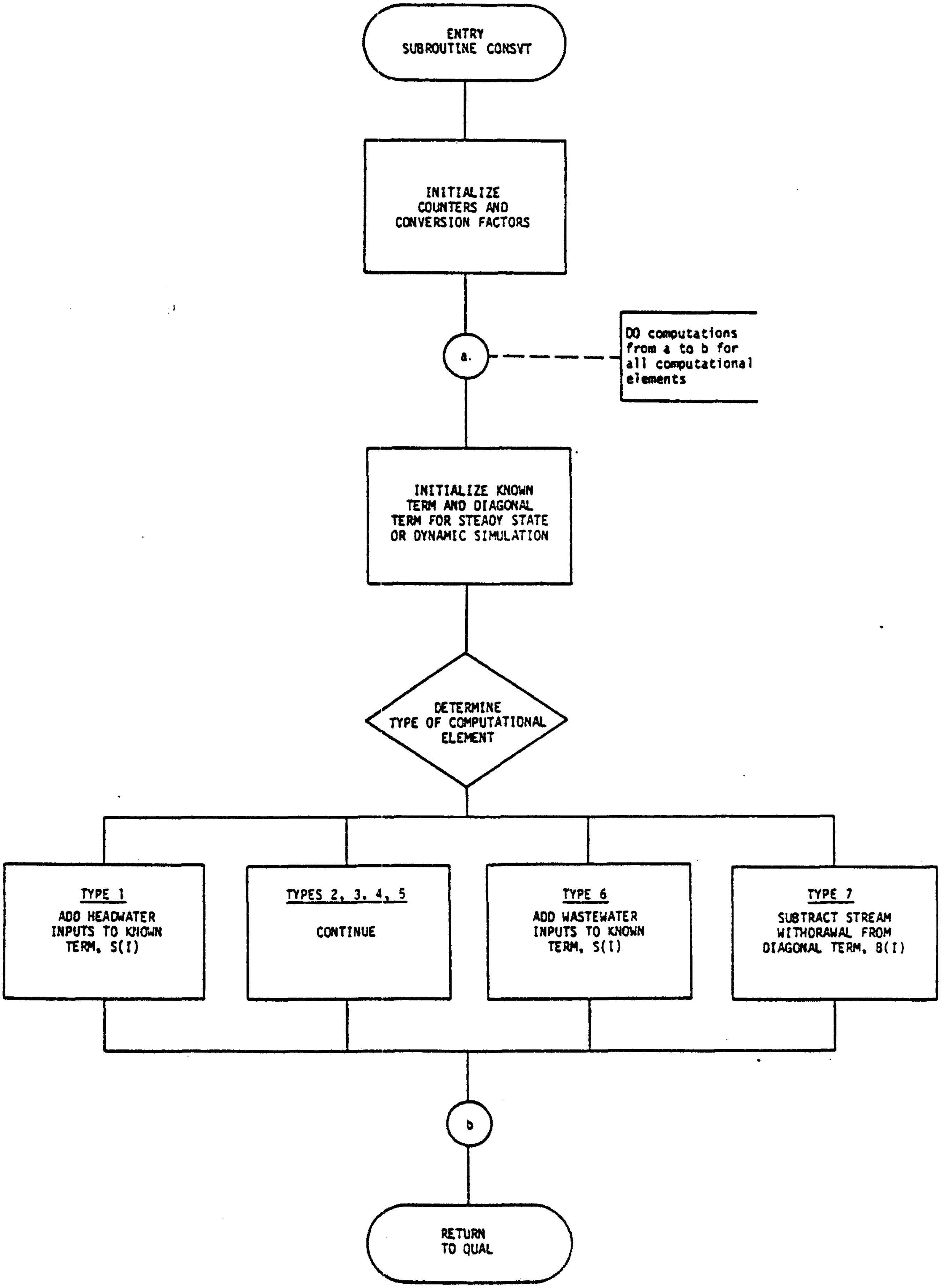

FIGURE VI-7. FLOW CHART FOR SUBROUTINE CONSVT

```
      SUBROUTINE CONSVT
C
C                              CONSVT PERFORMS A CONSERVATIVE MINERAL
C                              BALANCE FOR EACH COMPUTATIONAL ELEMENT
C                              IN THE SYSTEM.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
      COMMON/SSTATE/X(500),ISS
C
C                            INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                            LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      CONSIJ=QI(I)/CNCELR*CONSI(I,NC)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                            INITIALIZE DIAGONAL AND KNOWN TERMS
C
      B(IOR)=X(IOR)
      S(IOR)=CONS(IOR,NC)
      IF(ISS.GT.1) S(IOR)=0.0
      S(IOR)=S(IOR)+CONSIJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                            MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWCONS(NHW,NC)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSCONS(NWS,NC)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE DOS*

Subroutine DOS completes the setup of the equations necessary to calculate dissolved oxygen levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + (K_2)_i \Delta t$
7. Withdrawal	$b_i = x_i + (K_2)_i \Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT and the reaeration rate reaeration constant, $(K_2)_i$, is determined in Subroutine REAERC.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

$$S_i = \phi_i^* + q_i'\phi_i' \frac{\Delta t}{V_i} + (\alpha_3\mu_i - \alpha_4\rho) A_i\Delta t - \alpha_5(K_7N_1)_i \Delta t$$

$$- \alpha_6(K_8N_2)_i \Delta t - K_4\Delta x \frac{\Delta t}{V_i} + (K_2C_s)_i \Delta t - K_1L_i\Delta t$$

and is corrected for headwater conditions or a waste input as follows:

---

*All symbols used are defined at the end of this section of the Documentation Report.

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = S_i - a_i\phi_h$
6. Waste Input	$S_i = S_i + q_w\phi_w \frac{\Delta t}{V_i}$

For steady-state simulation, the only difference is that the value from the previous time step, ϕ_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-8 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

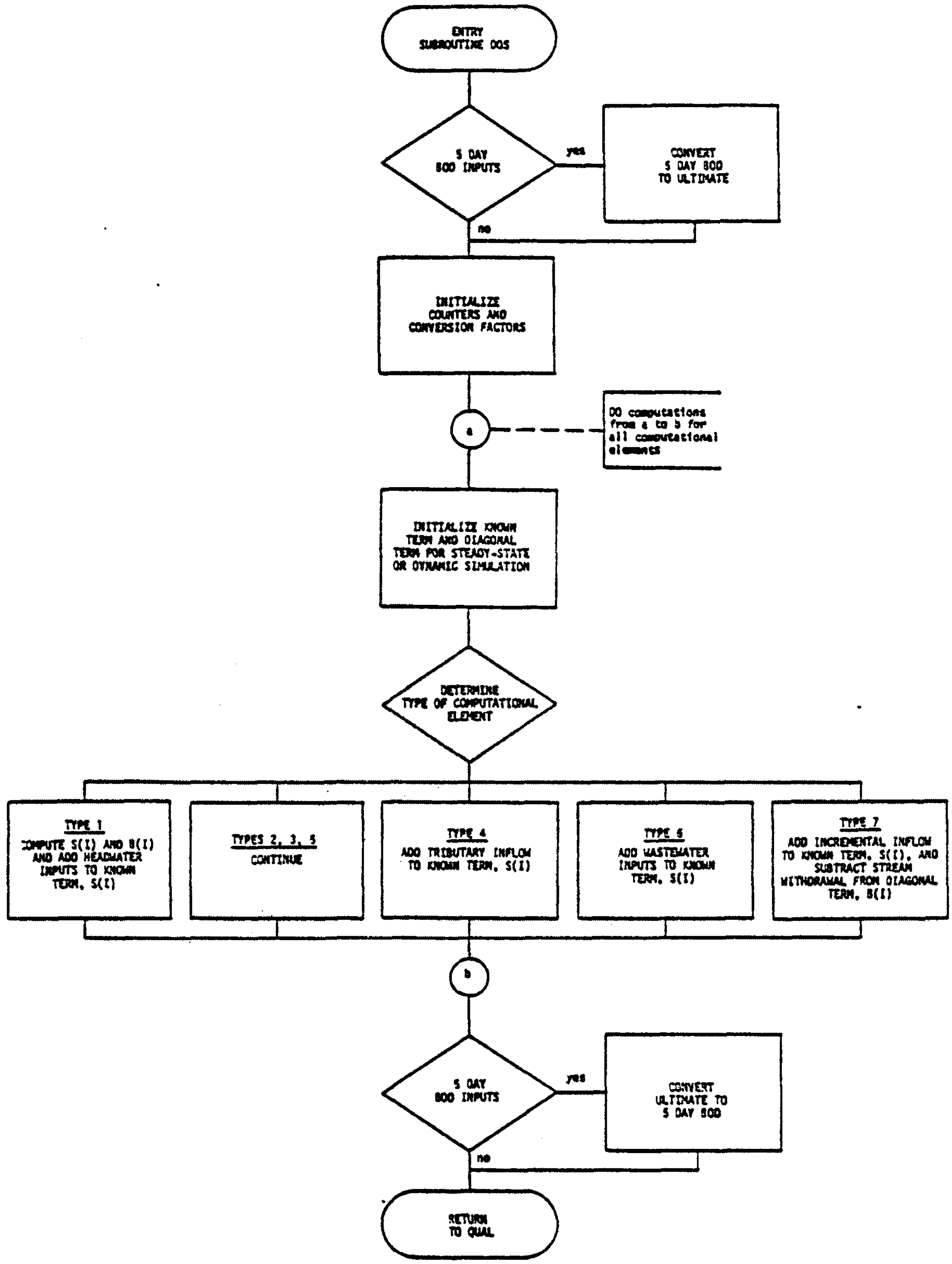

FIGURE VI-8. FLOW CHART FOR SUBROUTINE DOS

```
      SUBROUTINE DOS
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHA0(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/SSTATE/X(500),ISS
      REAL K1,K2,KO
      REAL KNH3,KNO2
      DATA UBOD/4H 5-D/
C-.....
C.....CONVERT BETWEEN ULTIMATE AND 5-DAY BOD BASED ON AN ASSUMED
C.....LAB DECAY RATE OF 0.23/DAY (BASE E )........WRN......
C.....
      IF(TITLE(7,6).NE.UBOD) GO TO 50
      CFBOD = 1.0 - EXP( -5.0*0.23 )
      IVERT = 0
   10 IVERT = IVERT + 1
      IF( NHWTRS .LE. 0 ) GO TO 25
      DO 20 J = 1, NHWTRS
      HWBOD(J) = HWBOD(J) / CFBOD
   20 CONTINUE
   25 IF( NWASTE .LE. 0 ) GO TO 35
      DO 30 J = 1, NWASTE
      WSBOD(J) = WSBOD(J) / CFBOD
   30 CONTINUE
   35 DO 45 J = 1, NREACH
      BODI(J) = BODI(J) / CFBOD
      NCELR = NCELRH(J)
      DO 40 K = 1, NCELR
      IOR = ICLORD(J,K)
      BOD(IOR) = BOD(IOR) / CFBOD
   40 CONTINUE
   45 CONTINUE
      IF( IVERT .GE. 2 ) RETURN
      CFBOD = 1.0 / CFBOD
C
C                           INITIALIZE COUNTERS
C
   50 CONTINUE
      NHW=0
      NWS=0
      IJUNC=0
```

```
            FACT = 1.0 / (28.3 * 86400.0)
      C
      C                                 LOOP THROUGH REACHES AND COMP. ELEMENTS
      C
            DO 100 I=1,NREACH
            NCELR=NCELRH(I)
            CNCELR=NCELR
            DOIJ=QI(I)/CNCELR*DOI(I)
      C     RATIO=1.0/(1.0-EXP(-5.0*CK1(I)))
            DO 100 J=1,NCELR
            IOR=ICLORD(I,J)
      C
      C                                 INITIALIZE DIAGONAL AND KNOWN TERMS
      C
            S(IOR)=DO(IOR)
            IF (ISS.GT.1) S(IOR)=0.0
            IF (MODOPT(4).LT.1) GO TO 90
            AREACT=(ALPHA3*GROWTH(IOR)-ALPHA4*RESPRR(IOR))*D1LT
            S(IOR) = S(IOR) + AREACT*ALGAE(IOR)
         90 IF (MODOPT(6).LT.1) GO TO 92
            S(IOR) = S(IOR) - (ALPHA5*KNH3(IOR)*CNH3(IOR)+
           1                  ALPHA6*KNO2(IOR)*CNO2(IOR))*D1LT
         92 S(IOR) = S(IOR) - CK4(I)*DELX*DTOVCL(IOR)*FACT
            TC=0.556*(T(IOR)-68.0)
      C     K1(IOR)=K1(IOR)*RATIO
            DOSAT=24.89-0.4259*T(IOR)+0.003734*T(IOR)**2-0.00001328*T(IOR)**3
            IF (DO(IOR).GT.DOSAT) DO(IOR) = DOSAT
            IFL=IFLAG(I,J)
      C
      C                                 MODIFY DIAGONAL AND/OR KNOWN TERMS
      C
            GO TO (101,102,102,104,102,103,105), IFL
      C
        101 NHW=NHW+1
            KO=K2(IOR)*1.0159**TC
            REACT=D1LT*(KO*DOSAT-K1(IOR)*BOD(IOR))
            S(IOR)=S(IOR)+REACT+DOIJ*DTOVCL(IOR)-A(IOR)*HWDO(NHW)
            B(IOR)=X(IOR)+D1LT*KO
            GO TO 100
      C
        102 KO=(0.5*(K2(IOR-1)+K2(IOR)))*1.0159**TC
            REACT=D1LT*(KO*DOSAT-K1(IOR)*BOD(IOR))
            S(IOR)=S(IOR)+REACT+DOIJ*DTOVCL(IOR)
            B(IOR)=X(IOR)+D1LT*KO
            GO TO 100
      C
        103 NWS=NWS+1
            KO=(0.5*(K2(IOR-1)+K2(IOR)))*1.0159**TC
            REACT=D1LT*(KO*DOSAT-K1(IOR)*BOD(IOR))
            S(IOR)=S(IOR)+REACT+(DOIJ+WSFLOW(NWS)*WSDO(NWS))*DTOVCL(IOR)
            B(IOR)=X(IOR)+D1LT*KO
            GO TO 100
      C
        104 IJUNC=IJUNC+1
            NS=1
            NN=JUNC(IJUNC,NS)
            KO=(0.25*(K2(IOR-1)+K2(NN)+2.0*K2(IOR)))*1.0159**TC
            REACT=D1LT*(KO*DOSAT-K1(IOR)*BOD(IOR))
            S(IOR)=S(IOR)+REACT+DOIJ*DTOVCL(IOR)
            B(IOR)=X(IOR)+D1LT*KO
            GO TO 100
      C
        105 NWS=NWS+1
            KO=(0.5*(K2(IOR-1)+K2(IOR)))*1.0159**TC
            REACT=D1LT*(KO*DOSAT-K1(IOR)*BOD(IOR))
            S(IOR)=S(IOR)+REACT+DOIJ*DTOVCL(IOR)
            B(IOR)=X(IOR)+D1LT*KO-WSFLOW(NWS)*DTOVCL(IOR)
        100 CONTINUE
            IF(TITLE(7,6).NE.UBOD) RETURN
            GO TO 10
            END
```

SUBROUTINE FLOAUG

Subroutine FLOAUG remains unchanged from the original version of QUAL as documented by the Texas Water Development Board (1970). According to that reference:

> *After steady-state conditions have been reached, FLOAUG checks the calculated dissolved oxygen concentration against the pre-specified target levels for dissolved oxygen in each reach. If the computed dissolved oxygen is below the target level, the routine then searches all of the upstream headwaters for those sources that the user has specified to have dilution water. Dilution water is then added equally from all sources and calculations are repeated. This sequence continues until all target levels are satisfied, whereupon a summary is written.*

The theory of FLOAUG according to Frank D. Masch and Associates and the Texas Water Development Board (1971) is:

> *When environmental conditions are such that the dissolved-oxygen concentration in a stream drops below some required target level, flow augmentation may be desirable. The amount of augmentation water required to bring dissolved-oxygen concentrations up to required standards cannot be computed by an exact functional relationship; however, a good approximation can be given by*

$$DO_R = DO_T - C_c$$

and

$$Q_R = Q_c \frac{DO_R}{DO_T}$$

where

DO_R = *dissolved-oxygen concentration required to meet target conditions, mg/l*

DO_T = *some required target level of dissolved oxygen, mg/l*

C_c = *minimum dissolved-oxygen concentration (critical level) in the oxygen sag curve, mg/l*

Q_R = *amount of flow augmentation required, cfs,*

Q_c = *flow at the critical point in the oxygen sag curve, cfs*

The flow chart for FLOAUG shown in Figure VI-9 is taken from the referenced report. The program listing follows the figure.

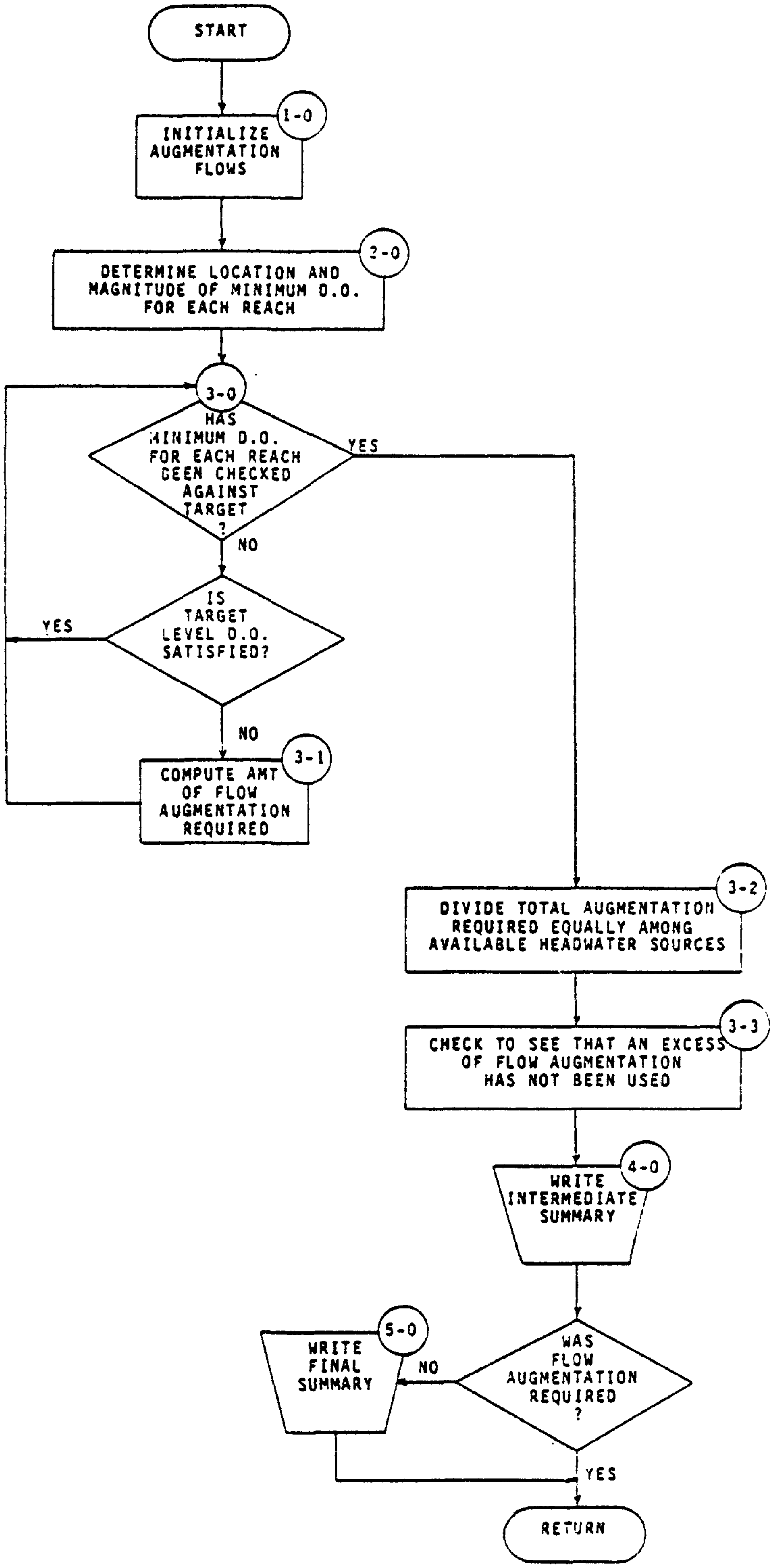

FIGURE VI-9. FLOW CHART FOR SUBROUTINE FLOAUG

```
      SUBROUTINE FLOAUG
C
C                             FLOAUG SEARCHES THROUGH THE SYSTEM BY
C                             REACH TO DETERMINE THE MINIMUM DO LEVEL
C                             WITHIN EACH REACH. EACH OF THESE MINIMUM
C                             DO LEVELS IS CHECKED AGAINST A SELECTED
C                             TARGET LEVEL. IF FLOW AUGMENTATION IS
C                             REQUIRED, THIS FLOW IS DISTRIBUTED
C                             EQUALLY AMONG THE HEADWATER SOURCES THAT
C                             ARE AVAILABLE TO A GIVEN REACH.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      DIMENSION IORMIN(75),RMILE(75),DOMIN(75),IORDER(75),QAUG(15)
C
C
C                                      STEP 1-0
C                                      INITIALIZE AUMENTATION FLOWS
      DO 5 NHW=1,NHWTRS
      QAUG(NHW)=0.0
    5 CONTINUE
C
C
C                                      STEP 2-0
C                                      LOOP THROUGH SYSTEM OF NREACH RE
C                                      AND NCELR COMPUTATIONAL ELEMENTS
C                                      REACH TO DETERMINE MINIMUM DO LE
C                                      REACH AND ITS LOCATION BY RIVER
C
      DO 50 I=1,NREACH
      DOMIN(I)=100.0
      IF(NHWWAR(I).EQ.0) GO TO 50
      NCELR=NCELRH(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      IF (DO(IOR).GE.DOMIN(I)) GO TO 100
      DOMIN(I)=DO(IOR)
```

```
          IORMIN(I)=IOR
          XMIN=J
          RMILE(I)=RMTHOR(I)-XMIN*DELX/5280.0
      100 CONTINUE
       50 CONTINUE
          NBTARG=0
C
C                                                  STEP 3-0
C                                                  LOOP THROUGH NREACH REACHES TO S
C                                                  MINIMUM DO LEVEL IS BELOW TARGET
C
          DO 25 I=1,NREACH
          IF (DOMIN(I).GE.TARGDO(I)) GO TO 25
C
C                                                  STEP 3-1
C                                                  IF TARGET LEVEL IS NOT MET, COMP
C                                                  AMOUNT OF FLOW AUGMENTATION REQU
C
          NBTARG=NBTARG+1
          IORDER(NBTARG)=I
          IOR=IORMIN(I)
          RMILE(NBTARG)=RMILE(I)
          DOREQD=TARGDO(I)-DOMIN(I)+0.1
          QREQD = FLOW(IOR)*(DOREQD/TARGDO(I) + 0.15*
         *(DOREQD/TARGDO(I))**2)
          QSUM=0.0
          NHWAR=NHWWAR(I)
          DO 350 J=1,NHWAR
          NHW=IAUGOR(I,J)
          QSUM=QSUM+QAUG(NHW)
      350 CONTINUE
C
C                                                  STEP 3-2
C                                                  DIVIDE TOTAL AUGMENTATION REQUIR
C                                                  EQUALLY AMONG THE UPSTREAM HEADW
C                                                  SOURCES AVAILABLE TO A GIVEN REA
C                                       GIVEN REACH.
C
          QADD=QREQD/NHWWAR(I)
C
C                                                  STEP 3-3
C                                                  CHECK TO SEE THAT AN EXCESS OF F
C                                                  AUGMENTATION HAS NOT BEEN USED.
C
          IF (QREQD.LT.QSUM) GO TO 25
          NHWAR=NHWWAR(I)
          DO 375 J=1,NHWAR
          NHW=IAUGOR(I,J)
          QAUG(NHW)=QADD
      375 CONTINUE
       25 CONTINUE
          IF (NBTARG.EQ.0) GO TO 300
C
C                                                  STEP 4-0
C                                                  WRITE SUMMARY OF FLOW AUG'MT. RE
```

```
C
      WRITE (NJ,200)
  200 FORMAT (1H1,38X,39H* * * REACHES WITH OXYGEN DEFICIT * * *,//,23X,
     *       52HREACH NO.     REACH IDENTIFICATION        MINIMUM DO.,
     *       15H      RIVER MILE,/)
      TIME=0.0
      DO 250 K=1,NBTARG
      I=IORDER(K)
      WRITE (NJ,255) I,(RCHID(I,J),J=1,5),DOMIN(I),RMILE(I)
  255 FORMAT (22X,I5,10X,5A4,7X,F5.1,11X,F6.1)
  250 CONTINUE
      WRITE (NJ,260)
  260 FORMAT (1H0,30X,38H* * * FLOW AUGMENTATION REQUIRED * * *,//,
     *       5X,100HHEADWATER NO.     HEADWATER IDENTIFICATION      EXIS
     *TING HEADWATER FLOW (CFS)     AUG. REQUIRED (CFS),/)
      DO 270 NHW=1,NHWTRS
      WRITE (NJ,275) NHW,(HWTRID(NHW,J),J=1,5),HWFLOW(NHW),QAUG(NHW)
  275 FORMAT (8X,I5,12X,5A4,16X,F10.1,20X,F10.1)
  270 CONTINUE
      DO 380 NHW=1,NHWTRS
      HWFLOW(NHW) = HWFLOW(NHW) + QAUG(NHW)
  380 CONTINUE
      GO TO 310
  300 CONTINUE
C
C                                              STEP 5-0
C                                              WRITE FINAL SUMMARY OF FLOW
C                                              AUGMENTATION REQUIREMENTS.
C
      WRITE (NJ,261)
  261 FORMAT (1H0,33X,32HTOTAL FLOW AUGMENTATION REQUIRED,//,
     *5X,101HHEADWATER NO.     HEADWATER IDENTIFICATION       INITIAL  HE
     *ADWATER FLOW (CFS)     AUG. REQUIRED (CFS),/)
      DO 305 NHW=1,NHWTRS
      HWFLOI=QATOT(NHW)
      QATOT(NHW)=HWFLOW(NHW)-HWFLOI
      HWFLOW(NHW)=HWFLOI
      WRITE (NJ,275) NHW,(HWTRID(NHW,J),J=1,5),HWFLOW(NHW),QATOT(NHW)
  305 CONTINUE
  310 CONTINUE
      RETURN
      END
```

SUBROUTINE HEATEX/HEATER

Subroutine HEATEX is used in the dynamic simulation of temperature. It remains unchanged from the original version of QUAL as documented by the Texas Water Development Board (1970). According to that reference:

> *This routine computes the net amount of heat radiation flux being transferred across the air-water interface. It is based on an energy budget which considers solar radiation, atmospheric radiation, back radiation, conduction, and evaporation.*

Detailed equations for all of the heat budget terms are presented in Section IV.

The flow chart for Subroutine HEATEX shown in Figure VI-10 is taken from the Texas Water Development Board reference. The program listing follows the figure.

Subroutine HEATER is used in the steady-state simulation of temperature. Calculations performed in HEATER are identical to those performed in HEATEX except that the step (3-0)--see Figure VI-10--is not included in HEATER. Back radiation, evaporation, and conduction losses are computed in TEMPSS. The program listing for HEATER follows the listing for HEATEX.

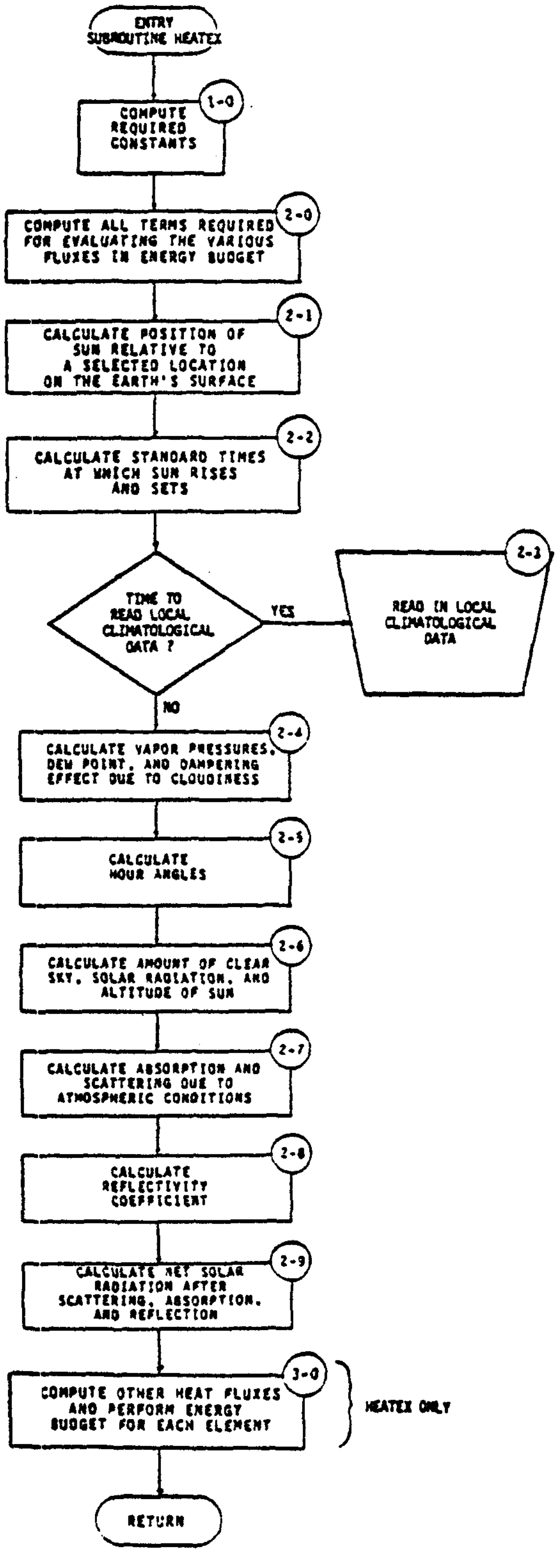

FIGURE VI-10. FLOW CHART FOR SUBROUTINE HEATEX/HEATER

```
      SUBROUTINE HEATEX
C
C                            HEATEX COMPUTES THE NET AMOUNT OF HEAT
C                            RADIATION FLUX BEING TRANSFERRED ACROSS
C                            THE AIR-WATER INTERFACE BASED ON AN
C                            ENERGY BUDGET WHICH CONSIDERS SOLAR
C                            RADIATION, ATMOSPHERIC RADIATION, BACK
C                            RADIATION, CONDUCTION, AND EVAPORATION.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORO(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2DDX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/METER/METRIC,METOUT
C
C
C
      REAL LLM,LSM,LAT
C
C                                      STEP 1-0
C                                      COMPUTE REQUIRED CONSTANTS
C
      PI=3.141628
      CON1=2.0*PI/365.0
      CON2=PI/180.0*LAT
      CON3=180.0/PI
      CON4=23.45*PI/180.0
      CON5=PI/12.0
      CON6=12.0/PI
      DELTSL=(LLM-LSM)/15.0
      SOLCON=438.0
      ELEXP=EXP(-ELEV/2532.0)
C
C                                      STEP 2-0
C                                      COMPUTE ALL TERMS REQUIRED FOR
C                                      EVALUATING THE VARIOUS FLUXES IN
C                                      ENERGY BUDGET
C
      IF (TOFDAY.NE.0.0) GO TO 77
C
C                                      STEP 2-1
C                                      COMPUTE SEASONAL AND DAILY POSIT
C                                      SUN RELATIVE TO A SELECTED LOCAT
C                                      THE EARTH'S SURFACE.
C
      REARTH=1.0+0.017*COS(CON1*(186.0-DAYOFY))
      DECLIN=CON4*COS(CON1*(172.0-DAYOFY))
      RR=REARTH**2
      EQTIME=0.000121-0.12319*SIN(CON1*(DAYOFY-1.0)-0.07014)
     *       -0.16549*SIN(2.0*CON1*(DAYOFY-1.0)+0.3088)
      DECLON=ABS(DECLIN)
      ACS=TAN(CON2)*TAN(DECLON)
      IF (ACS.EQ.0.0) GO TO 8
      X=SQRT(1.0-ACS*ACS)
      X=X/ACS
```

```
      ACS=ATAN(X)
      IF (DECLIN.GT.0.0) ACS=PI-ACS
      GO TO 9
    8 ACS=PI/2.0
    9 CONTINUE
C
C                                                STEP 2-2
C                                                COMPUTE STANDARD TIMES AT WHICH
C                                                RISES AND SETS.
C
      STR=12.0-CON6*ACS+DELTSL
      STS=24.0-STR+2.0*DELTSL
      STB=0.0
      STE=STB+D2LT
      GO TO 78
   77 STB=STB+D2LT
      STE=STB+D2LT
   78 CONTINUE
C
C                                                STEP 2-3
C                                                READ IN LOCAL CLIMATALOGICAL DAT
C                                                AT DESIRED TIME INTERVAL (MINIMU
C                                                INTERVAL IS THREE HOURS).
C
      IF (TRLCD.NE.0.0) GO TO 82
      READ 12, CLOUD,DRYBLB,WETBLB,ATMPR,WIND
   12 FORMAT (40X,5F8.0)
      IF(METRIC.EQ.0)GO TO 13
      DRYBLB=DRYBLB*1.8+32.0
      WETBLB=WETBLB*1.8+32.0
      ATMPR=ATMPR*(29.9/1000.)
      WIND=WIND/0.3048
   13 CONTINUE
      WIND=WIND*0.6818
C
C                                                STEP 2-4
C                                                COMPUTE VAPOR PRESSURES, DEW POI
C                                                DAMPENING EFFECT OF CLOUDINESS.
C
      VPWB=0.1001*EXP(0.03*WETBLB)-0.0837
      VPAIR=VPWB-0.000367*ATMPR*(DRYBLB-WETBLB)
     *     *(1.0+(WETBLB-32.0)/1571.0)
      DEWPT=ALOG((VPAIR+0.0837)/0.1001)/0.03
      CS=1.0-0.65*CLOUD**2
      IF (CLOUD.GT.0.9) CS=0.50
      CNL=CLOUD*10.0+1.0
      NL=CNL
   82 CONTINUE
      TRLCD=TRLCD+D2LT
      IF (TRLCD.LT.2.9) GO TO 84
      TRLCD=0.0
   84 CONTINUE
      IF (STS.LE.STB.OR.STR.GE.STE) GO TO 35
      IF(STR.GT.STB.AND.STR.LT.STE) GO TO 41
      IF (STS.LT.STE.AND.STS.GT.STB) GO TO 42
C
C                                                STEP 2-5
C                                                COMPUTE HOUR ANGLES
C
      TB=STB-12.0-DELTSL+EQTIME
      TE=STE-12.0-DELTSL+EQTIME
      GO TO 43
   41 TB=STR-12.0-DELTSL+EQTIME
      TE=STE-12.0-DELTSL+EQTIME
      GO TO 43
   42 TB=STB-12.0-DELTSL+EQTIME
      TE=STS-12.0-DELTSL+EQTIME
   43 CONTINUE
      TALT=(TB+TE)/2.0
C
```

```
      C                                              STEP 2-6
      C                                              COMPUTE AMT OF CLEAR SKY, SOLAR
      C                                              RADIATION, AND ALTITUDE OF SUN.
      C
            SOLAR=SOLCON/RR*(SIN(CON2)*SIN(DECLIN)*(TE-TB)+CON6*COS(CON2)*
           *      COS(DECLIN)*(SIN(CON5*TE)-SIN(CON5*TB)))
            ALPHA=SIN(CON2)*SIN(DECLIN)+COS(CON2)*COS(DECLIN)*COS(CON5*TALT)
            IF (ABS(ALPHA).EQ.1.0) GO TO 4
            Y=SQRT(1.0-ALPHA*ALPHA)
            Y=ALPHA/Y
            ALPHA=ATAN(Y)
            GO TO 5
          4 IF (ALPHA.EQ.-1.0) GO TO 6
            ALPHA=PI/2.0
            GO TO 5
          6 ALPHA=-PI/2.0
          5 CONTINUE
            IF (ALPHA.LT.0.01) GO TO 35
      C
      C                                              STEP 2-7
      C                                              COMPUTE ABSORPTION AND SCATTERIN
      C                                              DUE TO ATMOSPHERIC CONDITIONS.
      C
            PWC=0.00614*EXP(0.0489*DEWPT)
            OAM=ELEXP/(SIN(ALPHA)+0.15*(ALPHA*CON3+3.885)**(-1.253))
            A1=EXP(-(0.465+0.0408*PWC)*(0.129+0.171*EXP(-0.880*OAM))*OAM)
            A2=EXP(-(0.465+0.0408*PWC)*(0.179+0.421*EXP(-0.721*OAM))*OAM)
      C
      C                                              STEP 2-8
      C                                              COMPUTE REFLECTIVITY COEFFICIENT
      C
            GO TO (30,31,31,31,31,31,32,32,32,32,33), NL
         30 AR=1.18
            BR=-0.77
            GO TO 34
         31 AR=2.20
            BR=-0.97
            GO TO 34
         32 AR=0.95
            BR=-0.75
            GO TO 34
         33 AR=0.35
            BR=-0.45
         34 CONTINUE
            RS=AR*(CON3*ALPHA)**BR
            ATC=(A2+0.5*(1.0-A1-DAT))/(1.0-0.5*RS*(1.0-A1+DAT))
      C
      C                                              STEP 2-9
      C                                              COMPUTE NET SOLAR RADIATION AFTE
      C                                              SCATTERING, ABSORPTION, AND REFL
      C
            SONET=SOLAR*ATC*CS*(1.0-RS)
      C + + + + + + + FEB 1980 REVISIONS NO. 6
            IF(SONET.LE.0)GO TO 35
      C + + + + + + +
            GO TO 36
         35 SONET=0.0
         36 CONTINUE
            CLC=1.0+0.17*CLOUD**2
      C
      C                                              STEP 3-0
      C                                              COMPUTE OTHER HEAT FLUXES AND PE
      C                                              ENERGY BUDGET FOR EACH COMPUTATI
      C                                              ELEMENT.
      C
            HA=0.97*1.73E-09*2.89E-06*(DRYBLB+460.0)**6*CLC*D2LT
            DO 70 I=1,NREACH
            NCELR=NCELRH(I)
            DO 70 J=1,NCELR
            ICR=ICLORD(I,J)
```

```
      VPW=0.1001*EXP(0.03*T(IOR))-0.0837
      HB=0.97*1.73E-09*(T(IOR)+460.0)**4*D2LT
      EVAP=62.4*(AE+BE*WIND)
      HE=EVAP*(VPW-VPAIR)*(1084.0-0.5*T(IOR))*D2LT
      HC=0.01*EVAP*(DRYBLB-T(IOR))*(1084.0-0.5*T(IOR))*D2LT
      HSNET(IOR)=SONET+HA-HB+HC-HE
   70 CONTINUE
      TOFDAY=TOFDAY+D2LT
      IF (TOFDAY.LT.23.9) GO TO 85
      TOFDAY=0.0
      DAYOFY=DAYOFY+1.0
   85 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE HEATER(NITER)
C
C                              HEATEX COMPUTES THE NET AMOUNT OF HEAT
C                              RADIATION FLUX BEING TRANSFERRED ACROSS
C                              THE AIR-WATER INTERFACE BASED ON AN
C                              ENERGY BUDGET WHICH CONSIDERS SOLAR
C                              RADIATION, ATMOSPHERIC RADIATION, BACK
C                              RADIATION, CONDUCTION, AND EVAPORATION.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *        TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *        ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *        CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *        EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *        QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *        JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *        HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *        WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *        A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *        FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *        HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *        DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *        NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *        LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *        ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/METER/METRIC,METOUT
C
C + + + + + + + FEB 1980 REVISIONS NO. 7
C
      COMMON/AUG/IAUGIT
C + + + + + + + +
C
C
      COMMON/SSTEMP/JT(500),SOLRCH(75),CLDRCH(75),PATRCH(75),
     *              TDBRCH(75),TWBRCH(75),WINRCH(75)
      REAL LLM,LSM,LAT
C
C                                        STEP 1-0
C                                        COMPUTE REQUIRED CONSTANTS
C
      PI=3.141628
      CON1=2.0*PI/365.0
      CON2=PI/180.0*LAT
      CON3=180.0/PI
      CON4=23.45*PI/180.0
      CON5=PI/12.0
      CON6=12.0/PI
      DELTSL=(LLM-LSM)/15.0
      SOLCON=438.0
      ELEXP=EXP(-ELEV/2532.0)
C
C                                        STEP 2-0
C                                        COMPUTE ALL TERMS REQUIRED FOR
C                                        EVALUATING THE VARIOUS FLUXES IN
C                                        ENERGY BUDGET
C
      IF (TOFDAY.NE.0.0) GO TO 77
C
C                                        STEP 2-1
C                                        COMPUTE SEASONAL AND DAILY POSIT
C                                        SUN RELATIVE TO A SELECTED LOCAT
C                                        THE EARTH'S SURFACE.
C
      REARTH=1.0+0.017*COS(CON1*(186.0-DAYOFY))
      DECLIN=CON4*COS(CON1*(172.0-DAYOFY))
      RR=REARTH**2
      EQTIME=0.000121-0.12319*SIN(CON1*(DAYOFY-1.0)-0.07014)
```

```
     *       -0.16549*SIN(2.0*CON1*(DAYOFY-1.0)+0.3088)
      DECLON=ABS(DECLIN)
      ACS=TAN(CON2)*TAN(DECLON)
      IF (ACS.EQ.0.0) GO TO 8
      X=SQRT(1.0-ACS*ACS)
      X=X/ACS
      ACS=ATAN(X)
      IF (DECLIN.GT.0.0) ACS=PI-ACS
      GO TO 9
    8 ACS=PI/2.0
    9 CONTINUE
C
C                                               STEP 2-2
C                                               COMPUTE STANDARD TIMES AT WHICH
C                                               RISES AND SETS.
C
      STR=12.0-CON6*ACS+DELTSL
      STS=24.0-STR+2.0*DELTSL
      STB=0.0
      STE=STB+D2LT
      GO TO 78
   77 STB=STB+D2LT
      STE=STB+D2LT
   78 CONTINUE
C
C                                               STEP 2-3
C                                               READ IN LOCAL CLIMATALOGICAL DAT
C                                               AT DESIRED TIME INTERVAL (MINIMU
C                                               INTERVAL IS THREE HOURS).
C
      IF (TRLCD.NE.0.0) GO TO 82
C + + + + + + + FEB 1980 REVISIONS NO. 8
C
      IF(IAUGIT.LE.0) READ(NI,12) CLOUD,DRYBLB,WETBLB,ATMPR,WIND
C + + + + + + +
C
   12 FORMAT(40X,5F8.0)
      IF(METRIC.EQ.0)GO TO 13
      DRYBLB=DRYBLB*1.8+32.0
      WETBLB=WETBLB*1.8+32.0
      ATMPR=ATMPR*(29.9/1000.)
      WIND=WIND/0.3048
   13 CONTINUE
      WIND=WIND*0.6818
      DO 922 I=1,NREACH
      TWBRCH(I)=WETBLB
      TDBRCH(I)=DRYBLB
      CLDRCH(I)=CLOUD
      WINRCH(I)=WIND
      PATRCH(I)=ATMPR
  922 CONTINUE
C
C                                               STEP 2-4
C                                               COMPUTE VAPOR PRESSURES, DEW POI
C                                               DAMPENING EFFECT OF CLOUDINESS.
C
      VPWB=0.1001*EXP(0.03*WETBLB)-0.0837
      VPAIR=VPWB-0.000367*ATMPR*(DRYBLB-WETBLB)
     *      *(1.0+(WETBLB-32.0)/1571.0)
      DEWPT=ALOG((VPAIR+0.0837)/0.1001)/0.03
      CS=1.0-0.65*CLOUD**2
      IF (CLOUD.GT.0.9) CS=0.50
      CNL=CLOUD*10.0+1.0
      NL=CNL
   82 CONTINUE
   84 CONTINUE
      IF (STS.LE.STB.OR.STR.GE.STE) GO TO 35
      IF(STR.GT.STB.AND.STR.LT.STE) GO TO 41
      IF (STS.LT.STE.AND.STS.GT.STB) GO TO 42
C
```

```
C                                                      STEP 2-5
C                                                      COMPUTE HOUR ANGLES
C
        TB=STB-12.0-DELTSL+EQTIME
        TE=STE-12.0-DELTSL+EQTIME
        GO TO 43
     41 TB=STR-12.0-DELTSL+EQTIME
        TE=STE-12.0-DELTSL+EQTIME
        GO TO 43
     42 TB=STB-12.0-DELTSL+EQTIME
        TE=STS-12.0-DELTSL+EQTIME
     43 CONTINUE
        TALT=(TB+TE)/2.0
C
C                                                      STEP 2-6
C                                                      COMPUTE AMT OF CLEAR SKY, SOLAR
C                                                      RADIATION, AND ALTITUDE OF SUN.
C
        SOLAR=SOLCON/RR*(SIN(CON2)*SIN(DECLIN)*(TE-TB)+CON6*COS(CON2)*
     *        COS(DECLIN)*(SIN(CON5*TE)-SIN(CON5*TB)))
        ALPHA=SIN(CON2)*SIN(DECLIN)+COS(CON2)*COS(DECLIN)*COS(CON5*TALT)
        IF (ABS(ALPHA).EQ.1.0) GO TO 4
        Y=SQRT(1.0-ALPHA*ALPHA)
        Y=ALPHA/Y
        ALPHA=ATAN(Y)
        GO TO 5
      4 IF (ALPHA.EQ.-1.0) GO TO 6
        ALPHA=PI/2.0
        GO TO 5
      6 ALPHA=-PI/2.0
      5 CONTINUE
        IF (ALPHA.LT.0.01) GO TO 35
C
C                                                      STEP 2-7
C                                                      COMPUTE ABSORPTION AND SCATTERIN
C                                                      DUE TO ATMOSPHERIC CONDITIONS.
C
        PWC=0.00614*EXP(0.0489*DEWPT)
        OAM=ELEXP/(SIN(ALPHA)+0.15*(ALPHA*CON3+3.885)**(-1.253))
        A1=EXP(-(0.465+0.0408*PWC)*(0.129+0.171*EXP(-0.880*OAM))*OAM)
        A2=EXP(-(0.465+0.0408*PWC)*(0.179+0.421*EXP(-0.721*OAM))*OAM)
C
C                                                      STEP 2-8
C                                                      COMPUTE REFLECTIVITY COEFFICIENT
C
        GO TO (30,31,31,31,31,31,32,32,32,32,33), NL
     30 AR=1.18
        BR=-0.77
        GO TO 34
     31 AR=2.20
        BR=-0.97
        GO TO 34
     32 AR=0.95
        BR=-0.75
        GO TO 34
     33 AR=0.35
        BR=-0.45
     34 CONTINUE
        RS=AR*(CON3*ALPHA)**BR
        ATC=(A2+0.5*(1.0-A1-DAT))/(1.0-0.5*RS*(1.0-A1+DAT))
C
C                                                      STEP 2-9
C                                                      COMPUTE NET SOLAR RADIATION AFTE
C                                                      SCATTERING, ABSORPTION, AND REFL
C
        SONET=SOLAR*ATC*CS*(1.0-RS)
        GO TO 36
     35 SONET=0.0
     36 CONTINUE
        DO 923 I=1,NREACH
```

```
      SOLRCH(I)=SONET
  923 CONTINUE
      TOFDAY=TOFDAY+D2LT
      IF (TOFDAY.LT.23.9) GO TO 85
      TOFDAY=0.
      DAYOFY=DAYOFY+1.
   85 CONTINUE
      RETURN
      END
```

SUBROUTINE HYDRAU

Subroutine HYDRAU remains largely unchanged from the original version of QUAL as documented by the Texas Water Development Board (1970). According to that reference:

> *This routine performs a hydrologic balance for a branching stream or canal system based on continuity of flow. It then computes velocities, volumes, and dispersion coefficients for every computational element in the system.*

The only change from the original version is that Subroutine CHANL is now called in steps 2-1, 2-2, 2-3, and 2-4 to compute velocity and depth in each element.

The flow chart for Subroutine HYDRAU shown in Figure VI-11 is taken from the Texas Water Development Board reference. The program listing follows the figure.

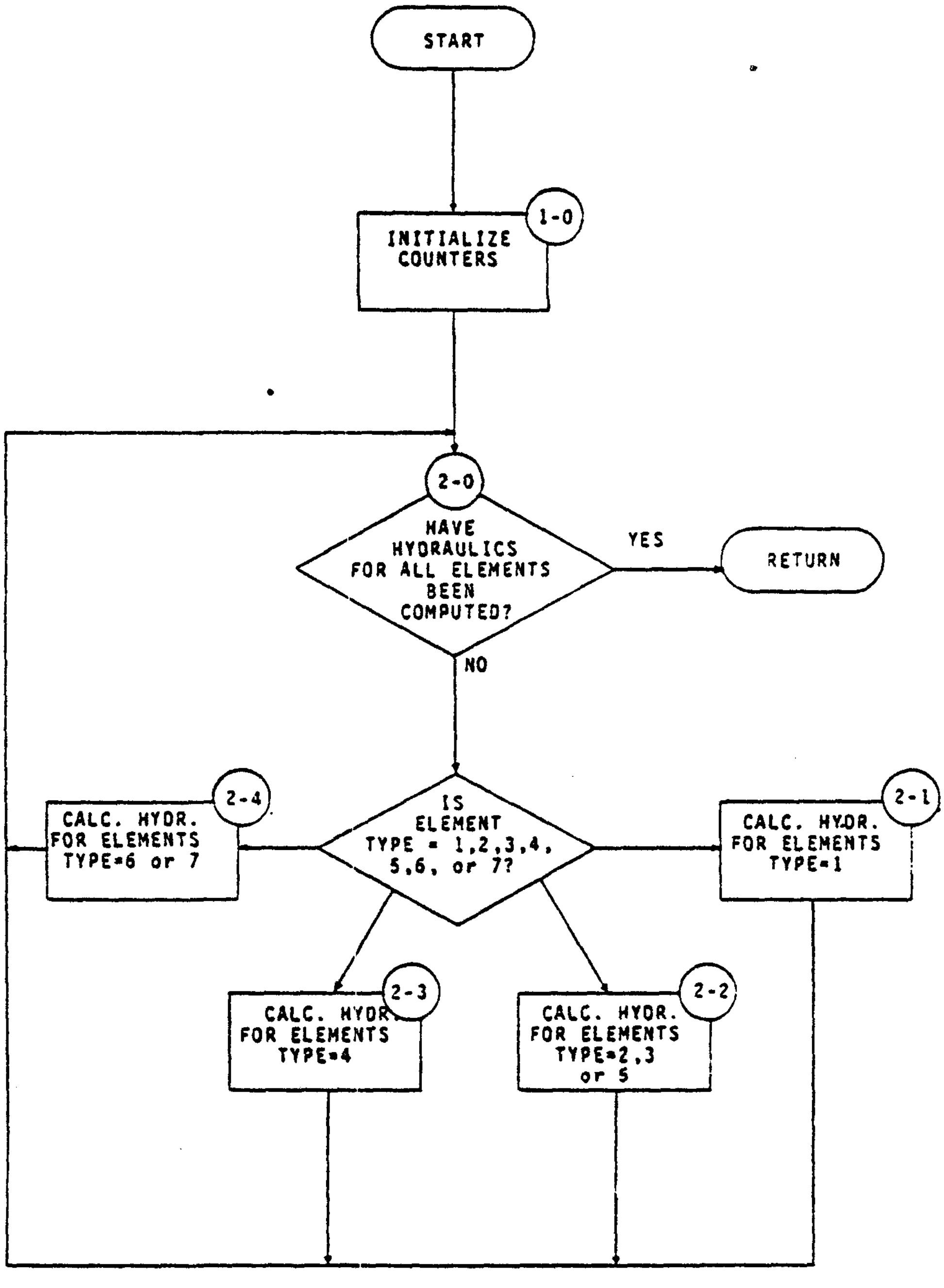

FIGURE VI-11. FLOW CHART FOR SUBROUTINE HYDRAU

```
      SUBROUTINE HYDRAU
C
C
C                         HYDRAU PERFORMS A HYDROLOGIC BALANCE ON
C                         THE SYSTEM BASED ON CONTINUITY. IT
C                         COMPUTES THE FLOW, VELOCITY, VOLUME,
C                         DEPTH, AND DISPERSION COEFFICIENT FOR
C                         EVERY ELEMENT IN THE SYSTEM.
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
C                                   STEP 1-0
C                                   INITIALIZE COUNTERS FOR HEADWATE
C                                   WASTE INPUTS OR WITHDRAWLS, AND
C                                   JUNCTIONS.
C
      NHW=0
      NWS=0
      IJUNC=0
C
C                                   STEP 2-0
C                                   LOOP THROUGH SYSTEM OF NREACH RE
C                                   AND NCELR COMPUTATIONAL ELEMENTS
C                                   REACH.
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      QR=QI(I)/CNCELR
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      IFL=IFLAG(I,J)
      GO TO (101,102,102,103,102,104,104), IFL
C
C                                   STEP 2-1
C                                   COMPUTE HYDRAULICS FOR AN ELEMEN
C                                   TYPE 1.
C
```

```
  101 NHW=NHW+1
      FLOW(IOR)=HWFLOW(NHW)+QR
      CALL CHANL(I,HWFLOW(NHW),VHW(NHW),DEPHW(NHW))
      DLHW(NHW)=22.6*CMANN(I)*VHW(NHW)*DEPHW(NHW)**0.833
      CALL CHANL(I,FLOW(IOR),VEL(IOR),DEPTH(IOR))
      DTOVCL(IOR)=DT20DX/(HWFLOW(NHW)/VHW(NHW)+FLOW(IOR)/VEL(IOR))
      GO TO 105
C
C                                      STEP 2-2
C                                      COMPUTE HYDRAULICS FOR ELEMENTS
C                                      2,3, OR 5.
C
  102 FLOW(IOR)=FLOW(IOR-1)+QR
      CALL CHANL(I,FLOW(IOR),VEL(IOR),DEPTH(IOR))
      DTOVCL(IOR)=DT20DX/(FLOW(IOR-1)/VEL(IOR-1)+FLOW(IOR)/VEL(IOR))
      GO TO 105
C
C                                      STEP 2-3
C                                      COMPUTE HYDRAULICS FOR AN ELEMEN
C                                      TYPE 4.
C
  103 IJUNC=IJUNC+1
      NS=1
      NN=JUNC(IJUNC,NS)
      FLOW(IOR)=FLOW(IOR-1)+FLOW(NN)+QR
      CALL CHANL(I,FLOW(IOR),VEL(IOR),DEPTH(IOR))
      DTOVCL(IOR)=DT20DX/(FLOW(IOR-1)/VEL(IOR-1)+FLOW(IOR)/VEL(IOR)+
     *            FLOW(NN)/VEL(NN))
      GO TO 105
C
C                                      STEP 2-4
C                                      COMPUTE HYDRAULICS FOR ELEMENTS
C                                      6 OR 7.
C
  104 NWS=NWS+1
      FLOW(IOR)=FLOW(IOR-1)+WSFLOW(NWS)+QR
      CALL CHANL(I,FLOW(IOR),VEL(IOR),DEPTH(IOR))
      DTOVCL(IOR)=DT20DX/(FLOW(IOR-1)/VEL(IOR-1)+FLOW(IOR)/VEL(IOR))
  105 CONTINUE
      DL(IOR)=22.6*CMANN(I)*VEL(IOR)*DEPTH(IOR)**0.833
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE INDATA

Subroutine INDATA reads and prints all data required by the model except the climatological data which is read in Subroutine HEATEX/HEATER or ALGAE*. INDATA reads a set of title cards and 11 different types of data that are prepared on 19 different data forms. Seven of the data forms are optional depending on the parameters to be simulated. Chapter V contains additional details concerning data preparation, descriptions of data forms and an example data set. If INDATA detects any data inconsistencies, it prints an error message and terminates execution.

Figure VI-12 illustrates the flow chart for INDATA and the following pages contain the program listing. All program variables in COMMON are defined in Section VII.

---

*The criteria that determines which subroutine reads the climatological data are:

1. Dynamic Simulation - No Temperature Simulation:
   Read solar radiation values in ALGAE.
2. Dynamic Simulation - With Temperature Simulation:
   Read Climatological Data in HEATEX.
3. Steady-State Simulation:
   Read Climatological Data in HEATER.

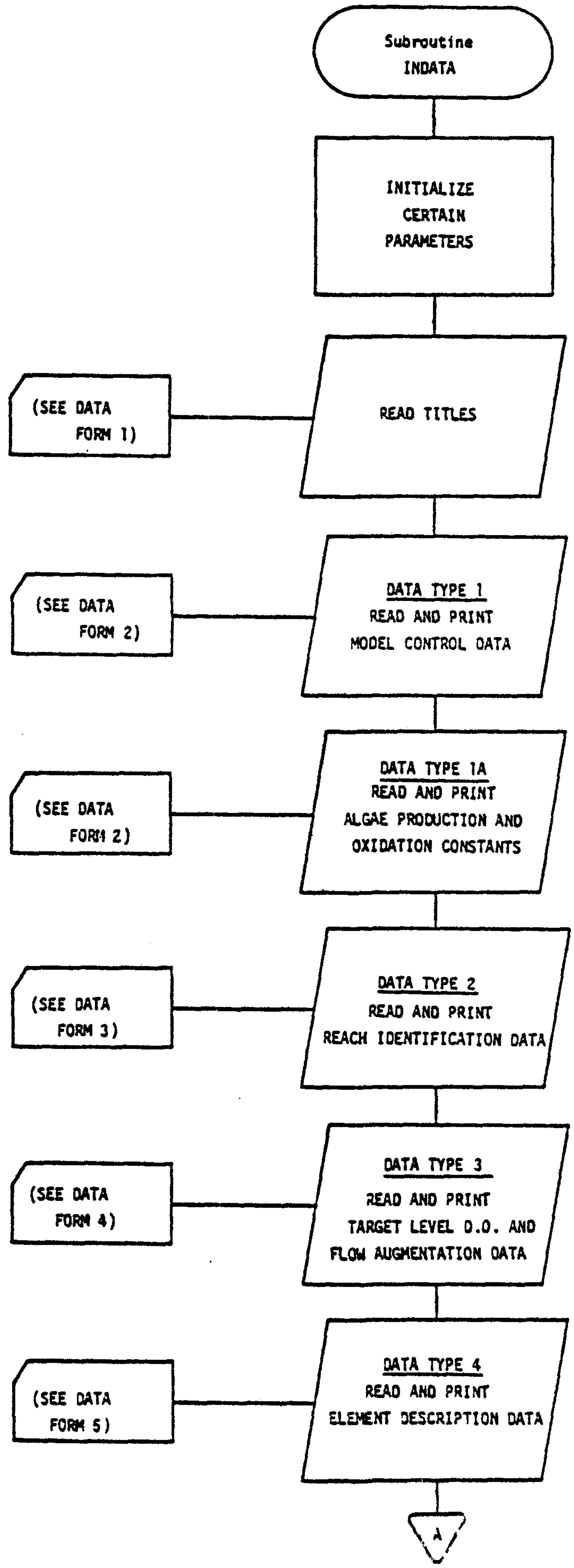

FIGURE VI-12. FLOW CHART FOR SUBROUTINE INDATA

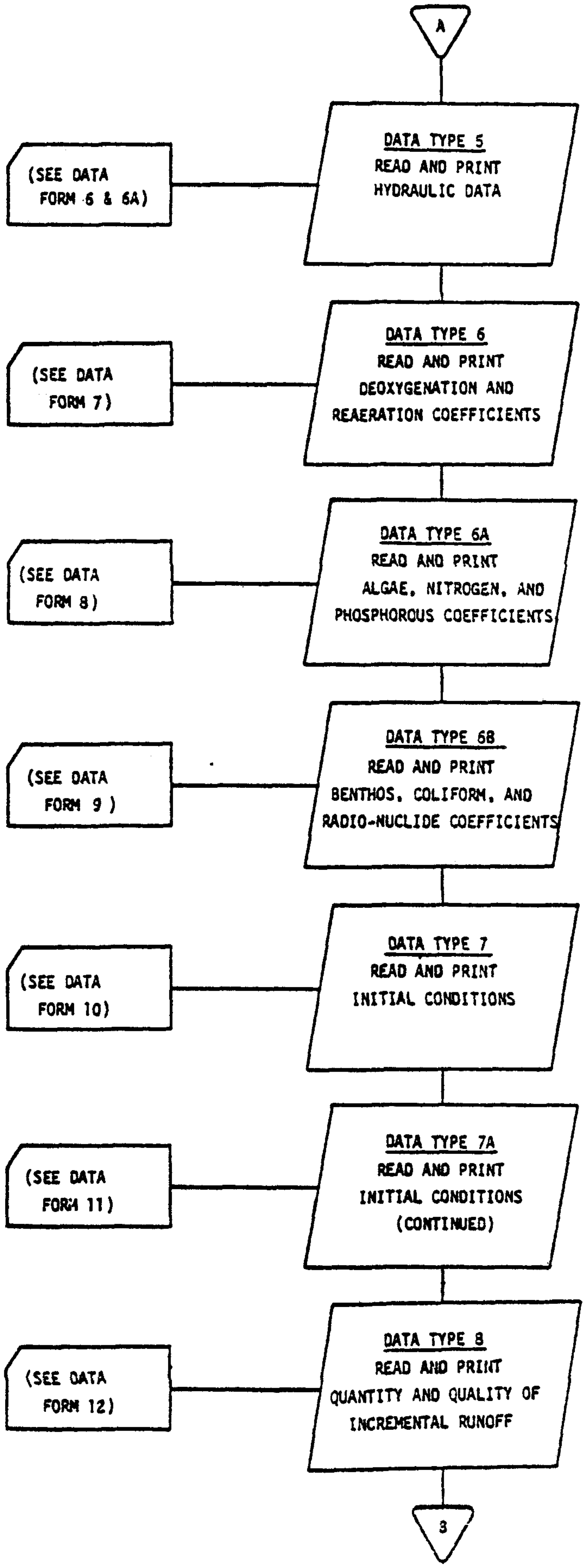

FIGURE VI-12 (Continued). FLOW CHART FOR SUBROUTINE INDATA

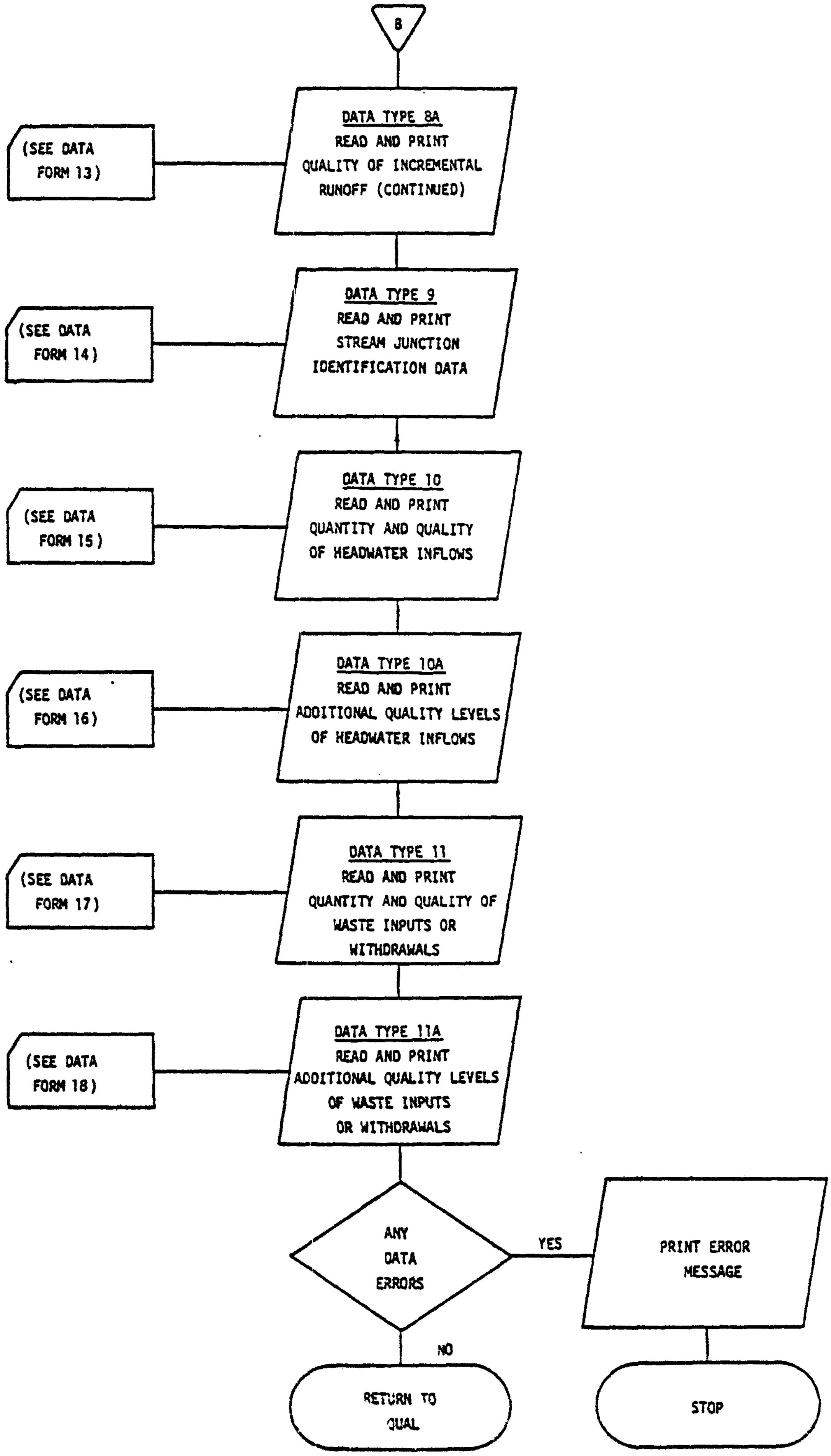

FIGURE VI-12 (Continued). FLOW CHART FOR SUBROUTINE INDATA

```
      SUBROUTINE INDATA(ILIST,IRPT1,IAUGOP,TMAX,NCELLS)
C
C
C                               THIS SUBROUTINE READS IN ALL DATA
C                               REQUIRED FOR THE OPERATION OF THE
C                               MODEL EXCEPT THE CLIMATOLOGICAL
C                               DATA FOR TEMPERATURE SIMULATION.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/RADION/ CK6(75),RADNIT(75),RADNI(75),HWRADN(15),WSRADN(90),
     *               RADIO(500)
C
C
      COMMON/SSTATE/ X(500),ISS
C
C
      COMMON/CDATA/SS1(75),SS2(75),WIDTH(75),SLOPE(75),ITRAP
C
C
      COMMON/METER/METRIC,METOUT
C
C
      DIMENSION DATA(91,25),CODE(14),CODE2(6)
C
      REAL K1,K2,LAT,LLM,LSM,JUNCID
C
      DATA ENDT/4HENDT/ , ENDA/4HENDA/ , YES/4H YES/
      DATA CODE/4HLIST,4HWRIT,4HFLOW,4HSTEA,4HTRAP,4HINPU,4HNUMB,
     *          4HNUM ,4HTIME,4HMAXI,4HLATI,4HSTAN,4HEVAP,4HELEV/
      DATA CODE2/4HO UP,4HO PR,4HN CO,4HALG ,4HN HA,4HLIGH/
C
C                                         STEP 1-0
C                                         INITIALIZE CERTAIN PARAMETERS
C
       DO 999 I=1,500
       ALGAE(I)=0.
       RESPRR(I)=0.
       GROWTH(I)=0.
  999 CONTINUE
```

```
      DO 1000 I=1,250
 1000 IRCHNO(I)=0
      ITRAP=0
      ILIST=0
      IRPT1=0
      IAUGOP =0
      ISS=0
      LAT=0.0
      LLM=0.0
      LSM=0.0
      DAYOFY=0.0
      AE=0.0
      BE=0.0
      ELEV=0.0
      DAT=0.0
      NERROR=0
      TIME=0.0
      TPRINT=0.0
      TOFDAY=0.0
      TRLCD=0.0
      CKL=0.0
      METRIC=0
      METOUT=0
      NI=5
      NJ=6
C
C                                                   STEP 2-0
C                                                   READ IN TITLES
C
      DO 30 I=1,16
      READ (NI,31) (TITLE(I,J),J=1,20)
   31 FORMAT (20A4)
      IF (TITLE(I,1)-ENDT) 30,35,30
   30 CONTINUE
      NERROR=1
   34 I=I+1
      READ (NI,31) (TITLE(I,J),J=1,20)
      IF (TITLE(I,1)-ENDT)34,39,34
   39 N=I-16
      WRITE (NJ,32) N
   32 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) TITLE CARDS READ)
      GO TO 33
   35 IF (I.GE.16) GO TO 33
      NERROR=1
      N=16-I
      WRITE (NJ,36) N
   36 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) TITLE CARDS READ)
   33 CONTINUE
      NTITLE=I
C                                                   STEP 2-1
C                                                   SET PARAMETER LIST TO BE SIMULAT
C                                                   INTO MODEL OPTION ARRAY (MODOPT)
C
      DO 1700 I=1,9
 1700 MODOPT(I)=0
      IF(TITLE(3,3) .EQ. YES) MODOPT(1)=1
      DO 1710 I=6,9
      IF(TITLE(I,3) .EQ. YES) MODOPT(I-4)=1
 1710 CONTINUE
      IF(TITLE(10,3) .EQ. YES) MODOPT(6)=1
      DO 1720 I=13,15
      IF(TITLE(I,3) .EQ. YES) MODOPT(I-6)=1
 1720 CONTINUE
C                                                   STEP 2-2
C                                                   SET NCS (NUMBER OF CONSERVATIVE
C                                                   CONSTITUENTS
C
      NCS=0
      IF(MODOPT(1) .LT. 1) GO TO 1730
      NCS=1
```

```
      IF(TITLE(4,3) .EQ. YES) NCS=2
      IF(TITLE(5,3) .EQ. YES) NCS=3
 1730 CONTINUE
C
C                                                STEP 3-0
C                                                READ IN ALL DATA REQUIRED FOR OP
C                                                OF THE MODELS.
C
C                                                STEP 3-1
C                                                READ IN DATA TYPE 1 (MODEL CONTR
C
      IDATA=0
      IF(MODOPT(4) .GT. 0) IDATA=1
      IF(MODOPT(5) .GT. 0) IDATA=1
      IF(MODOPT(6) .GT. 0) IDATA=1
      IF(MODOPT(8) .GT. 0) IDATA=1
      IF(MODOPT(9) .GT. 0) IDATA=1
      NCROS=15
      DO 20 I=1,NCROS
      READ (NI,21) (DATA(I,K),K=1,16)
   21 FORMAT (6A4,A1,F10.0,10X,6A4,A1,F10.0)
      IF (DATA(I,1)-ENDA)20,25,20
   20 CONTINUE
      NERROR=1
   24 I=I+1
      READ (NI,21) (DATA(I,K),K=1,16)
      IF (DATA(I,1)-ENDA)24,29,24
   29 N=I-NCROS
      WRITE (NJ,22) N
   22 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA1 CARDS READ)
      GO TO 23
   25 IF (I.GE.NCROS) GO TO 23
      IF(MODOPT(2)) 1920,1920,1930
C + + + + + + + FEB 1980 REVISIONS NO. 9
C
 1920 IF(I.EQ.11)GO TO 23
C
C + + + + + + +
 1930 NERROR=1
      N=NCROS-I
      WRITE (NJ,26) N
   26 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA1 CARDS READ)
   23 CONTINUE
      NCROS=I
      N=I-1
      DO 16 I=1,N
      DO 16 J=1,14
      IF (DATA(I,1)-CODE(J)) 16,2,16
    2 GO TO (3,4,5,6,7,8,9,10,11,12,13,14,15,18),J
    3 ILIST = 1
      GO TO 16
    4 IRPT1=1
      GO TO 16
    5 IAUGOP = 1
      GO TO 16
    6 ISS = 2
      GO TO 16
    7 ITRAP=1
      GO TO 16
    8 METRIC=DATA(I,8)
      METOUT=DATA(I,16)
      GO TO 16
    9 NREACH = DATA(I,8)
      NJUNC = DATA(I,16)
      GO TO 16
   10 NHWTPS = DATA(I,8)
      NWASTE = DATA(I,16)
      GO TO 16
   11 DELT = DATA(I,8)
      DELX = DATA(I,16)
```

```
      GO TO 16
   12 TMAX = DATA(I,8)
      PTIME = DATA(I,16)
      GO TO 16
   13 LAT = DATA(I,8)
      LLN = DATA(I,16)
      GO TO 16
   14 LSM = DATA(I,8)
      DAYOFY = DATA(I,16)
      GO TO 16
   15 AE = DATA(I,8)
      BE = DATA(I,16)
      GO TO 16
   18 ELEV=DATA(I,8)
      DAT=DATA(I,16)
   16 CONTINUE
      IF(NREACH-75) 610,610,620
  620 WRITE(NJ,515)  NREACH
  515 FORMAT(1H0,5X,'*****',I5,'REACHES EXCEED THE DIMENSIONS',
     *       ' OF 75')
      NERROR=1
  610 CONTINUE
      IF(NWASTE-75) 630,630,640
  640 WRITE(NJ,516)  NWASTE
  516 FORMAT(1H0,5X,'*****',I5,'WASTE LOADS EXCEED THE PROGRAM'
     *,      ' DIMENSIONS OF 75')
      NERROR=1
  630 CONTINUE
      IF (ILIST.EQ.0) GO TO 200
      WRITE (NJ,501)
  501 FORMAT(1H1,35X,31HWATER RESOURCES ENGINEERS, INC.,
     *//26X,16H* * * DATA LIST ,
     * 35H STREAM QUALITY ROUTING MODEL * * */32X,
     *34H* * * QUAL-II/SEMCOG VERSION * * * ,/)
      WRITE (NJ,502)
  502 FORMAT (1H0,10X,24H$$$ (PROBLEM TITLES) $$$,/)
      WRITE (NJ,201)
  201 FORMAT (10X,9HCARD TYPE,29X,22HQUAL-II PROGRAM TITLES)
      WRITE (NJ,503) ((TITLE(I,J),J=1,20),I=1,NTITLE)
  503 FORMAT (10X,20A4)
      WRITE (NJ,504)
  504 FORMAT (1H0,10X,34H$$$ DATA TYPE 1 (CONTROL DATA) $$$,/)
      WRITE (NJ,203)
  203 FORMAT (10X,9HCARD TYPE,36X,9HCARD TYPE)
      WRITE (NJ,103) ((DATA(I,J),J=1,16),I=1,NCRDS)
  103 FORMAT (2(10X,6A4,A1,F10.5))
  200 CONTINUE
      IF(METRIC.EQ.0) GO TO 199
      DELX=DELX/1.609
      IF(MODOPT(2).EQ.0) GO TO 199
      AE=3.2808*AE*(1000./29.9)
      BE=3.2808*BE*(1000./29.9)*(1609./3600.)
      ELEV=3.2808*ELEV
  199 CONTINUE
C
C                                            STEP 3-1A
C                                            READ IN DATA TYPE 1A (ALGAE PROD
C                                            AND NITROGEN OXIDATION CONSTANTS
C
      DO 1003 I=1,7
      READ (NI,1001) (DATA(I,J),J=1,18)
 1001 FORMAT (8A4,F7.0,2X,8A4,F7.0)
      IF (DATA(I,1)-ENDA) 1003,1021,1003
 1003 CONTINUE
      NERROR=1
 1005 I=I+1
      READ (NI,1001) (DATA(I ,J),J=1,18)
      IF (DATA(I,1)-ENDA) 1005,1007,1005
 1007 N=I-7
      WRITE (NJ,1020) N
```

```
 1020 FORMAT (1H0,5X,16H***** TOO MANY (,I3,20H) DATA 1A CARDS READ)
      GO TO 1004
 1021 IF (I.GE.7) GO TO 1004
      IF(IDATA) 1024,1024,1025
 1024 NCRDS=1
      GO TO 1026
 1025 NERROR=1
      N=7-I
      WRITE (NJ,1022) N
 1022 FORMAT (1H0,5X,15H***** TOO FEW (,I3,20H) DATA 1A CARDS READ)
 1004 CONTINUE
      N=I-1
      NCRDS=I
      DO 1006 I=1,N
      DO 1006 J=1,6
      IF(DATA(I,1)-CODE2(J))1006,1008,1006
 1008 GO TO (1009,1010,1011,1012,1013,1014), J
 1009 ALPHA5=DATA(I,9)
      ALPHA6=DATA(I,18)
      GO TO 1006
 1010 ALPHA3=DATA(I,9)
      ALPHA4=DATA(I,18)
      GO TO 1006
 1011 ALPHA1=DATA(I,9)
      ALPHA2=DATA(I,18)
      GO TO 1006
 1012 GROMAX=DATA(I,9)
      RESPRT=DATA(I,18)
      GO TO 1006
 1013 CKN=DATA(I,9)
      CKP=DATA(I,18)
      GO TO 1006
 1014 CKL=DATA(I,9)
      SONET=DATA(I,18)
 1006 CONTINUE
 1026 IF (ILIST .EQ. 0) GO TO 1015
      WRITE (NJ,1016)
 1016 FORMAT (1H0,10X,67H$$$ DATA TYPE 1A (ALGAE PRODUCTION AND NITROGEN
     * OXIDATION CONSTANTS ,5H) $$$,/)
      WRITE (NJ,1017)
 1017 FORMAT (10X,9HCARD TYPE,43X,9HCARD TYPE)
      WRITE (NJ,1018) ((DATA(I,J),J=1,18),I=1,NCRDS)
 1018 FORMAT(2(10X,8A4,F10.4))
 1015 CONTINUE
C
C                                              STEP 3-2
C                                              READ IN DATA TYPE 2 (REACH IDENT
C                                              RIVER MILE AT HEAD AND END OF RE
C
      II = NREACH+1
      DO 50 I=1,II
      READ (NI,51) (DATA(I,J),J=1,13)
   51 FORMAT (3A4,3X,F5.0,5A4,3X,A4,3X,F10.0,4X,A2,4X,F10.0)
      IF (DATA(I,1)-ENDA) 50,55,50
   50 CONTINUE
      NERROR=1
   54 I=I+1
      READ (NI,51) (DATA(I,J),J=1,13)
      IF (DATA(I,1)-ENDA) 54,59,54
   59 N=I-II
      WRITE (NJ,52) N
   52 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA2 CARDS READ)
      GO TO 53
   55 IF (I.GE.II) GO TO 53
      NERROR = 1
      N=II-I
      WRITE (NJ,56) N
   56 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA2 CARDS READ)
   53 CONTINUE
      NCRDS=I
```

```
      IMAX=0
      DO 1050 I=1,NREACH
      IRCH=IFIX(DATA(I,4)*10.+0.0001)
      IRCHNO(IRCH)=1
      IMAX=MAX0(IMAX,IRCH)
 1050 CONTINUE
      IORDER=0
      DO 1055 IRCH=1,IMAX
      IF (IRCHNO(IRCH)) 1055,1055,1052
 1052 IORDER=IORDER+1
      IRCHNO(IRCH)=IORDER
 1055 CONTINUE
      DO 57 I=1,NREACH
      IRCH=IFIX(DATA(I,4)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      DO 58 J=5,9
      K = J-4
      RCHID(NRCH,K) = DATA(I,J)
   58 CONTINUE
      RMTHOR(NRCH) = DATA(I,11)
      RMTEOR(NRCH) = DATA(I,13)
      IF(METRIC.NE.1)GO TO 57
       RMTHOR(NRCH)=RMTHOR(NRCH)/1.609
       RMTEOR(NRCH)=RMTEOR(NRCH)/1.609
   57 CONTINUE
      IF (ILIST.EQ.0) GO TO 425
      WRITE (NJ,505)
  505 FORMAT (1H0,10X,42H$$$ DATA TYPE 2 (REACH IDENTIFICATION) $$$,/)
      WRITE (NJ,205)
  205 FORMAT (10X,9HCARD TYPE,11X,21HREACH ORDER AND IDENT,
     *        15X,8HR. MI/KM,12X,8HR. MI/KM)
      WRITE (NJ,401) ((DATA(I,J),J=1,13),I=1,NCRDS)
  401 FORMAT (10X,3A4,3X,F5.1,2X,5A4,3X,A4,3X,F10.1,4X,A2,4X,F10.1)
  425 CONTINUE
C
C                                          STEP 3-3
C                                          READ IN DATA TYPE 3 (TARGET LEVE
C                                          AVAILABLE FLOW AUGMENTATION SOUR
C
      DO 60 I=1,II
      READ (NI,61) (DATA(I,J),J=1,14)
   61 FORMAT (5A4,5X,F5.0,5X,F5.0,F10.0,6F5.0)
      IF (DATA(I,1)-ENDA) 60,65,60
   60 CONTINUE
      NERROR = 1
   64 I=I+1
      READ (NI,61) (DATA(I,J),J=1,14)
      IF (DATA(I,1)-ENDA) 64,69,64
   69 N=I-II
      WRITE (NJ,62) N
   62 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA3 CARDS READ)
      GO TO 63
   65 IF (I.GE.II) GO TO 63
      IF(IAUGOP) 8623,8623,8624
 8623 NCRDS=1
      GO TO 8625
 8624 NERROR=1
      N=II-I
      WRITE (NJ,66) N
   66 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA3 CARDS READ)
   63 CONTINUE
      NCRDS=I
      DO 67 I=1,NREACH
      IRCH=IFIX(DATA(I,6)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      NHWAR = DATA(I,7)
      NHWWAR(NRCH) = NHWAR
      TARGDO(NRCH)=DATA(I,8)
      DO 68 J=9,14
      K = J-8
```

```
      IAUGOR(NRCH,K) = DATA(I,J)
   68 CONTINUE
   67 CONTINUE
 8625 IF (ILIST.EQ.0) GO TO 426
      WRITE (NJ,506)
  506 FORMAT (1H0,10X,36H$$$ DATA TYPE 3 (TARGET LEVEL DO AND,
     *                 31H FLOW AUGMENTATION SOURCES) $$$,/)
      WRITE (NJ,206)
  206 FORMAT (10X,9HCARD TYPE,18X,24HREACH  AVAIL HDWS TARGET,
     *        5X,22HORDER OF AVAIL SOURCES)
      WRITE (NJ,402) ((DATA(I,J),J=1,14),I=1,NCRDS)
  402 FORMAT (10X,5A4,5X,F5.0,5X,F5.0,F10.1,6F5.0)
  426 CONTINUE
C
C                                          STEP 3-4
C                                          READ IN DATA TYPE 4 (COMPUTATION
C                                          ELEMENT FLAG FIELD)
C                                              1  =  ELEMENT WHICH REPRESEN
C                                                    HEADWATER SOURCE.
C                                              2  =  AN ELEMENT WITH NO EXT
C                                                    INPUTS OTHER THAN INCR
C                                              3  =  AN ELEMENT ON THE MAIN
C                                                    IMMEDIATELY UPSTREAM F
C                                                    JUNCTION.
C                                              4  =  AN ELEMENT WHICH REPRE
C                                                    A STREAM JUNCTION.
C                                              5  =  AN ELEMENT WHICH REPRE
C                                                    THE LAST COMPUTATIONAL
C                                                    IN THE SYSTEM.
C                                              6  =  AN ELEMENT WITH A WAST
C                                              7  =  AN ELEMENT WITH A WITH
C
      DO 70 I=1,II
      READ (NI,71) (DATA(I,J),J=1,25)
   71 FORMAT (2A4,A2,5X,F5.0,5X,F5.0,10X,20F2.0)
      IF (DATA(I,1)-ENDA) 70,75,70
   70 CONTINUE
      NERROR=1
   74 I=I+1
      READ (NI,71) (DATA(I,J),J=1,25)
      IF (DATA(I,1)-ENDA) 74,79,74
   79 N=I-II
      WRITE (NJ,72) N
   72 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA4 CARDS READ)
      GO TO 73
   75 IF (I.GE.II) GO TO 73
      NERROR = 1
      N=II-I
      WRITE (NJ,76) N
   73 CONTINUE
   76 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA4 CARDS READ)
      NCRDS=I
      DO 77 I=1,NREACH
      IRCH=IFIX(DATA(I,4)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      NCELR = DATA(I,5)
      NCELRH(NRCH)=NCELR
      DO 78 J=6,25
      K = J-5
      IFLAG(NRCH,K)=DATA(I,J)
   78 CONTINUE
   77 CONTINUE
      IF (ILIST.EQ.0) GO TO 427
      WRITE (NJ,507)
  507 FORMAT (1H0,10X,36H$$$ DATA TYPE 4 (COMPUTATIONAL REACH,
     *                 16H FLAG FIELD) $$$,/)
      WRITE (NJ,207)
  207 FORMAT (10X,9HCARD TYPE,8X,20HREACH ELEMENTS/REACH,
     *        13X,19HCOMPUTATIONAL FLAGS)
      WRITE (NJ,403) ((DATA(I,J),J=1,25),I=1,NCRDS)
```

```
      403 FORMAT (10X,2A4,A2,5X,F5.0,5X,F5.0,10X,20F2.0)
      427 CONTINUE
          IOR=0
          DO 28 I=1,NREACH
          NCELR=NCELRH(I)
          DO 28 J=1,NCELR
          IOR=IOR+1
          ICLORD(I,J)=IOR
       28 CONTINUE
          IF(IOR-500)  650,650,660
      660 WRITE(NJ,517)  IOR
      517 FORMAT(1H0,5X,'*****',I5,'COMPUTATIONAL ELEMENTS EXECEED THE',
         *     ' PROGRAM DIMENSIONS OF 500')
          NERROR=1
      650 CONTINUE
          NCELLS=IOR
C
C                                                   STEP 3-5
C                                                   READ IN DATA TYPE 5 (HYDRAULIC C
C                                                   FOR COMPUTING VELOCITY AND DEPTH
C
          DO 80 I=1,II
          READ (NI,81) (DATA(I,J),J=1,9)
       81 FORMAT (2A4,A2,5X,F5.0,10X,5F10.0)
          IF (DATA(I,1)-ENDA) 80,85,80
       80 CONTINUE
          NERROR = 1
       84 I=I+1
          READ (NI,81) (DATA(I,J),J=1,9)
          IF (DATA(I,1)-ENDA) 84,89,84
       89 N=I-II
          WRITE (NJ,82) N
       82 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA5 CARDS READ)
          GO TO 83
       85 IF (I.GE.II) GO TO 83
          NERROR = 1
          N=II-I
          WRITE (NJ,86) N
       86 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA5 CARDS READ)
       83 CONTINUE
          NCRDS=I
          DO 87 I=1,NREACH
          IRCH=IFIX(DATA(I,4)*10.+0.0001)
          NRCH=IRCHNO(IRCH)
          IF(ITRAP.EQ.1) GO TO 183
          COEFQV(NRCH) = DATA(I,5)
          EXPOQV(NRCH) = DATA(I,6)
          COEFQH(NRCH) = DATA(I,7)
          EXPOQH(NRCH) = DATA(I,8)
          CMANN(NRCH) = DATA(I,9)
          GO TO 184
      183 SS1(NRCH)=DATA(I,5)
          SS2(NRCH)=DATA(I,6)
          WIDTH(NRCH)=DATA(I,7)
          SLOPE(NRCH)=DATA(I,8)
          CMANN(NRCH)=DATA(I,9)
      184 CONTINUE
C + + + + + + + FEB 1980 REVISIONS NO. 10
          IF(CMANN(NRCH).LE.0.)CMANN(NRCH)=0.020
C + + + + + + +
          IF(METRIC.EQ.0)GO TO 87
          CVXX=3.2808/35.3133**EXPOQV(NRCH)
          COEFQV(NRCH)=COEFQV(NRCH)*CVXX
          CVXX=3.2808/35.3133**EXPOQH(NRCH)
          COEFQH(NRCH)=COEFQH(NRCH)*CVXX
       87 CONTINUE
C + + + + + FEB 1980 REVISIONS NO. 11
C + + + + + (DELETION OF LINES)
       88 IF (ILIST.EQ.0) GO TO 428
          WRITE (NJ,508)
```

```
  508 FORMAT (1H0,10X,31H$$$ DATA TYPE 5 (HYDRAULIC DATA,
     *                40H FOR DETERMINING VELOCITY AND DEPTH) $$$,/)
      IF(ITRAP.EQ.0 ) WRITE(NJ,208)
      IF(ITRAP.NE.0 )WRITE(NJ,1208)
 1208 FORMAT(10X,9HCARD TYPE,8X,5HREACH,13X,16H  SS1        SS2  ,
     *          4X,25HWIDTH      SLOPE      CHANN)
  208 FORMAT (10X,9HCARD TYPE,8X,5HREACH,13X,16HCOEFQV     EXPOQV,
     *          4X,25HCOEFQH    EXPOQH      CHANN)
      WRITE (NJ,404) ((DATA(I,J),J=1, 9),I=1,NCRDS)
  404 FORMAT (10X,2A4,A2,5X,F5.0,10X,5F10.3)
  428 CONTINUE
C
C                                          STEP 3-6
C                                          READ IN DATA TYPE 6 (REACTION CO
C                                          DEOXYGENATION AND REAERATION).
C
      DO 90 I=1,II
      READ (NI,91) (DATA(I,J),J=1,10)
   91 FORMAT (2A4,A2,5X,F5.0,6F10.0)
      IF (DATA(I,1)-ENDA) 90,95,90
   90 CONTINUE
      NERROR = 1
   94 I=I+1
      READ (NI,91) (DATA(I,J),J=1,10)
      IF (DATA(I,1)-ENDA) 94,99,94
   99 N=I-II
      WRITE (NJ,92) N
   92 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA6 CARDS READ)
      GO TO 93
   95 IF (I.GE.II) GO TO 93
      NERROR = 1
      N=II-I
      WRITE (NJ,96) N
   96 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA6 CARDS READ)
   93 CONTINUE
      NCRDS=I
      DO 97 I=1,NREACH
      IRCH=IFIX(DATA(I,4)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      CK1(NRCH) = DATA(I,5)
      CK3(NRCH) = DATA(I,6)
      K2OPT(NRCH) = DATA(I,7)
      CK2(NRCH) = DATA(I,8)
      COEQK2(NRCH) = DATA(I,9)
      EXPQK2(NRCH) = DATA(I,10)
      IF(METRIC.EQ.0) GO TO 97
      IF(K2OPT(NRCH).EQ.7) COEQK2(NRCH)=COEQK2(NRCH)*(1.0/35.3133)**EXPQK2(NRCH)
      IF(K2OPT(NRCH).EQ.8) COEQK2(NRCH)=COEQK2(NRCH)/3.2808
   97 CONTINUE
      IF (ILIST.EQ.0) GO TO 429
      WRITE (NJ,509)
  509 FORMAT (1H0,10X,38H$$$ DATA TYPE 6 (REACTION COEFFICIENTS,
     *                38H FOR DEOXYGENATION AND REAERATION) $$$,/)
      WRITE (NJ,209)
  209 FORMAT (10X,9HCARD TYPE,8X,12HREACH      K1,8X,2HK3,8X,5HK2OPT,
     *           5X,26HK2      COEQK2, OR  EXPQK2,,/,
     *          74X,20HTSIV COEF   OR SLOPE,/,
     *          74X,21HFOR OPT 8   FOR OPT 8)
      IF((DATA(I,10)*1000.).GT.10.) GO TO 98
      WRITE (NJ,411) ((DATA(I,J),J=1,10),I=1,NCRDS)
  411 FORMAT (10X,2A4,A2,5X,F5.0,2F10.2,F10.0,F10.2,F10.3,5X,F10.5)
      GO TO 429
   98 WRITE (NJ,405) ((DATA(I,J),J=1,10),I=1,NCRDS)
  405 FORMAT (10X,2A4,A2,5X,F5.0,2F10.2,F10.0,F10.2,2F10.3)
  429 CONTINUE
C
C                                          STEP 3-6A
C                                          READ IN DATA TYPE 6A (ALGAE, NIT
C                                          AND PHOSPHORUS COEF.)
C
```

```
      DO 1100 I=1,II
      READ(NI,1101) (DATA(I,J),J=1,12)
 1101 FORMAT(5A4,5X,F5.0,2X,6F8.0)
      IF (DATA(I,1)-ENDA) 1100,1105,1100
 1100 CONTINUE
      NERROR=1
 1104 I=I+1
      READ(NI,1101) (DATA(I,J),J=1,12)
      IF (DATA(I,1)-ENDA)1104,1109,1104
 1109 N=I-II
      WRITE (NJ,1102) N
 1102 FORMAT (1H0,5X,16H***** TOO MANY (,I3,19H) DATA6A CARDS READ)
      GO TO 1103
 1105 IF(I.GE.II) GO TO 1103
      IF(IDATA) 1120,1120,1130
 1120 NCRDS=1
      GO TO 1140
 1130 NERROR=1
      N=II-I
      WRITE (NJ,1106) N
 1106 FORMAT (1H0,5X,15H***** TOO FEW (,I3,19H) DATA6A CARDS READ)
 1103 CONTINUE
      NCRDS=I
      DO 1107 I=1,NREACH
      IRCH=IFIX(DATA(I,6)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      ALPHAO(NRCH)=DATA(I,7)
      ALGSET(NRCH)=DATA(I,8)
      CKNH3(NRCH)=DATA(I,9)
      CKNO2(NRCH)=DATA(I,10)
      SNH3(NRCH)=DATA(I,11)
      SPHOS(NRCH)=DATA(I,12)
      IF (METRIC.EQ.0) GO TO 1107
       ALGSET(NRCH)=3.2808*ALGSET(NRCH)
      SNH3(NRCH)=SNH3(NRCH)/3.2808
      SPHOS(NRCH)=SPHOS(NRCH)/3.2808
 1107 CONTINUE
 1140 IF(ILIST .EQ. 0) GO TO 1199
      WRITE(NJ,1110)
 1110 FORMAT(1H0,10X,65H $$$ DATA TYPE 6A (ALGAE, NITROGEN, AND PHOSPHOR
     $US CONSTANTS) $$$,/)
      WRITE(NJ,1111)
 1111 FORMAT(10X,9HCARD TYPE,17X,6H REACH,2X,6HALPHAO,3X,6HALGSET,2X,
     *  5HCKNH3,5X,5HCKNO2,6X,4HSNH3,6X,4HSPO4)
      WRITE(NJ,1112) ((DATA(I,J), J=1,12), I=1,NCRDS)
 1112 FORMAT(10X,5A4,2X,F8.0,F8.1,1X,2F8.2,1X,F9.2,2F10.1)
 1199 CONTINUE
C
C                                               STEP 3-6B
C                                               READ IN DATA TYPE 6B (OTHER COEF
C
      DO 1200 I=1,II
      READ(NI,1201) (DATA(I,J),J=1,12)
 1201 FORMAT(5A4,5X,F5.0,2X,6F8.0)
      IF (DATA(I,1)-ENDA) 1200,1205,1200
 1200 CONTINUE
      NERROR=1
 1204 I=I+1
      READ(NI,1201) (DATA(I,J),J=1,12)
      IF (DATA(I,1)-ENDA)1204,1209,1204
 1209 N=I-II
      WRITE (NJ,1202) N
 1202 FORMAT (1H0,5X,16H***** TOO MANY (,I3,19H) DATA6B CARDS READ)
      GO TO 1203
 1205 IF(I.GE.II) GO TO 1203
      IF(IDATA) 1220,1220,1230
 1220 NCRDS=1
      GO TO 1250
 1230 NERROR=1
      N=II-I
```

```
      WRITE (NJ,1206) N
 1206 FORMAT (1H0,5X,15H***** TOO FEW (,I3,19H) DATA6B CARDS READ)
 1203 CONTINUE
      NCRDS=I
      DO 1207 I=1,NREACH
      IRCH=IFIX(DATA(I,6)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      CK4(NRCH)=DATA(I,7)
      CK5(NRCH)=DATA(I,8)
      EXCOEF(NRCH)=DATA(I,9)
      CK6(NRCH)=DATA(I,10)
      IF(METRIC.EQ.0) GO TO 1207
      CK4(NRCH)=CK4(NRCH)/3.2808
      EXCOEF(NRCH)=EXCOEF(NRCH)/3.2808
 1207 CONTINUE
 1250 IF(ILIST.EQ.0) GO TO 1299
      WRITE(NJ,1210)
 1210 FORMAT(1H0,10X,41H$$$ DATA TYPE 6B (OTHER COEFFICIENTS) $$$,/)
      WRITE(NJ,1211)
 1211 FORMAT(10X,9HCARD TYPE,18X,6H REACH,4X,3HCK4,6X,3HCK5,3X,6HEXCOEF,
     *5X,3HCK6)
      WRITE(NJ,1212) ((DATA(I,J), J=1,10), I=1,NCRDS)
 1212 FORMAT(10X,5A4,2X,F9.0,4F9.2)
 1299 CONTINUE
C
C                                         STEP 3-7
C                                         READ IN DATA TYPE 7 (INITIAL CON
C
      DO 110 I=1,II
      READ (NI,111) (DATA(I,J),J=1,12)
  111 FORMAT (5A4,5X,F5.0,F10.0,2F5.0,3F10.0)
      IF (DATA(I,1)-ENDA) 110,115,110
  110 CONTINUE
      NERROR=1
  114 I=I+1
      READ (NI,111) (DATA(I,J),J=1,12)
      IF (DATA(I,1)-ENDA) 114,119,114
  119 N=I-II
      WRITE (NJ,112) N
  112 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA7 CARDS READ)
      GO TO 113
  115 IF (I.GE.II) GO TO 113
      NERROR = 1
      N=II-I
      WRITE (NJ,116) N
  116 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA7 CARDS READ)
  113 CONTINUE
      NCRDS=I
      DO 117 I=1,NREACH
      IRCH=IFIX(DATA(I,6)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      TINIT(NRCH) = DATA(I,7)
      IF(METRIC.EQ.1)TINIT(NRCH)=TINIT(NRCH)*1.8+32.
      DOINIT(NRCH) = DATA(I,8)
      BOINIT(NRCH) = DATA(I,9)
      COINIT(NRCH,1)=DATA(I,10)
      COINIT(NRCH,2)=DATA(I,11)
      COINIT(NRCH,3)=DATA(I,12)
  117 CONTINUE
      IF (ILIST.EQ.0) GO TO 430
      WRITE (NJ,510)
  510 FORMAT (1H0,10X,40H$$$ DATA TYPE 7 (INITIAL CONDITIONS) $$$,/)
      WRITE (NJ,210)
  210 FORMAT (10X,9HCARD TYPE,18X,33HREACH    TEMP      D.O.       BOD,
     *           6X,26HCM-1       CM-2       CM-3  )
      WRITE (NJ,406) ((DATA(I,J),J=1,12),I=1,NCRDS)
  406 FORMAT (10X,5A4,5X,F6.0,F9.1,5F10.1)
  430 CONTINUE
C
```

```
C                                               STEP 3-7A
C                                               READ IN DATA TYPE7A (INITIAL CON
C                                               FOR CHLOROPHYLL,NITROGEN,PHOSPHO
C                                               COLIFORM,AND RADIONUCLIDE)
C
      DO 1302 I=1,II
      READ(NI,1301) (DATA(I,J), J=1,12)
 1301 FORMAT(3A4,A2,5X,F5.0,7F8.0)
      IF (DATA(I,1)-ENDA) 1302,1303,1302
 1302 CONTINUE
      NERROR=1
 1304 I=I+1
      READ(NI,1301) (DATA(I,J), J=1,12)
      IF (DATA(I,1)-ENDA) 1304,1305,1304
 1305 N=I-II
      WRITE (NJ,1306) N
 1306 FORMAT (1H0,5X,16H***** TOO MANY (,I3,20H) DATA 7A CARDS READ)
      GO TO 1307
 1303 IF (I.GE.II) GO TO 1307
      IF(IDATA) 1321,1321,1330
 1321 NCRDS=1
       GO TO 1350
 1330 NERROR=1
      N=II-I
      WRITE (NJ,1308) N
 1308 FORMAT (1H0,5X,15H***** TOO FEW (,I3,20H) DATA 7A CARDS READ)
 1307 CONTINUE
      NCRDS=I
      DO 1309 I=1,NREACH
      IRCH=IFIX(DATA(I,5)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      ALGIT(NRCH)=DATA(I,6)/ALPHAO(NRCH)
      CNH3IT(NRCH)=DATA(I,7)
      CNO2IT(NRCH)=DATA(I,8)
      CNO3IT(NRCH)=DATA(I,9)
      PHOSIT(NRCH)=DATA(I,10)
      COLIIT(NRCH)=DATA(I,11)
      RADNIT(NRCH)=DATA(I,12)
 1309 CONTINUE
 1350 IF (ILIST.EQ.0) GO TO 1320
      WRITE (NJ,1310)
 1310 FORMAT (1H0,10X,47H$$$ DATA TYPE 7A (INITIAL CONDITIONS FOR CHOROP
     *         29HHYLL A, NITROGEN, PHOSPHORUS,/30X,19HCOLIFORM AND SELECT
     *         36HED NON-CONSERVATIVE CONSTITUENT) $$$,/)
      WRITE (NJ,1311)
 1311 FORMAT (10X,9HCARD TYPE,15X,5HREACH,5X,6HCHLORA,5X,5HNH3/N,5X,
     *         5HNO2/N,5X,5HNO3/N,7X,3HDOP,6X,4HCOLI,4X,6HNONCON)
      WRITE(NJ,1312) ((DATA(I,J), J=1,12), I=1,NCRDS)
 1312 FORMAT (10X,3A4,A2,3X,F6.0,6X,F6.1,4X,F6.2,3F10.2,F10.2,F10.3)
 1320 CONTINUE
C
C                                               STEP 3-8
C                                               READ IN DATA TYPE 8 (INCREMENTAL
C                                               CONDITIONS).
C
      DO 120 I=1,II
      READ (NI,121) (DATA(I,J),J=1,13)
  121 FORMAT (5A4,5X,5F5.0,3F10.0)
      IF (DATA(I,1)-ENDA) 120,125,120
  120 CONTINUE
      NERROR=1
  124 I=I+1
      READ (NI,121) (DATA(I,J),J=1,13)
      IF (DATA(I,1)-ENDA) 124,129,124
  129 N=I-II
      WRITE (NJ,122) N
  122 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA8 CARDS READ)
      GO TO 123
  125 IF (I.GE.II) GO TO 123
      NERROR = 1
      N=II-I
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```
      WRITE (NJ,126) N
  126 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA8 CARDS READ)
  123 CONTINUE
      NCRDS=I
      DO 127 I=1,NREACH
      IRCH=IFIX(DATA(I,6)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      QI(NRCH) = DATA(I,7)
      TI(NRCH) = DATA(I,8)
      DOI(NRCH) = DATA(I,9)
      BODI(NRCH) = DATA(I,10)
      CONSI(NRCH,1)=DATA(I,11)
      CONSI(NRCH,2)=DATA(I,12)
      CONSI(NRCH,3)=DATA(I,13)
      IF(METRIC.EQ.0)GO TO 127
      QI(NRCH)=35.3133*QI(NRCH)
      TI(NRCH)=1.8*TI(NRCH)+32.0
  127 CONTINUE
      IF (ILIST.EQ.0) GO TO 431
      WRITE (NJ,511)
  511 FORMAT (1H0,10X,35H$$$ DATA TYPE 8 (INCREMENTAL INFLOW,
     *        16H CONDITIONS) $$$)
      WRITE (NJ,211)
  211 FORMAT (10X,9HCARD TYPE,17X,5HREACH,5X,1HQ,5X,4HTEMP,6X,
     *        4HD.O.,7X,3HBOD,6X,4HCM-1,6X,4HCM-2,6X,4HCM-3)
      WRITE (NJ,407) ((DATA(I,J),J=1,13),I=1,NCRDS)
  407 FORMAT (10X,5A4,5X,F5.0,F8.3,F8.1,5F10.1)
  431 CONTINUE
C
C                                        STEP 3-8A
C                                        READ IN DATA TYPE 8A (INCREMENTA
C                                        CONDITIONS FOR CHLOROPHYLL, NITR
C                                        PHOSPHOROUS, COLIFORM AND RADION
C
      DO 1400 I=1,II
      READ(NI,1401) (DATA(I,J), J=1,12)
 1401 FORMAT(3A4,A2,5X,F5.0,7F8.0)
      IF (DATA(I,1)-ENDA) 1400,1402,1400
 1400 CONTINUE
      NERROR=1
 1403 I=I+1
      READ(NI,1401) (DATA(I,J), J=1,12)
      IF (DATA(I,1)-ENDA) 1403,1404,1403
 1404 N=I-II
      WRITE (NJ,1405) N
 1405 FORMAT (1H0,5X,16H***** TOO MANY (,I3,20H) DATA 8A CARDS READ)
      GO TO 1406
 1402 IF (I.GE.II) GO TO 1406
      IF(IDATA)1420,1420,1430
 1420 NCRDS=1
      GO TO 1450
 1430 NERROR=1
      N=II-I
      WRITE (NJ,1407) N
 1407 FORMAT (1H0,5X,15H***** TOO FEW (,I3,20H) DATA 8A CARDS READ)
 1406 CONTINUE
      NCRDS=I
      DO 1408 I=1,NREACH
      IRCH=IFIX(DATA(I,5)*10.+0.0001)
      NRCH=IRCHNO(IRCH)
      ALGI(NRCH)=DATA(I,6)/ALPHAO(NRCH)
      CNH3I(NRCH)=DATA(I,7)
      CNO2I(NRCH)=DATA(I,8)
      CNO3I(NRCH)=DATA(I,9)
      PHOSI(NRCH)=DATA(I,10)
      COLIR(NRCH)=DATA(I,11)
      RADNI(NRCH)=DATA(I,12)
 1408 CONTINUE
 1450 IF(ILIST .EQ.0) GO TO 1409
      WRITE (NJ,1410)
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 1410 FORMAT (1H0,10X,36H$$$ DATA TYPE 8A (INCREMENTAL INFLOW ,
     *        40H CONDITIONS FOR CHLOROPHYLL A, NITROGEN,/30X,
     *        51HPHOSPHORUS, COLIFORM AND SELECTED NON-CONSERVATIVE ,
     *        16HCONSTITUENT) $$$,/)
      WRITE (NJ,1411)
 1411 FORMAT(10X,9HCARD TYPE,15X,12HREACH CHLORA,3X,5HNH3/N,3X,5HNO2/N,
     *      3X,5HNO3/N,5X,3HDOP,7X,4HCOLI,2X,6HNONCON)
      WRITE(NJ,1412) ((DATA(I,J), J=1,12), I=1,NCRDS)
 1412 FORMAT(10X,3A4,A2,8X,F6.0,5F8.2,F11.1,F8.3)
 1409 CONTINUE
C
C                                                   STEP 3-9
C                                                   READ IN DATA TYPE 9 (STREAM JUNC
C                                                   IDENTIFICATION AND THE ORDER OF
C                                                   CONNECTING ELEMENTS TAKEN CLOCKW
C                                                   AROUND THE JUNCTION).
C
      II=NJUNC+1
      DO 130 I=1,II
      READ (NI,131) (DATA(I,J),J=1,13)
  131 FORMAT (3A4,A3,5X,F5.0,5X,5A4,3(5X,F5.0))
      IF (DATA(I,1)-ENDA) 130,135,130
  130 CONTINUE
      NERROR=1
  134 I=I+1
      READ (NI,131) (DATA(I,J),J=1,13)
      IF (DATA(I,1)-ENDA) 134,139,134
  139 N=I-II
      WRITE (NJ,132) N
  132 FORMAT (1H0,5X,16H***** TOO MANY (,I3,18H) DATA9 CARDS READ)
      GO TO 133
  135 IF (I.GE.II) GO TO 133
      NERROR = 1
      N=II-I
      WRITE (NJ,136) N
  136 FORMAT (1H0,5X,15H***** TOO FEW (,I3,18H) DATA9 CARDS READ)
  133 CONTINUE
      NCRDS=I
      DO 137 I=1,NJUNC
      IJUNC = DATA(I,5)
      DO 138 J=6,10
      K = J-5
      JUNCID(IJUNC,K)=DATA(I,J)
  138 CONTINUE
      JUNC(IJUNC,1) = DATA(I,11)
      JUNC(IJUNC,2) = DATA(I,12)
      JUNC(IJUNC,3) = DATA(I,13)
  137 CONTINUE
      IF (ILIST.EQ.0) GO TO 432
      WRITE (NJ,512)
  512 FORMAT (1H0,10X,38H$$$ DATA TYPE 9 (STREAM JUNCTIONS) $$$,/)
      WRITE (NJ,212)
  212 FORMAT (10X,9HCARD TYPE,14X,24HJUNCTION ORDER AND IDENT,
     *         9X,25HUPSTRM   JUNCTION    TRIB)
      WRITE (NJ,408) ((DATA(I,J),J=1,13),I=1,NCRDS)
  408 FORMAT (10X,3A4,A3,5X,F5.0,5X,5A4,5X,F5.0,5X,F5.0,5X,F5.0)
  432 CONTINUE
C
C                                                   STEP 3-10
C                                                   READ IN DATA TYPE 10 (HEADWATER
C                                                   AND THEIR CHARACTERISTICS).
C
      II = NHWTRS+1
      DO 140 I=1,II
      READ (NI,141) (DATA(I,J),J=1,16)
  141 FORMAT (2A4,A2,5X,F5.0,5A4,F10.0,6F5.0)
      IF (DATA(I,1)-ENDA) 140,145,140
  140 CONTINUE
      NERROR=1
  144 I=I+1
```

```
      READ (NI,141) (DATA(I,J),J=1,16)
      IF (DATA(I,1)-ENDA) 144,149,144
  149 N=I-II
      WRITE (NJ,142) N
  142 FORMAT (1H0,5X,16H***** TOO MANY (I3,19H) DATA10 CARDS READ)
      GO TO 143
  145 IF (I.GE.II) GO TO 143
      NERROR = 1
      N=II-I
      WRITE (NJ,146) N
  146 FORMAT (1H0,5X,15H***** TOO FEW (,I3,19H) DATA10 CARDS READ)
  143 CONTINUE
      NCRDS=I
      DO 147 I=1,NHWTRS
      NHW = DATA(I,4)
      DO 148 J=5,9
      K = J-4
      HWTRID(NHW,K) = DATA(I,J)
  148 CONTINUE
      HWFLOW(NHW) = DATA(I,10)
      HWTEMP(NHW) = DATA(I,11)
      IF(METRIC.GT.0)HWFLOW(NHW)=35.3133*HWFLOW(NHW)
      IF(METRIC.GT.0)HWTEMP(NHW)=1.8*HWTEMP(NHW)+32.0
      HWDO(NHW) = DATA(I,12)
      HWBOD(NHW) = DATA(I,13)
      HWCONS(NHW,1)=DATA(I,14)
      HWCONS(NHW,2)=DATA(I,15)
      HWCONS(NHW,3)=DATA(I,16)
      QATOT(NHW)=HWFLOW(NHW)
  147 CONTINUE
      IF (ILIST.EQ.0) GO TO 433
      WRITE (NJ,513)
  513 FORMAT (1H0,10X,40H$$$ DATA TYPE 10 (HEADWATER SOURCES) $$$,/)
      WRITE (NJ,213)
  213 FORMAT (10X,9HCARD TYPE,10X,23HHDWATER ORDER AND IDENT,
     *        5X,28HFLOW    TEMP    D.O.     BOD,
     *        24H    CM-1    CM-2    CM-3)
      WRITE (NJ,409) ((DATA(I,J),J=1,16),I=1,NCRDS)
  409 FORMAT (10X,2A4,A2,5X,F5.0,2X,5A4,F9.3,5F8.2,F8.3)
  433 CONTINUE
C
C                                          STEP 3-10A
C                                          READ IN DATA TYPE 10A (HEADWATER
C                                          CHLOROPHYLL, NITROGEN, PHOSPHORU
C                                          COLIFORM AND RADIONUCLIDE CONDIT
C
      DO 1500 I=1,II
      READ(NI,1501) (DATA(I,J), J=1,12)
 1501 FORMAT(3A4,A2,5X,F5.0,7F8.0)
      IF (DATA(I,1)-ENDA) 1500,1502,1500
 1500 CONTINUE
      NERROR=1
 1503 I=I+1
      READ(NI,1501) (DATA(I,J), J=1,12)
      IF (DATA(I,1)-ENDA) 1503,1504,1503
 1504 N=I-II
      WRITE (NJ,1505) N
 1505 FORMAT (1H0,5X,16H***** TOO MANY (,I3,21H) DATA 10A CARDS READ)
      GO TO 1506
 1502 IF (I.GE.II) GO TO 1506
      IF(IDATA) 1520,1520,1530
 1520 NCRDS=1
      GO TO 1550
 1530 NERROR=1
      N=II-I
      WRITE (NJ,1507) N
 1507 FORMAT (1H0,5X,15H***** TOO FEW (,I3,21H) DATA 10A CARDS READ)
 1506 CONTINUE
      NCRDS=I
      DO 1508 I=1,NHWTRS
```

```
      NHW=DATA(I,5)
      HWALG(NHW)=DATA(I,6)/ALPHAO(1)
      HWNH3(NHW)=DATA(I,7)
      HWNO2(NHW)=DATA(I,8)
      HWNO3(NHW)=DATA(I,9)
      HWPHOS(NHW)=DATA(I,10)
      HWCOLI(NHW)=DATA(I,11)
      HWRADN(NHW)=DATA(I,12)
 1508 CONTINUE
 1550 IF(ILIST .EQ. 0) GO TO 1509
      WRITE (NJ,1510)
 1510 FORMAT(1H0,10X,29H$$$ DATA TYPE 10A (HEADWATER ,
     *      28HCONDITIONS FOR CHLOROPHYLL,
     *       21HNITROGEN, PHOSPHORUS,/30X,25HCOLIFORM AND SELECTED NON
     *       30H-CONSERVATIVE CONSTITUENT) $$$,/)
      WRITE (NJ,1511)
 1511 FORMAT (10X,9HCARD TYPE,12X,24HHDWATER  CHLORA NH3/N
     *        39HNO2/N   NO3/N     DOP      COLI  NONCON)
      WRITE(NJ,1512) ((DATA(I,J), J=1,12), I=1,NCRDS)
 1512 FORMAT (10X,3A4,A2,8X,F6.0,2X,F6.1,F6.2,3F8.2,F10.2,F8.3)
 1509 CONTINUE
C
C                                                 STEP 3-11
C                                                 READ IN DATA TYPE 11 (WASTE INPU
C                                                 WITHDRAWLS AND THEIR CHARACTERIS
C
      II = NWASTE+1
      DO 150 I=1,II
      READ (NI,151) (DATA(I,J),J=1,17)
  151 FORMAT (2A4,A2,F5.0,5A4,F5.0,F10.0,6F5.0)
      IF (DATA(I,1)-ENDA) 150,155,150
  150 CONTINUE
      NERROR = 1
  154 I = I + 1
      READ (NI,151) (DATA(I,J),J=1,17)
      IF (DATA(I,1)-ENDA) 154,159,154
  159 N=I-II
      WRITE (NJ,152) N
  152 FORMAT (1H0,5X,16H***** TOO MANY (,I3,19H) DATA11 CARDS READ)
      GO TO 153
  155 IF (I.GE.II) GO TO 153
      NERROR = 1
      N=II-I
      WRITE (NJ,156) N
  156 FORMAT (1H0,5X,15H***** TOO FEW (,I3,19H) DATA11 CARDS READ)
  153 CONTINUE
      NCRDS=I
      DO 157 I=1,NWASTE
      NWS = DATA(I,4)
      DO 158 J=5,9
      K = J-4
      WASTID(NWS,K)=DATA(I,J)
  158 CONTINUE
      TRFACT(NWS) = DATA(I,10)
      WSFLOW(NWS) = DATA(I,11)
      WSTEMP(NWS) = DATA(I,12)
      WSDO(NWS) = DATA(I,13)
      WSBOD(NWS) = DATA(I,14)
      WSCONS(NWS,1)=DATA(I,15)
      WSCONS(NWS,2)=DATA(I,16)
      WSCONS(NWS,3)=DATA(I,17)
      IF (METRIC.EQ.0) GO TO 157
      WSFLOW(NWS)=35.3133*WSFLOW(NWS)
      WSTEMP(NWS)=1.8*WSTEMP(NWS)+32.0
  157 CONTINUE
      IF (ILIST.EQ.0) GO TO 434
      WRITE (NJ,514)
  514 FORMAT (1H0,10X,38H$$$ DATA TYPE 11 (POINT SOURCE / POINT,
     *        28H SOURCE CHARACTERISTICS) $$$,/)
      WRITE (NJ,214)
```

```
  214 FORMAT (10X,42HCARD TYPE  POINT SOURCE ORDER AND ID   EFF,
     *        4X,36HFLOW    TEMP    D.O.     BOD    CM-1,4X,
     *        12HCM-2    CM-3)
      WRITE (NJ,410) ((DATA(I,J),J=1,17),I=1,NCRDS)
  410 FORMAT (10X,2A4,A2,F5.0,2X,5A4,F5.2,F8.3,5F8.2,F8.3)
  434 CONTINUE
C
C                                             STEP 3-11A
C                                             READ IN DATA TYPE 11A (WASTE INP
C                                             CHARACTERISTICS ALGAE, NITROGEN,
C                                             PHOROPHOROUS COLIFORMS AND RADIO
      DO 1602 I=1,II
      READ(NI,1601) (DATA(I,J), J=1,12)
 1601 FORMAT(3A4,A2,5X,F5.0,7F8.0)
      IF (DATA(I,1)-ENDA) 1602,1621,1602
 1602 CONTINUE
      NERROR=1
 1605 I=I+1
      READ(NI,1601) (DATA(I,J), J=1,12)
      IF (DATA(I,1)-ENDA) 1605,1607,1605
 1607 N=I-II
      WRITE (NJ,1620) N
 1620 FORMAT (1H0,5X,16H***** TOO MANY (,I3,21H) DATA 11A CARDS READ)
      GO TO 1604
 1621 IF (I.GE.II) GO TO 1604
      IF(IDATA) 1630,1630,1640
 1630 NCRDS=0
      GO TO 1650
 1640 NERROR=1
      N=II-I
      WRITE (NJ,1622) N
 1622 FORMAT (1H0,5X,15H***** TOO FEW (,I3,21H) DATA 11A CARDS READ)
 1604 CONTINUE
      NCRDS=I
      DO 1606 I=1,NWASTE
      NWS=DATA(I,5)
      WSALG(NWS)=DATA(I,6)/ALPHAO(1)
      WSNH3(NWS)=DATA(I,7)
      WSNO2(NWS)=DATA(I,8)
      WSNO3(NWS)=DATA(I,9)
      WSPHOS(NWS)=DATA(I,10)
      WSCOLI(NWS)=DATA(I,11)
      WSRAON(NWS)=DATA(I,12)
 1606 CONTINUE
 1650 IF(ILIST .EQ. 0) GO TO 1699
      WRITE (NJ,1610)
 1610 FORMAT (1H0,10X,41H$$$ DATA TYPE 11A (POINT SOURCE CHARACTER,
     *        45HISTICS - CHLOROPHYLL A, NITROGEN, PHOSPHORUS,/30X,
     *        51HCOLIFORMS AND SELECTED NON-CONSERVATIVE CONSTITUENT
     *        5H) $$$,/)
      WRITE(NJ,1611)
 1611 FORMAT (10X,9HCARD TYPE,6X,25HPOINT SOURCE ORDER AND ID,3X,
     *        46HCHLORA   NH3/N   NO2/N   NO3/N     DOP    COLI,
     *        11H     NONCON)
      NCRDS=NCRDS-1
      IF (IDATA.EQ.0) GO TO 1655
      DO 1615 I=1,NCRDS
      NWS=DATA(I,5)
      FNWS=NWS
      WRITE(NJ,1612)(DATA(I,J), J=1,4),FNWS,(WASTID(NWS,K), K=1,5),
     * (DATA(I,J), J=6,12)
 1612 FORMAT (10X,3A4,A2,F6.0,1X,5A4,F8.3,4F8.2,F11.2,F8.3)
 1615 CONTINUE
 1655 WRITE (NJ,1612) (DATA(NCRDS+1,J),J=1,3)
 1699 CONTINUE
      WRITE (NJ,2055)
 2055 FORMAT (1H1)
C
C                                             STEP 4-0
C                                             IF THE CORRECT NO. OF DATA CARDS
```

```
C                                              NOT BEEN READ IN, THE PROGRAM WI
C                                              TERMINATE.
C
      IF (NERROR.EQ.0) GO TO 888
      WRITE (NJ,2066)
 2066 FORMAT (1H1,15X,34H* * * * * * * * * * * * * * * * * * ,
     *                    33H* * * * * * * * * * * * * * * * *,//,
     *            16X,34H* E X E C U T I O N   W A S   T E ,
     *                    33HR M I N A T E D   B E C A U S E *,//,
     *            16X, 1H*,31X,3HO F,31X,1H*,//,
     *            16X,34H*             E R R O R S   I N   ,
     *                    33HI N P U T   D A T A           *,//,
     *            16X,34H* * * * * * * * * * * * * * * * * * ,
     *                    33H* * * * * * * * * * * * * * * * *)
      STOP
  888 RETURN
      END
```

SUBROUTINE NH3S*

Subroutine NH3S completes the setup of the equations necessary to calculate ammonia nitrogen concentration levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + (K_7)_i \Delta t$
7. Withdrawal	$b_i = x_i + (K_7)_i \Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = (N_1)_i^* + q_i' (N_1)_i' \frac{\Delta t}{V_i} - a_i (N_1)_h + \alpha_1 \rho A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$
6. Waste Input	$S_i = (N_1)_i^* + q_i' (N_1)_i' \frac{\Delta t}{V_i} + q_w (N_1)_w \frac{\Delta t}{V_i} + \alpha_1 \rho A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

TYPE	RIGHT HAND SIDE
All Others	$S_i = (N_1)_i^* + q_i' (N_1)_i' \frac{\Delta t}{V_i} + \alpha_1 \rho A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$

For steady-state simulation, the only difference is that the value from the previous time step, $(N_1)_i^*$, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-13 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

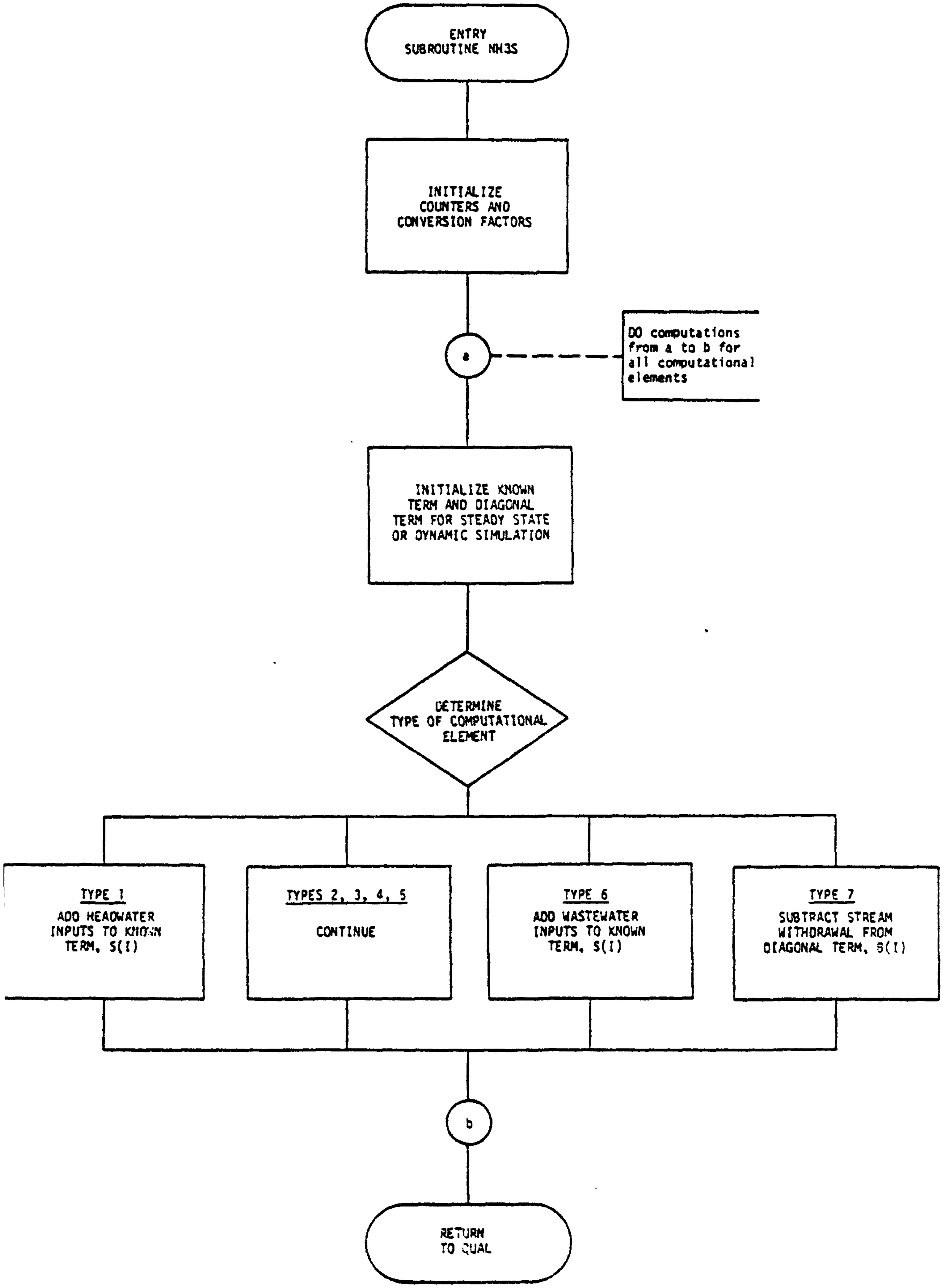

FIGURE VI-13. FLOW CHART FOR SUBROUTINE NH3S

```
      SUBROUTINE NH3S
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTQVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
      COMMON/SSTATE/X(500),ISS
      REAL KNH3
C
C                               INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
      FACT = 1.0 / (28.3 * 86400.0)
C
C                               LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      CNH3IJ=QI(I)/CNCELR*CNH3I(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                               INITIALIZE DIAGONAL AND KNOWN TERMS
C
      IF (MODOPT(4).EQ.0) ALGAE(IOR)=0.0
```

```
      TC=0.556*(T(IOR)-68.0)
      KNH3(IOR)=CKNH3(I)*1.047**TC
      REACT=ALPHA1*RESPRR(IOR)*ALGAE(IOR)*D1LT+SNH3(I)*DELX*
     *      DTOVCL(IOR) * FACT
      B(IOR)=X(IOR)+D1LT*KNH3(IOR)
      S(IOR)=CNH3(IOR)
      IF (ISS.GT.0) S(IOR)=0.0
      S(IOR)=S(IOR)+REACT+CNH3IJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                             MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWNH3(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSNH3 (NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE NO2S*

Subroutine NO2S completes the setup of the equations necessary to calculate nitrite nitrogen levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + (K_8)_i \Delta t$
7. Withdrawal	$b_i = x_i + (K_8)_i \Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = (N_2^*)_i + q_i' (N_2')_i \frac{\Delta t}{V_i} - a_i (N_2)_h + (K_7N_1)_i \Delta t$
6. Waste Input	$S_i = (N_2^*)_i + q_i' (N_2')_i \frac{\Delta t}{V_i} + q_w (N_2)_w \frac{\Delta t}{V_i} + (K_7N_1)_i \Delta t$
All Others	$S_i = (N_2^*)_i + q_i' (N_2')_i \frac{\Delta t}{V_i} + (K_7N_1)_i \Delta t$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, $(N^*)_i$, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-14 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

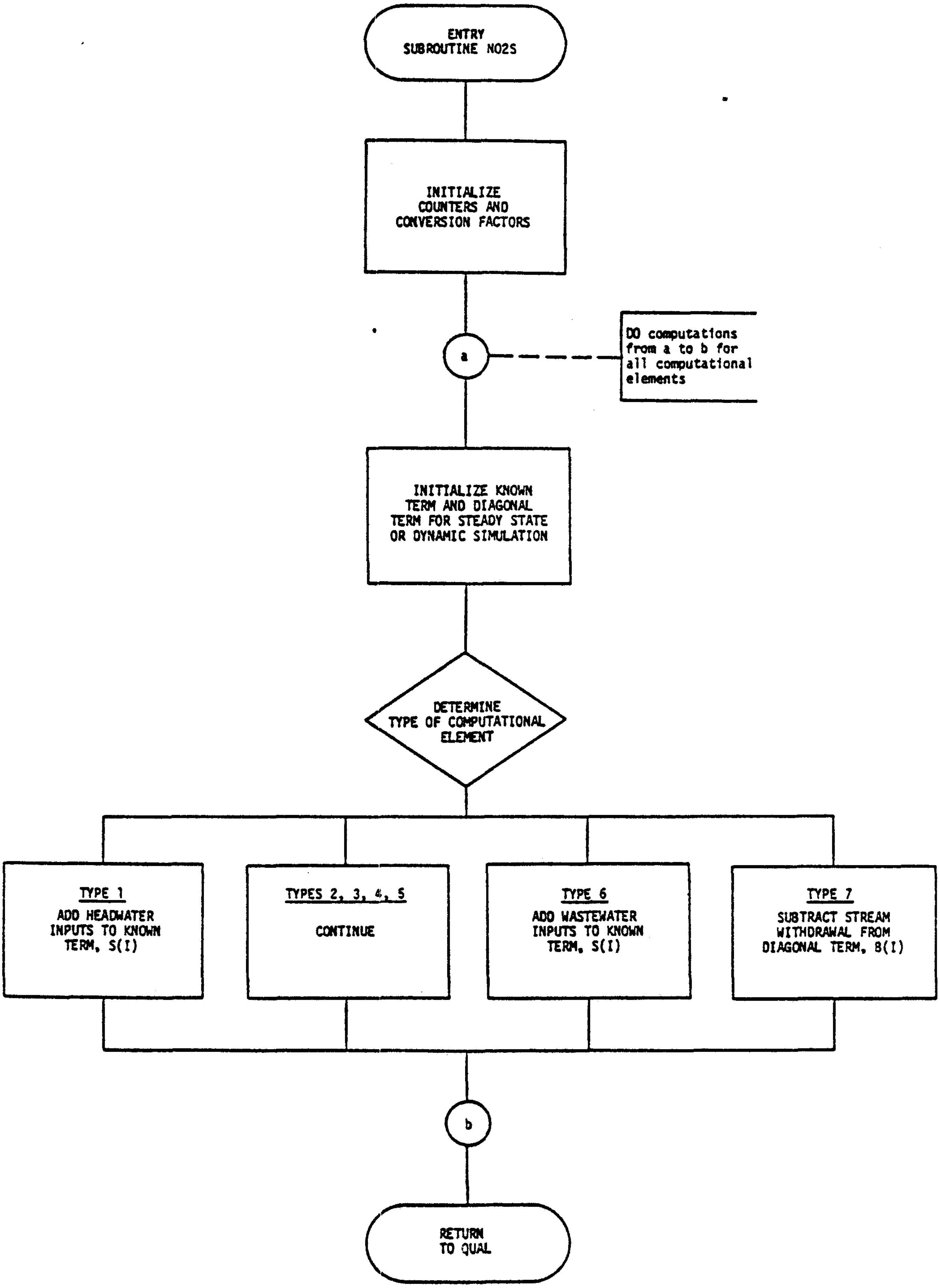

FIGURE VI-14. FLOW CHART FOR SUBROUTINE NO2S

```
      SUBROUTINE NO2S
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
      COMMON/SSTATE/X(500),ISS
      REAL KNO2, KNH3
C
C                             INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                             LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      CNO2IJ=QI(I)/CNCELR*CNO2I(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                             INITIALIZE DIAGONAL AND KNOWN TERMS
C
      TC=0.556*(T(IOR)-68.0)
      KNO2(IOR)=CKNO2(I)*1.047**TC
```

```
      REACT=DILT*KNH3(IOR)*CNH3(IOR)
      B(IOR)=X(IOR)+DILT*KNO2(IOR)
      S(IOR)=CNO2(IOR)
      IF (ISS.GT.0) S(IOR)=0.0
      S(IOR)=S(IOR)+REACT+CNO2IJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                          MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWNO2(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSNO2 (NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE NO3S*

Subroutine NO3S completes the setup of the equations necessary to calculate nitrate nitrogen levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i$
7. Withdrawal	$b_i = x_i - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE

1. Headwater $S_i = (N_3^*)_i + q_i'(N_3')_i \frac{\Delta t}{V_i} - a_i(N_3)_h + (K_8N_2)_i \Delta t - \alpha_1\mu_iA_i\Delta t$

6. Waste Input $S_i = (N_3^*)_i + q_i'(N_3')_i \frac{\Delta t}{V_i} + q_w(N_3)_w \frac{\Delta t}{V_i} + (K_8N_2)_i \Delta t - \alpha_1\mu_iA_i\Delta t$

All Others $S_i = (N_3^*)_i + q_i'(N_3')_i + (K_8N_2)_i \Delta t - \alpha_1\mu_iA_i\Delta t$

*All symbols used are defined at the end of this section in the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, $(N_3^*)_i$, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-15 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

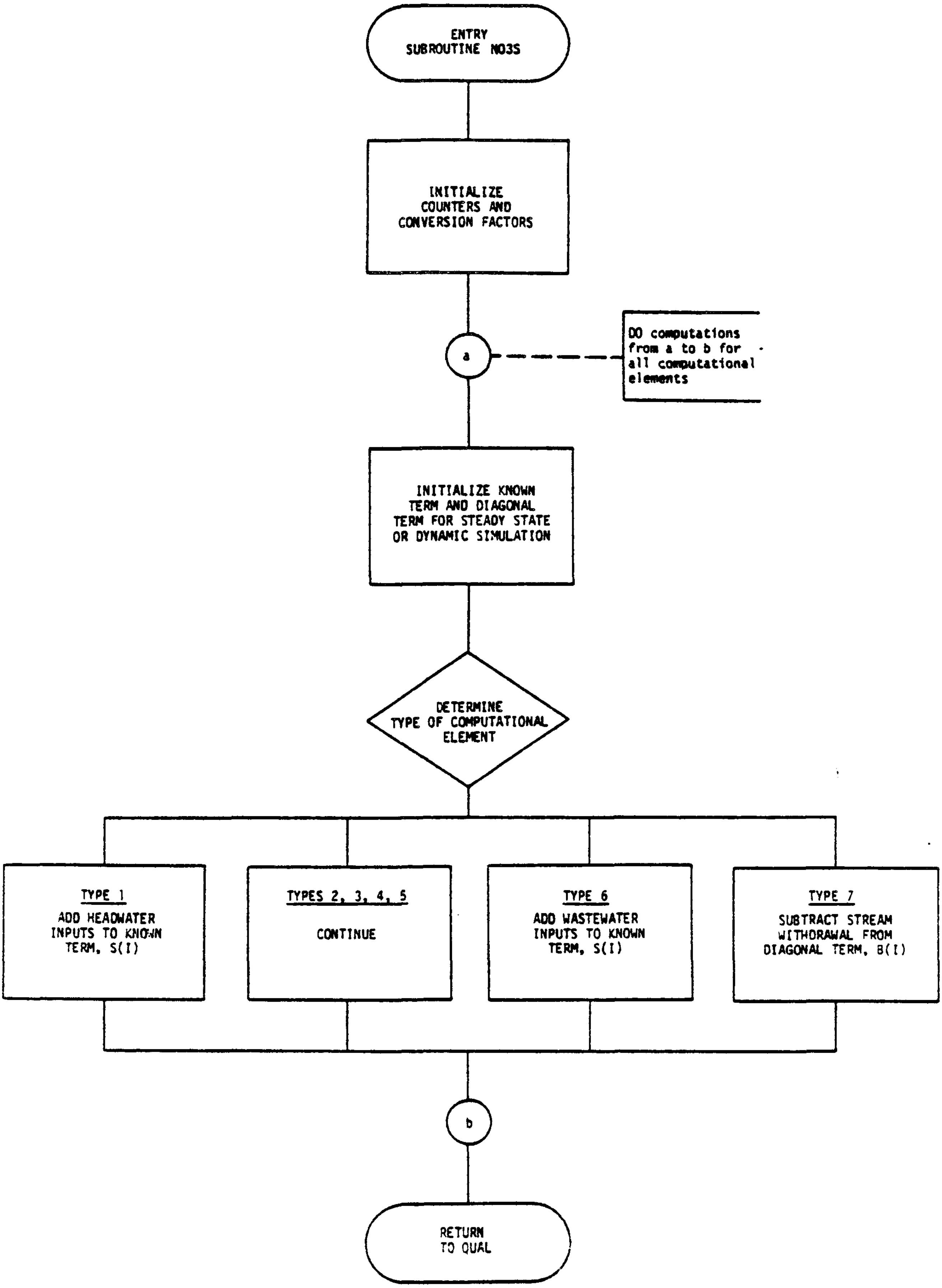

FIGURE VI-15. FLOW CHART FOR SUBROUTINE NO3S

```
      SUBROUTINE NO3S
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTQVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
      COMMON/SSTATE/X(500),ISS
      REAL KNO2
C
C                                  INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                                  LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      CNO3IJ=QI(I)/CNCELR*CNO3I(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                                  INITIALIZE DIAGONAL AND KNOWN TERMS
C
      IF (MODOPT(4).EQ.0) ALGAE(IOR)=0.0
      REACT=D1LT*KNO2(IOR)*CNO2(IOR)-D1LT*ALPHA1*GROWTH(IOR)*ALGAE(IOR)
```

```
      B(IOR)=X(IOR)
      S(IOR)=CNO3(IOR)
      IF (ISS.GT.0) S(IOR)=0.0
      S(IOR)=S(IOR)+REACT+CNO3IJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                                  MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWNO3(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSNO3 (NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE PO4S*

Subroutine PO4S completes the setup of the equations necessary to calculate phosphorus levels in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i$
7. Withdrawal	$b_i = x_i - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for eacn type of element for dynamic simulation is:

TYPE	
1. Headwater	$S_i = P_i^* + q'P' \frac{\Delta t}{V_i} - a_i P_h + \alpha_2 (\rho - \mu_i) A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$
6. Waste Input	$S_i = P_i^* + (q'P' + q_w P_w) \frac{\Delta t}{V_i} + \alpha_2 (\rho - \mu_i) A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$
All Others	$S_i = P_i^* + q'P' \frac{\Delta t}{V_i} + \alpha_2 (\rho - \mu_i) A_i \Delta t + \sigma_3 \Delta x \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, P_i^*, is set equal to zero and $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-16 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

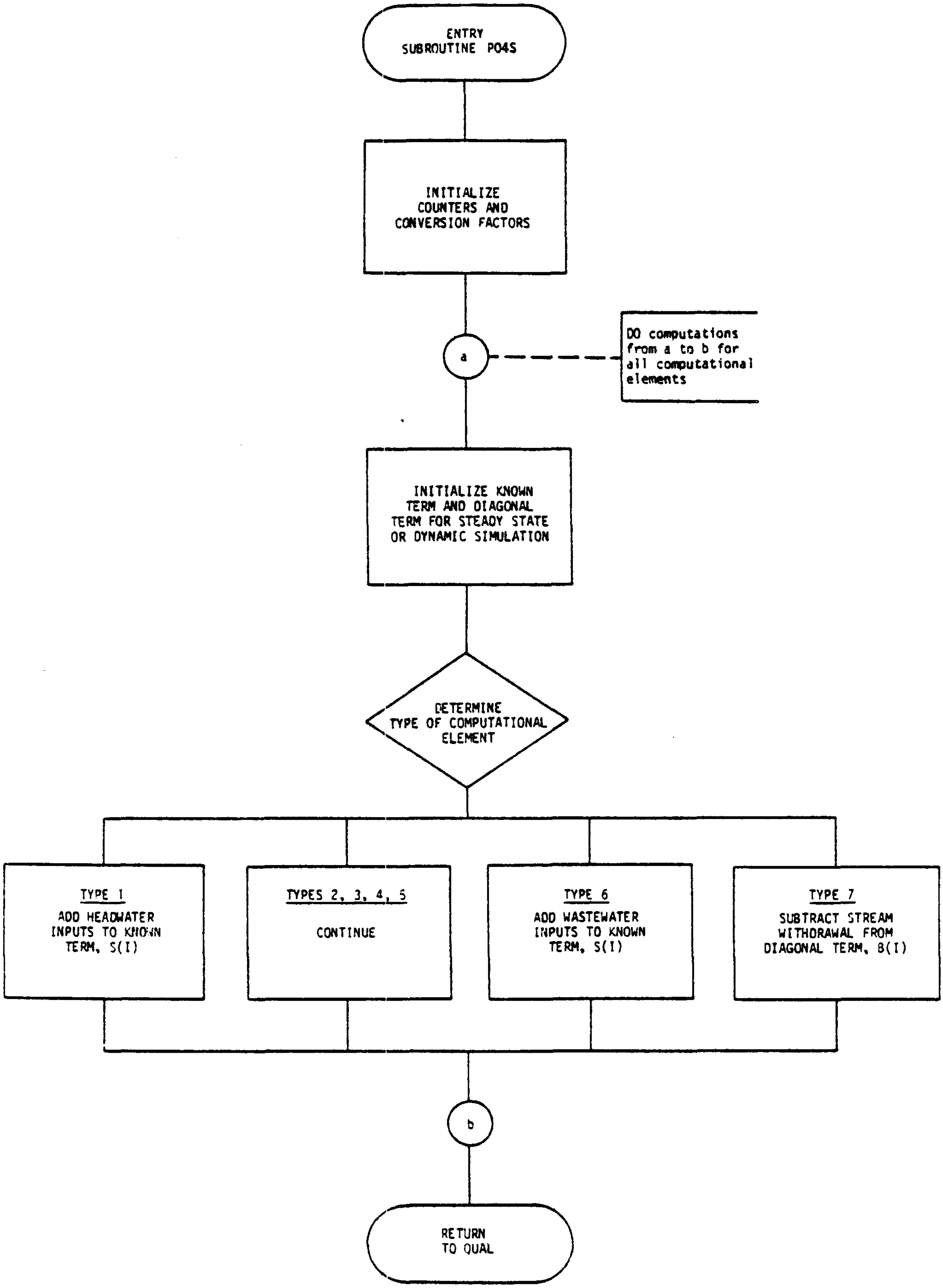

FIGURE VI-16. FLOW CHART FOR SUBROUTINE PO4S

```
      SUBROUTINE PO4S
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHA0(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
      COMMON/SSTATE/X(500),ISS
C
C
C                                INITIALIZE COUNTERS
      NHW=0
      NWS=0
      FACT = 1.0 / (28.3 * 86400.0)
C
C                                LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      PHOSIJ = QI(I)/CNCELR*PHOSI(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                                INITIALIZE DIAGONAL AND KNOWN TERMS
C
      S(IOR)=PHOS(IOR)
      B(IOR)=X(IOR)
```

```
      IF(ISS.GT.1) S(IOR)=0.0
      PSORCE=SPHOS(I)*DELX*DTOVCL(IOR) * FACT
      REACT = ALPHA2*(RESPRR(IOR)-GROWTH(IOR))*DELT
      S(IOR)=S(IOR)+PHOSIJ*DTOVCL(IOR)+REACT*ALGAE(IOR)+PSORCE
      IFL=IFLAG(I,J)
C
C                                MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR) = S(IOR) - A(IOR)*HWPHOS(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR) = S(IOR) + WSFLOW(NWS)*WSPHOS(NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR) = B(IOR) - WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE RADIOS*

Subroutine RADIOS completes the setup of the equations necessary to calculate the concentration of an arbitrary nonconservative constituent in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + K_6 \Delta t$
7. Withdrawal	$b_i = x_i + K_6 \Delta t - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and, in the case of dynamic simulation, the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = R_i^* + q_i' R_i' \frac{\Delta t}{V_i} - a_i R_h$
2. Waste Input	$S_i = R_i^* + q_i' R_i' \frac{\Delta t}{V_i} + q_w R_w \frac{\Delta t}{V_i}$
All Others	$S_i = R_i^* + q_i' R_i' \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

For steady-state simulation, the only difference is that the value from the previous time step, R_i^*, is set equal to zero and at $\Delta t = 1.0$.

The subroutine flow chart is illustrated in Figure VI-17 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

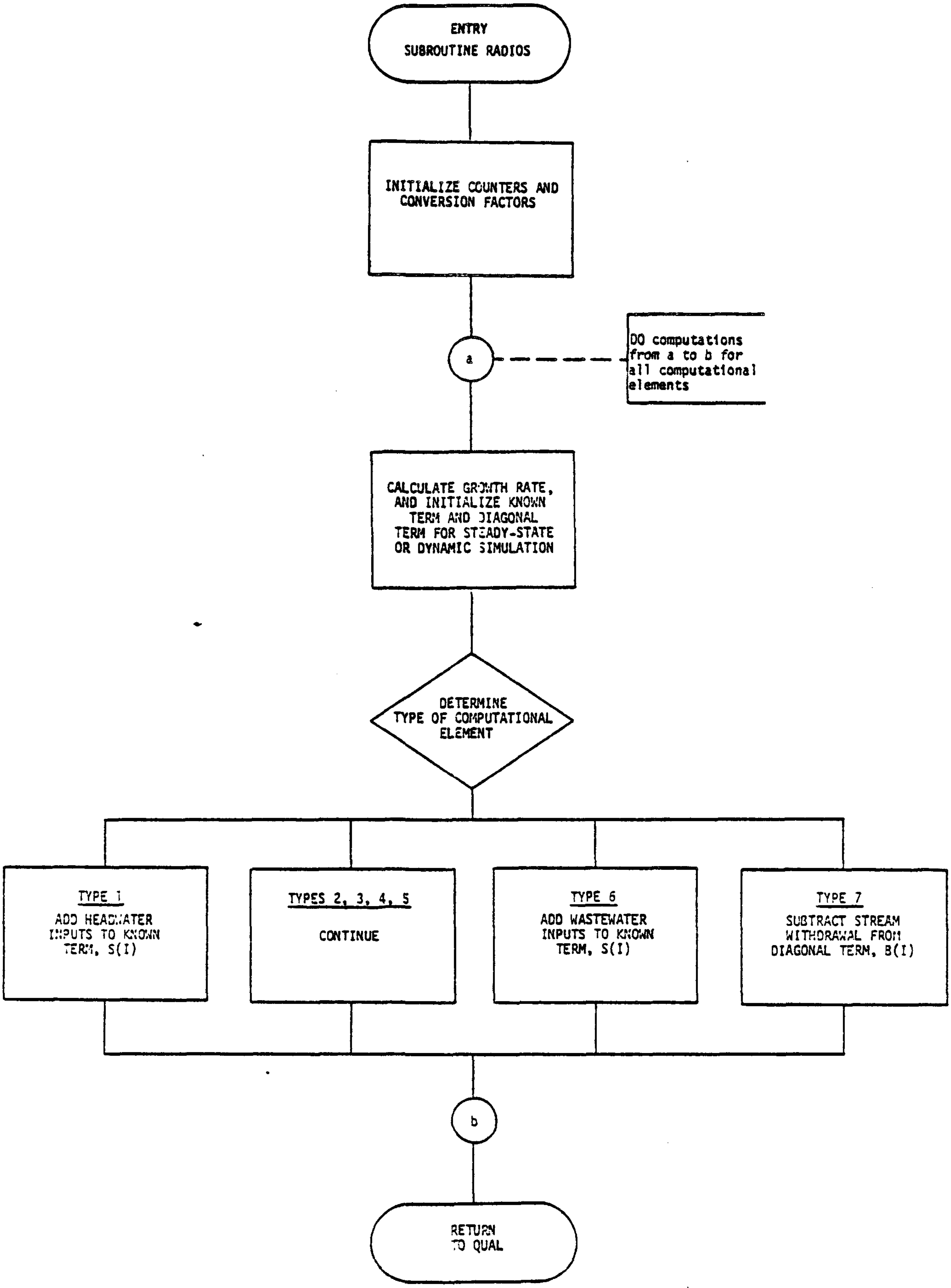

FIGURE VI-17. FLOW CHART FOR SUBROUTINE RADIOS

```
      SUBROUTINE RADIOS
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/RADION/ CK6(75),RADNIT(75),RADNI(75),HWRADN(15),WSRADN(90),
     *                RADIO(500)
C
C
      COMMON/SSTATE/X(500),ISS
      REAL K6
C
C                          INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
C
C                          LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      RADIJ=QI(I)/CNCELR*RADNI(1)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
```

```
C
C                                     INITIALIZE DIAGONAL AND KNOWN TERMS
C
      TC=0.556*(T(IOR)-68.0)
      K6=CK6(I)*1.047**TC
      REACT=DILT*K6
      B(IOR)=X(IOR)+REACT
      S(IOR)=RADIO(IOR)
      IF (ISS.GT.0) S(IOR)=0.0
      S(IOR)=S(IOR)+RADIJ*DTOVCL(IOR)
      IFL=IFLAG(I,J)
C
C                                     MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,100,100,100,100,103,104), IFL
C
  101 NHW=NHW+1
      S(IOR)=S(IOR)-A(IOR)*HWRADN(NHW)
      GO TO 100
C
  103 NWS=NWS+1
      S(IOR)=S(IOR)+WSFLOW(NWS)*WSRADN(NWS)*DTOVCL(IOR)
      GO TO 100
C
  104 NWS=NWS+1
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE REAERC*

Subroutine REAERC determines the reaeration coefficient for each computational element through the use of any one of seven different procedures. However, the same procedure must be used for all computational elements within an individual reach. The choice of which procedure to use is controlled by input options for each reach. The seven options, procedures, and references are:

OPTION & PROCEDURE	REFERENCE
1. Read-in K_2 values	None
2. $K_2 = 5.026 \frac{u^{0.969}}{D^{1.673}} \times 2.31$	Churchill et al (1962)
3. $K_2 = \frac{(D_m u)^{0.5}}{D^{1.5}} \times 86,400$	O'Conner and Dobbins (1958)
4. $K_2 = 9.4 \frac{u^{0.67}}{D^{1.85}} \times 2.31$	Owens et al (1964)
5. $K_2 = 10.8(1 + \sqrt{F}) \cdot \frac{u^*}{D} \times 2.31$	Thackston and Krenkel (1966)
6. $K_2 = 3.3 \frac{u}{D^{1.333}} \times 2.31$	Langbien and Durum (1967)
7. $K_2 = aQ^b$	None
8. $K_2 = 3600KS_e u$	Tsivoglou and Wallace (1972)

*This subroutine is unchanged from the original version of QUAL except for the addition of the Tsivoglou option. All symbols used are defined at the end of this section of the Documentation Report.

where

u	=	velocity (feet/sec)
D	=	depth (feet)
D_m	=	molecular diffusion coefficient (2.25×10^{-8} ft^2/sec)
F	=	Froude Number = $u/\sqrt{Dg}$
u^*	=	shear velocity (ft/sec)
	=	$u\ n\ \sqrt{g}/1.49\ D^{0.167}$
g	=	acceleration of gravity (32.2 ft/sec^2)
n	=	Manning's roughness coefficient
K	=	constant (range approximately 0.05 to 0.1/ft)

The subroutine flow chart is illustrated in Figure VI-18 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

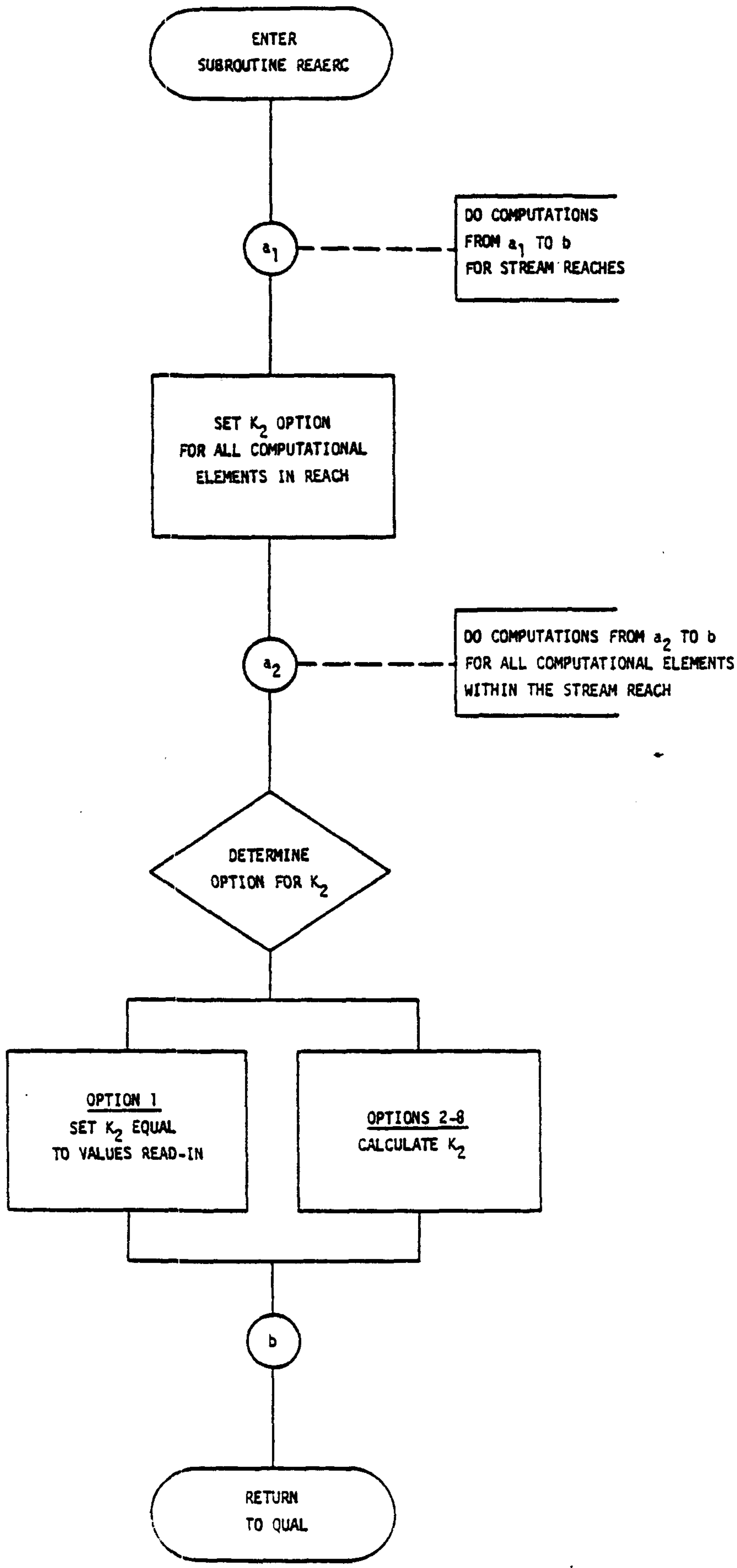

FIGURE VI-18. FLOW CHART FOR SUBROUTINE REAERC

```
      SUBROUTINE REAERC
C
C
C                                  REAERC CAN EITHER READ IN REAERATION
C                                  COEFFICIENTS (OPTION1), COMPUTE THEM
C                                  USING A SELECTED EQUATION (OPTION 2,3,
C                                  4,5, AND 6), OR COMPUTE THEM BASED ON
C                                  K2=A*Q**B.  ALL K2'S  ARE TO THE BASE E.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *      TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *      ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *      CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *      EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *      QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *      JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *      HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *      WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *      A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *      FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *      HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *      DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *      NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *      LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *      ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
      REAL K2,K2T
C
C                                            STEP 1-0
C                                            LOOP THROUGH SYSTEM OF NREACH RE
C                                            AND NCELR COMPUTATIONAL ELEMENTS
C                                            REACH.
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      KOPT=K2OPT(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      IFL=IFLAG(I,J)
C
C                                            STEP 1-1
C                                            SELECT K2'S FOR ANY OPTION AS DE
C                                            BY REACH.
C
C
C                                            KOPT = 1  K2 IS READ IN.
C                                            KOPT = 2  CHURCHILL (1962)
C                                            KOPT = 3  O'CONNER - DOBBINS (19
C                                            KOPT = 4  OWENS, EDWARDS, - GIBB
C                                            KOPT = 5  THACKSTON - KRENKEL (1
C                                            KOPT = 6  LANGBIEN - DURUM (1967
C                                            KOPT = 7  K2 = A * Q ** B
C                                            KOPT = 8  TSIVOGLOU - WALLACE (1
```

```
C
      GO TO (101,102,103,104,105,106,107,108), KOPT
  101 K2(IOR)=CK2(I)
      GO TO 100
  102 K2(IOR)=5.026*VEL(IOR)**0.969/DEPTH(IOR)**1.673*2.31
      GO TO 100
  103 DM=2.25E-08
      K2(IOR)=SQRT(DM*VEL(IOR))/DEPTH(IOR)**1.5*8.64E+04
      GO TO 100
  104 K2(IOR)=9.4*VEL(IOR)**0.67/DEPTH(IOR)**1.85*2.31
      GO TO 100
  105 F=0.176*VEL(IOR)/SQRT(DEPTH(IOR))
      SHRVEL=5.675*VEL(IOR)*CMANN(I)/(1.49*DEPTH(IOR)**1.167)
      K2(IOR)=10.8*(1.0+SQRT(F))*SHRVEL*2.31
      GO TO 100
  106 K2(IOR)=3.3*VEL(IOR)/DEPTH(IOR)**1.333*2.31
      GO TO 100
  107 K2(IOR)=COEQK2(I)*FLOW(IOR)**EXPQK2(I)
      GO TO 100
  108 CC2 = COEQK2(I)
      SLOPE = EXPQK2(I)
      IF(SLOPE.GT.0.0) GO TO 81
      IF(CMANN(I).GT.0.0) GO TO 82
      WRITE(NJ,999)
  999 FORMAT(1H1,10X,54H***IMPROPER PARAMETER SPECIFICATION FOR K2 OPTIO
     1N 8 -- /11X,42H***MUST SPECIFY CHANNEL SLOPE OR ROUGHNESS )
      CALL EXIT
C  CALCULATE DELTA H FROM CHANNEL SLOPE
   81 K2(IOR) = SLOPE * VEL(IOR) * CC2 * 3600.
      GO TO 100
C  CALCULATE DELTA H FROM MANNING EQ.
   82 K2T = CMANN(I)*CMANN(I)*VEL(IOR)**3/DEPTH(IOR)**(4./3.)
      K2(IOR) = CC2*K2T*1630.3
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE SOVMAT

Subroutine SOVMAT remains unchanged from the original version of QUAL as documented by the Texas Water Development Board (1970). According to that reference:

> *Subroutine SOVMAT solves a system of simultaneous linear equations whose coefficient matrix is of tri-diagonal form by using a modified Gaussian Elimination algorithm.*

The solution algorithm is presented, in detail, in Section V. The subroutine flow chart shown in Figure VI-19 is taken from the Texas Water Development Board reference. The program listing follows the Figure.

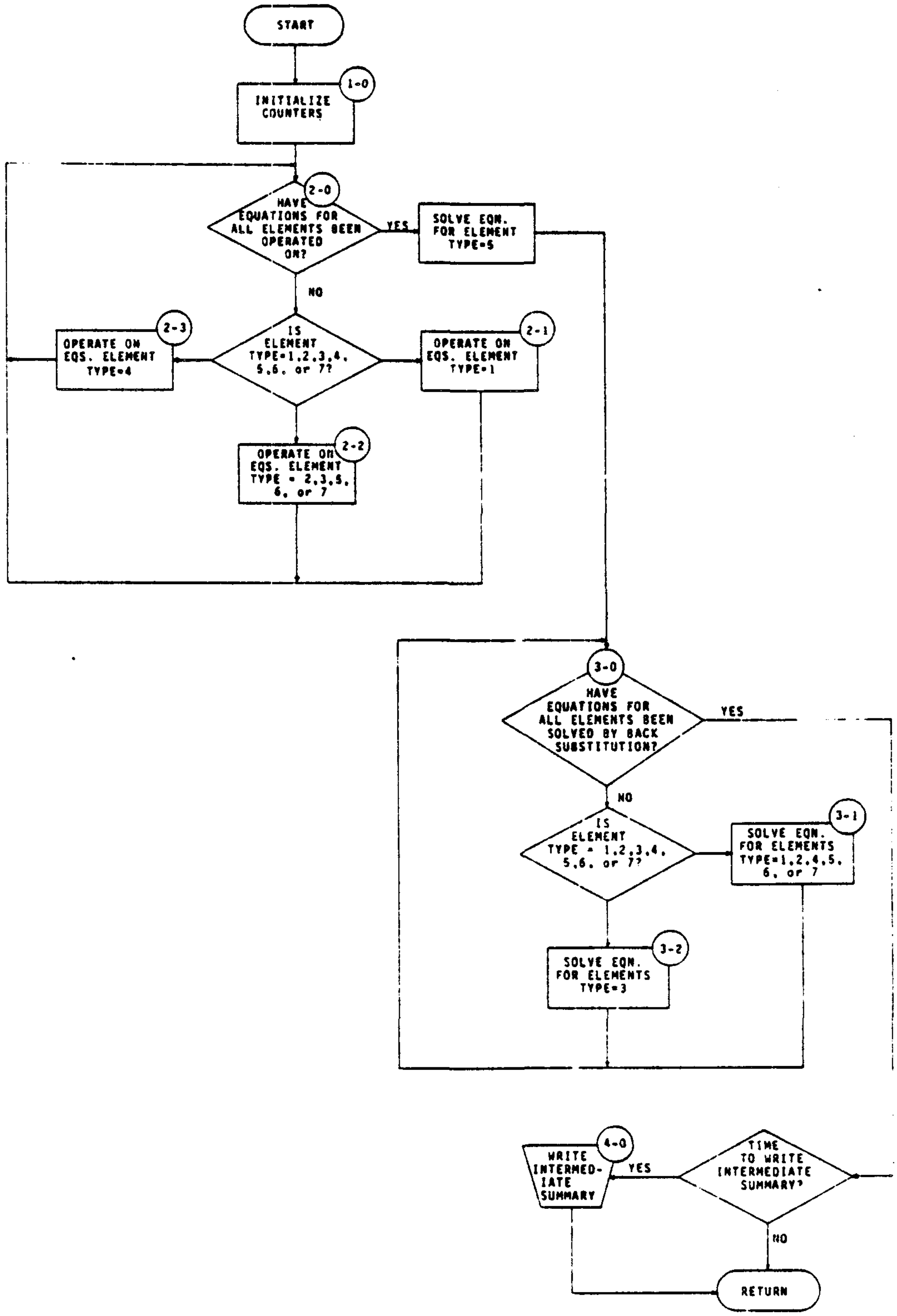

FIGURE VI-19. FLOW CHART FOR SUBROUTINE SOVMAT

```
      SUBROUTINE SOVMAT
C
C
C                                SOVMAT SOLVES A SYSTEM OF SIMULTANEOUS
C                                LINEAR EQUATIONS WHOSE COEFFICIENT
C                                MATRIX IS OF TRIDIAGONAL FORM USING
C                                A MODIFIED GAUSSIAN ELIMINATION TYPE OF
C                                ALGORITHM.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C + + + + + + FEB 1980 REVISIONS NO. 12
      COMMON/OUTPUT/IRPT1
C + + + + + +
C
      DIMENSION IFLG(500)
C
C                                          STEP 1-0
C                                          INITIALIZE COUNTER FOR STREAM JU
C
      IJUNC=0
C
C                                          STEP 2-0
C                                          LOOP THROUGH SYSTEM OF NREACH RE
C                                          WITH NCELR COMPUTATIONAL ELEMENT
C                                          REACH.
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      IFL=IFLAG(I,J)
      IFLG(IOR)=IFL
      GO TO (101,102,102,103,102,102,102), IFL
C
C                                          STEP 2-1
C                                          OPERATE ON EQUATION FOR AN ELEME
C                                          TYPE 1.
C
  101 W(IOR)=C(IOR)/B(IOR)
      G(IOR)=S(IOR)/B(IOR)
      GO TO 100
C
C                                          STEP 2-2
C                                          OPERATE ON EQUATION FOR ELEMENTS
C                                          2,3,5,6, OR 7.
C
  102 DENOM=B(IOR)-A(IOR)*W(IOR-1)
      W(IOR)=C(IOR)/DENOM
      G(IOR)=(S(IOR)-A(IOR)*G(IOR-1))/DENOM
      GO TO 100
C
C                                          STEP 2-3
C                                          OPERATE ON EQUATION FOR AN ELEME
```

```
C                                                     TYPE 4.
C
  103 IJUNC=IJUNC+1
      NS=1
      NN=JUNC(IJUNC,NS)
      S(IOR)=S(IOR)-D(IJUNC)*G(NN)
      DENOM=B(IOR)-A(IOR)*W(IOR-1)-D(IJUNC)*W(NN)
      W(IOR)=C(IOR)/DENOM
      G(IOR)=(S(IOR)-A(IOR)*G(IOR-1))/DENOM
  100 CONTINUE
C
C                                                     STEP 3-0
C                                                     SOLVE SYSTEM OF NREACH BY NCELR
C                                                     EQUATIONS USING BACK SUBSTITUTIO
C
      Z(IOR)=G(IOR)
      IF (Z(IOR).LT.0.0) Z(IOR) = 0.0
  109 IOR=IOR-1
      IFL=IFLG(IOR)
      GO TO (106,106,107,106,106,106,106), IFL
C
C                                                     STEP 3-1
C                                                     SOLVE THE EQUATION FOR ELEMENTS
C                                                     1,2,4,5,6, OR 7.
C
  106 Z(IOR)=G(IOR)-W(IOR)*Z(IOR+1)
      IF (Z(IOR).LT.0.0) Z(IOR)=0.0
      GO TO 108
C
C                                                     STEP 3-2
C                                                     SOLVE THE EQUATION FOR AN ELEMEN
C                                                     TYPE 3.
C
  107 NS=1
      DO 98 IJ=1,NJUNC
      IF (IOR.EQ.JUNC(IJ,NS)) IJUNC=IJ
   98 CONTINUE
      NS=2
      NN=JUNC(IJUNC,NS)
      Z(IOR)=G(IOR)-W(IOR)*Z(NN)
      IF (Z(IOR).LT.0.0) Z(IOR)=0.0
  108 CONTINUE
      IF (IOR.NE.1) GO TO 109
C
C                                                     STEP 4-0
C                                                     IF DESIRED, WRITE REPORT2 WHICH
C                                                     AN INTERMEDIATE SUMMARY OF CONDI
C                                                     WITHIN THE SYSTEM AT ANY GIVEN T
C
      IF (IPRINT.LT.PTIME) GO TO 99
      IF(IRPT1.EQ.1)CALL WRPT2 (Z)
   99 CONTINUE
      RETURN
      END
```

SUBROUTINE TEMPS*

Subroutine TEMPS is used for dynamic temperature simulations and completes the setup of the equations necessary to calculate temperatures in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i$
7. Withdrawal	$b_i = x_i - q_0 \frac{\Delta t}{V_i}$

where x_i is defined in Subroutine TRIMAT.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows and incremental runoff, and the concentration in the previous time step. The known term for each type of element for dynamic simulation is:

TYPE	
1. Headwater	$S_i = T_i^* + \frac{h_i}{\zeta \bar{D}_i} + q_i' \, T_i' \, \frac{\Delta t}{V_i} - a_i T_h$
6. Waste Input	$S_i = T_i^* + \frac{h_i}{\zeta \bar{D}_i} + q_i' \, T_i' \, \frac{\Delta t}{V_i} + q_w T_w \frac{\Delta t}{V_i}$
All Others	$S_i = T_i^* + \frac{h_i}{\zeta \bar{D}_i} + q_i' \, T_i' \, \frac{\Delta t}{V_i}$

*All symbols used are defined at the end of this section of the Documentation Report.

The subroutine flow chart is illustrated in Figure VI-20 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

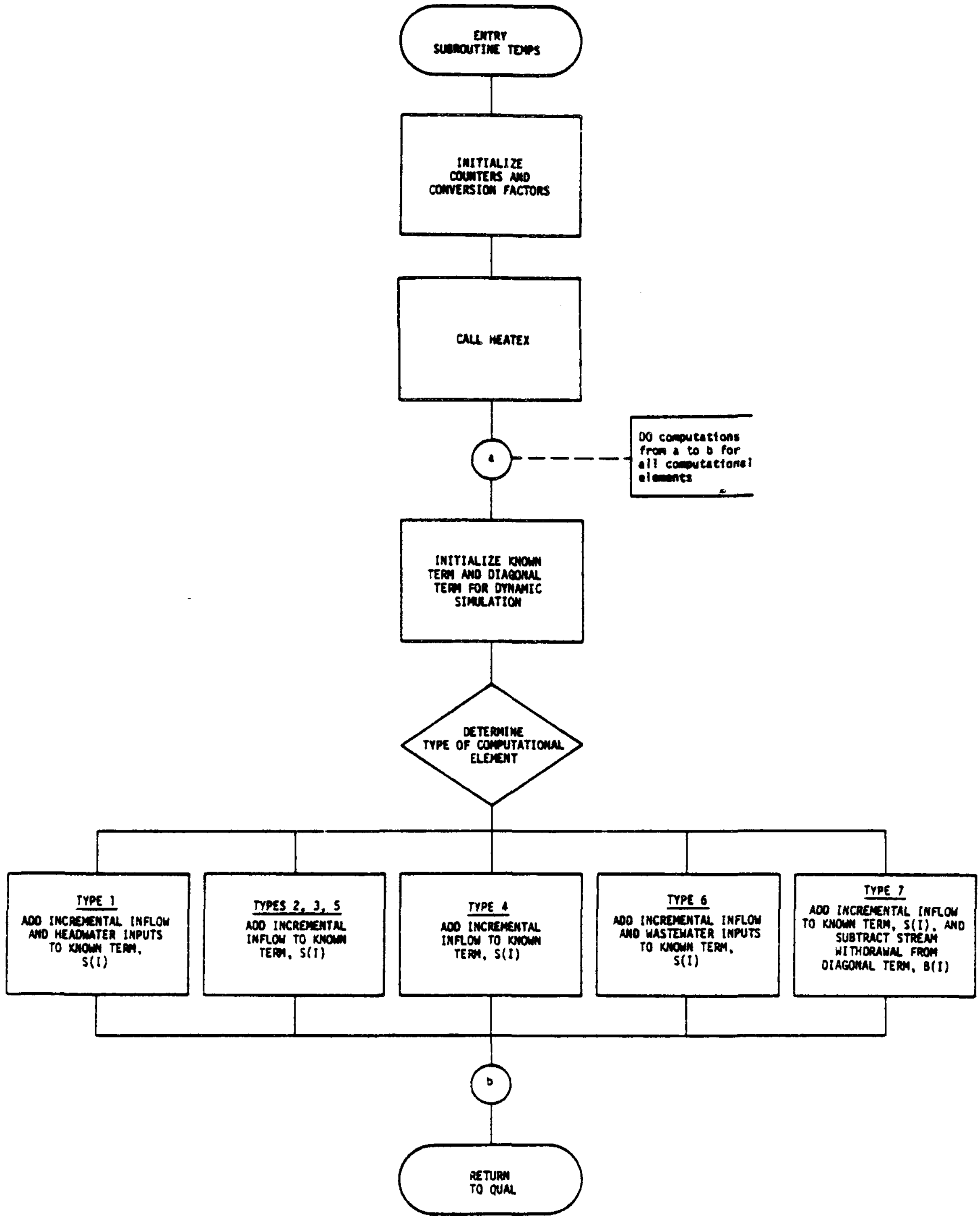

FIGURE VI-20. FLOW CHART FOR SUBROUTINE TEMPS

```
      SUBROUTINE TEMPS
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *      EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *      QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *      JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *      HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *      WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *      A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *      FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *      HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *      DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *      NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
C
      COMMON /SSTATE/ X(500),ISS
C
C                             INITIALIZE COUNTERS
C
      NHW=0
      NWS=0
      IJUNC=0
      RHOCP=62.4
      CALL HEATEX
C
C                             LOOP THROUGH REACHES AND COMP. ELEMENTS
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      CNCELR=NCELR
      TPIJ=QI(I)/CNCELR*TI(I)
C
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
C
C                             INITIALIZE KNOWN TERMS
C
      B(IOR)=X(IOR)
      IFL=IFLAG(I,J)
C
C                             MODIFY DIAGONAL AND/OR KNOWN TERMS
C
      GO TO (101,102,102,104,102,103,105), IFL
C
  101 NHW=NHW+1
      ADEPTH=0.5*(DEPHW(NHW)+DEPTH(IOR))
      REACT=HSNET(IOR)/(RHOCP*ADEPTH)
      S(IOR)=T(IOR)+REACT+TPIJ*DTOVCL(IOR)-A(IOR)*HWTEMP(NHW)
```

```
      GO TO 100
C
  102 ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=HSNET(IOR)/(RHOCP*ADEPTH)
      S(IOR)=T(IOR)+REACT+TPIJ*DTOVCL(IOR)
      GO TO 100
C
  103 NWS=NWS+1
      ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=HSNET(IOR)/(RHOCP*ADEPTH)
      S(IOR)=T(IOR)+REACT+(TPIJ+WSFLOW(NWS)*WSTEMP(NWS))*DTOVCL(IOR)
      GO TO 100
C
  104 IJUNC=IJUNC+1
      NS=1
      NN=JUNC(IJUNC,NS)
      ADEPTH=0.25*(DEPTH(IOR-1)+DEPTH(NN)+2.0*DEPTH(IOR))
      REACT=HSNET(IOR)/(RHOCP*ADEPTH)
      S(IOR)=T(IOR)+REACT+TPIJ*DTOVCL(IOR)
      GO TO 100
C
  105 NWS=NWS+1
      ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=HSNET(IOR)/(RHOCP*ADEPTH)
      S(IOR)=T(IOR)+REACT+(TPIJ)*DTOVCL(IOR)
      B(IOR)=B(IOR)-WSFLOW(NWS)*DTOVCL(IOR)
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE TEMPSS*

Subroutine TEMPSS is used for steady-state simulations and has two main functions. First, the heat flux terms that were not computed in HEATER (i.e. those that are dependent on water temperature: back radiation, evaporation, and conduction losses) are computed. These heat budget terms correspond to those calculated in step (3-0) of HEATEX (dynamic simulations) except that in TEMPSS, the loss terms are combined and the water temperature dependent terms separated out. In order that these terms be separable, functional relationships for the computation of back radiation and evaporation must be linearized, as noted in Section IV.

The second main function of TEMPSS is the same as that of TEMPS, namely to complete the setup of the equations necessary to calculate temperature in each computational element. Specifically, the subroutine completes the definition of the diagonal term of the coefficient matrix and defines the vector of known terms on the right hand side of the equations.

The additions to the diagonal term represent the individual constituent changes caused by constituent reactions and interactions, and mass changes caused by stream withdrawals. The resulting diagonal term for each type of computational element is:

TYPE	DIAGONAL TERM
All except type 7	$b_i = x_i + \frac{[h(T)]_i}{\zeta \bar{D}_i}$
7. Withdrawal	$b_i = x_i + \frac{[h(T)]_i}{\zeta \bar{D}_i} - \frac{q_0}{v_i}$

where x_i is defined in Subroutine TRIMATE, and $[h(T)]_i$ refers to the temperature dependent heat flux terms.

*All symbols used are defined at the end of this section of the Documentation Report.

The right hand side term contains all known inputs, which include headwater inflows, wastewater discharges, tributary flows, incremental runoff, and in this case, the heat flux terms that are not dependent on water temperature. The known term for each type of element for steady-state simulation is:

TYPE	RIGHT HAND SIDE
1. Headwater	$S_i = \dfrac{h_i^{\dagger}}{\zeta \bar{D}_i} + \dfrac{q_i' T_i'}{V_i} - a_i T_h$
6. Waste Input	$S_i = \dfrac{h_i^{\dagger}}{\zeta \bar{D}_i} + \dfrac{q_i' T_i'}{V_i} + \dfrac{q_w T_w}{V_i}$
All Others	$S_i = \dfrac{h_i^{\dagger}}{\zeta \bar{D}_i} + \dfrac{q_i' T_i'}{V_i}$

where $h_i^{\dagger}$ refers to water temperature independent heat flux terms.

In comparing these terms with those computed in TEMPS for dynamic simulations, note that the heat flux term (h_i) has been separated into a water temperature dependent term $[h(T)]_i$ and a water temperature independent term $h_i^{\dagger}$, the former considered an unknown and the latter a known term in the solution. Note also the absence of Δt terms and the temperature from the previous time step (T_i^*), since this is a steady-state solution.

The subroutine flow chart is illustrated in Figure VI-21 and is followed by the program listing. All program variables contained in COMMON are defined in Section VII.

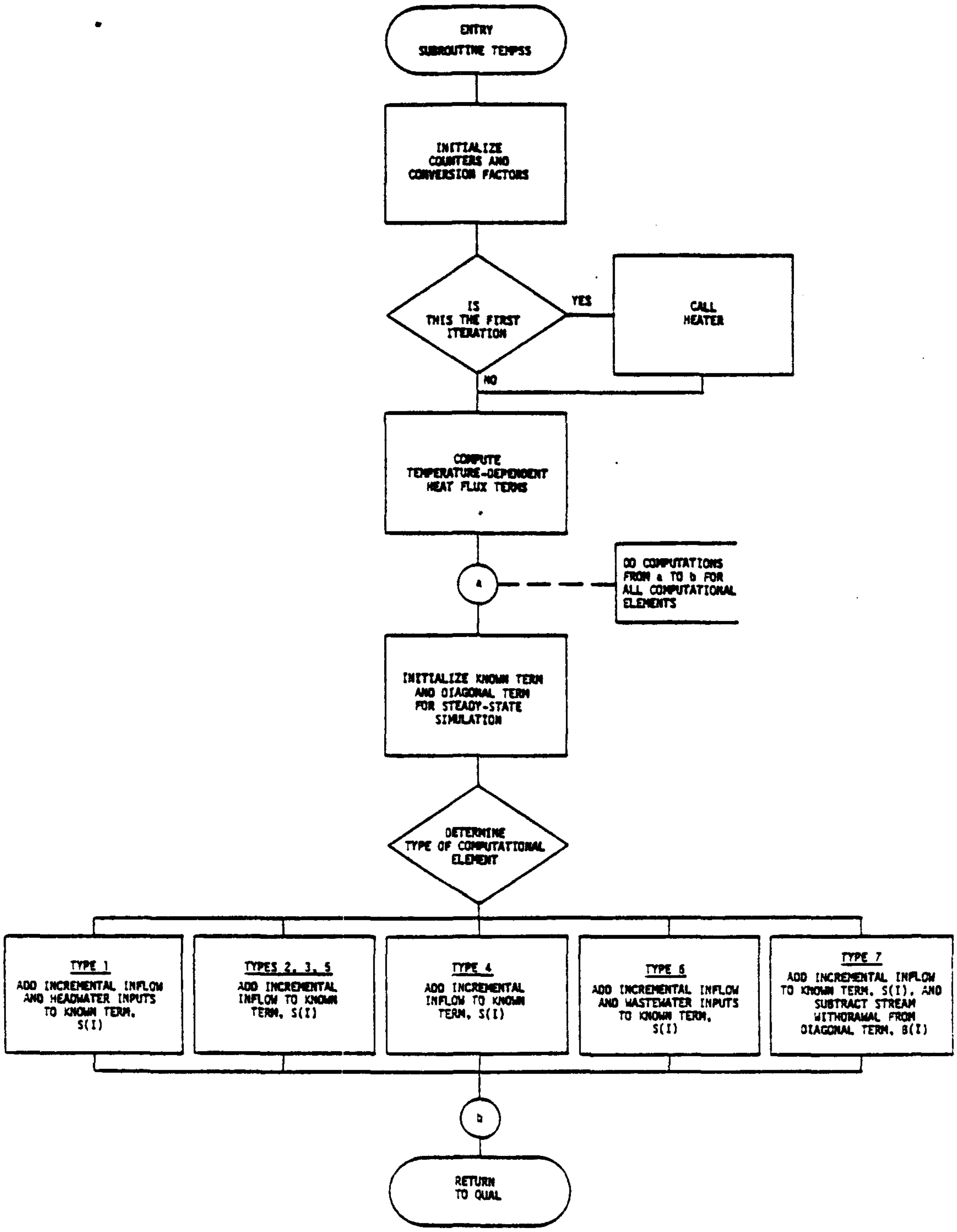

FIGURE VI-21. FLOW CHART FOR SUBROUTINE TEMPSS

```
      SUBROUTINE TEMPSS(NITER)
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
      COMMON/SSTATE/X(500),ISS
      DIMENSION ALPHA1(21),ALPHA2(21),BETA1(21),BETA2(21)
      DATA ALPHA1/-0.105,-0.161,-0.260,-0.360,-0.503,
     $             -0.671,-0.892,-1.144,-1.474,-1.842,
     A    -2.318,-2.858,-3.504,-4.264,-5.146,
     B    -6.202,-7.375,-8.767,-10.342,-12.162,-14.214/
      DATA BETA1/0.0088,0.0102,0.0124,0.0144,0.0170,
     $             0.0198,0.0232,0.0268,0.0312,0.0358,
     A    0.0414,0.0474,0.0542,0.0618,0.0702,
     B    0.079,0.090,0.107,0.114,0.128,0.143/
      DATA ALPHA2/71.84,70.80,69.63,68.33,66.90,65.34,
     $             63.39,61.43,59.33,56.93,54.38,51.68,
     A    48.83,45.43,42.28,38.59,34.76,30.70,26.39,21.83,17.02/
      DATA BETA2/0.826,0.852,0.878,0.904,0.930,0.956,
     $             0.986,1.014,1.042,1.072,1.102,1.132,
     B    1.162,1.196,1.226,1.259,1.292,1.326,1.361,1.396,1.431/
      COMMON/SSTEMP/JT(500),SOLRCH(75),CLDRCH(75),PATRCH(75),
     *             TDBRCH(75),TWBRCH(75),WINRCH(75)
      REAL MU,LAMBDA
      IF (NITER.EQ.0) CALL HEATER(NITER)
      NHW=0
      NWS=0
      IJUNC=0
      RHOCP=62.4
      DO 100 I=1,NREACH
      VPWB=0.1001*EXP(0.03*TWBRCH(I))-0.0837
      VPAIR=VPWB
     *    -0.000367*PATRCH(I)*(TDBRCH(I)-TWBRCH(I))*
     *       (1.0+(TWBRCH(I)-32.0)/1571.0)
      CLC=1.0+0.17*CLDRCH(I)**2
      HA=4.85E-15*(TDBRCH(I)+460.0)**6*CLC
      NCELR=NCELRH(I)
      CNCELR=NCELR
      TPIJ=QI(I)/CNCELR*TI(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      IFL=IFLAG(I,J)
```

```
      S(IOR)=0.
      TJ=(T(IOR)-35.)/5.
      M=TJ+1
      JT(IOR)=M
      HLAT=1084.-0.5*T(IOR)
      B1=RHOCP*HLAT*(AE+BE*WINRCH(I))
      B2=BETA1(M)+3.342E-01
      LAMBDA=BETA2(M)+B1*B2
      B3=ALPHA1(M)-VPAIR-3.342E-01*TDBRCH(I)
      HS=3.687*SOLRCH(I)/24.
      MU=HS+HA-ALPHA2(M)-B1*B3
      GO TO (101,102,102,104,102,103,105), IFL
  101 NHW=NHW+1
      ADEPTH=0.5*(DEPHW(NHW)+DEPTH(IOR))
      REACT=MU*D2LT/(RHOCP*ADEPTH)
      ST=TPIJ*DTOVCL(IOR)-A(IOR)*HWTEMP(NHW)
      S(IOR)=S(IOR)+REACT+ST
      B(IOR)=X(IOR)+LAMBDA*D2LT/(RHOCP*ADEPTH)
      GO TO 100
  102 ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=MU*D2LT/(RHOCP*ADEPTH)
      S(IOR)=S(IOR)+REACT+TPIJ*DTOVCL(IOR)
      B(IOR)=X(IOR)+LAMBDA*D2LT/(RHOCP*ADEPTH)
      GO TO 100
  103 NWS=NWS+1
      ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=MU*D2LT/(RHOCP*ADEPTH)
      ST=(TPIJ+WSFLOW(NWS)*WSTEMP(NWS))*DTOVCL(IOR)
      S(IOR)=S(IOR)+REACT+ST
      B(IOR)=X(IOR)+LAMBDA*D2LT/(RHOCP*ADEPTH)
      GO TO 100
  104 IJUNC=IJUNC+1
      NS=1
      NN=JUNC(IJUNC,NS)
      ADEPTH=0.25*(DEPTH(IOR-1)+DEPTH(NN)+2.*DEPTH(IOR))
      REACT=MU*D2LT/(RHOCP*ADEPTH)
      S(IOR)=S(IOR)+REACT+TPIJ*DTOVCL(IOR)
      B(IOR)=X(IOR)+LAMBDA*D2LT/(RHOCP*ADEPTH)
      GO TO 100
  105 NWS=NWS+1
      ADEPTH=0.5*(DEPTH(IOR-1)+DEPTH(IOR))
      REACT=MU*D2LT/(RHOCP*ADEPTH)
      S(IOR)=S(IOR)+REACT+TPIJ*DTOVCL(IOR)
      BT=WSFLOW(NWS)*DTOVCL(IOR)
      B(IOR)=X(IOR)+LAMBDA*D2LT/(RHOCP*ADEPTH)-BT
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE TRIMAT

Subroutine TRIMAT computes all coefficients for the implicit, finite difference advection-dispersion equation for each computational element except for the diagonal term. In the case of the diagonal term, b_i, TRIMAT computes that portion of term that is fixed and independent of the constituent to be simulated. This fixed portion of the diagonal term is designated as x_i.

In general, the basic equation that TRIMAT sets up for a computational element, i, is:

$$a_i z_{i-1} + b_i z_i + c_i z_{i+1} = S_i$$

where

b_i = x_i + (constituent dependent terms)

a_i, c_i = off-diagonal terms

S_i = known term

z = variable

In the case of a computational element that contains a junction and the upstream element in the tributary stream is n, the basic equation becomes:

$$a_i z_{i-1} + b_i z_i + c_i z_{i+1} + d_i z_n = S_i$$

Table VI-1 contains the equations for each term in each type of computational element.

The subroutine flow chart is illustrated in Figure VI-22 followed by the program listing. All program variables in COMMON are defined in Section VII.

TABLE VI-1

SUBROUTINE TRIMAT EQUATIONS

FOR VARIOUS TYPES OF COMPUTATIONAL ELEMENTS*

Reach Type	a	x	c	d
1. Headwater	$-D_h \frac{\Delta t}{\Delta x^2} - Q_h \frac{\Delta t}{V_i}$	$(1.0 + (D_n + D_i) \frac{\Delta t}{\Delta x^2} + Q_i \frac{\Delta t}{V_i})$	$-D_i \frac{\Delta t}{\Delta x^2}$	none
2. Regular	$-D_{i-1} \frac{\Delta t}{\Delta x^2} - Q_{i-1} \frac{\Delta t}{V_i}$	$(1.0 + (D_{i-1} + D_i) \frac{\Delta t}{\Delta x^2} + Q_i \frac{\Delta t}{V_i})$	same as 1	none
3. Upstream from junction	same as 2	same as 2	same as 2	none
4. Junction (with n)	same as 2	$(1.0 + (D_{i-1} + 2D_i + D_n) \frac{\Delta t}{\Delta x^2} + Q_i \frac{\Delta t}{V_i})$	same as 2	$-D_n \frac{\Delta t}{\Delta x^2} - Q_n \frac{\Delta t}{V_i}$
5. End of Reach	$-(D_{i-1}+D_i) \frac{\Delta t}{\Delta x^2} - Q_{i-1} \frac{\Delta t}{V_j}$	same as 2	-0-	none
6. Input	same as 2	same as 2	same as 2	none
7. Withdrawal	same as 2	same as 2	same as 2	none

*Equations shown are for dynamic simulations. For steady-state simulations, the 1.0 in the x term is 0.0 and the Δt's in all terms are set to 1.0.

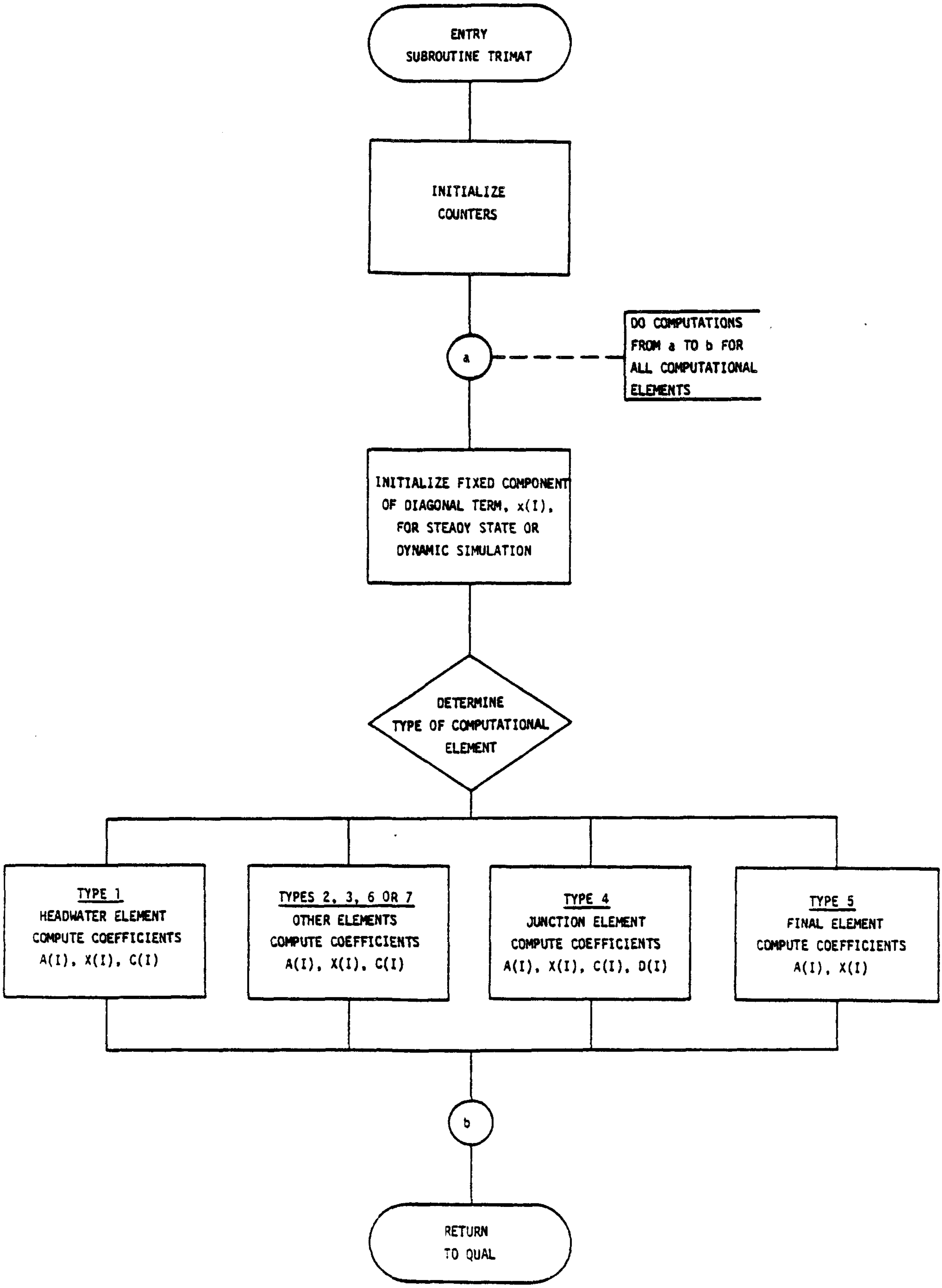

FIGURE VI-22. FLOW CHART FOR SUBROUTINE TRIMAT

```
      SUBROUTINE TRIMAT
C
C
C                                  TRIMAT COMPUTES THE COEFFICIENT MATRIX
C                                  FOR THE IMPLICIT-FINITE-DIFFERENCE FORM
C                                  OF THE ONE-DIMENSIONAL (ADVECTION +
C                                  DISPERSION) TRANSPORT EQUATION.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
      COMMON/SSTATE/X(500),ISS
C
C                                                STEP 1-0
C                                                INITIALIZE COUNTERS FOR HEADWATE
C                                                WASTE LOADS OR WITHDRAWLS, AND S
C                                                JUNCTIONS.
C
      NHW=0
      NWS=0
      IJUNC=0
C
C                                                STEP 2-0
C                                                LOOP THROUGH SYSTEM OF NREACH RE
C                                                WITH NCELR COMPUTATIONAL ELEMENT
C                                                REACH.
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      DO 100 J=1,NCELR
      IOR=ICLORD(I,J)
      X(IOR) = 1.0
      IF (ISS.GT.0) X(IOR) = 0.0
      IFL=IFLAG(I,J)
      GO TO (101,102,102,103,104,102,102), IFL
C
C                                                STEP 2-1
C                                                COMPUTE COEFFICIENTS B AND C FOR
C                                                ELEMENT OF TYPE 1.
```

```
C
  101 NHW=NHW+1
      A(IOR)=-DTODX2*DLHW(NHW)-HWFLOW(NHW)*DTOVCL(IOR)
      X(IOR)=X(IOR)+DTODX2*(DLHW(NHW)+DL(IOR))+FLOW(IOR)*DTOVCL(IOR)
      C(IOR)=-DTODX2*DL(IOR)
      GO TO 100
C
C                                                    STEP 2-2
C                                                    COMPUTE COEFFICIENTS A,B, AND C
C                                                    ELEMENTS OF TYPE 2,3,6, OR 7.
C
  102 A(IOR)=-DTODX2*DL(IOR-1)-FLOW(IOR-1)*DTOVCL(IOR)
      X(IOR)=X(IOR)+DTODX2*(DL(IOR-1)+DL(IOR))+FLOW(IOR)*DTOVCL(IOR)
      C(IOR)=-DTODX2*DL(IOR)
      GO TO 100
C
C                                                    STEP 2-3
C                                                    COMPUTE COEFFICIENTS A,B,C, AND
C                                                    ELEMENT OF TYPE 4.
C
  103 IJUNC=IJUNC+1
      NS=1
      NN=JUNC(IJUNC,NS)
      D(IJUNC)=-DTODX2*DL(NN)-FLOW(NN)*DTOVCL(IOR)
      A(IOR)=-DTODX2*DL(IOR-1)-FLOW(IOR-1)*DTOVCL(IOR)
      X(IOR)=X(IOR)+DTODX2*(DL(IOR-1)+DL(NN)+2.0*DL(IOR))+FLOW(IOR)*
     *         DTOVCL(IOR)
      C(IOR)=-DTODX2*DL(IOR)
      GO TO 100
C
C                                                    STEP 2-4
C                                                    COMPUTE COEFFICIENTS A AND B FOR
C                                                    ELEMENT OF TYPE 5.
C
C
  104 A(IOR)=-DTODX2*(DL(IOR-1)+DL(IOR))-FLOW(IOR-1)*DTOVCL(IOR)
      X(IOR)=X(IOR)+DTODX2*(DL(IOR-1)+DL(IOR))+FLOW(IOR)*DTOVCL(IOR)
      C(IOR)=0.
  100 CONTINUE
      RETURN
      END
```

SUBROUTINE WRPT2

Subroutine WRPT2 is basically the same program as documented by the Texas Water Development Board (1970). Minor changes to report headings and formats are the only differences from the original version of the program. For dynamic simulation QUAL-II uses WRPT2 to print intermediate summaries of simulation results at preselected time intervals. For steady-state simulations, the report is an optional form of outputting the solution. WRPT2 writes the concentration of the quality constituents simulated for each reach and all computational elements within the reach. For steady-state simulations the WRPT2 also reports within the reach. For steady-state simulations the WRPT2 also reports the number of computational elements that do not satisfy the convergent criteria. The following pages illustrate an example output report from WRPT2 for a steady-state simulation.

WRPT2 is produced by entering "WRITE INTERMEDIATE REPORT" on card number 2 of the TYPE 1 input data (see User's Manual Form 2).

Figure VI-23 illustrates the subroutine flow chart and the following pages contain the program listing. Variables in COMMON are defined in Section VII.

TEMPERATURE ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	73.30	73.55	74.30	74.10	74.58	74.90	75.10	75.04	75.18	75.28	75.34	75.39	75.42	75.44	75.45	75.46				
2	73.87	75.11	75.49	75.61	75.64															
3	74.45	75.42																		
4	75.62	75.65	75.66	75.66	75.66	75.66	75.66	75.66	73.36	74.18										
5	75.23	75.35	75.43	75.49	75.53	75.48	75.52	75.55	75.57	75.55	75.57	75.58								

DISSOLVED OXYGEN IN MG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8.19	8.08	8.00	7.94	7.87	7.81	7.75	7.71	7.67	7.62	7.58	7.54	7.51	7.47	7.44	7.42				
2	8.19	8.21	8.19	8.18	8.18															
3	8.20	8.20																		
4	8.18	8.16	8.15	8.15	8.14	8.14	8.14	8.15	7.88	7.95										
5	7.58	7.57	7.55	7.53	7.51	7.46	7.45	7.43	7.42	7.39	7.38	7.37								

5-DAY BIOCHEMICAL OXYGEN DEMAND ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.94	2.14	2.30	2.39	2.51	2.62	2.73	2.75	2.84	2.92	2.99	3.06	3.13	3.20	3.26	3.31				
2	1.95	1.90	1.85	1.80	1.76															
3	1.92	1.84																		
4	1.74	1.69	1.65	1.62	1.58	1.54	1.51	1.47	1.73	1.70										
5	2.92	3.00	3.08	3.15	3.23	3.33	3.40	3.46	3.51	3.58	3.64	3.70								

AMMONIA AS N IN MG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03				
2	0.02	0.02	0.02	0.02	0.02															
3	0.02	0.02																		
4	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.17	0.17										
5	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06								

NITRITE AS N IN MG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
2	0.00	0.00	0.00	0.00	0.00															
3	0.00	0.00																		
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00										
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01								

NITRATE AS N IN MG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.49	0.49	0.49	0.49	0.48	0.48	0.48	0.62	0.61	0.61	0.60	0.60	0.60	0.59	0.59	0.59				
2	0.50	0.49	0.49	0.49	0.49															
3	0.50	0.49																		
4	0.49	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.76	0.76										
5	0.63	0.63	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.61	0.61	0.61								

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.09				
2	0.10	0.10	0.10	0.10	0.10															
3	0.10	0.10																		
4	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.18	0.18										
5	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11								

ALGAE AS CHL.A IN UG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	9.77	12.34	12.12	13.86	13.64	13.43	13.23	14.18	14.00	13.83	13.65	13.49	13.32	13.16	13.00	12.84				
2	9.64	9.29	8.96	8.65	8.35															
3	9.41	8.87																		
4	8.40	8.25	8.11	7.97	7.84	7.70	7.57	7.45	16.94	16.88										
5	13.94	13.86	13.78	13.71	13.63	13.35	13.27	13.19	13.12	12.95	12.88	12.80								

FECAL COLIFORM IN NO./100 ML ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10
1	4.03E 05	3.54E 05	3.25E 05	3.11E 05	2.87E 05	2.65E 05	2.44E 05	2.31E 05	2.14E 05	1.98E 05
CL	11	12	13	14	15	16	17	18	19	20
	1.83E 05	1.69E 05	1.57E 05	1.45E 05	1.34E 05	1.24E 05				

RCH/CL	1	2	3	4	5	6	7	8	9	10
2	1.80E 05	1.62E 05	1.46E 05	1.31E 05	1.18E 05					

RCH/CL	1	2	3	4	5	6	7	8	9	10
3	1.73E 05	1.49E 05								

RCH/CL	1	2	3	4	5	6	7	8	9	10
4	1.18E 05	1.09E 05	1.00E 05	9.20E 04	8.46E 04	7.78E 04	7.15E 04	6.58E 04	2.52E 05	2.37E 05
CL	11	12	13	14	15	16	17	18	19	20

RCH/CL	1	2	3	4	5	6	7	8	9	10
5	1.47E 05	1.37E 05	1.28E 05	1.19E 05	1.11E 05	1.02E 05	9.48E 04	8.84E 04	8.24E 04	7.63E 04
CL	11	12	13	14	15	16	17	18	19	20
	7.13E 04	6.64E 04								

CONSERVATIVE MINERAL I TDS IN MG/L ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	82.53	88.96	88.51	92.86	92.45	92.04	91.64	96.15	95.75	95.37	94.99	94.62	94.25	93.90	93.54	93.20				
2	97.62	97.25	96.88	96.52	96.17															
3	97.54	97.10																		
4	96.35	96.17	95.98	95.80	95.62	95.44	95.26	95.09	109.63	109.52										
5	97.79	97.65	97.50	97.35	97.21	96.36	96.22	96.08	95.94	95.80	95.67	95.52								

ALGAE GROWTH RATES IN PER DAY ARE ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.30	0.28	0.29	0.27	0.27	0.27	0.27	0.29	0.29	0.28	0.28	0.28	0.28	0.28	0.27	0.27				
2	0.42	0.43	0.43	0.43	0.43															
3	0.44	0.45																		
4	0.39	0.39	0.39	0.39	0.39	0.39	0.38	0.38	0.40	0.41										
5	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29								

PHOTOSYNTHESIS-RESPIRATION RATIOS ARE ITERATION 3

RCH/CL	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	2.12	1.97	1.95	1.83	1.82	1.80	1.78	1.92	1.90	1.89	1.87	1.86	1.84	1.83	1.81	1.80				
2	2.90	2.88	2.86	2.85	2.83															
3	2.99	2.97																		
4	2.58	2.57	2.56	2.55	2.55	2.54	2.53	2.52	2.78	2.78										
5	1.95	1.94	1.94	1.93	1.93	1.91	1.90	1.90	1.89	1.88	1.91	1.91								

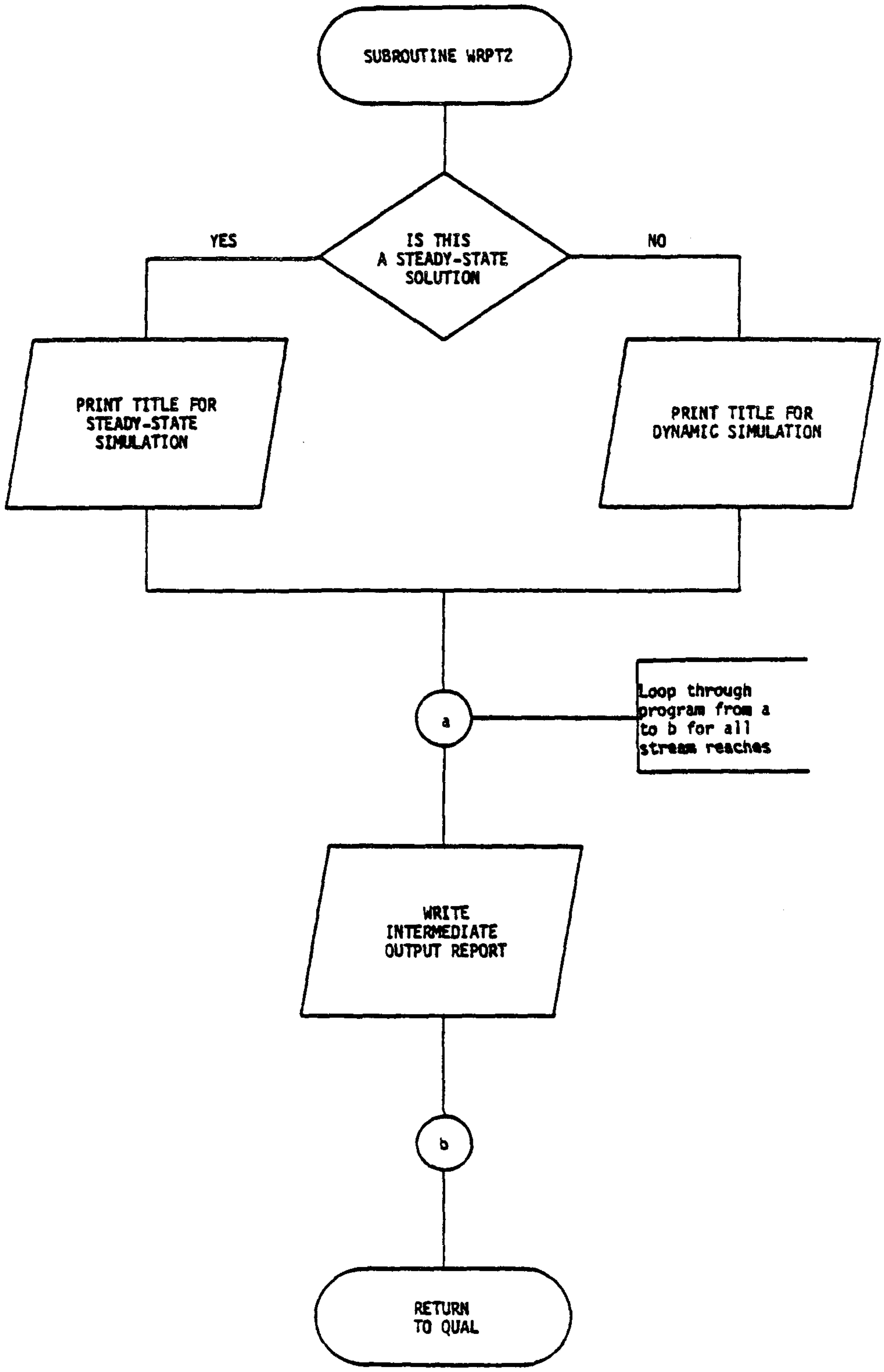

FIGURE VI-23. FLOW CHART FOR SUBROUTINE WRPT2

```
      SUBROUTINE WRPT2(CONC)
C
C
C                                   WRPT2 WRITES AN INTERMEDIATE SUMMARY
C                                   OF THE SELECTED QUALITY CONSTITUENTS.
C                                   THESE CONSTITUENTS ARE WRITTEN BY REACH
C                                   AND BY ELEMENT.  THIS SUMMARY CAN BE
C                                   GIVEN AT A TIME INTERVAL OF DELT OR
C                                   SOME MULTIPLE OF DELT.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *      TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *      ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *      CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *      EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *      QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *      JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *      HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *      WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *      A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *      FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *      HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *      DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *      NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *      LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *      ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *      CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *      ALPHA5,ALPHA6,GROMAX,RESPRT,ALGSET(75),SPHOS(75),
     *      SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *      ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *      COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *      CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *      CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *      WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *      HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *      MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/RADION/ CK6(75),RADNIT(75),RADNI(75),HWRADN(15),WSRADN(90),
     *               RADIO(500)
C
      COMMON/SSTATE/X(500),ISS
      DIMENSION P(20),CONC(500)
C
      IF (ISS) 20,20,10
   10 ITIME=TIME
      WRITE (NJ,15) (TITLE(NT,J),J=6,20),ITIME
   15 FORMAT (1H0,19X,15A4,4X,9HITERATION,I3)
      GO TO 55
   20 CONTINUE
      TINDAY=TIME/24.0
```

```
      WRITE (NJ,50) (TITLE(NT,J),J=6,20),TINDAY
   50 FORMAT (1H0,19X,15A4,1X,F5.2,5H DAYS,/)
C                                         STEP 1-0
   55 CONTINUE
      IF(NT.EQ.14) GO TO  400
      WRITE(NJ,60)
   60 FORMAT (2X,123HRCH/CL  1     2     3     4     5     6     7     8
     *     9    10    11    12    13    14    15    16    17    18    19
     *    20,/)
C
C                                         LOOP THROUGH SYSTEM OF NREACH RE
C                                         BY NCELR COMPUTATIONAL ELEMENTS
C                                         REACH.
C
      DO 100 I=1,NREACH
      NCELR=NCELRH(I)
      DO 200 J=1,NCELR
      IOR=ICLORD(I,J)
      P(J)=CONC(IOR)
      IF(NT .EQ. 8) P(J)=P(J)*ALPHAO(I)
  200 CONTINUE
C
C                                         STEP 1-1
C                                         WRITE INTERMEDIATE SUMMARY.
C
      WRITE (NJ,300) I,(P(J),J=1,NCELR)
  300 FORMAT (2X,I3,20F6.2)
  100 CONTINUE
      RETURN
  400 CONTINUE
C
C        SPECIAL PRINT FOR COLIFORMS
C
      DO 150 I=1,NREACH
      NCELR=NCELRH(I)
      DO 160 J=1,NCELR
      IOR=ICLORD(I,J)
      P(J)=CONC(IOR)
C + + + + + + THIS LINE DELETED PER T.BARNWELL
C     P(J)=P(J)*1000.
C + + + + + +
  160 CONTINUE
      WRITE(NJ,410) I,(P(J),J=1,NCELR)
  410 FORMAT(2X,102HRCH/CL      1         2         3         4         5
     A         6         7         8         9        10,/,2X,I3,3X,10(1
     BPE10.2),/,2X,102H     CL    11        12        13        14
     C 15        16        17        18        19        20,/,8X,10(1PE
     D10.2))
  150 CONTINUE
      RETURN
      END
```

SUBROUTINE WRPT3

Subroutine WRPT3 is used to print the final output from the water quality simulations for both the steady-state solution and the dynamic case. WRPT3 prints a complete history of all quality and temperature parameters included in QUAL-II; any parameter not simulated in the current simulation will be printed either at the value to which it was initialized (as in the case of temperature) or as zero. The following pages illustrate an example output report from WRPT3 for a steady-state simulation.

Figure VI-24 illustrates the subroutine flow chart, and the following pages contain the program listing. Variables in COMMON are defined in Section VII.

***** STEADY STATE SIMULATION *****

RCH NUM	ELT NUM	FROM KILO	TO KILO	FLOW (CMS)	POINT SOURCE	INCR FLOW	TEMP DEG C	DO (MG/L)	BOD (MG/L)	NH3-N (MG/L)	NO3-N (MG/L)	DIS-O-P (MG/L)	CHL A (UG/L)	COLI /100ML	( )	TDS (MG/L)	( )	( )
1	1	1	46.0	45.0	0.98	0.0	0.02	22.94	8.19	1.94	0.03	0.49	0.10	9.77	403.	0.0	82.53	0.0	0.0
2	1	2	45.0	44.0	1.21	0.22	0.02	23.08	8.08	2.14	0.02	0.49	0.10	12.34	354.	0.0	88.96	0.0	0.0
3	1	3	44.0	43.0	1.23	0.0	0.02	23.50	8.00	2.30	0.02	0.49	0.10	12.12	325.	0.0	88.51	0.0	0.0
4	1	4	43.0	42.0	1.47	0.22	0.02	23.39	7.94	2.39	0.02	0.49	0.10	13.86	311.	0.0	92.86	0.0	0.0
5	1	5	42.0	41.0	1.48	0.0	0.02	23.66	7.87	2.51	0.02	0.48	0.09	13.64	287.	0.0	92.45	0.0	0.0
6	1	6	41.0	40.0	1.50	0.0	0.02	23.83	7.81	2.62	0.02	0.48	0.09	13.43	265.	0.0	92.04	0.0	0.0
7	1	7	40.0	39.0	1.51	0.0	0.02	23.95	7.75	2.73	0.02	0.48	0.09	13.23	244.	0.0	91.64	0.0	0.0
8	1	8	39.0	38.0	1.69	0.16	0.02	23.91	7.71	2.75	0.03	0.62	0.10	14.18	231.	0.0	96.15	0.0	0.0
9	1	9	38.0	37.0	1.71	0.0	0.02	23.99	7.67	2.84	0.03	0.61	0.10	14.00	214.	0.0	95.75	0.0	0.0
10	1	10	37.0	36.0	1.72	0.0	0.02	24.04	7.62	2.92	0.03	0.61	0.10	13.83	198.	0.0	95.37	0.0	0.0
11	1	11	36.0	35.0	1.74	0.0	0.02	24.08	7.58	2.99	0.03	0.60	0.10	13.65	183.	0.0	94.99	0.0	0.0
12	1	12	35.0	34.0	1.76	0.0	0.02	24.11	7.54	3.06	0.03	0.60	0.10	13.49	169.	0.0	94.62	0.0	0.0
13	1	13	34.0	33.0	1.77	0.0	0.02	24.12	7.51	3.13	0.03	0.60	0.10	13.32	157.	0.0	94.25	0.0	0.0
14	1	14	33.0	32.0	1.79	0.0	0.02	24.13	7.47	3.20	0.03	0.59	0.10	13.16	145.	0.0	93.90	0.0	0.0
15	1	15	32.0	31.0	1.80	0.0	0.02	24.14	7.44	3.26	0.03	0.59	0.10	13.00	134.	0.0	93.54	0.0	0.0
16	1	16	31.0	30.0	1.82	0.0	0.02	24.15	7.42	3.31	0.03	0.59	0.09	12.84	124.	0.0	93.20	0.0	0.0
17	2	1	15.0	14.0	0.18	0.0	0.00	23.26	8.19	1.95	0.02	0.50	0.10	9.64	180.	0.0	97.62	0.0	0.0
18	2	2	14.0	13.0	0.18	0.0	0.00	23.95	8.21	1.90	0.02	0.49	0.10	9.29	162.	0.0	97.25	0.0	0.0
19	2	3	13.0	12.0	0.18	0.0	0.00	24.16	8.19	1.85	0.02	0.49	0.10	8.96	146.	0.0	96.88	0.0	0.0
20	2	4	12.0	11.0	0.19	0.0	0.00	24.23	8.18	1.80	0.02	0.49	0.10	8.65	131.	0.0	96.52	0.0	0.0
21	2	5	11.0	10.0	0.19	0.0	0.00	24.25	8.18	1.76	0.02	0.49	0.10	8.35	118.	0.0	96.17	0.0	0.0
22	3	1	2.0	1.0	0.14	0.0	0.00	23.58	8.20	1.92	0.02	0.50	0.10	9.41	173.	0.0	97.54	0.0	0.0
23	3	2	1.0	-0.0	0.14	0.0	0.00	24.12	8.20	1.84	0.02	0.49	0.10	8.87	149.	0.0	97.10	0.0	0.0
24	4	1	10.0	9.0	0.33	0.0	0.00	24.24	8.18	1.74	0.02	0.49	0.10	8.40	118.	0.0	96.35	0.0	0.0
25	4	2	9.0	8.0	0.33	0.0	0.00	24.25	8.16	1.69	0.02	0.49	0.10	8.25	109.	0.0	96.17	0.0	0.0
26	4	3	8.0	7.0	0.34	0.0	0.00	24.25	8.15	1.65	0.02	0.48	0.10	8.11	100.	0.0	95.98	0.0	0.0
27	4	4	7.0	6.0	0.34	0.0	0.00	24.26	8.15	1.62	0.02	0.48	0.09	7.97	92.	0.0	95.80	0.0	0.0
28	4	5	6.0	5.0	0.34	0.0	0.00	24.26	8.14	1.58	0.02	0.48	0.09	7.84	85.	0.0	95.62	0.0	0.0
29	4	6	5.0	4.0	0.34	0.0	0.00	24.26	8.14	1.54	0.02	0.48	0.09	7.70	78.	0.0	95.44	0.0	0.0
30	4	7	4.0	3.0	0.34	0.0	0.00	24.26	8.14	1.51	0.02	0.48	0.09	7.57	72.	0.0	95.26	0.0	0.0
31	4	8	3.0	2.0	0.34	0.0	0.00	24.26	8.15	1.47	0.02	0.48	0.09	7.45	66.	0.0	95.09	0.0	0.0
32	4	9	2.0	1.0	0.75	0.41	0.00	22.98	7.88	1.73	0.17	0.76	0.18	16.94	252.	0.0	109.63	0.0	0.0
33	4	10	1.0	0.0	0.76	0.0	0.00	23.43	7.95	1.70	0.17	0.76	0.18	16.88	237.	0.0	109.52	0.0	0.0
34	5	1	30.0	29.0	2.59	0.0	0.01	24.02	7.58	2.92	0.07	0.63	0.12	13.94	147.	0.0	97.79	0.0	0.0
35	5	2	29.0	28.0	2.59	0.0	0.01	24.08	7.57	3.00	0.07	0.63	0.12	13.86	137.	0.0	97.65	0.0	0.0
36	5	3	28.0	27.0	2.60	0.0	0.01	24.13	7.55	3.08	0.07	0.63	0.12	13.78	128.	0.0	97.50	0.0	0.0
37	5	4	27.0	26.0	2.61	0.0	0.01	24.16	7.53	3.15	0.07	0.63	0.12	13.71	119.	0.0	97.35	0.0	0.0
38	5	5	26.0	25.0	2.62	0.0	0.01	24.18	7.51	3.23	0.07	0.63	0.12	13.63	111.	0.0	97.21	0.0	0.0
39	5	6	25.0	24.0	2.67	0.04	0.01	24.15	7.46	3.33	0.07	0.62	0.12	13.35	102.	0.0	96.36	0.0	0.0
40	5	7	24.0	23.0	2.68	0.0	0.01	24.18	7.45	3.40	0.06	0.62	0.12	13.27	95.	0.0	96.22	0.0	0.0
41	5	8	23.0	22.0	2.69	0.0	0.01	24.19	7.43	3.46	0.06	0.62	0.11	13.19	88.	0.0	96.08	0.0	0.0
42	5	9	22.0	21.0	2.70	0.0	0.01	24.21	7.42	3.51	0.06	0.62	0.11	13.12	82.	0.0	95.94	0.0	0.0
43	5	10	21.0	20.0	2.73	0.02	0.01	24.19	7.39	3.58	0.06	0.61	0.11	12.95	76.	0.0	95.80	0.0	0.0
44	5	11	20.0	19.0	2.54	0.20	0.01	24.20	7.38	3.64	0.06	0.61	0.11	12.88	71.	0.0	95.67	0.0	0.0
45	5	12	19.0	18.0	2.54	0.0	0.01	24.21	7.37	3.70	0.06	0.61	0.11	12.80	66.	0.0	95.52	0.0	0.0

***** STEADY STATE SIMULATION *****

	RCH ORD	ELT NUM	FROM KILO	TO KILO	STREAM VEL (MPS)	STREAM DEPTH (M)	OXYGEN REAIR (1/DY)	BOD DECAY (1/DY)	NH3 DECAY (1/DY)	NO2 DECAY (1/DY)	COLI DECAY (1/DY)	ALGAE GROWTH (1/DY)	ALGAE RESPR (1/DY)
1	1	1	46.0	45.0	0.248	0.43	7.20	0.69	0.17	1.14	1.72	0.30	0.11
2	1	2	45.0	44.0	0.265	0.49	6.73	0.69	0.17	1.15	1.73	0.28	0.12
3	1	3	44.0	43.0	0.266	0.49	6.25	0.70	0.18	1.17	1.76	0.29	0.12
4	1	4	43.0	42.0	0.280	0.54	5.86	0.70	0.18	1.17	1.75	0.27	0.12
5	1	5	42.0	41.0	0.281	0.55	5.52	0.71	0.18	1.18	1.77	0.27	0.12
6	1	6	41.0	40.0	0.282	0.55	5.49	0.72	0.18	1.19	1.79	0.27	0.12
7	1	7	40.0	39.0	0.283	0.55	5.46	0.72	0.18	1.20	1.80	0.27	0.12
8	1	8	39.0	38.0	0.293	0.59	5.25	0.72	0.18	1.20	1.80	0.29	0.12
9	1	9	38.0	37.0	0.293	0.59	5.04	0.72	0.18	1.20	1.80	0.29	0.12
10	1	10	37.0	36.0	0.294	0.59	5.01	0.72	0.18	1.20	1.81	0.28	0.12
11	1	11	36.0	35.0	0.295	0.60	4.98	0.72	0.18	1.21	1.81	0.28	0.12
12	1	12	35.0	34.0	0.296	0.60	4.95	0.72	0.18	1.21	1.81	0.28	0.12
13	1	13	34.0	33.0	0.297	0.60	4.92	0.73	0.18	1.21	1.81	0.28	0.12
14	1	14	33.0	32.0	0.298	0.61	4.89	0.73	0.18	1.21	1.81	0.28	0.12
15	1	15	32.0	31.0	0.298	0.61	4.86	0.73	0.18	1.21	1.81	0.27	0.12
16	1	16	31.0	30.0	0.299	0.61	4.84	0.73	0.18	1.21	1.81	0.27	0.12
17	2	1	15.0	14.0	0.202	0.18	24.45	0.70	0.17	1.16	1.74	0.42	0.12
18	2	2	14.0	13.0	0.203	0.18	24.64	0.72	0.18	1.20	1.80	0.43	0.12
19	2	3	13.0	12.0	0.203	0.18	24.57	0.73	0.18	1.21	1.82	0.43	0.12
20	2	4	12.0	11.0	0.204	0.18	24.44	0.73	0.18	1.21	1.82	0.43	0.12
21	2	5	11.0	10.0	0.205	0.18	24.29	0.73	0.18	1.22	1.82	0.43	0.12
22	3	1	2.0	1.0	0.141	0.15	25.89	0.71	0.18	1.18	1.77	0.44	0.12
23	3	2	1.0	-0.0	0.142	0.16	26.02	0.73	0.18	1.21	1.81	0.45	0.12
24	4	1	10.0	9.0	0.253	0.26	20.53	0.73	0.18	1.21	1.82	0.39	0.12
25	4	2	9.0	8.0	0.253	0.26	15.95	0.73	0.18	1.22	1.82	0.39	0.12
26	4	3	8.0	7.0	0.254	0.26	15.90	0.73	0.18	1.22	1.82	0.39	0.12
27	4	4	7.0	6.0	0.254	0.26	15.84	0.73	0.18	1.22	1.82	0.39	0.12
28	4	5	6.0	5.0	0.255	0.26	15.79	0.73	0.18	1.22	1.82	0.39	0.12
29	4	6	5.0	4.0	0.255	0.26	15.74	0.73	0.18	1.22	1.82	0.39	0.12
30	4	7	4.0	3.0	0.255	0.26	15.69	0.73	0.18	1.22	1.82	0.38	0.12
31	4	8	3.0	2.0	0.256	0.27	15.64	0.73	0.18	1.22	1.82	0.38	0.12
32	4	9	2.0	1.0	0.342	0.43	11.96	0.69	0.17	1.15	1.72	0.40	0.11
33	4	10	1.0	0.0	0.343	0.43	8.66	0.70	0.18	1.17	1.76	0.41	0.12
34	5	1	30.0	29.0	0.301	0.62	5.77	0.72	0.18	1.20	1.80	0.29	0.12
35	5	2	29.0	28.0	0.301	0.62	4.77	0.72	0.18	1.21	1.81	0.29	0.12
36	5	3	28.0	27.0	0.302	0.62	4.76	0.73	0.18	1.21	1.81	0.29	0.12
37	5	4	27.0	26.0	0.302	0.62	4.76	0.73	0.18	1.21	1.82	0.29	0.12
38	5	5	26.0	25.0	0.302	0.62	4.75	0.73	0.18	1.21	1.82	0.29	0.12
39	5	6	25.0	24.0	0.304	0.62	4.73	0.73	0.18	1.21	1.82	0.29	0.12
40	5	7	24.0	23.0	0.305	0.63	4.71	0.73	0.18	1.21	1.82	0.29	0.12
41	5	8	23.0	22.0	0.305	0.63	4.71	0.73	0.18	1.21	1.82	0.29	0.12
42	5	9	22.0	21.0	0.305	0.63	4.70	0.73	0.18	1.21	1.82	0.29	0.12
43	5	10	21.0	20.0	0.306	0.63	4.69	0.73	0.18	1.21	1.82	0.29	0.12
44	5	11	20.0	19.0	0.299	0.61	4.75	0.73	0.18	1.21	1.82	0.29	0.12
45	5	12	19.0	18.0	0.299	0.61	4.81	0.73	0.18	1.21	1.82	0.29	0.12

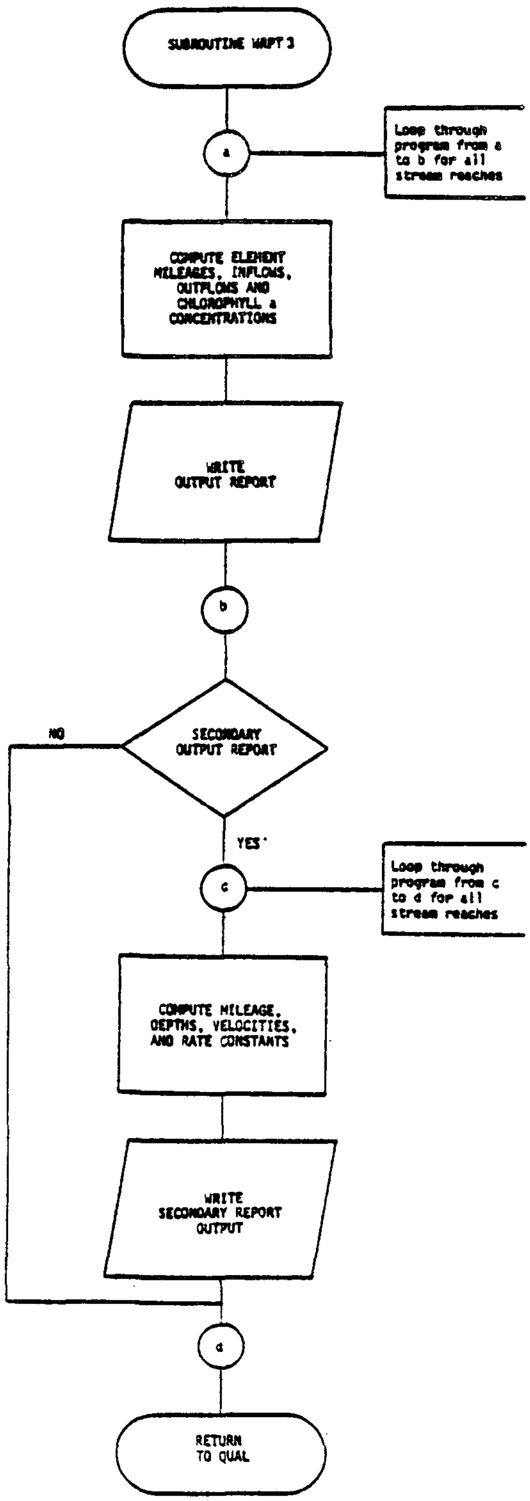

FIGURE VI-24. FLOW CHART FOR SUBROUTINE WRPT3

```
      SUBROUTINE WRPT3
C
C
C                            WRPT3 WRITES THE FINAL CONCENTRATION
C                            OF THE SELECTED QUALITY CONSTITUENTS.
C                            THESE CONSTITUENTS ARE WRITTEN BY REACH
C                            AND BY ELEMENT.
C
C
      COMMON TITLE(20,20),RCHID(75,5),RMTHOR(75),RMTEOR(75),NHWWAR(15),
     *       TARGDO(75),IAUGOR(75,6),NCELRH(75),IFLAG(75,20),
     *       ICLORD(75,20),COEFQV(75),EXPOQV(75),COEFQH(75),EXPOQH(75),
     *       CMANN(75),CK1(75),CK3(75),K2OPT(75),CK2(75),COEQK2(75),
     *       EXPQK2(75),TINIT(75),DOINIT(75),BOINIT(75),COINIT(75,3),
     *       QI(75),TI(75),DOI(75),BODI(75),CONSI(75,3),JUNCID(15,5),
     *       JUNC(15,3),HWTRID(15,5),HWFLOW(15),HWTEMP(15),HWDO(15),
     *       HWBOD(15),HWCONS(15,3),WASTID(90,5),TRFACT(90),WSFLOW(90),
     *       WSTEMP(90),WSDO(90),WSBOD(90),WSCONS(90,3),QATOT(15),
     *       A(500),B(500),C(500),D(15),S(500),Z(500),W(500),G(500),
     *       FLOW(500),DEPTH(500),VEL(500),DTOVCL(500),K2(500),K1(500),
     *       HSNET(500),DL(500),VHW(15),DEPHW(15),DLHW(15),T(500),
     *       DO(500),BOD(500),CONS(500,3),PTIME,TPRINT,DELX,
     *       NHWTRS,NREACH,NWASTE,NJUNC,DELT,D1LT,D2LT,DTODX2,DT2ODX,
     *       LAT,LSM,LLM,ELEV,DAT,AE,BE,DAYOFY,DRYBLB,WETBLB,DEWPT,
     *       ATMPR,WIND,CLOUD,SONET,NI,NJ,TRLCD,TOFDAY,NT,NC,TIME,NCS
C
      COMMON/MODIF/ CK4(75),CK5(75),CKNH3(75),CKNO2(75),CKNO3(75),
     *       CKN,CKP,CKL,ALPHAO(75),ALPHA1,ALPHA2,ALPHA3,ALPHA4,
     *       ALPHA5,ALPHA6,GROMAX,RESPHT,ALGSET(75),SPHOS(75),
     *       SNH3(75),KNH3(500),KNO2(500),RESPRR(500),COLI(500),
     *       ALGAE(500),PHOS(500),CNH3(500),CNO2(500),CNO3(500),
     *       COLIR(75),ALGI(75),PHOSI(75),CNH3I(75),CNO2I(75),
     *       CNO3I(75),COLIIT(75),ALGIT(75),PHOSIT(75),CNH3IT(75),
     *       CNO2IT(75),CNO3IT(75),WSCOLI(90),WSALG(90),WSPHOS(90),
     *       WSNH3(90),WSNO2(90),WSNO3(90),HWCOLI(15),HWALG(15),
     *       HWPHOS(15),HWNH3(15),HWNO2(15),HWNO3(15),GROWTH(500),
     *       MODOPT(10),IRCHNO(750),EXCOEF(75)
C
C
      COMMON/RADION/ CK6(75),RADNIT(75),RADNI(75),HWRADN(15),WSRADN(90),
     *               RADIO(500)
C
      COMMON/SSTATE/X(500),ISS
      COMMON/METER/METRIC,METOUT
      REAL   K1,K2,KNH3,KNO2
      DATA NPAGE/0/
C
      NHW = 0
      NWS = 0
      LP = 0
      DELM = DELX / 5280.0
      IF( METOUT .GT. 0 ) DELM = DELM * 1.609
      DO 300 I = 1, NREACH
      IF( METOUT .GT. 0 ) RMTHOR(I)=RMTHOR(I)*1.609
      NCELR = NCELRH(I)
      CNCELR = NCELR
      QINC = QI(I) / CNCELR
      IF( METOUT .GT. 0 ) QINC = QINC / 35.3133
      DO 300 J = 1, NCELR
      LP = LP + 1
      IF(MOD(LP,48).NE.1)GO TO 288
      NPAGE = NPAGE + 1
      WRITE(NJ,6005) NPAGE
      IF( ISS .EQ. 0 ) WRITE(NJ,6007) TIME
      IF( ISS .GT. 0 ) WRITE(NJ,6008)
      IF( METOUT .EQ. 0 ) WRITE(NJ,6010) TITLE(15,13),(TITLE(II,13),
     *II=3,5),TITLE(15,15),(TITLE(II,15),II=3,5)
      IF( METOUT .GT. 0 ) WRITE(NJ,6011) TITLE(15,13),(TITLE(II,13),
     *II=3,5),TITLE(15,15),(TITLE(II,15),II=3,5)
  288 IOR = ICLORD(I,J)
```

```
      QHWD = 0.0
      QWSI = 0.0
      IFL = IFLAG(I,J)
      GO TO (290,296,296,296,296,292,294), IFL
  290 NHW = NHW + 1
      QHWD = HWFLOW(NHW)
      GO TO 296
  292 NWS = NWS + 1
      QWSI = WSFLOW(NWS)
      GO TO 296
  294 NWS = NWS + 1
      QWSI = - WSFLOW(NWS)
  296 XMH = RMTHOR(I) - FLOAT( J - 1 ) * DELM
      CALGAE = ALGAE(IOR) * ALPHAD(I)
      XME = XMH - DELM
      QXXX = FLOW(IOR)
      TXXX = T(IOR)
      IF( METOUT .EQ. 0 ) GO TO 297
      QWSI = QWSI / 35.3133
      QXXX = QXXX / 35.3133
      TXXX = ( TXXX - 32.0 ) / 1.8
  297 CONTINUE
      WRITE(6,6015)LP,I,J,XMH,XME,QXXX,QWSI,QINC,TXXX,DO(IOR),
     1  BOD(IOR),CNH3(IOR),CNO3(IOR),PHOS(IOR),CALGAE,
     2  COLI(IOR),RADIO(IOR),CONS(IOR,1),CONS(IOR,2),CONS(IOR,3)
  300 CONTINUE
C-
C-..... OUTPUT SECONDARY INFORMATION.....
C-
      IF( ISS .EQ. 0 .AND. PTIME .LT. 0.0 ) RETURN
      LP = 0
      IJUNC = 0
      DO 400 I = 1, NREACH
      NCELR = NCELRH(I)
      DO 400 J = 1, NCELR
      LP = LP + 1
      IF(MOD(LP,48).NE.1)GO TO 350
      NPAGE = NPAGE + 1
      WRITE(NJ,6005) NPAGE
      IF( ISS .EQ. 0 ) WRITE(NJ,6007) TIME
      IF( ISS .NE. 0 ) WRITE(NJ,6008)
      IF( METOUT .EQ. 0 ) WRITE(NJ,6020)
      IF( METOUT .GT. 0 ) WRITE(NJ,6021)
  350 IOR = ICLORD(I,J)
      IFL = IFLAG(I,J)
      TC = 0.556*(T(IOR)-68.0)
      XK5 = CK5(I)*1.047**TC
      GO TO (352,354,354,356,354,354,354), IFL
  352 XK2 = K2(IOR)*1.0159**TC
      GO TO 370
  354 XK2 = ( 0.5*(K2(IOR-1)+K2(IOR)))*1.0159**TC
      GO TO 370
  356 IJUNC = IJUNC + 1
      NN = JUNC(IJUNC,1)
      XK2 = (0.25*(K2(IOR-1)+K2(NN)+2.0*K2(IOR)))*1.0159**TC
  370 XMH = RMTHOR(I) - FLOAT(J-1)*DELM
      XME = XMH - DELM
      VXXX = VEL(IOR)
      DXXX = DEPTH(IOR)
      IF( METOUT .EQ. 0 ) GO TO 375
      VXXX = VXXX / 3.2808
      DXXX = DXXX / 3.2808
  375 CONTINUE
      WRITE(NJ,6025) LP,I,J,XMH,XME,VXXX,DXXX ,XK2,K1(IOR),
     1  KNH3(IOR),KNO2(IOR),XK5,GROWTH(IOR),RESPRR(IOR)
  400 CONTINUE
      RETURN
 6005 FORMAT( 1H1 /
     * 10X, 25HSTREAM QUALITY SIMULATION, 35X, 19HOUTPUT PAGE NUMBER ,I5
     *   /  10X, 36HQUAL II STREAM QUALITY ROUTING MODEL, 24X,
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     * 18HWRE/SEMCOG VERSION )
6007 FORMAT( / 10X, 19HSYSTEM STATUS AFTER, F8.2, 27H HOURS OF DYNAMIC
    1OPERATION  )
6008 FORMAT( / 10X, 35H***** STEADY STATE SIMULATION *****  )
6010 FORMAT(//4X,    'RCH ELT   FROM      TO   FLOW   POINT  INCR   TEMP
    1     DO    BOD  NH3-N  NO3-N DIS-O-P CHL A  COLI',3X,A4,
    23(3X,A4),/
    3 4X,   'NUM NUM   MILE   MILE   (CFS) SOURCE  FLOW  DEG F (MG/L) (
    4MG/L) (MG/L) (MG/L) (MG/L) (UG/L) /100ML',' (',A4,')',
    53(' (',A4,')'))
6011 FORMAT(//4X,    'RCH ELT   FROM      TO    FLOW  POINT  INCR   TEMP
    1     DO    BOD  NH3-N  NO3-N DIS-O-P CHL A  COLI',3X,A4,
    23(3X,A4),/
    3 4X,   'NUM NUM   KILO   KILO   (CMS) SOURCE  FLOW  DEG C (MG/L) (
    4MG/L) (MG/L) (MG/L) (MG/L) (UG/L) /100ML',' (',A4,')',
    53(' (',A4,')'))
6015 FORMAT(I4,I3,I4,2F7.1,F8.2,F7.2,F6.2,7F7.2,F7.0,4F7.2)
6020 FORMAT(/27X, 62HSTREAM STREAM OXYGEN    BOD    NH3    NO2   COLI
    1ALGAE  ALGAE    /
    2  5X, 92HRCH ELT   FROM     TO    VEL  DEPTH  REAIR  DECAY  DECAY
    4 DECAY  DECAY GROWTH  RESPR CON-III   /
    5  5X, 91HORD NUM   MILE   MILE  (FPS)    (FT) (1/DY) (1/DY) (1/DY)
    6(1/DY) (1/DY) (1/DY) (1/DY) (MG/L)    )
6021 FORMAT(/27X, 62HSTREAM STREAM OXYGEN    BOD    NH3    NO2   COLI
    1ALGAE  ALGAE     /
    2  5X, 92HRCH ELT    FROM     TO    VEL  DEPTH  REAIR  DECAY  DECAY
    4 DECAY  DECAY GROWTH  RESPR            /
    5  5X, 91HORD NUM   KILO  KILO  (MPS)    (M) (1/DY) (1/DY) (1/DY)
    6(1/DY) (1/DY) (1/DY) (1/DY)           )
6025 FORMAT(3I4,2F7.1,F7.3,9F7.2)
      END
```

DEFINITION OF SYMBOLS

The following tabulation defines the symbols used in the right hand side of the equations shown in each subroutine description, except TRIMAT, which is self-explanatory.

SYMBOL	DEFINITION
a	Coefficient in convection-diffusion equation due to upstream stream segment
A	Algal biomass
α_1	Fraction of respired algal biomass resolubilized as ammonia nitrogen by bacterial action
α_2	Fraction of algal biomass that is phosphorus
α_3	Rate of oxygen production per unit of algae (photosynthesis)
α_4	Rate of oxygen uptake per unit of algae respired
α_5	Rate of oxygen uptake per unit of ammonia oxidation
α_6	Rate of oxygen uptake per unit of nitrite nitrogen oxidation
C	Concentration of a conservative material
C_s	Oxygen saturation concentration
D	Average stream depth
$\bar{D}$	Average stream depth
D_m	Molecular diffusion coefficient
ϕ	Concentration of oxygen
E	Concentration of coliform
F	Froude number
g	Acceleration of gravity

SYMBOL	DEFINITION
λ	Light extinction coefficient
h	Net heat flux
K_L	Empirical half-saturation constant, light
K_N	Empirical half-saturation constant, nitrogen
K_P	Empirical half-saturation constant, phosphorus
K_1	Rate of decay of carbonaceous BOD
K_2	Aeration rate in accordance with the Fickian diffusion analogy
K_3	Rate of loss of carbonaceous BOD due to settling
K_4	Constant benthic uptake of oxygen
K_5	Rate of coliform die-off
K_6	Rate of arbitrary nonconservative decay
K_7	Rate constant for the biological oxidation of ammonia nitrogen
K_8	Rate constant for the oxidation of nitrite nitrogen
L	Intensity of light (ALGAES)
L	Concentration of carbonaceous BOD (BODS)
μ	Algal specific growth rate
$\hat{\mu}$	Maximum specific algal growth rate
n	Manning's roughness coefficient
N_1	Concentration of ammonia nitrogen
N_2	Concentration of nitrite nitrogen
N_3	Concentration of nitrate nitrogen
P	Concentration of orthophosphate
ρ	Algal respiration rate
q	Stream flow
σ_1	Algal settling rate
σ_2	Benthos source rate for ammonia
σ_3	Benthos source rate for phosphorus
R	Concentration of arbitrary nonconservative

SYMBOL	DEFINITION
t	Time
T	Temperature
u	Velocity
u^*	Shear velocity
v	Volume
x	Length
ζ	Specific heat times density
h (subscript)	Headwater
i (subscript)	Element
o (subscript)	Taken out of system
w (subscript)	Waste load
* (superscript)	Previous time step value
' (superscript)	Upstream element

SECTION VII

QUAL-II

DESCRIPTION OF VARIABLES IN COMMON

Variable Name	Definition	English Units
A(IOR)	= Vector below diagonal in tridiagonal coefficient matrix for computational element IOR	---
AE	= Evaporation coefficient	ft/hour-in. Hg
ALGAE(IOR)	= Concentration of algae in computational element IOR	mg/l
ALGI(I)	= Incremental inflow concentration of chlorophyll a into reach J	µg/l
ALGIT(I)	= Initial concentration of chlorophyll a in reach I	µg/l
ALGSET(I)	= Local settling rate for algae in reach I	ft/day
ALPHAO(I)	= Ratio of chlorophyll a to algae biomass in reach I	$\frac{\mu g\ Chl\text{-}a}{mg\ A}$
ALPHA1	= Fraction of algae biomass which is N	$\frac{mg\ N}{mg\ A}$
ALPHA2	= Fraction of algae biomass which is P	$\frac{mg\ P}{mg\ A}$
ALPHA3	= O_2 production per unit of algae growth	$\frac{mg\ O}{mg\ A}$
ALPHA4	= O_2 uptake per unit of algae respired	$\frac{mg\ O}{mg\ A}$
ALPHA5	= O_2 uptake per unit of NH_3 oxidation	$\frac{mg\ O}{mg\ A}$
ALPHA6	= O_2 uptake per unit of NO_2 oxidation	$\frac{mg\ O}{mg\ A}$
ATMPR	= Local barometric pressure	in. Hg

Variable Name	Definition	English Units
B(IOR)	= Diagonal vector in tridiagonal coefficient matrix for computational element IOR	---
BE	= Evaporation coefficient	ft/hour-in. Hg-MPH
BOD(IOR)	= Ultimate BOD in computational element IOR	mg/l
BODI(I)	= Ultimate BOD of incremental inflow in reach I	mg/l
BOINIT(I)	= Initial ultimate BOD in reach I	mg/l
C(IOR)	= Vector above diagonal in tridiagonal coefficient matrix for computational element IOR	---
CK1(I)	= BOD decay rate coefficient (base e) for reach I	1/day
CK2(I)	= Reaeration coefficient (base e) for reach I	1/day
CK3(I)	= Rate of settling or scouring of BOD (base e) in reach I	1/day
CK4(I)	= Benthos source rate for BOD in reach I	$\frac{mg}{day\text{-}foot}$
CK5(I)	= Coliform die-off rate in reach I	1/day
CK6(I)	= Radionuclide decay rate in reach I	1/day
CKN	= Nitrogen half-saturation constant for algae growth	mg/l
CKNH3(I)	= Rate constant for biological oxidation of $NH_3 \rightarrow NO_2$ in reach I	1/day
CKNO2(I)	= Rate constant for biological oxidation of $NO_2 \rightarrow NO_3$ in reach I	1/day
CKL	= Light half-saturation constant for algae growth	Langleys/day

Variable Name	Definition	English Units
CKP	= Phosphorus half-saturation constant for algae growth	mg/l
CLDRCH(I)	= Average fraction of cloud cover in reach I (SS temp)	tenths
CLOUD	= Fraction of sky covered (cloudiness express as decimal)	---
CMANN(I)	= Manning's channel roughness coefficient for reach I	---
CNH3(IOR)	= Concentration of NH_3 in computational element IOR	mg/l
CNH3I(I)	= Incremental inflow concentration of NH_3 in reach I	mg/l
CNH3IT(I)	= Initial concentration of NH_3 in reach I	mg/l
CNO2(IOR)	= Concentration of NO_2 in computational element IOR	mg/l
CNO2I(I)	= Incremental inflow concentration of NO_2 in reach I	mg/l
CNO2IT(I)	= Initial concentration of NO_2 in reach I	mg/l
CNO3(IOR)	= Concentration of NO_3 in computational element IOR	mg/l
CNO3I(I)	= Incremental inflow concentration of NO_3 in reach I	mg/l
CNO3IT(I)	= Initial concentration of NO_3 in reach I	mg/l
COEFQH(I)	= Coefficient of flow for depth-discharge relationship in reach I	---
COEFQV(I)	= Coefficient of flow for velocity-discharge relationship in reach I	---

Variable Name	Definition	English Units
COEQK2(I)	= Coefficient of flow for reaeration-discharge relationship in reach I	---
COINIT(I,NC)	= Initial conservative mineral concentration in reach I	mg/l
COLI(IOR)	= Concentration of coliform in computational element IOR	$\frac{1000}{100 \text{ ml}}$
COLIR(I)	= Incremental inflow concentration of coliform in reach I	$\frac{1000}{100 \text{ ml}}$
COLIIT(I)	= Initial concentration of coliform in reach I	$\frac{1000}{100 \text{ ml}}$
CONS(IOR,NC)	= Concentration of conservative minerals in computational element IOR	mg/l
CONSI(I,NC)	= Concentration of conservative minerals in incremental inflow in reach I	mg/l
D(IJUNC)	= Vector of coefficients not in the tridiagonal portion of the coefficient matrix for junction IJUNC	---
DAT	= Dust attenuation coefficient	---
DAYOFY	= Day of the year on which temperature routing begins (from January 1)	days
DELT	= Time interval of integration (time step over which the solution to the routing equation is advanced)	seconds
DELX	= Space interval of integration (length of computational element)	miles
DEPHW(NHW)	= Depth of headwater source NHW	feet
DEPTH(IOR)	= Depth in computational element IOR	feet

Variable Name	Definition	English Units
DEWPT	= Dew point temperature	degrees Fahr.
DL(IOR)	= Dispersion coefficient in computational element IOR	ft^2/sec
DLHW(NHW)	= Dispersion coefficient at headwater source NHW	ft^2/sec
DO(IOR)	= Dissolved oxygen concentration in computational element IOR	mg/l
DOI(I)	= Dissolved oxygen concentration in incremental inflow in reach I	mg/l
DOINIT(I)	= Initial dissolved oxygen concentration in reach I	mg/l
DRYBLB	= Dry bulb temperature	degrees Fahr.
DTODX2	= $DELT/DELX^2$	sec/ft^2
DT2ODX	= (2.0 x DELT)/DELX	sec/ft
DTOVCL(IOR)	= DT2ODX/(FLOW(IOR)/VEL(IOR) + FLOW(IOR-1)/VEL(IOR-1))	sec/ft^3
D1LT	= Time interval of integration	days
D2LT	= Time interval of integration	hours
ELEV	= Mean elevation of river basin	ft
EXCOEF(I)	= Light extinction coefficient in reach I	1/ft
EXPOQH(I)	= Exponent of flow for depth-discharge relationship in reach I	---
EXPOQV(I)	= Exponent of flow for velocity-discharge relationship in reach I	---
EXPQK2(I)	= Exponent of flow for reaeration discharge relationship in reach I	---
FLOW(IOR)	= Discharge in computational element IOR	CFS

Variable Name	Definition	English Units
G(IOR)	= Array used in solution of tri-diagonal matrix	---
GROMAX	= Maximum specific growth rate of algae	1/day
GROWTH(IOR)	= Algae growth rate in computation element IOR	1/day
HSNET(IOR)	= Net heat exchanged through air-water interface in computational element IOR	BTU/ft^2
HWALG(NHW)	= Concentration of chlorophyll A in headwater source NHW	ug/l
HWBOD(NHW)	= Ultimate BOD of headwater source NHW	mg/l
HWCOLI(NHW)	= Concentration of coliform in headwater source NHW	$\frac{1000}{100\ ml}$
HWCONS(NHW,NC)	= Concentration of conservative minerals at headwater source NHW	mg/l
HWDO(NHW)	= Dissolved oxygen concentration at headwater source NHW	mg/l
HWFLOW(NHW)	= Discharge at headwater source NHW	CFS
HWNH3(NHW)	= Concentration of NH_3 in headwater source NHW	mg/l
HWNO2(NHW)	= Concentration of NO_2 in headwater source NHW	mg/l
HWNO3(NHW)	= Concentration of NO_3 in headwater source NHW	mg/l
HWPHOS(NHW)	= Concentration of PO_4 in headwater source NHW	mg/l
HWRADN(NHW)	= Concentration of radionuclide in headwater source NHW	---
HWTEMP(NHW)	= Temperature in headwater source NHW	degrees Fahr.

Variable Name	Definition	English Units
HWTRID(NHW,15)	= Alphanumeric name of headwater source NHW	---
IAUGOR(I,NHW)	= Order of headwater sources available for flow augmentation	---
ICLORD(I,J)	= Order of computation	---
IFLAG(I,J)	= Computational flag field	---
IRCHNO(250)	= Number of inserted reach	---
ISS	= Internal flag for dynamic or steady-state simulation	---
ITRAP	= Flag for trapezoidal channel cross-sections	---
JT(IOR)	= Temperature range number in computational element IOR (SS temp)	---
JUNC(IJUNC,3)	= Order of computational elements clockwise around junction IJUNC	---
JUNCID(IJUNC,15)	= Alphanumeric name of stream junction IJUNC	---
K1(IOR)	= BOD decay rate (base e) coefficient in computational element IOR	1/day
K2(IOR)	= Reaeration coefficient (base e) in computational element IOR	1/day
K2OPT(I)	= Option for determining reaeration coefficient in reach I	---
KNH3(IOR)	= Internal variable, temperature corrected $CKNH_3$ in computational element IOR	---
KNO2(IOR)	= Internal variable, temperature corrected $CKNO_2$ in computational element IOR	---

Variable Name	Definition	English Units
LAT	= Mean latitude of river basin	degrees
LLM	= Local meridian of river basin	degrees
LSM	= Standard meridian of time zone in which river basin is located	degrees
METOUT	= Flag for metric units output	---
METRIC	= Flag for metric units input	---
MODOPT(10)	= Model option, program internal variable	---
NC	= Counter for the conservative mineral being routed	---
NCELRH(I)	= Number of computational elements in reach I (maximum = 20)	---
NCS	= Number of conservative minerals being routed (maximum = 3)	---
NHWTRS	= Number of headwaters in stream system (maximum = 15)	---
NHWWAR(I)	= Number of headwater sources available for flow augmentation	---
NI	= Input tape	---
NJ	= Output tape	---
NJUNC	= Number of stream junctions in system (maximum = 15)	---
NREACH	= Number of reaches in system (maximum = 75)	---
NT	= Counter for printing titles	---
NWASTE	= Number of waste discharges or withdrawals (maximum = 90)	---
PATRCH(I)	= Average barometric pressure for reach I (SS temp)	in. Hg

Variable Name	Definition	English Units
PHOS(IOR)	= Concentration of PO_4 in computational element IOR	mg/l
PHOSI(I)	= Incremental inflow concentration of PO_4 in reach I	mg/l
PHOSIT(I)	= Initial concentration of PO_4 in reach I	mg/l
PTIME	= Time interval for writing intermediate summary	hours
QATOT(NHW)	= Total flow augmentation from each headwater source used	CFS
QI(I)	= Incremental inflow in reach I	CFS
RADIO(IOR)	= Concentration of arbitrary nonconservative in computational element IOR	mg/l
RADNI(I)	= Incremental inflow concentration of radionuclides in reach I	---
RADNIT(I)	= Initial concentration of radionuclides in reach I	---
RCHID(I,15)	= Alphanumeric name of reach I	---
RESPRR(IOR)	= Algae respiration rate in computation element IOR	1/day
RESPRT	= Algae respiration rate	1/day
RMTEOR(I)	= River mile at end of reach I	miles
RMTHOR(I)	= River mile at head of reach I	miles
S(IOR)	= Vector of the known heat or material balance obtained in computational element IOR	degrees Fahr. or mg/l
SLOPE(I)	= Longitudinal slope of trapezoidal channel of reach I	ft/ft
SNH3(I)	= Benthos source rate for NH_3 in reach I	$\frac{mg\ N}{day\text{-}foot}$

Variable Name	Definition	English Units
SOLRCH(I)	= Average light intensity for reach I (SS temp)	Langleys/day
SS1(I)	= Side slope 1 (run/rise) of trapezoidal channel of reach I	---
SS2(I)	= Side slope 2 (run/rise) of trapezoidal channel of reach I	---
T(IOR)	= Temperature in computational element IOR	degrees Fahr.
TARGDO(I)	= Minimum allowable target level for dissolved oxygen concentration in reach I	mg/l
TDBRCH(I)	= Average dry bulb temperature in reach I (SS temp)	degrees Fahr.
TI(I)	= Temperature of incremental inflow in reach I	degrees Fahr.
TIME	= Length of time over which a quality constituent has been routed	hours
TINIT(I)	= Temperature of incremental inflow in reach I	degrees Fahr.
TITLE(I,J)	= Alphanumeric program titles	---
TOFDAY	= Hour of day	hours
TPRINT	= Time counter to determine when to write intermediate summary	hours
TRFACT(NWS)	= Treatment plant efficiency (decimal fraction) for waste discharge NWS	---
TRLCD	= Time counter to determine when to reach Local Climatological Data	hours
TWBRCH(I)	= Average wet bulb temperature in reach I (SS temp)	degrees Fahr.

Variable Name	Definition	English Units
VEL(IOR)	= Velocity in computational element IOR	FPS
VHW(NHW)	= Velocity at headwater source NHW	FPS
W(IOR)	= Array used in solution of tri-diagonal matrix	---
WASTID(NWS,90)	= Alphanumeric name of treatment plant, withdrawal, or point source NWS	---
WETBLB	= Wet bulb temperature	degrees Fahr.
WIDTH(I)	= Bottom width of trapezoidal channel of reach I	feet
WIND	= Wind velocity	KNOTS
WINRCH(I)	= Average wind speed for reach I (SS temp)	ft/sec
WSALG(NWS)	= Input concentration of chlorophyll a for waste load or point source NWS	µg/l
WSBOD(NWS)	= Ultimate BOD of waste loading or point source NWS	mg/l
WSCOLI(NWS)	= Input concentration of fecal coliform for waste load or point source NWS	1000
WSCONS(NWS,NC)	= Concentration of conservative mineral in waste load or point source NWS	mg/l
WSDO(NWS)	= Concentration of dissolved oxygen in waste load or point source NWD	mg/l
WSFLOW(NWS)	= Discharge of waste load, withdrawal or point source NWS	CFS
WSNH3(NWS)	= Input concentration of NH_3 for waste load or point source NWS	mg/l

Variable Name	Definition	English Units
WSNO2(NWS)	= Input concentration of NO2 for waste load or point source NWS	mg/l
WSNO3(NWS)	= Input concentration of NO3 for waste load or point source NWS	mg/l
WSPHOS(NWS)	= Input concentration of PO4 for waste load or point source NWS	mg/l
WSRADN(NWS)	= Input concentration of radionuclide for waste load or point source NWS	---
WSTEMP(NWS)	= Temperature of waste load or point source NWS	degrees Fahr.
X(IOR)	= Program internal variable for computational element IOR	---
Z(IOR)	= Temporary storage vector for computational element IOR	---

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