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Waterways Experiment Station

Environmental and Water Quality Operational Studies

CE-QUAL-R1: A Numerical One-Dimensional Model of Reservoir Water Quality; User's Manual

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PREFACE

This manual was sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), as a part of the Environmental and Water Quality Operational Studies (EWQOS), Work Unit IC (CWIS Work Unit 31595), entitled "Improve and Verify Existing One-Dimensional Reservoir Water Quality and Ecological Predictive Techniques." The HQUSACE Technical Monitors were Mr. Earl Eiker, Dr. John Bushman, and Mr. James L. Gottesman.

Some of the foundation work for this manual was performed as part of the Corps of Engineers' Environmental Impact Research Program. Work for this version of the User's Manual was conducted during the period September 1982-February 1986 by the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS., under the general supervision of Dr. John W. Keeley, Director, EL, and Mr. Donald L. Robey, Chief, Environmental Processes and Effects Division, and under the direct supervision of Dr. Mark S. Dortch, Chief, Water Quality and Contaminant Modeling Branch.

Development and evaluation of CE-QUAL-RI since the previous revision of the User's Manual were accomplished by Drs. Joseph H. Wlosinski, Carol D. Collins, Allan S. Lessem; Ms. Linda S. Johnson; Ms. Sandra L. Bird; and Messrs. Jack B. Waide and Mark S. Dortch. Various changes to this version of the User's Manual were written by Drs. Wlosinski, Collins, Lessem, Dortch, and Mr. Mike Schneider. Ms. Sandra E. Berry was responsible for the development and description of the preprocessors. Mr. Rick Plummer developed the windows and plotting package for the PC version. Ms. Dorothy E. Hamlin was responsible for translation of the models from the WQMG VAX computer to the Cybernet CDC computer. Sections of the draft User's Manual were reviewed by Drs. James L. Martin, Stephen P. Schreiner, Marc J. Zimmerman; Messrs. Dortch, Ross W. Hall, Isaac Jefferson, and Craig Oldham; Ms. Bird; Ms. Berry; Ms. Hamlin; and Ms. Judy L. Fairchilds. Previous contributions by Drs. Dennis E. Ford, Kent W. Thornton, Marc J. Zimmerman; Mr. Joseph L. Norton; and Ms. Connie A. Stirgus are gratefully acknowledged.

During publication of the revision of this manual, Dr. Robert W. Whalin was Director of WES. COL Bruce K. Howard, EN, was Commander.

The manual is published in loose-leaf format and is structured for ease of periodic update. Revisions will be distributed automatically to all holders of record. It is the responsibility of each user to advise WES of address changes.

This report should be cited as follows:

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CE-QUAL-R1: A NUMERICAL ONE-DIMENSIONAL MODEL OF RESERVOIR WATER QUALITY

USER'S MANUAL

PART I: INTRODUCTION

An Overview of CE-QUAL-R1

CE-QUAL-R1 is a mathematical model of water quality that describes the vertical distribution of thermal energy and biological and chemical materials in a reservoir through time. It is used to study preimpoundment and postimpoundment water quality problems and the effects of reservoir management operations on water quality. The model also addresses problems of water quality associated with reservoir eutrophication with possible anaerobic conditions. CE-QUAL-R1 simulates the dynamics of 27 water quality variables, calculating both vertical in-pool and downstream release magnitudes. In addition, 11 other variables, which represent materials in the sediments, are modeled.

The model requires an extensive data base including initial conditions, geometric and physical coefficients, biological and chemical reaction rates, and time sequences of hydrometeorological and inflowing water quality concentrations. A substantial effort by a multidisciplinary staff is necessary to acquire data; create and debug the data base; add site-specific factors to the computer code as necessary; and compute, plot, and analyze results. Experience suggests that staff personnel need several months to accomplish these tasks. Typically, 40 percent of the time will be spent on data preparation, 10 percent on computation, and 50 percent on analysis of output.

Besides CE-QUAL-R1, the User's Manual also describes CE-THERM-R1, a stand-alone model describing profiles for temperature, total dissolved solids, and suspended solids. Unless otherwise stated, most of this User's Manual is applicable to both CE-QUAL-R1 and CE-THERM-R1, although only CE-QUAL-R1 may be explicitly mentioned.

Summary of Attributes

CE-QUAL-R1 is spatially one dimensional and horizontally averaged; temperature and concentration gradients are computed only in the vertical direction. The reservoir is conceptualized as a vertical sequence of horizontal layers where thermal energy and materials are uniformly distributed in each layer (Figure 1). The mathematical structure of the model is based on horizontal layers whose thicknesses depend on the balance of inflowing and outflowing waters. Variable layer thicknesses permit accurate mass balancing during periods of large inflow and outflow.

The distribution of inflowing waters among the horizontal layers is based on density differences. Simulations of surface flows, interflows, and underflows are possible. Similarly, outflowing waters are withdrawn from layers after considering layer densities, discharge rates, and outlet configuration.

Reservoir outflows may take place according to a specified schedule of port releases. Alternately, specification of total release and desired release temperatures can be made. In this case, the model will select port flows. In addition, both continuous (normal) and scheduled operations can be simulated. Continuous operation refers to normally uninterrupted port or weir outflows. Scheduled operation refers to fluctuating generation outflows or pumpback inflows.

Vertical transport of thermal energy and materials occurs through entrainment and turbulent diffusion. Entrainment is a transport process that sharpens gradients and determines the depth of the upper mixed region and the onset of stratification. It is calculated from the turbulent kinetic energy influx generated by wind shear and convective mixing. Turbulent diffusion is a transport process that reduces gradients and is calculated using a turbulent diffusion coefficient that is dependent on wind speed, inflow and outflow magnitudes, and density stratification.

The interaction of numerous biological and chemical factors is a major attribute of CE-QUAL-R1. Most of the constituents and processes

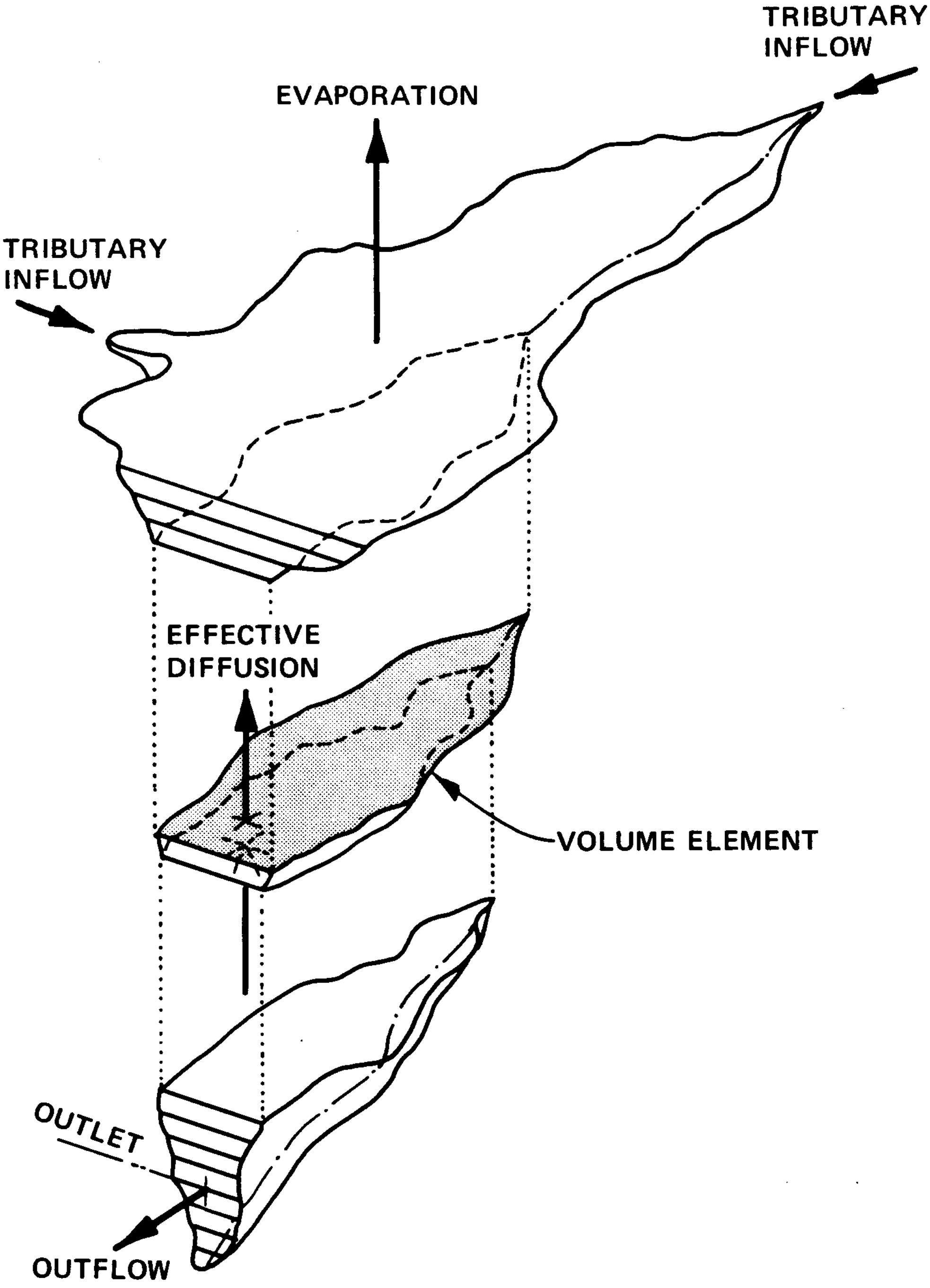


Figure 1. Geometric representation of a stratified reservoir and mass transport mechanisms

included in CE-QUAL-R1 are outlined in Figure 2. The model simulates interactions of physical factors (such as flow and temperature), chemical factors (such as nutrients), and biological assemblages in both aerobic and anaerobic environments.

The model can perform stochastic simulations using Monte Carlo methods. Statistical data describing biological and chemical coefficients are used to provide probabilistic estimates of key output variables.

The thermal analysis portion of CE-QUAL-R1 is provided as an independent model (CE-THERM-R1) to simplify simulation of water budgets and temperature profiles. CE-THERM-R1 includes the variables of temperature, suspended solids, and total dissolved solids. Algorithms representing physical processes are the same as in CE-QUAL-R1.

A number of utilities are also provided with CE-QUAL-R1. These include preprocessors, which are aids in assembling a usable data set, two graphic utilities, statistics for comparing measured and predicted data, and a flux model. The flux model calculates and lists the rates of change for all biological processes, which should aid the users of CE-QUAL-R1 to correctly predict variable concentrations.

Background

This manual is a product of a program of evaluation and refinement of mathematical ecosystem models conducted at the Waterways Experiment Station (WES). It describes the reservoir model CE-QUAL-R1, which is a direct descendant of the reservoir portion of a model called "Water Quality for River-Reservoir Systems" (WQRRS). WQRRS was assembled for the Hydrologic Engineering Center of the Corps of Engineers by Resource Management Associates, Inc. (1978). The definitive origin of WQRRS was the work of Chen and Orlob (1972).

Readers familiar with WQRRS will discover that CE-QUAL-R1 preserves much of its basic structure, organization, and naming conventions. The input data set for CE-QUAL-R1, for example, is an outgrowth of that for the editor preprocessor of WQRRS. However, so many refinements and

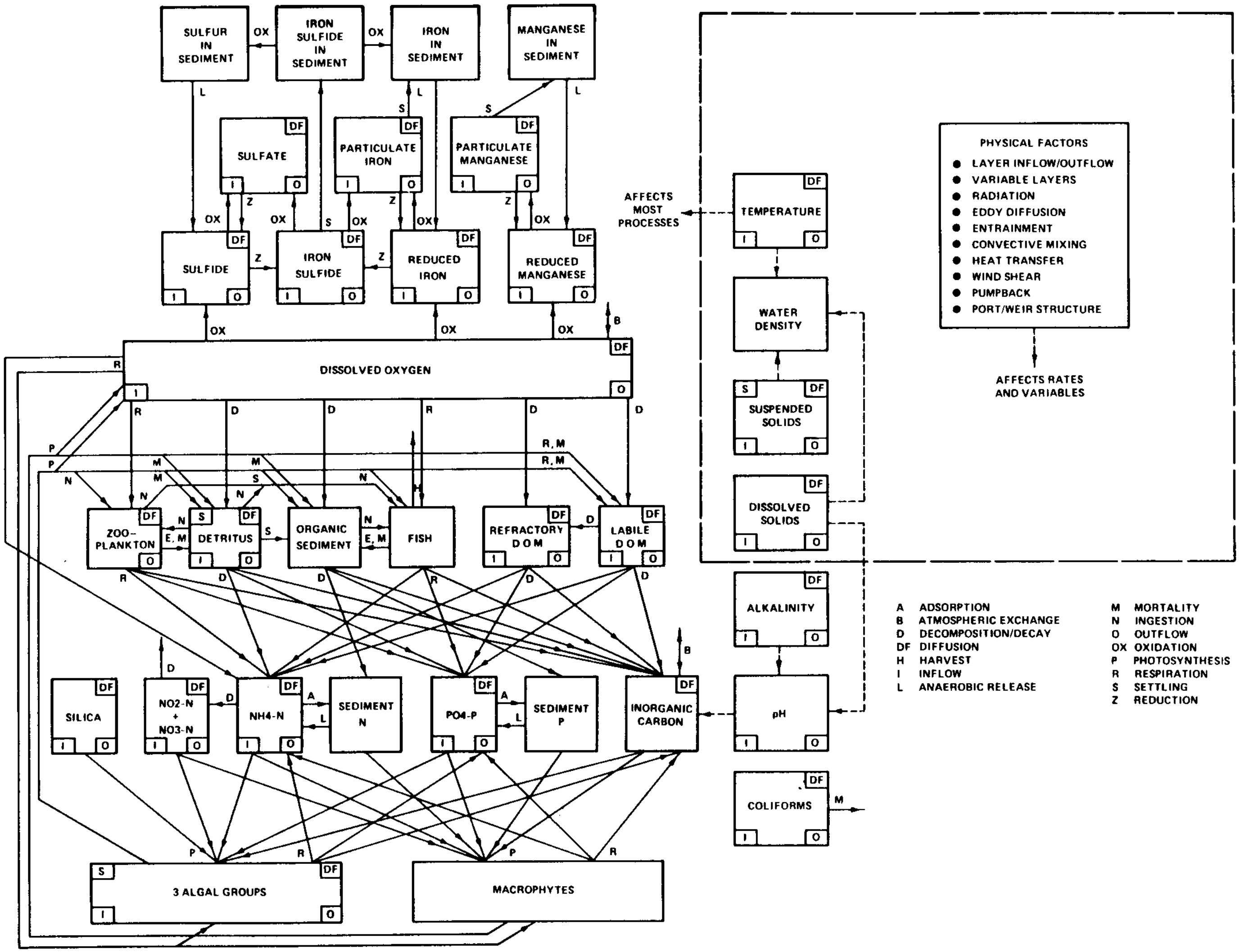


Figure 2. Overall organization of CE-QUAL-R1. CE-THERM-R1 is represented in the large dashed box. Solid lines represent processes and the transfer of mass. Short dashed lines represent information transfer

improvements describing reservoir processes have been incorporated that it is meaningful to document CE-QUAL-R1 in detail and to provide guidance on its use.

1986 Version

Numerous changes to the model have been made since the previous User's Guide (Environmental Laboratory 1982) was issued. Many of the changes are results of developmental work and evaluation using data collected at DeGray Lake (Wlosinski and Collins 1985a) and the Eau Galle Reservoir (Wlosinski and Collins 1985b). Other changes and additions have been made to make the model easier to use, to represent conditions not modeled in previous versions, or to better simulate measured conditions.

Although most of the algorithms, coefficients, and variables have not been changed, some changes to the data set structure were needed. Therefore, data sets compiled for previous versions of CE-QUAL-R1 will have to be revised before use with the present version of the model.

Major additions to the model included algorithms describing scheduled operations, including interrupted outflow and pumpback from an afterbay, macrophytes, and a third algal compartment. Major changes included uniting three fish compartments into one, uniting benthos and sediment, uniting nitrite and nitrate, and splitting dissolved organic matter into labile and refractory components. New utilities have also been added to the model.

Organization of the Manual

The manual is organized into five major parts with several appendixes. In Part I, CE-QUAL-R1 is introduced to the reader by summarizing its major usages, attributes, and historical development.

Part II addresses model capabilities, assumptions and limitations, and basic equations. It supplies the necessary information to understand the model without getting into specific details.

Part III is concerned with specific constructs of CE-QUAL-R1. It describes each subroutine in detail. Part III can be skipped initially if the user is not interested in specific details and will not be modifying the program.

Part IV describes how to determine the various coefficients, constants, and updates required by CE-QUAL-R1. It also describes how to calibrate the model and interpret output.

Part V describes a number of utilities associated with CE-QUAL-R1. These include preprocessors to aid users in preparing data sets, two graphic routines, statistical analysis, and a flux program.

The appendixes include: A, a glossary of computer variables used in Part III; B, examples of output; C, a diagram describing the data records needed for various simulation options; D, a diagram describing the structure of data sets; E, examples of data sets; and F, information concerning CE-THERM-R1, the thermal portion of CE-QUAL-R1.

PART II: BASIC STRUCTURE

General Comments

CE-QUAL-R1 is a comprehensive reservoir water quality model. It deals with the major physical, chemical, and biological processes that occur within an impounded body of water. Because of the complexity of the system being simulated, simplification of processes is a necessity. Although the model reflects a simplification of natural interactions, the computer implementation is still complex. It has been a goal of the developers of CE-QUAL-R1 to organize and document the computer code to enhance conceptual clarity rather than computational efficiency.

Before initiating a modeling study, it is recommended that the user review this part and Part IV to determine the type and amount of information required to simulate reservoir water quality. It is only after the user has reviewed the data requirements and available data that an intelligent decision can be made on whether simulation is the appropriate tool to address specific reservoir water quality problems. This decision should be made *before* initiating the modeling study. Although it is impossible to specify a list of absolute minimum data requirements, certain items are essential. These include reservoir morphometry, inflows, outflows, meteorological data, and an estimation of inflowing concentrations. Ultimately, the objectives of the study determine the minimum data requirements and appropriate study approach.

The purpose of this section is to describe the basic structure of CE-QUAL-R1, its capabilities, and its limitations. It is essential that the potential users of CE-QUAL-R1 understand this section completely before attempting to apply the model.

Model Capabilities

Factors considered

Factors considered by CE-QUAL-R1 include the following:

a. Physical factors.

    - (1) Shortwave and longwave solar radiation at the water surface.
    - (2) Net heat transfer across the air-water interface.
    - (3) Convective and radiative heat transfer within the water body.
    - (4) Convective mixing due to density instabilities.
    - (5) Placement of inflowing waters at depths with comparable density.
    - (6) Withdrawal of outflowing waters from depths influenced by the outlet structure, discharge rate, and density stratification.
    - (7) Conservative substance routing.
    - (8) Suspended solids routing and settling.
- b. Chemical and biological factors.
    - (1) Accumulation, dispersion, and depletion of dissolved oxygen through aeration, photosynthesis, respiration, and organic decomposition.
    - (2) Uptake-excretion kinetics and regeneration of nitrogen and phosphorus and nitrification-denitrification processes under aerobic and anaerobic conditions.
    - (3) Carbon cycling and dynamics and alkalinity-pH-CO_2 interactions.
    - (4) Dynamics and trophic relationships of phytoplankton and macrophytes.
    - (5) Transfers through higher trophic levels of the food chain.
    - (6) Accumulation, dispersion, and decomposition of detritus and sediment.
    - (7) Coliform bacteria mortality.
    - (8) Accumulation, dispersion, and reoxidation of manganese, iron, and sulfide when anaerobic conditions prevail.

Problems addressed

Water quality problems that can be addressed by CE-QUAL-R1 include:

- a. Onset, extent, and duration of thermal stratification.
- b. Location of selective withdrawal ports required to meet a downstream temperature objective.
- c. Effect of structural modifications on water quality.
- d. The development of anoxic conditions.

e. Magnitude, composition, and timing of algal blooms.

f. Factors affecting the growth of algae and macrophytes.

g. Effects of storm events on in-pool and release water quality.

h. Effects of upstream land use on in-pool and release water quality.

i. Effects of project operation changes such as:

  (1) Altered release level.

  (2) Change in minimum or maximum release rates.

  (3) Pool elevation changes.

  (4) Destratification.

  (5) Changes in scheduled operations.

Model Assumptions and Limitations

All models are, by definition, simplified representations of the actual prototype. One of the benefits of this simplified representation is that the model can be manipulated for less cost and in a shorter time than experimentation on the prototype. One of the costs associated with this benefit is that a number of assumptions are used to simplify the real system, and these assumptions impose limitations on the use and interpretation of model results. The major assumptions and limitations of this version of CE-QUAL-R1 are discussed in the following paragraphs.

One-dimensional assumption

The model assumes a reservoir can be represented by a vertical series of well-mixed horizontal layers (Figure 1). The model limitations associated with this assumption are:

a. Longitudinal and lateral variations in water quality constituents cannot be predicted.

b. All inflow quantities and constituents are instantaneously dispersed throughout the horizontal layers.

c. Model predictions are probably most representative of water quality conditions near the dam or in the deepest part of the reservoir.

Conservation of mass assumption

The model assumes that the dynamics of each physical, chemical, and biological component can be described by the principle of conservation of mass. The model considers:

- a. Mass added by inflows.
- b. Mass removed by outflows.
- c. Diffusion of mass.
- d. Internal changes due to ecological processes.

Because equations are not solved in closed form, minor errors concerning the conservation of mass may occur.

Simplified ecological representations

Ecological relationships and interactions, by necessity, must be simplified. Several hundred or more biological species exist in nearly all ecosystems, and it is virtually impossible to obtain information on all of them. These species, then, must be aggregated into functional groupings for representation in the model. In all cases, this aggregation is severe--one compartment each for all zooplankton and fish species, three compartments for all algal species, and one compartment representing all organic matter in sediments. It is assumed, however, that the major pathways and interactions for material flow in the pelagic area of a reservoir are represented.

The model therefore does not:

- a. Consider competition between individual species.
- b. Predict precise numbers of any species.
- c. Consider all ecological processes occurring in a reservoir.

Anaerobic environment

CE-QUAL-R1 depicts materials and processes that assume importance in anaerobic circumstances. The natural complexity of chemical and biological interactions under such conditions cannot be simulated in great detail. The model focuses broadly on those reduced chemical species that have historically proved troublesome in reservoir management. They are manganese, iron, and sulfide. Several other materials necessary for basic consistency are simulated. The simulation of the dynamics of anaerobic materials results in improved accuracy in computing oxygen deficits and the return of the system to aerobic conditions.

Ice and snow cover

The model presently does not contain an ice cover algorithm. Model predictions are therefore limited to periods from the breakup of ice to the onset of ice formation. However, the process descriptions for simulating ice cover have been developed and can be incorporated into the model if the need arises.

Density function

The density of water is assumed to be a function of temperature and suspended and dissolved solids. It is important to relate the influence of all three factors on water density since density effects in the model determine:

- a. Vertical placement of an inflow.
- b. Thickness of an inflow zone.
- c. Thickness of an outflow zone.
- d. Mixing coefficients.

Model Operations

Basic model operations include data assembly, model simulation, and presentation of results. CE-QUAL-R1 was designed for user convenience in each of these operations.

Data assembly

Processing. Before any computations can be made, data must be read into the computer. Data include reservoir characteristics, initial conditions, coefficients, and driving variables (boundary conditions or updates). The specifics of data input are discussed in Part IV. Data are grouped by type to simplify this task.

Data set preprocessors have been developed for both CE-THERM-R1 and CE-QUAL-R1. The preprocessors are designed to check the type and sequence of the variables against model expectations. The magnitude of selected variables is examined in a second part of the preprocessors. Use of the preprocessors can be a valuable time-saving tool, especially for first-time users of the model.

One unique aspect of CE-QUAL-R1 is the processing of updates. Updates are time-varying model inputs that include meteorological data, flow data, and inflowing constituent concentrations. In many instances, these are not all available at the same time intervals. Meteorological data, for example, are generally available on a 3-hr basis, while flow data may be available from a stream gage on a continuous basis. The biological and chemical data, however, are generally a function of the sampling interval in a monitoring program. Many monitoring programs collect data on a monthly basis. Update variable data, then, may range from continuous to one value per month. CE-QUAL-R1, however, requires an update value for each variable during every computational interval. To assemble these data and make the necessary conversions from the collection time interval to the computational interval, the update values for each variable are written to separate scratch files, i.e., one scratch file per update variable. If the computational interval is longer than the collection interval, average values for the computational interval should be read into the scratch file. A daily computational interval, for example, would use daily average meteorological and flow data since values for these variables are available at a shorter time interval than one day. To obtain update values for computational intervals that are shorter than the collection interval, CE-QUAL-R1 linearly interpolates between data points. Individual scratch files permit the use of update data collected at differing intervals and provide values at fixed (user-specified) intervals.

Reservoir options. A number of options are available to the user to represent different reservoirs. These options, along with constraints, are illustrated in Figure 3. Normal mode represents continuous outflow operations. Scheduled mode represents reservoirs where releases are scheduled to meet peak electrical demands. Some of these reservoirs are fitted for pumpback operation from an afterbay during periods of low electrical demand.

Specified is an option used where outflow through specified ports and/or weirs is known. Alternately, if the user wishes to meet a downstream temperature objective, regulation can be chosen.

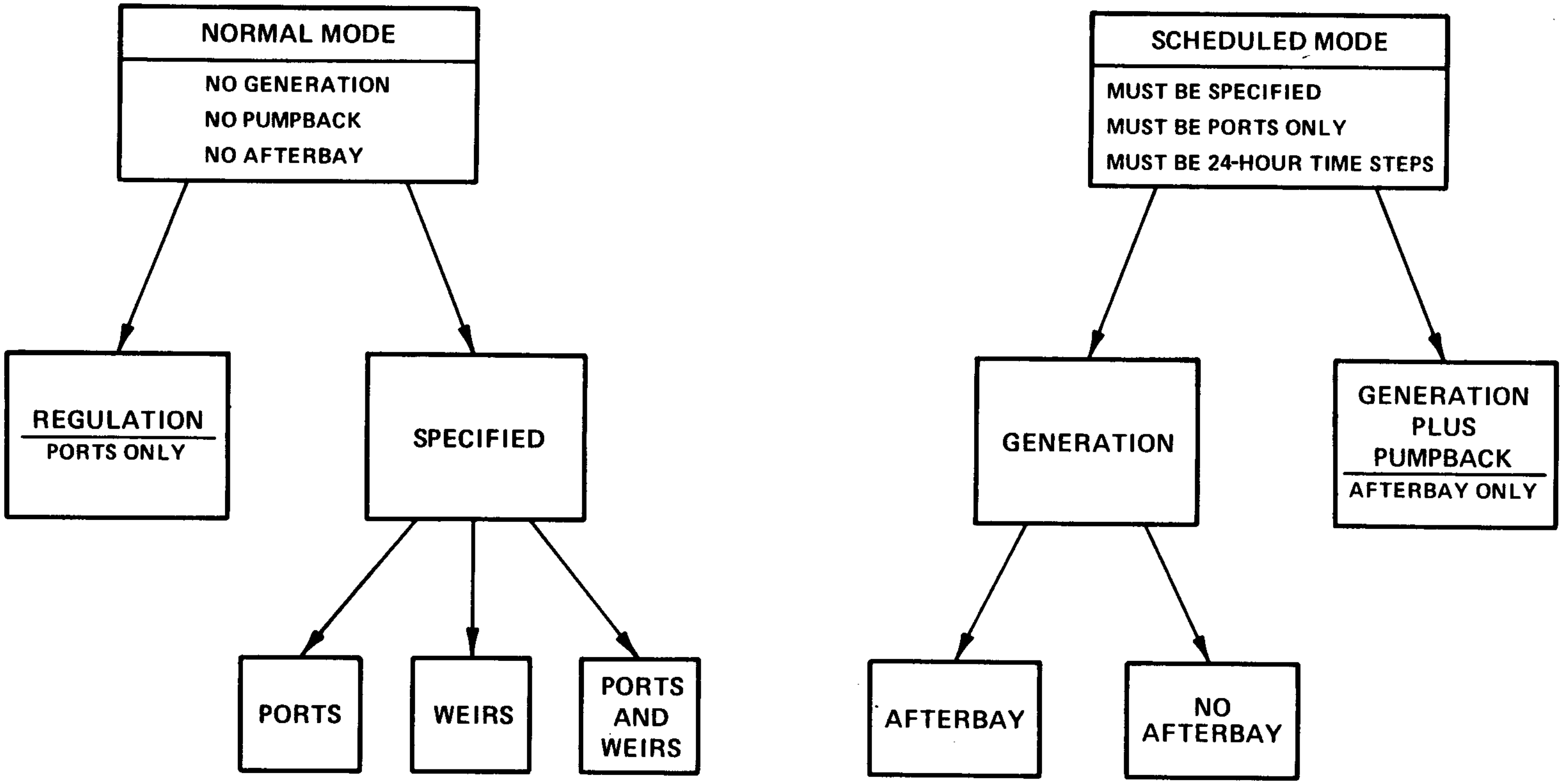


Figure 3. Options available in CE-QUAL-R1 to represent different reservoirs

Model simulation

Sequence and timing of computations. The computational sequence is illustrated in Figure 4. Activity blocks with dotted outlines are user options. For the case where all indicated activities are functioning, an estimate is given for the percentage of simulation time spent in each.

The main loop indicated in Figure 4 covers a time period called the computation interval. In CE-QUAL-R1, this interval may be 1, 2, 3, 4, 6, 8, 12, or 24 hr. Once the computation interval is selected, all the other time factors are expressed as an integral multiple of it. This procedure simplifies model timing yet allows different intervals to be assigned to the numerous updated variables as needed.

Relationships corresponding to the model's two major structural modes, continuous (normal) outlet operations and scheduled generation or pumpback operations, are depicted in Figures 5 and 6, respectively. The numerous water quality components common to both modes are shown in Figure 7.

The computational sequence indicated in Figures 5-7 must be maintained in this exact order. The physical processes are simulated first because they compute variables required for the chemical and biological computations. The sequence of biological and chemical computations generally flows from components with relatively slow dynamics or turnover times to components with relatively rapid dynamics or faster turnover times.

Because it is possible to predict zero values for biological compartments, a very small positive value is added if the concentration goes to zero. This is done because the concentration of a compartment is multiplied by the rate terms to estimate the rate of change for each compartment. Some biological compartments, such as macrophytes, have no transport terms to increase their concentrations and would remain at zero even though conditions warranted net growth. This small positive value permits a number of variables to recover if environmental conditions again become conducive for net growth, and corrects the computational problem of division by zero.

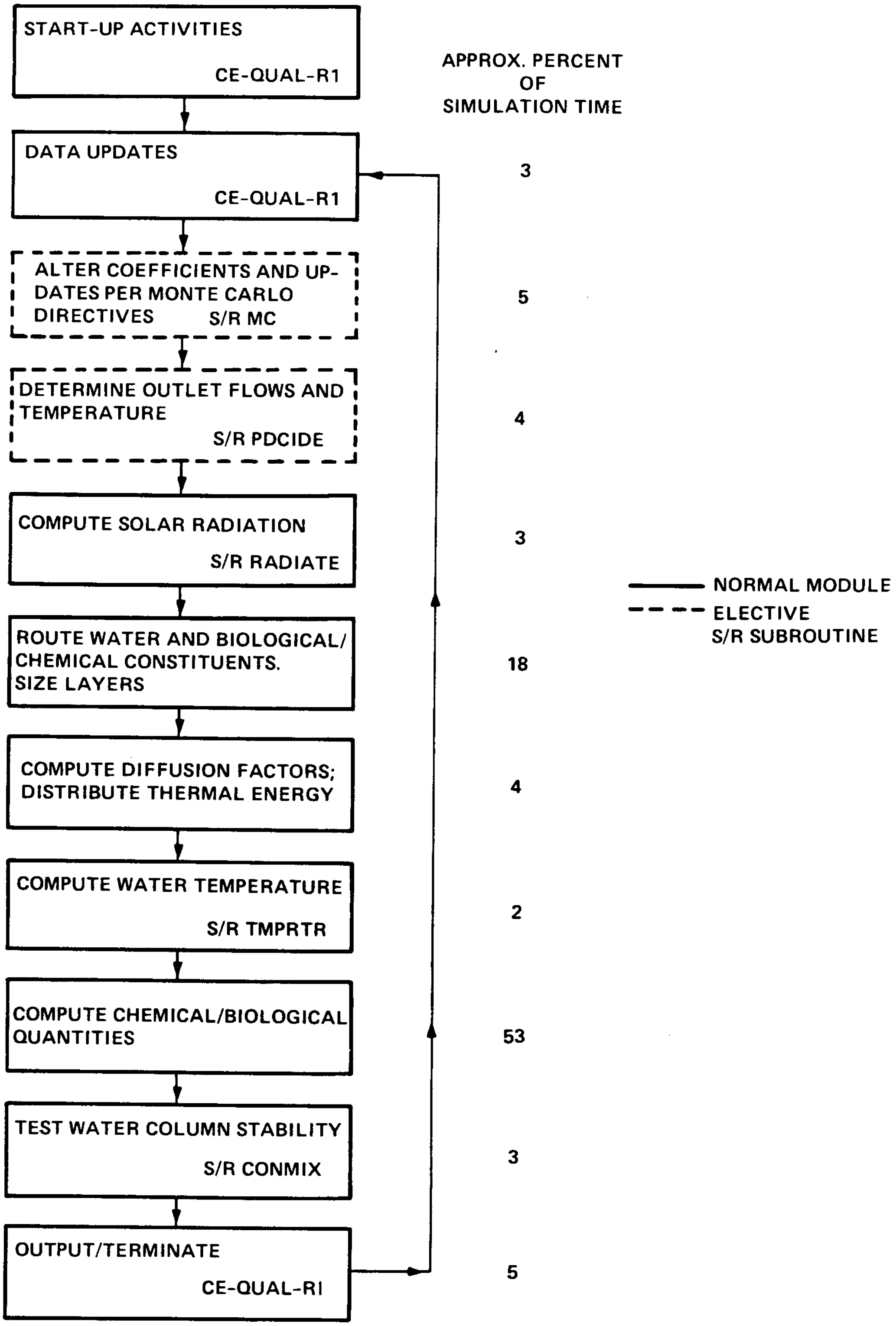


Figure 4. Sequence and timing of CE-QUAL-R1 elements

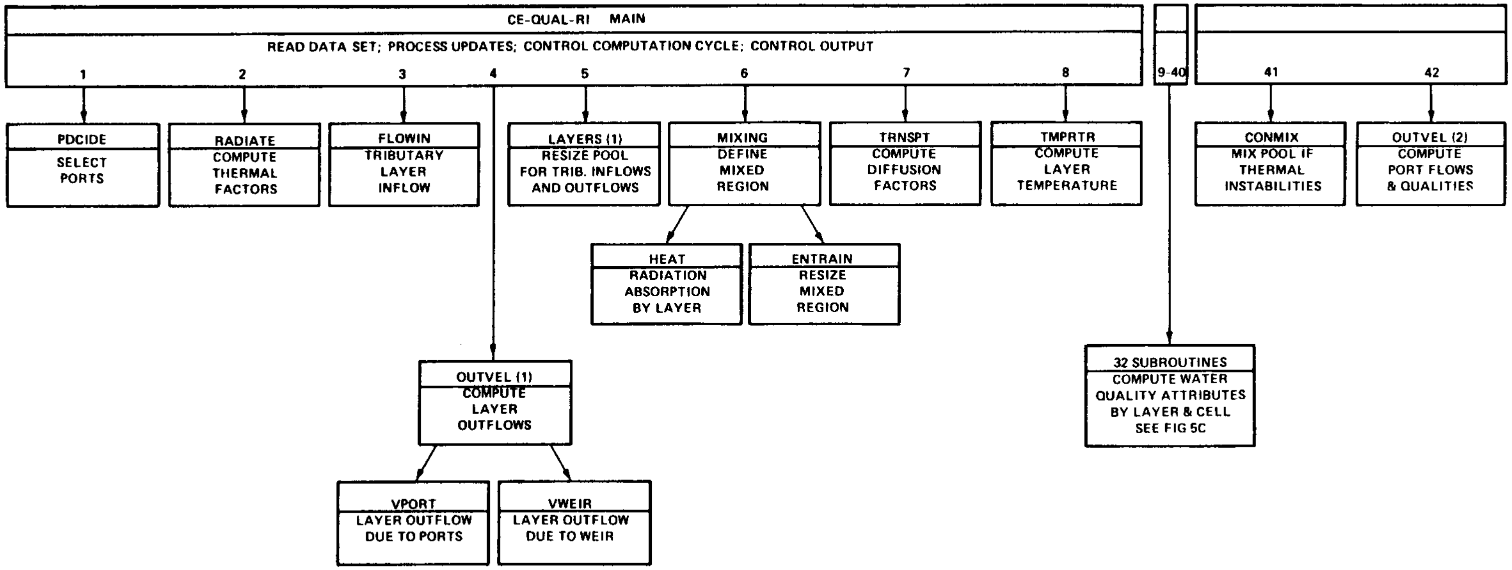


Figure 5. Relationships of water quality components for normal operations mode

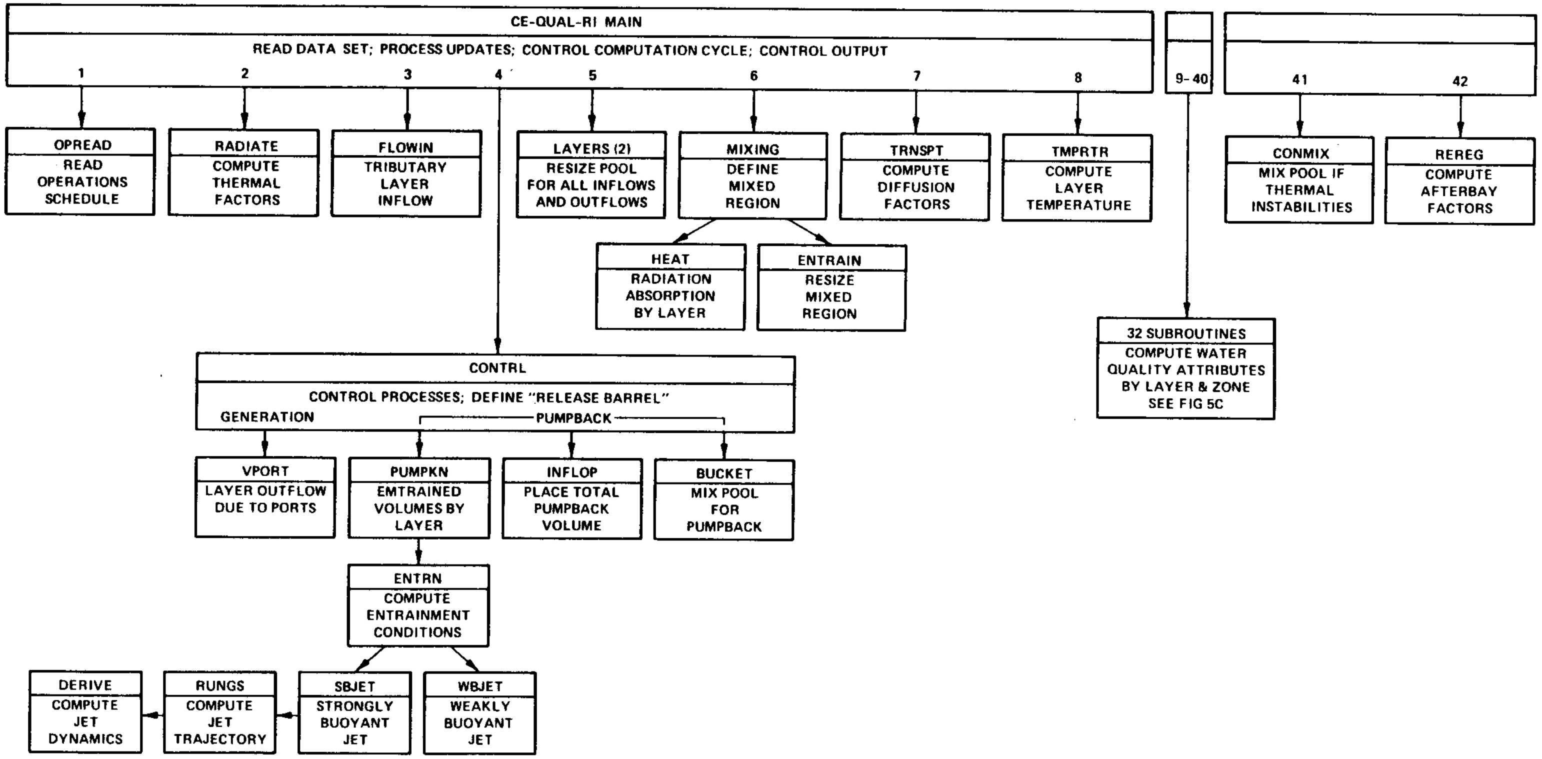
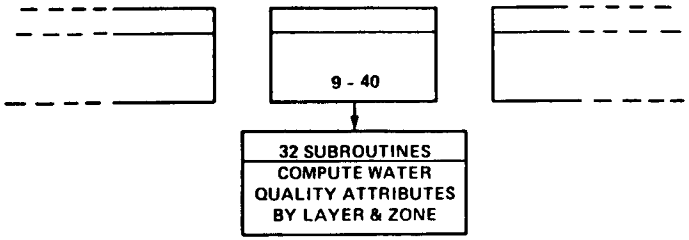


Figure 6. Relationships of water quality components for scheduled generation mode



SEQUENCE	NAME	PURPOSE
9	RMULT	TEMPERATURE-DEPENDENT MULTIPLIER FOR BIOLOGICAL AND CHEMICAL PROCESS RATES.
10	SOLIDS	LAYER SUSPENDED SOLIDS CONCENTRATION.
11	FISHERY	IN-POOL FISH BIOMASS.
12	ZOPLANK	LAYER ZOOPLANKTON CONCENTRATION.
13	PHYTO	LAYER PHYTOPLANKTON·CONCENTRATION.
14	PLNTS	PERIMETER ZONE LAYER MACROPHYTE MASS.
15	DETRITS	LAYER DETRITUS CONCENTRATION.
16	SEDMENT	LAYER ORGANIC SEDIMENT MASS.
17	ORGNICS	LAYER LABILE ORGANIC MATTER CONCENTRATION.
18	REFRACT	LAYER REFRACTORY ORGANIC MATTER CONCENTRATION.
19	PHOSPHOR	LAYER CONCENTRATION OF PHOSPHORUS AS PHOSPHATE.
20	SILICA	LAYER SILICA CONCENTRATION.
21	CARB	LAYER INORGANIC CARBON CONCENTRATION.
22	AMMONIA	LAYER CONCENTRATION OF NITROGEN AS AMMONIUM.
23	NITRATE	LAYER CONCENTRATION OF NITROGEN AS NITRATE PLUS NITRITE.
24	MNFOUR	LAYER CONCENTRATION OF OXIDIZED MANGANESE.
25	MNSED	LAYER MASS OF MANGANESE IN SEDIMENT.
26	MNTWO	LAYER CONCENTRATION OF REDUCED MANGANESE.
27	FETHREE	LAYER CONCENTRATION OF OXIDIZED IRON.
28	FESED	LAYER MASS OF IRON IN SEDIMENT.
29	FETWO	LAYER CONCENTRATION OF REDUCED IRON.
30	FESSED	LAYER MASS OF IRON SULFIDE IN SEDIMENT.
31	FESWC	LAYER CONCENTRATION OF IRON SULFIDE IN WATER.
32	SO4TWO	LAYER CONCENTRATION OF SULFATE.
33	SSED	LAYER MASS OF SULFUR IN SEDIMENT.
34	STWO	LAYER CONCENTRATION OF SULFIDE.
35	PO4SED	LAYER MASS OF PHOSPHATE IN SEDIMENT.
36	NSED	LAYER MASS OF NITROGEN IN SEDIMENT.
37	OXYGEN	LAYER CONCENTRATION OF DISSOLVED OXYGEN.
38	COLIFRM	LAYER CONCENTRATION OF COLIFORM BACTERIA.
39	TDSALK	LAYER CONCENTRATIONS OF TOTAL DISSOLVED SOLIDS AND ALKALINITY.
40	PHCO2	LAYER CONCENTRATION OF CARBON DIOXIDE AND LAYER ATTRIBUTE OF 'pH'.

Figure 7. Relationships of water quality components common to both operating modes

Solution method. As is elaborated in subsequent portions of this manual, the mathematical structure of each compartment of the model is a differential equation that expresses conservation of mass in each horizontal layer, i. The general equation is

$$\frac{d}{dt}V_iC_i = A_{i1}C_{i-1} + A_{i2}C_i + A_{i3}C_{i+1} + P_i \qquad i = 2...n-1 \tag{1}$$

where C is a concentration, V is a layer volume, A is a factor that includes transport and biological and chemical rate effects which are concentration dependent, and P is a factor that includes inflow and other biological and chemical transfers that are concentration independent. There is an equation of this general form for each constituent of each layer. Factors A and P are different for each computational interval. The equations express the fact that each layer is influenced only by its immediate neighbors (above and below). The bottom layer (i = 1) can only be influenced by the layer above it, and its equation is

$$\frac{d}{dt}V_1C_1 = A_{11}C_1 + A_{12}C_2 + P_1 \tag{2}$$

Similarly, the top layer (i = n) can only be influenced by the layer lying immediately below it. Its equation is

$$\frac{d}{dt}V_nC_n = A_{n1}C_{n-1} + A_{n2}C_n + P_n \tag{3}$$

When expressed in matrix form, the equations contain a coefficient matrix of tridiagonal form. The equations are integrated every computational interval by an implicit numerical method that consists of Gaussian elimination implemented to minimize error growth and storage requirements (Thomas algorithm). An Eulerian scheme is used to solve equations for the variables that are not advected or diffused.

Presentation of results

A number of options are available to the users of CE-QUAL-R1 or CE-THERM-R1 to examine model predictions. Tabular listings are available for any specified period. These listings include initial conditions and coefficients, meteorological conditions, and constituent concentrations or amounts in the inflow, outflow, and each modeled layer.

An interactive graphics utility program allows users to examine and display data created by the execution of CE-QUAL-R1 through the use of an interactive graphics terminal. Ancillary files containing actual field data for comparison with simulated values or other support files are also accepted by this utility program.

Using the simulation input file, numerous simulation output files are created. These, together with the input file and confirmation files, are accessible by the interactive graphics utility. When run in Monte Carlo mode, CE-QUAL-R1 creates a single output file. Each task offered by the utility results in a graphic display on the CRT screen. Hard copies can be made by a unit attached to the terminal and by requests to the utility to redirect output to a plot file to be remotely transmitted to the user's plotting facility. Six forms of graphic output are available.

a. Constituent depth profiles. Any physical, biological, or chemical constituent may be graphed as a function of elevation in the water column at a given time. Graphs may also be overlaid from different times and data sources to compare values of the same constituent. This may include profiles at the same time from different simulations, profiles at different times within the same simulations, or comparisons of predicted and observed profiles for a given simulation at a given time.

b. Constituent time histories. Any of the simulated constituents may be graphed as a function of time at a given location. The given locations are specified layers, specified elevations, inflow, outflow, or, for the algae compartments, an integrated euphotic zone value. Graphs may again be overlaid for comparisons with other locations during the same simulation or for a comparison at the same location for different simulations.

c. Inflow and outflow zones. With elevation depicted on the vertical axis and time on the horizontal axis, the distribution of inflow or outflow within the pool can be displayed through time. Viewing the outflow distribution is particularly useful when the downstream target temperature option is used.

d. Anoxic zones. This output is similar to item *c*, except that zones are displayed where dissolved oxygen is zero.

e. Isoplots. With elevation depicted on the vertical axis and time on the horizontal axis, lines of constant constituent magnitude are graphed over a specified range of values. Surface elevation is shown on the plot. The contouring algorithm currently used was selected for its small resource requirements. As such, it works best on open contours such as are usually displayed by temperature isoplots.

f. Monte Carlo plots. Using data generated from a Monte Carlo run of CE-QUAL-R1, time histories are graphed of either the mean or the median value of a selected constituent, and of its error margins expressed as either 25- or 75-percent quartiles or as plus-or-minus one standard deviation from the mean. The user may elect to see the data from which these statistical measures are obtained. Because of the large amount of data generated by a Monte Carlo simulation, the constituents currently available for graphing in this manner are limited to top-layer temperature, bottom-layer oxygen, euphotic zone algae, and all outflowing constituents.

For those occasions when the user wishes to examine the same set of constituents many times, as during model calibration, batch graphics is provided. For any specified time step and constituent, both predicted and measured values are graphed as profiles. Eight graphs can be printed per page, and any number of pages can be copied, without user assistance, on a unit attached to the CRT terminal. One of the same plot files that was generated for the interactive graphics utility is used. This file has all unnecessary data removed by a data utility, with the resultant file being used for batch graphics and statistical analysis.

Statistical analysis can be performed using predicted versus measured data. Statistics include: (a) reliability index (Leggett and Williams 1981); (b) paired t-test for means (Sokal and Rohlf 1969); (c) normalized mean error (Gordon 1981, see also Wlosinski 1982); and

(d) coefficients for the linear regression equation for plotting observed versus predicted values (Thomann 1980).

In order to ensure reliable models for a particular system, a flux utility is provided to allow the user to examine the factors controlling predicted concentrations. Chapra et al. (1983), Collins and Wlosinski (1984), Scavia (1980), and Wlosinski (1979, 1985) have shown the need to examine predicted flux values in addition to predicted mass or concentration values. They note that evaluating models by concentrating solely on the comparison of measured versus predicted concentrations can produce a model that predicts reasonable values but for the wrong reasons. The utility provides flux values listed in Table 1 for any time step, or accumulated over any number of time steps. The fluxes are listed by layer, or are summed over all layers.

The relationship of data files and computer programs is shown in Figure 8. Files representing simulation input, confirmation data, and other minor files (not depicted) must be generated by the user.

Computer Requirements

CE-QUAL-R1 and its utilities reside on the Cybernet Services interactive time-sharing computer system. The model is coded in FORTRAN-4 and is currently running on a CDC 865 computer. CE-QUAL-R1 and CE-THERM-R1 require approximately 60K and 35K words of storage, respectively, to execute. For a reservoir with approximately 50 layers, approximately 25 CPU sec of run time for CE-THERM-R1 (and 90 CPU sec for CE-QUAL-R1) are needed for a 1-year simulation on the Cybernet system. VAX and Harris computer versions are also available.

WES maintains a current version of CE-QUAL-R1 that incorporates the latest improvements on the CDC computer. Updates to the User's Manual are forwarded to all registered users of the model as improvements are incorporated in the system. Transfer of the model to other computer systems is the responsibility of the user.

Since 1989, WES has been distributing CE-QUAL-R1 and CE-THERM-R1 for 386 or higher processing personal computers (PC). Both models are in standard FORTRAN with the exception of the INCLUDE compiler command. CE-QUAL-R1

Table 1

Process Rates Available from the Flux Utility

TO

FROM	FISH	ZOOPLANKTON	ALGAE1	ALGAE2	ALGAE3	SILICA	DETRITUS	SEDIMENT	OTHOPHOSPHATE PHOS.	CARBON	AMMONIA NITR.	NO2+NO3 NITR.	OXYGEN	LABILE DOM	REFRACTORY DOM	SEDIMENT PHOS.	SEDIMENT NITR.	MACROPHYTES	SURFACE	DOWNSTREAM
FISH								Z	R	R	R								H	
ZOOPLANKTON	I	F					Z		R	R	R									O
ALGAE1	I	I	Y				M	S	R	R	R		P	N						O
ALGAE2	I	I		Y			M	S	R	R	R		P	N						O
ALGAE3	I	I			Y		M	S	R	R	R		P	N						O
SILICA					P	F														O
DETRITUS	I	I					Y	S	D	D	D									O
SEDIMENT	I									D						D	D		G	
ORTHOPHOSPHATE PHOS.			P	P	P				U							T		P		O
CARBON			P	P	P					F								P	X	O
AMMONIA NITR.			P	P	P						U	D					T	P		O
NO2+NO3 NITR.			P	P	P							F						P	D	O
OXYGEN	R	R	R	R	R		D	C			D		F	D	D			R	X	O
LABILE DOM									D	D	D			F	D					O
REFRACTORY DOM									D	D	D				F					O
SEDIMENT PHOS.									A									P	G	
SEDIMENT NITR.											A							P	G	
MACROPHYTES							M	M	R	R	R		P	N					G	
SURFACE								G		X			X			G	G			
UPSTREAM			W	W	W	W	W		W	W	W	W	W	W	W					

A	anaerobic release
C	decay plus anaerobic oxidation
D	decay or decomposition
DOM	dissolved organic matter
F	diffusion and convection
G	gain or loss caused by depth change
H	fishing harvest
I	ingestion
M	nonpredatory mortality
N	respiration plus mortality
NITR.	nitrogen
O	outflow
P	photosynthesis
PHOS.	phosphorus
R	respiration
S	settling
T	adsorptive settling
U	diffusion plus convection plus adsorption
W	inflow
X	exchange at the air-water interface
Y	settling plus diffusion plus advection
Z	egestion and nonpredatory mortality

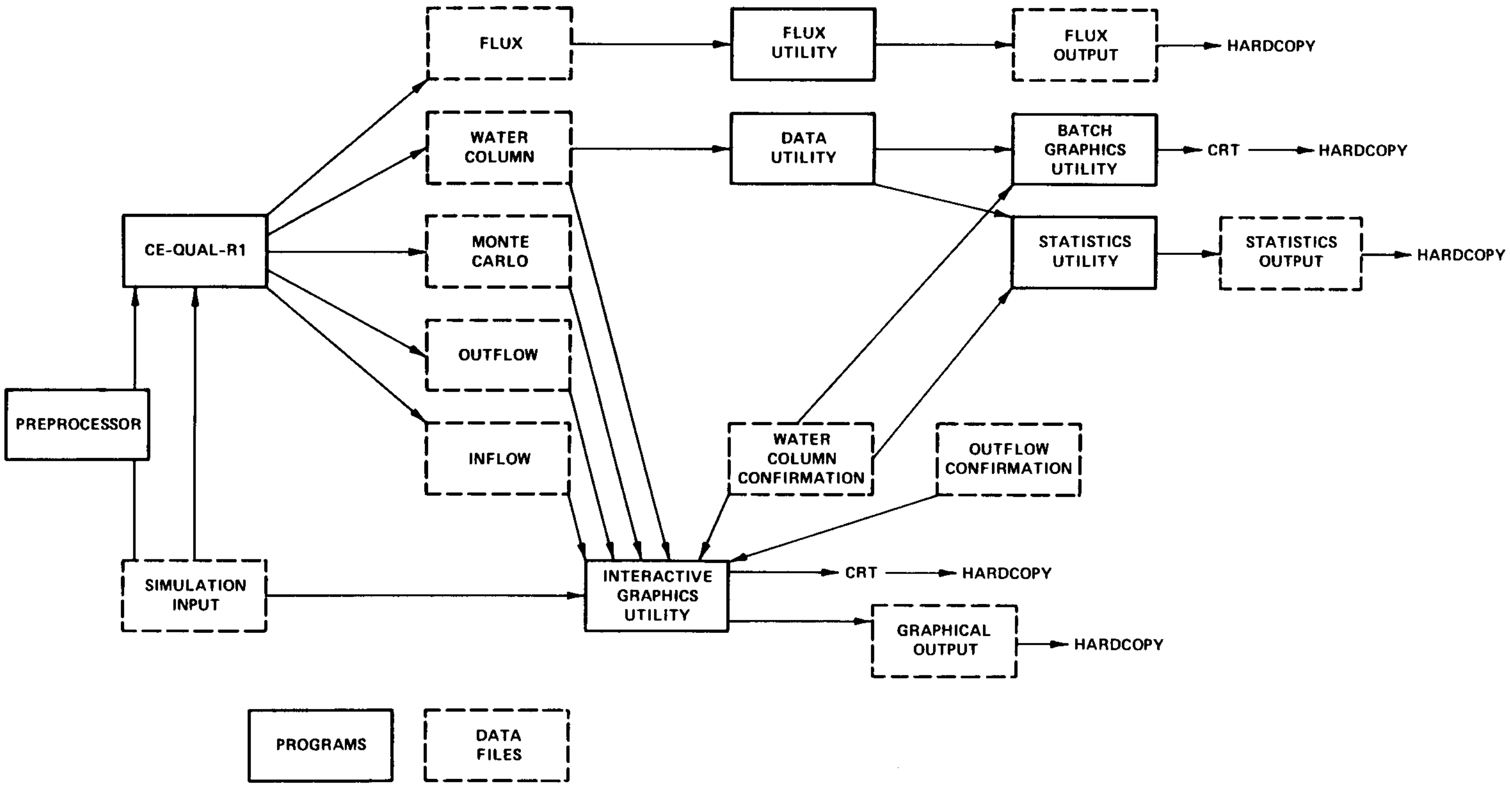


Figure 8. The relationship of computer programs and data files for CE-QUAL-R1

will run on a 640K machine using extended memory totaling 780K. Users can use any spreadsheet software package to plot CE-QUAL-R1 simulation results by outputting the results in a spreadsheet format (column data).

Monte Carlo Strategy

A major feature of CE-QUAL-R1 is its adaptation for use in a stochastic or Monte Carlo mode. This permits coefficients and updates to be varied randomly or according to predetermined statistical distributions and allows simulations to be repeated so that response statistics can be compiled.

Substantial uncertainty accompanies choices of biological and chemical coefficients. Maximum ingestion rates, respiration rates, decomposition and decay rates, and half-saturation coefficients are examples of coefficients that are difficult to estimate. It is important to assess the impact of coefficient uncertainties. That impact is seen as the prediction of events of interest over a range of intervals and a range of magnitudes rather than a single interval and magnitude. For example, the expression of occurrences of algae blooms or anoxic conditions would be in terms of a range of starting dates and a range of durations.

The Monte Carlo strategy involves specification by the user of those coefficients and updates to be randomized and the number of simulation repetitions. Each coefficient and update can be perturbed randomly about a nominal value or can be generated independently. Randomization is done according to a probability distribution selected from among four choices. This selection is independent for each coefficient and update.

The organization of CE-QUAL-R1 for Monte Carlo operations is shown in Figure 9. The solid-line elements are normal CE-QUAL-R1 components. The dashed-line elements show the additional components required for Monte Carlo simulations. The simulation data set contains Monte Carlo directives that specify whether coefficients or updates or both are to be randomized and whether randomization is to be effected once per computation interval or once per simulation.

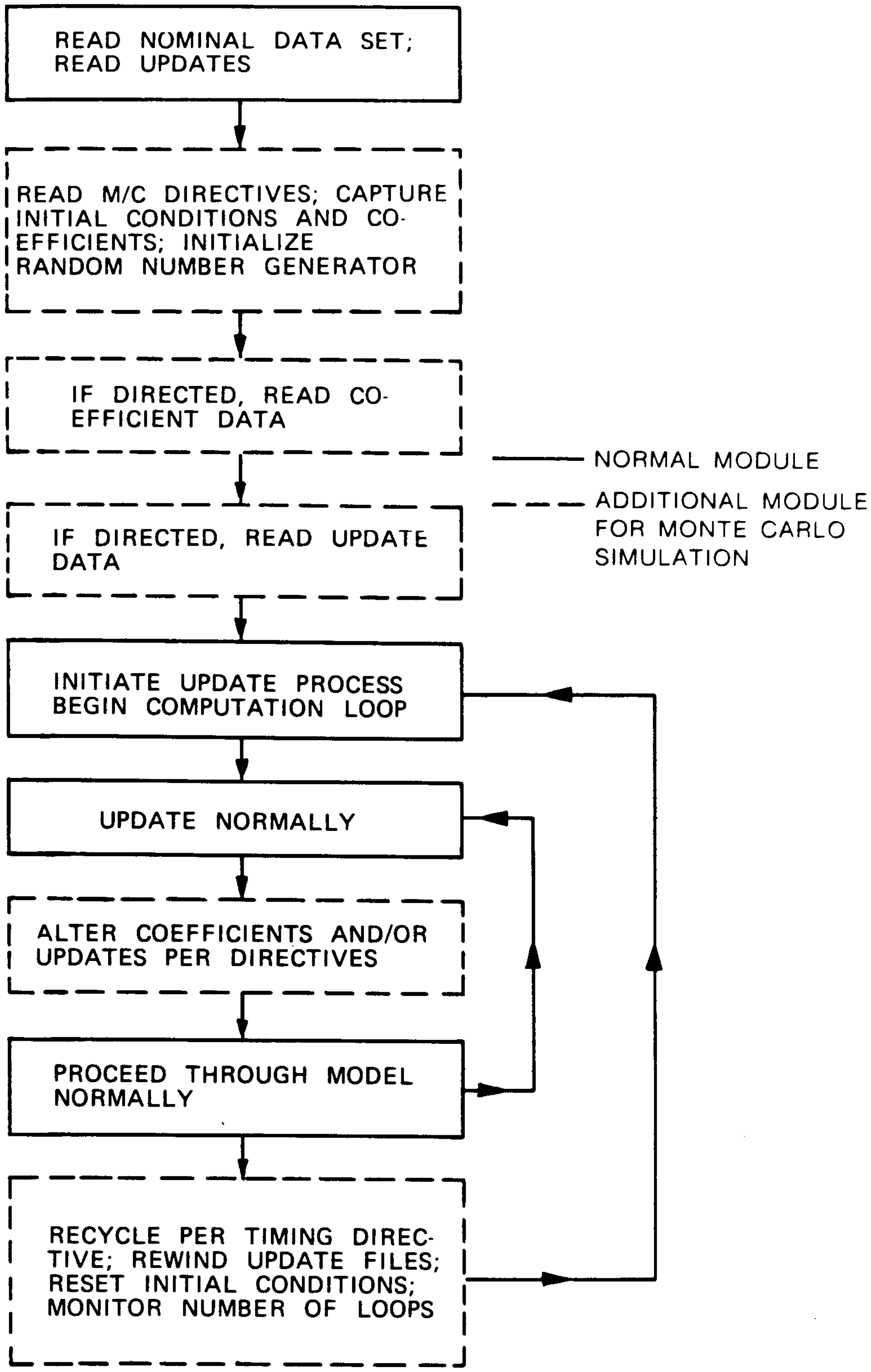


Figure 9. Monte Carlo operations

PART III: DETAILED STRUCTURE

General Comments

This part of the manual describes model details. It is included for reference and to answer specific questions concerning model constructs. Reading of this part may not be essential for successful application of the model.

This part follows the organization of Part II. First, the model's basic formulation in regard to conservation of mass and simplified ecological representations is discussed in more detail. Then the model constructs, as described in Part II and shown in Figures 5-7, are presented. The individual subroutines are discussed in the order they are called in the model. Emphasis is placed on the significance of the model constructs.

Model Formulation

Conservation of mass

The mathematical structure of CE-QUAL-R1 is based on a set of differential equations that express conservation of mass or energy in each horizontal layer. Their solution provides material or energy concentrations (i.e. temperature) as functions of time and depth. The general conservation of mass is:

$$\begin{bmatrix}\text{Rate of}\\ \text{Change}\\ \text{of}\\ \text{Mass}\\ \text{g/hr}\end{bmatrix} = \sum \begin{bmatrix}\text{Advected}\\ \text{Mass Inflow}\\ \text{Rate}\\ \text{g/hr}\end{bmatrix} - \begin{bmatrix}\text{Advected}\\ \text{Mass Outflow}\\ \text{Rate}\\ \text{g/hr}\end{bmatrix} + \begin{bmatrix}\text{Net Diffusive}\\ \text{Mass Inflow}\\ \text{Rate}\\ \text{g/hr}\end{bmatrix}$$

$$+ \begin{bmatrix}\text{Physical,}\\ \text{Biological,}\\ \text{Chemical Mass}\\ \text{Source Rates}\\ \text{g/hr}\end{bmatrix} - \begin{bmatrix}\text{Physical,}\\ \text{Biological,}\\ \text{Chemical Mass}\\ \text{Sink Rates}\\ \text{g/hr}\end{bmatrix}$$

Mathematically, this equation is written as

$$\frac{\partial}{\partial t}(VC) = \sum_{k} Q_{in}C_{in} - Q_{out}C + \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + \begin{matrix}\text{Source}\\\text{Rates}\end{matrix} - \begin{matrix}\text{Sink}\\\text{Rates}\end{matrix} \tag{4}$$

where

k = index for tributaries

V = layer volume (DVOL), m^3

C = material concentration, g/m^3

Q_{in} = layer inflow (QHI), in m^3/hr

C_{in} = inflow concentration, g/m^3

Q_{out} = layer outflow (QHO), m^3/hr

D = diffusion coefficient (DC), m^2/hr

A = horizontal surface area of the layer (AREA), m^2

ΔZ = layer thickness (SDZ), m

t = time, hr

z = layer elevation, m

and computer names are shown in parentheses where uniquely applicable. All terms are represented in units of energy or mass per unit time, so a form of Equation 4 can be used to represent all of the constituents, for each layer, in the model. Since temperature is a thermal energy concentration, it can also be represented by Equation 4. The units shown above are those used in the body of the model, although some quantities (such as tributary inflow rates) are expressed more conveniently in the data set and converted internally.

This equation form is generally used throughout the model to describe the dynamics of the various compartments. Each of the various terms will, therefore, be briefly discussed.

Since the model consists of a series of tightly coupled partial differential equations, a change in any of the model compartments could ultimately affect other model compartments and the interactions among compartments. It is not possible, *a priori*, to determine what these effects will be. This coupling or linkage among equations is extremely important to keep in mind if various compartments are modified or recoded.

The inflow and outflow terms are relatively self-explanatory. The mass transfer into the reservoir is a function of the tributary inflow volumes and inflowing constituent concentrations. The mass transfer out of the reservoir is a function of the outflow volume and concentration of the constituent in each layer that contributes to the total outflow mass transfer. There is no vertical flow component between layers in CE-QUAL-R1. Instead, layer thicknesses are allowed to vary to account for the net flow of water volume into or out of a layer.

The diffusive transfer term in the mass balance equation for a constituent is an attempt to account for the exchange or mixing of mass across a concentration gradient due to penetrative convective mixing, wind mixing, or other hydromechanical and molecular mechanisms. This term is very difficult to describe, estimate, and model since several mechanisms may be contributing to this mixing exchange between elements. In the present model, an analogy is made from the diffusion and mixing of heat to the diffusion and mixing of all other mass transfers, including particulate mass forms such as detritus, algae, and zooplankton. The eddy diffusivity coefficient is assumed to be the same for each mass transfer equation and equivalent to the thermal diffusivity coefficient. This approach is felt to be suitable because nonmolecular transfers predominate. The diffusivity modeling approach is coupled with a mixed layer approach where an energy balance is used to determine the depth of a fully mixed surface layer. This approach has been more successful than attempting to estimate diffusion coefficients throughout the depth of the lake.

An additional source of mixing is present in the model although no term for it appears in the mass balance equation. This is called numerical dispersion and is the result of the model schematization in space and time. Since each volume element is considered to be mixed continuously, mass that crosses an interface between two elements is immediately mixed throughout the volume. Concentration gradients thus become mixed more rapidly in the model than they would in a purely analytical or closed form solution. The amount of numerical dispersion that occurs, relative to that which explicitly appears in the model terms, increases with larger time increments and/or larger volume elements. Detailed discussions on this modeling phenomenon can be found in numerical analysis textbooks. The use of a variable layer approach in CE-QUAL-R1 has significantly reduced numerical dispersion.

The source and sink terms represent the various rate processes within a reservoir that produce a specific water quality manifestation. The majority of these processes are depicted in Figure 2. Each compartment will be discussed in detail in the following sections.

Monod formulations

Gross production for phytoplankton and macrophytes and ingestion for zooplankton and fish are, in part, a function of the available substrate concentration or food supply (Figure 10). For any given temperature for each biological assemblage, there is a maximum rate at which these processes can occur.

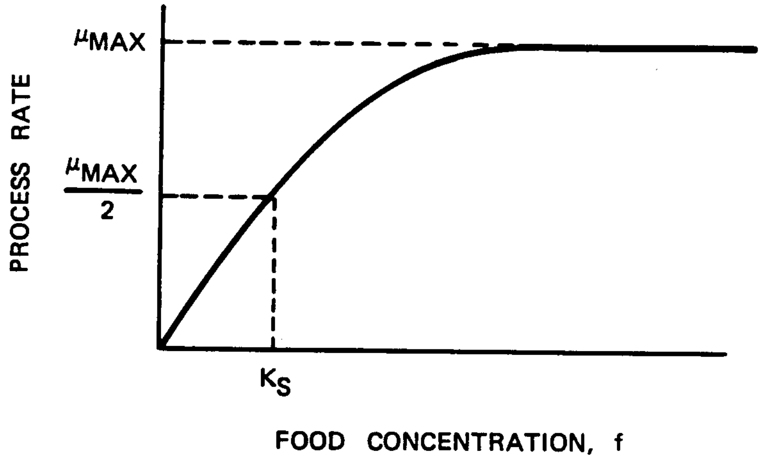


Figure 10. Monod formulation for the processes of gross production and ingestion

The equation used to represent Figure 10 is generally referred to as the Monod formulation. The form of the equation used in the model is

$$I = \gamma_1 \gamma_2 \mu_{max} \left(\frac{f}{K_S + f} \right) \tag{5}$$

where

I = gross production or ingestion rate, 1/hr

$\gamma_1\gamma_2$ = temperature rate multiplier (RTMLT1(•,I)*RTMLT2(•,I)) dimensionless

μ_{max} = maximum gross production or ingestion rate, 1/hr

f = substrate or food concentration, g/m^3

K_S = half-saturation coefficient, g/m^3

The characteristics of the equation are: (a) at low food concentrations, when $f << K_S$, gross production or ingestion is proportional to f; (b) at high food concentrations, when $f >> K_S$, gross production or ingestion is independent of the food supply. The half-saturation coefficient, K_S, is the substrate or food concentration where production or ingestion occurs at one-half its maximum rate (Figure 10). The rate multiplier, $\gamma_1\gamma_2$, modifies growth according to temperature. Temperature corrections are discussed in detail in a later section. Because the rate, I, is multiplied by the mass of the receiver compartment, it might be possible for a predator to consume more prey or phytoplankton or uptake more nutrients than are available. To prevent this from occurring in CE-QUAL-R1, the flux between compartments is limited to the available food or nutrient supply.

Model Operations

Reservoir morphometry

The mathematical structure of CE-QUAL-R1 is based on a set of differential equations that express conservation of mass or energy in each horizontal layer. Their solution provides material or energy concentrations as functions of time and depth. The accuracy of the solution will therefore depend on how well the reservoir morphometry can be represented in the model. The relationships among elevation, boundary area, and total volume can be specified by one of two options:

1) $$\texttt{AREA(I) = ACOEF(1)*Z(I)**ACOEF(2)} \tag{6}$$

$$\texttt{VOL(I) = ACOEF(1)/(ACOEF(2)+1.)*Z(I)**(ACOEF(2)+1.)} \tag{7}$$

or 2) $$\texttt{AREA(I) = ACOEF(1) + ACOEF(2)*Z(I) + ACOEF(3)*Z(I)*Z(I)} \tag{8}$$

$$\begin{aligned}\texttt{VOL(I) = ACOEF(1)*Z(I) + ACOEF(2)*Z(I)*Z(I)/2.}\\ \texttt{+ ACOEF(3)*Z(I)*Z(I)*Z(I)/3.}\end{aligned} \tag{9}$$

where ACOEF(1) , ACOEF(2) and ACOEF(3) are user-specified coefficients. Note that the volumes in these formulations are the total volumes beneath a horizontal surface at elevation Z(I) .

A definition sketch for elevations, surfaces, and volumes for a typical layer, I , is shown in Figure 11. The lower surface,

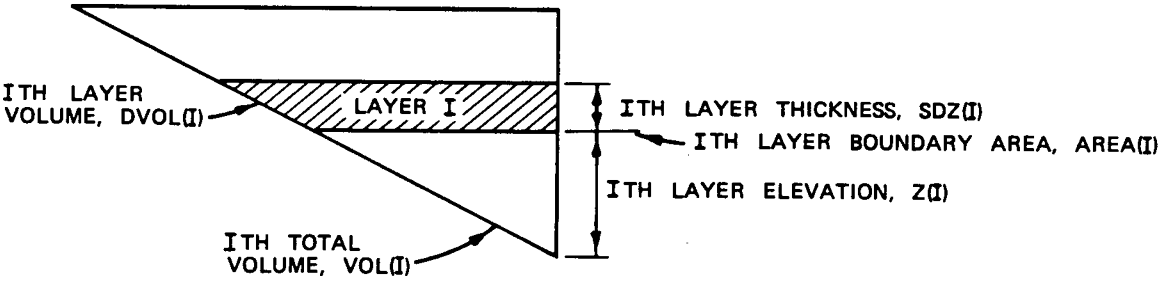


Figure 11. Layer geometric factors

AREA (I) , of layer I is at elevation Z(I) . Its upper surface, AREA(I+1) , is at elevation Z(I+1) . The thickness of the layer, SDZ(I) , is given by

$$SDZ(I) = Z(I+1) - Z(I) \tag{10}$$

The volume of the Ith layer, DVOL(I) , is determined by subtracting the total volume below surface I from the volume below surface I + 1 . That is,

$$DVOL(I) = VOL(I+1) - VOL(I) \tag{11}$$

Since each layer is uniform in its biological, chemical, and thermal attributes, layer parameters are assigned to the midpoint of the layer when presenting results.

Variable layers

An important feature of CE-QUAL-R1 is the variable thickness of each layer. Each layer can expand or contract along the vertical axis to accommodate water flowing into and out of that layer. An excess of inflow over outflow results in storage of extra water in a layer and causes it to expand. An excess of outflow over inflow results in contraction. These inflows and outflows are not necessarily the overall tributary inflows or outflows, but rather the flows that result after the partitioning among the layers (discussed in Part 3, subroutine LAYERS). The net expansion or contraction of the impounded waters (i.e., change in surface elevation) is the sum of the layer contributions and corresponds to the overall water balance.

The advantage of a variable-layer formulation is significant. Numerical dispersion is reduced because vertical flows between layers are not required. If vertical flows were used, they would advect materials and energy from fixed layer to fixed layer resulting in increased mixing. This circumstance is avoided by expanding and contracting layers. It is necessary to account specifically for variable-layer volumes in the basic differential equations (discussed in Part III, Composition of Compartment Differential Equations).

Functions TDELT and EDELT

As explained earlier, CE-QUAL-R1 computes rates of change of model constituents on a per hour basis. Thus, biological and chemical rate coefficients supplied by the user in units of per day must be converted to units of per hour. The following two functions effect these rate transformations:

$$K1 = \frac{2}{\Delta t} \frac{(e^{K\Delta t/24} - 1)}{(e^{K\Delta t/24} + 1)} \tag{12}$$

$$K1 = \frac{1}{\Delta t} (e^{K\Delta t/24} - 1) \tag{13}$$

where

K = user-supplied rate coefficient, day^{-1}

$K1$ = transformed rate coefficient, hr^{-1}

Δt = length of the computation interval, hr

The first of these functions (Equation 12), termed TDELT, is applied to all rate coefficients associated with model state variables that are solved via the implicit numerical integration routine discussed elsewhere in the manual (subroutine INTEGR).

The second function (Equation 13), termed EDELT, applies to those coefficients influencing fish and variables associated with the reservoir bottom which are solved via a simpler Euler integration routine.

Ordinarily one might expect to make the rate transformation according to the equation

$$K1 = \frac{K}{24} \tag{14}$$

In fact, in the limit as Δt approaches zero, both Equations 12 and 13 converge to Equation 14. However, the functions transforming input rate coefficients must take into explicit account the length of the computation interval, or incorrectly transformed coefficients will result. An analogy with the growth of money invested at 12 percent interest annually will help to illustrate this fact. If the interest were compounded annually, then a gain of exactly 12 percent would be realized. But, if a rate of interest of 1 percent were applied monthly, the total gain realized after 12 months would be greater than 12 percent because of the compounding effect. In fact, it would be approximately 12.58 percent. Similarly, an interest rate of 3 percent per quarter would yield an annual return of about 12.55 percent. In order to realize exactly 12 percent annual interest, the monthly and quarterly interest rates would have to be approximately 0.95 and 2.87 percent, respectively. Similarly, unless Equations 12 and 13 are used to transform the rate coefficients, the rate of change realized for a model constituent after 24 hr (i.e., after $24/\Delta t$ computation intervals) will be greater than the growth rate expected based on the input coefficient K.

In order to illustrate the derivation of the rate transforming functions TDELT and EDELT, the following simple differential equation will be considered:

$$\dot{x} = Kx \tag{15}$$

where K is a user-supplied rate constant having units of 1/day. Although this is one of the simplest differential equations that could be considered, all equations used in CE-QUAL-R1 are composed of sums of such terms (Equation 108), so that the results derived here are quite general in application. The continuous solution to Equation 15 is given by

$$x(t) = x_o e^{Kt} \tag{16}$$

where x_o is the value of $x(t)$ at initial time $t = t_o$.

Consideration must now be given to the way in which Equation 15 is solved in CE-QUAL-R1. Those variables solved via subroutine INTEGR use the following modified Euler, implicit integration scheme:

$$x(t_o + \Delta t) = x(t_o) + \frac{\Delta t}{2}\dot{x}(t_o) + \frac{\Delta t}{2}\dot{x}(t_o + \Delta t) \tag{17}$$

This equation may be simplified by letting $t_o = 0$, and by substituting Equation 15 for $\dot{x}$. Thus,

$$x(\Delta t) = x_o + \frac{\Delta t}{2} K1 x_o + \frac{\Delta t}{2} K1 x(\Delta t) \tag{18}$$

where K1 has been substituted for K since computations are being made on per hour basis. This equation may be solved for $x(\Delta t)$, with the result

$$x(\Delta t) = x_o \left(\frac{2 + \Delta t K1}{2 - \Delta t K1}\right) \tag{19}$$

After 24 hr, or $24/\Delta t$ computation intervals, the following equation would be obtained:

$$x \frac{24}{\Delta t} = x_o \left(\frac{2 + \Delta t K1}{2 - \Delta t K1}\right)^{24/\Delta t} \tag{20}$$

In order for the value of x calculated in Equation 20, using rate coefficient K1 (hr^{-1}), to be equal to the value of x calculated with Equation 16, using K (day^{-1}) (with $t = 1$ day in Equation 16), the following equality must hold:

$$e^K = \left(\frac{2 + \Delta t K1}{2 - \Delta t K1}\right)^{24/\Delta t} \tag{21}$$

Solving this last equation for K1 yields Equation 12 or the function TDELT. In other words TDELT calculates a discrete growth rate constant K1, in units of per hour, which when applied over $24/\Delta t$ computation intervals yields the desired 24-hr growth function e^K.

A slightly different but parallel derivation is appropriate for those rate coefficients associated with fish and those variables found at the reservoir bottom which do not call subroutine INTEGR. For those variables, the following one-step Euler integration routine is employed:

$$x(t_o + \Delta t) = x(t_o) + \Delta t\dot{x}(t_o) \tag{22}$$

The same steps given above may be followed in order to derive the function EDELT:

$$x(\Delta t) = x_o + \Delta t K1 x_o \tag{23}$$

$$x(\Delta t) = x_o(1 + \Delta t K1) \tag{24}$$

$$x\left(\frac{24}{\Delta t}\right) = x_o(1 + \Delta t K1)^{24/\Delta t} \tag{25}$$

$$e^K = (1 + \Delta t K1)^{24/\Delta t} \tag{26}$$

Equations 23-26 parallel Equations 18-21. Again, the final equation above (Equation 26) is solved for $K1$, the result being Equation 13, or the function EDELT.

Figure 12 illustrates the use of the functions TDELT and EDELT for calculating transformed rate coefficients. Shown in this figure are the results of numerical integrations of the simple differential equation given earlier (Equation 15), for three different time steps (Δt = 6, 12, 24 hr; note that the discrete, linear, approximating solutions are not graphed for $\Delta t = 6$ hr in the graphs for TDELT and EDELT, since they coincide so closely with the true solution). In these plots, results of numerical integrations using $K1 = \text{TDELT}(K,\Delta t)$, or $K1 = \text{EDELT}(K,\Delta t)$ are compared with integrations employing the transforming function $K1 = K/24$. Also graphed is the continuous solution function, Equation 16.

Examination of the results graphed in Figure 12 shows that, where the functions TDELT and EDELT are used appropriately to transform

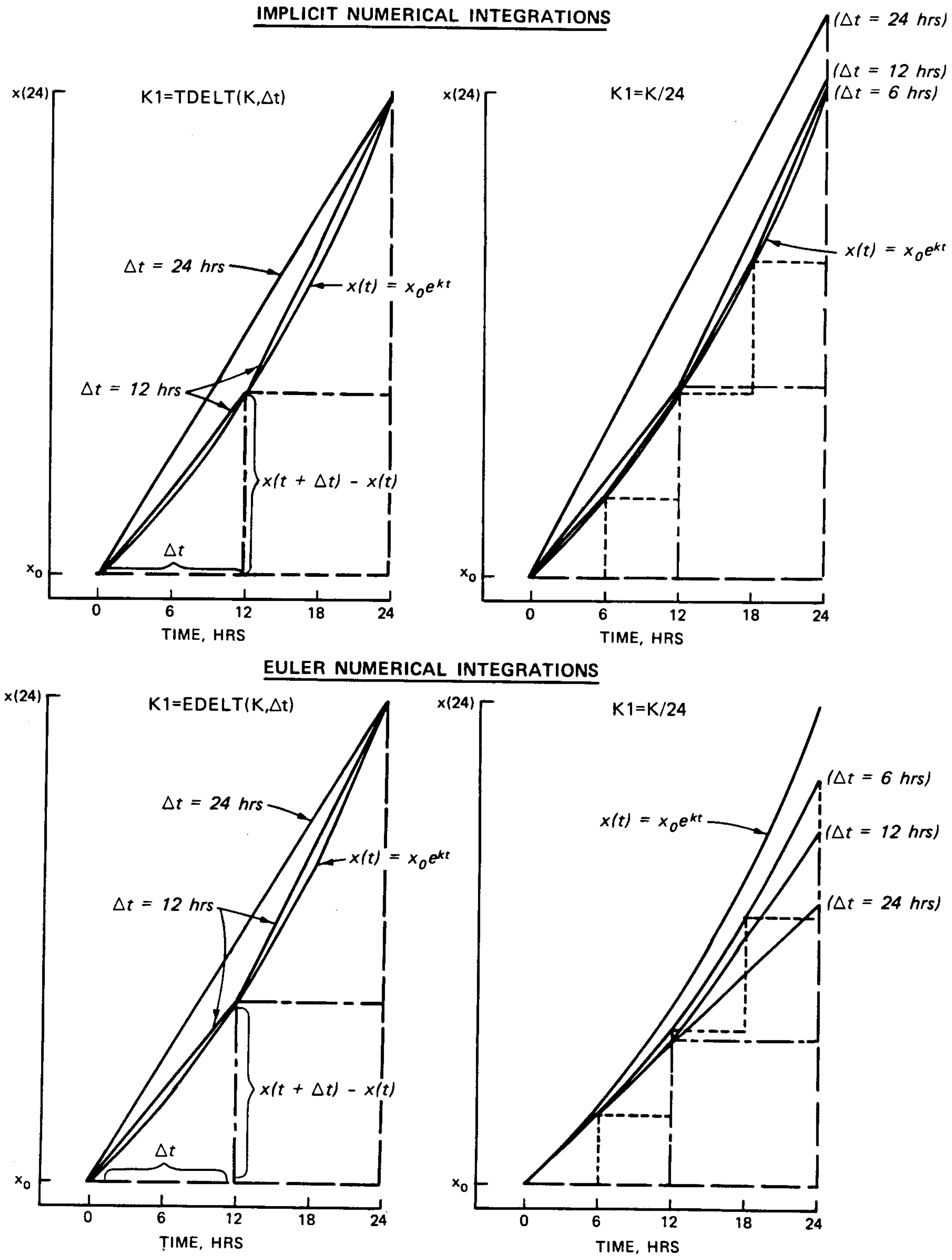


Figure 12. Rate transforms

user-input rate coefficients (i.e., TDELT with the implicit numerical integration algorithm, EDELT with the one-step Euler algorithm), the results of the integrations are "correct." That is, the continuous exponential function and the discrete approximating functions coincide at every Δt discrete points in time. If $K/24$ is used in place of TDELT, the discrete approximations overestimate the expected solution. Conversely, the numerical results underestimate the true solution when $K/24$ replaces EDELT. In both cases, the magnitude of the resulting error increases with the length of the simulation time step. These results show that the major advantage of using the rate-transforming functions TDELT and EDELT (Equations 12 and 13) is that they allow biological and chemical rate coefficients to be scaled appropriately to the time step and numerical integration routine employed in CE-QUAL-R1 simulations. Moreover, they allow the user the flexibility of using other than daily time steps. Thus, expected rates of change of model constituents are realized and problems of numerical instability are reduced.

Finally, it must be emphasized that, in the derivation of the functions TDELT and EDELT, it was assumed that the user is supplying rate coefficients appropriate to continuous exponential growth functions rather than to discrete growth functions. For example, suppose that one desires to calculate the maximum rate of algal growth from laboratory data obtained under nonlimiting conditions. If the mass of the experimental algal population doubled in 24 hr (t = 1 day), then one would calculate the growth rate based on Equation 16 as follows:

$$x(t) = x_o e^{Kt} \tag{27}$$

$$\frac{x(t)}{x_o} = e^{Kt} \tag{28}$$

$$\frac{x(1)}{x_o} = 2 = e^{K \cdot 1} = e^{K} \tag{29}$$

$$K = \ln 2 = 0.693 \text{ day}^{-1} \tag{30}$$

It is assumed that rate coefficients used in CE-QUAL-R1 are in this "continuous" form.

On the other hand, one may also calculate the growth rate of the same algal population according to a discrete growth law, as follows ($\Delta t = 1$ day, $n = 1$):

$$x(t_o + n\Delta t) = x_o(1 + K)^n \tag{31}$$

$$x(t_o + 1) = x_o(1 + K) \tag{32}$$

$$\frac{x(t_o + 1)}{x_o} = 1 + K \tag{33}$$

$$K = 2 - 1 = 1.0 \text{ day}^{-1} \tag{34}$$

If the user has calculated rate coefficients in this "discrete" form, he should transform them to the continuous form given above before entering them as coefficients for CE-QUAL-R1. The relation between the two rate laws is as follows:

$$K_c = \ln(1 + K_d) \tag{35}$$

$$K_d = e^{K_c} - 1 \tag{36}$$

where K_c and K_d are rate coefficients having identical units of per time, derived according to continuous and discrete rate laws, respectively. Again, K_c is the form to be input to CE-QUAL-R1.

However, if the user feels more comfortable in working with discrete growth laws, and prefers to enter all model rate coefficients in such a form (i.e., as K_d above), he may replace, in the computer code for CE-QUAL-R1, the continuous transforming functions, Equations 12 and 13, with the following discrete equivalents:

$$K1 = \frac{2}{\Delta t}\left[\frac{(1 + K)^{\Delta t/24} - 1}{(1 + K)^{\Delta t/24} + 1}\right] \tag{37}$$

$$K1 = \frac{(1 + K)^{\Delta t/24} - 1}{\Delta t} \tag{38}$$

These functions are derived similarly to Equations 12 and 13 except that in Equations 21 and 26, e^K is replaced with $(1 + K)$.

Subroutine PDCIDE

Reservoir releases through multilevel ports can be specified or subroutine PDCIDE can be called to choose port flows in order to meet a release temperature objective. If the latter option is selected, outflows through each port must be determined before layers are resized.

PDCIDE compares target temperatures with water temperatures adjacent to each port and attempts to blend outflowing waters to obtain the temperature objective. Data required are total outflows and target temperatures as well as specific information describing the outlet structure.

The intake structure is assumed to have two wet wells for the selective withdrawal system and a flood-control system that is specified as either separated or integrated. The procedures in PDCIDE seek which intakes must be open, and the flows they must pass, to meet (as close as possible) the temperature objective and to satisfy flow requirements. When the flow capacity of the selective withdrawal system is reached, the flood-control system is also used to fulfill flow requirements. Blending can be accomplished in this routine only through the use of the two wet wells; thus, only one intake can be open in a wet well at any given time. The number of selective withdrawal intakes is specified, and each intake is identified as to belonging to wet well No. 1 or 2. The code is presently dimensioned for eight water quality intakes. All eight intakes could be placed in the same well to simulate a single wet-well structure. However, at present, no blending in single wet-well structures can be simulated.

The computational procedure invokes numerous constraints reflecting maximum and minimum flow capacities of each port and of the flood control gates. Specific operational constraints include:

a. Only one or two wet wells can be simulated. Blending can occur only between intakes located in different wet wells. Only one intake can be open at a time for each wet well.

b. In addition to specifying a maximum and minimum flow for each port, a maximum selective withdrawal capacity must also be specified. Minimum and maximum flows for the flood control gates are also specified.

c. If total outflow specified during any computational interval is less than the minimum release, the minimum is released.

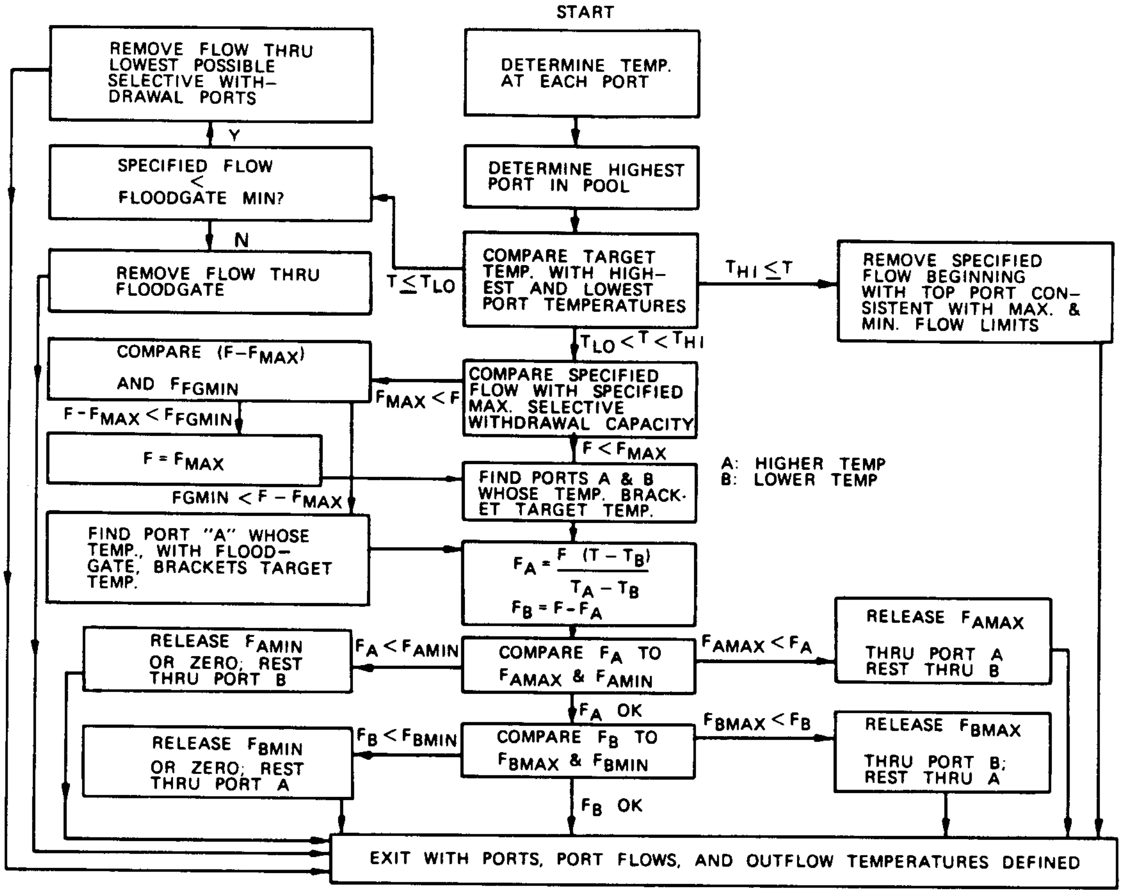
d. If the total outflow specified during any computational interval is greater than the outflow capacity of the structure, this excess water is stored until it can be released.

e. Each intake must be sufficiently submerged to be operated.

The maximum permissible flow may be decreased by the program logic to prevent flow control from shifting from a downstream control gate to the intake. The intake elevation, the pool elevation, and the intake area are used to compute this maximum allowable flow. If this value is greater than the maximum permissible intake flow input by the user, then the latter is used as the intake flow constraint. The flood-control system is used when the total desired flow rate exceeds the capacity of the selective withdrawal system. Additionally, the flood-control intakes might be used when the target temperature is cold, requiring the release of water near the bottom, as the elevation of the flood-control intakes must be located below the lowest port elevation.

The flood-control system can either be integrated with the selective withdrawal system, where a flood-control gate is located within each selective withdrawal wet well, or it can be separate, with the flood-control gate operating independently of the selective withdrawal system. If an integrated system is simulated with two floodgates, the elevations of the flood-control intakes are assumed to be the same. The elevation of the flood-control intake(s) and the system configuration are specified by the user.

For the integrated system, the flood-control gates are used for both flood control and selective withdrawal releases, and the logic of the coding ensures that only one intake is open (either a flood or water quality intake) in each of the two wet wells/gate passages. For the separated system, both wet wells and the floodgate can be operated simultaneously. For two floodgates (integrated system), the capacity of each floodgate is half the total flood-control capacity. Use of the flood-control system can be prevented by setting the minimum and maximum permissible floodgate flows greater than any flow that would be encountered. Figure 13 displays the essential features of subroutine PDCIDE although numerous special-case logic pathways are not shown. The version of PDCIDE used in CE-QUAL-R1 was obtained from the Hydraulics Laboratory, WES, on 20 December 1985.



NOTE: NUMEROUS SPECIAL CASES NOT SHOWN

Figure 13. Subroutine PDCIDE (F = flow; T = temperature; FG = floodgate)

Subroutine RADIATE

Principal components of the heat budget of a reservoir are calculated in subroutine RADIATE from meteorological updates. These components include shortwave radiation, longwave radiation, back radiation, evaporative heat loss, and the conductive-convective term (Figure 14). Evaporation loss is required to calculate the water budget of the reservoir.

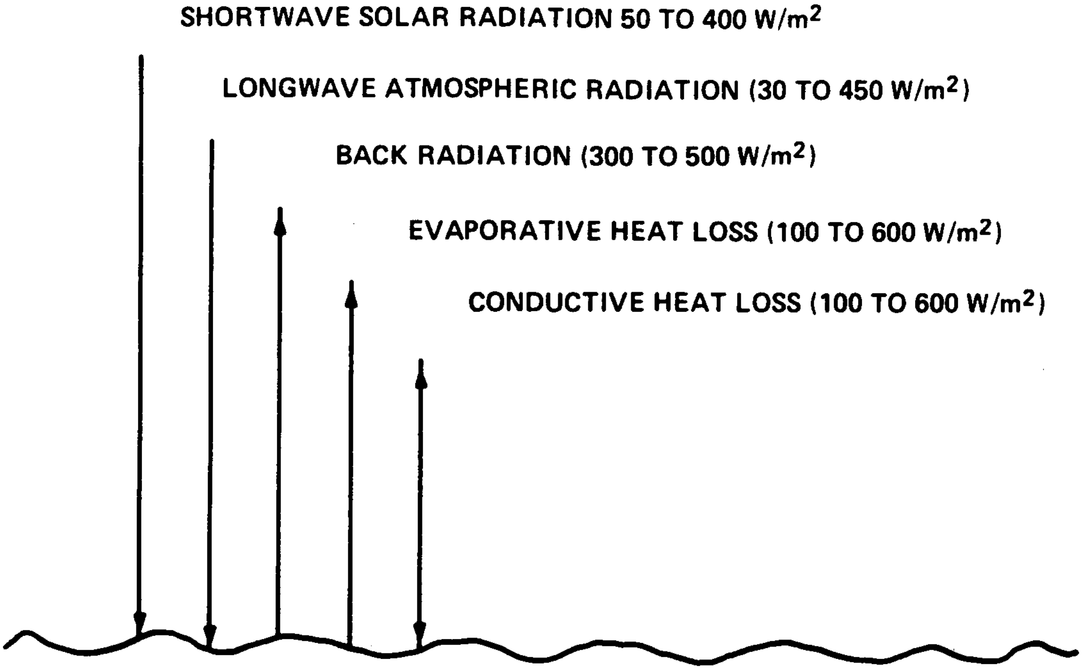


Figure 14. Principal components of the heat budget at the air-water interface (after Edinger, Brady, and Geyer 1974)

Solar radiation. In CE-QUAL-R1, solar or shortwave radiation is calculated from relationships presented in Eagleson (1970) and Water Resources Engineers, Inc. (1967) and described below. Net solar radiation is

$$Q_{ns} = F_r \cdot F_c \cdot F_s \cdot \frac{Q_o}{R^2} \sin \alpha \qquad (39)$$

where

Q_{ns} = net solar radiation at the water surface, Kcal/m^2/sec (RAD)

F_r = reflection factor

F_c = cloudiness factor

F_s = atmospheric transmission term

Q_o = incoming solar radiation at the outer limits of the atmosphere (approximately 0.33 Kcal/m^2/sec)

R = relative earth-sun distance (REARTH)

α = sun angle, rad (SINA)

The relative earth-sun distance is:

$$R = 1. + 0.017 \cos \left[\frac{2\pi}{365} (186 - \text{NDAY})\right] \tag{40}$$

where

NDAY = Julian day

Computer names for the components are shown in parentheses where uniquely applicable. As illustrated in Figure 15, the several factors multiplying Q_o express the reduction of transmitted radiation as atmosphere and cloud layers are traversed and as the water surface is encountered.

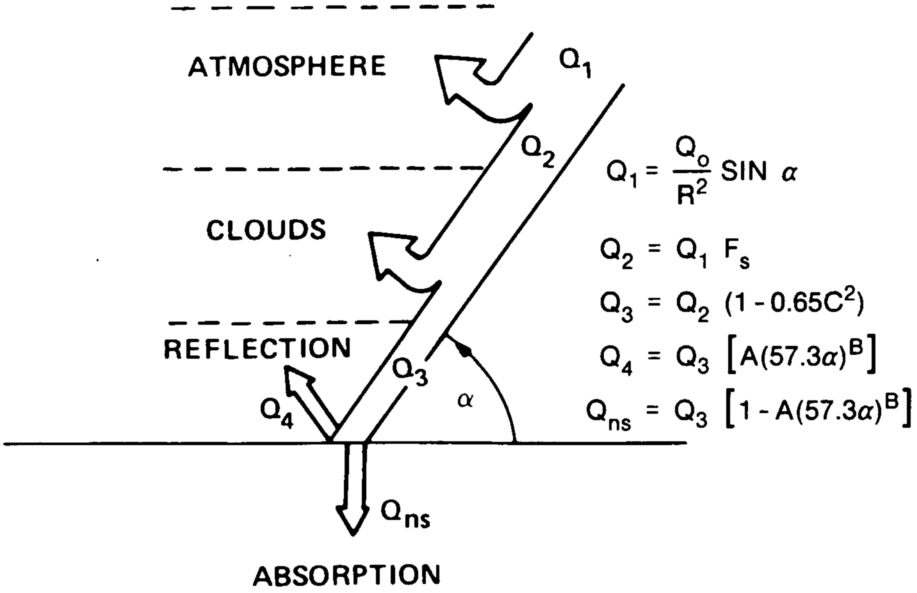


Figure 15. Insolation decrement factors

The atmospheric transmission term is:

$$F_s = \frac{a'' + 0.5(1 - a' - d)}{1 - 0.5\ k\ (1 - a' + d)} \tag{41}$$

where

a'' = mean atmospheric transmission coefficient after scattering and absorption (A11)

a' = mean atmospheric coefficient (A1)

d = dust attenuation coefficient (TURB)

k = reflection coefficient (ALBEDO)

The value for a'' is computed as:

$$a'' = \exp\left\{-\left[0.465 + 0.0408\left(0.00614\ e^{0.0489T_d}\right)\right]\left(0.179 + 0.421\ e^{-0.721\theta_{am}}\right)\theta_{am}\right\} \tag{42}$$

where

T_d = dewpoint temperature, °F

θ_{am} = optical air mass (AMASS)

Optical air mass is given by the equation:

$$\theta_{am} = \frac{\exp\,(-ALT/2{,}532)}{\sin\alpha + 0.15\left(\frac{180\alpha}{\pi}\right)^{-1.253}} \tag{43}$$

where

ALT = elevation of the site (ft) calculated from ELEMSL and the reservoir depth (RESEL)

The mean atmospheric coefficient a' is represented as:

$$a' = \exp\left\{-\left[0.465 + 0.0408\left(0.00614\ e^{0.0489T_d}\right)\right]\left(0.129 + 0.171\ e^{-0.88\theta_{am}}\right)\theta_{am}\right\} \tag{44}$$

The cloudiness factor (F_c) is included in the parentheses for the computation of Q_3 in Figure 15, where C is the sky cover fraction or cloudiness (CLD). The reflection factor (F_r) equals unity minus the albedo. The albedo is included in the brackets for the computation of Q_4 in Figure 15 where A and B are functions of cloudiness (C) as expressed below (from Eagleson 1970) and shown in Figure 16.

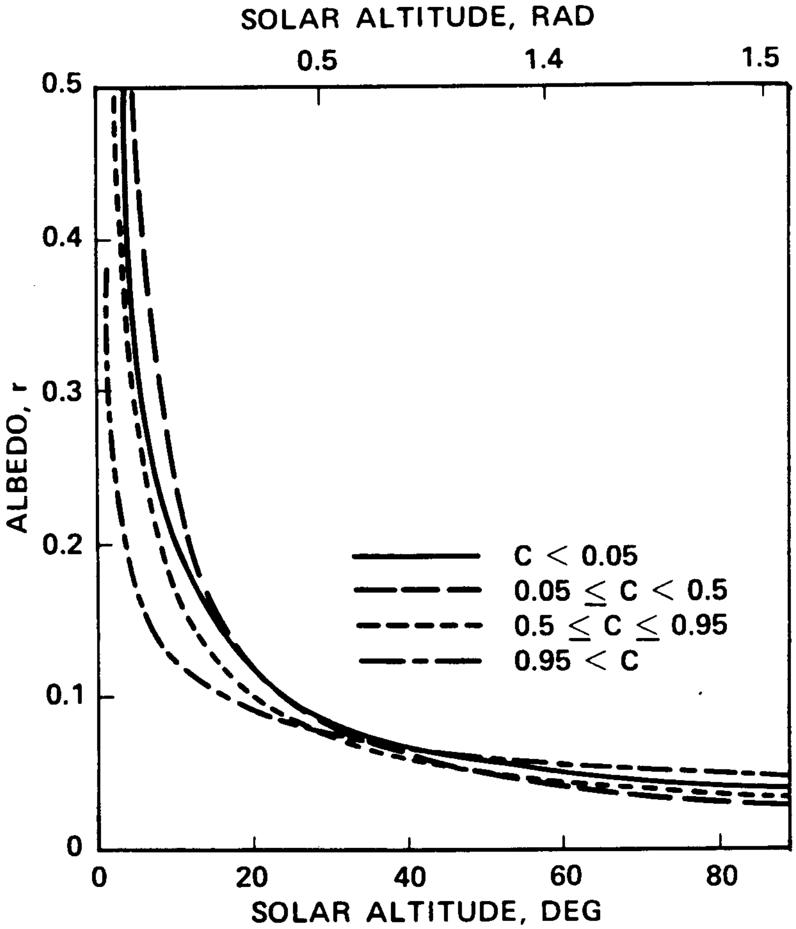


Figure 16. Reflection of insolation

Cloudiness, C	A	B
$C < 0.05$	1.18	-0.77
$0.05 \le C < 0.5$	2.20	-0.97
$0.5 \le C \le 0.95$	0.95	-0.75
$0.95 < C$	0.35	-0.45

The solar altitude α is computed from:

$$\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos \omega \qquad \alpha \geq 0.01 \tag{45}$$

where

ϕ = latitude, rad

δ = solar declination, rad

ω = solar hour angle, rad

In turn, δ and ω are computed from:

$$\delta = 0.4092 \cos\left[\frac{2\pi}{365}(172 - \mathrm{JDAY})\right] \tag{46}$$

where JDAY is the Julian day, and:

$$\omega = \frac{\pi}{12}(t - t_L - 12) \tag{47}$$

where

t = simulation hour, local standard time

t_L = fraction of a 15-deg increment by which the local meridian is west of the standard meridian for the time zone. This is numerically the same as the fraction of an hour for the sun to cross the sky between the two meridians.

For the continental United States, CE-QUAL-R1 places standard time zone meridians at 75, 90, 105, and 120 deg.

Solar altitude and absorbed radiation are calculated only when the simulation hour falls between sunrise and sunset. At sunset, α is zero and:

$$0 = \sin\phi \sin\delta + \cos\phi \cos\delta \cos\omega \tag{48}$$

or

$$\cos\omega = -\frac{\sin\phi \sin\delta}{\cos\phi \cos\delta} \tag{49}$$

This means that the sunset hour, t_{ss}, is

$$\frac{\pi}{12}\left(t_{ss} - t_L - 12\right) = \cos^{-1}\left(- \frac{\sin \phi \sin \delta}{\cos \phi \cos \delta}\right) \tag{50}$$

or

$$t_{ss} = \frac{12}{\pi} \cos^{-1}\left(- \frac{\sin \phi \sin \delta}{\cos \phi \cos \delta}\right) + t_L + 12 \tag{51}$$

The hour angle is defined to be at its maximum at noon when the solar altitude is maximum. Because sunrise and sunset hours are symmetrical about the noon hour, the sunrise hour, t_{su} , is given by:

$$\frac{\pi}{12}\left(t_{su} - t_L - 12\right) = \frac{-\pi}{12}\left(t_{ss} - t_L - 12\right) \tag{52}$$

or

$$t_{su} = -t_{ss} + 2t_L + 24 \tag{53}$$

or

$$t_{su} = - \frac{12}{\pi} \cos^{-1}\left(- \frac{\sin \phi \sin \delta}{\cos \phi \cos \delta}\right) + t_L + 12 \tag{54}$$

Note that perturbations in these times due to seasonal variations in the earth's velocity (as much as 0.25 hr in February and November) are not included in the CE-QUAL-R1 formulation.

Longwave radiation. Atmospheric longwave radiation is the major source of heat to a reservoir on warm cloudy days. Its magnitude depends primarily on air temperature and relative humidity. Atmospheric radiation is calculated by assuming the atmosphere emits radiation as a gray body with an emissivity dependent on many factors. The empirical relationship used in CE-QUAL-R1, which includes 3.0 percent reflection, is taken from Tennessee Valley Authority (1972) and is

$$Q_{NA} = 1.23 \times 10^{-16} \times (T_a + 273)^6 \times (1 + 0.17\ C^2) \qquad (55)$$

where

Q_{NA} = atmospheric radiation (QNA), Kcal/m^2/sec
T_a = dry bulb air temperature (DB), °C
C = cloud cover fraction (CLD)

A graph of this relationship is shown in Figure 17.

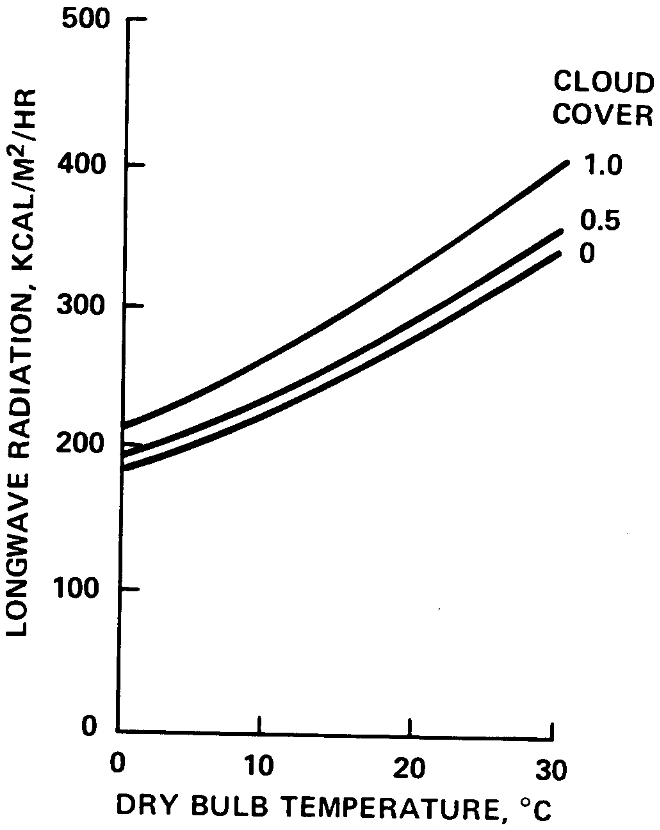


Figure 17. Longwave radiation

Back radiation. Water emits radiation as an almost perfect blackbody. Its magnitude can be determined from

$$Q_b = 0.97 \sigma (T + 273)^4 \qquad (56)$$

where

Q_b = back radiation, Kcal/m^2/sec

σ = Stefan-Boltzmann constant

T = water temperature, °C

This relationship is shown in Figure 18. To simplify the water temperature solution, Q_b is approximated by a sequence of straight-line segments of the form

$$Q_b = \text{gamma}_j + \text{sigma}_j T \qquad j = 1, 2...8 \qquad (57)$$

where T = temperature of surface layer water, °C, and gamma and sigma are as follows:

T	j	Gamma	Sigma
$0 \le T < 5$	1	0.07298	0.00110
$5 \le T < 10$	2	0.07267	0.00116
$10 \le T < 15$	3	0.07204	0.00122
$15 \le T < 20$	4	0.07106	0.00129
$20 \le T < 25$	5	0.06971	0.00136
$25 \le T < 30$	6	0.06795	0.00142
$30 \le T < 35$	7	0.06579	0.00150
$35 \le T < 40$	8	0.06316	0.00157

Evaporative heat loss. Evaporative heat loss is proportional to the difference between the saturated vapor pressure at the temperature of the water surface and the actual vapor pressure at the temperature of the air. It is approximated in CE-QUAL-R1 by

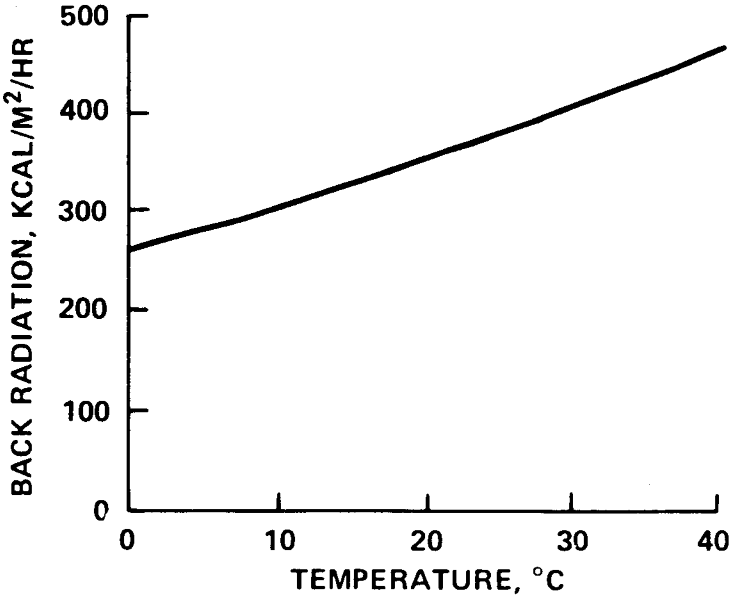


Figure 18. Back radiation

$$Q_e = \rho L(a + bW)(e_s - e_a) \qquad e_s > e_a \tag{58}$$
$$= 0 \qquad e_s < e_a$$

where

Q_e = evaporative heat loss in Kcal/m^2/sec
L = latent heat of vaporization, Kcal/kg ($L = 597 - 0.57T$ as shown in Figure 19)
ρ = density of water, kg/m^3
a = empirical coefficient (AA)
b = empirical coefficient (BB)
W = wind speed (XWND), m/sec
e_s = saturated vapor pressure at the water surface temperature (ES), mb
e_a = vapor pressure at the air temperature (EA), mb

Variation of saturated vapor pressure with temperature is shown in Figure 20. Actual vapor pressure, e_a, is numerically equal to the saturation vapor pressure at the dewpoint temperature, T_d. It is calculated as

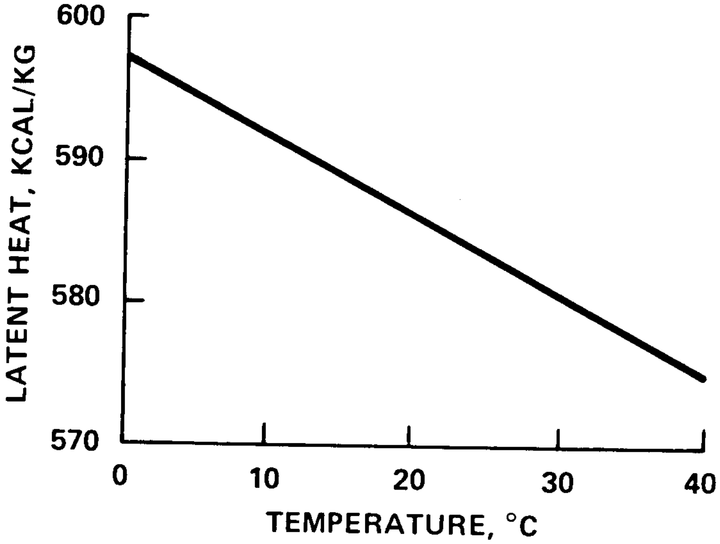


Figure 19. Latent heat

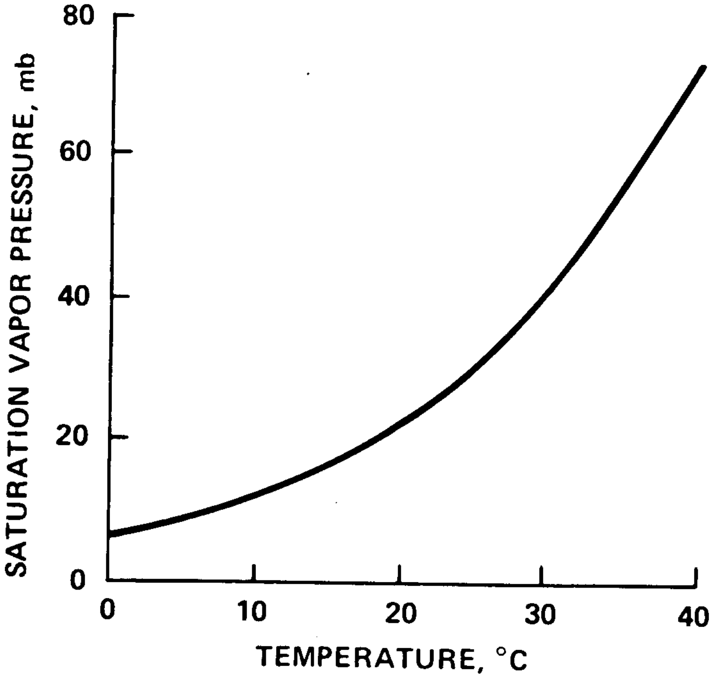


Figure 20. Saturation vapor pressure

$$e_a = 2.171 \times 10^8 \exp\left(\frac{-4{,}157}{T_d + 239.09}\right) \qquad (59)$$

where T_d = dewpoint temperature (XDPT), °C.

To keep the temperature solution simple, e_s is approximated by a sequence of straight-line segments of the form

$$e_s = \text{alpha}_j + \text{beta}_j\ T \qquad j = 1, 2\ldots8 \qquad (60)$$

where T = temperature of surface layer water, °C, and alpha and beta are as follows:

T	j	Alpha	Beta
$0 \le T \le 5$	1	6.05	0.522
$5 \le T < 10$	2	5.10	0.710
$10 \le T < 15$	3	2.65	0.954
$15 \le T < 20$	4	-2.04	1.265
$20 \le T < 25$	5	-9.94	1.659
$25 \le T < 30$	6	-22.29	2.151
$30 \le T < 35$	7	-40.63	2.761
$35 \le T < 40$	8	-66.90	3.511

Conductive heat transfer. The conductive heat transfer is approximated by

$$Q_c = \rho L(a + bW)(C_B + 10^{-3} P)(T - T_a) \qquad (61)$$

where

Q_c = conductive heat transfer, Kcal/m^2/sec
C_B = 0.61 deg C^{-1} (Bowen's Ratio)
P = barometric pressure (XAPR), mb

The direction of heat transfer depends on which of the two temperatures is higher.

Synthesis. The last step in RADIATE is to combine all of the heat fluxes with the exception of solar radiation into the proper form for the solution technique. Solar radiation is not considered at this time because it is absorbed exponentially with depth (see subroutine HEAT). All of the other fluxes act only at the water surface and therefore affect only the surface layer.

As outlined in Part II under Model Operations, the solution technique used in CE-QUAL-R1 considers terms that are concentration independent, concentration dependent, and dependent on the concentrations in the layers lying immediately above and below the layer of interest. To fit into this format, the equations for back radiation and water surface saturation vapor pressure were linearized. The equation

$$Q^* = QNA - Q_b - Q_e - Q_c \tag{62}$$

can then be put in the form

$$Q^* = F_1 - F_2T \tag{63}$$

where

$$F_1 = QNA - gamma_j - L^*(\alpha_j - e_a - 6.1 \times 10^{-4} P \cdot T_a) \tag{64}$$

$$F_2 = L^*(B_j + 6.1 \times 10^{-4} \cdot P) + sigma_j \tag{65}$$

$$L^* = \rho(a + bW)L \tag{66}$$

Note that in the above equations L is calculated based on T from the previous time interval.

Subroutine FLOWIN

Subroutine FLOWIN has three functions.

- a. Place the inflow at the correct level in the reservoir.
- b. Determine the thickness of the inflow zone.
- c. Vertically distribute the inflowing water and accompanying materials in the reservoir.

The subroutine treats each tributary separately. Note that it is impossible to simulate the horizontal propagation of the inflow into the reservoir because of the one-dimensional assumption.

Inflow placement. As shown in Figure 21, inflow placement is addressed in CE-QUAL-R1 by comparing the inflow density with each of the layer densities from the previous computational time step. The center line of inflow zone is assumed to be the layer that most closely matches inflow density. If the inflow density is less than any of the layer densities, the inflow is placed in the surface layer. Conversely, if inflow density is greater than any layer density, inflow is placed at the bottom of the reservoir.

Inflow thickness. If inflow enters a stratified region, the thickness of the inflow zone depends upon the inflow rate and the existing density gradient over the zone of inflowing water. The theoretical relationship between these quantities was derived by Yih (1958) and verified experimentally by Debler (1959). (Note that this work originally applied to outflows from stratified water bodies rather than to inflows. In the absence of other theoretical results, it has been employed in many reservoir models to calculate the thickness of inflow zones.) Based on these studies, CE-QUAL-R1 uses the following formula to calculate the thickness of the inflow zone:

$$d = 1.35\left(\frac{QL}{A}\,\frac{1}{\sqrt{g\,\frac{\Delta\rho}{\rho_o}}}\right)^{2/3} \qquad (67)$$

where

d = one-half the thickness of the inflow zone, m

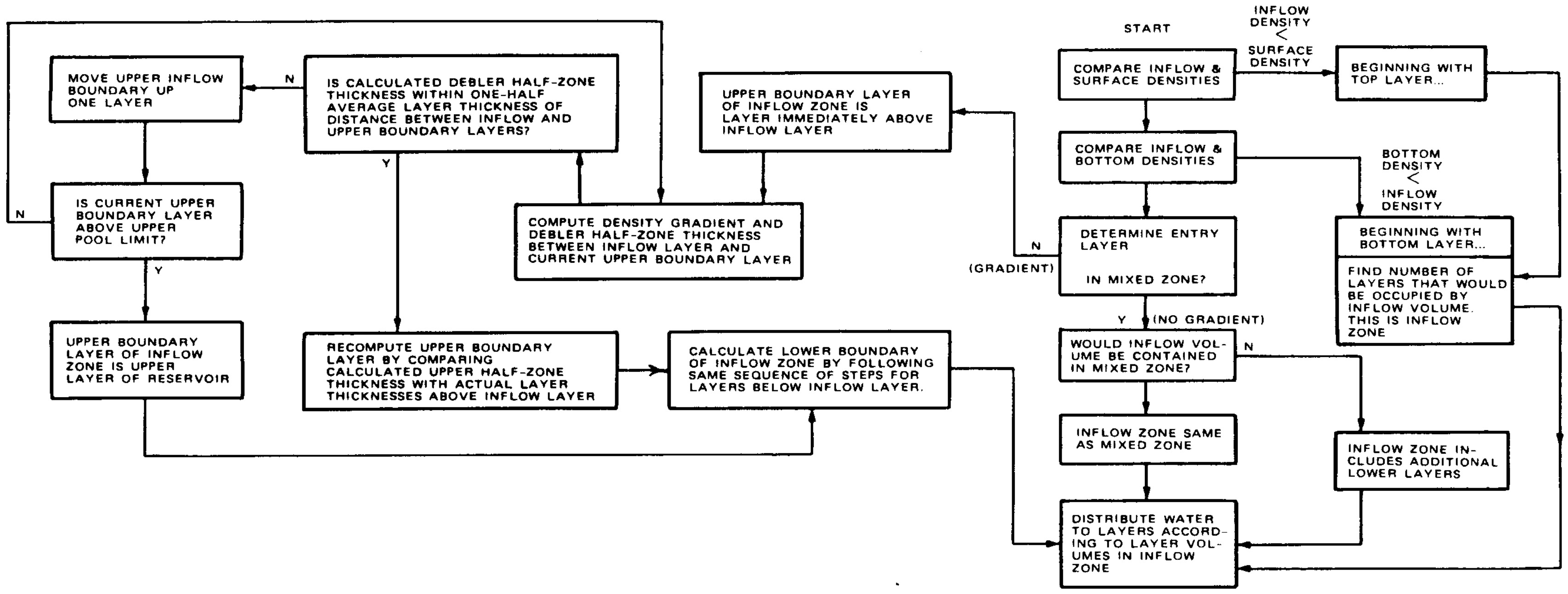


Figure 21. Subroutine FLOWIN

Q = inflow rate (QIN), m^3/sec

L = effective reservoir length (RLEN), m

A = lower horizontal surface area of the inflow layer (AREA), m^2

g = acceleration due to gravity, m/sec^2

$\Delta\rho$ = the actual difference in density between the inflow layer and the upper (lower) boundary layer of the inflow zone, kg/m^3. (Note that $\Delta\rho$ is always calculated so that it is a positive quantity, even though the density gradient with respect to elevation is always negative.)

ρ_o = the density of the inflow layer, kg/m^3

This half-zone thickness is calculated separately for upper and lower inflow half-zones (Figure 21).

Equation 67 is solved iteratively until the calculated half-zone thickness, based upon the actual inflow, Q, and the actual density difference, $\Delta\rho$, is within one-half average layer thickness of the distance between the mid-point elevations of the inflow and upper (lower) boundary layers. Then the boundary layer is reset by comparing the calculated half-zone thickness with actual layer thicknesses above (below) the inflow layer. If Equation 67 fails to converge before the upper pool limit (the reservoir bottom) is reached, then the upper (lower) boundary layer is set at the upper pool limit (reservoir bottom). The layers between and including the upper and lower boundary layers, determined as summarized above, constitute the inflow zone.

The constant in Equation 67 is determined from the formula $(1/2F)^{2/3}$, where F is the densimetric Froude number. The value of 1.35 used here is based on the theoretically derived value of $F = 1/\pi$ (Yih 1958). In the original formulation of the Froude number-inflow thickness relationship, from which Equation 67 was derived, the inflow volume was normalized per unit width. In CE-QUAL-R1, the effective reservoir length is used to calculate an effective width of the inflow layer (i.e., $W = A/L$). Thus, the quantity QL/A is the flow per unit width of the inflow layer.

When placed in a well-mixed region, where no density gradient exists (e.g., within the epilimnion or hypolimnion), the inflow is distributed throughout the mixed region. This may include the entire pool during periods of unstratified or weakly stratified density profiles.

Inflow distribution. Once the inflow zone is determined by any one of the above strategies, the inflowing water is distributed to individual layers according to a volume-weighting function expressed as:

$$\begin{bmatrix}\text{Layer}\\ \text{Inflow}\\ \text{m}^3\text{/hr}\end{bmatrix} = \begin{bmatrix}\text{Tributary}\\ \text{Inflow}\\ \text{m}^3\text{/hr*}\end{bmatrix} \cdot \begin{bmatrix}\text{Layer}\\ \text{Volume}\\ \text{m}^3\end{bmatrix} \div \begin{bmatrix}\text{Inflow}\\ \text{Zone}\\ \text{m}^3\end{bmatrix} \tag{68}$$

This formulation assumes a constant inflow velocity over the entire inflow zone. Influx of material carried into each layer by its inflow is expressed as:

$$\begin{bmatrix}\text{Materials}\\ \text{Inflow}\\ \text{Rate}\\ \text{g/hr}\end{bmatrix} = \begin{bmatrix}\text{Layer}\\ \text{Inflow}\\ \text{m}^3\text{/hr}\end{bmatrix} \cdot \begin{bmatrix}\text{Materials}\\ \text{Concentration}\\ \text{g/m}^3\end{bmatrix} \tag{69}$$

and influx of thermal energy is expressed as:

$$\begin{bmatrix}\text{Thermal}\\ \text{Energy}\\ \text{Inflow}\\ \text{Rate}\\ \text{Kcal/hr}\end{bmatrix} = \begin{bmatrix}\text{Layer}\\ \text{Inflow}\\ \text{m}^3\text{/hr}\end{bmatrix} \cdot \begin{bmatrix}\text{Inflow}\\ \text{Temperature}\\ ^\circ\text{C}\end{bmatrix} \cdot \begin{bmatrix}\text{Inflow}\\ \text{Density}\\ \text{kg/m}^3\end{bmatrix} \cdot \begin{bmatrix}\text{Specific}\\ \text{Heat}\\ \text{Kcal/kg/}^\circ\text{C}\end{bmatrix} \tag{70}$$

---

* The actual inflow is in cubic metres per second and converted to cubic metres per hour internally.

Scheduled operations subroutines

Because release water quality is influenced by the in-pool withdrawal zone that is functionally dependent on the discharge rate, it may be necessary to specify the instantaneous (or hourly) outflow rate rather than the daily average outflow rate at some projects. For example, discharge rates within a day can be significantly greater than the daily average outflow rate at peaking hydropower projects. By using a daily time step and specifying discharge rates and discharge periods within each day, the actual (instantaneous) flow rate can be used to accurately compute the withdrawal zone while computing the water budget and changes in water quality using a daily time step. The term "scheduled operations" refers to the fact that flow rates and periods within a day are specified.

Pumped-storage operations are often associated with peaking hydropower projects. Pumped-storage inflow jets can cause significant entrainment and mixing of ambient reservoir water, which can result in redistribution of in-pool water quality. The effects of pumped-storage inflows can be simulated as an option of scheduled operations. The appropriate subroutines to simulate the pumped-storage inflow entrainment, mixing, and placement have been included in the code and are also presented within this section on scheduled operations.

CE-QUAL-R1 simulates scheduled operations and pumped-storage effects with a set of subroutines organized as follows:

Subroutine	Purpose
OPREAD	Reads the operations schedule in the data set, which can include pumped-storage operations.
CONTRL	Controls the calling of other subroutines for outflow (generation) and pumpback computations.
PUMPKN	Controls the calculation of pumped-storage inflow entrainment water volumes.
ENTRN	Determines buoyancy and other attributes of the pumped-storage inflow jet.

Subroutine	Purpose
WBJET	Determines distribution of pool volumes entrained when the jet is weakly buoyant.
SBJET	Determines distribution of pool volumes entrained when the jet is strongly buoyant.
RUNGS	Used by SBJET to determine jet trajectory.
DERIVE	Used by RUNGS to determine jet dynamics.
INFLOP	Determines placement in the water column of total pumped-storage inflow volume (includes jet and entrained ambient water volumes).
BUCKET	Simulates in-pool vertical mixing induced by pumped-storage inflow.
REREG	Computes simplified water and material budgets for the afterbay. This subroutine is called after all variables in the main pool have been calculated.

The actions of subroutine OPREAD are illustrated in Figure 22. Straightforward reading and storage of the operations schedule takes place. As presently configured, four individual peaking generation and/or pumpback events can be specified for each day. For each event, flow rate, flow period, port number, and type of operation (generation G or pumpback P) are specified. Note that when CE-QUAL-R1 is operated in scheduled mode, the only admissible computation time step is 24 hr.

OPREAD makes use of a "change-day" concept that can simplify data preparation. When an operations schedule is invariant over a period of days, the data set need reflect only the first such day. In subroutine CONTRL, the schedule for days remaining in the period is patterned after the first day. The change-day is the first day of the period of invariant operation and is read by OPREAD.

Subroutine CONTRL determines the appropriate computation sequence for each generation or pumpback event (see Figure 23). A generation event views all outflow as occurring through a single specified port. Likewise, pumped-storage inflows enter at a specified elevation. Ports

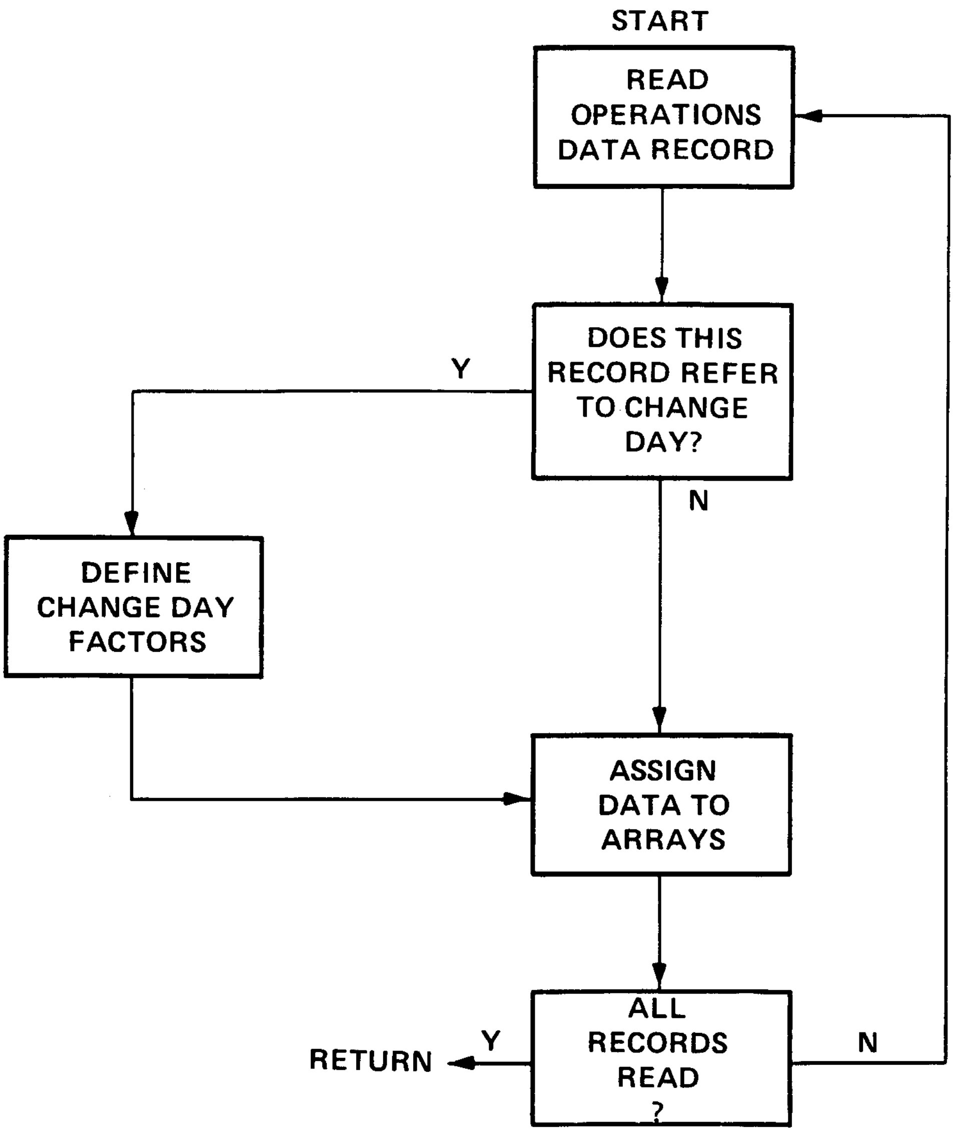


Figure 22. Flowchart representing subroutine OPREAD

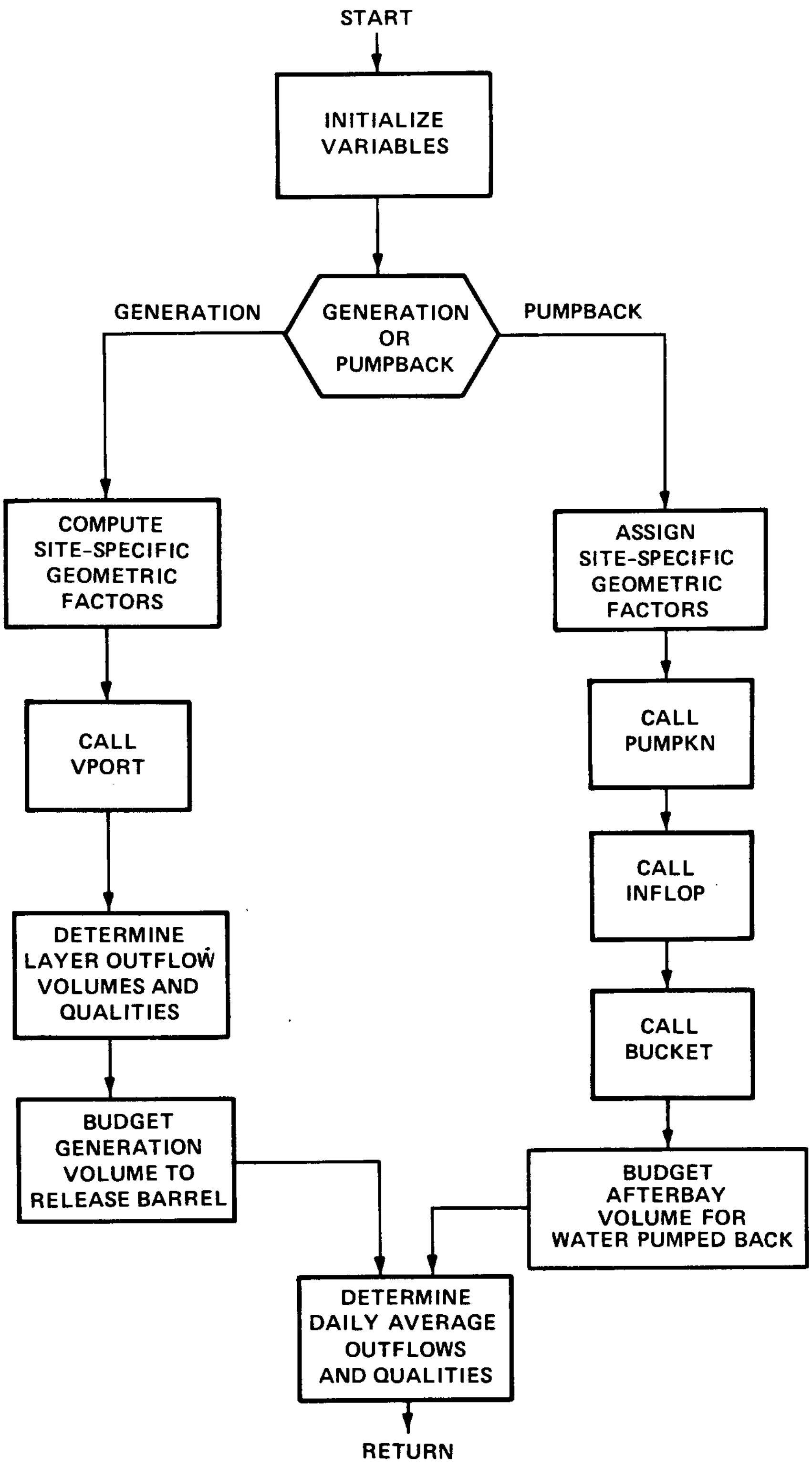


Figure 23. Flowchart representing subroutine CONTRL

can be different from one event to another. The appropriate withdrawal and pumped-storage inflow subroutines are called from CONTRL.

Mixing created by pumped-storage inflows is basically handled in four steps. First the characteristics of the inflow jet and ambient stratification are used to determine the amount and vertical distribution of the entrainment of ambient water in the jet. This is necessary because the amount of entrainment caused by an inflow jet can be significant. Second, the volume and qualities of water entrained during the pumpback period are mixed with the pumped-storage inflow volume to produce a new total volume with new constituent concentrations. This total volume is placed into the neutrally buoyant layer of the pool. Third, to account for the additional vertical mixing that occurs with density current intrusions such as this, the thickness of the intrusion zone is computed and a small amount of mixing is accomplished in this zone. Fourth, to provide mass continuity and the withdrawal effect of entrainment, the entrainment flow obtained in the first step is treated as an additional outflow (withdrawal) event and is handled in the same manner as reservoir outflow.

Subroutine PUMPKN (Figure 24) sets the stage for determination of water volume entrained by the pumpback jet and ensures that computed flows are properly scaled so contributory layer volumes sum properly to the total entrained volume.

Subroutine ENTRN (Figure 25) determines pertinent attributes of the pumpback jet and the ambient environment into which the jet is placed. Attributes of interest are the buoyancy and momentum of the jet, related respectively to the difference in density between jet and ambient and to the jet velocity. The density gradient across the pumpback port serves as a measure of stratification. These factors contribute to the calculation of characteristic length scales and ratios which, in turn, classify the jet as strongly or weakly buoyant.

Subroutine WBJET (Figure 26) computes entrainment distribution for weakly buoyant jets by use of experimental results presented by Roberts and Dortch (1985). Given jet source properties and ambient stratification, the subroutine computes entrained volume flux for each layer.

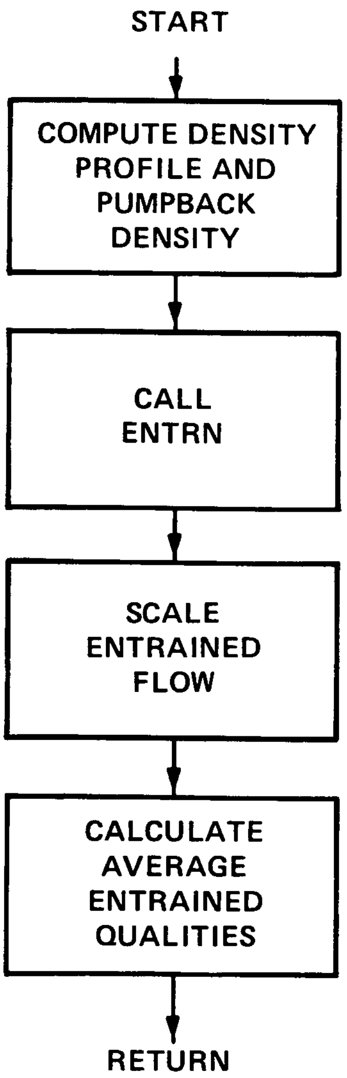


Figure 24. Flowchart for subroutine PUMPKN

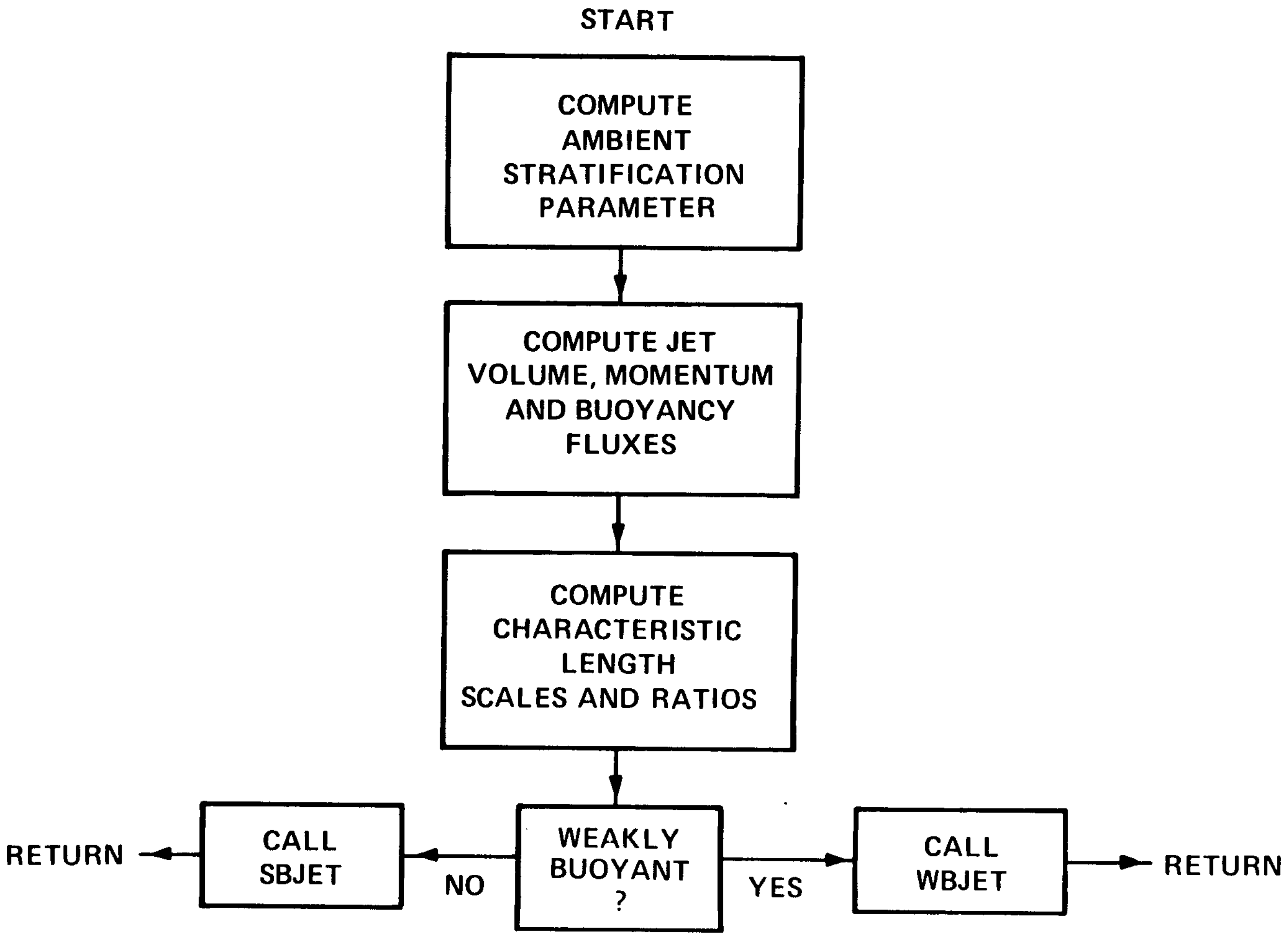


Figure 25. Flowchart for subroutine ENTRN

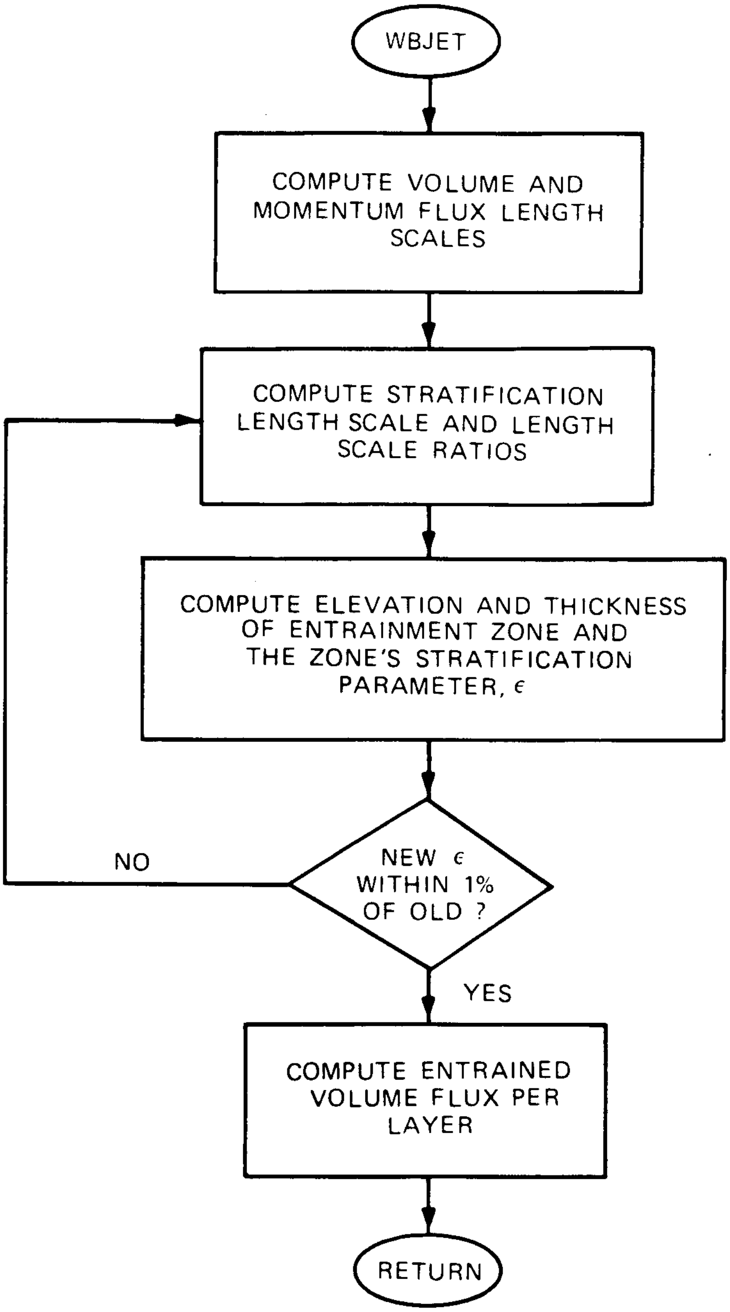


Figure 26. Flowchart for subroutine WBJET

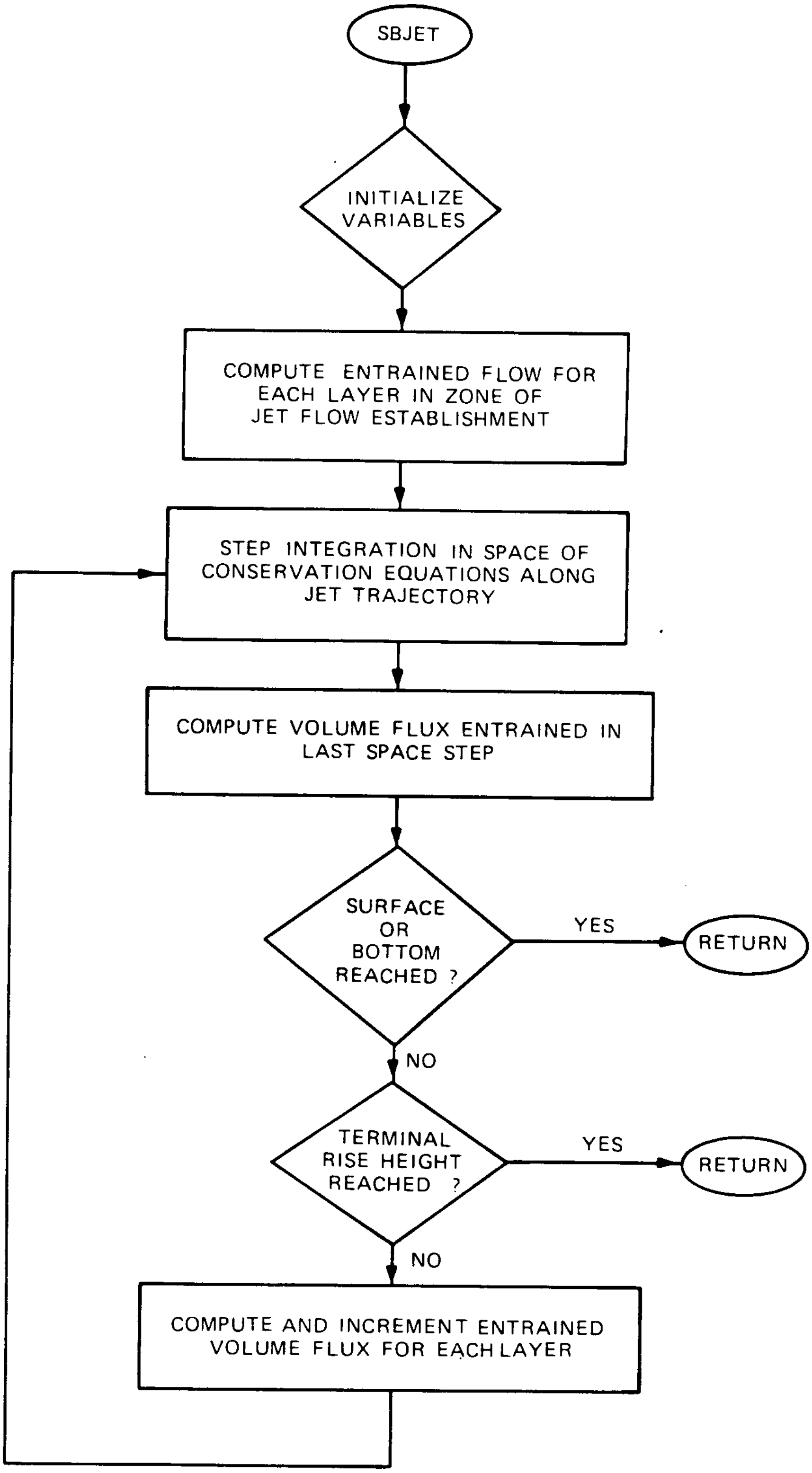


Figure 27. Flowchart for subroutine SBJET

Subroutine SBJET (Figure 27) computes entrainment distribution for strongly buoyant jets by use of a version of the Fan and Brooks (1969) integral model as modified by Roberts and Dortch (1985). Given jet source properties and ambient stratification, the subroutine computes entrained volume flux for each layer. This subroutine uses subroutines RUNGS and DERIVE to solve equations for jet trajectory.

Subroutine INFLOP (Figure 28) mixes pumpback and entrained water volumes and determines the layer in the water column into which this total volume is placed. This determination is based on a density match.

Subroutine BUCKET (Figure 29) seeks to account for vertical mixing that occurs with a pumped-storage inflow density current. This effect is simulated by mixing among layers within the intrusion zone. Thickness of the intrusion zone is first computed with a balance of momentum and hydrostatic pressure (Dortch et al. 1976). A mixing coefficient is defined for each layer within the zone by means of an exponential equation (Fontane et al. 1977). The amount of each layer to be mixed is the product of the mixing coefficient and the layer volume. Contributions from all layers within the zone are mixed together (in a "bucket"), and the mixed water is returned to the layers. Finally, each layer is individually mixed with the water returned to that layer.

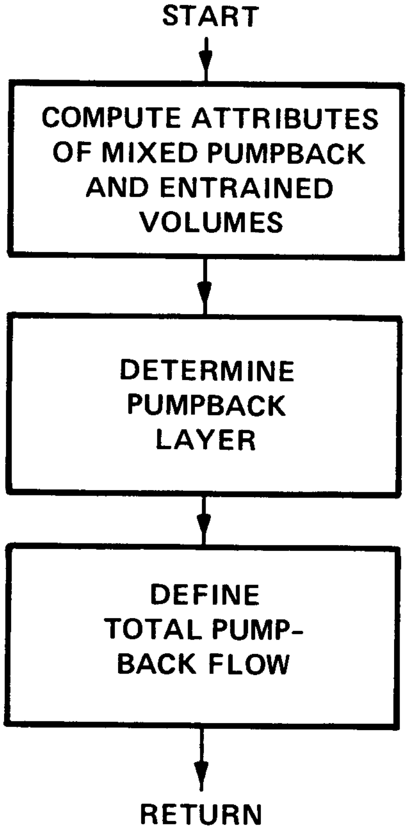


Figure 28. Flowchart for subroutine INFLOP

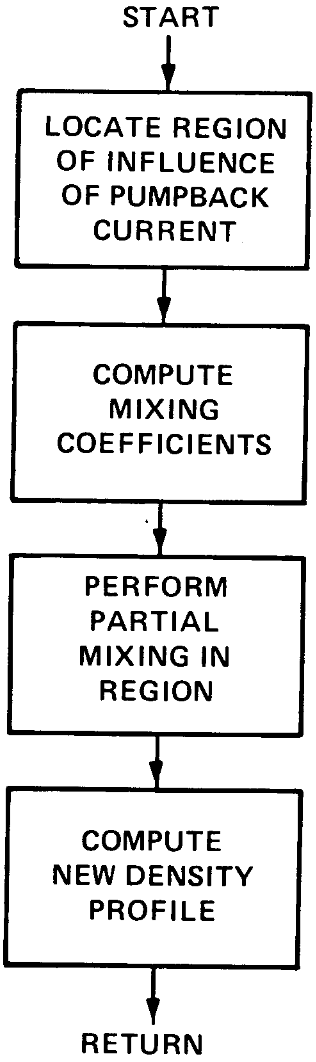


Figure 29. Flowchart for subroutine BUCKET

Subroutines OUTVEL, VPORT, and VWEIR

Layer outflows are determined by subroutine OUTVEL (Figure 30). This subroutine is called initially to calculate the vertical distribution of outflow. After all new variable concentrations in the pool are calculated, it is again called to withdraw flow from layers and compute release qualities. Subroutine OUTVEL calls subroutine VPORT (Figure 31) when port releases are involved, and/or subroutine VWEIR (Figure 32) when weir flows are involved. Total port flows for subroutine VPORT could have been specified by the user or generated from subroutine PDECIDE. Sketches representing the velocity distribution of ports and weirs are shown in Figures 33a and 33b (for ports) and Figure 32c (for weirs).

Analysis of port flows is based on results of laboratory experiments performed by Bohan and Grace (1973) and was subsequently updated to reflect approach flow obstructions by Smith et al. (1987). Their results indicate that a (usually nonsymmetric) withdrawal zone is associated with each discharging port. Its limits are found by solving for Z_i in the equation:

$$C_H C_{Vi} Q - Z_i^2 \sqrt{\frac{\Delta\rho}{\rho} g \cdot Z_i} = 0 \tag{71}$$

where

C_H = 180/θ horizontal obstruction coefficient, dimensionless;
θ = horizontal withdrawal angle, deg

C_{vi} = vertical obstruction coefficient, dimensionless

$$C_{v1} = 1$$

$$C_{v2} = \frac{\left(1 = \frac{b/D}{1-b/D}\right)^3}{\frac{1}{2}\left(1 + \frac{1}{\pi} \sin\left(\frac{b/d}{1-b/D}\pi\right) + \frac{b/D}{1-b/D}\right)} \tag{72}$$

$$C_{v3} = 1$$

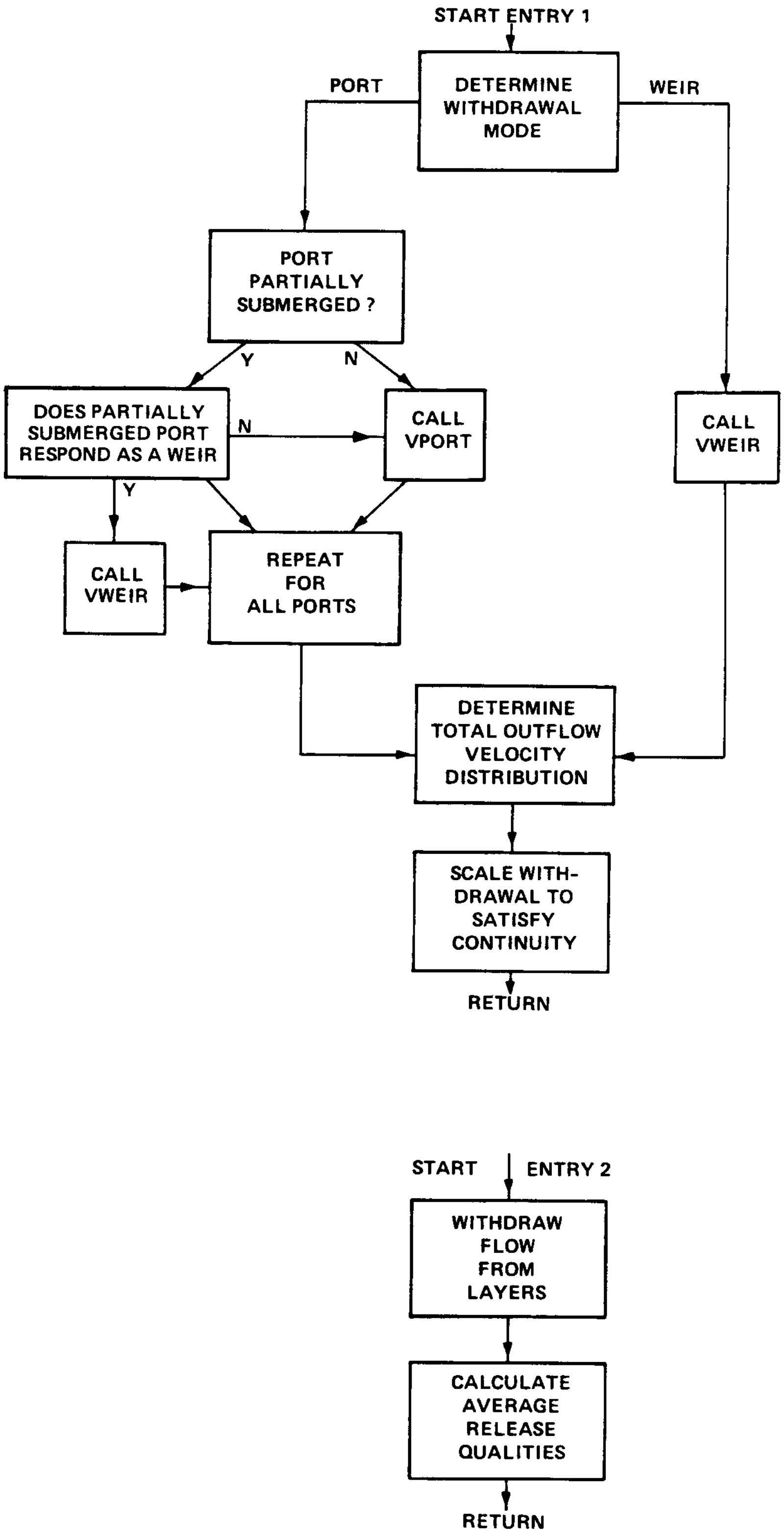


Figure 30. Flowchart for subroutine OUTVEL

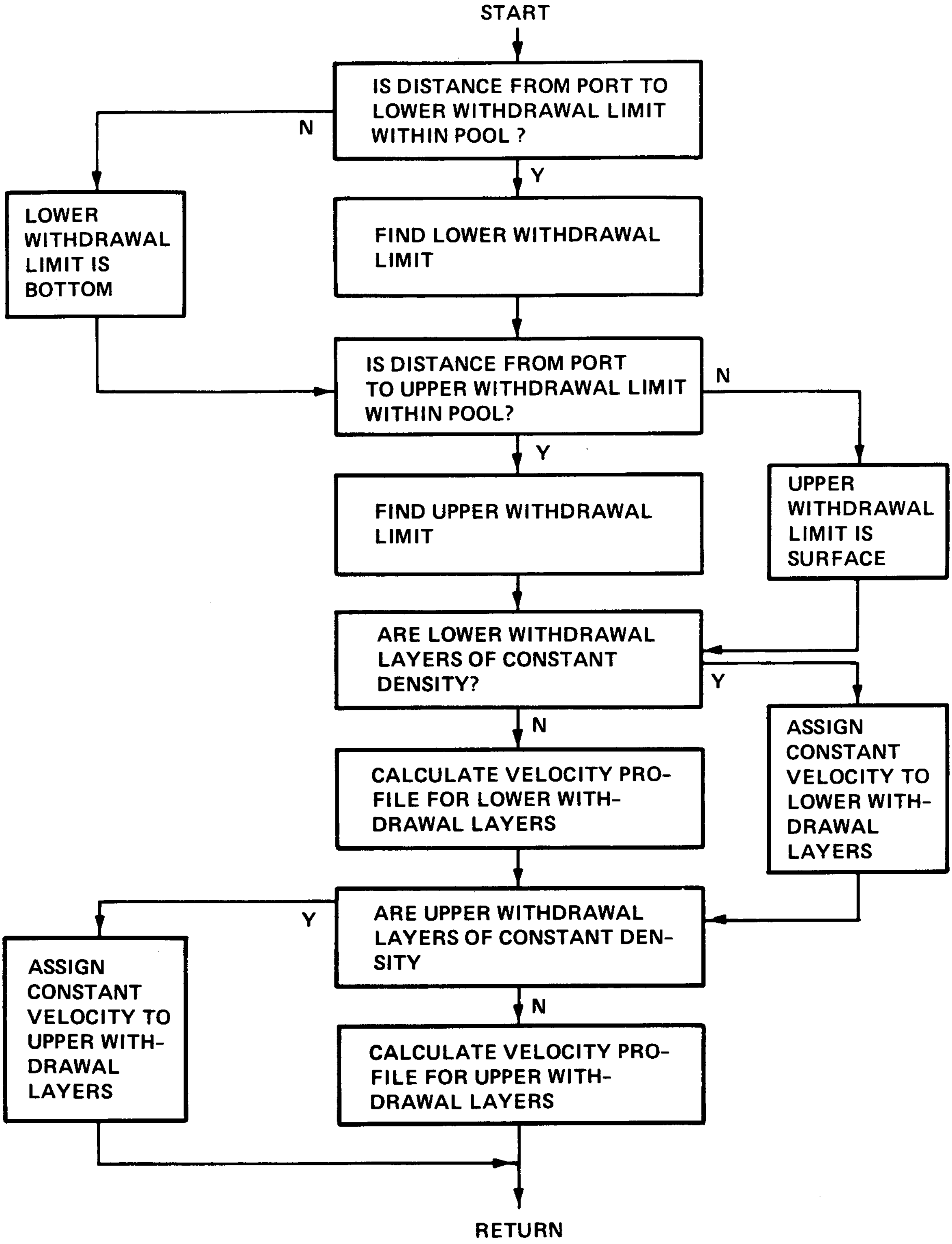


Figure 31. Flowchart for subroutine VPORT

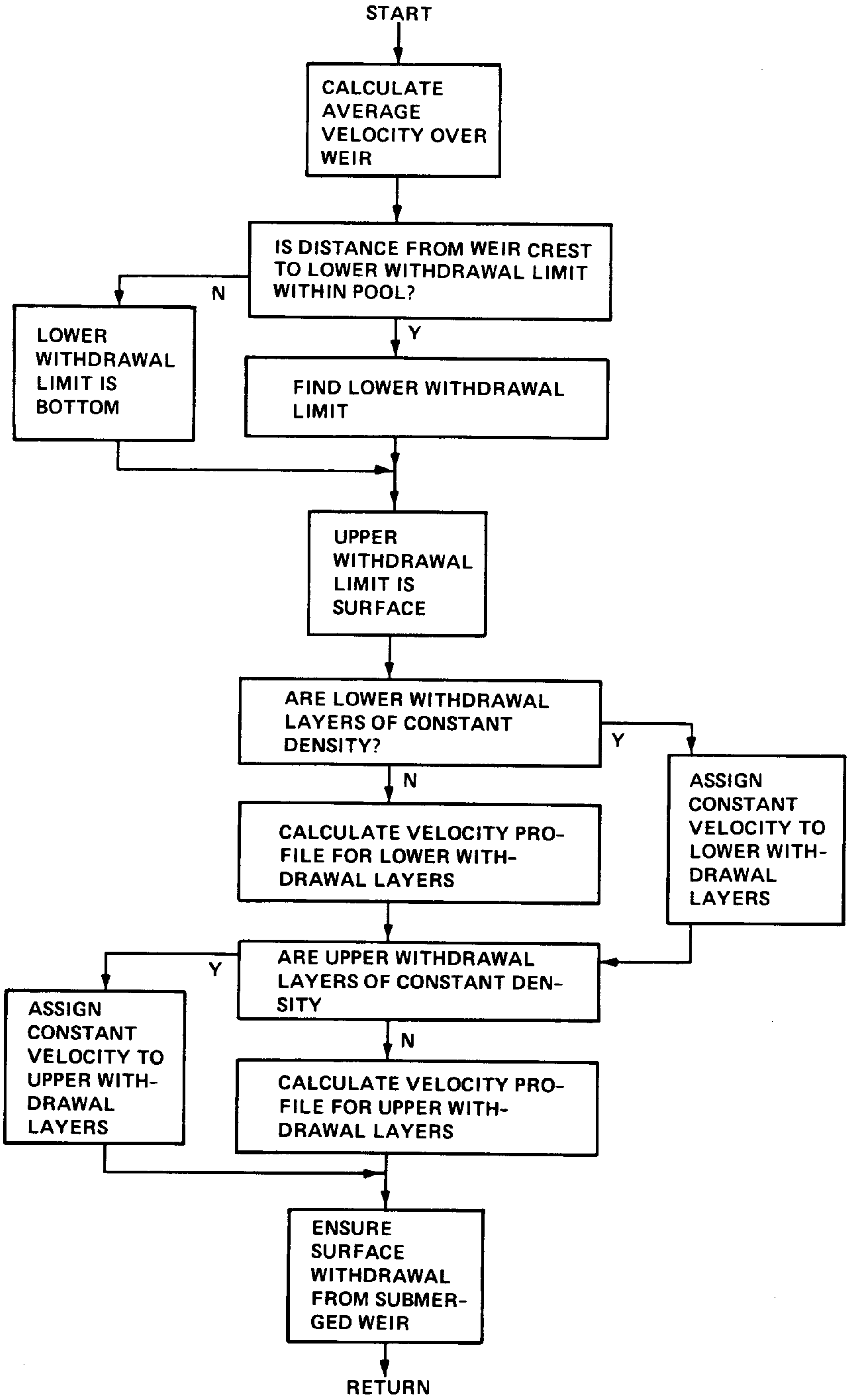
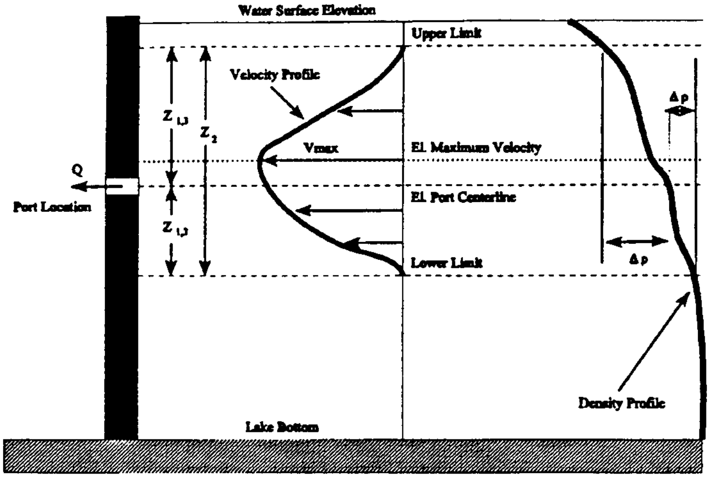
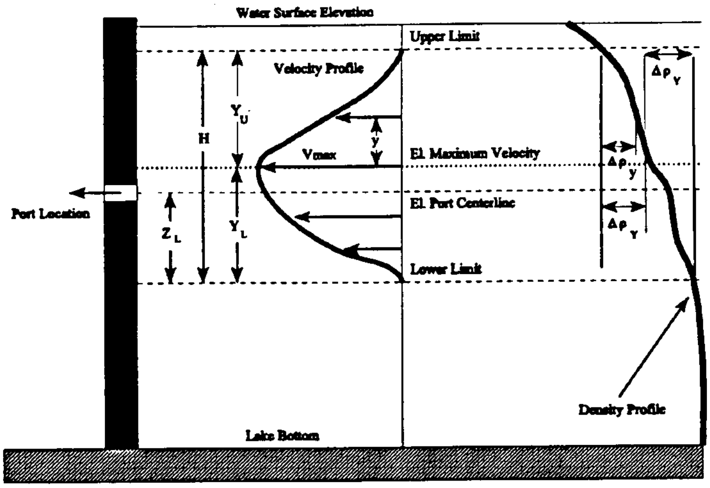


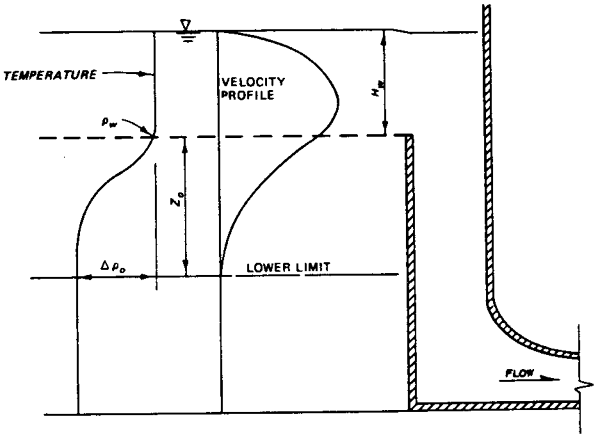
Figure 32. Flowchart for subroutine VWEIR



a. Maximum velocity and velocity distribution determination



b. Variables for port withdrawal



c. Weir withdrawal

Figure 33. Definition sketches

i = 1 for flow fields with two free withdrawal limits
= 2 for flow fields with one free withdrawal limit
= 3 for flow fields with no free withdrawal limits
Q = discharge through port, m^3/hr
Z_1 = distance from port to upper (lower) withdrawal limit, m
Z_2 = distance from bounded withdrawal limit to free withdrawal limit, m
Z_3 = distance from port to imaginary upper (lower) withdrawal limit, m
Δ_ρ = density difference between port and upper (lower) withdrawal limit, kg/m
ρ = water density at port, kg/m
g = acceleration because of gravity, m/hr^2
b = distance from port to interfered withdrawal limit, m
d = distance from interfered withdrawal limit to free withdrawal limit, m

Within these limits, the profile of velocities of outflowing waters is approximately parabolic. Depending on the density gradient near the port, the maximum velocity may or may not coincide with the location of the port center line. The location of the maximum velocity is computed from the following equation:

$$\frac{Y_L}{H} = \sin^2\left(\frac{\pi}{2} \cdot \frac{Z_L}{H}\right) \tag{73}$$

where

Y_L = distance from lower withdrawal limit to elevation of maximum velocity, m
H = total vertical thickness of withdrawal zone, m
Z_u = distance from lower withdrawal limit to port, m

Within the withdrawal zone, the velocity profile is given by:

$$u = u_m\left[1 - \left(\frac{y \cdot \Delta\rho_y}{Y \cdot \Delta\rho_m}\right)\right]^2 \tag{74}$$

where

u = velocity, m/sec

u_m = maximum velocity, m/sec

$\Delta\rho_y$ = density difference from elevation of velocity being computed to elevation of maximum velocity, kg/m^3

y = distance from elevation of velocity being computed to elevation of maximum velocity, m

Y = distance from elevation of maximum velocity to elevation of upper (lower) limit, m

$\Delta\rho_m$ = density difference from elevation of maximum velocity to elevation of upper (lower) limit, kg/m^3

Figures 33a and 33b depict the relationships among the variables used in Equations 71-74. When two or more selective withdrawal zones overlap, superposition is used to get the total velocity profile.

Withdrawal characteristics for a weir-type outlet are computed in subroutine VWEIR. Analysis of weir flow is based on the results of Bohan and Grace (1973), Harleman and Elder (1965), and experiments conducted at the WES more recently. For withdrawal over a weir, the upper limit of withdrawal is assumed to be the water surface, and the lower limit of withdrawal is computed from

$$\frac{Q}{L} - \left(C - \frac{DH_w}{Z_o + H_w}\right)\sqrt{\frac{\Delta\rho_o}{\rho_w}\, g\, (Z_o + H_w)^3} = 0 \tag{75}$$

where

C = dimensionless coefficient, $C = 0.54$ for $Z_o \geq H_w$
$C = 0.78$ for $Z_o < H_w$

C = dimensionless coefficient, $D = 0.0$ for $Z_o \geq H_w$
$D = 0.70$ for $Z_o < H_w$

Q = discharge over weir, m^3/hr

L = weir length opening, m

H_w = vertical distance from water surface to weir crest, m

Z_o = vertical distance from weir crest to lower limit of withdrawal, m

$\Delta\rho_o$ = density difference between elevation of weir crest and lower limit of withdrawal, kg/m^3

ρ_w = density at elevation of weir crest, kg/m^3

The above variables are shown in a definition sketch (Figure 33C). Equation 75 requires an iterative solution for Z_o .

Layer discharges for flow over a weir are determined according to weir type in subroutine VPORT. For a submerged weir, the velocity profile below the point of maximum velocity is given by

$$u = u_m \left[1 - \left(\frac{y \cdot \Delta\rho}{Y \cdot \Delta\rho_m} \right) \right]^3 \tag{76}$$

and above the point of maximum velocity by

$$u = u_m \left[1 - \left(\frac{y \cdot \Delta\rho}{Y \cdot \Delta\rho_m} \right)^2 \right] \tag{77}$$

For a free weir, the maximum velocity occurs at the surface. The velocity profile below the surface is given by

$$u = u_m \left[1 - \left(\frac{y \cdot \Delta\rho}{Y \cdot \Delta\rho_m} \right)^p \right] \tag{78}$$

where the exponent p is defined empirically in terms of the free weir discharge coefficient as 4.35 minus the value 1.04 times an input coefficient (COEF).

Subroutine LAYERS

Water balance, layer, and constituent concentration adjustment occur once each computational interval. Subroutine FLOWIN determines how inflowing water is partitioned among individual layers. Composition of outflows from individual layers is determined by subroutine OUTVEL for continuous operations and by subroutine CONTRL for scheduled operations. Once these tasks have been accomplished, subroutine LAYERS performs a materials balance for each layer and adjusts layer geometry accordingly.

When there is a net increase in water, layer volume expands as required; when there is a net decrease, layer volume diminishes. If volume diminishes to zero, water is withdrawn from the next higher layer. Beginning at the bottom, each layer is examined and its new volume determined. In terms of the known elevation of its lower boundary and its new volume, the elevation of the upper boundary is calculated. This elevation becomes the known lower-boundary elevation of the next higher layer. When the layers have been resized, the sum of their heights is, by definition, the water surface elevation.

Layers that become too large or too small can eventually lead to problems of resolution or numerical errors. This situation is circumvented by resizing layers that have exceeded user-specified height limits. A layer that has exceeded the maximum thickness is divided in half; one that has diminished below the minimum thickness is merged with its upper neighbor. Figure 34 illustrates these points. When layers are divided or merged, their geometric attributes are recalculated and all materials and energy concentrations are redefined. Layer sizes are repeatedly scanned for division or merger until all sizes are within the specified limits.

Variables associated with the reservoir bottom are not expressed on a volumetric basis but rather on an areal one. As layers are resized, the mass of these variables is also proportioned to reflect the appropriate densities for the resized layer to which they are adjacent. If the water surface elevation decreases, variables in the dewatered drawdown zone are no longer considered in the computations. If the

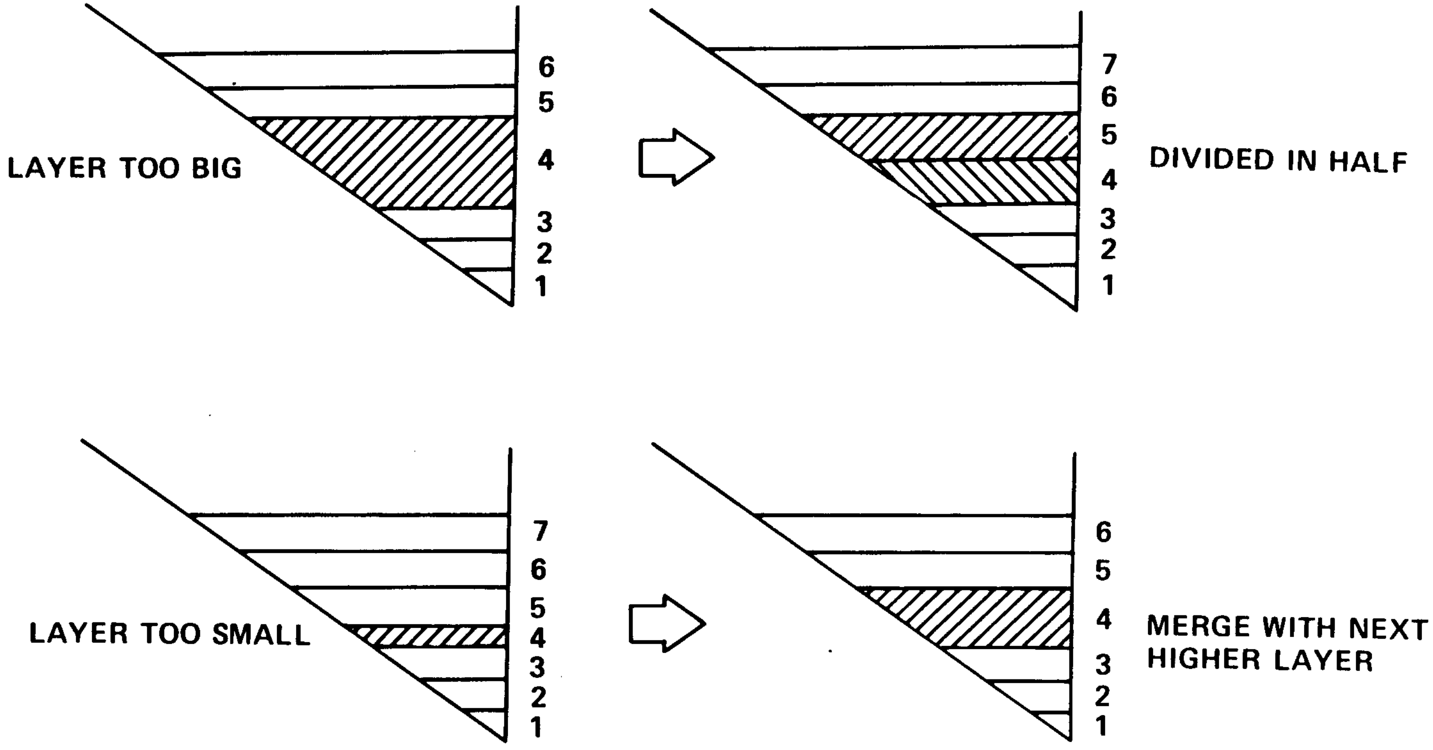


Figure 34. Resizing layers

water surface elevation increases and inundates new areas, the sediment density in this new area is equated to the sediment density adjacent to the surface layer in the previous computational interval.

Subroutine MIXING

Vertical temperature profiles in lakes typically show a well-mixed surface region. Depending on hydrometeorological conditions, the depth of this upper mixed region may vary from less than 1 m on calm, sunny days to the maximum lake depth during periods of overturn. The purpose of subroutine MIXING is to determine the depth of the upper mixed region using an integral energy approach.

Integral energy models assume that a lake is composed of two regions: a well-mixed surface region overlying a stable lower region (Figure 35). Depth of the mixed region is determined by comparing turbulent kinetic energy (TKE) influx from wind shear and convective mixing in a time increment, Wt , to work required (W_L) to lift a layer of metalimnetic water from its position at the bottom of the mixed region to the center of mass of the mixed region. If TKE is larger than W_L , entrainment occurs and yields an increase in the depth and volume of the mixed region. Entrainment continues until TKE is no longer larger than W_L . If the starting TKE is smaller than W_L , no entrainment occurs.

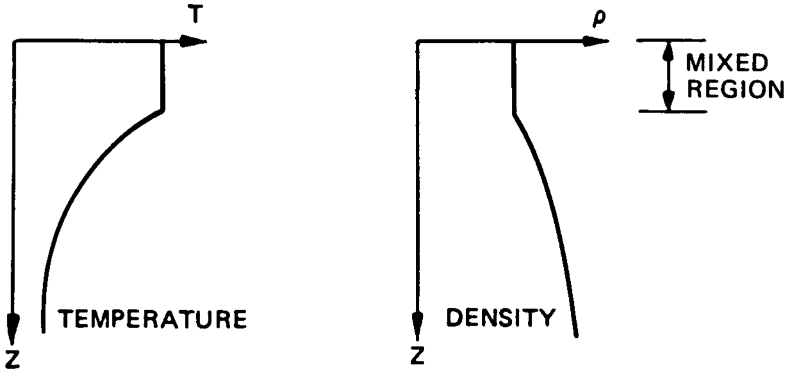


Figure 35. Integral energy lake structure

Subroutine MIXING computes:

- a. Rate of wind work.
- b. TKE released by convection.
- c. Entrainment efficiencies.
- d. Entrainment.

Wind work. When wind blows over a water surface, the resulting shear stress creates TKE by direct production, breaking of waves, and interaction with mean motion, among other processes. TKE available for possible entrainment from wind shear can be estimated by

$$TKE_w = \int_{A_s} C W_* \tau \Delta t dA \qquad (79)$$

in which

TKE_w = wind shear turbulent kinetic energy (TKEW), kg-m^2/sec^2
A_s = water surface area (AREA(NUME+1)), m^2
C = empirical coefficient (SHELCF)
W_* = shear velocity of water (SVEL), m/sec
τ = shear stress at the air-water interface (TAU), kg/m-sec^2
Δt = time step (NHOI), sec

The shear velocity, W_*, is defined by

$$W_* = \sqrt{\frac{\tau}{\rho_w}} \qquad (80)$$

in which ρ_w = water density, kg/m^3.

The shear stress at the air-water interface is given by

$$\tau = \rho_a C_d W^2 \qquad (81)$$

where

ρ_a = air density (1.177 kg/m^3)

C_d = dimensionless drag coefficient (CD)
W = wind speed (XWIND), m/sec

The drag coefficient is taken from Wu (1969):

$$C_d = \begin{cases} 0.0005\sqrt{W} & W < 15 \text{ m/sec} \\ \\ 0.0026 & W \geq 15 \text{ m/sec} \end{cases} \tag{82}$$

This relationship is shown in Figure 36.

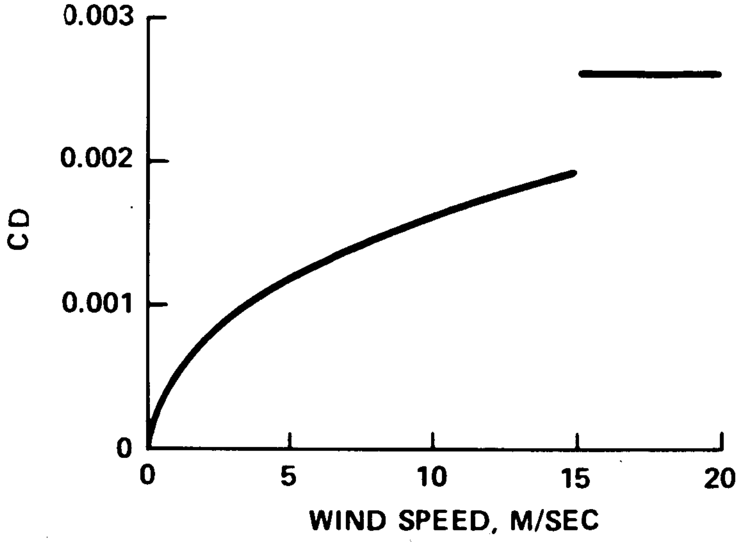


Figure 36. Drag coefficient

In many lakes, wind stress does not act on the entire surface area because of sheltering effects from surrounding terrain. Variable TKE_w, Equation 79, is therefore modified by a site-dependent sheltering coefficient that is the ratio of the water surface area exposed to the wind to total water surface area. The coefficient has a maximum value of 1 when sheltering is insignificant.

<u>Penetrative convection.</u> TKE is also produced by convection currents during periods of cooling. It is assumed to be proportional to net heat flux. The TKE available for possible entrainment from overturn convection can be estimated by

$$TKE_c = -C_c \cdot Q_n \cdot A_s \cdot Z_{mix} \cdot g \cdot \alpha \, \Delta t / c_p \qquad (83)$$

in which

TKE_c = convective turbulent kinetic energy (TKEC), kg - m^2/sec^2
C_c = empirical calibration coefficient (PEFRAC)
Q_n = net heat flux across the air-water interface (QNET), Kcal/m^2 - sec
Z_{mix} = depth of the mixed region (ZMIX), m
g = acceleration due to gravity, m/sec^2
α = coefficient of thermal expansion for water (CTHRMX), per °C
c_p = specific heat of water, Kcal/kg - °C

In Equation 83, TKE_c equals 0 when Q_n is positive. Total TKE available for entrainment is

$$TKE = TKE_w + TKE_c \qquad (84)$$

Mixing efficiencies. Because mixing processes are dissipative and not efficient and because different processes dominate at different times, Equation 84 must be modified. Based on parameterization of the TKE balance at a density interface, Bloss and Harleman (1980) determined a Richardson number function, $f(R_i)$, to modify TKE:

$$f(R_i) = 0.057 \, R_i \left(\frac{29.46 - \sqrt{R_i}}{14.20 + R_i} \right) \qquad (85)$$

in which the Richardson number $R_i = Z_{mix} g \Delta\rho / \rho_w W_*^2$; $\Delta\rho$ is the density difference across the interface. Total TKE available for entrainment is

$$TKE = TKE \cdot f(R_i) \qquad (86)$$

Entrainment. Prior to calculating entrainment, a temporary temperature (density) structure is computed for the computational interval. This structure considers internal absorption of solar radiation, net heat transfer at the air-water interface, inflows, and outflows. It does not consider mixing between layers.

Work, W_L, required to entrain or lift the mass, $\Delta\rho \cdot \Delta V$, from its position immediately below the mixed region to the center of mass of the mixed region is

$$W_L = \Delta\rho \cdot \Delta V \cdot g \cdot (Z_{mix} - Z_g) \tag{87}$$

in which

W_L = entrainment work (WL), $kg - m^2/sec^2$

$\Delta\rho$ = density difference between the mixed region and underlying layer, kg/m^3

ΔV = incremental volume to be entrained, m^3

g = acceleration due to gravity, m/sec^2

Z_{mix} = center of mixed layer, m

Z_g = depth of the center of mass of the mixed layer, m

The depth of the mixed region is calculated after comparing Equations 86 and 87. If TKE is larger than W_L, entrainment occurs and Z_{mix} increases. Entrainment continues until TKE is no longer larger than W_L.

Subroutine HEAT

Subroutine HEAT is called from subroutine MIXING to calculate the solar radiation absorbed in each layer. This energy forms the concentration independent term used in S/R TMPRTR to compute the temperature structure of the reservoir.

Solar radiation is absorbed at the water surface and selectively with depth depending on the wavelength of the light, properties of the water, and the matter suspended in the water. This absorption is usually assumed to be exponential with depth (i.e., Beer's Law), but surface effects result in minor discrepancies in the top metre or so of a reservoir (Figure 37). To incorporate these discrepancies in the model, a certain fraction, β , of the solar radiation, Q_{ns} , is assumed to be absorbed in a 0.6-m-thick surface zone. The remaining fraction $(1 - \beta)Q_{ns}$ is absorbed exponentially with depth with an extinction coefficient, η . That is

$$\Phi(Z) = (1 - \beta)Q_{ns}e^{-\eta Z*} \tag{88}$$

where

$\Phi(Z)$ = flux of solar radiation at depth Z (SWS), kcal/m^2/sec

$Z*$ = water depth starting 0.6 m below the surface (i.e., $Z* = Z - 0.6$ m)

These fluxes are illustrated in Figure 38.

The amount of solar radiation absorbed in any model layer and therefore available for heating water in that layer is equal to the difference between fluxes entering and leaving that layer. For example, in the surface layer, the flux Q_{ns} enters the layer and the flux $(1 - \beta)Q_{ns}$ leaves. The quantity of energy absorbed in the surface layer is

$$\text{SW(NUME)} = Q_{ns}\text{AREA(NUME + 1)} - (1 - \beta)Q_{ns}\text{AREA(NUME)}e^{-\eta Z*} \tag{89}$$

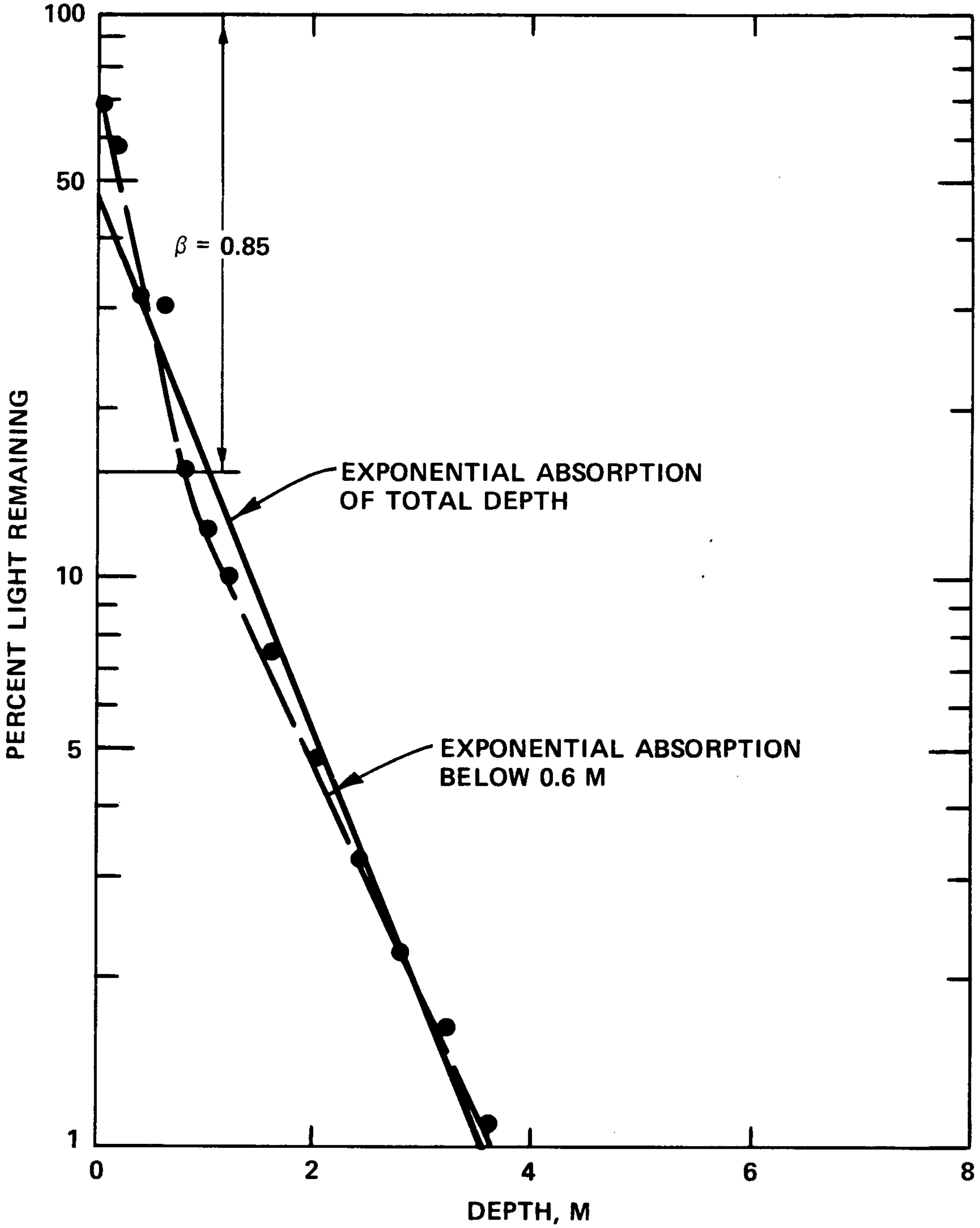


Figure 37. Deviation from exponential absorption in the surface layer, C. J. Brown Lake, Ohio

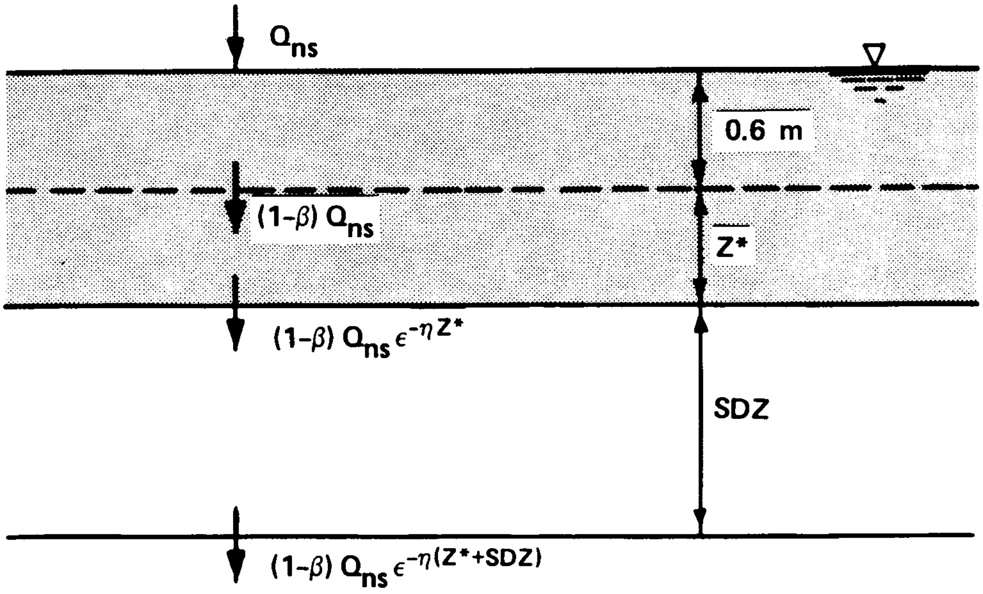


Figure 38. Solar radiation fluxes with depth

where

SW(NUME) = energy absorbed in a surface layer NUME, Kcal/sec

AREA(NUME + 1) = surface area of the reservoir, m^2

AREA(NUME) = lower boundary area of top layer, m^2

For the general case of a layer, I, of thickness SDZ(I) that is bounded by surface AREA(I + 1) and AREA(I), and located 0.6 m + Z m below the water surface, the absorbed energy is

$$\mathrm{SW(I)} = (1 - \beta)Q_{ns}e^{-\eta Z^*}\,\mathrm{AREA(I + 1)} - (1 - \beta)Q_{ns}e^{-\eta(Z^* + \mathrm{SDZ(I)})}\mathrm{AREA(I)} \tag{90}$$

The extinction coefficient, η, is dependent on the quantity and type of matter suspended in the water. The extinction coefficient is therefore partitioned into two parts:

$$\eta = \eta_w + \Sigma k_j C_j \tag{91}$$

where

η = extinction coefficient (TEXCO), 1/m

η_w = background extinction coefficient of clear water (EXCO), 1/m

k_j = self-shading coefficient for constituent C_j (EXTINP,EXTINS), $1/m/(g/m^3)$

In CE-QUAL-R1, it is assumed that suspended solids, algae, zooplankton, and detritus affect the extinction of light.

Subroutine ENTRAIN

As stated for subroutine MIXING, the vertical structure of a lake is assumed to be composed of a well-mixed region characterized by constant density overlying a series of lower layers of varying density. Since the thickness of the upper mixed region may be greater than the maximum allowed thickness for any one layer (SDZMAX), the upper mixed region may actually be composed of several model layers. The variable IMIX is, therefore, used to denote the bottom-most model layer in the upper mixed region. If IMIX equals NUME , the depth of the upper mixed region is the thickness of the uppermost model layer (i.e., layer NUME). If the lake is completely mixed from top to bottom, then the depth of the upper mixed region is the depth of the lake and IMIX = 1 . The upper mixed region is therefore composed of all model layers between IMIX and NUME .

Subroutine ENTRAIN is called from subroutine MIXING when sufficient turbulent kinetic energy is available to entrain layer IMIX-1 into the mixed region and thereby increase the depth of the mixed region. The function of ENTRAIN is to redefine state variables for the upper mixed region by volume weighting attributes of layer IMIX-1 with attributes of the mixed region. The depth of the new center of mass of the upper mixed region is also calculated. Subroutine ENTRAIN can be called by MIXING up to NUME times during any one computational interval.

Subroutine TRNSPT

Subroutine TRNSPT calculates diffusion coefficients and invariant transport matrix elements.

Diffusion coefficients. Vertical mixing in reservoirs results from the cumulative effects of inflows, outflows, wind-generated currents, surface and internal waves, turbulence, natural convection, etc. Since the overall contribution of these phenomena to mixing is not completely understood, their cumulative effects are combined in an eddy or effective diffusivity term. The eddy diffusivity approach is based on an analogy with molecular diffusion and assumes that the flux or transport of a variable concentration is equal to an eddy diffusivity coefficient (square metres/second) times a concentration gradient. This flux is the third term on the right-hand side of Equation 4 and is shown in Figure 39.

It is generally accepted that eddy diffusivities are functions of wind speed, inflows and outflows, stability of the density stratification, and size of space and time scales. These factors are included in the formulation used in CE-QUAL-R1 by computing turbulent kinetic energy generated by wind, inflows, and outflows. Eddy diffusion coefficients are assumed to be proportional to the dissipation of this energy and therefore vary with the magnitude of each energy source. Eddy coefficients are decreased in zones of density stratification because of the stabilizing effect of density gradients.

For large reservoirs, with theoretical hydraulic residence times greater than several months, wind is the major source of energy for mixing. It directly impacts the mixed layer by entrainment and indirectly impacts the metalimnion and hypolimnion via seiche motion, internal waves, etc. As shown in subroutine MIXING, wind work on the water surface is

$$TKE_w = \int_{A_s} CW_* \Delta t \tau dA \qquad (92)$$

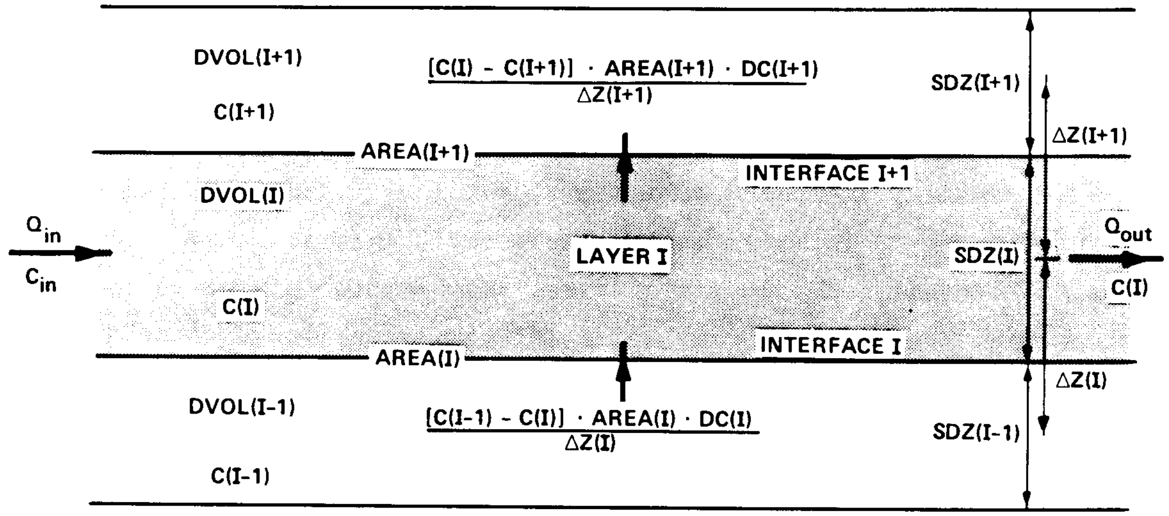


Figure 39. Elements of concentration-dependent transport

Since this energy is available for mixing the entire lake, dissipation per unit mass is

$$\text{DISW} = \frac{\text{TKE}_w}{\rho_w V \Delta t} \tag{93}$$

where V = lake volume (VOL(NUME +1)), m^3.

Mixing also results from inflows and outflows. This localized mixing is restricted to regions of flow. The turbulent kinetic energy generated by these flows is

$$\text{AKE(I)} = \frac{1}{2}\,\rho_w q(\text{I})\Delta t \left(\frac{q(\text{I})}{\text{B(I)} \cdot \Delta \text{Z(I)}}\right)^2 \tag{94}$$

in which

q(I) = flow rate in m^3/sec, layer I
B(I) = width of layer (WIDTH), I , m (see Equation 190)
ΔZ(I) = thickness of layer I (SDZ), m

Since this energy is restricted to layer I, the dissipation per unit mass is

$$\mathrm{DISF(I)} = \frac{\mathrm{AKE(I)}}{\rho_w \Delta V(I) \Delta t} \tag{95}$$

where $\Delta V(I)$ = volume of layer I.

If a Richardson number is defined as

$$\mathrm{Ri} = \frac{\frac{g}{\rho_w} \frac{\partial \rho}{\partial Z}}{\left(\frac{u_*}{KD}\right)^2} \tag{96}$$

where

D = depth of layer from surface, m

u_* = shear velocity, m/sec $\left(u_* = \sqrt{\frac{\tau}{\rho}}\right)$

Ri = Richardson number

g = acceleration due to gravity, m/sec^2

ρ_w = density of water, kg/m^3

$\frac{\partial \rho}{\partial Z}$ = local density gradient, kg/m^3/m

K = von Karmon's constant (0.4)

and a densimetric Froude number is defined as

$$\mathrm{Fr} = \frac{u}{\left(\frac{\Delta \rho}{\rho_w} g \Delta Z\right)^{1/2}} \tag{97}$$

where

Fr = densimetric Froude number

u = longitudinal velocity, m/sec $\left[u = \frac{q(I)\ \mathrm{RLEN}}{\Delta V(I)}\right]$

$\Delta \rho$ = local density change, kg/m^3

ΔZ = layer thickness, m

RLEN = effective reservoir length, m

then the vertical eddy diffusivity coefficient for interface I is

$$\mathrm{DC(I)} = \Delta t^2 \left\{ \left[\frac{\mathrm{CDIFW} * \mathrm{DISW}}{1 + \mathrm{Ri}} \right] + \left[\frac{\mathrm{CDIFF} * (\mathrm{DISF(I)} + \mathrm{DISF(I+1)})/2}{1 + \left(\frac{1}{\mathrm{Fr}} \right)^2} \right] \right\} \qquad (98)$$

where CDIFW and CDIFF are calibration coefficients with values ranging from 0 to 1. If DC(I) (m^2/hr) is calculated by the above equation to be less than the molecular diffusion coefficient for temperature, DC(I) is set equal to the molecular diffusion coefficient, 0.0005148 m^2/hr. The maximum diffusion coefficient allowed is 20.0 m^2/hr, which is a reasonable upper bound from literature values. If the user chooses not to calibrate the thermal coefficients using measured temperature profiles, DC(I) is set to 0.007722 m^2/hr; this value is based on previous modeling studies.

Transport matrix. As described in the section Model Assumptions and Limitations, CE-QUAL-R1 is based on conservation of mass. Although each compartment uses different rates and different formulations for source and sink terms, the same general equation, Equation 4, is solved in each compartment. Since most of the constituents in CE-QUAL-R1 are hydrodynamically passive, they are controlled by similar hydrodynamic transports. These transports, which are dependent on the layer concentration C_i, include diffusion and outflow (Figure 39) and can be described in the following form:

$$XX_{1i} = \left[\frac{AD}{\Delta Z} \right]_i \qquad (99)$$

$$XX_{2i} = \left[\frac{AD}{\Delta Z} \right]_i + \left[\frac{AD}{\Delta Z} \right]_{i+1} + Q_{out} \qquad (100)$$

$$XX_{3i} = \left[\frac{AD}{\Delta Z} \right]_{i+1} \qquad (101)$$

where

$$\Delta Z_i = \frac{1}{2}\,SDZ_{i-1} + \frac{1}{2}\,SDZ_i \qquad (102)$$

$$\Delta Z_{i+1} = \frac{1}{2}\,SDZ_i + \frac{1}{2}\,SDZ_{i+1} \qquad (103)$$

and

A_i = bottom boundary area of layer i (AREA(I)), m^2
D_i = eddy diffusivity across A_i (DC(I)), m^2/sec
SDZ_i = thickness of layer i, m

In this form, these transports can be used in all compartments without recalculation.

Subroutine TMPRTR

The distribution of thermal energy in a reservoir has a significant influence on reservoir operations and water quality. Water temperature is a dominant factor determining density which, in turn, controls the placement of inflowing water, associated constituent load, and the outflow distribution. Water temperature also affects many biological and chemical rate processes. For these reasons, temperature structure is calculated first.

Subroutine TMPRTR calculates the vertical distribution of energy based on heat fluxes calculated in subroutines RADIATE and HEAT and the transport matrix calculated in subroutine TRNSPT. Since temperature is a thermal energy concentration, the general conservation of mass equation is applicable. For any layer i, the general thermal energy equation is

$$\rho_i C_p \frac{\partial}{\partial t}(T_i V_i) = \frac{\partial}{\partial z}\left(\rho_i C_p D_i A_i \frac{\partial T}{\partial z}\right)\Delta Z_i + \frac{\partial}{\partial z}(\phi_i A_i)\Delta Z_i + \rho_i C_p (Q_{in} T_{in} + Q_p T_p - T_i Q_{out}) \qquad (104)$$

$$\begin{bmatrix}\text{Rate of}\\ \text{Change}\\ \text{Kcal/hr}\end{bmatrix} = \begin{bmatrix}\text{Diffusion}\\ \text{Kcal/hr}\end{bmatrix} + \begin{bmatrix}\text{Internal Absorption}\\ \text{of Solar Radiation}\\ \text{Kcal/hr}\end{bmatrix} + \begin{bmatrix}\text{Advection}\\ \text{Kcal/hr}\end{bmatrix}$$

where

ρ_i = density of water, kg/m^3
C_p = specific heat of water, $\frac{\text{Kcal}}{°\text{C} - \text{kg}}$
T_i = temperature, °C
V_i = layer volume, m^3
D_i = diffusivity, m^2/hr
A_i = layer area, m^2
ΔZ_i = layer thickness, m
ϕ_i = flux of solar radiation, Kcal/m^2/hr
Q_{in} = layer inflow volume, m^3/hr

T_{in} = inflow temperature, °C
Q_p = pumpback volume, m^3/hr
T_p = pumpback temperature, °C
Q_{out} = layer outflow volume, m^3/hr

Advection includes terms for outflow and for tributary and pumpback inflow. Entrainment due to pumpback is included in the outflow term. The last step in subroutine TMPRTR is to call subroutine INTEGR and calculate a new vertical temperature profile. For the surface layer, net heat flux across the air-water interface must be added to the right-hand side of Equation 104. This flux was calculated in RADIATE.

Factors pertinent to the numerical implementation of Equation 104 are presented in the section "Composition of compartment differential equations." In keeping with nomenclature conventions expressed there, the following cross reference relates the names of temperature compartment variables to their computer counterparts.

Nomenclature Cross Reference

Equation	Computer Code
T	TEMP
V	DVOL
ϕ	SW
A	AREA
D	DC
ΔZ	SDZ
Q_{in}	QHI
Q_{out}	QHO
Q_p	PBFLOW/PHOURS
T_{in}	TEMPIN
T_P	MXQUAL(14)

Subroutine RMULT

Most biological and chemical rates are temperature dependent. Subroutine RMULT calculates the temperature dependence for all such rates. It is called after TMPRTR so that the temperature of the current computational interval is used.

A representative rate multiplier function is shown in Figure 40 with its K and T parameters. The shape of the curve represents, in general, how biological process rates exhibit an optimum range and diminish (asymmetrically) at higher and lower temperatures. Curvature details differ from process to process. CE-QUAL-R1 uses a mathematical representation of Figure 40 that allows a broad range of curves to be represented (Thornton and Lessem 1978).

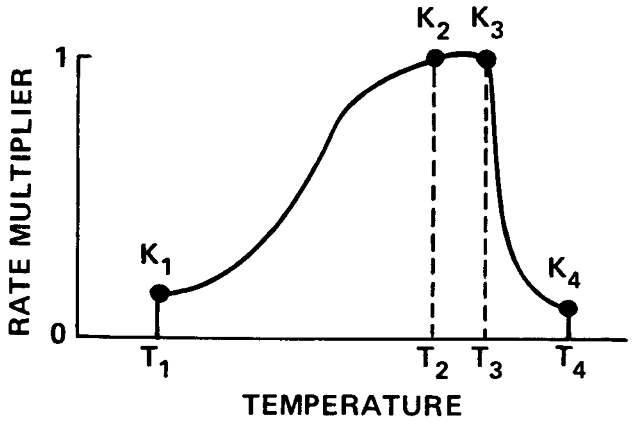


Figure 40. The temperature rate multiplier

$$R(T) = \begin{cases} 0 & T \le T_1 \\ \dfrac{K_1 e^{\lambda_1 (T-T_1)}}{1 + K_1 \left[e^{\lambda_1 (T-T_1)} - 1 \right]} \cdot \dfrac{K_4 e^{\lambda_2 (T_4-T)}}{1 + K_4 \left[e^{\lambda_2 (T_4-T)} - 1 \right]} & T_1 < T < T_4 \\ 0 & T \ge T_4 \end{cases} \qquad (105)$$

where

$$\lambda_1 = \frac{1}{T_2 - T_1} \ln \frac{K_2(1 - K_1)}{K_1(1 - K_2)} \tag{106}$$

$$\lambda_2 = \frac{1}{T_4 - T_3} \ln \frac{K_3(1 - K_4)}{K_4(1 - K_3)} \tag{107}$$

The user supplies temperatures T_1 to T_4 and multiplier factors K_1 and K_4. CE-QUAL-R1 assumes K_2 and K_3 are equal to 0.98. Temperatures T_1 and T_4 represent mortality limits and T_2 and T_3 are used to define the optimum range. The maximum reaction rates supplied by the user are multiplied by $R(T)$ to determine rates corresponding to the local water column temperatures on a layer-by-layer basis.

Composition of compartment differential equations

Although the differential equations that describe compartment dynamics are derived from a straightforward mass balance principle, their numerical implementation can be somewhat obscure at first to new users of CE-QUAL-R1. The purposes of this section are to establish conventions by which the compartment equations may be written down by examining block diagrams showing intercompartment fluxes, and to trace the pathway from diagrams to numerical formulation.

Figure 41 represents an example block diagram that is subsequently detailed for each compartment. Assigned to each process arrow is an appropriate mathematical expression for the process rate in grams per hour. The sum of all such terms, with influxes taken as positive and effluxes taken as negative, constitutes the differential equation expressing the rate of change of compartment mass. Most of the processes are shown in Figure 2. The equation representing this hypothetical compartment of Figure 41 would be

$$\frac{\partial}{\partial t} (VC) = \frac{\partial}{\partial z} \left(DA \frac{\partial C}{\partial z}\right) \Delta Z + \Sigma Q_{in} C_{in} + Q_p C_p - Q_o C - K_B VC \tag{108}$$

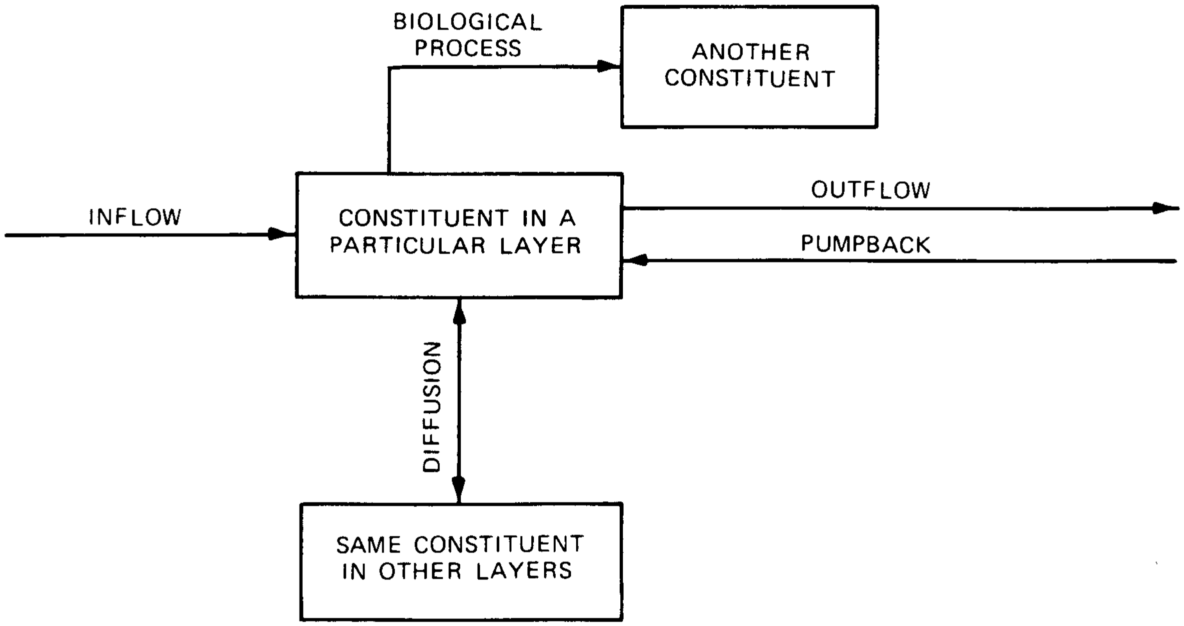


Figure 41. Example of a compartment block diagram

where the five terms on the right side of the equation represent diffusion, inflow, pumpback flow, outflow, and a biological process, respectively. It must be remembered that this equation would be solved for each layer in the reservoir. For ease of documentation, subscripts denoting layers are not included, unless the concentration of the layer being described is affected by the layer above, as in the case of settling, in which case the concentration of the variable in that layer is denoted by C_+. The pumpback process also causes the entrainment of ambient water in the reservoir. Volumes lost from layers as entrainment, which become part of the pumpback flow, are handled as outflows.

Because of the large number of subroutines, the same symbol may represent different variables in different equations. Thus, when explaining oxygen, C represents the concentration of oxygen, whereas in subroutine ZOPLANK it represents the concentration of zooplankton. For each equation, a symbol table will be provided showing the equivalent computer code name. Explanations of all computer code names used in the equations are given in Appendix A. In general, C represents concentrations, K represents rates of change, P represents other coefficients or parameters, and ϕ and γ represent other calculations, most of which are calculated previously within a time step.

The transition from differential equation to numerical implementation is accomplished as follows. As suggested by Figure 39 and Equations 99 to 103, the diffusion process term for a given layer,

$$\frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z$$

is replaced by

$$\left(\frac{AD}{\Delta Z}\right)_{i+1} C_{i+1} - \left[\left(\frac{AD}{\Delta Z}\right)_{i+1} + \left(\frac{AD}{\Delta Z}\right)_{i}\right] C_i + \left(\frac{AD}{\Delta Z}\right)_{i} C_{i-1}$$

Then, Equation 108 is written as

$$V\,\frac{\partial C}{\partial t} = \left(\frac{AD}{\Delta Z}\right)_{i+1} C_{i+1} - \left[\left(\frac{AD}{\Delta Z}\right)_{i+1} + \left(\frac{AD}{\Delta Z}\right)_{i} + Q_o + K_B V + (Q_{in} + Q_p - Q_o)\right] C_i + \left(\frac{AD}{\Delta Z}\right) C_{i-1} + Q_p C_p + \sum Q_{in} C_{in} \qquad (109)$$

in which the term

$$\frac{\partial}{\partial t}\,(VC)$$

has been replaced by its variable layer counterpart

$$V\,\frac{\partial C}{\partial t} + C\,\frac{\partial V}{\partial t}$$

and $\partial V/\partial t$ was replaced by $Q_{in} - Q_{out} + Q_p$ with V in Equation 109 being the new layer volume computed for the time step.

The form of the equation is now seen to be

$$V_i \frac{\partial C_i}{\partial t} = A_{i1}C_{i-1} + A_{i2}C_i + A_{i3}C_{i+1} + P_i \tag{110}$$

Coefficient A_{i2} arises from all processes involving the constituent concentration in a given layer. Most processes shown in Table 1 are of such a nature. Coefficient A_{i1} involves the concentration in the next lower layer and arises from the diffusion process only. Coefficient A_{i3} involves the concentration in the next higher layer and arises from diffusion and settling. The term P_i collects all process contributions, for layer i, from inflows, pumpback flows, and concentrations of constituents in other compartments.

It is important to note that although differential equations are composed as shown above, they are never stated in their entirety at any one point in CE-QUAL-R1. Figure 42 presents the management of equation components. The TRNSPT subroutine computes the diffusion process parts plus layer outflow (the XX array) of the A coefficient. The constituent compartment subroutine computes the remaining process parts

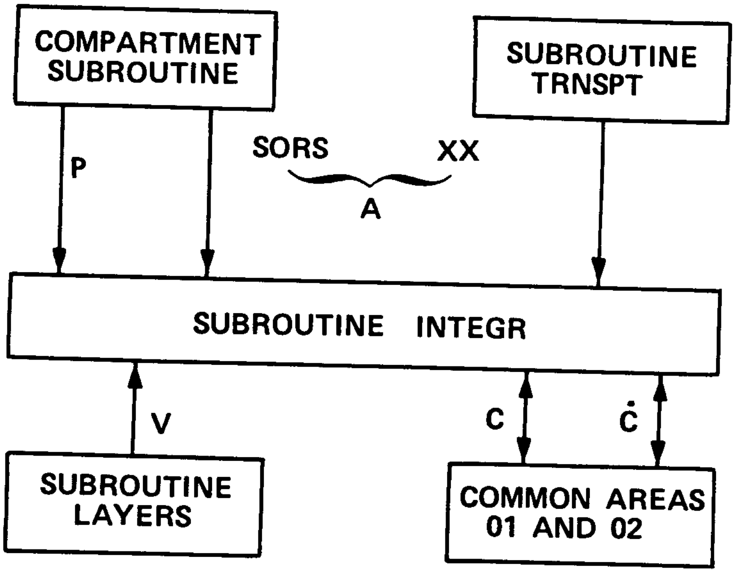


Figure 42. Mechanics of integration

(the SORS array) of the A coefficients and assembles the P term. Subroutines FLOWIN, CONTRL, OUTVEL, and LAYERS determine the current layer volume V , and the constituent magnitude and rate of change are exchanged between the COMMONS area and subroutine INTEGR. It is in subroutine INTEGR that multiplication of the A coefficients and the C concentrations takes place.

Subroutine SOLIDS

Suspended solids concentrations are important in any discussion of reservoir water quality because of their influence on both density and light regimes. Increased suspended solids concentrations reduce light penetration in the water column and, therefore, may influence temperature and algal oxygen and biomass production. In CE-QUAL-R1, the suspended solids compartment represents inorganic suspended materials. Organic solids, such as phytoplankton, zooplankton, and detritus, are modeled separately. For CE-THERM-R1, the user may wish to include all suspended solids in this compartment. Before a decision is made, users should read information concerning the coefficient EXTINS in Appendix F.

With reference to Figure 43, the compartment equation for suspended solids is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC$$

$$+ FKV_+C_+/\Delta Z_+ - KVC/\Delta Z \qquad (111)$$

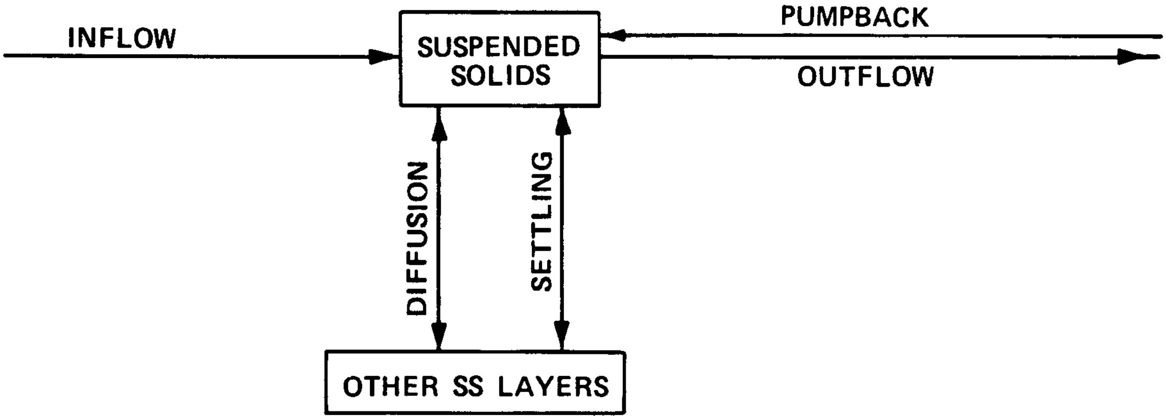


Figure 43. Fluxes for the suspended solids compartment

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	Q_{in}	QHI(I)
C	SSOL(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_{in}	SSOLIN(J), PSSOL(I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL(16)	V	DVOL(I)
C_+	SSOL(I+1)	V_+	DVOL(I+1)
D	DC(I)	ΔZ	SDZ(I)
F	FRACT(I+1)	ΔZ_+	SDZ(I+1)
K	SSETL		

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 111 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, settling from above, and settling to below, respectively.

Total dissolved solids (TDS) and suspended solids (SS) also influence the density of water according to the following relation

$$\rho(\text{fluid}) = \rho(T) + (0.00062)SS + (0.00078)TDS \tag{112}$$

where

$\rho(\text{fluid})$ = density of the fluid

$\rho(T)$ = density of water at a given temperature, T

SS = suspended solids concentration, g/m^3

TDS = total dissolved solids concentration, g/m^3

Subroutine FISHERY

The fishery compartment is included primarily to complete the representation of aquatic ecosystems by including higher trophic levels. The fishery compartment, through predation, helps maintain the ecological system by providing a means of control on lower trophic levels. The fishery compartment is not intended to provide predictions for harvest or management potential.

One fish assemblage is simulated based primarily on feeding preferences and habits. The fish compartment FISHB should be parameterized to represent a composite of all fish in a reservoir. Feeding on zooplankton, each algal group, detritus, or organic sediment is controlled with preference factors.

Since fish are highly mobile organisms, this compartment is simulated differently than other constituents in the model. For each time step, the mass, which is reported on an areal basis as kilograms per hectare, is apportioned to layers, with an oxygen concentration of at least 3 g/m^3, in proportion to the total amount of food in a layer. Computational units for fish are grams per cubic metre.

With reference to Figure 44, the compartment equation for fish is

$$\frac{d}{dt}(VC) = \gamma_1 \gamma_2 P_1 K_i [X/(P_2 + X)]VC - \gamma_1 K_r VC - (1 - \gamma_2) K_m VC - K_h \qquad (113)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
C	FISHB(I)	V	DVOL(I)
K_h	HARVST	X	(ALGAE(I,1)*FPALG(1)) + (ALGAE(I,2)*FPALG(2)) + (ALGAE(I,3)*FPALG(3)) + (ZOO(I)*FPZOO) + (DETUS(I)*FPDET) + (CSED(I)*FPSED)
K_i	FSHMAX		
K_m	FMORTA		
K_r	FRESP		
P_1	FEFFIC	γ_1	RTMLT1(9,I)
P_2	FS2FSH	γ_1	RTMLT2(9,I)

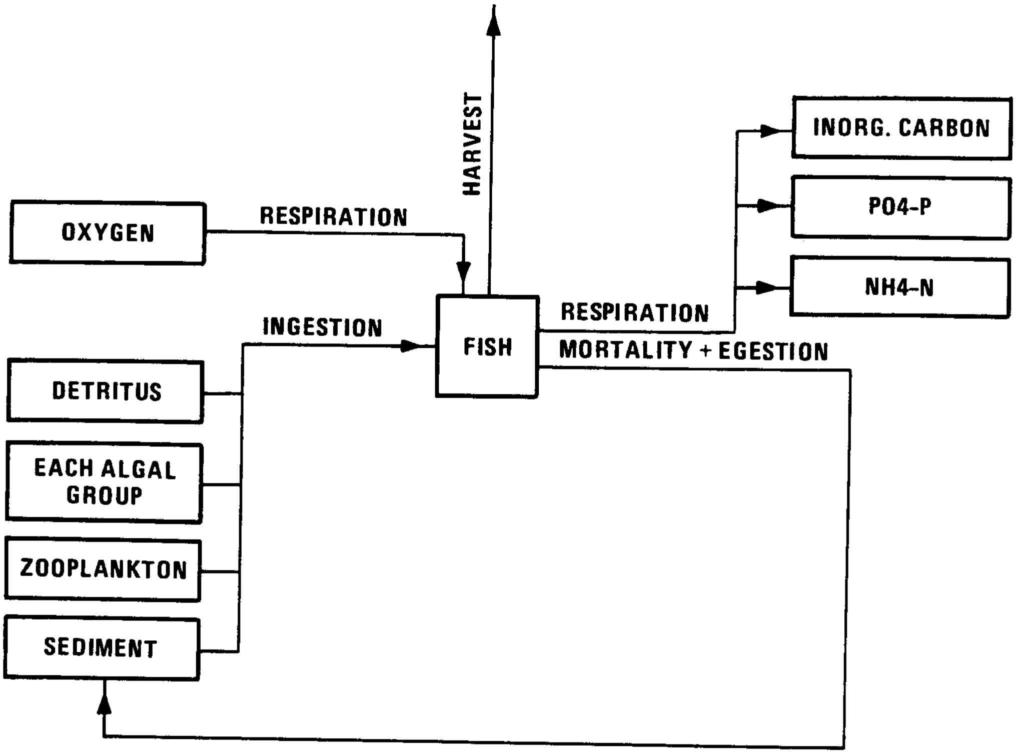


Figure 44. Fluxes for the fish compartment

where I, under Computer Code, represents individual layers.

Terms in Equation 113 represent ingestion, respiration, mortality, and harvest. Ingestion rate is modified as a function of temperature and a Monod constant that was discussed earlier. Respiration is modified by the rising limb of the temperature function only. Mortality also is modified by a temperature function. However, since mortality is expected to be maximal at high temperatures and minimal under low to optimum temperature regimes, the temperature multiplier is subtracted from one. Calculated values for all terms can be zero by proper choice of coefficients. Other information concerning physiological processes can be found in Part IV, under calibration procedures for water quality compartments.

Since fish are reported on an areal basis, these compartments, unlike most of the other state variables, are solved using an Eulerian solution scheme.

Subroutine ZOPLANK

Zooplankton species are aggregated into a single compartment. These animals are treated by the model as true plankters, being nonmotile and subject only to diffusive and advective forces. Vertical migration of zooplankton is not simulated by the model. To do so would make this model far too complex for the needs of the CE. This compartment is included in the model mainly because zooplankton can have a great effect on algal populations and, hence, on oxygen. Tests, using data collected on CE reservoirs, have shown reasonable results with zooplankton modeled at this level of resolution.

With reference to Figure 45, the compartment equation for zooplankton is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + Q_pC_p - Q_oC + \gamma_1\gamma_2P_1K_i[(X - P_2)/(X + P_3)]VC \\ - (1 - \gamma_2)K_mVC - \gamma_1K_rVC - VC_fK_fP_4CV/Y \qquad (114)\end{aligned}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_3	ZS2P
C	ZOO(I)	P_4	FPZOO
C_p	MXQUAL(17)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_f	FISHB(I)	Q_p	PBFLOW/PHOURS
D	DC(I)	V	DVOL(I)
K_i	ZMAX	Y	FSHEAT(I)(X of Equation 113)
K_m	ZMORTA	ΔZ	SDZ(I)
K_r	ZRESP	γ_1	RTMLT1(8,I)
K_f	FMU(I)	γ_2	RTMLT2(8,I)

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
P_1	ZEFFIC	X	PREF(1)*ALGAE(I,1) + PREF(2)*ALGAE(I,2) + PREF(3)*ALGAE(I,3) + PREF(4)*DETUS(I)
P_2	ZOOMIN		

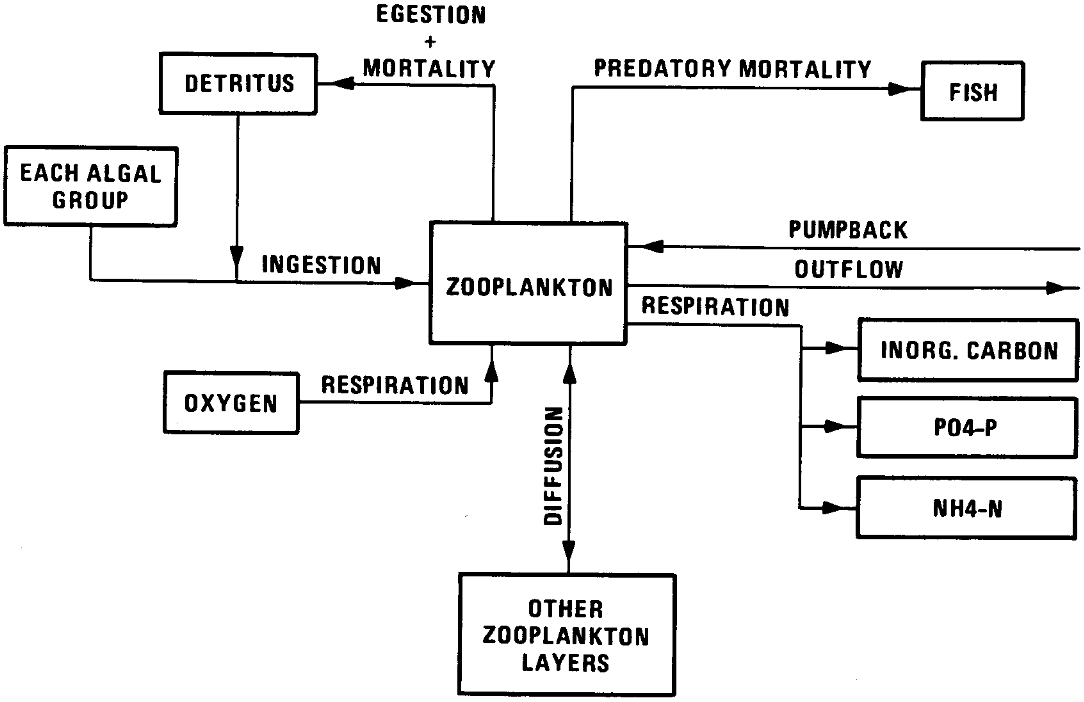


Figure 45. Fluxes for the zooplankton compartment

where I , under Computer Code, represents individual layers. Terms in Equation 114 represent diffusion, pumpback inflow, outflow and entrainment due to pumpback, ingestion, mortality, respiration, and fish ingestion. Food sources for zooplankton include the three phytoplankton compartments and detritus. Zooplankton ingestion is modeled using a modified Michaelis-Menten equation that includes a low-threshold food concentration below which zooplankton do not feed. At oxygen concentrations below 2 g m^{-3}, feeding ceases and the mortality rate is doubled. Zooplankton inflow is not considered by the model. Calculated values for many of the terms in Equation 114 can be zero by proper choice of coefficients.

Subroutine PHYTO

CE-QUAL-R1 has three compartments representing phytoplankton assemblages. The aggregation forces a gross representation of phytoplankton dynamics, but proper aggregation can provide insight into potential problems associated with simulated algal biomass magnitudes and timing of blooms. Site-specific characteristics become important during aggregation and interpretation. The compartments can simulate specific assemblages representing various trophic characteristics or problem groups depending on the specific questions being addressed. Because the third group is silica limited, it usually represents diatoms.

Phytoplankton compartments serve as focal points in the model since they represent important parts of the food chain base for higher trophic levels and integrate effects of biotic and abiotic components. Phytoplankton concentrations also provide one estimate of the eutrophication potential for the reservoir and an indication of potential problems. High phytoplankton concentrations not only contribute to undesirable aesthetic conditions, but also to potential anaerobic conditions in the metalimnion or hypolimnion. Phytoplankton respiration and microbial decomposition contribute to high oxygen demands. In many reservoirs, following phytoplankton blooms, this demand may contribute to metalimnetic and hypolimnetic anoxia. Anoxic conditions, of course, lead to the release of iron, manganese, and hydrogen sulfide as well as to the release of nitrogen and phosphorus from the sediments. The phytoplankton compartments, therefore, are among the most important in CE-QUAL-R1.

With reference to Figure 46, the compartment equation for each algal group is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC + FK_sV_+C_+/\Delta Z_+$$

$$- K_sVC/\Delta Z + \gamma_1\gamma_2K_pMIN(\phi_i)VC - \gamma_1K_rVC - K_e(1 - \phi_1)VC \qquad (115)$$

$$- K_me^{(T-P_1)}VC - VC_f\gamma_3P_2CV/\gamma_4 - VC_z\gamma_5P_3C/\gamma_6$$

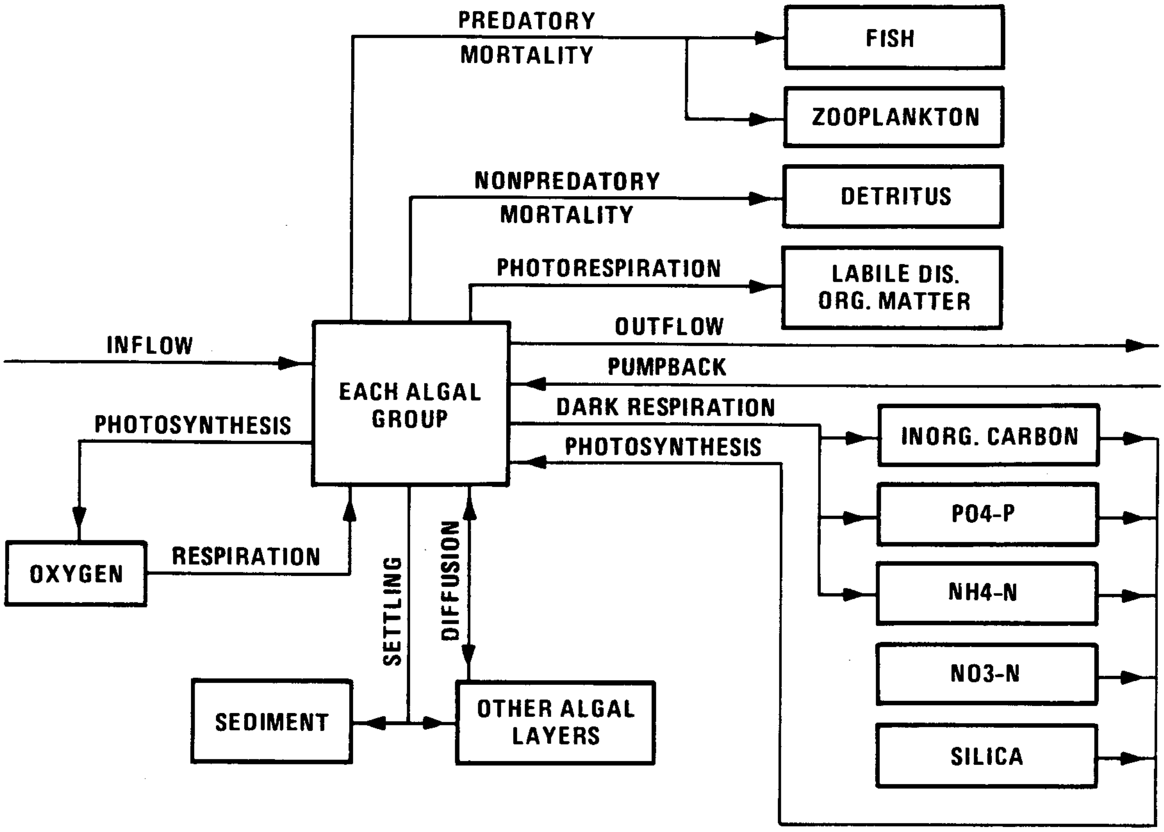


Figure 46. Fluxes for the algal compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_4	PISAT(J)
C	ALGAE(I,J)	MIN	MINI (computer function)
C_+	ALGAE(I+1,J)	T	TEMP(I)

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
C_f	FISHB(I)	V	DVOL(I)
C_{in}	ALGAIN(N,J), PALGAE(I,J)	V_+	DVOL(I+1)
C_p	MXQUAL(J)	ΔZ	SDZ(I)
C_z	ZOO(I)	ΔZ_+	SDZ(I+1)
D	DC(I)	γ_1	RTMLT1(J+4,I)
F	FRACT(I+1)	γ_2	RTMLT2(J+4,I)
K_e	PEXCR(J)	γ_3	FMU(I)
K_m	PMORT(J)	γ_4	FSHEAT(I)
K_p	PMAX(J)	γ_5	ZMU(I)
K_r	PRESP(J)	γ_6	TALGAE(I)
K_s	SETL(J)	$\phi(Z)$	0.5*(SWS(I) + SWS(I+1))
Q_{in}	QHI(I)	ϕ_1	XL
Q_o	QHO(I), PBENTR(I)/PHOURS	ϕ_2	XP
Q_p	PBFLOW/PHOURS	ϕ_3	XN
P_1	ALGT4(J)	ϕ_4	XC
P_2	FPALG(J)	ϕ_5	XS
P_3	PREF(J)	ϕ_i	XL, XP, XN, XC, XS

where, under Computer Code, I represents layers, J represents algal compartments, and N represents tributaries.

The terms in Equation 115 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, settling from above, settling to below, production, dark respiration, excretion, mortality, fish ingestion, and zooplankton ingestion. Gross production is calculated using a maximum rate that is modified by temperature and a single limiting environmental factor. This factor is the minimum value calculated from the Monod function for phosphorus (ϕ_2), nitrogen (ϕ_3), carbon (ϕ_4), or silica (ϕ_5), or the Steele (1962) function for light (ϕ_1). Silica is used only in the third algal compartment. Steele's (1962) light equation can represent photoinhibition at light intensities greater than the saturation value. The Monod function was described earlier in Part III. The Steele equation has the following form

$$\phi_1 = \frac{\phi(Z)}{P_4} e^{\left\{1.-[\phi(Z)/P_4]\right\}} \qquad (116)$$

Algal dark respiration is computed using the rising limb of the temperature function. Algal photorespiration (excretion) is evaluated as an inverse relation to the Steele equation. Excretion rates increase at low and high irradiance levels. Products of photorespiration go to the labile dissolved organic matter compartment. Nonpredatory mortality of senescent algae is accelerated by critically high temperatures and is computed using the falling limb of the temperature function. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine PLNTS

Submersed aquatic plants or macrophytes often contribute significantly to the productivity of lakes and reservoirs. Macrophytes can become so abundant that they become a nuisance to recreational and navigational activities. The littoral zones of many eutrophic systems are often dominated by a single species of macrophyte. However, many species may coexist and are often in competition with phytoplankton for light and nutrients.

CE-QUAL-R1 has one compartment representing macrophyte assemblages, a compartment that is spatially modeled differently than other variables (Collins, Park, and Boylen 1985). It must be remembered that other variables in a layer can be affected by layers immediately above and below it. But a single plant may grow through many layers, with the growth in higher layers being affected by sediment many layers below. To overcome this problem, vertical segments are superimposed above the sediment in each layer, creating, in effect, a two-dimensional representation of plant mass. Rather than calculating the flux once for each layer, it is calculated per cell. This representation is shown in Figure 47. Plant mass is calculated for each column; if a plant mass is too great for the layer next to the sediment, say, for example, cell (5,5), the

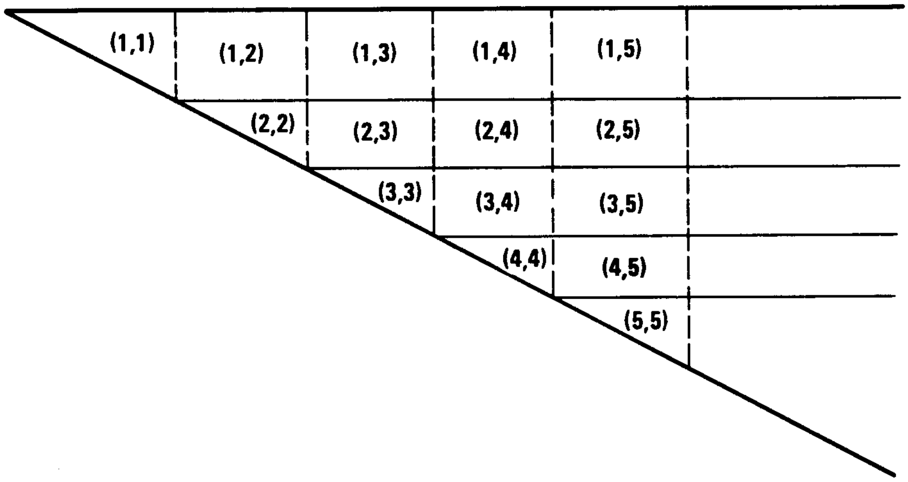


Figure 47. Representation of plant cells in CE-QUAL-R1

remaining mass "grows" into cell (4,5), and if the mass is great enough, "grows" toward the surface of the column. Because layers and, hence, cells may change size during each time step, mass may continually shift from one cell to another. This calculation is made in subroutine LAYERS. Computationally, macrophytes have units of grams per cell; fluxes for all cells in a layer or all cells in a column are summed to find the total effect of macrophytes in a layer or on a particular sediment layer.

With reference to Figure 48, the compartment equation for macrophytes is

$$\frac{d}{dt}(C) = C\gamma_1\gamma_2K_a\text{MIN}[\phi_i]\gamma_3 - C\gamma_1K_r - (1 - \gamma_3)K_eC - CK_m \qquad (117)$$

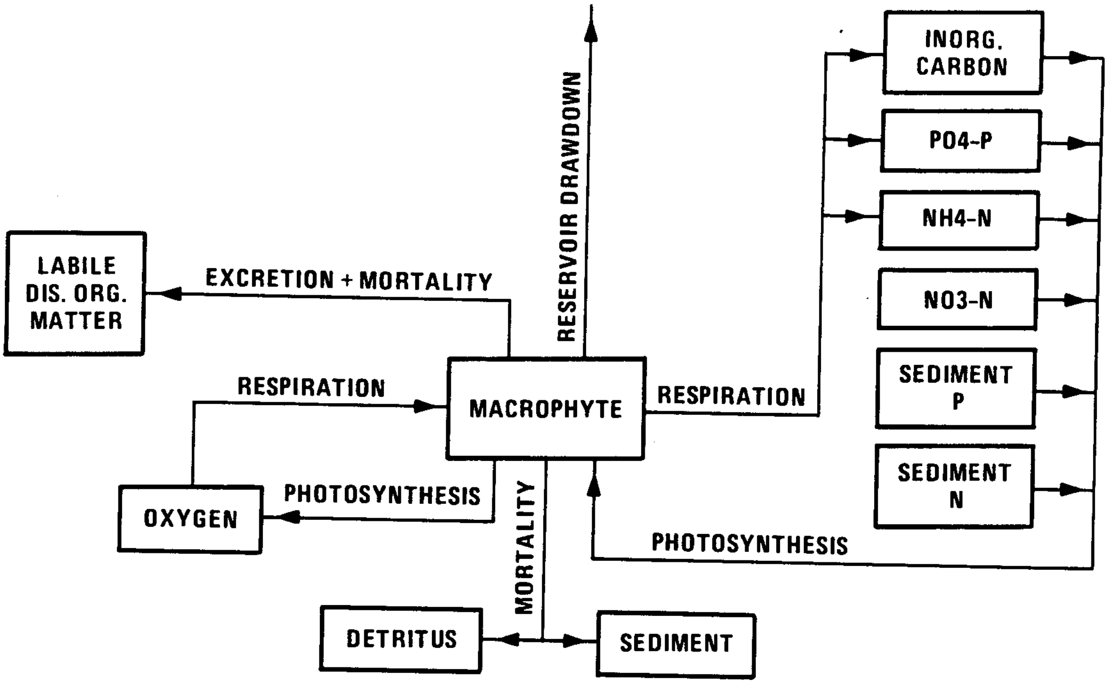


Figure 48. Fluxes between the macrophyte compartment and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
C	PLNT(J,I)	γ_2	RTMLT2(10,I)
K_a	PLTMAX	γ_3	GROLIT
K_e	EXCRM	ϕ_1	XLIMP
K_m	PLMORT	ϕ_2	XLIMN
K_r	RESPM	ϕ_3	XLIMC
MIN	MIN1 (computer function)	ϕ_i	XLIMN, XLIMC, XLIMP
γ_1	RTMLT1(10,I)		

where, under Computer Code, I represents layers (rows) and J represents columns. Rows and columns signify cells (Figure 47).

Terms in Equation 117 represent photosynthesis, dark respiration, photorespiration (excretion), and mortality, respectively. Productivity of macrophytes is a function of light intensity, temperature, and sediment and water column nutrient concentrations. Dark respiration is a function of temperature. Photorespiration is a function of light intensity and allows nutrients in the sediment to be transported and released into the water column. Mortality is a function of temperature.

A maximum gross productivity rate is modified by temperature, light intensity γ_3, and a single limiting nutrient that is evaluated to be either phosphorus ϕ_1, nitrogen ϕ_2, or carbon ϕ_3. Temperature limitation is calculated using the equations of Thornton and Lessem (1978). Nutrient limitation is dependent upon the concentrations of nitrogen and phosphorus in the water column and sediment and on water column carbon content according to the Monod equation. Light limitation is represented using Steele's (1962) equation (see Equation 116).

Dark respiration is computed using the rising limb of the temperature function previously used to modify production. Photorespiration (excretion) is evaluated as an inverse relation to the Steele equation. Excretion increases at low and high light intensities. Products of photorespiration go to the labile dissolved organic matter compartment. Macrophyte mortality occurs in periods when temperature rapidly decreases at a continuous rate. Mortality is fractioned between detritus, sediment, and labile dissolved organic matter. Calculated values for all terms can be zero by proper choice of coefficients. Terms used in other compartments are summed in this subroutine because of the two-dimensional nature of the algorithm.

Subroutine DETRITS

Detritus represents fine organic material suspended in the water column but capable of settling to the bottom. It serves as a food source for fish and zooplankton and, through decomposition processes, as a source of the chemical nutrients, nitrogen, phosphorus, and carbon. Microbial processes are included in the model through decomposition of organic matter. Detritus, therefore, serves as a surrogate, implicitly simulating microbial decomposition of particulate organic matter and mineralization of nutrients. A stoichiometric relationship is used to release ammonium-nitrogen, phosphorus, and carbon, and an oxygen demand is exerted as detritus decomposes. When detritus settles to the bottom, it is converted to organic sediment.

With reference to Figure 49, the compartment equation for detritus is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC + FK_sV_+C_+/\Delta Z_+ \\ - K_sVC/\Delta Z - \gamma_1K_dVC + VC_a\gamma_2P_1 + \gamma_3P_2 \qquad (118) \\ - VC_f\gamma_4P_3CV/\gamma_5 - VC_z\gamma_6P_4C/\gamma_7 + VC_z[\gamma_8 + (\gamma_6 - \gamma_6P_5)]\end{aligned}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_5	ZEFFIC
C	DETUS(I)	Q_{in}	QHI(I)
C_+	DETUS(I+1)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_a	ALGAE(I,J)	Q_p	PBFLOW/PHOURS
C_f	FISHB(I)	V	DVOL(I)
C_{in}	DETUIN(N), PDET(I)	V_+	DVOL(I+1)
C_p	MXQUAL(10)	ΔZ	SDZ(I)
C_z	ZOO(I)	ΔZ_+	SDZ(I+1)

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
D	DC(I)	γ_1	RTMLT1(4,I)
F	FRACT(I+1)	γ_2	ANPM(I,J)
K_d	DETUDK	γ_3	PLFLX(I,5)
K_s	DSETL	γ_4	FMU(I)
P_1	ALDIGO	γ_5	FSHEAT(I)
P_2	PLDIGO(2)	γ_6	ZMU(I)
P_3	FPDET	γ_7	TALGAE(I)
P_4	PREF(4)	γ_8	ZMT(I)

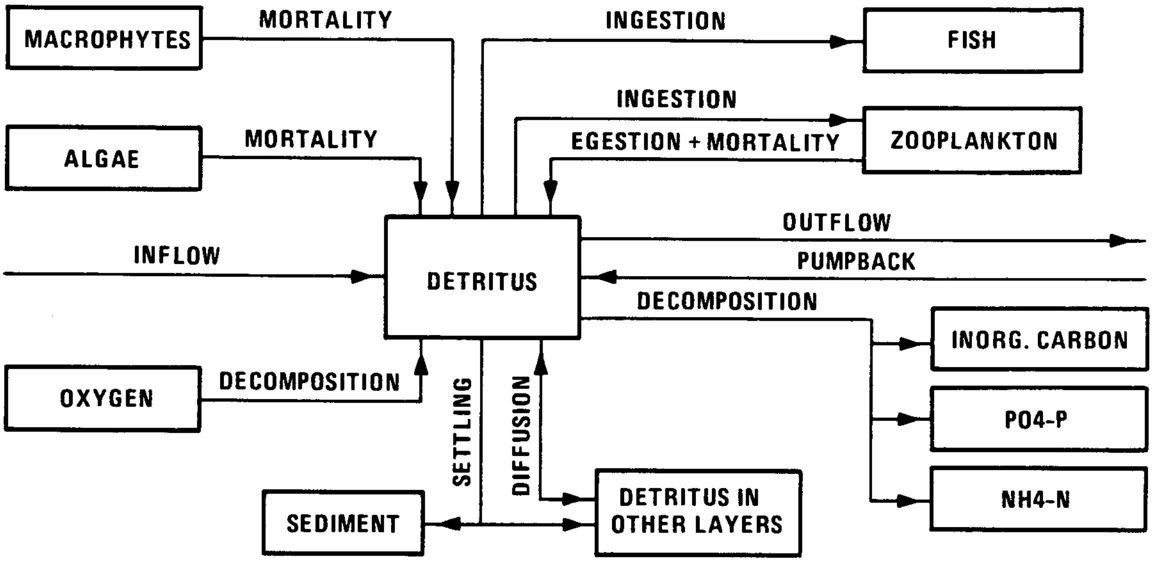


Figure 49. Fluxes for the detritus compartment

where, under Computer Code, I represents layers, J represents algal groups, and N represents tributaries.

Terms in Equation 118 represent diffusion, tributary inflow, pumpback flow, outflow and entrainment due to pumpback, settling from above, settling to below, decomposition, algal mortality, macrophyte mortality, fish ingestion, zooplankton ingestion, and zooplankton egestion, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine SEDMENT

Sediment consists of organic material and benthic organisms. It does not incorporate inorganic material directly. Sediment is not advectively transported so there are no inflow or outflow contributions. Units for sediment input and output are grams per square metre. Computationally, sediment has units of grams per layer, and the equation is solved using an Eulerian solution scheme.

With reference to Figure 50, the compartment equation for sediment is

$$\frac{d}{dt}(C) = -CK_d\gamma_1 + VC_f\gamma_2 - V\gamma_3 C_f P_1 C/\gamma_4 + VC_f\gamma_3(1 - P_2) + VC_aK_{sa}(1 - F)/\Delta Z + FC_dK_{sd}(1 - F)/\Delta Z + \gamma_5 P_3 \tag{119}$$

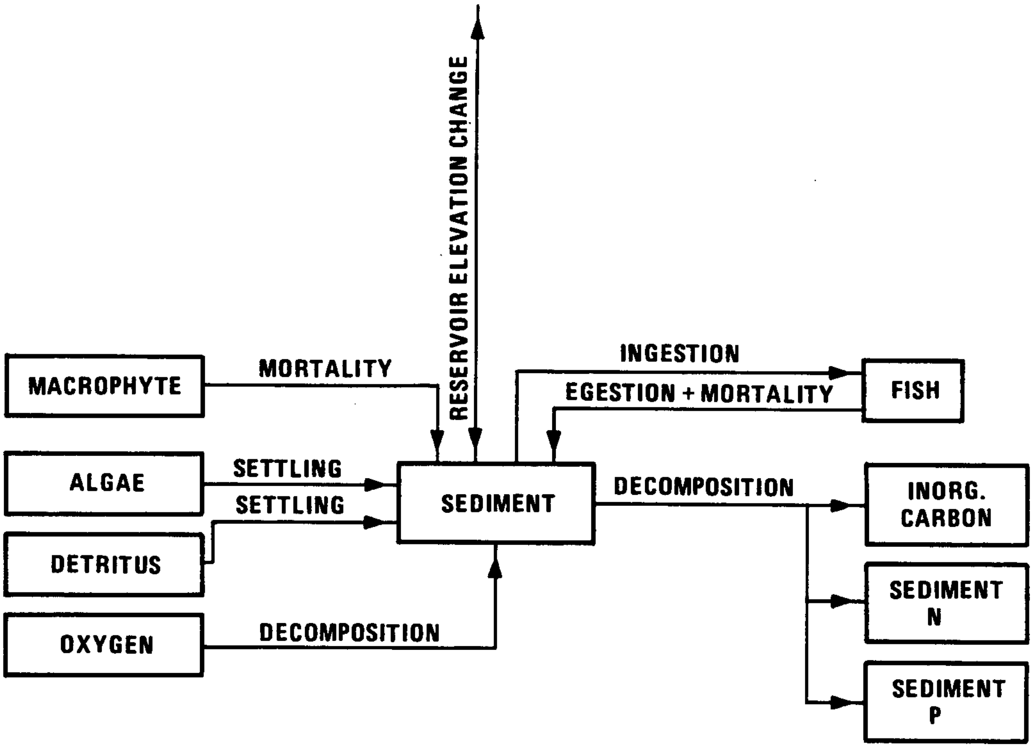


Figure 50. Fluxes for the sediment compartment

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
C	CSED(I)	P_2	FEFFIC
C_a	ALGAE(I,J)	P_3	PLDIGO(3)
C_d	DETUS(I)	V	DVOL(I)
C_f	FISHB(I)	ΔZ	SDZ(I)
F	FRACT(I)	γ_1	RTMLT1(4,I)
K_d	SEDDK	γ_2	FMT(I)
K_{sa}	SETL(J)	γ_3	FMU(I)
K_{sd}	DSETL	γ_4	FSHEAT(I)
P_1	FPSED	γ_5	PLFLX(I,6)

where, under Computer Code, I represents layers and J represents algal groups.

The terms in Equation 119 represent decomposition, fish mortality, fish ingestion, fish egestion, settling of algae, settling of detritus, and macrophyte mortality, respectively. Products of decomposition increase inorganic carbon as well as sediment nitrogen and phosphorus. Oxygen is also used during decomposition. Sediment is considered lost from the system with a decrease in surface elevation. When the surface rises, sediment is gained in the same proportion as is found in the surface layer. Calculated values for all of the terms in Equation 119 can be zero by proper choice of coefficients.

Subroutine ORGNICS

Because of the importance of dissolved oxygen in reservoirs, it is imperative to include as model variables all constituents that exert an oxygen demand. This demand is often measured in rivers as the biochemical oxygen demand (BOD), which includes, for example, microbial respiration and metabolism of various organic and inorganic compounds such as detritus or ammonia, respectively. In CE-QUAL-R1, however, the major constituents or components of BOD are modeled on an individual basis. One of these constituents is dissolved organic matter (DOM), which is composed of labile and refractory organic compounds. In CE-QUAL-R1, DOM is represented in separate compartments because of the different decomposition rates of the two groups. Subroutine ORGNICS represents the labile fraction of DOM.

With reference to Figure 51, the compartment equation for labile DOM is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = {} & \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - \gamma_1K_dVC \\ & + \gamma_2 + \gamma_3P_1 + C_aV\gamma_4 + V(1 - P_2)\gamma_5C_a - VCK_t\end{aligned} \qquad (120)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	Q_{in}	QHI(I)
C	DOM(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_a	ALGAE(I,J)	Q_p	PBFLOW/PHOURS
C_{in}	DOCIN(N), PDOM(I)	V	DVOL(I)
C_p	MXQUAL(5)	ΔZ	SDZ(I)
D	DC(I)	γ_1	RTMLT1(1,I)
K_d	DOMDK	γ_2	PLFLX(I,4)
K_t	DOMRFR	γ_3	PLFLX(I,5)
P_1	PLDIGO(1)	γ_4	AEXCR(I,J)
P_2	ALDIGO	γ_5	ANPM(I,J)

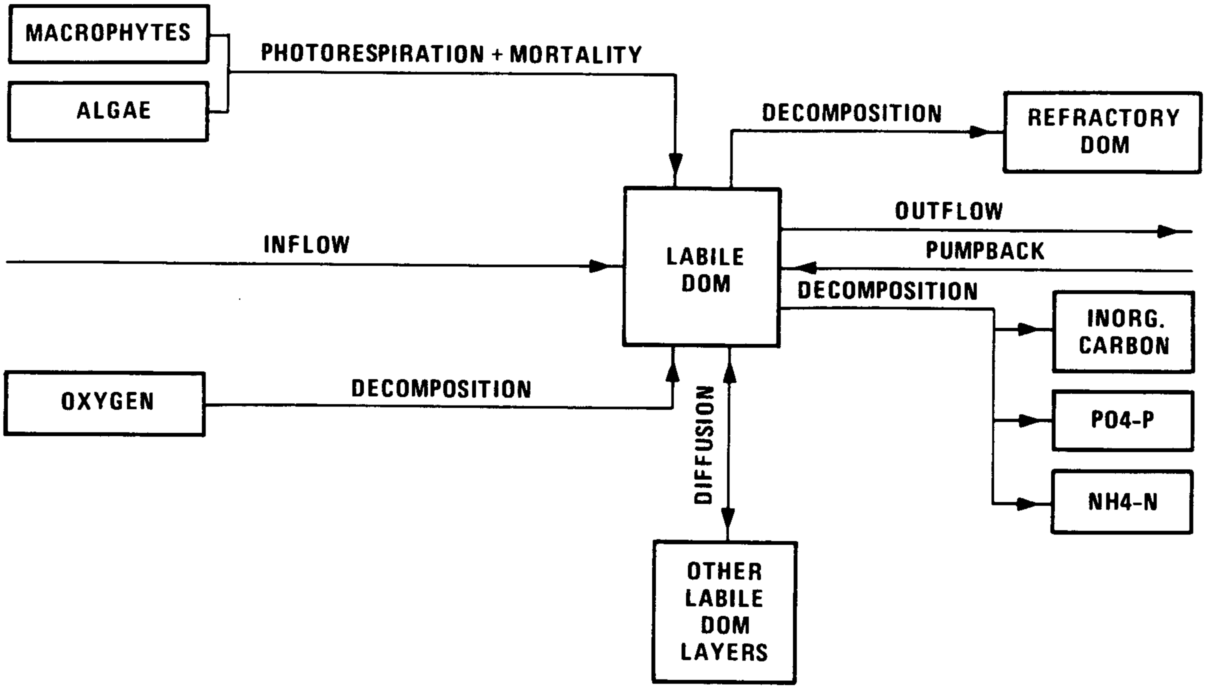


Figure 51. Fluxes for the labile DOM compartment

where, under Computer Code, I represents layers, N represents tributaries, and J represents algal groups.

Terms in Equation 120 represent diffusion, tributary inflow, pumpback flow, outflow and entrainment due to pumpback, decomposition to elemental constituents, macrophyte photorespiration, macrophyte mortality, algae photorespiration, algae mortality, and decomposition to refractory DOM. Calculated values for many of the terms in Equation 120 can be zero by proper choice of coefficients.

Subroutine REFRACT

Refractory DOM is composed of recalcitrant compounds that decompose at a relatively slow rate in the aquatic environment. When labile DOM decomposes, many of the compounds are converted to a more refractory state, represented in the model as refractory DOM. With respect to Figure 52, the compartment equation for refractory DOM is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - K_d\gamma_1 VC + VC_1K_t\gamma_1 \tag{121}$$

where, under Computer Code, I represents layers and N represents tributaries.

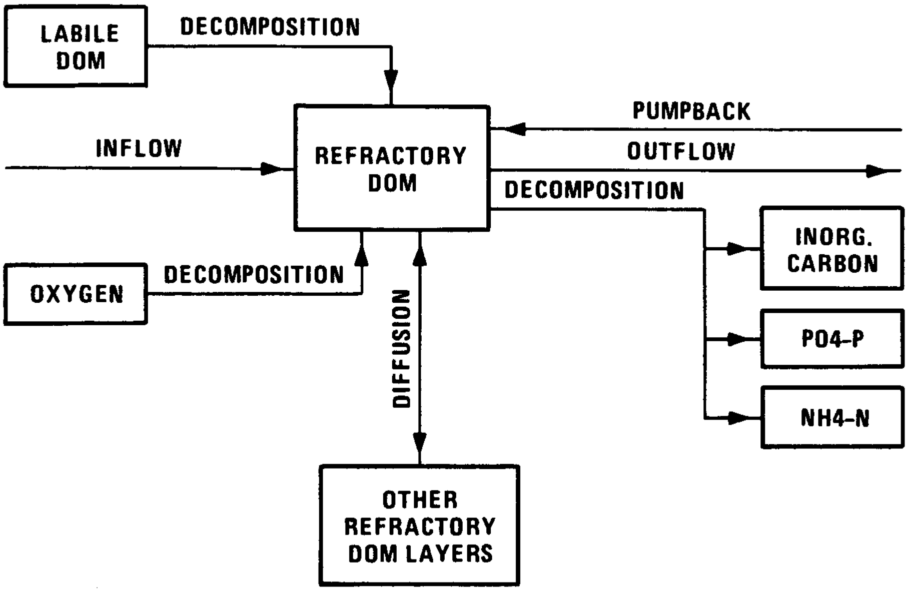


Figure 52. Fluxes among refractory DOM
and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_t	DOMRFR
C	RFR(I)	Q_{in}	QHI(I)
C_{in}	RFRIN(N), PRFR(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_1	DOM(I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL(8)	V	DVOL(I)
D	DC(I)	ΔZ	SDZ(I)
K_d	RFRDK	γ_1	RTMLT1(1,I)

Terms in Equation 121 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, decomposition, and decomposition of labile DOM, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine PHOSPHR

Phosphorus is an important element in aquatic ecosystems since it serves as one of the primary nutrients for phytoplankton. In addition to serving as a nutrient for plants, phosphorus is extremely important in all biological organisms for its various forms as energy storage. Formation of high-energy bonds in compounds such as ATP provides energy for many life processes. Algae, through photosynthesis, are able to convert inorganic elements such as phosphorus, nitrogen, carbon, hydrogen, and oxygen into organic compounds such as carbohydrates, lipids, and proteins. In many fresh waters, phosphorus is considered to be the element that limits the maximum production of phytoplankton biomass (Schindler 1971; Schindler et al. 1973; Vollenweider 1968, 1976). Phosphorus, therefore, is an important compartment in the model.

Phosphorus is assumed to be in a completely available form as orthophosphate (PO_4) for uptake by phytoplankton. Measurements of soluble reactive phosphorus most closely fit the form used in the model.

With reference to Figure 53, the compartment equation for phosphorus is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = {} & \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC \\ & - VC\phi_1\phi_2P_3 \Big/ \left\{\gamma_1\Delta Z\left[(1/P_1) + C\right]\right\} \\ & + V_+C_+P_3\phi_3\phi_2F \Big/ \left\{\gamma_1\Delta Z_+\left[(1/P_1) + C_+\right]\right\} \\ & + \gamma_2C_aVP_2 - \gamma_3C_aVP_2 + VC_dK_d\gamma_4P_2 + VC_ZP_2\gamma_5 + VC_fP_2\gamma_6 \\ & + VC_1P_2\gamma_7K_{d1} + VC_rP_2\gamma_7K_{dr} + P_4A_s + \gamma_8P_2 - \gamma_9P_2P_5\end{aligned} \tag{122}$$

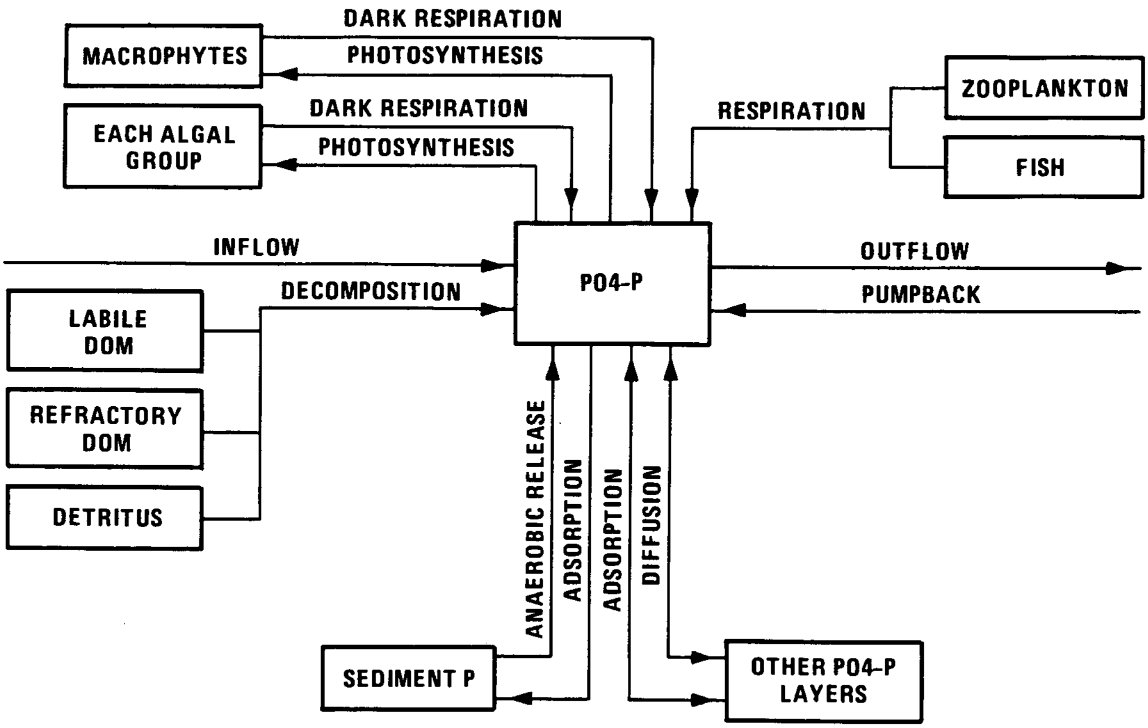


Figure 53. Fluxes for the orthophosphate phosphorus compartment

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	ϕ_1	FE3(I) + CMN4(I) + DETUS(I) +SSOL(I) + ALGAE(I,J)
A_s	AREA(I+1) - AREA(I)	ϕ_2	DSETL + FE3STL + SETL(J) +SSETL + MN4STL
C	PO4(I)	ϕ_3	FE3(I+1) + CMN4(I+1) + DETUS (I+1) + SSOL(I+1) + ALGAE(I+1,J)
C_+	POR(I+1)	Q_{in}	QHI(I)
C_a	ALGAE(I,J)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_d	DETUS(I)	Q_p	PBFLOW/PHOURS
C_f	FISHB(I)	V	DVOL(I)
C_{in}	PO4IN(N), PPO4(I)	V_+	DVOL(I+1)
C_l	DOM(I)$^+$	ΔZ	SDZ(I)
C_p	MXQUAL(12)	ΔZ_+	SDZ(I+1)
C_r	RFR(I)		
C_z	ZOO(I)		
D	DC(I)		

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
F	FRACT(I)	γ_1	SUMJ
K_d	DETUDK	γ_2	ART(I,J)
K_{d1}	DOMDK	γ_3	AMU(I,J)
K_{dr}	RFRDK	γ_4	RTMLT1(4,I)
P_1	ADSRBP	γ_5	ZRT(I)
P_2	BIOP	γ_6	FRT(I)
P_3	ADMAXP	γ_7	RTMLT1(1,I)
P_4	XP4REL	γ_8	PLFLX(I,3)
P_5	PLFRAC	γ_9	PLFLX(I,1)

where, under Computer Code, I represents layers, N represents tributaries, and J represents algal compartments.

Terms in Equation 122 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, adsorption or complexing with solids, which has the effect of moving phosphorus to lower layers or the sediment, gain of phosphorus because of adsorption and settling from the layer above, respiration of algae summed over all algal compartments, algal production, summed over all algal compartments, detritus decomposition, zooplankton respiration, fish respiration, decomposition of labile DOM, decomposition of refractory DOM, release of phosphorus from the sediments during anaerobic conditions, respiration of macrophytes, a term that was calculated in subroutine PLNTS, and production of macrophytes, which was calculated in subroutine PLNTS. Phosphorus may be mobilized from both the water column and the sediment phosphorus compartment, hence the term P_5 . Calculated values for many of the terms can be zero by proper choice of coefficients.

Adsorption of phosphorus onto solids is not modeled explicitly. To do so would make the model more complex than is needed. In the real system, available phosphorus is partitioned between the solute remaining in solution and that part adsorbed onto solids. At equilibrium, the relationship between them can be described by an adsorption isotherm. Rather than modeling two different compartments, the amount adsorbed is assumed to be in equilibrium with that part in solution. The amount assumed to be adsorbed per unit mass of solids increases with the increasing concentration of solute. The amount "adsorbed" then settles into lower layers or into the sediment phosphorus compartment. The amount of phosphorus available for algae and macrophytes is not lowered because of phosphorus being "adsorbed."

Subroutine SILICA

Silica is used in the synthesis of diatom cells. In CE-QUAL-R1, the third algal group can be limited by silica. Once silica is used by the third algal group during photosynthesis, it is lost to the system. No recycling of silica takes place in the model. With reference to Figure 54, the compartment equation for silica is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - V\phi_1 C_a P_1 \qquad (123)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_1	ALGAS
C	SI(I)	Q_{in}	QHI(I)
C_a	ALGAE(I,3)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_{in}	SIIN(N), PSI(I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL (13)	V	DVOL(I)
D	DC(I)	ΔZ	SDZ(I)
		ϕ_1	AMU(I,3)

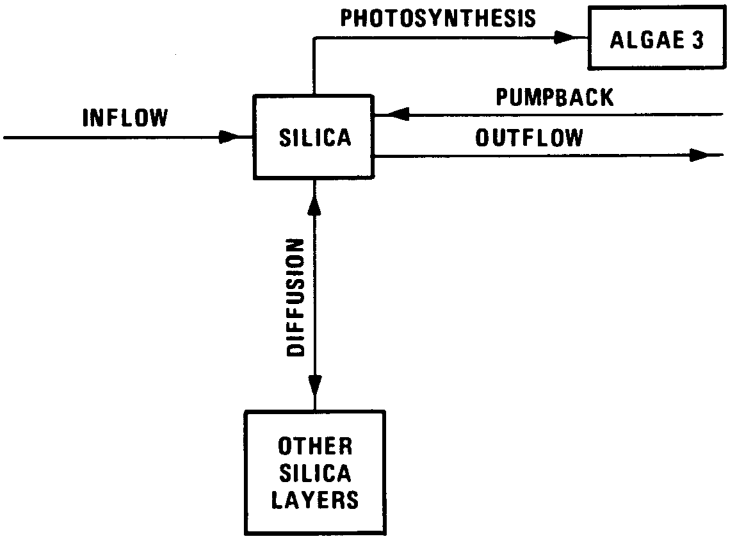


Figure 54. Fluxes among silica and other compartments

where, under Computer Code, I represents layers and N represents tributaries.

The terms in Equation 123 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, and photosynthesis of the third algal group. Calculated values for many terms can be zero by proper choice of coefficients.

Subroutine CARB

Carbon, oxygen, and hydrogen are the most abundant elements of living matter and form the essential backbone of organic material. Inorganic carbon, modeled by this compartment, also directly influences the pH and buffering capacity of water.

With reference to Figure 55, the compartment equation for inorganic carbon is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = {} & \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC + V\phi_1C_aP_1 \\ & - V\phi_2C_aP_1 + V\gamma_1K_{dl}C_{dl}P_1 + V\gamma_1K_{dr}C_{dr}P_1 + \gamma_2VK_{dd}C_{dd}P_1 \qquad (124) \\ & + \gamma_2K_{ds}C_sP_1 + V\phi_3C_zP_1 + V\phi_4C_fP_1 + \phi_5P_1 - \phi_6P_1 + \phi_7\end{aligned}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_{ds}	SEDDK
A_+	AREA(NUME+1)	P_1	BIOC
C	CARBON(I)	Q_{in}	QHI(I)
C_a	ALGAE(I,J)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_c	CO2(NUME)	Q_p	PBFLOW/PHOURS
C_{dd}	DETUS(I)	T	TEMP(NUME)
C_{dl}	DOM(I)	V	DVOL(I)
C_{dr}	RFR(I)	W	WIND
C_f	FISHB(I)	ΔZ	SDZ(I)
C_{in}	CARBIN(N), PCAR(I)	ϕ_1	ART(I,J)
C_p	MXQUAL(18)	ϕ_2	AMU(I,J)
C_s	CSED(I)	ϕ_3	ZRT(I)
C_z	ZOO(I)	ϕ_4	FRT(I)
D	DC(I)	ϕ_5	PLFLX(I,3)
D_c	DMCO2	ϕ_6	PLFLX(I,1)
K_{dd}	DETUDK	γ_1	RTMLT1(1,I)

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
K_{dl}	DOMDK	γ_2	RTMLT1(4,I)
K_{dr}	RFRDK		

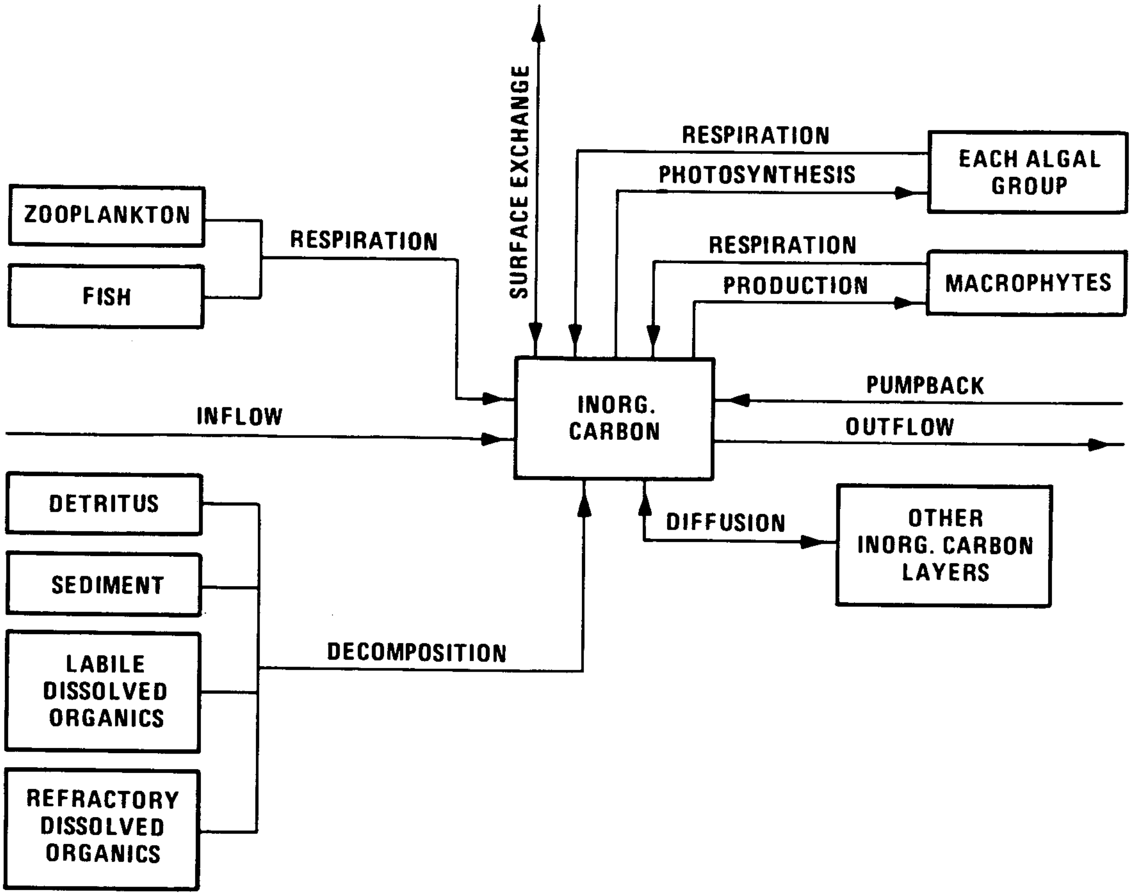


Figure 55. Fluxes for the inorganic carbon compartment

where, under Computer Code, I represents layers, J represents algal compartments, N represents tributaries, NUME represents the top modeled layer, and NUME+1 represents the upper surface of the top layer.

Terms in Equation 124 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, algal respiration, algal photosynthesis, labile DOM decomposition, refractory DOM decomposition, detritus decomposition, sediment decomposition, zooplankton respiration, fish respiration, macrophyte respiration, macrophyte photosynthesis, and exchange at the air-water interface, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

The concentration of carbon in the inflow is not read in as a driving variable as are other inflowing concentrations. Instead, carbon concentrations are calculated based on the inflow values for temperature, alkalinity, and pH.

The carbon compartment incorporates gas exchange of CO_2 (ϕ_7) at the air-water interface.

$$\phi_7 = \frac{A_{+}D_c\left(0.286e^{-0.0314T} - C_c\right)}{\left[200 - (60\sqrt{0.2778W})\right] \cdot 1 \times 10^{-6}} \qquad (125)$$

The rate of exchange is modeled as a diffusion process across a thin film at the water surface (after Kanwisher 1963). The process is driven by the difference between the present value of dissolved CO_2 in the surface layer and its equilibrium value. Both are expressed as functions of the surface layer temperature. The surface film thickness is dependent on wind speed, diminishing as wind speed increases. The expression for the equilibrium value of dissolved CO_2 is obtained from a curve fit to data expressing the temperature dependence of the Henry's Law constant relating the partial pressure of gas to its mole fractions dissolved in water. This expression allows carbon flux to either enter or leave the reservoir from the top layer being modeled. The output units of CO_2 are in grams of carbon.

Total carbon and CO_2 values are also used during the pH-CO_2 calculations, so care must be exercised if any changes are made in this compartment that might impact other subroutines.

Subroutine AMMONIA

Ammonium nitrogen is a nutrient that is used by algae and macrophytes during photosynthesis to form proteins. Un-ionized ammonia is an important compound in aquatic systems since it can be highly toxic to aquatic organisms. Please refer to Hutchinson (1957) and Trussell (1972) for information concerning these compounds.

With reference to Figure 56, the compartment equation for ammonia is

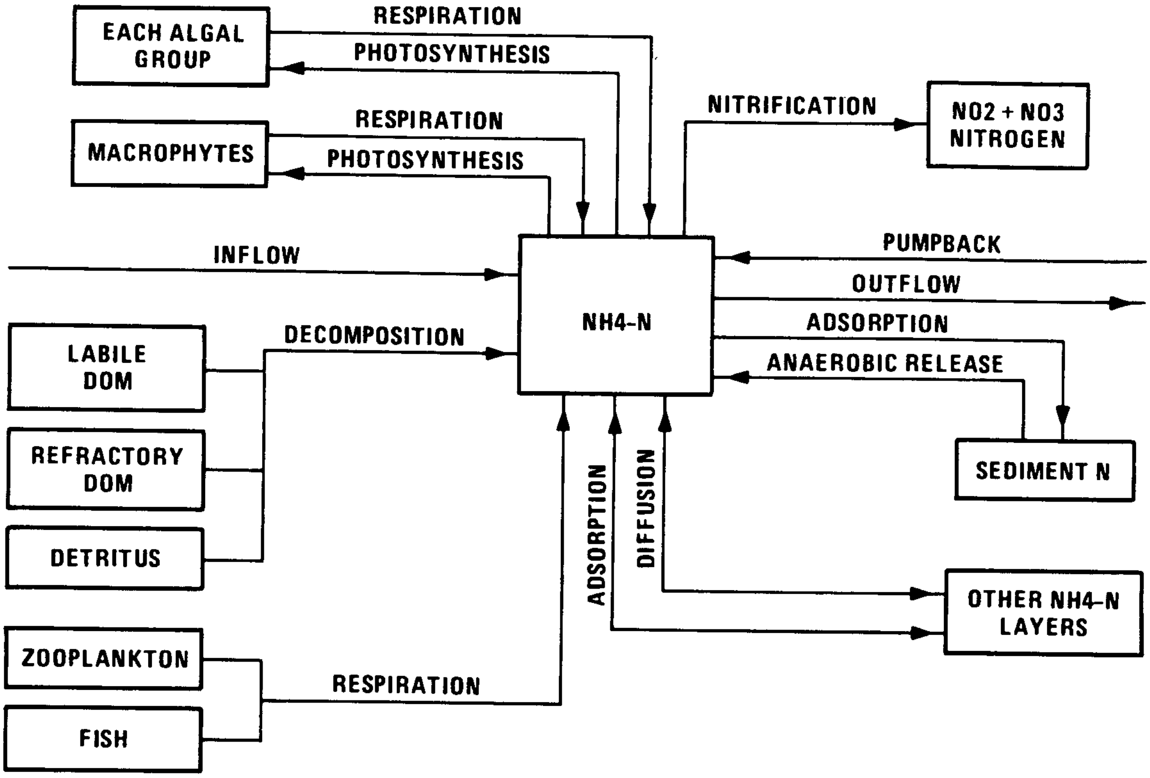


Figure 56. Fluxes for the ammonia-nitrogen compartment

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - \gamma_1K_dVC$$

$$- VCP_3\phi_1\phi_2/\left\{\gamma_2\Delta Z\left[(1/P_1) + C\right]\right\} + V_+C_+P_3\phi_3\phi_2F/\left\{\gamma_1\Delta Z_+\left[(1/P_1) + C_+\right]\right\}$$

$$+ P_2\gamma_3VC_a - VCP_2\gamma_4C_a/\gamma_5 + \gamma_6VK_{dd}C_{dd}P_2 + V\gamma_7C_zP_2$$

$$+ V\gamma_8C_fP_2 + V\gamma_9K_{dl}C_{dl}P_2 + V\gamma_9K_{dr}C_{dr}P_2 + P_4A_s \qquad (126)$$

$$+ \gamma_{10}P_2 - \gamma_{11}P_5C\gamma_5P_2$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	ϕ_1	DETUS(I) + SSOL(I) + ALGAE(I,J)
A_s	AREA(I+1) - AREA(I)	ϕ_2	DSETL + SSETL + SETL(J)
C	CNH3(I)	ϕ_3	DETUS(I+1) + SSOL(I+1) + ALGAE(I+1,J)
C_+	CNH3(I+1)	Q_{in}	QHI(I)
C_a	ALGAE(I,J)	Q_o	QHO(I), PBENTR(I)/ PHOURS
C_{dd}	DETUS(I)	Q_p	PBFLOW/PHOURS
C_{dl}	DOM(I)	V	DVOL(I)
C_{dr}	RFR(I)	V_+	DVOL(I+1)
C_f	FISHB(I)	ΔZ	SDZ(I)
C_{in}	CNH3IN(N), PNH3(I)	ΔZ_+	SDZ(I+1)
C_p	MXQUAL(6)	γ_1	RTMLT1(2,I)
C_z	ZOO(I)	γ_2	SUMJ
D	DC(I)	γ_3	ART(I,J)
F	FRACT(I)	γ_4	AMU(I,J)
K_d	CNH3DK	γ_5	CNTOT(I)
K_{dd}	DETUDK	γ_6	RTMLT1(4,I)
K_{dl}	DOMDK		
K_{dr}	RFRDK		

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
P_1	ADSRBN	γ_7	ZRT(I)
P_2	BION	γ_8	FRT(I)
P_3	ADMAXN	γ_9	RTMLT1(1,I)
P_4	CNREL	γ_{10}	PLFLX(I,3)
P_5	PLFRAC	γ_{11}	PLFLX(I,1)

where, under Computer Code, N represents tributaries, I represents layers, and J represents algal groups.

Terms in Equation 126 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, nitrification, adsorption and movement to below, gain due to adsorption and settling from above, dark respiration of algae, algal photosynthesis, detritus decay, zooplankton respiration, fish respiration, labile DOM decomposition, refractory DOM decomposition, release of nitrogen from sediments during anaerobic conditions, dark respiration of macrophytes, and macrophyte production, respectively. Nitrification of ammonia to nitrite-nitrate is allowed only in layers with positive oxygen concentrations. Calculated values for many terms can be zero by proper choice of coefficients.

Subroutine NITRATE

This compartment represents nitrite plus nitrate nitrogen. Nitrite is an intermediate product in nitrification between ammonia and nitrate. Nitrate is used by algae and macrophytes during photosynthesis.

Nitrogen may be the limiting nutrient for algae in systems with high phosphorus loadings. Some species of blue-green algae are capable of fixing atmospheric nitrogen for use in photosynthesis. Nitrogen fixation has not been coded in the model, so simulations of assemblages dominated by nitrogen-fixing blue-green algae should be interpreted cautiously.

With reference to Figure 57, the compartment equation for nitrite plus nitrate nitrogen is

$$\begin{aligned}\frac{\partial}{\partial t}(VC) = {} & \frac{\partial}{\partial z}\left(DA\,\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - VCK_d \\ & + V\gamma_1K_nC_n - VC_a\gamma_2(1 - C_n/\gamma_3)P_2 - \phi_1P_1CP_2/\gamma_3\end{aligned} \tag{127}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_2	BION
C	CNO3(I)	Q_{in}	QHI(I)
C_a	ALGAE(I,J)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_{in}	CNO3IN(N), PNO3(I)	Q_p	PBFLOW/PHOURS
C_n	CNH3(I)	V	DVOL(I)
C_p	MXQUAL(7)	γ_1	RTMLT1(2,I)
D	DC(I)	γ_2	AMU(I,2)
K_d	CNO3DK	γ_3	CNTOT(I)
K_n	CNH3DK	ϕ_1	PLFLX(I,1)
P_1	PLFRAC	ΔZ	SDZ(I)

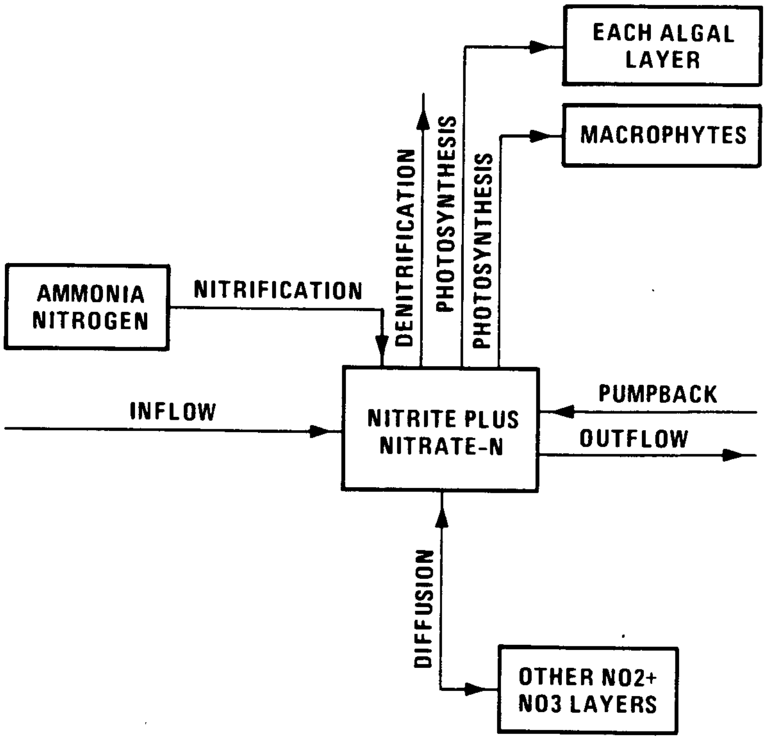


Figure 57. Fluxes for the nitrite plus nitrate-nitrogen compartment

where, under Computer Code, I represents layers, N represents tributaries, and J represents algal compartments.

Terms in Equation 127 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, denitrification (during anaerobic conditions), nitrification of ammonia, algal photosynthesis and macrophyte photosynthesis, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

Anaerobic Subroutines--General Comments

Low concentrations of dissolved oxygen in impoundments can lead to the generation of undesirable, reduced chemical products. These products, which include soluble manganese, iron, and sulfur, can degrade recreational aesthetics and fisheries and cause taste, odor, and staining problems that increase water treatment costs. Hydrogen sulfide is known to cause illness to reservoir project operators, and it also accelerates corrosion of outlet works. In addition, increased regeneration rates of orthophosphate and ammonium from sediments may stimulate nuisance algal blooms.

A series of 13 subroutines describe the chemistry associated with anoxia in reservoirs. Their interrelationship is shown in Figure 2. Each subroutine deals with a specific water quality variable and its interaction with other variables. The subroutines initiate simulations of reduction and oxidation processes in a specific layer when a given dissolved oxygen concentration (OXYLIM) is reached. If oxygen falls to or below this level, reduction processes and sediment release of NH_4^+-N, PO_4^{-3}-P, Mn^{+2}, Fe^{+2}, and S^{-2} take place; when oxygen exceeds OXYLIM, oxidation of reduced materials occurs.

Sediments release almost all the anaerobic materials generated in CE-QUAL-R1 simulations; reduction and inflow account for the remainder. Sediment thickness (SEDTHK in centimetres) and sediment concentrations (in grams per cubic metre) combine to give the mass of a particular anaerobic material available for release from a square metre of sediment surface.

Oxygen demands in CE-QUAL-R1 are created by processes of respiration, decomposition, nitrification, and oxidation of reduced products of anaerobic reactions. Values for these oxygen requirements are found in Part IV in the description of the CHEM data card. When anaerobic conditions occur, decomposition of organic materials (DOM, detritus, and sediment) slows considerably; in the current version of the model, organic decay is suspended during anoxia. Although not explicit in the following equations, most of the reactions for the anaerobic subroutines are dependent on the amount of oxygen present in each layer being modeled. Thus, oxidation reactions may be taking place in some layers while reduction mechanisms are controlling other layers.

Subroutine MNFOUR

Mn(IV), the oxidized form of manganese, is produced by the oxidation of aqueous Mn^{+2} and is assumed to occur as the particulate oxyhydroxide, MnOOH.

With reference to Figure 58, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - VCK_s/\Delta Z$$

$$+ FK_sV_+C_+/\Delta Z_+ - VCK_r + K_oC_mV \qquad (128)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_r	MN4RED
C	CMN4(I)	K_o	MN2OXI
C_+	CMN4(I+1)	Q_{in}	QHI(I)
C_{in}	CMN4IN(J), PMN4(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_m	CMN2(I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL(19)	V	DVOL(I)
D	DC(I)	V_+	DVOL(I+1)
F	FRACT(I+1)	ΔZ	SDZ(I)
K_s	MN4STL	ΔZ_+	SDZ(I+1)

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 128 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, settling to below, settling from above, reduction to Mn^{+2} when oxygen falls below a trigger value, and oxidation of Mn^{+2}, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

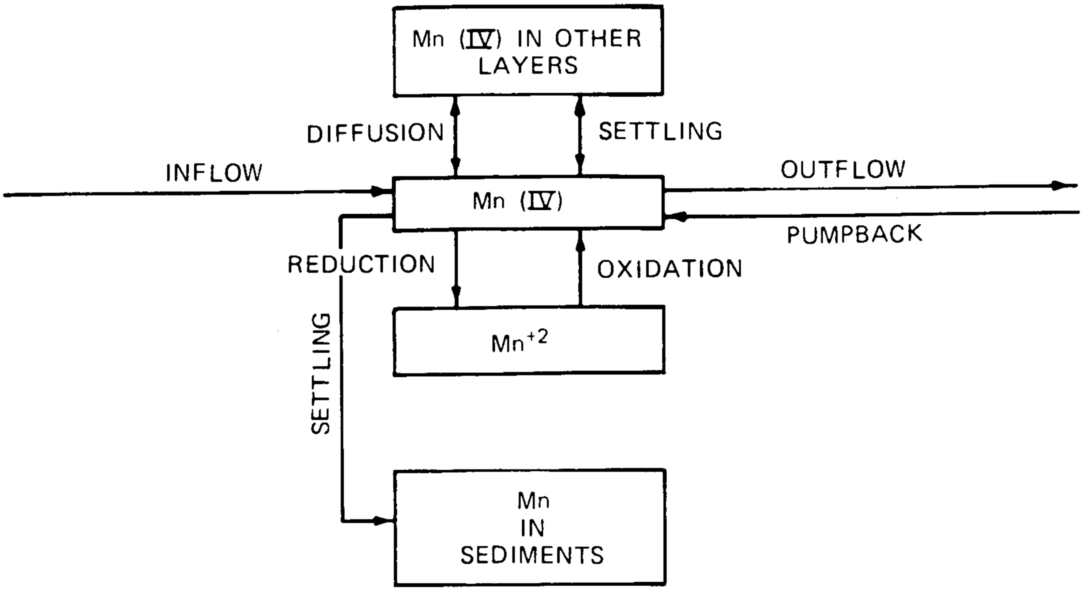


Figure 58. Fluxes affecting Mn(IV)

Subroutine MNSED

Sediment is the primary source of dissolved Mn^{+2} which is released under anaerobic conditions. Sediment Mn concentrations may increase as a result of the settling of particulate Mn(IV). Computationally, sediment Mn has units of grams per layer and the equation is solved using an Eulerian solution scheme.

With reference to Figure 59, the compartment differential equation is

$$\frac{d}{dt}(C) = K_s C_m V(1 - F)/\Delta Z - PA \tag{129}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I+1) - AREA(I)	K_s	MN4STL
C	CMN(I)	P	MNREL
C_m	CMN4(I)	V	DVOL(I)
F	FRACT(I)	ΔZ	SDZ(I)

where I represents layers.

The two terms in Equation 129 represent the settling of particulate Mn(IV) and the release of dissolved Mn^{+2} under anaerobic conditions. The calculated value of these terms can be zero with proper choice of coefficients.

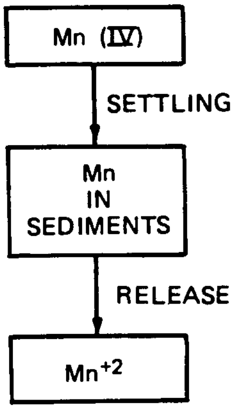


Figure 59. Fluxes affecting Mn in sediments

Subroutine MNTWO

Dissolved, reduced manganese, Mn^{+2}, in the water column is generated by sediment release and Mn(IV) reduction under anaerobic conditions. Mn^{+2} oxidizes to Mn(IV) by the following reaction mechanism which requires 0.14 g O_2 per gram Mn^{+2} oxidized.

$$2Mn^{+2} + 1/2\ O_2 + 3H_2O = 2MnOOH + 4H^+ \tag{130}$$

With reference to Figure 60, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - K_oVC + PA_s + K_mC_mV \tag{131}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_m	MN4RED
A_s	AREA(I+1) - AREA(I)	P	MNREL
C	CMN2(I)	Q_{in}	QHI(I)
C_{in}	CMN2IN(J), PMN2(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_p	MXQUAL(20)	Q_p	PBFLOW/PHOURS
D	DC(I)	V	DVOL(I)
K_o	MN2OXI	ΔZ	SDZ(I)

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 131 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, oxidation, release from the sediments, and the reduction of Mn(IV). Oxidation, release, and reduction depend on predicted oxygen concentrations. Calculated values for many of the terms can be zero by proper choice of coefficients.

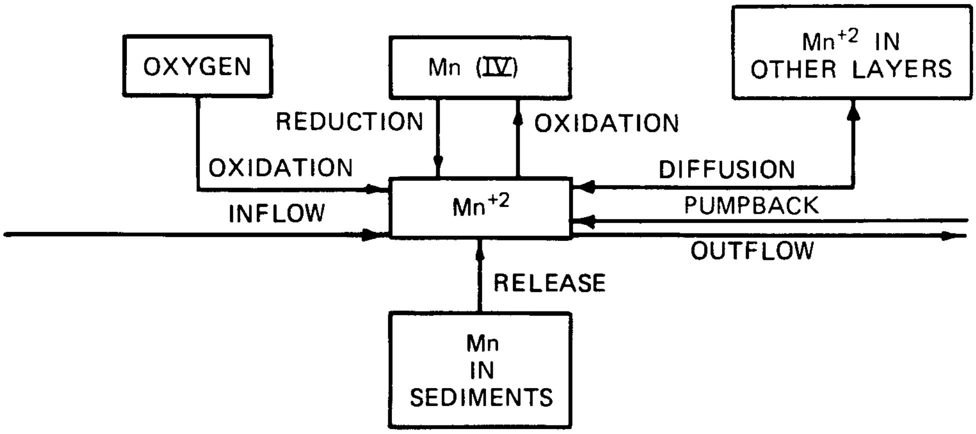


Figure 60. Fluxes for the reduced manganese compartment

Subroutine FETHREE

Fe(III), the oxidized form of iron, is produced by the oxidation of aqueous Fe^{+2} or FeS and is assumed to occur as the particulate oxyhydroxide, FeOOH.

With reference to Figure 61, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - VCK_s/\Delta Z$$

$$+ V_+K_sFC_+/\Delta Z_+ - K_rVC + K_dC_fV(56/88) + K_oC_eV \qquad (132)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_o	FE2OXI
C	FE3(I)	K_r	FE3RED
C_+	FE3(I+1)	K_s	FE3STL
C_e	FE2(I)	Q_{in}	QHI(I)
C_f	FESB(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_{in}	FE3IN(J), PFE3(I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL(21)	V	DVOL(I)
D	DC(I)	V_+	DVOL(I+1)
F	FRACT(I+1)	ΔZ	SDZ(J)
K_d	FESBDK	ΔZ_+	SDZ(I+1)

where, under Computer Code, J represents tributaries and I represents layers.

Terms in Equation 132 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, settling to below, settling from above, reduction, oxidation of FeS in the water column, and oxidation of Fe^{+2} in the water column, respectively. The value 56/88 represents the fraction of iron in FeS. Calculated values for many of the terms can be zero by proper choice of coefficients.

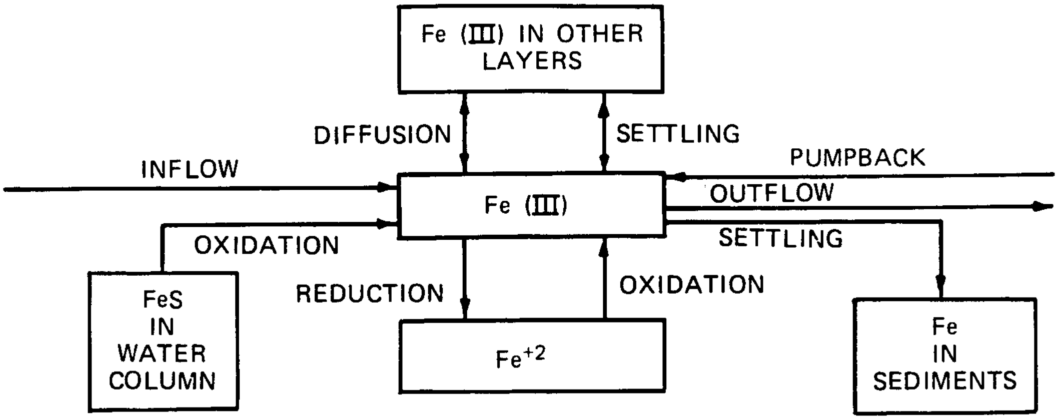


Figure 61. Fluxes for the Fe(III) compartment

Subroutine FESED

Sediment iron is the primary source of Fe^{+2} which is released under anaerobic conditions. Computationally, sediment iron has units of grams per layer, and the equation is solved using an Eulerian solution scheme.

With reference to Figure 62, the compartment differential equation is

$$\frac{d}{dt}(C) = C_f V(1 - F)K_s/\Delta Z + K_d C_e (56/88) - PA \qquad (133)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I+1) - AREA(I)	K_d	FESADK
C	FE(I)	K_s	FE3STL
C_e	FESA(I)	P	FEREL
C_f	FE3(I)	V	DVOL(I)
F	FRACT(I)	ΔZ	SDZ(I)

where, under Computer Code, I represents layers. The terms in Equation 133 represent settling, oxidation of FeS in the sediments, and release of Fe^{+2} under anaerobic conditions, respectively. The value 56/88 represents the fraction of iron in FeS. Calculated values for these terms can be zero by proper choice of coefficients.

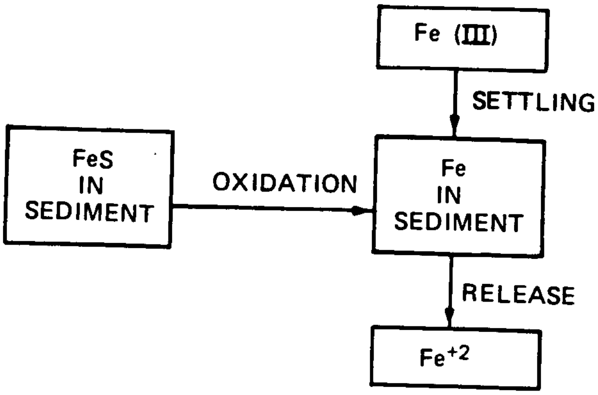


Figure 62. Fluxes among sediment iron and other compartments

Subroutine FETWO

Dissolved, reduced iron, Fe^{+2}, in the water column is generated by sediment release and Fe(III) reduction under anaerobic conditions. Fe^{+2} may combine with S^{-2} to form insoluble FeS. The following reaction mechanism describes the oxidation of Fe^{+2} to Fe(III), which requires 0.15 g O_2 per gram Fe^{+2} oxidized.

$$4Fe^{+2} + O_2 + 4H^+ = 4Fe(III) + 2H_2O \qquad (134)$$

With reference to Figure 63, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - VCK_o - VC_sK_d(56/32) + PA_s + K_rC_fV \qquad (135)$$

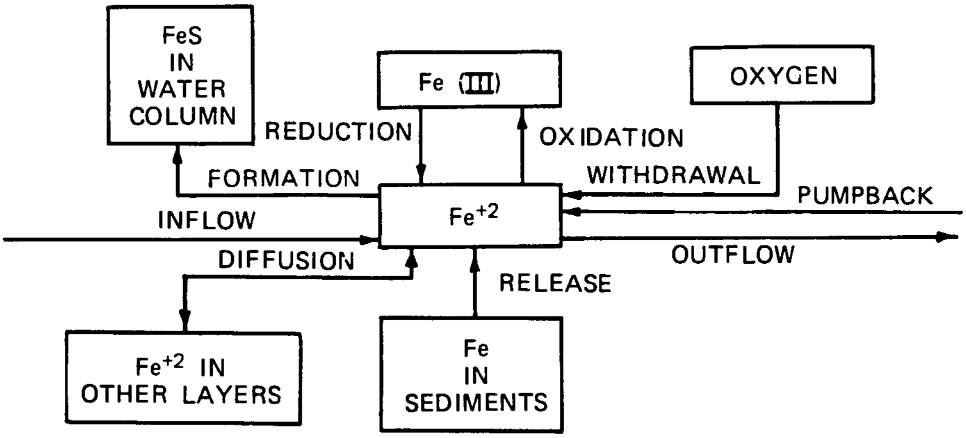


Figure 63. Fluxes among Fe^{+2} and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_d	S2DK
A_s	AREA(I+1) - AREA(I)	K_r	FE3RED

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
C	FE2(I)	P	FEREL
C_f	FE3(I)	Q_{in}	QHI(I)
C_{in}	FE2IN(J)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_p	MXQUAL(22)	Q_p	PBFLOW/PHOURS
C_s	S2(I)	V	DVOL(I)
D	DC(I)	ΔZ	SDZ(I)
K_o	FE2OXI		

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 135 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, oxidation, reaction with S^{-2}, sediment release of Fe^{+2}, and the reduction of Fe(III), respectively. The value 56/32 represents the ratio of Fe^{+2} to S^{-2} in the formation of FeS. The S^{-2} concentration controls the amount of Fe^{+2} that can be lost via this process. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine FESSED

FeS in sediments is derived solely from settling of particulate FeS from the water column. Computationally, FeS in the sediment has units of grams per layer, and the equation is solved using an Eulerian solution scheme.

With reference to Figure 64, the compartment differential equation is

$$\frac{d}{dt}(C) = -K_dC + K_sC_fV(1 - F)/\Delta Z \tag{136}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
C	FESA(I)	K_s	FESSTL
C_f	FESB(I)	V	DVOL(I)
F	FRACT(I)	ΔZ	SDZ(I)
K_d	FESADK		

where, under Computer Code, I represents layers. Terms in Equation 136 represent oxidation and the settling of FeS. Calculated values for these terms can be zero by proper choice of coefficients.

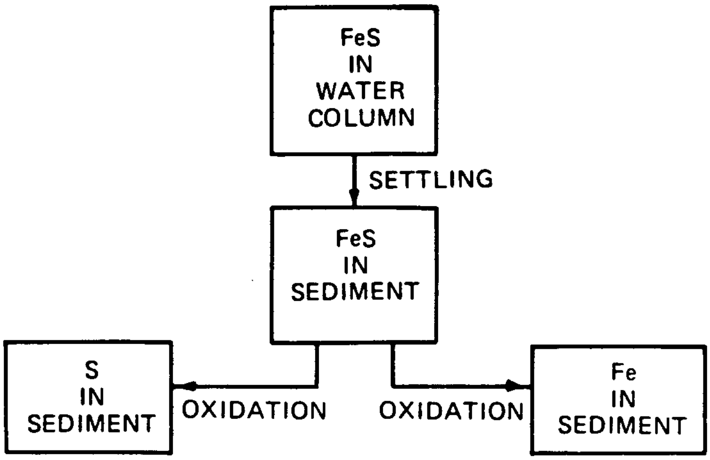


Figure 64. Fluxes among sediment FeS and other compartments

Subroutine FESWC

FeS is produced in the water column when Fe^{+2} and S^{-2} occur simultaneously under anaerobic conditions. Because FeS is a solid, it may be lost through settling.

With reference to Figure 65, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC$$

$$- VCK_d - VCK_s/\Delta Z + V_+C_+K_sF/\Delta Z_+ + VK_fC_s(88/32) \qquad (137)$$

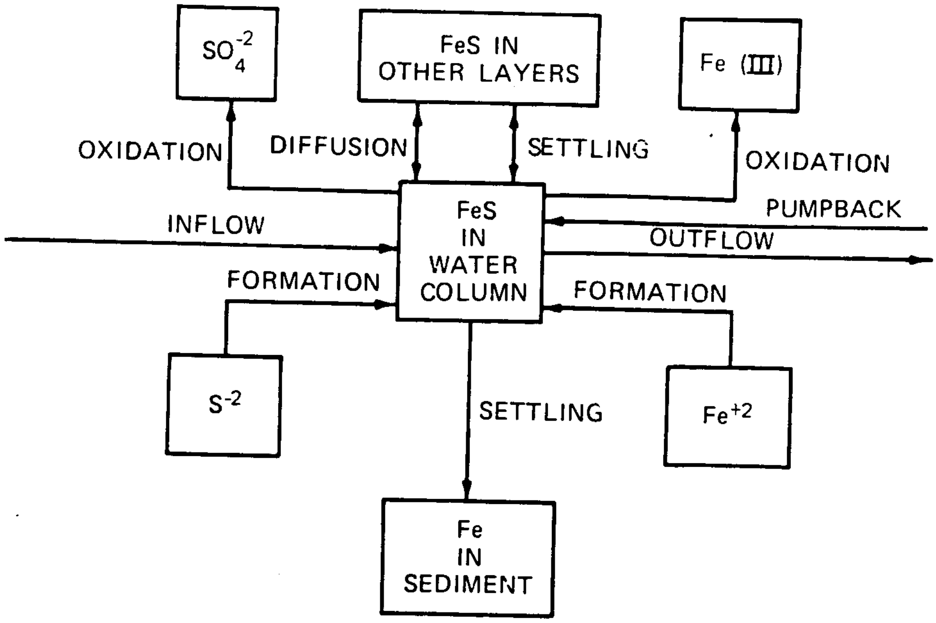


Figure 65. Fluxes among FeS in the water column and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_f	S2DK
C	FESB(I)	K_s	FESSTL
C_+	FESB(I+1)	Q_{in}	QHI(I)
C_{in}	FESBIN(J)	Q_o	QHO(I), PBENTR(I)/PHOURS

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
C_p	MXQUAL(23)	Q_p	PBFLOW/PHOURS
C_s	S2(I)	V	DVOL(I)
D	DC(I)	V_+	DVOL(I+1)
F	FRACT(I+1)	ΔZ	SDZ(I)
K_d	FESBDK	ΔZ_+	SDZ(I+1)

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 137 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, oxidation, settling to below, settling from above, and formation from Fe^{+2} and S^{-2} under anaerobic conditions, respectively. The value 88/32 relates the amount of FeS formed to the rate of change in concentration of free sulfide (S^{-2}). Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine SO4TWO

Sulfate (SO_4^{-2}), the dissolved, oxidized form of sulfur, is likely to be present in relatively high concentrations (several grams per cubic metre) in the water column and inflowing waters.

With reference to Figure 66, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - K_rVC + VC_sK_o + VC_fK_d(32/88) \tag{138}$$

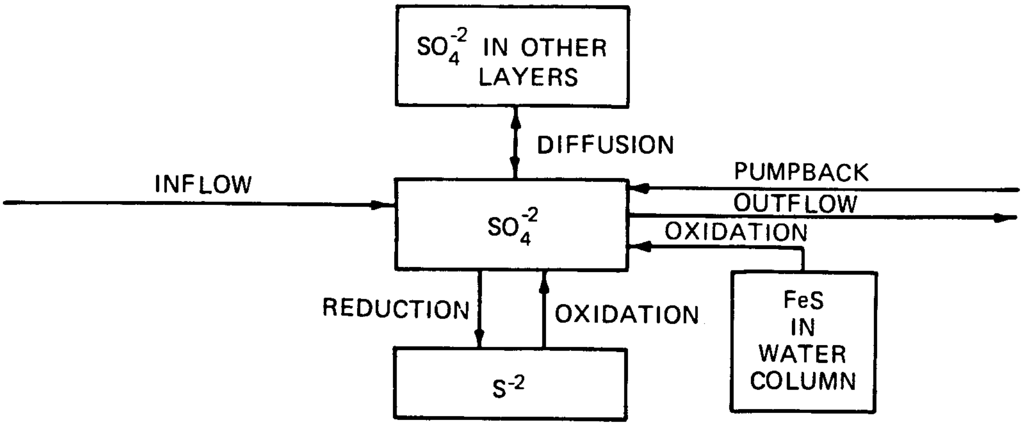


Figure 66. Fluxes affecting SO_4^{-2}

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_o	S2OXI
C	SO4(I)	K_r	SO4RED
C_f	FESB(I)	Q_{in}	QHI(I)
C_{in}	SO4IN(J), PSO4(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_p	MXQUAL(24)	Q_p	PBFLOW/PHOURS
C_s	S2(I)	V	DVOL(I)
D	DC(I)	ΔZ	SDZ(I)
K_d	FESBDK		

where, under Computer Code, I represents layers and J represents tributaries.

Terms in Equation 138 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, reduction to sulfide, oxidation of sulfide, and oxidation of FeS, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine SSED

SSED represents sulfur in the sediments. Computationally, the variable S has units of grams per layer, and the equation is solved using an Eulerian solution scheme. With reference to Figure 67, the compartment differential equation is

$$\frac{d}{dt}(C) = K_d C_f (32/88) - PA \tag{139}$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I+1) - AREA(I)	K_d	FESADK
C	S(I)	P	SREL
C_f	FESA(I)		

where I represents layers. Terms in Equation 139 represent the oxidation of FeS in the sediment and the release of S^{-2}. Calculated values for these terms can be zero by proper choice of coefficients.

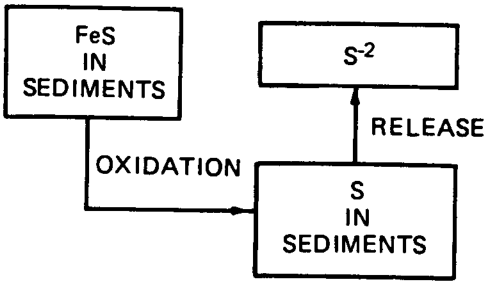


Figure 67. Fluxes among sediment S and other compartments

Subroutine STWO

Sulfide, S^{-2}, in the water column is generated under anaerobic conditions by SO_4^{-2} reduction or sediment release. The following equation describes the oxidation of S^{-2} to SO_4^{-2}, which requires 2.0 g O_2 per gram S^{-2} oxidized.

$$S^{-2} + 2O_4 = SO_4^{-2} \tag{140}$$

With reference to Figure 68, the compartment differential equation is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - K_oVC - K_dVC + PA_s + C_sVK_r \tag{141}$$

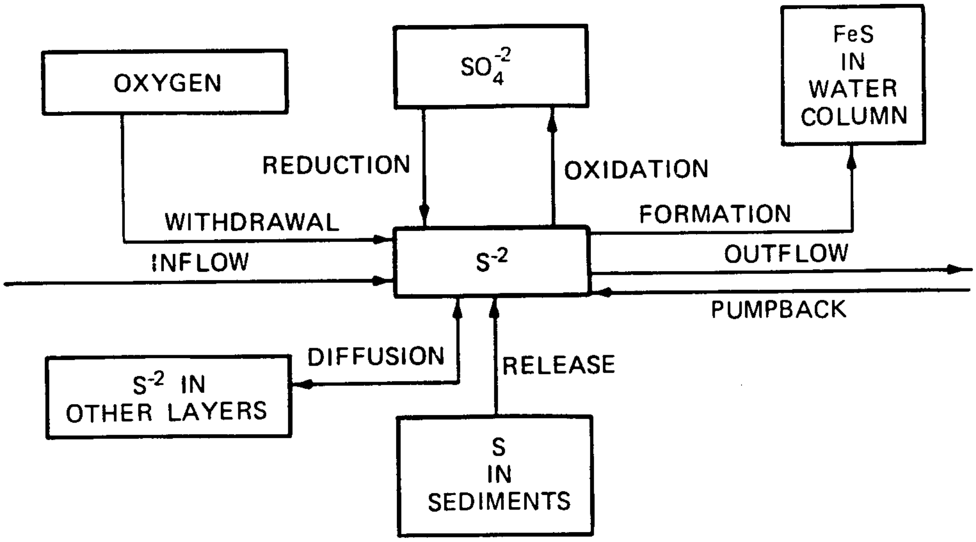


Figure 68. Fluxes among S^{-2} and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	K_o	S2OXI
A_s	AREA(I+1) - AREA(I)	K_r	SO4RED
C	S2(I)	P	SREL
C_{in}	S2IN(J), PS2(I)	Q_{in}	QHI(I)
C_p	MXQUAL(25)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_s	SO4(I)	Q_p	PBFLOW/PHOURS
D	DC(I)	V	DVOL(I)
K_d	S2DK	ΔZ	SDZ(I)

where, under Computer Code, J represents tributaries and I represents layers.

Terms in Equation 141 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, oxidation to sulfate, reaction with Fe^{+2} to form FeS, release from sediments, and sulfate reduction, respectively. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine PO4SED

PO4SED represents orthophosphate phosphorus when it is associated with the bottom sediments. The units for this variable are grams per layer, and the equation is solved using an Eulerian solution scheme.

With reference to Figure 69, the compartment differential equation is

$$\frac{d}{dt}(C) = C_s K_d P_1 \gamma_1 - P_2 A - \gamma_2 (1 - P_3) P_1 + V C_p P_5 \phi_1 \phi_2 (1 - F) / \left\{ \gamma_3 \Delta Z [(1/P_6) + C_p] \right\} \tag{142}$$

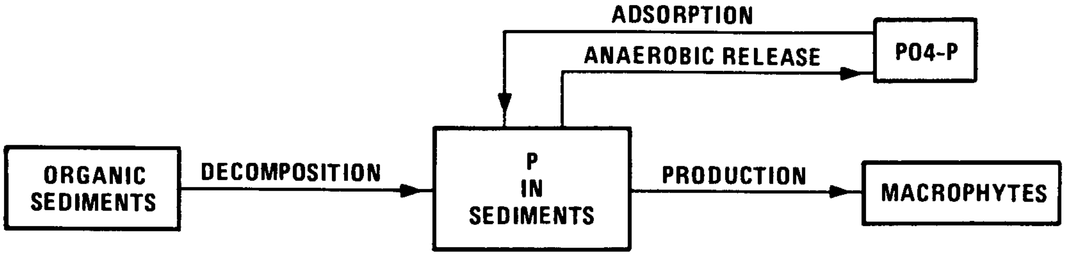


Figure 69. Fluxes among sediment phosphorus and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I+1) - AREA(I)	ϕ_2	DSETL + FE3STL + SETL(J) + SSETL + MN4STL
C	XPO4(I)		
C_p	PO4(I)	P_4	ADSRBP
C_s	CSED(I)	P_5	ADMAXP
F	FRACT(I)	V	DVOL(I)
K_d	SEDDK	ΔZ	SDZ(I)
P_1	BIOP	γ_1	RTMLT1(4,I)
P_2	XP4REL	γ_2	PLFLX(I,2)
P_3	PLFRAC	γ_3	SUMJ
ϕ_1	SSOL(I) + DETUS(I) + ALGAE(I,J) + FE3(I) + CMN4(I)		

(Continued)

where, under Computer Code, I represents layers and J represents algal compartments.

Terms in Equation 142 represent sediment decay, release of orthophosphate phosphorus during anaerobic conditions, macrophyte production, and the settling of adsorbed orthophosphate phosphorus, respectively. Calculated values for these terms can be zero by proper choice of coefficients.

Subroutine NSED

NSED represents nitrogen, utilizable by macrophytes, when it is bound by the sediments. The units for this variable are grams per layer, and the equation is solved using an Eulerian solution scheme. With reference to Figure 70 the compartment differential equation is

$$\frac{d}{dt}(C) = C_s K_d P_1 \gamma_1 - P_2 A - \gamma_2 (1 - P_3) P_1 + V C_a P_5 \phi_1 \phi_2 (1 - F) / \left\{ \gamma_3 \Delta Z \left[(1/P_4) + C_a \right] \right\} \tag{143}$$

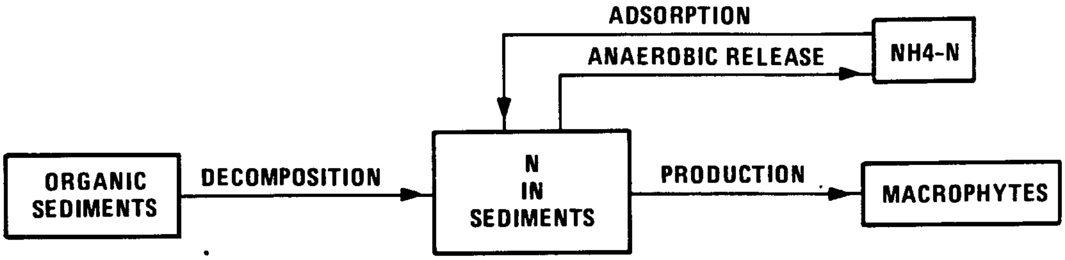


Figure 70. Fluxes among sediment nitrogen and other compartments

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I+1) - AREA(I)	P_4	ADSRBN
C	CN(I)	P_5	ADMAXN
C_a	CNH3(I)	ϕ_1	SSOL(I) + DETUS(I) + ALGAE(I,J)
C_s	CSED(I)	ϕ_2	DSETL + SETL(J) + SSETL
F	FRACT(I)	V	DVOL(I)
K_d	SEDDK	ΔZ	SDZ(I)
P_1	BION	γ_1	RTMLT1(4,I)
P_2	CNREL	γ_2	PLFLX(I,2)
P_3	PLFRAC	γ_3	SUMJ

where, under Computer Code, I represents layers and J represents algal compartments. Terms in Equation 143 represent sediment decay, release of ammonia nitrogen during anaerobic conditions, macrophyte production, and the settling of adsorbed ammonia nitrogen, respectively. Calculated values for each of these terms can be zero by proper choice of coefficients.

Subroutine OXYGEN

Oxygen is one of the most important elements in aquatic ecosystems. It is essential for higher forms of life, controls many chemical reactions through oxidation, and is a surrogate variable indicating the health or general condition of aquatic systems.

CE-QUAL-R1 includes both aerobic and anaerobic constituents. Inclusion of compartments for anaerobic materials permits the simulation to continue through anaerobic periods until aerobic conditions again occur. Oxygen dynamics provide insight into algae blooms, oxygen depletion rates, and zones of oxygen depletion. Simulations can identify the possibilities for both metalimnetic and hypolimnetic oxygen depletion and the effects of various management alternatives. If a single variable were to be measured in aquatic systems that would provide maximum information about the system state, it would be dissolved oxygen.

With reference to Figure 71, the compartment differential equation for oxygen is

$$\frac{\partial}{\partial t}(VC) = \frac{\partial}{\partial z}\left(DA\frac{\partial C}{\partial z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC + VP_1\phi_1C_a - VP_2\phi_2C_a$$

$$- VP_3\gamma_1K_dC_m - P_4\gamma_2VK_cC_d - P_4\gamma_2C_sK_s - VP_2\phi_3C_z - VP_2\phi_4C_f \qquad (144)$$

$$- VP_5\gamma_3K_oC_o - VP_5\gamma_3K_rC_r - VP_6C_gK_g - VC_eK_eP_7 - VC_vK_vP_8 - \phi_5P_2 + \phi_6P_1 + \phi_7$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	P_1	O2FAC
A_+	AREA(I+1)	P_2	O2RESP
C	OXY(I)	P_3	O2NH3
C_a	ALGAE(I,J)	P_4	O2DET
C_d	DETUS(I)	P_5	O2DOM

(Continued)

SYMBOL TABLE (Concluded)

Equation	Computer Code	Equation	Computer Code
C_e	FE2(I)	P_6	O2MN2
C_f	FISHB(I)	P_7	O2FE2
C_g	CMN2(I)	P_8	O2S2
C_{in}	OXYIN(K), POXY(I)	P_9	DMO2
C_m	CNH3(I)	Q_{in}	QHI(I)
C_o	DOM(I)	Q_o	QHO(I), PBENTR(I)/PHOURS
C_p	MXQUAL(11)	Q_p	PBFLOW/PHOURS
C_r	RFR(I)	T	TEMP(NUME)
C_s	CSED(I)	V	DVOL(I)
C_v	S2(I)	W	WIND
C_z	ZOO(I)	ΔZ	SDZ(I)
D	DC(I)	γ_1	RTMLT1(2,I)
K_c	DETUDK	γ_2	RTMLT1(4,I)
K_d	CNH3DK	γ_3	RTMLT1(1,I)
K_e	FE2OXI	ϕ_1	AMU(I,J)
K_g	MN2OXI	ϕ_2	ART(I,J)
K_o	DOMDK	ϕ_3	ZRT(I)
K_r	RFRDK	ϕ_4	FRT(I)
K_s	SEDDK	ϕ_5	PLFLX(I,3)
K_v	S2OXI	ϕ_6	PLFLX(I,1)

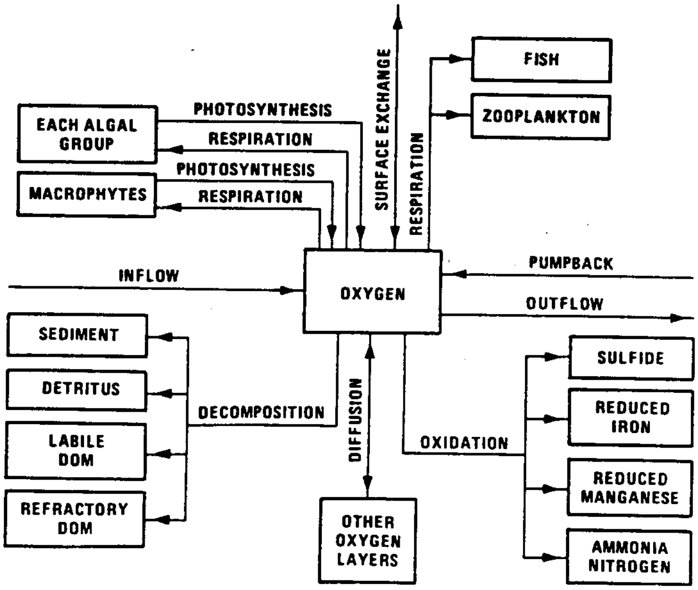


Figure 71. Fluxes among oxygen and other compartments

Terms in Equation 144 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, algal production, algal respiration, nitrification, detritus decomposition, sediment decomposition, zooplankton respiration, fish respiration, decay of labile DOM, decay of refractory DOM, oxidation of Mn^{+2}, oxidation of Fe^{+2}, oxidation of S^{-2}, macrophyte respiration, macrophyte production, and the exchange of oxygen at the air-water interface.

There are two choices in modeling surface exchange in CE-QUAL-R1. The original formulation is from Kanwisher (1963) and is similar to CO_2 exchange (see subroutine CARB) with the equation being:

$$\Phi_7 = \frac{A_+ P_9 \{14.6 \exp - [(0.027767 - 0.00027T + 0.000002T^2)T] - C)\}}{[200 - 60\sqrt{0.2278W}\ ] * 1x10^{-6}} \qquad (145a)$$

The second wind reaeration formulation is from O'Connor (1983). The O'Connor formulation is a more theoretical point of view for the surface transfer coefficient and is written as:

$$K_L = \frac{U_*}{\dfrac{\Gamma\, Sc^{2/3}}{K^{1/3}\sqrt{\rho_r}} + \sqrt{\dfrac{K\, z_{o+}\, Sc}{\rho_r}}} \qquad (145b)$$

where

K_L = mass transfer coefficient caused by wind stress, cm/s

U_* = shear velocity, cm/s

K = Von Karman's constant

Sc = Schmidt number

ρ_r = air-water density ratio

Γ = dimensionless viscous sublayer thickness

z_{o+} = dimensionless roughness length

The parameters Γ and z_{o+} are expressed by:

$$\Gamma = \Gamma_o \quad \text{when } U_* < U_{*c}$$

$$\Gamma = \Gamma_o \frac{U_*}{U_{*c}} e^{1-U_*/U_{*c}} \quad \text{when } U_* \geq U_{*c}$$

$$z_{o+} = \frac{1}{\dfrac{\nu}{z_e U_*} + \lambda_1 e^{-U_*/U_{*t}}}$$

where

Γ_o = dimensionless viscous sublayer thickness for smooth flow

U_{*c} = critical shear velocity at which rapid erosion of viscous sublayer occurs, cm/s

U_{*t} = shear velocity that characterizes transition from smooth to rough flow, cm/s

ν = kinematic viscosity, cm^2/s

λ_1 = reciprocal roughness Reynolds number

z_e = equilibrium roughness length

Values used for these parameters in the wind reaeration formulation are listed in Table 1 and represent the midrange of values suggested for a large-scale system (O'Connor 1983).

Care must be taken when using the predicted oxygen concentrations in the outflow because reaeration is possible as water flows through the outlet structure (Wilhelms and Smith 1981). The values reported by the model represent oxygen concentrations as they enter the port. Calculated values for many of the terms can be zero by proper choice of coefficients.

Subroutine COLIFRM

The abundance of coliform bacteria has traditionally been used as an indicator of pathogen contamination. Standards and criteria have been formulated and promulgated based on coliform concentrations to indicate the safety of water for drinking or recreation purposes.

Table 1

Parameters Used in Computation of the Wind Reaeration Coefficient

Parameter (1)	Value (2)	Parameter (3)	Value (4)
C_d	0.0013	S_c	500
U_{*c} (cm/s)	9.2	U_{*t} (cm/s)	10
z_e (cm)	0.25	Γ_o	4
K	0.4	λ_1	2.5
ν (cm^2/s)	0.15	ρ_r	0.0012

Predictions of coliform bacteria are, therefore, important because of their impact on project purposes such as recreation and water supply.

Total coliforms, fecal coliforms, or fecal streptococci can be simulated with this compartment. CE-QUAL-R1 considers the initial coliform loading from the tributaries, die-off, and dilution due to mixing and entrainment. This compartment is independent of all other quality compartments except temperature. Only the transport matrix (subroutine TRNSPT) is required.

With reference to Figure 72, the compartment equation for coliforms is

$$\frac{\delta}{\delta t}(VC) = \frac{\delta}{\delta z}\left(DA\frac{\delta C}{\delta z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC - KP^{(T-20)}VC \qquad (146)$$

SYMBOL TABLE

Equation	Computer Code	Equation	Computer Code
A	AREA(I)	Q_{in}	QHI(I)
C	COLIF(I)	Q_o	QHO(I), PBENTR/PHOURS
C_{in}	COLIN(J), PCOLIF (I)	Q_p	PBFLOW/PHOURS
C_p	MXQUAL(9)	T	TEMP(I)
K	COLIDK	V	DVOL(I)
P	Q10COL	ΔZ	SDZ(I)

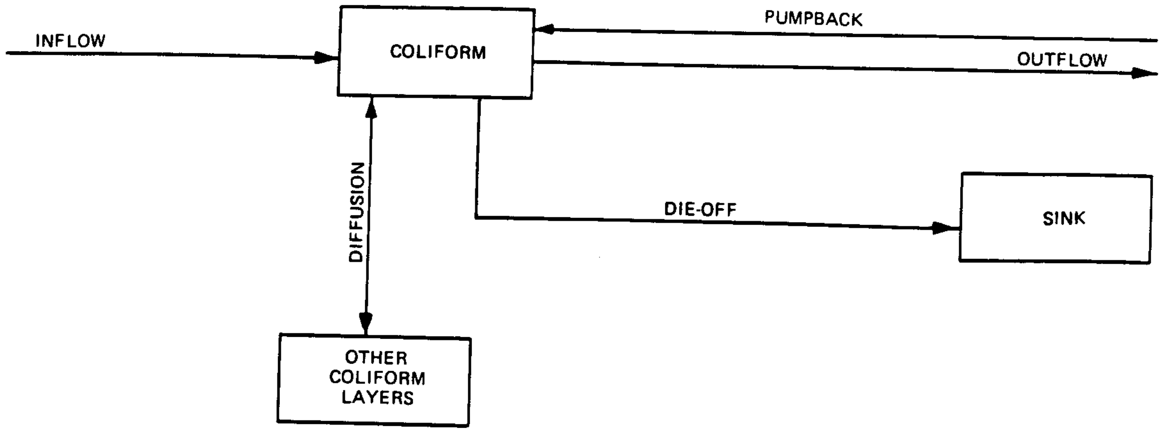


Figure 72. Fluxes for the coliform compartment

where, under Computer Code, I represents layers and J represents tributaries. Terms in Equation 146 represent diffusion, tributary inflow, pumpback inflow, outflow and entrainment due to pumpback, and die-off, respectively.

The Q10 formulation arises from a doubling of the reaction rate for chemical reactions with each 10° increase in temperature. This doubling has not been found at lower temperatures (Hargrave 1972b) and is quite variable for various reactions (Giese 1968). Low coliform concentrations in the simulation should not be interpreted to imply that violations may not occur within the reservoir. The one-dimensional assumption may invalidate predicted coliform concentrations in the headwaters or cove areas where coliform concentrations may be expected to be higher. High predicted concentrations, however, may indicate that severe conditions will probably occur in other areas. Modeling coliform bacteria is discussed in detail in Zison et al. (1978).

Subroutine TDSALK

Two variables, total dissolved solids (TDS) and alkalinity, are modeled in this subroutine. Both are treated as conservatives and are only advected and diffused. The equation for a conservative substance is

$$\frac{\delta}{\delta t}(VC) = \frac{\delta}{\delta z}\left(DA\frac{\delta C}{\delta z}\right)\Delta Z + \Sigma Q_{in}C_{in} + Q_pC_p - Q_oC \qquad (147)$$

SYMBOL TABLE

Equation	Computer Code
A	AREA(I)
C	TDS(I) OR ALKA(I)
C_{in}	TDSIN(J), PTDS(I) OR ALKAIN(J), PALK(I)
C_p	MXQUAL(15) OR MXQUAL(4)
D	DC(I)
Q_{in}	QHI(I)
Q_o	QHO(I), PBENTR/PHOURS
Q_P	PBFLOW/PHOURS
V	DVOL(I)
ΔZ	SDZ(I)

where, under Computer Code, I represents layers and J represents tributaries. Terms in Equation 147 represent diffusion, tributary inflow, pumpback inflow, and outflow and entrainment due to pumpback, respectively. Figures 73 and 74 show the interactions of TDS and alkalinity.

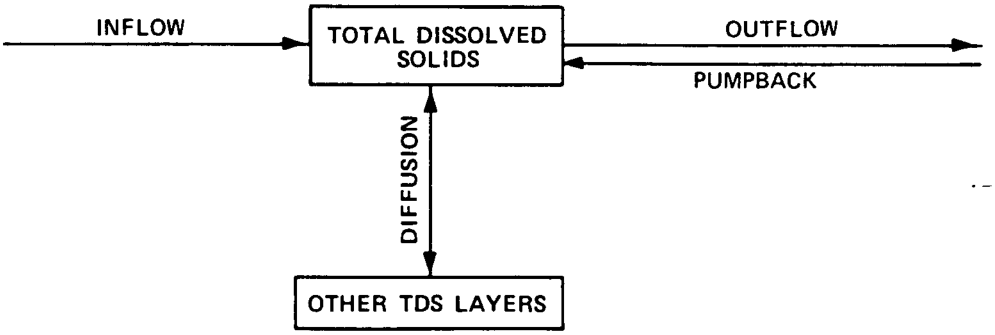


Figure 73. Fluxes for TDS compartment

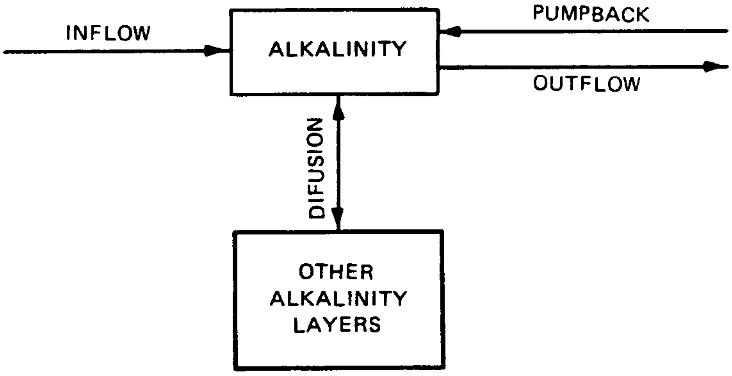


Figure 74. Fluxes for alkalinity

Total alkalinity provides an indication of the buffering capacity of the system and its resistance to large pH changes. The various dissociation forms of inorganic carbon that comprise alkalinity, such as bicarbonate, carbonate, and hydroxyl ions, are discussed in subroutine PHCO2.

TDS is simulated since there is a recommended EPA criteria for TDS in drinking water and because TDS affects the density of water. Many states also have standards for TDS. TDS is also used in subroutine PHCO2 to obtain an approximation of ionic strength.

Subroutine CONMIX

Subroutine TMPRTR solves the conservation of thermal energy equation to predict the thermal structure of a reservoir. It contains no check to determine if the predicted temperature (density) structure is unstable. Subroutine CONMIX performs this check at the end of the computational interval. If a 24-hr computation interval is used, mixing can be interpreted as resulting from nighttime cooling.

CONMIX examines the water densities layer by layer, beginning with the lowest, to detect if water in any layer is overlain by denser water (i.e., check for density instabilities). Should such an unstable condition exist, densities in the unstable layers are averaged according to layer volumes. The search and averaging, if necessary, continue to the surface. A similar process then is conducted downward from the location of the first occurrence to ensure that earlier averaging has not introduced a density inversion. When the process is completed, all water quality variables are subjected to the same volume-weighted averaging process.

Subroutine INTEGR

All of the model variables except for fish and those found in the sediments call subroutine INTEGR to solve the conservation of mass equation (Equation 110). The basic equation is

$$V_i \frac{\partial}{\partial t} (C_i) = A_{i1}C_{i-1} + A_{i2}C_i + A_{i3}C_{i+1} + P_i \ , \quad i = 2,3...N-1 \qquad (148)$$

where N is the number of layers in the reservoir. The values for A_{i1} , A_{i2} , A_{i3} , and P_i are determined in each compartment every computational interval. The transport matrix XX(i,j) is calculated in subroutine TRNSPT. The source terms SORS(i,j) are calculated in each compartment. They are combined in INTEGR.

The mechanics of integration, though straightforward in concept, are intricate in execution. The integration process is most easily explained by referring to the simplest structure to which it pertains and following it in detail. Such a structure is one containing three layers. When Equation 148 is applied to three layers, the following three equations result. (The dot notation signifies the first derivative with respect to time.)

$$V_1\dot{C}_1 = A_{11}C_1 + A_{12}C_2 + P_1 \qquad (149)$$

$$V_2\dot{C}_2 = A_{21}C_1 + A_{22}C_2 + A_{23}C_3 + P_2 \qquad (150)$$

$$V_3\dot{C}_3 = A_{32}C_2 + A_{33}C_3 + P_3 \qquad (151)$$

The numerical strategy for solving these equations involves a formulation of counterpart difference equations in which the concentrations for the next point in time are expressed directly in terms of the present concentrations and their rates of change and implicitly in terms of the rates of change at the next point. Such a strategy is stable in the sense that any departure of the computed solution of the difference equations from the true solution of the basic differential equations is not the result of propagation of numerical errors. By defining:

$$C^* \equiv C(t + \Delta t) \tag{152}$$

Equations 149-151 can be expressed as well for the next point in time as:

$$V_1\dot{C}_1^* = A_{11}C_1^* + A_{12}C_2^* + P_1 \tag{153}$$

$$V_2\dot{C}_2^* = A_{21}C_1^* + A_{22}C_2^* + A_{23}C_3^* + P_2 \tag{154}$$

$$V_3\dot{C}_3^* = A_{32}C_2^* + A_{33}C_3^* + P_3 \tag{155}$$

The implicit nature of the strategy is manifested in the approximation

$$C_1^* = C_1 + \frac{\Delta t}{2}\dot{C}_1 + \frac{\Delta t}{2}\dot{C}_1^* \tag{156}$$

$$C_2^* = C_2 + \frac{\Delta t}{2}\dot{C}_2 + \frac{\Delta t}{2}\dot{C}_2^* \tag{157}$$

$$C_3^* = \dot{C}_3 + \frac{\Delta t}{2}\dot{C}_3 + \frac{\Delta t}{2}\dot{C}_3^* \tag{158}$$

If Equations 156-158 are substituted into Equations 153-155 and algebraically rearranged to solve the $\dot{C}^*$ terms, the result in matrix notation is

$$\begin{bmatrix} V_1 - A_{11}\frac{\Delta t}{2} & -A_{12}\frac{\Delta t}{2} & 0 \\ -A_{21}\frac{\Delta t}{2} & V_2 - A_{22}\frac{\Delta t}{2} & -A_{23}\frac{\Delta t}{2} \\ 0 & -A_{32}\frac{\Delta t}{2} & V_3 - A_{33}\frac{\Delta t}{2} \end{bmatrix} \cdot \begin{bmatrix} \dot{C}_1^* \\ \dot{C}_2^* \\ \dot{C}_3^* \end{bmatrix}$$

$$= \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{21} & A_{22} & A_{23} \\ 0 & A_{32} & A_{33} \end{bmatrix} \cdot \begin{bmatrix} C_1 + \frac{\Delta t}{2}\dot{C}_1 \\ C_2 + \frac{\Delta t}{2}\dot{C}_2 \\ C_3 + \frac{\Delta t}{2}\dot{C}_3 \end{bmatrix} + \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix} \tag{159}$$

In projecting from the present point in time to the next, all terms on the right-hand side are known so that the result is a matrix of constants. This fact, together with a redefinition of the terms of the left-hand-side matrix of coefficients results in the following equations:

$$S_{11}\dot{C}_1^* + S_{12}\dot{C}_2^* = P_1' \tag{160}$$

$$S_{21}\dot{C}_1^* + S_{22}\dot{C}_2^* + S_{23}\dot{C}_3^* = P_2' \tag{161}$$

$$S_{32}\dot{C}_2^* + S_{33}\dot{C}_3^* = P_3' \tag{162}$$

Eliminating $\dot{C}_1^*$ from the first two equations results in

$$\left(S_{22} - \frac{S_{21}S_{12}}{S_{11}}\right)\dot{C}_2^* + S_{23}\dot{C}_3^* = \left(P_2' - \frac{S_{21}P_1'}{S_{11}}\right) \qquad (163)$$

Redefining the parenthesized terms, this becomes

$$S_{22}'\dot{C}_2^* + S_{23}\dot{C}_3^* = P_2'' \qquad (164)$$

But from above

$$S_{32}\dot{C}_2^* + S_{33}\dot{C}_3^* = P_3' \qquad (165)$$

So that a solution for $\dot{C}_3^*$ can be obtained as

$$\dot{C}_3^* = \frac{P_3'S_{22}' - S_{32}P_2''}{S_{33}S_{22}' - S_{32}S_{23}} \qquad (166)$$

Then the other concentration rates can be determined in reverse order. Equations 156-158 are then used to find the concentrations.

Note that each redefinition of terms is accomplished in INTEGR by overwriting previously used storage locations. This approach is known as the Thomas method. Application of this method to many layers involves no new factors, although the algebraic implementation is tedious. Fortunately, the redefinition of coefficients can be done recursively. This fact greatly simplifies the computer code which, nevertheless, remains somewhat opaque. The user should refer to Shamir and Harleman (1966) for more details.

Subroutine PHCO2

Calculations based on the equilibrium reactions of the several inorganic carbon ionic species result in the pH value reported for each layer. The pH is then used to calculate the CO_2 concentration, which is used in subroutine CARB to calculate the contribution to total carbon of CO_2 diffusing across the air-water interface. In addition, CO_2 contributes to phytoplankton growth in subroutine PHYTO.

Subroutine PHCO2 is called from the main program to calculate the initial CO_2 and carbon arrays, to calculate the CO_2 and carbon arrays at each water quality update interval, and to calculate the pH and CO_2 arrays at the end of each computational interval.

The subroutine uses information on alkalinity, temperature, TDS, and total carbon. Information returned to the main program includes pH and carbon dioxide. No sources or sinks for constituents exist within the subroutine; therefore, mass balance is not affected.

Calculations performed by PHCO2 are based on carbonate-bicarbonate equilibrium reactions (Stumm and Morgan 1970):

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^- \tag{167}$$

$$HCO_3^- \rightleftarrows CO_3^= + H^+ \tag{168}$$

$$H_2O \rightleftarrows H^+ + OH^- \tag{169}$$

These equilibria express that the source of bicarbonate and carbonate ions, alkaline constituents of fresh waters, is the dissolution of atmospheric CO_2 in water. The contribution of calcium and magnesium carbonate to the alkalinity is not overtly expressed. The equilibrium state in terms of the equilibrium constants, K_i is:

$$K_1 = \frac{\left[H^+\right]\left[HCO_3^-\right]}{\left[H_2CO_3\right]} \tag{170}$$

$$K_2 = \frac{[H^+]\ [CO_3^=]}{[HCO_3^-]} \qquad (171)$$

$$K_w = \frac{[H^+]\ [OH^-]}{[H_2O]} \qquad (172)$$

where

$[X]$ = molar concentration of X

$[H_2O]$ = unity (by definition)

The alkalinity imparted to the water can be defined as

$$[ALK] = [HCO_3^-] + 2\ [CO_3^=] + [OH^-] - [H^+] \qquad (173)$$

in which, on a molecule-by-molecule basis, the excess of negative charges over positive charges is expressed. In addition, by viewing the abundance of bicarbonate and carbonate ions as arising from the dissolution of carbonic acid, the following concentration condition prevails:

$$[H_2CO_3] + [HCO_3^-] + [CO_3^=] = CONST = C_T \qquad (174)$$

By combining Equations 170, 171, and 174, the quantities $[HCO_3^-]$ and $[CO_3^=]$ can be expressed in terms of $[H^+]$ and the constant C_T . In addition, Equation 172 allows $[OH^-]$ to be expressed in terms of $[H^+]$. When these expressions are installed in Equation 173, the result is

$$[ALK] = \frac{C_T[H^+]K_1}{[H^+]K_1 + K_1K_2 + [H^+]^2}\ \frac{[H^+] + 2K_2}{[H^+]} + \frac{K_w}{[H^+]} - [H^+] \qquad (175)$$

CE-QUAL-R1 interprets the constant C_T as moles per litre of total inorganic carbon and regards the quantity [ALK] as known. Equation 175 is iteratively solved in subroutine PHCO2 until the value of $[H^+]$ converges. The negative logarithm of $[H^+]$ is pH.

Once Equation 175 has been solved for $[H^+]$, the abundance of $[H_2CO_3]$ is calculated as

$$[H_2CO_3] = \frac{C_T}{1 + \frac{K_1}{[H^+]} + \frac{K_1K_2}{[H^+]^2}} \tag{176}$$

and is the same as that of $[CO_2]$ in units of grams of carbon.

The equilibrium constants used in the preceding equations are obtained by first expressing a thermodynamic temperature dependence for a related constant K_i^* :

$$\log K_i^* = a + \frac{b}{T} + cT + d \log T \tag{177}$$

The constants a , b , c , and d are given as follows:

	a	b	c	d
K_w^*	35.3944	-5242.39	-0.00835	11.8261
K_1^*	14.8435	-3404.71	-0.032786	0
K_2^*	6.4980	-2902.39	-0.02379	0

The relation between K_i and K_i^* is obtained from the definition of the activity of a chemical species.

$$\{X\} = \gamma[X] \tag{178}$$

where

$\{X\}$ = activity of species X in moles per litre

γ = dimensionless activity coefficient

$[X]$ = concentration in moles per litre

For the reaction

$$A + B \rightleftarrows C + D \tag{179}$$

the equilibrium constant K^* is

$$K^* = \frac{\{C\}\ \{D\}}{\{A\}\ \{B\}} \tag{180}$$

thus

$$K^* = \frac{\gamma_C[C]\gamma_D[D]}{\gamma_A[A]\gamma_B[B]} = \frac{\gamma_A\gamma_B}{\gamma_A\gamma_B} K \tag{181}$$

and

$$K = \frac{\gamma_A\gamma_B}{\gamma_C\gamma_D} K^* \tag{182}$$

The activity coefficients are obtained from an extension of Debye-Huckel theory as:

$$\log \gamma = \frac{-AZ^2 \sqrt{I}}{1 + 0.33a\sqrt{I}} + k_1 + k_2 I + k_3 I^2 \tag{183}$$

where

I = ionic strength

Z = ionic charge

A = approximately 0.5 for water at 25° C

a = ionic size parameter

k_i = empirical coefficients

The ionic strength is approximated (Sawyer and McCarty 1967) as

$$I = 2.5 \times 10^{-5} \cdot \begin{bmatrix} \text{Total} \\ \text{Dissolved} \\ \text{Solids} \\ \text{mg}/\ell \end{bmatrix} \qquad (184)$$

The values of the other parameters as used by CE-QUAL-R1 are given as follows:

	Z	a	k_1	k_2	k_3
HCO_3^-	1	4	0.0047	0.042	-0.0093
$CO_3^=$	2	4.5	0.0121	0.0972	-0.0207

The activity coefficients for $[H^+]$, $[H_2O]$, $[H_2CO_3^-]$, and $[OH^-]$ are treated as special cases:

$[H^+]$ $\gamma = 1$

$[H_2O]$ $\gamma = 1$

$\left[H_2CO_3^-\right]$ $\gamma = 0.0755I$

$[OH^-]$ $\gamma = 0.0755I$

Subroutine OUTPT1

This subroutine, called one time per simulation, prints information concerning the simulation. Included as output are a data summary listing most of the coefficients used in the simulation and initial geometric attributes of each layer of the reservoir on the day initial values are given. If CE-QUAL-R1 is run in batch mode, information generated from this subroutine is stored in a permanent file. An example of this output is shown in Appendix B.

Subroutine OUTPT2

Most of the tabular output is generated by subroutine OUTPT2, which is called at regular simulation intervals. Information printed by OUTPT2 includes date of output, average meteorological quantities, inflowing and outflowing quantities and qualities, a vertical profile of temperature and water quality constituents, and other variables such as primary production, Secchi disk depth, and community respiration. If not all water quality constituents are of interest, the user can receive output concerning only temperature, dissolved oxygen, and total algae on a per layer basis. When CE-QUAL-R1 is run in the batch mode, this information is stored, along with information from OUTPT1, on a permanent file. An example of this output is shown in Appendix B.

Subroutine OBLOUT

Subroutine OBLOUT is called once each time step. It can write inflow and outflow information as part of the tabular output. In addition, it writes all the information needed for plot and statistical utilities. This includes inflow and outflow concentrations and all in-pool water quality variables. Variables written to plot files are not necessarily the same as those represented in the subroutine. The intention is to plot variables similar to those measured in the field.

Subroutine OUTPT3

This subroutine prints output relating to generation and pumpback events. It is called at the same simulation intervals as subroutine OUTPT2.

Subroutine REREG

This subroutine defines the water quality and geometric attributes of the afterbay. Subroutine REREG (Figure 75) computes water, thermal, and material balances for the afterbay (also referred to as the reregulation pool). Currently, all water quality variables are considered conservative in the afterbay except for temperature, because heat transfer is provided in the afterbay. Reactions for other variables in the afterbay can be added if needed for a specific site.

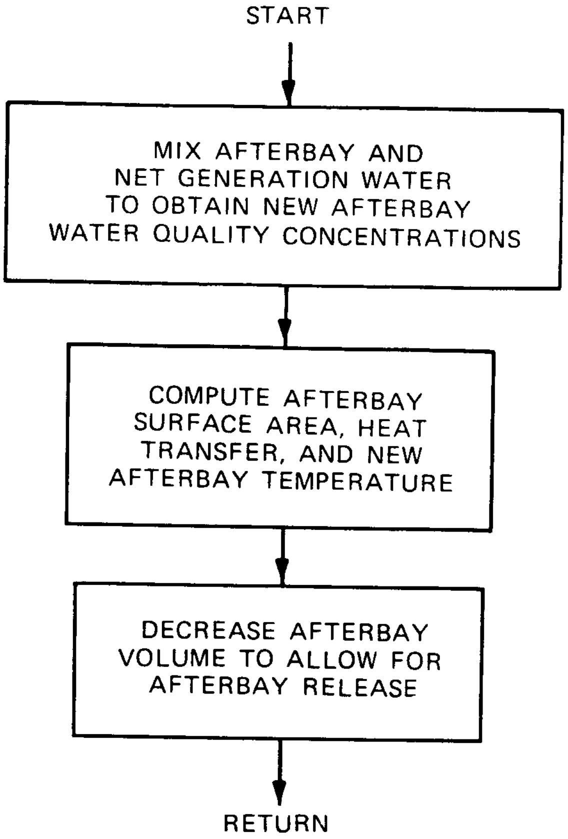


Figure 75. Flowchart for subroutine REREG

The afterbay is assumed to be well mixed from day to day, which is a valid assumption for many CE afterbays. However, a simple accounting procedure is used to keep up with small heterogeneities that can exist within a day. These differences can affect afterbay release quality and pumpback quality. The daily accounting procedure considers:

(a) upper lake release (generation) volume that is not pumped back and is added to the afterbay; (b) pregeneration afterbay volume that is pumped back; and (c) afterbay volume that is released downstream. The accounting procedure proceeds in the following order:

- a. Net contributions of generation volumes with their respective qualities are added to the postpumpback afterbay volume and a volume-weighted average is computed for each quality variable in the afterbay.
- b. Daily surface heat exchange is applied to the surface area of the afterbay, and a new afterbay temperature is computed.
- c. Afterbay volume is decreased to account for the release from the afterbay.

Afterbay release water quality is equal to the afterbay value for that water quality variable (because each variable is considered conservative) except in the case of temperature (which is allowed to change due to afterbay heat exchange). The daily afterbay release temperature can be set equal to the afterbay temperature immediately after step a above (see NFTRBY on the AFTERBAY record, PART IV). This order will result in afterbay release temperatures that approach the one-dimensional (longitudinal), steady-state, analytical solution with instantaneous total mixing. This approach would be more appropriate for small, bowl-shaped afterbays. The afterbay release temperature can also be set equal to the afterbay temperature after step b above. This order will result in afterbay release temperatures that approach the one-dimensional, steady-state, analytical solution with plug flow. This approach would be appropriate for long, narrow afterbays.

If generation does not occur, on the same day, prior to pumpback, the quality of the pumpback volume is defined as the quality of the afterbay. However, if generation occurs prior to pumpback during a day, the quality of the pumped volume is determined by mixing a selected volume of pregeneration afterbay water with water released during prior generation. Pumpback quality is computed as a volume-weighted average of the two qualities. A weighting factor, designated PBCOEF in the code, is specified by the user to express the percentage of total pumpback volume contributed by the prior generation water.

Subroutine FLUX

It is possible to predict reasonable concentrations of variables for the wrong reason. This can be done during calibration, and even during verification or confirmation, by relying only on comparisons of predicted versus measured concentrations. To ensure that reasonable concentrations are being predicted for correct reasons, a utility is provided so users may investigate predicted flux values. Flux values represent the gains and losses to each variable by different processes.

This subroutine stores values needed by the flux utility and passes this information to a permanent file at the end of a simulation. Use of the flux utility is presented in Part V.

Subroutine MC

Stochastic simulation with CE-QUAL-R1 is accomplished through subroutine MC, the Monte Carlo portion of the model. Subroutine MC is called several times during execution of a Monte Carlo simulation. The general nature of the Monte Carlo operation is shown in Figure 9. The figure indicates a simulation utilizing daily randomization of updates and coefficients cycling through an annual iterative loop. Other options are possible. The first call to subroutine MC establishes options to be utilized in the simulation, fills the Monte Carlo common arrays, and initializes the random number generator.

The second call to subroutine MC is made if randomization of coefficients is specified. Only biological and chemical coefficients such as half-saturation coefficients or decay rates are eligible for Monte Carlo operations. If randomization is desired for one coefficient, however, the disposition of all coefficients must be specified. Based upon randomization options selected, specific combinations of statistics are required. The user may choose to randomize by perturbation or generation or to skip randomization entirely. Perturbation refers to using the deterministic data set value of the coefficient as the mean of a specified probability distribution, or as the nominal value in terms of which a maximum percent of deviation is specified. Generation refers to abandonment of the data set coefficient in favor of a random variate selected from a completely specified distribution.

One of four distributions may be specified: uniform, normal, log normal, and rotated log normal (Figure 76). The appropriate distribution can be selected by constructing a frequency histogram of literature values of the coefficient in question and determining which of the four distributions most closely approximates the shape. Then, by providing the appropriate statistics, the distribution is generated and values are selected randomly from within specified bounds. If a value is generated that lies outside the bounds, the mean value is selected. The coefficient is replaced and the subroutine loops back to consider the next coefficient.

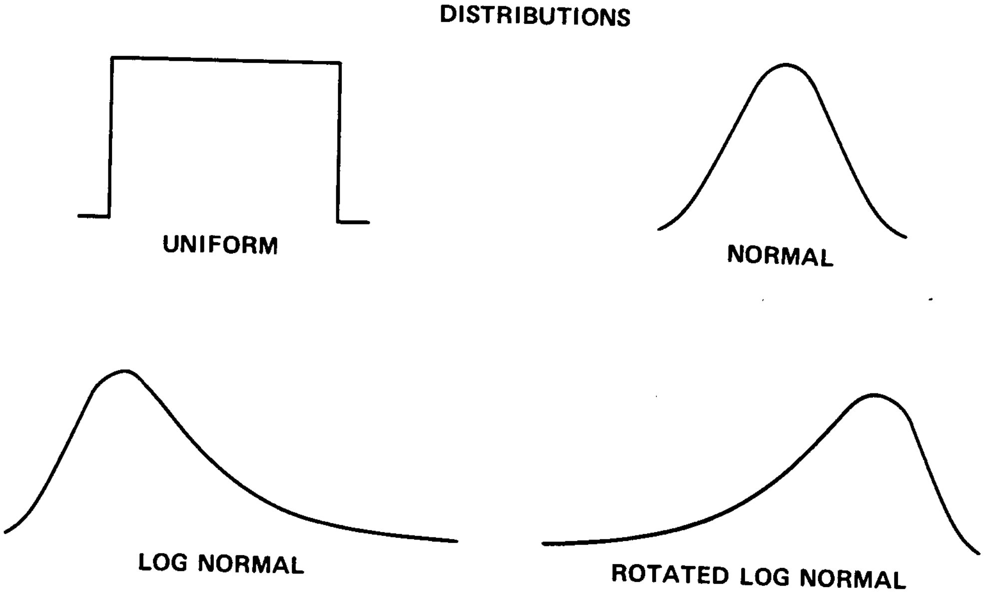


Figure 76. Randomization distributions available for subroutine MC

The third call to subroutine MC results if randomization of updates is specified. Water quality updates are subject to a randomization process identical to that discussed above. Again, if Monte Carlo randomization is required for one update, specifications must be supplied for all.

The fourth call to subroutine MC is made when a new set of values is required. Two options are available to the user to specify frequency of coefficient and update generation when operating CE-QUAL-R1 in the Monte Carlo mode. Under the DELTA-T scenario, the model cycles through MC at each computational interval. The alternative, or TOTAL-T scenario, causes the model to cycle through MC only once per simulation period, and the selected values are used for the entire period (e.g. annual). A schematic of the fourth call is presented as Figure 77.

The fifth call restores updates to the initial conditions for the next annual cycle, if so desired; the sixth call prepares the plot files prior to simulation termination.

Results from the Monte Carlo simulation are maintained as cumulative statistics that are most readily presented by the interactive graphics utility. Here, time histories of several state variables can

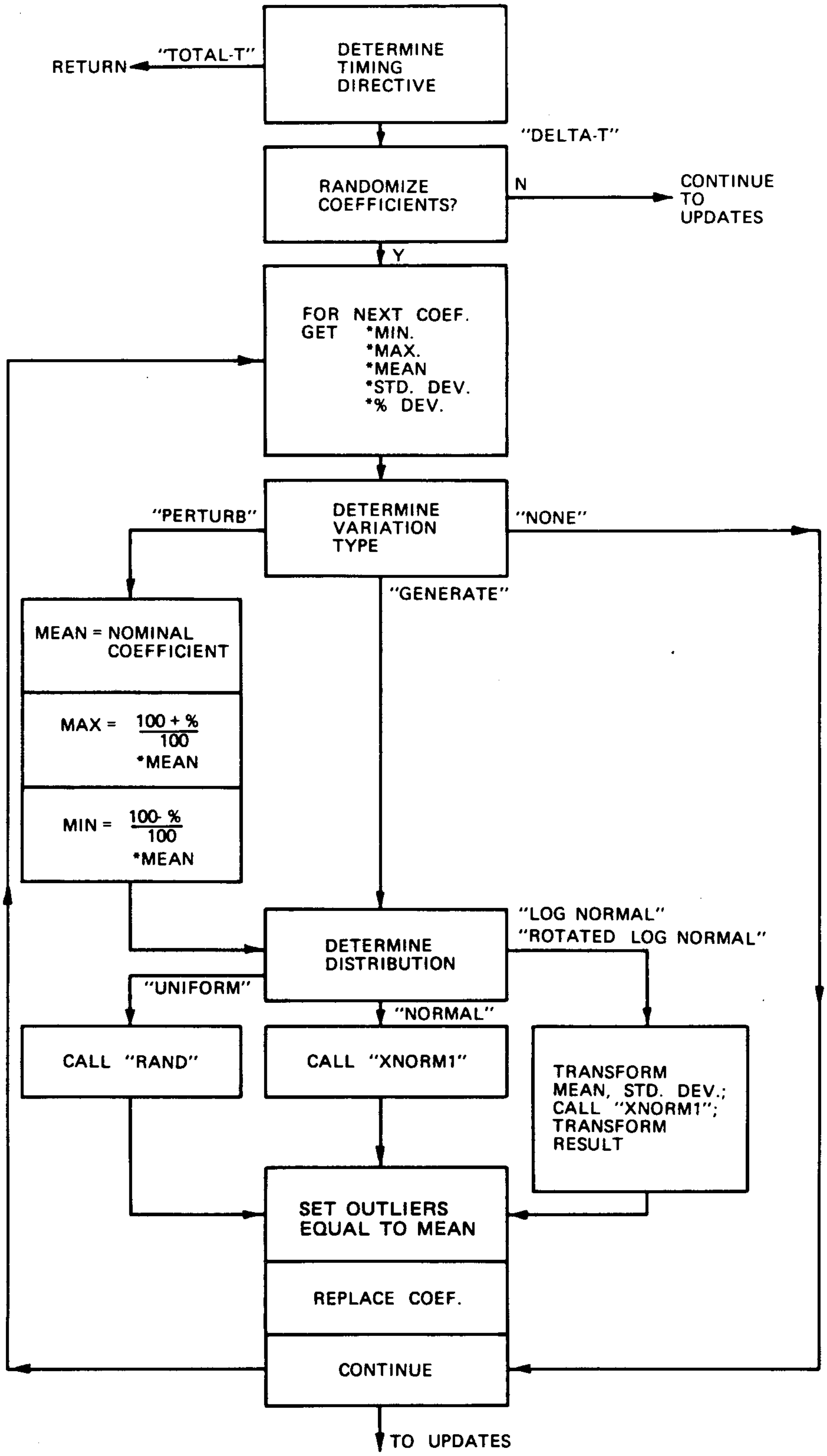


Figure 77. Coefficient randomization in subroutine MC

be plotted with confidence intervals of one standard deviation or upper and lower quartiles about the mean or median values generated.

Although it would be desirable to perform many hundreds of runs of the model in the Monte Carlo mode to provide greatest confidence in the information generated, practical experience dictates a more cost-effective approach. The model is usually run until indications of convergence appear in the results. Convergence here is described by a stabilization of the mean value and the standard error of the mean.

PART IV: OPERATIONS

General Comments

As suggested in the opening paragraphs of this manual, the tasks of data assembly, calibration, and analysis are major tasks whose time and labor requirements should not be underestimated. Of the time spent on a simulation project, only 10 percent is actually spent running the model on the computer. About 40 percent of the time is used for data and model preparation, and the remaining 50 percent for analysis of results.

Adequate data preparation and analyses require a thorough knowledge of the site and its specific features. Familiarization with the reservoir, watershed, dam, outlet structure, project operation, and sampling stations is essential. Many site-specific characteristics are not discernible from topographic maps. Infrared photography may provide information on general vegetative patterns, but will not necessarily indicate such factors as septic tank leakage and agricultural fertilizer application. In addition, the location of sampling stations heavily influences water quality results. In general, previous studies have found that CE-THERM-R1 and CE-QUAL-R1 best represent conditions near the dam, in the deepest part of the reservoir.

Involvement of a multidisciplinary working group is critical for the success of this type of modeling effort. Expertise is required in the areas of reservoir hydrodynamics and stratified flow, project operation, water chemistry, and aquatic biology. Decisions made in both the data assembly stage and output analysis stage require in-depth knowledge in these areas. These decision points are identified in the following sections.

It is recommended that CE-THERM-R1 be used first even if information on other water quality variables is needed. CE-THERM-R1 can be used to calibrate water balance and thermal profiles, and the data set is directly transferable to CE-QUAL-R1. Because temperature is used in many of the biological algorithms in CE-QUAL-R1, the user should not attempt to use CE-QUAL-R1 unless satisfactory predictions are made using CE-THERM-R1.

General Procedure

The recommended procedure for any modeling study includes the following steps:

- a. Determination of whether the model can address the study objectives. Consideration must be given to the model assumptions and limitations and to the factors the model addresses (see Part II). The user must answer the question: Is a modeling study required and is CE-THERM-R1 or CE-QUAL-R1 appropriate? Will site-specific changes to the code have to be made?
- b. Collection of necessary information to run the model.
- c. Determination of whether sufficient data are available to run the model. This is a difficult question to answer, but model predictions are only as good as model input. If all the input data are synthetic, the validity of the output must be seriously questioned.
- d. Data assembly. This topic is discussed in detail later in Part IV. Also consider using Appendixes C and D.
- e. Model checkout. Consider using the preprocessors (Part V) to check the data set. The initial model simulations are used to determine if the program executes correctly. Format corrections are easily handled by reexamining the input deck with the aid of Appendixes C and D.
- f. Calibration. The calibration procedures for CE-QUAL-R1 are discussed in detail later in Part IV. Careful selection of data input elements will minimize the calibration effort.
- g. Output interpretation, which is discussed in detail later in Part IV. This is the step where the study objectives are addressed and management alternatives are compared.

Data Requirements

The data required by CE-QUAL-R1 consist of initial conditions, coefficients, and updates (driving variables or boundary conditions). Initial conditions refer to values of temperature and of all biological and chemical constituents on a per layer basis that prevail at the start of a simulation. Coefficients refer to the numerous constant factors, such as maximum chemical and biological process rates, in units for which the compartments have been parameterized. Updates refer to the time sequences of meteorological, hydrological, and water quality values required every computational interval during the simulation.

Before attempting to assemble a data set, it is recommended that the user review all of Part IV to determine the type and amount of information required to simulate reservoir water quality. The information (i.e., maps, manuals, reports, hydrometeorological data, water quality data) should be gathered. It is only after the user has reviewed the data requirements and available data that an intelligent decision can be made whether sufficient data are available to simulate a reservoir. This decision should be made before attempting to assemble a data set. Although it is impossible to specify a list of absolute minimum data requirements, certain items are essential. These include reservoir descriptions, inflows, outflows, meteorological data, and information on in-pool water quality. Ultimately, the objectives of the study determine the minimum data requirements.

Guides

A number of guides are available to assist the user in preparing a data set. These are described below:

a. Dot diagram. A number of different options are available in simulating a reservoir. For example, a particular site may or may not have a weir or afterbay. For different options that the user may choose, different records are needed in the data set. The dot diagram lists the records that are required for each option. A record is recognized by a name that is located in columns 1 through 8, left justified. This record name is used in subsequent sections of the user manual. The dot diagrams for CE-THERM-R1 and CE-QUAL-R1 are located in Appendix C. Specific options are defined later in this section under the records MODE and LECTRIC.

b. Data set structure. A listing of all records with the names of all variables for each record is provided as Appendix D.

c. Data identification. Later in Part IV a description of each variable, for each record, is given in detail. Guidance is given with respect to how each data entry is used, and how it could be calculated or determined. For many coefficients, literature values are also given.

d. Example data set. An example data set is given in Appendix E. The output from this example is listed in Appendix B.

e. Preprocessors. Two utilities, one for CE-THERM-R1 and one for CE-QUAL-R1, are designed to check the correct sequence of records and the type of variables (real or integer) required in each field of a record. The magnitude of selected variables is also examined. Information concerning the use of the preprocessors can be found in Part V.

Coefficients

In the following pages neither the information concerning coefficient measurements nor the coefficient values listed should be considered to represent an exhaustive search of the literature. In many cases, the coefficient values found in the literature were inappropriate to use in the model because of (a) the lack of information necessary to convert the value to the proper units or (b) improper experimental design. Therefore, this report includes literature values for experiments that were already in appropriate form for use in CE-QUAL-R1 or were readily transformable. Although parameter values for a given coefficient may range over several orders of magnitude, it was felt inappropriate to recommend a single value for a parameter. Instead, experimentally determined values are presented to provide the user with a range of values.

Coefficient types

For those coefficients that are involved in equations as rates of change, the user must supply values that are appropriate to continuous exponential functions. These values should be appropriate for the equation:

$$X(t) = X_o e^{K_c t} \tag{185}$$

where

$X(t)$ = final condition
X_o = initial condition
K_c = coefficient in units of 1/day in continuous form
t = time in days

For those coefficients that are negative (e.g., mortality rate), the negative sign is introduced internally by the model. If values are reported in the discrete form suitable for the equation

$$X(t) = X_o (1 + K_d)^n \tag{186}$$

where

K_d = coefficient in units of 1/day in discrete form
n = the number of time steps in days

the coefficient must be transformed. If the user has coefficients in the discrete form in units of 1/day, they can be transformed to the proper continuous form by using the following relationship:

$$K_c = \ln (1 + K_d) \tag{187}$$

For a detailed explanation of the type of coefficients used by CE-QUAL-R1, please refer to the section "Functions TDELT and EDELT" in Part III. Values included in this report are in the continuous form. This entailed transforming values for those citations that were reported in the discrete form; transformations of units to the form used by the model were also necessary.

Physiological processes

For zooplankton and fish, the physiological processes modeled are ingestion, respiration, and assimilation efficiency. The units for ingestion are 1/day. Assimilation efficiency is dimensionless and is multiplied by ingestion to account for the assimilation rate. In the literature, ingestion (I) or consumption is equal to assimilation (A) + egestion (E). The amount assimilated may be separated into that amount respired (R) and growth (G). The products of growth may be separated into excretion (X), predatory mortality (PM), nonpredatory mortality (NM), exuviae (V), secretion (S), eggs or young (Y), harvest (H), and the change in weight (WT).

In CE-QUAL-R1 predictions are made regarding WT. In the literature it usually equals

$$WT = I - E - R - X - PM - NM - V - S - Y - H \tag{188}$$

Ingestion, respiration, predatory mortality, nonpredatory mortality, and harvest are explicitly modeled. Egestion is calculated using ingestion and the assimilation efficiency. Eggs or young are not considered lost in the model and are not included in the equation. Excretion, exuviae, and secretion are considered as part of the nonpredatory mortality term. Values for growth should be used with caution. Model users must know exactly what is included in the growth term so that correct coefficient estimates can be made.

The rates used in the model represent the maximum rate for each process under conditions normally found in reservoirs. These maximum rates are scaled down in the model due to predicted conditions such as temperature, nutrient, or food concentrations. Values found in the literature for rates are often measured at a set of specific conditions and may not represent a true maximum rate. Values found in this report may not necessarily be maximum rates, but the authors felt that the information may still be of use in selecting coefficients. The ingestion rate must be greater than the combined mortality and respiration rates divided by the assimilation efficiency.

Data Assembly

The following pages discuss each variable required for each record. The record name is at the top of each page and corresponds to the dot diagram (Appendix C) and data set structure diagram (Appendix D). The words "QUAL, THERM" in parentheses next to the record name indicate that the record may be used for both CE-QUAL-R1 and CE-THERM-R1. The word "QUAL" indicates the record is used only in CE-QUAL-R1. The word "OPTIONAL" indicates that the record is used only for certain conditions. Each record starts with the record name (starting in column 1) in columns 1 through 8. Unless otherwise specified, all variables are in fields of eight columns, right justified. The record name is in field 1. Fields two through ten are in columns 9 through 80. The variable names, for fields 2 through 10, are underlined as paragraph headings. The variable names are also listed in Appendix D. Fields representing integer values (variables starting with the letters I, J, K, L, M, and N) cannot contain a decimal point. Unless otherwise noted, the same information is suitable for CE-THERM-R1 and CE-QUAL-R1. The data set structure diagram (Appendix D) should be used as the authority to indicate which variables are needed for each record.

TITLE (QUAL, THERM)

The first five records in CE-QUAL-R1 should be used for informational purposes. This information is presented at the top of the first page of tabular output. These cards should not be overlooked since this may be the only information available to differentiate between different simulations when reviewing model output several months later. Information that should be displayed includes:

- a. Lake name and simulation year.
- b. Purpose of simulation. Is the simulation a calibration run, a sensitivity run, various scenarios of different project operations, etc.?
- c. Is there anything unique about the simulation? (Dry year, wet year, etc.)
- d. Are any coefficients, updates, etc., changed?

All five cards must be included, even if they are blank, to maintain the continuity of the data set.

JOB (QUAL, THERM)

IFIRST. IFIRST refers to the first Julian day for which initial meteorological and update data are specified. It is not necessarily the first simulation day (see ISTART below). Generally, the meteorological and update data are assembled for a calendar year.

ILAST. ILAST refers to the last inclusive Julian simulation day.

NHOI. This is the computation interval. It can be 1, 2, 3, 4, 6, 8, 12, or 24 hr. A 24-hr interval should be considered based on the analysis of the one-dimensional assumption by Ford and Thornton (1980), but no one choice may be best for all simulation objectives.

IPRT. IPRT is the interval in hours for tabular output. It can be any multiple of NHOI. A value of 720 would provide monthly output. Many pages of output may be printed for each simulation time step. This value of IPRT does not affect the use of the graphics packages, which uses information stored after each computational interval.

ISTART. This is the first simulation day (JULIAN). It is the day on which initial conditions are specified. This value must be equal to or greater than IFIRST. If ISTART is greater than IFIRST, the meteorological and update files are advanced to correspond to ISTART. ISTART can add considerable flexibility to the simulations. The starting date should correspond to a day where in-pool water quality profiles are available. The most desirable starting time is spring turnover, when conditions are isothermal. For preimpoundment studies, where no in-pool profiles are available, the starting day should coincide with the period of spring turnover or mixing. It is difficult to specify profiles for all parameters considered by the model under stratified conditions.

IYEAR. This represents the last two digits of the simulation year, for example, 75 for 1975.

NFLX. A value of 1 will cause flux information to be saved on a permanent file. Because of the number of variables, layers, processes, and time steps, this file can be quite large. This variable is used only in CE-QUAL-R1.

NALG. This represents the number of algal compartments to be modeled. The only choices are 1, 2, or 3. The three compartments are treated exactly the same, except that the third compartment is also silica limited, and should represent diatoms if this group is to be modeled. This variable is used only in CE-QUAL-R1.

OUTPUT (QUAL)

OUTPUT. Two forms of tabular output are available from CE-QUAL-R1. A complete output of all variables by layer is available by specifying COMPLETE in field 2 for the variable OUTPUT. Output will be printed each IPRT time steps. Anything other than COMPLETE in field 2 will provide a limited output. Profiles of temperature, dissolved oxygen, and algae alone will be produced. This option is designed for initial calibration runs to verify that the output is as desired.

Plot files for the graphics utilities are always created.

MODE (QUAL, THERM)

MODE. Please refer to Figure 3 for options for the following three variables. This variable refers to the way water is withdrawn from the reservoir. If NORMAL is specified, continuous flow is assumed. If anything other than NORMAL is specified, scheduled operation is assumed. This means water may flow for only short periods during the day, as when electricity is being generated, or when water is pumped back into the reservoir. For scheduled operations, only a 24-hr time step (NHOI) is allowed.

STRUCT. Three options are available for this variable. If PORT is chosen, all flow is withdrawn from ports. If WEIR is chosen, all flow is withdrawn from weirs. If PORTWEIR is chosen, flow may be divided between the two structures.

CHOICE. This variable is used to show whether flow amounts are specified by port, or whether the user wishes the model to choose which ports water should be selected from in order to meet a downstream temperature objective. In the latter case, subroutine PDCIDE will be used.

If SPECIFY is selected for the second field, the outflows from each port are specified on the SOUTL2 records. Flows out of the flood control gates are also specified. The number of ports (NOUTS) specified on the OUTLET card must include the flood control gates. In other words, the number for NOUTS equals the number of ports plus the flood control gate, and NOUTS PHYS3 records are needed. If WEIR or PORTWEIR was chosen for variable STRUCT, then SPECIFY must be selected for CHOICE.

If anything else is written in the second field, the total outflow and target temperature are specified on the ROUTL2 records and subroutine PDCIDE will be invoked. The value for NOUTS should reflect only the number of ports. The number of PHYS3 records will be one more than the value for NOUTS.

CALBRAT. The letters NO in columns 39 and 40 signify that no temperature profiles are available for calibration. In this case, the diffusion coefficient (DC) in subroutine TRNSPT will be set to 0.007722, which has been found to be suitable for many reservoirs. However, more accurate temperature predictions can probably be made by calibrating, against measured data, with coefficients CDIFF and CDIFW (on the MIXING record). Input other than NO for the variable will cause a diffusion coefficient to be calculated using variables CDIFF and CDIFW.

AREATE. This variable determines which wind reaeration formulation is used by CE-QUAL-R1. The user should enter KANWISH or OCONNOR in columns 41 through 48 right justified. This variable is not needed in CE-THERM-R1.

LECTRIC (QUAL, THERM, OPTIONAL)

This record can be included only if MODE is not NORMAL.

PUMPBK. If the second field contains PUMPBACK, it is assumed that water will be pumped back into the reservoir. These flows will be included on the OPSCH2 records.

FTRBAY. If the third field contains AFTERBAY, an afterbay will be modeled as part of the simulation. If the pumpback option is chosen, an afterbay must be modeled.

AFTERBAY (QUAL, THERM, OPTIONAL)

This record can be included only if AFTERBAY was chosen for variable FTRBAY. This record contains the coefficients needed to describe the surface area of the afterbay as a function of volume. The coefficients can be obtained using regression techniques for the equation

$$\text{AREA} = C_1 + C_2\text{VOLUME} + C_3\text{VOLUME}^2 \qquad (189)$$

where AREA refers to the afterbay area (m^2) and VOLUME refers to afterbay volume (m^3).

AFBCOF(1). Field 2 contains the value of C_1 from Equation 189.

AFBCOF(2). Field 3 contains the value of C_2 from Equation 189.

AFBCOF(3). Field 4 contains the value of C_3 from Equation 189.

NFTRBY. A "1" in column 40 signifies a small, bowl-shaped afterbay. A "2" in column 40 is more appropriate for long, narrow afterbays. (See subroutine REREG, Part III.)

PUMPBACK (QUAL, THERM, OPTIONAL)

This record can be included only if PUMPBACK was specified in field 2 of the LECTRIC record for variable PUMPBK.

PBCOEF. This is a weighting factor to express the percentage of total pumpback volume that is contributed by prior generation water. Values range from 0.0 to 1.0. Typically, use a value of 0.5. A more accurate determination can be made through physical model studies.

THETAO. This is the angle of the pumped-storage inflow jet with respect to the horizontal, in degrees. Values range from 0 (horizontal) to 90 (vertical). The inlet/outlet design dictates the value.

PHYS1 (QUAL, THERM)

NTRIBS. This variable represents the number of inflow tributaries. Presently, only two tributaries may be specified by the user. Three or more tributaries may be added only by modifying the common blocks. Because of the one-dimensional assumption, however, the major reason for distinguishing among tributaries is because the inflows may be placed in the reservoir at different depths. This will depend on the density (temperature, suspended solids, and TDS concentrations) of the rivers. If the rivers are of the same density, they will enter the reservoir at the same depth; for practical reasons, the inflows can be combined provided the quality parameters are volume weighted. Care should be exercised in combining tributaries where no water quality data exist. Consideration must be given to land use, watershed size, and location of sewage treatment plants. These points need to be considered on an individual basis and require hydrologic considerations and an understanding of storm loadings. These must be considered on a site-specific basis.

NUME. This variable represents the initial number of layers. NUME will depend on the minimum layer thickness, SDZMIN, and the maximum layer thickness, SDZMAX, specified on the PHYS2 record. The thickness of each layer must be between these two extremes. For most reservoirs, a 1-m average layer thickness is recommended. For deep reservoirs where the hypolimnion is large, layers of 2 or 3 m may be appropriate to reduce computation time.

XLAT. This variable represents the latitude of the project which is expressed in decimal degrees (i.e., 96.5° not 96°30'). Project latitude is used in subroutine RADIATE to calculate solar radiation. This information is available on USGS quad sheets and records and in various project documents.

XLON. This is the project longitude, in decimal degrees.

TURB. This is the dust attenuation coefficient. It is used in the solar radiation calculation (RADIAT) and represents the attenuation of solar radiation by dust due to scattering and absorption. It is dimensionless and varies with the optical air mass, season of the year, and geographic location. Water Resources Engineers, Inc. (1967) gives a range of 0.0 to 0.13 for several locations. A value near 0.06 has been used in previous modeling studies.

AA. The variables AA and BB (see below) are empirical coefficients used in the wind function to calculate evaporative and convective heat fluxes in subroutine RADIATE. Table 2 summarizes values and units for AA and BB from various field studies. The values recommended by Rimsha and Donchenko (1957) (see Table 2) have been used successfully in several applications of this model.

BB. See AA above.

ELEMSL. This is the elevation (metres) above sea level for the bottom of the pool.

Table 2

Empirical Formulas for the Wind Speed Function

Information Source*	Lakes	AA m/mb-sec	BB 1/mb
Meyer (1928)	--	4.18×10^{-9}	0.95×10^{-9}
Marciano and Harbeck (1952)	Hefner	0	1.02×10^{-9}
Rimsha and Donchenko (1957)	Various in Russia	2.49×10^{-9}	1.20×10^{-9}
Harbeck, Koberg, and Hughes (1959)	Colorado city	0	1.51×10^{-9}
Morton (1965)	Various in Canada	3.45×10^{-9}	1.26×10^{-9}
Brady, Geyer, and Sculley (1971)	1 in Maryland	2.21×10^{-9}	0
Ryan and Harleman (1973)	1 in Australia	2.83×10^{-9}	1.26×10^{-9}

* As referenced by Edinger, Brady, and Geyer (1974).

PHYS2 (QUAL, THERM)

RLEN. This is the reservoir length, in metres. It is used in subroutine FLOWIN to calculate the thickness of the inflow zone. Field studies have shown that inflows tend to follow the thalweg of the inundated river channel. RLEN should therefore reflect the length of the old river channel.

SDZMIN. The variables SDZMIN and SDZMAX (see below) are the minimum and maximum layer thicknesses, in metres. Constraints on the layer thicknesses are used in LAYERS to readjust layer size. The minimum layer thickness should be taken as one-half the average layer thickness, and the maximum layer thickness should be two times the average layer thickness. It is recommended that the minimum layer thickness not be less than 0.4 m.

SDZMAX. See SDZMIN above. SDZMAX must be greater than twice SDZMIN.

PHYS2+ (QUAL, THERM)

SDZ(I). The PHYS2+ cards are used to initialize each layer thickness, SDZ(I), starting at the bottom of the reservoir, with I going from 1 to the number of layers (NUME). The number of records required will depend on the number of layers. Nine SDZ values are placed on each record except, possibly, the last. It is important to note that the sum of all layer thicknesses must equal the initial depth (initial reservoir elevation minus reservoir bottom elevation). The thicknesses of all layers must fall between SDZMIN and SDZMAX specified on the PHYS2 record.

OUTLET (QUAL, THERM, OPTIONAL)

This record can only be included if PORT or PORTWEIR was specified for variable STRUCT.

NOUTS. This is the number of outlet ports. The number of outlets specified by the user will depend on the designation of variable CHOICE. If SPECIFY was denoted, then NOUTS equals the total number of outlets (ports plus the flood control gates) for which outflows are specified on the SOUTL2 records. If SPECIFY was not denoted, then NOUTS equals only the number of selective withdrawal ports. The floodgates are considered separately. As presently dimensioned, the value for NOUTS can be between 1 and 8.

PHYS3 (QUAL, THERM, OPTIONAL)

These records can be included only if PORT or PORTWEIR was specified for variable STRUCT.

These records are used to specify information on the withdrawal ports. One record is required for each port. If SPECIFY was chosen for variable CHOICE, then NOUTS records are required. Otherwise NOUTS+1 records are required. The extra record is required to specify information on the flood control gates, whose elevation must be below the lowest port. As presently written, spillways cannot be used with selective withdrawal. The records are ordered from the top port down. Information required on these records is available from Corps Design Memorandums and Operation Manuals. If SPECIFY was chosen, only elevation (ELOUT(I)) and port dimensions (PVDIM(I), PHDIM(I)) need to be specified on these records.

Extreme care must be taken when describing port dimensions, location, and flow characteristics. Scale model tests may be necessary to correctly characterize such factors. For example, a narrow approach channel can restrict selective withdrawal and cause outflows to behave as if they were being withdrawn from elevations different than the actual elevation of the outlet port.

ELOUT(I). This is the elevation (in metres) of the I^{th} port numbered from the top downward. Assuming the port is operated fully open, the elevation of the port corresponds to the center-line height from the reservoir bottom. For large intakes, such as flood control gates, the center-line elevation specified should be representative of the average gate opening during the major portion of the simulation period and not the elevation at the midpoint of the gate. The number in parentheses indicates the port for which information is being provided. If two ports in a dual wet-well system are at the same elevation, for convenience, the one on the left (looking downstream) should be numbered first.

PVDIM(I). This is the vertical dimension (m) of port I.

PHDIM(I). This is the horizontal dimension (m) of port I.

NWELL(I). This is the wet-well number of port I. NWELL is used to distinguish the wet-well within which a selective withdrawal port is located. There can be either one or two wet-wells. Flows can be released and blended between ports only if they are located in different wet-wells.

FMIN(I). This is the minimum flow (m^3/sec) of port I. A minimum flow that can be released from any one port must be specified. The minimum will depend on the structure and type of gate.

FMAX(I). This is the maximum flow (m^3/sec) of port I.

WANGLE(I). This is the withdrawal angle in degrees (i.e., 180, 90, etc).

PHYS3+ (QUAL, THERM, OPTIONAL)

This record can be included only if SPECIFY was not selected for variable CHOICE.

SELMAX. This is the maximum total flow for both wetwells (m^3/sec) under selective withdrawal conditions. Subroutine PDCIDE limits flow to this value.

BELOW. This is a parameter that determines whether a port that has become partially exposed due to a falling water surface is to be included in subsequent selective withdrawal calculations. If the reservoir depth minus ELOUT(I) is less than BELOW, then that port will not be used. BELOW is a distance (in metres) usually equal to one-half the vertical dimension of the top port.

NUMWEL. This is the number of wetwells. Only one or two wetwells are allowed.

QFLOOD. If floodgates are present, TRUE should be in columns 29-32. Otherwise, the program will assume that no floodgates are present.

QSAME. TRUE in columns 37-40 signifies that floodgates are housed within the wet wells. Any other entry in this field signifies that the selective withdrawal and floodgate systems are separate rather than integrated.

WEIR (QUAL, THERM, OPTIONAL)

This record can be included only if WEIR or PORTWEIR was selected for variable STRUCT.

WRLNG. This is the weir length (in metres).

WRHGT. This is the height of the crest of the weir from the reservoir bottom. The value is in metres, measured from the pool bottom.

COEF. This is the discharge coefficient for free weir flow. Values can range from about 3.0 to 4.8. The value can be estimated from a hydraulics handbook. If a value for COEF is not specified, submerged weir flow is assumed (see SUBROUTINE VWEIR).

CURVE (QUAL, THERM)

CURVE. If a power curve (Equation 6) is used to predict area (in square metres) as a function of elevation (in metres), the second field should contain POWER. Otherwise, Equation 8 (a polynomial curve) will be used to denote this relationship. If a polynomial higher in order than Equation 8 is needed, minor modifications to the code would be required. This has been done for some applications.

AREAC (QUAL, THERM)

The data on the AREAC record are used to calculate the horizontal areas of the layers with respect to elevation. They are also used to calculate the layer volumes. The overall water and mass budgets of the reservoir will depend on how accurately the layers represent the reservoir. Elevation is used with respect to the reservoir bottom (in metres). The coefficients can be calculated with a hand calculator capable of simple regressions. The areas used to calculate the coefficients can be obtained from topographic maps, area-capacity curves, or sediment range maps. Current sediment range maps are preferred because sedimentation can substantially reduce the volume of a reservoir.

ACOEF(1). This is the value of ACOEF(1) from Equation 6 if POWER was chosen for variable CURVE. Otherwise it is the value of ACOEF(1) from Equation 8.

ACOEF(2). This is the value of ACOEF(2) from Equation 6 if POWER was chosen for variable CURVE. Otherwise it is the value of ACOEF(2) from Equation 8.

ACOEF(3). This is the value of ACOEF(3) from Equation 8 if POWER was not chosen for variable CURVE. This coefficient is not used if POWER was chosen for variable CURVE.

Coefficients chosen must supply a curve that is monotonically increasing.

WIDTHC (QUAL, THERM)

The reservoir width information is used in FLOWOT to calculate the volume of water removed from each layer within the withdrawal zone. The widths should be taken at a cross section located near the intake structure where flow patterns are considered representative of flow conditions approaching the intake. In general, the cross section should be located 300 m or more upstream from the structure to avoid local geometric factors that may not represent overall impoundment withdrawal characteristics. Particular attention should be given to the possibility of modified flow patterns due to constricted areas or other hydraulic control sections within the reservoir.

The widths can be obtained from bathymetric maps or sediment range cross sections. The selected cross section should be perpendicular to the general flow direction. CE-QUAL-R1 assumes that the widths can be approximated by the equation

$$\text{WIDTH} = \text{WCOEF}(1) * \text{ELEVATION} ** \text{WCOEF}(2) \qquad (190)$$

The coefficients can be found using a hand calculator with regression capabilities.

WCOEF(1). The value of WCOEF(1) from Equation 190.

WCOEF(2). The value of WCOEF(2) from Equation 190.

SHELCF. This is a sheltering coefficient (dimensionless). For impoundments bounded by high relief, the sheltering effect of the surrounding terrain can be significant. The sheltering coefficient is used to modify the turbulent kinetic energy (TKE) generated by the wind. It is the fraction of the total water surface area exposed to the wind and varies between 0 and 1. When SHELCF equals 0, no entrainment due to wind mixing occurs.

Initially, SHELCF can be estimated from the dominant wind direction by calculating the fraction of the surface area exposed to the wind. Typically, for abrupt changes in relief at the water's edge (for example, cliffs or tall trees), it will take a distance of approximately eight times the height of the relief before the wind field and resultant wind stress reattach to the water surface (Figure 78). It will take an additional fetch of 100 m before the new boundary layer grows to a

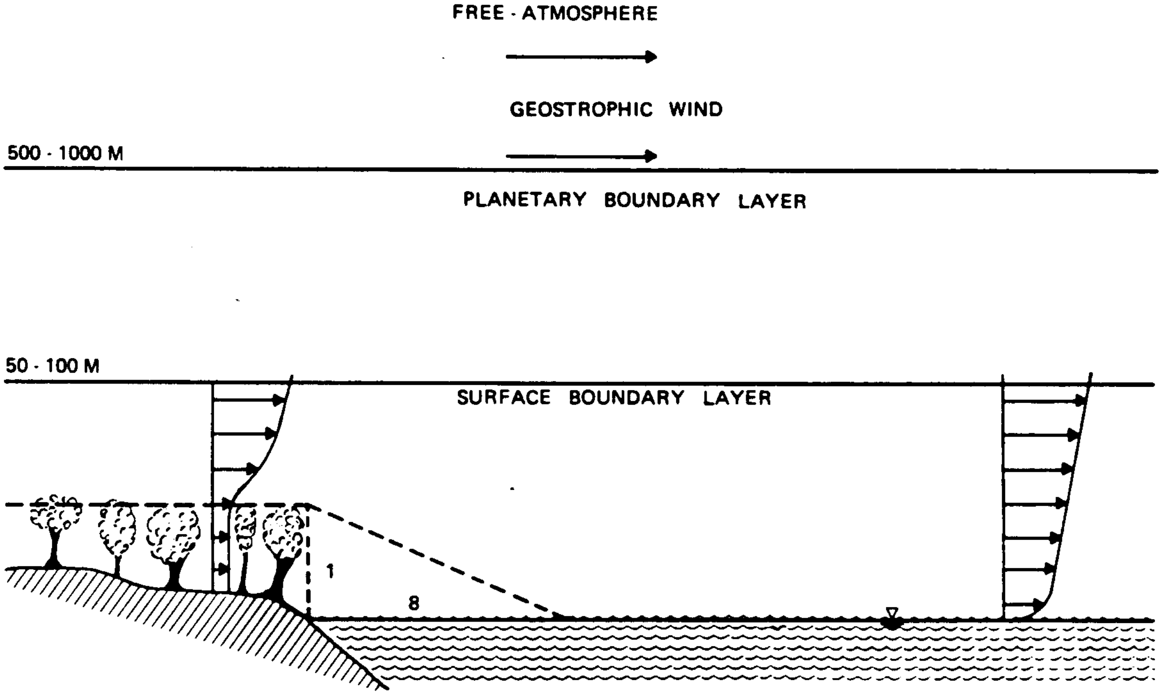


Figure 78. Sheltering effect

height of 10 m. For reservoirs with effective fetches less than three or four times such distances, sheltering effects can be significant. For reservoirs with significantly larger effective fetches, wind speeds will increase with fetch because the effective roughness of the water surface is always less than that of the natural terrain. For fetches greater than 10 km, the wind speed will no longer increase because the flow field is in equilibrium with the geostrophic flow in the upper atmosphere. Since model simulations are most sensitive to SHELCF during the spring period when stratification forms, the dominant wind direction should correspond with this period. SHELCF should be fine-tuned by matching mixed layer depths during periods of strong winds when convective cooling is negligible.

PEFRAC. This is a penetrative convection fraction (dimensionless). During periods of cooling, TKE is produced by natural convection. Part of this TKE (i.e., PEFRAC) is available for entrainment and deepening of the upper mixed layer. Under laboratory conditions, PEFRAC typically varies between 0.1 and 0.5 (Tennekes and Driedonks 1980). Calibration of PEFRAC is accomplished by comparing mixed layer depths during periods of cooling when the wind speed is negligible. However, experience has shown that the model is almost insensitive to PEFRAC; thus, a value of 0.3 is recommended.

CDIFW. See CDIFF.

CDIFF. CDIFW and CDIFF are the calibration parameters for computing eddy diffusion coefficients representing the contributions of wind and advection, respectively. They should initially be set to zero to simplify the calibration of SHELCF. When CDIFW and CDIFF are both zero, the default diffusion coefficient is 15 times molecular. If additional mixing is required to match temperature profiles in the metalimnion and hypolimnion, then CDIFW and CDIFF should be increased and adjusted to match the temperature profiles. CDIFW should be sensitive during periods of high wind and low advection (i.e., small inflows and outflows). Conversely, CDIFF should be sensitive during periods of no wind and large advection. If CALBRAT = NO, CDIFW and CDIFF are not used by the model. Previous modeling studies used values between 1.0×10^{-5} and 1.0×10^{-4} for CDIFW and between 1.0×10^{-6} and 1.0×10^{-5} for CDIFF, although the lower value for CDIFF seems to produce better results.

CDENS. This is the critical density (kg/m^3) used in subroutine FLOWIN to place the inflowing waters. If the density of the inflowing water is less than the density of the surface waters of the reservoir and if this density difference is greater than CDENS, the inflowing waters are assumed to move as an overflow along the water surface. Conversely, if the density of the inflowing waters is greater than the density of the bottom waters and if this density difference is greater than CDENS, the inflowing waters are assumed to move as an underflow directly into the bottom of the reservoir. A reasonable range for CDENS is 0.01 to 2.0 kg/m^3. However, experience with the model suggests a value of 0.1.

EXCO. This is the extinction coefficient (1/m). It can be estimated from Figure 79 if the maximum Secchi disk depth is known, or it can be measured directly with a photometer. Please refer to the section below.

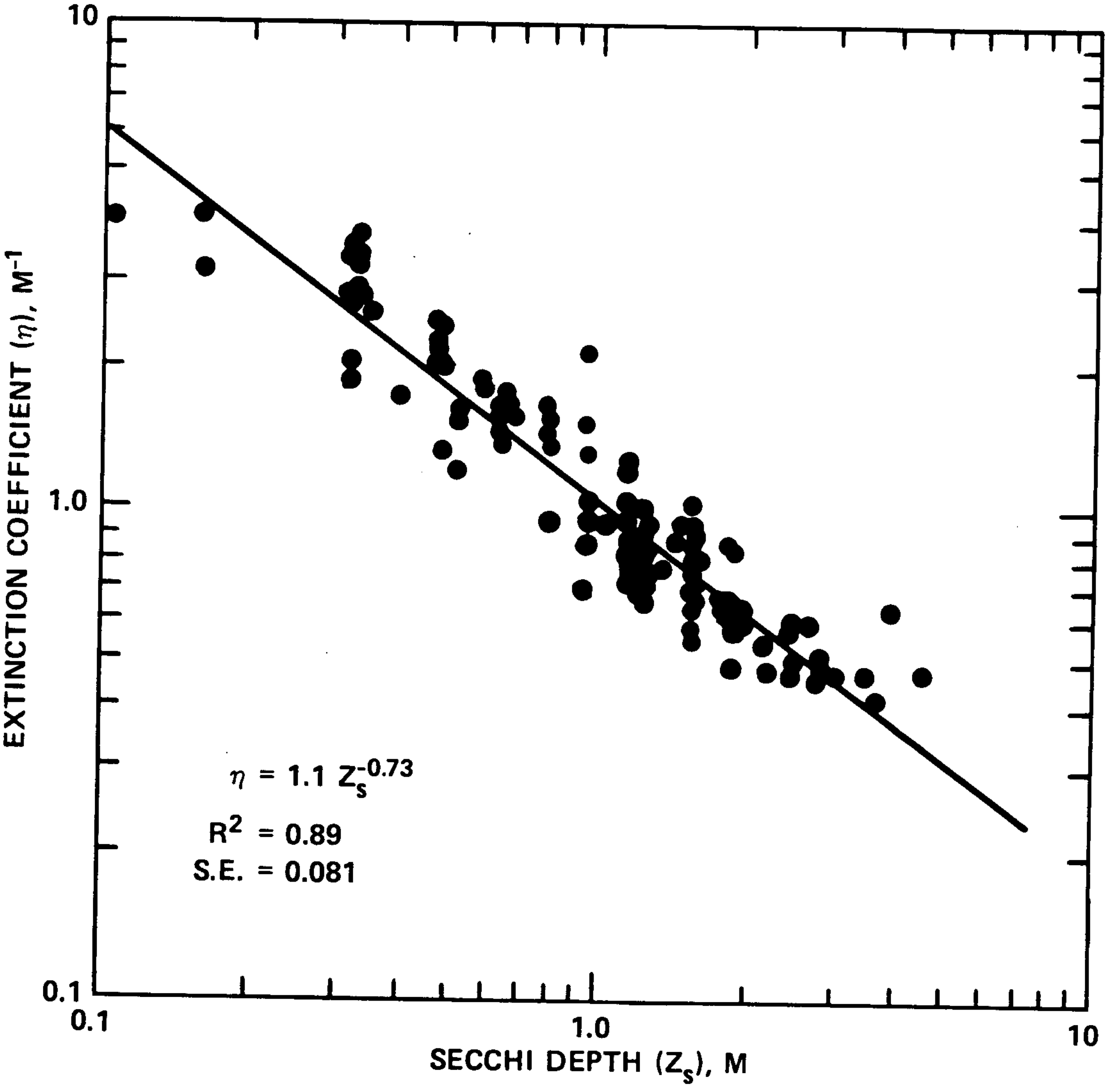


Figure 79. Relationship between the extinction coefficient and the Secchi disk depth (Williams et al. 1981)

SURFRAC. This the fraction of solar radiation absorbed in a 0.6-m surface layer (dimensionless). It is obtained from Figure 80 once EXCO is determined.

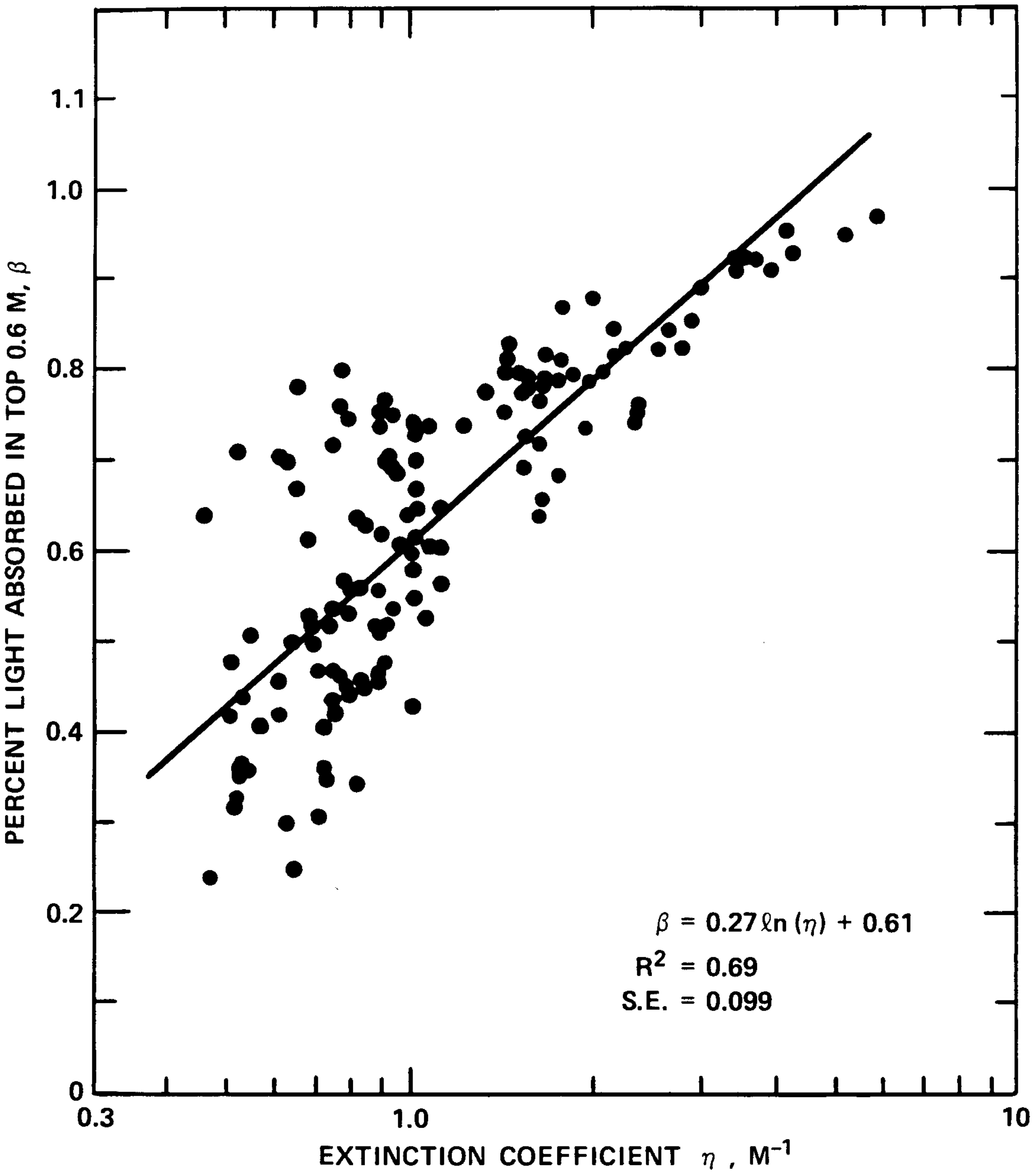


Figure 80. Relationship between the light absorbed in the surface layer and the extinction coefficient

EXTINS. This is the self-shading coefficient for suspended solids (1/m • mg/ℓ), which contributes to a concentration-dependent increment of the extinction coefficient.

Solar radiation is distributed vertically in the water column in subroutine HEAT (which is called from subroutine MIXING). The distribution is due in part to the absorption of light by water, including dissolved substances, and to absorption by particulate organic and inorganic materials. Care must be taken when estimating or measuring extinction coefficients, for the same coefficient may have a different meaning depending on whether it is used in CE-QUAL-R1 or CE-THERM-R1. Two extinction coefficients are used in CE-THERM-R1: EXCO and EXTINS; another, EXTINP, is used in CE-QUAL-R1 to account for extinction due to algae, zooplankton, and detritus.

EXCO is the extinction coefficient for water, including dissolved substances (1/m). It can be estimated from the equation (Williams et al. 1981)

$$\mathrm{EXCO} = 1.1 * Z ** (-0.73) \tag{191}$$

given the Secchi depth (Z) in metres, or it can be measured directly with a photometer using the Beers-Lambert Law

$$\mathrm{EXCO} = (\ln I - \ln I_z)/Z \tag{192}$$

where

I = irradiance at water surface
I_z = irradiance at depth z

However, in situ measurements for EXCO are likely to overestimate the extinction coefficient because it includes extinction due to detritus, phytoplankton, zooplankton, and inorganic suspended solids, which are modeled separately in CE-QUAL-R1. Therefore, the calculated value of EXCO should reflect the maximum light penetration (i.e., the maximum Secchi depth). This should minimize the overestimation problem. In CE-QUAL-R1 and CE-THERM-R1, self-shading due to these components is handled separately.

The light extinction coefficient for an ultra-oligotrophic to oligotrophic lake ranges from 0.03 to 1.0/m; for mesotrophic lakes, the figures are from 0.1 to 2.0/m; for eutrophic lakes, from 0.5 to 4.0/m;

and for dystrophic lakes, from 1.0 to 4.0/m (Likens 1975). The extinction coefficient of monochromatic light by a 1-m column of distilled water ranges from 0.0255 at 380 nm, 0.0054 at 460 nm, 0.078 at 580 nm, and 0.455 at 680 nm, to 2.42 at 820 nm (Hutchinson 1957). Other values are given in Table 3 for photosynthetically active radiation and other wavelengths.

EXTINS is the self-shading coefficient due to particulate inorganic material in both CE-QUAL-R1 and CE-THERM-R1. In CE-THERM-R1, because organic particulate materials are not explicitly modeled, the light attenuation due to these materials must be handled through either EXTINS or EXCO. If the suspended solids (SS) compartment has been incremented in value to include organic as well as inorganic particulates suspended in the water column, then EXTINS (1/m • mg/ℓ) represents the extinction coefficient for all suspended solids, including inorganic matter, phytoplankton, zooplankton, and suspended detritus. However, if the SS compartment in CE-THERM-R1 does not include organic particulates--i.e., if the magnitude of SS is identical in CE-QUAL-R1 and CE-THERM-R1--then light attenuation by organic matter suspended in the water column cannot be handled by EXTINS. Rather, the value of EXCO must be increased to handle the "extra" attenuation due to phytoplankton, zooplankton, and detritus. In either case, the magnitude of EXTINS should be the same in both models. It should typically be of the same order of magnitude as EXTINP.

Table 3

Extinction Coefficients for Water (1/m)

Site	Description	EXCO	Reference
Lake Tahoe, Calif.	Oligotrophic	0.2	Wetzel 1975
Wintergreen Lake, Mich.	Eutrophic	0.46-1.68	Wetzel 1975
Crystal Lake, Wis.	Oligotrophic	0.2	Wetzel 1975
Crater Lake, Oreg.	Oligotrophic, almost pure, blue	0.18	Spence 1981

(Continued)

Table 3 (Concluded)

Site	Description	EXCO	Reference
Loch Borralie, Scotland	Calcareous water, blue-green	0.34	Spence 1981
Neusiedlersee, Austria	Turbid water, sediment-colored	3.31	Spence 1981
Loch Unagan, Scotland	Yellow substances	0.93	Spence 1981
Black Loch, Scotland	Brown substances, peaty	1.53	Spence 1981
Loch Leven, Scotland	Turbid, dense phytoplankton	2.58	Spence 1981
Lake Paajarvi, Finland	Brown-stained	0.7	Verduin 1982
Highly stained lakes	Average	4.0	Wetzel 1975

DIFC (QUAL)

DMO2. This is the molecular diffusion coefficient for dissolved oxygen (m^2/sec).

DMCO2. This is the molecular diffusion coefficient for carbon dioxide (CO_2) (m^2/sec).

The transfer of dissolved oxygen and CO_2 across the air-water interface is determined by an empirical relationship developed by Kanwisher (1963). This relationship requires the molecular diffusivities for O_2 (DMO2) and CO_2 (DMCO2). Representative values are 0.204×10^{-9} and 0.204×10^{-10} m^2/sec at 300° K, respectively. Both values increase with temperature.

BIO (QUAL)

All of the mass that leaves one compartment by way of a particular process does not necessarily enter one other compartment. For example, the products of zooplankton respiration are assumed to increment the carbon, ammonia, and orthophosphate compartments. For this reason, stoichiometric equivalents are needed.

BIOP. This is the stoichiometric equivalent between organic matter and orthophosphate.

BIOC. This is the stoichiometric equivalent between organic matter and carbon.

BION. This is the stoichiometric equivalent between organic matter and nitrogen.

These equivalents represent the fraction of each of the elements that make up organic matter. To aid in keeping a mass balance for different elements, the simplifying assumption is made that all organic matter is made up of the same fraction of different elements. Representative values are 0.005 for BIOP, 0.45 for BIOC, and 0.08 for BION.

Algae--general

CE-QUAL-R1 has the capability to simulate three groups of algae. The composition of these three groups must be determined before any of the required coefficients can be selected.

The first step in selecting groups is to determine the species composition of the reservoir. If the study is of a preimpoundment, then data from surrounding reservoirs with similar land use, morphometry, operation, etc., and local expertise may be helpful. The US Environmental Protection Agency National Eutrophication Survey reports are good references for an initial evaluation since they contain both nutrient information and phytoplankton species enumerations. Attention should be paid to the dominant algal species and the seasonal patterns in phytoplankton succession. In selecting appropriate compartments, specific consideration should be given to:

- a. Study objectives and project purposes.
- b. Problem groups.
- c. Dominant groups.
- d. Environmental requirements (nitrogen, phosphorus, silicon, carbon, light).
- e. Similarities in growth response.
- f. Seasonal succession.
- g. Similar morphology.
- h. Intradivisional similarity.

Some species will be difficult to incorporate in any assemblage because they exhibit properties that are not simulated by CE-QUAL-R1. *Ceratium* spp., for example, exhibit heterotrophic characteristics, which are not included in the phytoplankton formulations.

Past usage, when only two algal compartments were available, has included the following assemblages:

- a. ALGAE1. Nannoplankton; ALGAE2 - net plankton (Hall et al. 1977).
- b. ALGAE1. Greens, bluegreens; ALGAE2 - diatoms (Thornton, Ford, and Robey 1976).
- c. ALGAE1. Greens, bluegreens; ALGAE2 - diatoms, desmids (Ford et al. 1978).

d. ALGAE1. Diatoms, greens; ALGAE2 - bluegreens (Ford et al. 1978).

The third algal compartment, added since the above studies, usually represents diatoms because of silica limitation for that compartment only. These are not the only assemblages possible. The assemblages for each study must be determined independently of previous studies and are dependent only on the objectives of the current study.

ALGI (QUAL)

EXTINP. This is the self-shading coefficient due to organic particulate matter in CE-QUAL-R1 (1/m * mg/ℓ). The self-shading coefficient represents the decreased light penetration or increased light extinction resulting from phytoplankton, zooplankton, and detritus suspended in the water column. The light extinction coefficient in subroutine HEAT is modified as a function of the concentrations of these three constituents. Most measurements of EXTINP refer only to algal biomass; it is assumed in CE-QUAL-R1 that light extinction due to zooplankton and detritus is numerically equivalent to that due to phytoplankton. Megard et al. (1980) and Smith and Baker (1978) determined that each microgram per litre of chlorophyll increased the light extinction coefficient by about 0.022 and 0.016/m, respectively. Assuming a ratio of carbon to algal biomass of 0.45 and a carbon/chlorophyll (C/chl) ratio of 50, then algebraically each milligram per litre of algal biomass should increase the light extinction coefficient by about 0.20 to 0.14/m, respectively. The range of C/chl ratios, however, varies from 25-150, resulting in a range of self-shading coefficients from 0.40/m * mg/ℓ to 0.045/m * mg/ℓ. Values near 0.10 have previously produced reasonable results.

Light extinction by algae is computed from in situ light intensity measurements at depth intervals and in situ determinations of chlorophyll *a* using the modified Lambert-Bouguer Law (Megard et al. 1980). Bannister (1979) extracted chlorophyll from cell suspensions and measured the absorption spectrum to obtain the mean extinction coefficient. Theoretical estimates of the attenuation of photosynthetically active radiation by chlorophyll *a* in algae range between 0.06 and 0.018, depending on the size and chlorophyll content of cells and colonies (Kirk 1975). The extinction coefficient was determined to range between 0.0066 and 0.0205 1/m * mg/ℓ in laboratory analysis (Bannister 1979). Values for self-shading coefficients are given in Table 4. Values shown in this table were originally reported in units of 1/m * μ chl *a*/ℓ and have been converted to units used in CE-QUAL-R1 assuming a carbon to chlorophyll ratio of 50 and a carbon to biomass ratio of 0.45.

Table 4

Self-Shading Coefficients Due to Particulate Matter (1/m * mg/ℓ)

Type	Comment	Value	Reference
Suspensoids	Average	0.12	Verduin 1982
Suspensoids	Lake Paajarvi, Finland	0.24	Verduin 1982
Organic matter	Pacific Ocean	0.047	Verduin 1982
Phytoplankton	Pacific Ocean	0.033	Verduin 1982
Phytoplankton - diatoms	C/chl ratio = 120 dry wt/C ratio = 4	0.058	Verduin 1982
Phytoplankton - diatoms	C/chl ratio = 30 dry wt/C ratio = 4	0.014	Verduin 1982
Phytoplankton - greens	C/chl ratio = 100 dry wt/C ratio = 2	0.024	Verduin 1982
Phytoplankton - greens	C/chl ratio = 30 dry wt/C ratio = 2	0.007	Verduin 1982
Phytoplankton	Shagawa Lake, Minn.	0.03	Megard et al. 1980

ALDIGO. This is the fraction of algal biomass lost by nonpredatory mortality to the detritus compartment. The remainder of the fraction goes to labile dissolved organic matter. Otsuki and Hanya (1972) have reported a value of 0.8 for *Scenedesmus* sp.

ALGAS. This is the stoichiometric equivalent for silica for the third algal compartment. The minimum silica content ranges from 2 to 15 percent of algal dry weight (Coetzer, Toerien, and Schoeman 1977).

ALG2, ALG3, ALG4 (QUAL)

These three records contain the same information for three groups of algae. Variable NALG (JOB record) represents the number of algal compartments to be modeled. These three records must be included in the data sets even if NALG is less than three. Information for these variables is provided in the following paragraphs.

TPMAX. TPMAX is the maximum gross photosynthetic or production rate (1/day). CE-QUAL-R1 uses gross production rates to simulate the rate of change of algal biomass through time.

The physiological processes of phytoplankton that are being modeled are gross production and respiration. Gross production is the total rate of photosynthesis, which includes the storage rate of organic matter by the phytoplankton (net production) plus the organic matter used by phytoplankton in respiration. That is,

$$\text{gross production} = \text{net production} + \text{respiration} \qquad (193)$$

Net production is the organic matter used for other processes such as zooplankton grazing, sinking, excretion, and nonpredatory mortality. Care must be used in estimating these rates because the rates are often dependent on the experimental design. For example, the maximum growth rate is often used in modeling studies (see, for example, the Preliminary Generalized Computer Program, Water Quality for River-Reservoir Systems, October 1978, US Army Engineer Hydrologic Engineering Center, Davis, Calif.). The respiration rate is subtracted from the maximum growth rate in order to predict a new mass. However, the values of growth found in the literature are most equivalent to net production in the above equation and have already accounted for respiration; in other words, the model may predict low phytoplankton values because respiration is being accounted for twice. If growth is measured as the difference in mass between two points in time, it must be realized that algae may have been lost to grazing, sinking, etc. Also, the true growth figure may actually be higher than reported. Values are often reported as "production" without mention as to whether the figures represent gross or net production, and the reader may have to evaluate the experimental design to determine the correct value.

Four general methods are used to measure phytoplankton primary productivity (Janik, Taylor, and Lambou 1981). These involve the measurement of (a) changes in the oxygen content of water, (b) changes in the carbon dioxide content of water, (c) incorporation of ^{14}carbon (^{14}C) tracers into the organic matter of phytoplankton, and (d) measures of chlorophyll. Readers should refer to Janik, Taylor, and Lambou (1981) to gain insight into the problems associated with the four methods. For example, the ^{14}C technique gives a measurement that is between net and gross production, depending on the length of the experiment (Whittaker 1975).

The most frequently used method for measuring primary production by phytoplankton has been photosynthetic oxygen evolution and ^{14}C uptake. The light- and dark-bottle ^{14}C technique of Steemann-Nielsen (1952) requires the lowering of pairs of bottles injected with $H^{14}CO_3$ to fixed depths in the water column for time periods of 1-5 hr or by incubating the bottles under known conditions of light and temperature.

Under optimal conditions, a culture grows so that the rate of addition of cells is proportional to the number present (i.e., exponential growth). Cells divide in a characteristic time called the division, generation, or doubling time. Population growth follows the solution to the equation

$$dN/dt = k * N \qquad (194)$$

where

N = number or concentration of cells in the culture

t = time

k = growth constant - (1/t)

The solution to this equation is

$$k = \ln (N/N_o)/(t - t_o) \qquad (195)$$

Subscripts denote values at a known initial time, and ln indicates natural logarithms.

The growth constant k is the number of the logarithm (base e) units of increase per day. Growth rate is sometimes expressed as logarithm (base 10) units of increase per day k_{10} or as logarithm (base 2) units per day, k_2, where

$$k_{10} = \log_{10} (N/N_o)/(t - t_o) \tag{196}$$

$$k_2 = \log_2 (N/N_o)/(t - t_o) \tag{197}$$

Conversions among the expressions are as follows:

k = growth rate measured in ln units
k_{10} = growth rate measured in $\log_{10}$ units
k_2 = growth rate measured in $\log_2$ units

Now let an algal population of interest double in one day. Then

$$N = 2$$

$$N_o = 1$$

$$t - t_o = 1$$

and

$$k = 0.693 = \ln 2$$

$$k_{10} = 0.301 = \log_{10} 2, \; k = 2.3026 \; k_{10}$$

$$k_2 = 1.0 = \log_2 2, \; k = 0.6931 \; k_2$$

Or, let the algal population quadruple in one day. Then

$$N = 4$$

$$N_o = 1$$

$$t - t_o = 1$$

and

$$k = 1.386 = \ln 4$$

$$k_{10} = 0.602 = \log_{10} 4, \ k = 2.3026\ k_{10}$$

$$k_2 = 2.0 = \log_2 4, \ k = 0.6931\ k_2$$

Similarly, let the algal population halve in one day. Then

$$N = 0.5$$

$$N_o = 1$$

$$t - t_o = 1$$

and let

$$k = -0.693$$

$$k_{10} = -0.301, \ k = 2.3026\ k_{10}$$

$$k_2 = -1.0, \ k = 0.6931\ k_2$$

Thus, the relation between the various growth rates is given by

$$k = 2.3026\ k_{10} \tag{198}$$

$$k = 0.6931\ k_2 \tag{199}$$

The composite gross production rate for this compartment should also represent a weighted contribution of each species in the assemblage. The maximum gross production rates selected for each species should reflect the range of environmental conditions expected in the simulation. If mixed layer temperatures are expected to reach 25° C, maximum specific gross production rates should be selected that were measured at or near this temperature. These rates will be temperature corrected.

Many production rates may also have to be modified for use with a daily computational interval. Kramer and Nixon (1973) indicate that the use of square-wave average diurnal light input versus a sinusoidal half-wave diurnal input with the same total energy overestimated production by approximately 15 percent. However, if a daily time step is used, light is averaged over a 24-hr period, resulting in overestimation of production by nearly 100 percent. For daily computation intervals, then, production rates may have to modified to obtain similar production on an hourly basis with the diurnal period. This should become evident during calibration.

Literature values for TPMAX are given in Table 5.

TSETL. TSETL is the phytoplankton settling rate (m/day). Mechanisms of suspension can influence the settling or sinking rate of algae. Morphological mechanisms include cell size, colony formation, cyclomorphosis, protuberances, and flagella. Physiological mechanisms include fat accumulation; regulation of ionic composition of cell sap; and the response of an organism to light, photoperiod, and nutrient concentration. Physical mechanisms include water viscosity and the role of water movements.

Two methods used to measure sinking rates experimentally are (a) the settling chamber method with or without the use of a microscope and (b) the photometric technique. In the settling chamber, the descent time is determined (a) by following with a microscope or, in the case of large particles, with the naked eye, the cell trajectory between two marks at a known distance apart; (b) by measuring the time a cell takes to fall to the bottom of a settling chamber of known height placed on the stage of an inverted scope; or (c) using a 1-mm-deep Sedgwick Rafter counting chamber with a compound microscope. Estimation of relative sinking rate has been obtained by placing a

Table 5

Gross Production Rates of Pytoplankton (1/day)

Species	TPMAX	Temp, °C	Reference
Diatoms			
Asterionella formosa	0.81	20	Holm and Armstrong 1981
Asterionella formosa	0.69	10	Hutchinson 1957
Asterionella formosa	1.38	20	Hutchinson 1957
Asterionella formosa	1.66	25	Hutchinson 1957
Asterionella formosa	1.71	20	Fogg 1969
Asterionella formosa	0.28	4	Talling 1955
Asterionella formosa	0.69	10	Talling 1955
Asterionella formosa	1.38	20	Talling 1955
Asterionella formosa	2.2	20	Hoogenhout and Amesz 1965
Asterionella formosa	1.9	18.5	Hoogenhout and Amesz 1965
Asterionella japonica	1.19	22	Fogg 1969
Asterionella japonica	1.3	18	Hoogenhout and Amesz 1965
Asterionella japonica	1.7	25	Hoogenhout and Amesz 1965
Biddulphia sp.	1.5	11	Castenholz 1964
Coscinodiscus sp.	0.55	18	Fogg 1969
Cyclotella meneghiniana	0.34	16	Hoogenhout and Amesz 1965
Cyclotella nana	3.4	20	Hoogenhout and Amesz 1965
Detonula confervacea	0.62	2	Smayda 1969
Detonula confervacea	1.4	10	Hoogenhout and Amesz 1965
Ditylum brightwellii	2.1	20	Paasche 1968
Fragilaria sp.	0.85	20	Rhee and Gotham 1981b
Fragilaria sp.	1.7	11	Castenholz 1964
Melosira sp.	0.7	11	Castenholz 1964
Navicula minima	1.4	25	Hoogenhout and Amesz 1965
Navicula pelliculosa	2.0	20	Hoogenhout and Amesz 1965
Nitzschia palea	2.1	25	Hoogenhout and Amesz 1965
Nitzschia turgidula	2.5	20	Paasche 1968
Phaeodactylum tricornutum	1.66	25	Fogg 1969
Phaeodactylum tricornutum	2.7	19	Hoogenhout and Amesz 1965
Rhizosolenia fragillissima	1.20	21	Ignatiades and Smayda 1970
Skeletonema costatum	1.26	18	Fogg 1969
Skeletonema costatum	2.30	20	Jorgensen 1968
Skeletonema costatum	1.52	20	Steemann-Nielsen and Jorgensen 1968
Skeletonema costatum	1.23	20	Jitts et al. 1964
Synedra sp.	1.2	11	Castenholz 1964
Thalassiosira nordenskioldii	0.77	13	Jitts et al. 1964
Natural diatom community	3.10	20	Verduin 1952

(Continued)

(Sheet 1 of 3)

Table 5 (Continued)

Species	TPMAX	Temp, °C	Reference
Greens			
Ankistrodesmus braunii	2.33	25	Hoogenhout and Amesz 1965
Chlorella pyrenoidosa	2.22	28	Shelef 1968
Chlorella ellipsoidea	3.6	25	Hoogenhout and Amesz 1965
Chlorella luteoviridis	0.56	22.4	Hoogenhout and Amesz 1965
Chlorella miniata	0.87	25	Hoogenhout and Amesz 1965
Chlorella pyrenoidosa	2.14	25	Fogg 1969
Chlorella pyrenoidosa	1.95	25.5	Sorokin and Myers 1953
Chlorella pyrenoidosa	9.00	39	Castenholz 1969
Chlorella pyrenoidosa	9.2	39	Hoogenhout and Amesz 1965
Chlorella seccharophilia	1.2	25	Hoogenhout and Amesz 1965
Chlorella variegata	0.86	25	Hoogenhout and Amesz 1965
Chlorella vulgaris	2.9	25	Hoogenhout and Amesz 1965
Chlorella vulgaris	1.59	20	Goldman and Graham 1981
Dunaliella tertiolecta	1.0	16	Hoogenhout and Amesz 1965
Dunaliella tertiolecta	0.77	36	Jitts et al. 1964
Haematococcus pluvialis	1.2	23	Hoogenhout and Amesz 1965
Nanochloris atomus	1.0	20	Hoogenhout and Amesz 1965
Platymonas subcordiformia	1.5	16	Hoogenhout and Amesz 1965
Scenedesmus sp.	1.34	20	Rhee and Gotham 1981b
Scenedesmus costulatus	2.0	24.5	Hoogenhout and Amesz 1965
Scenedesmus obliquus	2.11	20	Goldman and Graham 1981
Scenedesmus obliquus	2.2	25	Hoogenhout and Amesz 1965
Scenedesmus quadricauda	4.1	25	Hoogenhout and Amesz 1965
Scenedesmus quadricauda	2.29	27	Goldman et al. 1972
Selenastrum capricornutum	2.45	27	Goldman et al. 1972
Selenastrum westii	1.0	25	Hoogenhout and Amesz 1965
Stichococcus sp.	0.70	20	Hoogenhout and Amesz 1965
Golden-brown			
Botrydiopsis intercedens	1.5	25	Hoogenhout and Amesz 1965
Bumilleriopsis brevis	2.9	25	Hoogenhout and Amesz 1965
Cricosphaera carterae	0.82	18	Fogg 1969
Isochrysis galbana	0.55	20	Fogg 1969
Isochrysis galbana	0.80	25	Hoogenhout and Amesz 1965
Monochrysis lutheri	1.5	15	Hoogenhout and Amesz 1965
Monochrysis lutheri	0.39	24	Jitts et al. 1964
Monodus subterraneus	0.93	25	Hoogenhout and Amesz 1965
Monodus subterraneus	0.39	30	Fogg 1969
Tribonema aequale	0.70	25	Hoogenhout and Amesz 1965
Tribonema minus	1.00	25	Hoogenhout and Amesz 1965

(Continued)

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Table 5 (Concluded)

Species	TPMAX	Temp, °C	Reference
Golden-brown (Cont'd)			
Vischeria stellata	0.70	25	Hoogenhout and Amesz 1965
Euglena gracilis	2.2	25	Hoogenhout and Amesz 1965
Dinoflagellate			
Amphidinium carteri	1.88	18	Fogg 1969
Amphidinium carteri	0.32	32	Jitts et al. 1964
Ceratium tropos	0.20	20	Fogg 1969
Gonyaulax polyedra	2.1	21.5	Hoogenhout and Amesz 1965
Gymnodinium splendens	0.92	20	Hoogenhout and Amesz 1965
Peridinium sp.	0.90	18	Hoogenhout and Amesz 1965
Prorocentrium gracile	0.83	18	Hoogenhout and Amesz 1965
Prorocentrium micans	0.71	25	Hoogenhout and Amesz 1965
Prorocentrium micans	0.30	20	Fogg 1969
Bluegreens			
Agmenellum quadriplaticum	8.0	39	Hoogenhout and Amesz 1965
Anabaena cylindrica	0.96	25	Hoogenhout and Amesz 1965
Anabaena variabilis	3.9	34.5	Hoogenhout and Amesz 1965
Anacystis nidulans	2.9	25	Hoogenhout and Amesz 1965
Anacystis nidulans	11.00	40	Castenholz 1969
Chloropseudomonas ethylicum	3.3	30	Hoogenhout and Amesz 1965
Cyanidium caldarium	2.4	40	Hoogenhout and Amesz 1965
Cylindrospermum sphaerica	0.17	25	Hoogenhout and Amesz 1965
Gloeotrichia echinulata	0.20	26.5	Hoogenhout and Amesz 1965
Microcystis aeruginosa	0.25	20	Holm and Armstrong 1981
Microcystis aeruginosa	1.6	23	Hoogenhout and Amesz 1965
Microcystis luminmosis	1.50	40	Castenholz 1969
Nostoc muscorum	2.9	32.5	Hoogenhout and Amesz 1965
Oscillatoria princips	0.50	40	Castenholz 1969
Oscillatoria terebriformis	3.36	40	Castenholz 1969
Oscillatoria rubescens	5.04	30	Zimmerman 1969
Rhodopseudomonas sphaeroides	10.8	34	Hoogenhout and Amesz 1965
Rhodospirllum rubrum	4.85	25	Hoogenhout and Amesz 1965
Schizothrix calcicola	3.4	30	Hoogenhout and Amesz 1965
Synechococcus lividus	4.98	40	Castenholz 1969
Synechococcus sp.	8.0	37	Hoogenhout and Amesz 1965
Tolypothrix tenuis	4.0	38	Hoogenhout and Amesz 1965
Leptocylindrus danicus	0.67-2.0	10-20	Verity 1981
Anabaena variabilis	0.07-2.0	10-35	Collins and Boylen 1982a

(Sheet 3 of 3)

well-mixed suspension of phytoplankton into a graduated cylinder and determining the concentration in various layers after a given time. Photometric determination of sinking rate measures changes in optical density of a phytoplankton suspension measured at 750 nm after introducing the phytoplankton suspension into a cuvette.

These techniques are influenced by the "wall effect," that is, the effect of the settling chamber wall and convection current on the sinking velocity. To provide adequate fall for attainment of terminal velocity and to minimize overcrowding, the selection of chamber size is important.

The sinking rates of natural populations have also been determined by comparing changes in population density with depth and calculating a mean rate of descent. However, determination of sinking rate in situ is complicated by water movements and losses due to grazing. Mathematical expressions may also be used to determine sinking rates (Riley, Stommel, and Bumpus 1949).

The application of experimentally determined sinking rates to natural populations or ecosystem models must be qualified and used with caution. In lakes and reservoirs, vertical gradients of light, temperature, and nutrient concentration contrast with the constancy of the settling chamber and photometer cuvette environments in sinking experiments. The influence of light and nutrients on sinking rates together with the turbulent motion of the natural environment suggest that in vitro sinking results may not be particularly representative of natural populations. Values for settling rates are given in Table 6.

PS2PO4. PS2PO4 is the phosphorus half-saturation coefficient (HSC) (mg/ℓ). In practical terms, the HSC of a nutrient approximately marks the upper nutrient concentration at which growth ceases to be proportional to that nutrient. The modeled uptake of phosphorus by algae follows Monod kinetics. The value of the HSC can be calculated for the hyperbola using the Monod equation. PS2PO4 is defined as the concentration of phosphorus at which the rate of uptake is one-half the maximum.

Table 6

Phytoplankton Settling Rates (m/day)

Species	TSETL	Reference
Diatoms		
Experimental studies		
Asterionella formosa	0.26-0.76	Smayda 1974
Asterionella formosa	0.4	Margalef 1961
Bacteriastrum hyalinum	0.39-1.27	Smayda and Boleyn 1966
Chaetoceros didymus	0.85	Eppley, Holmes, and Strickland 1967
Chaetoceros lauderi	0.46-1.54	Smayda and Boleyn 1966
Chaetoceros lauderi	0.46-1.54	Smayda and Boleyn 1966
Chaetoceros spp.	0.25	Margalef 1961
Chaetoceros spp.	4.0	Allen 1932
Coscinodiscus wailesii	7.0-30.2	Eppley, Holmes, and Strickland 1967
Coscinodiscus sp.	1.95-6.83	Eppley, Holmes, and Strickland 1967
Coscinodiscus sp.	14.7	Eppley, Holmes, and Strickland 1967
Cyclotella meneghiniana	0.08-0.24	Titman and Kilham 1976
Cyclotella nana	0.16-0.76	Eppley, Holmes, and Strickland 1967
Ditylum brightwellii	0.60-3.09	Eppley, Holmes, and Strickland 1967
Ditylum brightwellii	2.0	Eppley, Holmes, and Strickland 1967
Fragilaria crotonensis	0.27	Burns and Rosa 1980
Leptocylindrum danicus	0.08-0.42	Margalef 1961
Melosira agassizii	0.67-1.87	Titman and Kilham 1976
Nitzschia closterium	0.52	Margalef 1961
Nitzschia seriata	4.0	Allen 1932
Nitzschia seriata	0.35-0.50	Smayda and Boleyn 1965
Phaeodactylum tricornutum	0.05-0.06	Riley 1943
Phaeodactylum tricornutum	0.02-0.04	Riley 1943
Rhizosolenia hebetata f. semispina	0.22	Eppley, Holmes and Strickland 1967
Rhizosolenia setigera	0.11-2.23	Smayda and Boleyn 1966
Rhizosolenia setigera	0.10-6.30	Smayda and Boleyn 1966
Rhizosolenia stolterfothii	1.0-1.9	Eppley, Holmes, and Strickland 1967

(Continued)

(Sheet 1 of 3)

Table 6 (Continued)

Species	TSETL	Reference
Diatoms (Cont'd)		
Experimental studies (Cont'd)		
Rhizosolenia spp.	0-0.72	Margalef 1961
Skeletonema costatum	0.30-1.35	Smayda and Boleyn 1966
Stephanopyxis turris	1.1	Eppley, Holmes, and Strickland 1967
Stephanopyxis turris	2.1	Eppley, Holmes, and Strickland 1967
Thalassiosira fluviatilis	0.60-1.10	Eppley, Holmes, and Strickland 1967
Thalassiosira cf. *nana*	0.10-0.28	Smayda and Boleyn 1966
Thalassiosira rotula	1.15	Eppley, Holmes, and Strickland 1967
Thalassiosira rotula	0.39-2.10	Smayda and Boleyn 1966
Thalassiosira spp.	0-0.16	Margalef 1961
Theoretical		
Diatoms	0.3	Bramlette 1961
Dinoflagellates		
Experimental studies		
Gonyaulax polyedra	2.8-6.0	Eppley, Holmes, and Strickland 1967
Coccolithophorids		
Experimental studies		
Coccolithus huxleyi	0.28	Eppley, Holmes, and Strickland 1967
Coccolithus huxleyi	1.20	Eppley, Holmes, and Strickland 1967
Cricosphaera carterae	1.70	Eppley, Holmes, and Strickland 1967
Cricosphaera elongata	0.25	Eppley, Holmes, and Strickland 1967
Cyclococcolithus fragilis	13.2	Bernard 1963
Cyclococcolithus fragilis	13.6	Bernard 1963
Cyclococcolithus fragilis	10.3	Bernard 1963

(Continued)

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Table 6 (Concluded)

Species	TSETL	Reference
Coccolithophorids (Cont'd)		
Theoretical		
Coccoliths	1.5	Bramlette 1961
Microflagellates		
Experimental studies		
Cryptomonas erosa	0.31	Burns and Rosa 1980
Cryptomonas marsonii	0.32	Burns and Rosa 1980
Rhodomonas minuta	0.07	Burns and Rosa 1980
Dunaliella tertiolecta	0.18	Eppley, Holmes, and Strickland 1967
Monochrysis lutheri	0.39	Eppley, Holmes, and Strickland 1967
Monochrysis lutheri	0.39	Apstein 1910
Greens - experimental		
Closterium parvulum	0.18	Burns and Rosa 1980
Dunaliella tertiolecta	0.18	Eppley, Holmes, and Strickland 1967
Lagerhaemia quadriseta	0.08	Burns and Rosa 1980
Scenedesmus acutiformis	0.10	Burns and Rosa 1980
Selenastrum minutum	0.15	Burns and Rosa 1980
Bluegreens - experimental		
Anabaena spiroides	0.10	Burns and Rosa 1980
Gomphosphaeria lacustris	0.11	Burns and Rosa 1980

(Sheet 3 of 3)

Half-saturation coefficients generally increase with nutrient concentrations (Hendrey and Welch 1973, Carpenter and Guillard 1971; Toetz, Varga, and Loughran 1973). This fact reflects both the change in species composition of the phytoplankton assemblage and the adaptation of the plankton to higher nutrient levels. A reservoir characterized by low nutrient concentrations is generally also characterized by low HSCs.

Nitrogen/phosphorus (N/P) ratios also provide information on the limiting nutrient and should be calculated using N and P concentrations measured in the mixed layer for all sampling dates. Usually, N/P ratios greater than 16:1 indicate phosphorus limitations while ratios less than 12:1 indicate nitrogen limitation. Intermediate values give indeterminate information, indicating uncertainty over which nutrient may be limiting. Phosphorus is usually the nutrient that limits the growth of algae in lakes and reservoirs.

The procedure of measuring a phosphorus HSC involves the measurement of the net rate of loss of dissolved orthophosphate from the medium in which the experimental population is suspended.

Units of measurements must be expressed in terms of the chemical element and not the compound; i.e., the half-saturation coefficient for phosphorus should be specified as mg/ℓ of phosphorus and not mg/ℓ of orthophosphate. Micromoles per litre or microgram-atom values may be converted by multiplying by the molecular weight of the element times 10^{-3}. Values for the HSC are given in Table 7.

Table 7

Phytoplankton Half-Saturation Coefficients for P Limitation (mg/ℓ)

Species	PS2PO4	Reference
Asterionella formosa	0.002	Holm and Armstrong 1981
Asterionella japonica	0.014	Thomas and Dodson 1968
Biddulphia sinensis	0.016	Quasim, Bhattathiri, and Dovassoy 1973

(Continued)

Table 7 (Concluded)

Species	PS2PO4	Reference
Cerataulina bergonii	0.003	Finenko and Krupatkina-Aki-Nina 1974
Chaetoceros curvisetus	0.074-0.105	Finenko and Krupatkina-Aki-Nina 1974
Chaetoceros socialis	0.001	Finenko and Krupatkina-Aki-Nina 1974
Chlorella pyrenoidosa	0.38-0.475	Jeanjean 1969
Cyclotella nana	0.055	Fuhs et al. 1972
Cyclotella nana	0.001	Fogg 1973
Euglena gracilis	1.52	Blum 1966
Freshwater phytoplankton	0.02-0.075	Halmann and Stiller 1974
Microcystis aeruginosa	0.006	Holm and Armstrong 1981
Nitzschia actinastreoides	0.095	Von Muller 1972
Pithophora oedogonia	0.98	Spencer and Lembi 1981
Scenedesmus obliquus	0.002	Fogg 1973
Scenedesmus sp.	0.002-0.05	Rhee 1973
Thalassiosira fluviatilis	0.163	Fogg 1973

PS2N. PS2N is the nitrogen (N) HSC (mg/ℓ). Uptake rates of nitrate (NO_3^-) or ammonium (NH_4^+) by algae give hyperbolas when graphed against NO_3^- or NH_4^+ concentration in the environment. Half-saturation coefficients (i.e., the concentration of N at which the rate of production is one-half the maximum) can be calculated for the hyperbolas using the Monod equation. This constant reflects the relative ability of phytoplankton to use low levels of nitrogen.

The role of N as a growth-limiting factor has been relatively neglected when compared with phosphorus, presumably because the latter is the growth-limiting factor in most natural fresh waters. However, it has been found that N becomes the limiting nutrient where phosphorus is abundant because of its release from geological deposits or from external loadings.

There are several methods for measuring half-saturation coefficients for N limitation. The chemostat method requires the measurement of the remaining N concentration at a number of fixed dilution rates (i.e., growth rates) in nitrogen-limited chemostat cultures. Culture media are prepared with nitrate or ammonium as the N source, with one-fifth or less than the usual amount of NO_3^- or NH_4^+ added to the culture media to ensure that, during growth, N will be depleted before other nutrients. A second, less desirable method is to use nitrogen-starved cells as an inoculum for cultures containing known concentrations of N and then (a) measure the concentration of N in the extracellular fluid at some later time to determine the rate of N uptake and (b) measure the increasing cell concentration to determine growth kinetics. The problems associated with this method are that the organisms are poorly adapted to their subsequent growth environment, so growth can occur only after uptake of a substantial amount of N.

Some trends can be seen in the data for half-saturation coefficients: (a) organisms with a high HSC for nitrate usually have a high HSC for ammonium uptake as well, (b) large-celled species tend to show higher HSCs, and (c) fast-growing species tend to have lower HSCs than slow growers.

The nitrogen HSC as used in CE-QUAL-R1 should reflect the uptake of both the nitrite plus nitrate and ammonia nitrogen compartments. Both compounds are taken up for use in production in proportion to their concentration in the layer.

A factor that will lead to selection for a particular functional group or species is the availability of combined N. In situations where the level of combined N is relatively low compared with other essential elements, such as phosphorus, those bluegreen species that can fix N will be at a selective advantage. Nitrogen fixation is not explicitly included in the model formulation for phytoplankton; however, if bluegreen algae are an important component in one of the compartments, the N HSC may have to be reduced to a low value to reflect N fixation. Values for the HSC for N are given in Table 8.

PS2CO2. PS2CO2 is the HSC for carbon dioxide (mg/ℓ). The coefficient is used in the Monod equation to determine the rate factor for CO_2 limitation. PS2CO2 is defined as the concentration of CO_2 at which the rate of production is one-half the maximum. In practical terms,

Table 8

Phytoplankton Half-Saturation Coefficients for N Limitation (mg/ℓ)

Species	PS2N	Source	Reference
Diatoms			
Biddulphia aurita	0.056-0.197	NO_3^-	Underhill 1977
Chaetoceros gracilis	0.012	NO_3^-	Eppley, Rogers, and McCarthy 1969
Chaetoceros gracilis	0.007	NO4	Eppley, Rogers, and McCarthy 1969
Coscinodiscus lineatus	0.161	NO_3^-	Eppley, Rogers, and McCarthy 1969
Coscinodiscus lineatus	0.036	NH_4^+	Eppley, Rogers, and McCarthy 1969
Cyclotella nana	0.025-0.117	NO_3^-	Carpenter and Guillard 1971
Cyclotella nana	0.111		MacIsaac and Dugdale 1969
Cyclotella nana	0.027		Caperon and Meyer 1972
Cyclotella nana	0.031		Eppley, Rogers, and McCarthy 1969
Cyclotella nana	0.007	NH_4^+	Eppley, Rogers, and McCarthy 1969
Ditylum brightwellii	0.037	NO_3^-	Eppley, Rogers, and McCarthy 1969
Ditylum brightwellii	0.020	NH_4^+	Eppley, Rogers, and McCarthy 1969
Dunaliella teriolecta	0.013	NO_3^-	Caperon and Meyer 1972
Dunaliella teriolecta	0.003	NH_4^+	Caperon and Meyer 1972
Dunaliella teriolecta	0.087	NO_3^-	Eppley, Rogers, and McCarthy 1969
Fragilaria pinnata	0.037-0.100	NO_3^-	Carpenter and Guillard 1971
Leptocylindrous danicus	0.078	NO_3^-	Eppley, Rogers, and McCarthy 1969
Leptocylindrous danicus	0.013	NH_4^+	Eppley, Rogers, and McCarthy 1969
Navicula pelliculosa	0.923	NO_3^-	Wallen and Cartier 1975
Phaeodactylum tricornutum	0.161	NO_3^-	Ketchum 1939

(Continued)

(Sheet 1 of 3)

Table 8 (Continued)

Species	PS2N	Source	Reference
Diatoms (Cont'd)			
Rhizosolenia robusta	0.186	NO_3^-	Eppley, Rogers, and McCarthy 1969
Rhizosolenia robusta	0.135	NH_4^+	Eppley, Rogers, and McCarthy 1969
Rhizosolenia stolterfothii	0.105	NO_3^-	Eppley, Rogers, and McCarthy 1969
Rhizosolenia stolterfothii	0.009	NH_4^+	Eppley, Rogers, and McCarthy 1969
Skeletonema costatum	0.027	NO_3^-	Eppley, Rogers, and McCarthy 1969
Skeletonema costatum	0.014	NH_4^+	Eppley, Rogers, and McCarthy 1969
Bluegreens			
Anabaena cylindrica	4.34	NO_3^-	Hattori 1962
Anabaena cylindrica	2.48	NO_2^-	Hattori 1962
Asterionella formosa	0.074-0.093	NO_3^-	Eppley and Thomas 1969
Asterionella formosa	0.062	NH_4^+	Eppley and Thomas 1969
Oscillatoria agarthii	0.22	NO_3^-	van Lierre, Zevenboom, and Mur 1977
Microflagellates			
Bellochia sp.	0.001-0.016	NO_3^-	Carpenter and Guillard 1971
Monochrysis lutheri	0.026	NO_3^-	Caperon and Meyer 1972
Monochrysis lutheri	0.052	NH_4^+	Caperon and Meyer 1972
Monochrysis lutheri	0.037	NO_3^-	Eppley, Rogers, and McCarthy 1969
Monochrysis lutheri	0.007	NH_4^+	Eppley, Rogers, and McCarthy 1969
Coccolithophorids			
Coccolithus huxleyi	0.006	NO_3^-	Eppley, Rogers, and McCarthy 1969

(Continued)

(Sheet 2 of 3)

Table 8 (Concluded)

Species	PS2N	Source	Reference
Coccolithophorids (Cont'd)			
Coccolithus huxleyi	0.002	NH_4^+	Eppley, Rogers, and McCarthy 1969
Coccochloris stagnina	0.019	NO_3^-	Caperon and Meyer 1972
Greens			
Chlorella pyrendoidosa	0.006-0.014		Pickett 1975
Chlorella pyrendoidosa	1.15	NO_2^-	Knudsen 1965
Pithophora oedogonia	1.236	NO_3^-	Spencer and Lembi 1981
Dinoflagellates			
Gonyaulax polyedra	0.589	NO_3^-	Eppley, Rogers, and McCarthy 1969
Gonyaulax polyedra	0.099	NH_4^+	Eppley, Rogers, and McCarthy 1969
Gymnodinium splendens	0.235	NO_3^-	Eppley, Rogers, and McCarthy 1969
Gymnodinium splendens	0.019	NH_4^+	Eppley, Rogers, and McCarthy 1969
Gymnodinium wailesii	0.223	NO_3^-	Eppley, Rogers, and McCarthy 1969
Gymnodinium wailesii	0.088	NH_4^+	Eppley, Rogers, and McCarthy 1969
Chrysophytes			
Isochrysis galbana	0.006	NO_3^-	Eppley, Rogers, and McCarthy 1969

(Sheet 3 of 3)

the HSC approximately marks the upper nutrient concentration at which growth ceases to be proportional to that nutrient.

There is a diversity of opinions as to whether inorganic carbon (C) limits photosynthesis in phytoplankton. Goldman, Oswald, and Jenkins (1974) have argued that inorganic carbon almost never limits growth in natural algal populations. In contrast, King (1970) has shown that CO_2 availability limits the growth of aquatic populations. Johnson, Michalski, and Christie (1970) demonstrated CO_2 limitation in lakes contaminated by acid mine wastes, and Schindler and Fee (1973) demonstrated carbon limitation in a lake during the summer when nitrogen and phosphorus were available. Carbon dioxide limitation is clearly pH dependent. For example, the HSC for carbon dioxide given in Table 9 for *Scenedesmus capricornutum* increases with increasing pH. This is related to the effect of pH on the relative proportions of the inorganic carbon species of carbon dioxide, bicarbonate ion, and carbonate ion in solution. The HSC values for carbon dioxide are given in Table 9.

Table 9

Phytoplankton Half-Saturation Coefficients for CO_2 Limitation (mg/ℓ)

Species	PS2CO2	pH Range	References
Chlorella vulgaris	0.20	7.1-7.2	Goldman and Graham 1981
Chlorella emersonii	0.068-0.411		Beardall and Raven 1981
Mixed bluegreen algae	0.088		Golterman 1975
Mixed bluegreen algae	0.031		Forester 1971
Mixed bluegreen algae	0.057		Shamieh 1968
Scenedesmus quadricauda	0.14	7.1-7.2	Goldman, Oswald, and Jenkins 1974
Scenedesmus quadricauda	0.36	7.25-7.39	Goldman, Oswald, and Jenkins 1974
Scenedesmus quadricauda	0.54-0.71	7.44-7.61	Goldman, Oswald, and Jenkins 1974
Scenedesmus capricornutum	0.40-0.41	7.05-7.2	Goldman, Oswald, and Jenkins 1974
Scenedesmus capricornutum	0.63-1.0	7.25-7.39	Goldman, Oswald, and Jenkins 1974

(Continued)

Table 9 (Concluded)

Species	PS2CO2	pH Range	References
Scenedesmus capricornutum	1.2-1.5	7.43-7.59	Goldman, Oswald, and Jenkins 1974
Scenedesmus obliquus	0.16	7.1-7.2	Goldman and Graham 1981

PISAT. This is the saturating light intensity at the maximum photosynthetic rate and should be expressed as Kcal • m^{-2} • hr^{-1}. Suspended sediments may exert a significant influence on the light regime in reservoirs. Since phytoplankton adapt to low light regimes, saturation coefficients may be lower than those measured under laboratory conditions. Values reported in the literature may also overestimate this coefficient because they are measured under optimum conditions either in the laboratory or in the field. Literature values are reported in Table 10.

Table 10

Values of Light Intensity at the Maximum Photosynthetic Rate (Kcal • m^{-2} • hr^{-1})

Species	PISAT (Kcal • m^{-2} • hr^{-1})	Reference
Oscillatoria agardii	8.58	van Lierre, Zevenboom, and Mur 1977
Scenedesmus protuberans	20.59	van Lierre, Zevenboom, and Mur 1977
Mixed diatoms	72	Belay 1981
Mixed plankton	30	Belay 1981
Shade-adapted	15-24	Belay 1981
Oscillatoria rubescens	30-51	Konopka 1983
Cryptomonas ovata	10-30	Cloern 1977

TPEXCR. This is the maximum excretion rate or photorespiration rate (1/day). TPEXCR is further defined as the rate of extracellular release of organic compounds. In CE-QUAL-R1, this release increments the labile DOM compartment. Wetzel (1975) has stated that these rates can vary from less than 1 percent to the same rate as carbon fixation, but that most values are less than 20 percent of carbon fixation. Literature values can be found in Table 11.

Table 11

Maximum Extracellular Release Rate of Algae (1/day)

Species	TPEXCR	Reference
Actinastrum hantzschii	0.044	Nalewajko 1966
Ankistrodesmus falcatus	0.031	Nalewajko 1966
Asterococcus superbus	0.036	Nalewajko 1966
Chlorella pyrenoidosa	0.032	Nalewajko 1966
Eudorina elegans	0.023	Nalewajko 1966
Micractinium pusillum	0.014	Nalewajko 1966

TPMORT. This is the maximum algal nonpredatory mortality rate (1/day). Values from 0.01 to 0.03 have been used in previous modeling studies.

TPRESP. This variable represents the maximum dark respiration rate of algae (1/day). Respiration rates, in many instances, are expressed as millilitres of oxygen consumed per milligram of organism dry weight per hour. Since the model formulations require units of mg/mg/day or 1/day, these values must be converted. The following is one approach for converting millilitres of oxygen uptake to milligrams of biomass respired.

a. Compute the molecular weight equivalents of gas volume at STP

$$1 \text{ mole } O_2 = 22.1 \ \ell \text{ at } 32 \text{ g/1}, \ \frac{32 \text{ g}}{22.1} = 1.45 \text{ mg } O_2/\text{ml } O_2$$

$$1 \text{ mole } CO_2 = 22.1 \ \ell \text{ at } 44 \text{ g}/\ell, \ \frac{44 \text{ g}}{22.1} = 2.0 \text{ mg } CO_2/\text{ml } CO_2$$

b. Assume a Respiratory Quotient $\frac{CO_2}{O_2}$ of 0.9 for general metabolism or 1 ml $O_2 \rightarrow 0.9$ ml CO_2. Therefore, for each millilitre O_2 consumed,

$$\frac{12 \text{ (mol. wt. C)}}{44 \text{ (mol. wt. } CO_2)} \cdot 1.8 \text{ mg } CO_2 = 0.49 \text{ mg C respired} \qquad (200)$$

c. Assume a C/biomass stoichiometric equivalent of 0.45. Then, for each millilitre O_2 consumed/mg dry weight

$$\frac{0.49 \text{ mg C}}{0.45} = 1.08 \text{ mg biomass} \qquad (201)$$

d. However, milligrams O_2 per litre are consumed in the model, not millilitres. Therefore, for each millilitre of O_2 consumed

$$1.45 \text{ mg } O_2 \text{ consumed} = 1.08 \text{ mg biomass respired} \qquad (202)$$

or

$$1 \text{ ml } O_2 = 0.74 \text{ mg biomass respired/mg } O_2 \text{ consumed} \qquad (203)$$

e. This relationship may be used to convert millilitres O_2 to milligrams dry weight per unit time.

Literature values of dark respiration can be found in Table 12.

Table 12

Phytoplankton Dark Respiration Rates (1/day)

Species	TPRESP	Reference
Mesodinium rubrum	0.05	Smith 1979
Thalassiosira allenii small cells	0.14-0.59	Laws and Wong 1978
Thalassiosira allenii large cells	0.05-0.42	Laws and Wong 1978

(Continued)

Table 12 (Concluded)

Species	TPRESP	Reference
Monochrysis lutheri	0.15-0.32	Laws and Wong 1978
Dunaliella teriolecta	0.12-0.46	Laws and Wong 1978
Anabaena variabilis	0.10-0.92	Collins and Boylen 1982a
Coscinodiscus excentricus	0.075-0.11	Riley and von Aux 1949
Chlorella pyrenoidosa	0.01-0.03	Myers and Graham 1961
Phytoplankton	0.05-0.10	Ryther 1954

ALG5 (QUAL)

PS2SI. This is the silica HSC (mg/ℓ) for use in only the third algal compartment. If this compartment is used to represent an assemblage other than diatoms, the coefficient value for PS2SI should be set to zero so that no limitation by silica can occur. Values near 0.05 have been used in previous modeling studies.

ALG6, ALG7, ALG8 (QUAL)

These three records contain the same information for three groups of algal. ALG6 contains information on the first group, ALG7 for the second group, and ALG8 for the third group. These three records must be included in the data set even if less than three algal groups are being modeled.

The six variables on each record represent temperature coefficients (see subroutine RMULT and Figure 40, Part III). The first four have units of degrees, Celsius. The last two are dimensionless; their values have usually been around 0.1 in previous modeling studies.

ALGxT1 is the lower temperature bound at which phytoplankton metabolism continues.

ALGxT2 is the lowest temperature at which processes are occurring near the maximum rate.

ALGxT3 is the upper temperature at which processes are occurring at the maximum rate.

ALGxT4 is the upper lethal temperature. Biological temperature curves are generally asymmetrical, with the maximum rates occurring nearer the upper lethal temperatures than the lower temperatures.

ALGxK1 is the value of the temperature rate multiplier corresponding to the lower temperature, ALGxT1.

ALGxK4 is the value of the temperature rate multiplier corresponding to the upper temperature, ALGxT4.

The temperature coefficients for algal production are dependent upon the acclimation temperature and the length of time of exposure to this temperature (Collins and Boylen 1982b). For example, algae growing in a northern reservoir will have a lower optimum temperature (ALGxT2 and ALGxT3) than algae growing in a southern reservoir because the northern algae have become acclimated to different climatic regimes. The lower and upper temperature boundaries (ALGxT1 and ALGxT4) will also be affected by acclimation and will differ substantially among different functional groups of algae.

Unfortunately, there is no set rule to determine these coefficients based upon site-specific temperature regimes. One can estimate these values for a given species or functional group based upon reported experimental conditions or in situ study conditions. Several investigators have determined these values based upon studies where several physical factors such as light intensity, temperature, and day length have been varied simultaneously. Often the algae were preconditioned at a specific combination of these factors, which may help in parameter estimation for a particular site. Values for the temperature coefficients are given in Table 13.

Table 13

Temperature Coefficients for Phytoplankton (°C)

Species	ALG xT1	ALG xT2	ALG xT3	ALG xT4	Reference
Amphidinium carteri	18	24		35	Jitts et al. 1964
Anacystis nidulans		38	40		Castenholz 1969
Asterionella formosa		25	25		Rhee and Gotham 1981a
Asterionella formosa		25	29		Hutchinson 1957
Asterionella formosa	4	20	25		Talling 1955
Chlorella pyrenoidosa	1	28	38	40	Clendenning, Brown, and Eyster 1956
Chlorella pyrenoidosa	7	38	40	42	Sorokin and Krauss 1962
Chlorella sp.		20	25		Tamiya et al. 1965
Detonula confervacea	0	10	12	16	Guillard and Ryther 1962
Detonula confervacea	1	10	13	15	Smayda 1969
Ditylum brightwellii	5	23	26	30	Paasche 1968
Dunaliella teriolecta	8	31	33	36	Eppley and Sloan 1966
Dunaliella teriolecta	12	26	28	36	Jitts et al. 1964
Microcystis aeruginosa		38	40		Castenholz 1969
Monochrysis lutheri	9	19	22		Jitts et al. 1964
Nostoc muscorum	1	31	33	36	Clendenning, Brown, and Eyster 1956
Oscillatoria terebriformis		38	40		Castenholz 1969
Phaeodactylum tricornutum	0	20	21	30	Li and Morris 1982
Rhizosolenia fragillissima	7	21			Ignatiades and Smayda 1970
Scenedesmus sp.		19	20	21	Rhee and Gotham 1981a
Skeletonema costatum	1	20			Jorgensen 1968
Skeletonema costatum	2	20			Steemann-Nielsen and Jorgensen 1968
Thalassiosira nordenskioldii	4	13	14	16	Jitts et al. 1964

PLANT1 (QUAL)

TPLMAX. This is the maximum gross production rate for macrophytes (1/day). Since all macrophyte species are aggregated in one compartment, a weighting procedure similar to that previously described for phytoplankton should be used. Information on this and other variables dealing with macrophytes can be found in Collins, Park, and Boylen (1985). Values near 0.5 have been used in previous modeling studies.

TMRESP. This is the maximum dark respiration rate for macrophytes (1/day). Values near 0.05 have been used in previous modeling studies.

TMEXCR. This is the maximum excretion or photorespiration rate for macrophytes (1/day). Values near 0.02 have been used in previous modeling studies.

TMMORT. This is the maximum nonpredatory mortality rate for macrophytes (1/day). Mortality is assumed to occur only with a falling temperature. Plant mass that is part of the standing crop but is not viable cannot be modeled by CE-QUAL-R1. Values near 0.03 have been used in previous modeling studies.

PLDIGO(1). This is the fraction of macrophytes, dying during the time step, that increment the labile DOM compartment. The values of PLDIGO(1), PLDIGO(2), and PLDIGO(3) must add up to 1.0. Values from 0.01 to 0.1 were found by Wetzel and Manny (1975). Values to 0.3 have been used in previous modeling studies.

PLDIGO(2). This is the fraction of dead macrophytes that increment the detritus compartment. Godshalk and Wetzel (1978) reported a value of 0.29 for this variable. Values to 0.4 have been used in previous modeling studies.

PLDIGO(3). This is the fraction of dead macrophytes that increment the sediment compartment. A value of 0.18 was reported by Carpenter (1976). Values to 0.5 have been used in previous modeling studies.

TMPMAC. This is the maximum drop in temperature that macrophytes can withstand within a 7-day period. Any temperature decrease greater than this value will result in the die-off of macrophytes at the rate TMMORT. A value of 1.5 has been used in a previous modeling study.

PLANT2 (QUAL)

EXTINM. This is the self-shading coefficient (1/m • mg/ℓ) for macrophytes. The assumption is made in CE-QUAL-R1 that the surface area that macrophytes cover is a small fraction of the total reservoir surface area, so the macrophyte mass is not used in computing the light extinction for the heat budget. It is used only for self shading. A value of 0.04 has been used in previous modeling studies.

PLIMC. This is the HSC of macrophytes for inorganic carbon limitation (mg/ℓ). A value of 4.8 was reported by Van, Haller, and Bowes (1976).

PLIMN. This is the HSC of macrophytes for nitrogen limitation (mg/ℓ). The compartments representing ammonia, nitrite plus nitrate, and sediment nitrogen are included in these calculations (see PLFRAC). Nutrients are generally not limiting to plant growth in reservoirs since the supply of nutrients can be supplied from both sediments and water column. Values near 0.01 have been used in previous studies.

PLIMP. This is the HSC of macrophytes for phosphorus limitation (mg/ℓ). The compartments representing orthophosphate and sediment phosphorus are included in these calculations (see PLFRAC). Values near 0.005 have been used in previous studies.

PLDENS. This is a species-specific or mixed community coefficient representing the average density of plants and is expressed as grams-plant dry weight/m^3. This coefficient is used to determine how many layers above the sediment macrophytes will grow (see Figure 47). Values near 40 have been used in previous modeling studies.

PLITE. This is the saturating light intensity at the maximum production rate and is expressed as Kcal/m^2/hr. Values of 112 (Van, Haller, and Bowes 1976) and 196 (Barko et al. 1980) have been reported.

PLFRAC. As previously discussed, macrophytes obtain nitrogen and phosphorus from either the sediment, water column, or both. Some species may utilize nutrients from both the sediment or water column; other species will switch at a certain concentration threshold. The fraction of nutrients that is obtained from the water column is PLFRAC. The remainder of this fraction is obtained from the sediments.

PLNTDEP. This value represents the depth below which no macrophytes will grow (in metres).

PLANT3 (QUAL)

PLTT1. This is the critical low temperature below which macrophyte processes stop (°C).

PLTT2. This is the low optimum temperature for photosynthesis by macrophytes (°C).

PLTT3. This is the high optimum temperature for photosynthesis by macrophytes (°C).

PLTT4. This is the critical high temperature above which no macrophyte photosynthesis occurs.

PLTK1. This is the temperature rate multiplier at temperature PLTT1 (dimensionless; value must be between 0 and 0.98).

PLTK4. This is the temperature rate multiplier at temperature PLTT4 (dimensionless; value must be between 0 and 0.98).

ZOO1 (QUAL)

TZMAX. This is the maximum ingestion rate for zooplankton (1/day). The zooplankton compartment includes the groups Cladocera, Copepoda, and Rotatoria, which are classified as either herbivores or carnivores.

Two types of feeding behavior exist: filter feeding and grasping feeding. *Daphnia* and some copepods are filter feeders. They collect particulate matter, including algae and detritus, by sieving lake water through the fine meshes of their filtering apparatus (Jorgensen 1975). Algae are swept into the feeding appendages to the mouth region where they are ingested as boluses containing many cells. Filter-feeding zooplankton make up the greater proportion of the zooplankton community and have been studied in greater detail.

The filtering rate per animal decreases as food concentration increases; above a critical concentration of food, the feeding rate is independent of food concentration. Factors that influence food consumption by filter-feeding zooplankton include (a) animal density, size, sex, reproduction state, nutritional or physiological state as well as (b) the type, quality, concentration, and particle size of food. Other factors include water quality and temperature.

A second type of feeding behavior, raptorial or grasping feeding, is exhibited by most copepods and some cladocerans. They pursue prey and grasp large particles, including algae and detritus. Apparently, some copepods can switch feeding modes.

Several experiments have been able to demonstrate a maximum grazing rate allowing for long-term acclimation to food concentration above the incipient limiting level.

Dissolved organic matter is another potential source of food for zooplankters, although this feeding transfer is not modeled in CE-QUAL-R1. Values for maximum ingestion rates for zooplankton are given in Table 14. Other information on zooplankton can be found in a report by Leidy and Ploskey (1980).

TZMORT. This is the maximum nonpredatory mortality rate for zooplankton (1/day). Nonpredatory mortality rates may be obtained by measuring total mortality and predatory mortality and subtracting to

Table 14

Maximum Ingestion Rates for Zooplankton (1/day)

Item	Value	Food Source	Reference
Predator species			
Bosmina	0.01	Detritus	Bogdan and McNaught 1975
Brachionus rubens	3.438	*Chlorella vulgaris*	Pilarska 1977
Cladocerans	0.15	Detritus	Bogdan and McNaught 1975
Copepods	0.10	Detritus	Bogdan and McNaught 1975
Daphnia	0.01	Detritus	Bogdan and McNaught 1975
Daphnia magna	0.251	*Saccharomyces cervisiae*	McMahon and Rigler 1965
Daphnia magna	0.452	*Tetrahymena pyriformis*	McMahon and Rigler 1965
Daphnia magna	0.301	*Chlorella vulgaris*	McMahon and Rigler 1965
Daphnia magna	0.045	*Escherichia coli*	McMahon and Rigler 1965
Daphnia magna	0.760	*Chlorella vulgaris*	Kersting and Van De Leeuw-Leegwater 1976
Daphnia magna	0.350	*Saccharomyces cerivisiae*	Rigler 1961
Daphnia magna	1.9	*Chlorella vulgaris*	Ryther 1954
Daphnia magna	2.2	*Navicula pelliculosa*	Ryther 1954
Daphnia magna	2.3	*Scenedesmus quadricauda*	Ryther 1954
Daphnia pulex	0.120	*Chlorococcum* sp.	Monakov and Sorokin 1961
Daphnia rosea	0.900	*Rhodotorula glutinis*	Burns and Rigler 1967
Diaptomus	0.47	Detritus	Bogdan and McNaught 1975
In situ experiments			
Heart Lake, Canada	0.801	Various	Haney 1973
Lake Vechten, The Netherlands	0.24	Various	Gulati 1978
Lake Krasnoye, USSR	1.20	Various	Andronikova 1978

obtain the difference (a direct approach is to measure mortality rate and eliminate predators altogether). Nonpredatory mortality may be influenced by oxygen concentration, temperature, diet, age, and population density. Nonpredatory mortality rates are normally less than 1 percent per day. Values for maximum nonpredatory mortality rate are given in Table 15.

Table 15

Zooplankton Nonpredatory Mortality Rates (1/day)

Species	TZMORT	Reference
Calanus helgolandicus	0.003-0.048	Paffenhoffer 1976
Calanus helgolandicus	0.024	Mullin and Brooks 1970
Carnivorous zooplankton	0.002-0.013	Petipa, Pavlova, and Mironov 1970
Ceriodaphnia reticulata	0.0016	Clark and Carter 1974
Copepod nauplii	0.006-0.017	Petipa, Pavlova, and Mironov 1970
Daphnia galeata	0.017	Hall 1964
Daphnia pulex	0.012	Craddock 1976
Daphnia pulex	0.018-0.027	Frank, Boll, and Kelly 1957
Daphnia retrocurva	0.001	Clark and Carter 1974
Daphnia rosea	0.001-0.007	Dodson 1972
Daphnia rosea	0.001	Clark and Carter 1974
Daphnia spp.	0.002	Wright 1975
Diaptomus clavipes	0.004-0.155	Gehrs and Robertson 1975
Diaphanosoma leuchtenbergiana	0.001	Clark and Carter 1974
Omnivorous zooplankton	0.010-0.013	Petipa, Pavlova, and Mironov 1970
Paracalanus sp.	0.003-0.006	Petipa, Pavlova, and Mironov 1970
Rhincalanus nasutus	0.006-0.015	Mullin and Brooks 1970
Simocephalus serrulatus	0.003	Hall, Cooper, and Werner 1970

ZEFFIC. This is the zooplankton assimilation efficiency (A/G) (dimensionless). It is the proportion of food assimilated (A) to food consumed (G), i.e., food actually absorbed from an individual's digestive system. The assimilation efficiency is used to modify consumption and to determine the quantity of energy entering an individual or population.

Of the factors affecting assimilation efficiency, the most significant is food type. For herbivores-detrivores, the range in ZEFFIC is wide because these animals often consume foods of varying energy content and digestibility. Among the carnivores, for which food type varies little, A/G ranges between 0.80 and 0.95. Values for zooplankton assimilation efficiency are given in Table 16.

Table 16

Zooplankton Assimilation Efficiency

Coefficients (Dimensionless)

Species	ZEFFIC	Reference
Acartia clausi	0.66-0.73	Penchen'-Finenko 1977
Bosmina coregoni	0.09-0.77	Semenova 1974
Bosmina longirostris	0.32-0.31	Gutel'mackher 1977
Calanus finmarchicus	0.48-0.96	Marshall and Orr 1956
Calamoecia lucasi	0.63-0.67	Green 1975
Ceriodaphnia reticulata	0.106	Czeczuga and Bobiatynska-Ksok 1970
Ceriodaphnia reticulata	0.47-0.73	Czeczuga and Bobiatynska-Ksok 1970
Cyclops strennus	0.50	Schindler 1971
Cyclops vicimus	0.80	Monakov 1972
Daphnia longispina	0.10-0.25	Monakov and Sorokin 1961
Daphnia longispina	0.42	Monakov 1972
Daphnia magna	0.60-0.84	Schindler 1968
Daphnia pulex	0.14-0.31	Richman 1958
Daphnia schodleri	0.60-0.90	Hayward and Gallup 1976
Daphnia sp.	0.08-0.25	Cohen 1958
Diaptomus graciloides	0.81	Penchen'-Finenko 1977
Diaptomus graciloides	0.45-0.50	Klekowski and Shushkina 1966
Diaptomus siciloides	0.40-0.83	Comita 1972
Diaptomus oregonensis	0.77	Richman 1964
Eurycercus lamellatic	0.07-0.32	Smirnov 1962
Holopedium gibberrum	0.10-0.47	Gutel'mackher 1977
Leptodora kindtii	0.40	Cummins et al. 1969
Leptodora kindtii	0.87	Hillbricht-Ilkowska and Karabin 1970
Macrocyclops albidus	0.45-0.50	Klekowski and Shushkina 1966
Mesocyclops albidus	0.20-0.75	Klekowski and Shushkina 1966
Polyphemus pediculus	0.42	Monakov 1972
Sida crystallina	0.17-0.99	Monakov 1972
Simocephalus espinosus	0.46	Sorokin 1969
Simocephalus vetulus	0.31-0.72	Klekowski 1970
Simocephalus vetulus	0.31-0.72	Ivanova and Klekowski 1972
10 herbivores	0.476	Comita 1972

PREF1. This is the feeding preference factor (dimensionless) of zooplankton for the first algal compartment.

PREF2. This is the feeding preference factor (dimensionless) of zooplankton for the second algal compartment.

PREF3. This is the feeding preference factor (dimensionless) of zooplankton for the third algal compartment.

PREF4. This is the feeding preference factor (dimensionless) of zooplankton for the detritus compartment.

The values of the preference factors, PREF1, PREF2, PREF3, and PREF4, must total to 1.0. All zooplankters are selective feeders resulting from a combination of (a) an organism's mechanical limitations in capturing and processing food items of varying size and configuration, (b) the chemical composition of the food items, and (c) feeding behavior. Food preference is demonstrated if an organism consumes a food item in a proportion different from the food item's relative contribution to the total of all available foods in the environment. If all foods occur at the same concentration, the preference factors equal the fractions of ingestion contributed by each food compartment. Seasonal abundance of phytoplankton, bacteria, and detritus may be the main factor determining the percent composition of these components in the diets of many zooplankters.

Filamentous bluegreen algae are generally not considered to be as assimilable, as are other algal species. They are seldom found in the guts of zooplankton, because they either are not eaten or are actively rejected. Most species of green algae and diatoms are filtered at about the same rate and digested. However, it is not necessarily the taxonomic position of the alga that makes it suitable or unsuitable as food, but rather the attributes of each algal species such as size, shape, and toxicity.

Although ample evidence exists to show that detritus is consumed by zooplankton, no evidence exists to show that it is consumed preferentially; rather, detritus is ingested in proportion to its composition in the environment. When detritus is included as a food source in a grazing formulation, it should be given equal ranking with other suitable foods. It should be noted that bacteria that colonize detritus constitute an important source of protein in the diet.

Filter feeders discriminate among particles on the basis of size, shape, and texture. There are upper and lower limits to the sizes of particles that can be managed by zooplankton feeding appendages. Particles of 0.8 μ and larger can be retained; an upper limit is related to the size of the animal. Algae that clog the filtering appendages are rejected from them by a claw on the lower abdomen. Raptorial feeders can seize large prey and tear it apart before eating (Ambler and Frost 1974, Brandl and Fernando 1975), but there are limits to the size of prey they capture. Values for these preference factors are given in Table 17.

Table 17

Food Preference Factors of Zooplankton (Dimensionless)

Predator	PREF	Prey	Reference
Bosmina	0.33	Nannoplankton	Bogdan and McNaught 1975
Bosmina	0.33	Netplankton	Bogdan and McNaught 1975
Cladocerans	0.30	Nannoplankton	Bogdan and McNaught 1975
Cladocerans	0.30	Netplankton	Bogdan and McNaught 1975
Cladocerans	0.20	Bluegreen algae	Bogdan and McNaught 1975
Copepods	0.45	Nannoplankton	Bogdan and McNaught 1975
Copepods	0.15	Netplankton	Bogdan and McNaught 1975
Copepods	0.20	Bluegreen algae	Bogdan and McNaught 1975
Daphnia	0.33	Nannoplankton	Bogdan and McNaught 1975
Daphnia	0.17	Netplankton	Bogdan and McNaught 1975
Diaptomus	0.40	Nannoplankton	Bogdan and McNaught 1975
Diaptomus	0.17	Netplankton	Bogdan and McNaught 1975

TZRESP. This is the maximum zooplankton respiration rate (1/day). Respiration is the sum of all physical and chemical processes by which organisms oxidize organic matter to produce energy. Respiration rates of aquatic invertebrates usually are estimated directly by monitoring oxygen consumption. By multiplying oxygen consumed times an oxycaloric coefficient (i.e., 4.83 cal/ml 0_2 (Winberg et al. 1934)) and the energy-to-carbon relation for aquatic invertebrates (i.e., 10.98 cal/mg C (Salonen et al. 1976)), the amount of carbon metabolized can be determined and converted to biomass. Values for maximum zooplankton respiration rates are given in Table 18.

Table 18

Zooplankton Maximum Respiration Rates (1/day)

Species	TZRESP	Reference
Bosmina coregoni	0.170	Manuilova 1958
Bosmina longirostris	0.185	Sushchenya 1958
Ceriodaphnia reticulata	0.18-0.50	Gophen 1976
Copepoda	0.075-0.204	Bishop 1968
Copepod adults	0.043-0.131	Williams 1982
Copepod copepodites	0.054-0.171	Williams 1982
Copepod nauplii	0.165-0.695	Williams 1982
Copepod total	0.056-0.183	Williams 1982
Daphnia ashlandii	0.447-0.74	Duval and Geen 1976
Daphnia clavipes	0.117-0.165	Comita 1968
Daphnia cuculata	0.161	Manuilova 1958
Daphnia galeata	0.13-0.772	LaRow, Wilkinson, and Kumar 1975
Daphnia hyalina	0.179	Blazka 1966
Daphnia longispina	0.121-0.135	Tezuka 1971
Daphnia longispina	0.16	Manuilova 1958
Daphnia longispina	0.146	Shushkina and Pecen' 1964
Daphnia magna	0.085-0.175	Kersting and Van De Leeuw-Leegwater 1976
Daphnia magna	0.014	Sushchenya 1958
Daphnia oregonesis	0.194	Richman 1964
Daphnia pulex	0.582	Buikema 1972
Daphnia pulex	0.18-0.19	Tezuka 1971
Daphnia septopus	0.008-0.18	Comita 1968
Daphnia siciloides	0.006-0.52	Comita 1968
Diaphanosoma brachyurum	0.272	Sushchenya 1958
Diaptomus kenai	0.272-0.448	Duval and Geen 1976
Leptodora kindtii	0.471	Moshiri, Cummins, and Costa 1969
Leptodora kindtii	0.125	Hillbricht-Ilkowska and Karabin 1970
Simocephalus vetulus	0.131	Sushchenya 1958
Simocephalus vetulus	0.154	Manuilova 1958
Simocephalus vetulus	0.096-0.201	Ivanova and Klekowski 1972
Total zooplankton	0.063-0.210	Williams 1982

ZOOMIN. This is a threshold food concentration at which zooplankton feeding begins. Evidence for such a threshold was found by Parsons, LeBrasseur, and Fulton (1967) and McAllister (1970). Values near 0.1 g/m^3 have been used in previous modeling studies.

ZS2P. This is the zooplankton HSC for grazing on algae and detritus (mg/ℓ). It has been found that zooplankton exhibit reduced feeding rates at high food concentrations; the relationship between feeding rate and food concentration has been reported to be curvilinear by a number of investigators (Burns and Rigler 1967; Parsons, LeBrasseur, and Fulton 1967; McQueen 1970; Frost 1972; Monakov 1972; Gaudy 1974; and Chisholm, Stross, and Nobbs 1975).

The most realistic calculation of zooplankton grazing rate is based on their rate of removal of biomass of food (Mullin 1963); therefore, it is important that investigators report results in terms of biovolume or biomass instead of cell number. The method most used to determine ingestion rate is to count prey in controls and experimental chambers after feeding zooplankton. Values for zooplankton HSC are given in Table 19.

Table 19

Zooplankton Half-Saturation Coefficients (mg/ℓ)

Species	ZS2P	Reference
Bosmina coregoni	4.0	Scavia and Eadie 1976
Daphnia magna	9.6-15.0	Scavia and Eadie 1976
Daphnia rosea	0.16	Scavia and Eadie 1976
Diaptomus oregonensis	1.6	Scavia and Eadie 1976

ZOOT1. This is the critical temperature below which zooplankton processes stop (°C).

ZOOT2. This is the low optimum temperature for zooplankton processes (°C).

ZOOT3. This is the high optimum temperature for zooplankton processes (°C).

ZOOT4. This is the critical high temperature or lethal temperature for zooplankton (°C).

ZOOK1. This is the temperature rate multiplier at temperature

ZOOT1 (dimensionless; values must be between 0 and 0.98). Values used should be near 0.1.

ZOOK4. This is the temperature rate multiplier at temperature ZOOT4 (dimensionless; values must be between 0 and 0.98). Values used should be near 0.1.

Literature values for zooplankton temperature coefficients are listed in Table 20.

Table 20

Zooplankton Temperature Coefficients (°C)

Species	ZOOT1	ZOOT2	ZOOT3	ZOOT4	Reference
Calamoecia lucasi	NA*	20	24	NA	Green 1975
Ceriodaphnia reticulata	NA	24	27	NA	Gophen 1976
Daphnia galeata	NA	20	24	NA	Burns 1969
Daphnia longispina	NA	16	18	NA	Nauwerck 1959
Daphnia magna	NA	24	26	35	McMahon 1965
Daphnia magna	NA	25	NA	NA	Burns 1969
Daphnia middendorffiana	NA	24	25	NA	Kryutchkova and Kondratyuk 1966
Daphnia pulex	NA	20	24	NA	Burns 1969
Daphnia pulex	NA	20	24	NA	Geller 1975
Daphnia pulex	NA	NA	25	NA	Geller 1975
Daphnia rosea	NA	20	24	NA	Burns and Rigler 1967
Daphnia rosea	NA	14	15	NA	Kibby 1971
Daphnia schedleri	NA	20	22	NA	Burns 1969
Daphnia schedleri	NA	20	24	NA	Hayward and Gallup 1976
Diaptomus sp.	NA	16	18	NA	Nauwerck 1959

* NA = not available.

As with the phytoplankton, zooplankton are able to adapt to the ambient temperature with time. This is demonstrable throughout the different regions of the United States and at different times of the year. Zooplankton found in temperate regions of the United States are exposed to lower average temperatures throughout the year and consequently have lower temperature factors (i.e., ZOOT1, ZOOT2, ZOOT3, and ZOOT4) than those found in more southern regions. Again, these values are unavailable from the literature but have been estimated by Leidy and Ploskey

(1980) based upon acclimation temperatures (Table 21).

Table 21

Acclimation Temperature, Upper and Lower Lethal Temperature, and Temperature Range for a Constant Maximum Grazing Rate for Zooplankton Exposed to Rapid Temperature Stress (°C)

Acclimation Temperature	ZOOT1	ZOOT2	ZOOT3	ZOOT4
5	0	5	6	25
10	0	10	12	30
15	2	15	18	33
20	5	20	24	33
25	7	25	30	34
29	10	29	34	34
30	10	30	34	34
31	12	31	34	34
34	15	34	34	34
35		Lethal		

SOURCE: Leidy and Ploskey 1980.

TDSETL. This is the detrital settling velocity (m/day). Detrital settling velocities vary from 0.001 to over 20 m/day depending on the detrital characteristics and reservoir hydrodynamics. Settling rates should be obtained from quiescent settling chamber studies because advective and turbulent forces in the mixed layer that can reduce settling in a reservoir are modeled separately. For most studies, settling velocities are in the range of 0.05 to 1.0 m/day. Much higher values are often reported for fecal pellets; however, such high settling coefficients may be questionable because they produce unrealistically low detritus values in modeling studies. Values for detritus settling velocities are given in Table 22.

DETT1. This represents the lower temperature bound at which detritus decomposition continues (°C).

DETT2. This is the temperature at which decomposition occurs near the maximum rate (°C).

Table 22

Detritus Settling Velocities (m/day)

Source	TDSETL	Reference
Ceratium balticum	9.0	Apstein 1910
Chaetoceros borealis	5.0	Apstein 1910
Chaetoceros didymus	0.85	Eppley, Holmes, and Strickland 1967
Cricosphaera carterae	1.70	Eppley, Holmes, and Strickland 1967
Ditylum brightwellii	2.0	Apstein 1910
Fecal pellets: *Acartia clausii*	116.0	Smayda 1971
Fecal pellets: *Euphausia krohnii*	240.0	Fowler and Small 1972
Fecal pellets: *Euphausia pacifica*	43.0	Osterberg, Carey, and Curl 1963
Fecal pellets: *Pontella meadii*	54.0-88.0	Turner 1977

(Continued)

Table 22 (Concluded)

Source	TDSETL	Reference
Phaeodactylum tricornutum	0.02-0.04	Riley 1943
Rhizosolenia herbetata	0.22	Eppley, Holmes, and Strickland 1967
Stephanopyxis tunis	2.1	Eppley, Holmes, and Strickland 1967
Tabellaria flocculosa	0.46-1.5	Smayda 1971
Thalassiosira psuedonana	0.85	Hecky and Kilham 1974

DETK1. This is the rate multiplier corresponding to the lower temperature. Values should be near 0.1.

Detritus temperature coefficients are listed in Table 23.

Table 23

Temperature Coefficients for Decomposition (°C)

Substrate or Site	DETT1	DETT2	Reference
Pseudomonas fluorescens: natural substrate	0	25-30	Tison and Pope 1980
E. coli: natural substrate	0	37	Tison and Pope 1980
Glucose: Lake George, N. Y.	0	25	Tison, Pope, and Boylen 1980
Glucose	0	20-30	Bott 1975
Glucose: Lake Wingra, Wis.		25-30	Boylen and Brock 1973

FISH1 (QUAL)

TFMAX. This variable represents the maximum ingestion rate (1/day) of fish. Information on this and other fish coefficients can be found in Leidy and Jenkins (1977). In general, a TFMAX coefficient of 0.01 represents maintenance without growth; 0.04 to 0.05 represents optimum growth efficiency (Leidy and Jenkins 1977).

FS2FSH. To adjust the ingestion rate of fish due to the available food supply, HSCs are used; these represent the amount of food present that results in fish ingestion at half the maximum growth rate. It has been suggested that the HSC be considered to be 5 percent of fish wet body weight consumed per day at 20° C (Leidy and Jenkins 1977). Five percent of the body weight consumed per day corresponds closely with the food intake rate for optimum efficiency in growth (4 to 5 percent for many species). Users of CE-QUAL-R1 should refer to Leidy and Jenkins (1977) because of the difficulty in estimating HSCs.

FPSED. This is the preference factor of fish for benthos and sediment (dimensionless). Benthos is considered as part of the sediment in CE-QUAL-R1.

FPALG(1). This is the preference factor of fish for algae(1) (dimensionless).

FPALG(2). This is the preference factor of fish for algae(2) (dimensionless).

FPALG(3). This is the preference factor of fish for algae(3) (dimensionless).

FPZOO. This is the preference factor of fish for zooplankton (dimensionless).

FPDET. This is the preference factor of fish for detritus (dimensionless). Information relating to fish preference factors is supplied in Leidy and Jenkins (1977) and is presented herein as Table 24. Unfortunately, the different fish foods are expressed as fractions of the total diet rather than as quantities (i.e., grams) consumed, making preference factors difficult to estimate from this information. The summation of the six preference factors must equal 1.0.

Table 24

Fish Food Expressed as a Fraction of the Diet

Species	Plant	Detritus	ZOOPL	Benthos	Fish
Gizzard shad	0.10	0.80	0.05	0.05	
Threadfin shad (young)	0.30	0.50	0.10	0.10	
Threadfin shad (old)	0.30	0.05	0.15	0.55	0.10
Rainbow trout	0.05		0.60	0.15	
Brook trout			0.90	0.05	
Carp	0.30	0.40	0.20	0.10	
Minnows	0.20		0.20	0.60	
Carpsuckers	0.15	0.65	0.05	0.15	
Suckers	0.15	0.65	0.05	0.15	
Hogsuckers		0.80	0.05	0.15	
Buffalofish	0.05	0.40	0.05	0.15	
Redhorse			1.00		
Bullhead	0.10	0.25	0.50		0.15
Catfish	0.27	0.10			0.80
Madtoms			0.55		0.18
Silversides			0.20	0.80	
Temperate bass			0.20	0.10	0.70
Sunfish	0.10	0.05	0.65		0.05
Black bass			0.08		0.86
Crappie	0.05	0.05	0.20	0.15	0.55
Perch			0.20	0.20	0.60
Freshwater drum		0.08	0.58		0.34

SOURCE: Leidy and Jenkins 1977.

FISH2 (QUAL)

FSH1T1. This is the critical temperature below which fish processes stop (°C).

FSH1T2. This is the low optimum temperature for fish processes (°C).

FSH1T3. This is the high optimum temperature for fish processes (°C).

FSH1T4. This is the critical high temperature or lethal temperature for fish (°C).

FSH1K1. This is the temperature rate multiplier at temperature FSH1T1 (dimensionless; values must be between 0 and 0.98). Values should be near 0.1.

FSH1K4. This is the temperature rate multiplier at temperature FSH1T4 (dimensionless; values must be between 0 and 0.98). Values should be near 0.1.

Temperature coefficients for fish ingestion are reprinted here (Table 25) from Leidy and Jenkins (1977).

FEFFIC. This is the assimilation efficiency for fish (dimensionless). The assimilation efficiency is multiplied by the ingestion rate to obtain an assimilation rate. Values for fish assimilation efficiency are given in Table 26.

TFMORT. This is the nonpredatory mortality rate for fish (1/day). Mortality rate is that fraction of fish biomass that is converted to the sediment compartment by death. Nonpredatory mortality rates can be highly variable depending on species, age, exploitation rate, and numerous environmental variables. The average rate calculated by Leidy and Jenkins (1977) is 0.001 for exploited populations.

Ricker (1945) has reviewed techniques for calculating various mortality rates (total, instantaneous, conditional, natural, and fishing). Values for nonpredatory mortality are given in Table 27.

TFRESP. This is the fish respiration rate (1/day). Three types of respiration can be defined: (a) standard respiration—oxygen consumed in the absence of measurable movement (i.e., nonactive respiration, basal or resting metabolism), (b) routine respiration—rate of

Table 25

Temperature Coefficients for Fish Ingestion (°C)

Species	ACCL	FSH1T1	FSH1T2	FSH1T3	FSH1T4	Reference
Pickerels		0		24	34.4	Leidy and Jenkins 1977
Minnows		0	27		33.4	Leidy and Jenkins 1977
Catfish		0	30		37.1	Leidy and Jenkins 1977
Sunfish		2.5	27.5		35.7	Leidy and Jenkins 1977
Black bass		1.6	27		36.5	Leidy and Jenkins 1977
Crappie			23		32.5	Leidy and Jenkins 1977
Yellow perch		0	24.2		30.9	Leidy and Jenkins 1977
Yellow perch				29		Schneider 1973
Fingerling salmon			15			Brett, Shelbourn, and Shoop 1969
Bluntnose minnow	5				26.0	Hart 1947
Bluntnose minnow	10				28.3	Hart 1947
Bluntnose minnow	15	1.0			30.6	Hart 1947
Bluntnose minnow	20	4.2			31.7	Hart 1947
Bluntnose minnow	25	7.5			33.3	Hart 1947
Flathead minnow	10				28.2	Hart 1947
Flathead minnow	20	1.5			31.7	Hart 1952
Flathead minnow	30	10.5			33.2	Hart 1952
Creek chub	5				24.7	Hart 1952
Creek chub	10				27.3	Hart 1952
Creek chub	15				29.3	Hart 1952
Creek chub	20	0.7			30.3	Hart 1952
Creek chub	25	4.5			30.3	Hart 1952
Chub	14				27.1	Black 1953
Finescaled sucker	14				26.9	Black 1953
White sucker	25				31.2	Brett 1944
White sucker	5				26.3	Hart 1947
White sucker	10				27.7	Hart 1947
White sucker	15				29.3	Hart 1947
White sucker	20	2.5			29.3	Hart 1947
White sucker	25	6.0			29.3	Hart 1947
White sucker			27			McCormick and Mischuk 1973

(Continued)

(Sheet 1 of 3)

Table 25 (Continued)

Species	ACCL	FSH1T1	FSH1T2	FSH1T3	FSH1T4	Reference
Brown bullhead	5				27.8	Hart 1952
Brown bullhead	10				29.0	Hart 1952
Brown bullhead	15				31.0	Hart 1952
Brown bullhead	20				32.5	Hart 1952
Brown bullhead	25				33.8	Hart 1952
Brown bullhead	30				34.8	Hart 1952
Brown bullhead	34				34.8	Hart 1952
Black bullhead	23				35	Black 1953
Channel catfish	25				35.5	Allen and Strawn 1968
Channel catfish	35				38	Allen and Strawn 1968
Channel catfish			18			Andrews and Stickney 1972
Channel catfish	15	0.0			30.3	Hart 1952
Channel catfish	20	2.5			32.8	Hart 1952
Channel catfish	25	6.0			33.5	Hart 1952
Bluegill	15	2.5			30.7	Hart 1952
Bluegill	20	5.0			31.5	Hart 1952
Bluegill	25	7.5				Hart 1952
Bluegill	30	11.1			33.8	Hart 1952
Bluegill			22		33.8	McComish 1971
Longear sunfish	25				35.6	Neill, Strawn, and Dunn 1966
Longear sunfish	30				36.8	Neill, Strawn, and Dunn 1966
Longear sunfish	35				37.5	Neill, Strawn, and Dunn 1966
Pumpkinseed	25				24.5	Brett 1944
Smallmouth bass	35	1.6	26.3		35.0	Horning and Pearson 1973
Smallmouth bass			28.3			Peck 1965
Largemouth bass			27.5	30		Strawn 1961
Largemouth bass			25			Niimi and Beamish 1974
Largemouth bass	20	5.5			32.5	Hart 1952
Largemouth bass	25				34.5	Hart 1952
Largemouth bass	30	11.8			36.4	Hart 1952
Yellow perch	5				21.3	Hart 1947
Yellow perch	10	1.1			25.0	Hart 1947
Yellow perch	15				27.7	Hart 1947
Yellow perch	25	3.7			29.7	Hart 1947

(Continued)

(Sheet 2 of 3)

Table 25 (Concluded)

Species	ACCL	FSH1T1	FSH1T2	FSH1T3	FSH1T4	Reference
Yellow perch-juvenile	24		20	23.3		McCauley and Read 1973
Yellow perch-adult	24		17.6	20.1		McCauley and Read 1973
Yellow perch	8		18.6			Ferguson 1958
Yellow perch	10		19.3			Ferguson 1958
Yellow perch	15		23.0			Ferguson 1958
Yellow perch	20		23.1			Ferguson 1958
Yellow perch	25		24.5			Ferguson 1958
Yellow perch	30		26.7			Ferguson 1958
Sockeye salmon-fry	5	0			22.2	Brett 1952
Sockeye salmon-fry	10	3.1			23.4	Brett 1952
Sockeye salmon-fry	15	4.1			24.4	Brett 1952
Sockeye salmon-fry	20	4.7			24.8	Brett 1952
Sockeye salmon-juvenile	15		15	17		Brett, Shelbourn, and Shoop 1969
Coho salmon	5	0.2			20.9	Brett 1952
Coho salmon	10	1.7			23.7	Brett 1952
Coho salmon	15	3.5			24.3	Brett 1952
Coho salmon	20	4.5			25.0	Brett 1952
Chinook salmon			18.4			Olson and Foster 1955
Northern pike	25				32	Scott 1964
Lake trout			11.7			McCauley and Tait 1970
Lake trout			8	10.9		Rawson 1961
Rainbow trout	18		17	20		McCauley and Pond 1971
Brook trout	5				23.7	Fry, Hart, and Walter 1946
Brook trout	10				24.4	Fry, Hart, and Walter 1946
Brook trout	15				25.0	Fry, Hart, and Walter 1946
Brook trout	20				25.3	Fry, Hart, and Walter 1946
Brook trout	25	0.5			25.3	Fry, Hart, and Walter 1946
Brook trout			14	19		Graham 1949

SOURCE: Leidy and Jenkins 1977.

(Sheet 3 of 3)

Table 26

Assimilation Efficiencies of Fish (Dimensionless)

Species	FEFFIC	Reference
Bleak	0.80	Mann 1965
Blueback herring	0.80	Burbridge 1974
Bluegill	0.80	Pierce and Wissing 1974
Bluegill	0.97	Gerking 1955
Carnivorous fish	0.80	Winberg 1956
Carp	0.74	Ivlev 1939
Carp	0.95	Kobashi and Deguchi 1971
Cichlasoma bimaculatum	0.69-0.89	Warren and Davis 1967
Cutthroat trout	0.84-0.86	Krokhin 1959
Ctenopharyngodon	0.14	Fisher 1970
Dace	0.79	Mann 1965
Goldfish	0.71-0.86	Davies 1964
Green sunfish	0.94	Gerking 1952a
Longear sunfish	0.94-0.97	Gerking 1952a
Northern pike	0.72	Johnson 1966
Perca fluvatilis	0.35	Klekowski et al. 1970
Perch	0.79	Mann 1965
Reticulate sculpin	0.74-0.84	Davis and Warren 1965
Roach	0.78	Mann 1965
White bass	0.66-0.69	Wissing 1974

Table 27

Fish Nonpredatory Mortality Rates (1/day)

Species	TFMORT	Reference
American shad	0.002	Walburg 1961
Bluegill	0.002	Patriarche 1968
Bluegill	0.0002	Gerking 1952b
Bluegill	0.001	Ricker 1945
Brook trout	0.001	Latta 1962
Brook trout	0.003-0.004	Alexander and Shetter 1961
Brook trout	0.56-1.34	Hatch and Webster 1961
Brown bullhead	0.001	McCammon and Seeley 1961
Brown bullhead	0.001	Rawstron 1967
Channel catfish	0.001	Ricker 1958
Cutthroat trout	0.001-0.002	Hansen 1971
Cutthroat trout	0.001	Ball and Cope 1961
Freshwater drum	0.001	Butler 1965
Largemouth bass	0.00037	Mraz and Threinen 1955
Longnose sucker	0.002	Geen et al. 1966

(Continued)

Table 27 (Concluded)

Species	TFMORT	Reference
Northern pike	0.002	Groebner 1960
Northern pike	0.002	Johnson and Peterson 1955
Rock bass	0.002	Ricker 1947
Walleye	0.001	Olson 1957
White catfish	0.001	McCammon and Seeley 1961

oxygen consumption of fish during normal activity, and (c) active respiration--maximum rate of oxygen consumption under continuous forced active respiration. It would appear that the best estimates of the rate of respiration for normally active fish are values for routine metabolism (i.e., type (b) above) (Winberg 1956). Values for fish respiration rate are given in Table 28.

Table 28

Fish Maximum Respiration Rates (1/day)

Species	TFRESP	Type	Reference
Brown bullhead	0.001	Routine	Beamish 1964
Brook trout	0.003	Routine	Beamish 1964
Carp	0.001	Routine	Beamish 1964
Lake trout	0.001	Standard	Gibson and Fry 1954
Rainbow trout	0.002	Standard	Florke, Keiz, and Wangorsch 1954
Brook trout	0.006-0.024	Standard	Madsen, Markmann, and Rasmussen 1977
Brook trout	0.109-0.101	Active	Madsen, Markmann, and Rasmussen 1977
Sockeye salmon	0.002	Standard	Brett 1944
White sucker	0.002	Routine	Beamish 1964

DECAY1 (QUAL)

TDOMDK. This is the decomposition rate (1/day) of labile DOM.

TRFRDK. This is the decomposition rate (1/day) of refractory DOM. Dissolved organic matter in natural waters is one organic substrate for heterotrophic metabolism. The composition of natural DOM is highly variable and little understood, but its sources are generally grouped into (a) excretion from phytoplankton and macrophytes, (b) decomposition of phytoplankton and macrophytes, (c) excretion by animals, and (d) allochthonous drainage (e.g., humic compounds from upstream sources).

Aquatic bacteria appear to be chiefly responsible for the removal of DOM compounds from the water; they are the major agents for bacterial mineralization of organic solutes in fresh water (Wright 1975), using organic matter as an energy source. Various methods have been tested to determine the decay rate of DOM in water. Modification of the basic Parsons and Strickland (1963) technique have been developed to quantify the kinetics.

Dissolved organic matter decomposition rates have also been represented by filtered carbonaceous BOD decay rates. If sufficient oxygen is available, the aerobic biological decomposition of organics will continue until all the DOM is consumed. In the standard test for BOD, a sample is diluted with water containing a known amount of oxygen. The loss of oxygen after the sample has been incubated for 5 days at 20° C is known as the 5-day BOD. The value of the first-order decay rate is generally about 0.05 to 0.20 per day.

The BOD test suffers from several serious deficiencies. The test has no stoichiometric validity; for example: the arbitrary 5-day period usually does not correspond to the point at which all the organic matter is consumed.

Contributing to the errors involved in measuring decay rates of DOM is the extensive variability in the composition and stage of decomposition of DOM. Allochthonous inputs of DOM are likely to be more refractory than autochthonous inputs, and as a result, decomposition rates will be slower and decay may be incomplete; therefore, the length of time the organic matter is available for decomposition is important.

This is the main reason this version of the model includes two DOM compartments. Previous work (Wlosinski and Collins 1985a) has shown better predictions when two different rates, representing labile and refractory compounds, are used. Values for DOM decay rates are presented in Table 29.

Table 29

DOM Decay Rates (1/day)

Compound	Decay Rate	Reference
Acetate	0.2	Wright 1975
Amino acids	0.64	Williams, Yentsch, and Yentsch 1976
Glucose	0.24	Williams, Yentsch, and Yentsch 1976
Glucose	0.32-0.50	Toerien and Cavari 1982
Glucose	0.111	Wright 1975
Glutamate	0.11-0.625	Carney and Colwell 1976
Glycine	0.312-0.45	Vaccaro 1969
Glycine	0.048	Vaccaro 1969
Glycolate	0.024-0.432	Wright 1975
Glycolate	0.012-0.25	Wright 1975
Glycolic acid	0.004	Tanaka, Nakanishi, and Kadota 1974

TDOMRF. This variable represents the process by which labile DOM becomes refractory DOM (1/day) and should be viewed as part of the decomposition process. Values near 0.01 to 0.1 have been used in previous modeling studies.

TNH3DK. This is the ammonia decay rate (i.e., the rate at which ammonia is oxidized to nitrite plus nitrate) (1/day). Ammonia is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter, either directly from proteins or from other nitrogenous organic compounds. Although ammonia is a major excretion product, this nitrogen source is minor in comparison to decomposition.

Nitrification is the biological conversion of organic and inorganic N compounds from a reduced state to a more oxidized state (Alexander 1965) although only inorganic N is included for this process in CE-QUAL-R1. The nitrifying bacteria capable of oxidation of NH_4^+ to

NO_2^- are largely confined to the species *Nitrosomonas*, bacteria which are mesophilic (1-37° C).

Nitrification rates can be determined by a number of different techniques. Courchaine (1968) has plotted nitrogenous BOD on a logarithmic scale and determined the decay rate from the slope of the line. Thomann et al. (1971) used a finite-difference approximation to solve a set of simultaneous linear equations.

Laboratory measurements for the ammonia decay rate can produce results that differ from what might be measured in situ. Several environmental factors can influence the rate of nitrification including pH, temperature, suspended particulate concentration, hydraulic parameters, and benthos, although only temperature modifies this rate in CE-QUAL-R1.

Nitrification can be measured as a one- or two-step process. In the one-step method, only the end product of the entire reaction, nitrate, is measured. In the two-step method, (a) nitrite accumulation is measured as ammonia is oxidized to nitrite, and (b) nitrate accumulation is measured as nitrite is oxidized to nitrate. Because nitrite plus nitrate nitrogen is modeled as one compartment, rates for the one-step method should be used. Literature values are given in Table 30.

Table 30

Ammonia Oxidation Rates (1/day)

Site	TNH3DK	Reference
Wastewater treatment plant	0.05-0.30	Wild, Sawyer, and McMahon 1971
Grand River, Ill.	0.80	Bansal 1976
Grasmerer Lake, U. K.	0.001-0.013	Hall 1982
Truckee River, Nev.	0.09-1.30	Bansal 1976
Upper Mohawk River, N. Y.	0.23-0.40	Bansal 1976
Middle Mohawk River	0.30	Bansal 1976
Lower Mohawk River	0.30	Bansal 1976
Ohio River	0.25	Bansal 1976
Big Blue River, Nebr.	0.17-0.25	Bansal 1976
Flint River, Mich.	0.76-0.95	Bansal 1976

TDETDK. This is the detritus decay rate (1/day). Detritus, as defined by Wetzel et al. (1972), consists of organic carbon lost from an organism by nonpredatory means (including egestion, excretion, secretion, etc.) from any trophic level component, or input from sources external to the ecosystem that enter and cycle in the system (i.e., allochthonous organic carbon). For CE-QUAL-R1, this should be considered to be particulate material only.

The rate of detritus decay can be determined by measuring the use of oxygen during decomposition, with results expressed as a first-order decay coefficient (k base e = milligrams oxygen used/milligrams/day). Many workers have measured rates of oxygen uptake by detritus, suggesting that oxygen uptake is related to the organic matter available for decomposition. Odum and de la Cruz (1967) and Fenchel (1970), for example, demonstrated an inverse relation between detritus particle size and oxygen consumption. Oxygen uptake is an integrative measure of all oxidative processes occurring in the sample, both chemical and biological. Reduced substances are usually rapidly oxidized; respiration of the organisms associated with detritus is primarily bacterial, although algae, protozoa, and fungi may also contribute. Measurement of the oxygen uptake reflects the metabolism of communities of microorganisms involved in the decomposition of natural substances.

As a detrital particle decomposes with time, there is a decline in oxygen uptake accompanied by succession of communities of microorganisms. This decline occurs as matter changes from labile to refractory; refractory matter often accumulates in the sediment. Rates of decay are generally high initially and slow down as the material becomes refractory; the rate is influenced by temperature, detrital composition, and age of the detritus. Macrophyte communities are the primary source of detritus in many systems. Submersed and floating macrophytes generally decay more rapidly than the highly lignified emergent species. Particulate organic matter (POM) of dead bluegreen algae decomposes much faster than that derived from green algae, diatoms, and desmids. The POM is especially resistant (Gunnison and Alexander 1975). As detritus decays, there is a decrease in the C:N ratio as a result of a buildup of microbial protein (Mann 1972). A 1-g sample of detritus at 20° C consumes about 1 mg oxygen/hr (Hargrave 1972a).

Plant litter consists of a variety of compounds (i.e., sugars, hemicellulose, lignin, waxes) that decay at different rates. The decay curves initially tend to follow the exponential decay functions of the more readily degradable fractions, particularly aquatic macrophytes, which account for a large proportion of the weight of plant litter; therefore, the majority of the litter's weight loss occurs in the first year. Over the long term, the decay rates change, especially for deciduous leaf litter which has a larger proportion of decay-resistant material than do aquatic macrophytes, which therefore decay at a much slower rate.

Decay rates can also be measured by suspending a nylon mesh bag of detrital material in situ or under controlled conditions and determining weight loss with time. This actually measures weight loss due to enzymatic decomposition by bacteria and fungi, solution of soluble substances, and loss of fragments through the container pores.

Decay rates have also been determined by measuring the mineralization rates of carbon, nitrogen, and phosphorus (Otsuki and Hanya 1972). Decomposition of detritus generated from planktonic communities of surface lake water occurs at rates on the order of 10 percent per day (Saunders 1972), based upon radioactive carbon tracer studies.

Consideration should be given to the primary or expected sources of detritus. Decomposition rates for allochthonous detrital sources are generally lower than for autochthonous sources to reflect the more refractory nature of allochthonous material after its transport through the upper portions of the reservoir. While a one-dimensional model like CE-QUAL-R1 assumes instantaneous dispersal of inflow constituents, much of the decomposition in the prototype reservoir system occurs in the headwater area. The labile fraction of autochthonous detritus produced in the pelagic zones of the lower reservoir will decompose more rapidly in the water column and should have a higher decomposition rate than allochthonous detritus. However, in a stratified reservoir the POM in the hypolimnion may not be exchanged with the epilimnetic waters. The POM becomes more refractory with time, and rates of decomposition decrease.

Microbial decomposition of detritus can be represented by three stages: a very quick solution of soluble organic components, a relatively rapid decomposition of labile organic constituents, and slow decomposition of refractory organic constituents. Detritus decay rates are given in Table 31.

Table 31

Detritus Decay Rates (1/day)

Detritus Source	TDETDK	Reference
Beech	0.001-0.004	Hanlon 1982
Cladophera glomerata	0.007	Piecznska 1972
Dead green algae	0.016-0.076	Otsuki and Hanya 1972
Dead mixed algae	0.007-0.111	Jewell and McCarty 1971
Dead mixed algae	0.007-0.06	Fitzgerald 1964
Gloeotrichia echinulata	0.001-0.007	Piecznska 1972
Isoetes lancustris	0.003-0.015	Hanlon 1982
Leaf packs	0.005-0.017	Sedell, Triska, and Triska 1975
Osier	0.001-0.005	Hanlon 1982
Potamogeton crispus	0.002-0.004	Rogers and Breen 1982
Potomogeton perfoliatus	0.002-0.007	Hanlon 1982

TCOLDK. This is the coliform decay rate (1/day). Estimates of coliform die-off rates may be obtained in the laboratory or in situ. In situ, where there are no flow regime data, or where flows are of a transient nature, a commonly used method is to add a slug of a conservative tracer substance (a dye, rare element, or radioisotope) to steady-state discharge. The discharge plume is sampled, dilution is estimated from the concentration of tracer, and the decay rate is estimated from the dilution-corrected coliform counts. This technique gives misleading results in cases where the tracer is diluted by water heavily contaminated with the same discharge. Since the tracer was introduced as a slug, there is no way to know how many of the surviving coliforms originated in the tracer-dosed effluent and how many came from predosing or postdosing effluent. This problem is reduced where the flow regime is sufficiently stable (Zison et al. 1978).

There are two approaches to estimating die-off rates. Frost and

Streeter (1924) were able to estimate the die-off rate using seasonal averages of coliform counts from a downstream station, by assuming plug flow in the river. Errors in the rates determined by this approach are attributable to (a) dilution and longitudinal mixing that produced overestimates and (b) unconsidered sources of coliforms that produced underestimates.

In a second approach, a mathematical model of the flow and mixing in the system is used to correct the measurements for the effects of dilution. In this manner, Marais (1974) analyzed coliform die-off in wastewater maturation ponds as a first-order decay reaction in a series of completely mixed steady-state reactors. Errors in the decay rates determined in this way are primarily attributable to the reliability of the system model.

Table 32 gives decay rates for coliform and fecal streptococcus. In Table 33, from Mitchell and Chamberlain (1978), the median die-off value was 0.040/hr for freshwater coliform. In general, the die-off follows first-order decay kinetics, although a significant increase in coliform levels is commonly observed in the first several miles downstream from the outfall. Other rate information can be found in Thornton, Nix, and Bragg (1980) or Zison et al. (1978).

Table 32

Coliform and Fecal Streptococcus Decay Rates (1/day)

Species	TCOLDK	Reference
Fecal coliform	0.048-0.096	Evans et al. 1968
Fecal streptococci	0.063	Evans et al. 1968
Fecal streptococci	0.004-0.013	Geldreich et al. 1968
Total coliform	4.48-5.52	Kittrell and Furfari 1963
Total coliform	0.199-0.696	Klock 1971
Total coliform	1.99	Marais 1974
Total coliform	0.168-1.56	Geldreich et al. 1968
Total coliform	0.009-0.028	Klock 1971
Total coliform	0.021-0.038	Evans et al. 1968
Total coliform	0.045-0.049	Frost and Streeter 1924
Total coliform	0.024-0.105	Hoskins, Ruchhoft, and Williams 1927
Total coliform	0.48-2.04	Mitchell and Chamberlain 1978

Table 33

Freshwater Die-Off Rates of Coliform Bacteria Measured In Situ (1/day)

Site	Season/ Temperature	Rate	Reference
Ohio River	Summer 20° C	1.175	Frost and Streeter 1924
Ohio River	Winter 5° C	1.08	Frost and Streeter 1924
Upper Illinois River	June-Sept.	2.04	Hoskins, Ruchhoft, and Williams 1927
Upper Illinois River	Oct.-May	2.52	Hoskins, Ruchhoft, and Williams 1927
Upper Illinois River	Dec.-Mar.	0.567	Hoskins, Ruchhoft, and Williams 1927
Upper Illinois River	Apr.-Nov.	1.032	Hoskins, Ruchhoft, and Williams 1927
Lower Illinois River	June-Sept.	2.04	Hoskins, Ruchhoft, and Williams 1927
Lower Illinois River	Oct.-May	0.888	Hoskins, Ruchhoft, and Williams 1927
Lower Illinois River	Dec.-Mar.	0.624	Hoskins, Ruchhoft, and Williams 1927
Lower Illinois River	Apr.-Nov.	0.696	Hoskins, Ruchhoft, and Williams 1927
Shallow turbulent stream	Summer	15.12	Kittrell and Koschtitzky 1947
Missouri River	Winter	0.48	Kittrell and Furfari 1963
Tennessee River (Knoxville)	Summer	1.03	Kittrell and Furfari 1963
Tennessee River (Chattanooga)	Summer	1.32	Kittrell and Furfari 1963
Sacramento River, Calif.	Summer	1.752	Kittrell and Furfari 1963
Cumberland River, Md.	Summer	5.52	Kittrell and Furfari 1963
Ground-water stream	10° C	0.504	Wuhrmann 1972
Leaf River, Miss.	N/A	0.408	Mahloch 1974
Wastewater lagoon	7.9-25.5° C	0.199-0.696	Klock 1971
Maturation ponds	N/A	1.99	Marais 1974
Maturation ponds	19° C	1.68	Marais 1974
Oxidation ponds	20° C	2.59	Marais 1974

SOURCE: Mitchell and Chamberlain 1978.

Factors affecting coliform decay rate include sedimentation, solar radiation, nutrient deficiencies, predation, algae, bacterial toxins, and physiochemical factors.

TSEDDK. This is the sediment decomposition rate (1/day). While sediment consists primarily of settled organic detritus, the decomposition rate should reflect the more refractory nature of the detritus as it reaches the sediment. The labile portion of organic detritus may be readily decomposed as it settles through the water column. In addition, the weight of sediment, along with TSEDDK, will affect the amount of decomposition. If high initial values are used for sediment, TSEDDK may have to be lowered since only the top few millimetres of sediment are usually involved in aerobic decomposition. Because sediment decay can be a major factor causing anaerobic conditions, the flux of oxygen at the sediment-water interface caused by sediment decay should be compared to measured values.

In general, sediment values ($g\ m^{-2}$) times TSEDDK times a stoichiometric equivalent (1.4) should yield oxygen consumption rates at the sediment-water interface which can be compared with measured rates or literature values (in grams of oxygen utilized per square metre per day). This value may be reduced in CE-QUAL-R1 due to temperature effects. Martin, Effler, and Dobi (1984) have stated that sediment oxygen demand values reported in the literature are broad, with little central tendency. Other information can be found in Gunnison, Chen, and Brannon (1983) and Chen, Brannon, and Gunnison (1984).

TNO3DK. This variable represents the denitrification rate (1/day) of the nitrite plus nitrate compartment. Denitrification takes place only in layers that are considered anaerobic. Values used in previous modeling studies have been near 0.05.

DECAY2 (QUAL)

DOMT1. This is the lower temperature bound at which dissolved organic matter decays (°C).

DOMT2. This is the lowest temperature at which decomposition is occurring near the maximum rate (°C).

DOMK1. This is the rate multiplier corresponding to DOMT1 (dimensionless). Values should be near 0.1.

Temperature coefficients for DOM can be found in Table 34.

Table 34

Temperature Coefficients for DOM Decay (°C)

Substrate	DOMT1	DOMT2	Reference
Glucose	5.0	35.5	Toerien and Cavari 1982
Glucose: Lake George, N. Y.	0	25	Tison, Pope and Boylen 1980
Glucose	0	20-30	Bott 1975
Glucose: Lake Wingra, Wis.	0	25-30	Boylen and Brock 1973

DECAY3 (QUAL)

NH3T1. This is the lower temperature bound at which ammonium nitrification continues (°C).

NH3T2. This is the lowest temperature at which nitrification is occurring near the maximum rates (°C).

NH3K1. This is the rate multiplier corresponding to NH3T1 (dimensionless). Values should be near 0.1.

Values for these temperature coefficients are presented in Table 35.

Table 35

Temperature Coefficients for Ammonia Oxidation (°C)

Species or Site	NH3T1	NH3T2	References
Nitrosomonas	5	30	Knowles, Downing, and Barrett 1965
Wastewater treatment plant	5	25	Wild, Sawyer, and McMahon 1971
Ann Arbor, Mich.	2	20	Borchardt 1966

DECAY4 (QUAL)

NO3T1. This is the lower temperature bound at which denitrification continues (°C). The value should be near zero.

NO3T2. This is the lowest temperature at which denitrification occurs at its maximum rates (°C). Values near 25° C have been used in previous modeling studies.

NO3K1. This is the rate multiplier corresponding to NO3T1 (dimensionless). Values should be near 0.1.

SSETL (QUAL, THERM)

TSSETL. This is the suspended solids settling velocity (m/day). The settling rate is dependent on the type of particle, grain size, density, temperature, viscosity, and turbulence. Most of the larger particles entering a reservoir settle very quickly and should not be included in the inflow. Lane (1938) gives figures of 0.86 to 860.0 m/day for particle diameters of 0.002 to 0.1 mm. Particles found in the main body of a reservoir are usually at the lower end of this scale.

The variables below are used only in CE-QUAL-R1.

ADSRBP. This is the adsorption coefficient of phosphorus for use in the Langmuir isotherm (m^3 g^{-1}).

ADSRBN. This is the adsorption coefficient of nitrogen for use in the Langmuir isotherm (m^3 g^{-1}).

ADMAXP. This coefficient represents the maximum amount of phosphate adsorbed per gram of solids (g P m^{-3}/g solid m^{-3}).

ADMAXN. This coefficient represents the maximum amount of ammonia adsorbed per gram of solids (g N m^{-3}/g solid m^{-3}).

The coefficients ADSRBP and ADSRBN are related to the energy of adsorption. They are equal to the adsorption coefficient divided by the desorption coefficient in the Langmuir isotherm. The values 1/ADSRBP and 1/ADSRBN equal the concentration at one-half ADMAXP or ADMAXN. ADSRBP was found to be between 1.2 and 33.3 by Ku, Di Giano, and Feng (1978). Values for ADMAXP are given in Table 36.

Table 36

Values of ADMAXP (g P m^{-3}/g solid m^{-3})

ADMAXP (g/g)	Site	Reference
0.0021 to 0.002	Maumee River basin soils	Green, Logan, and Smeck 1978
0.0004 to 0.0005	Maumee River basin - clay fractions	Green, Logan, and Smeck 1978
0.0007 to 0.001	Maumee River basin - suspended sediments	Green, Logan, and Smeck 1978
0.0002 to 0.0003	Maumee River basin - bottom sediments	Green, Logan, and Smeck 1978

(Continued)

Table 36 (Concluded)

ADMAXP (g/g)	Site	Reference
0.001 to 0.002	Lake Warner	Ku, Di Giango, and Feng 1978
0.001	Lake Wyola	Ku, Di Giango, and Feng 1978
0.0002 to 0.0005	Blackstrap Lake	Hwang, Lackie, and Huang 1976

TMP (QUAL)

Q10COL. CE-QUAL-R1 uses a Q_{10} formulation to modify the coliform die-off rate as a function of temperature. All other rates are modified by temperature through the RMULT function. The Q_{10} coefficient is usually 1.04. A range of Q_{10} values can be found in Zison et al. (1978). If the preprocessor will be used, care should be taken to make the first 0 in the record name a number, and the second 0 a letter.

CHEM (QUAL)

O2NH3. This value indicates the number of grams of oxygen required to oxidize 1 g of NH_4^+ (as N) to NO_3^-. The value is 4.57 as derived from the following reaction.

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \qquad (204)$$

O2DET. The stoichiometric requirement for oxygen during the decomposition of detritus and organic sediment (assuming a constant organic composition) is 1.4.

$$5CO_2 + 2H_2O + NH_3 \rightleftarrows C_5H_7NO_2^* + 5O_2 \qquad (205)$$

where * refers to an average algal and bacterial composition (Golterman 1975, Wang et al. 1978).

O2RESP. The oxygen requirement for biological respiration (conversion of carbohydrate to CO_2 and H_2O) is 1.1.

$$6CO_2 + 6H_2O \rightleftarrows C_6H_{12}O_6 + 6O_2 \qquad (206)$$

O2FAC. The stoichiometric equivalent for oxygen production during photosynthesis taking into account the formation of proteins, etc., is 1.4. This value is derived from the reaction described under O2DET.

O2DOM. The stoichimetric requirement for oxygen in the decomposition of DOM is assumed to be the same as for detritus (1.4).

O2MN2. The following reaction indicates the oxygen requirement (O2MN2 = 0.15) for converting reduced manganese to manganese oxyhydroxide (Hem 1981).

$$2Mn^{+2} + \frac{1}{2} O_2 + 3H_2O = 2MnOOH + 4H^+ \qquad (207)$$

O2FE2. This reaction describes the oxygen requirement (O2FE2 = 0.14) for oxidizing reduced iron (Stumm and Morgan 1981).

$$O_2 + 4Fe^{+2} + 4H^+ = 4Fe^{+3} + 2H_2O \quad (208)$$

<u>02S2.</u> The following reaction demonstrates the oxygen requirement (02S2 = 2.0) for the oxidation of sulfide to sulfate.

$$S^{-2} + 2O_2 = SO_4^{-2} \quad (209)$$

ANAER1 (QUAL)

OXYLIM. OXYLIM is the dissolved oxygen concentration (mg/ℓ) which triggers anaerobic processes in the model. When the concentration is less than OXYLIM, anaerobic processes predominate. When dissolved oxygen exceeds OXYLIM, oxidation processes predominate. Setting OXYLIM = -1.0 will effectively prevent the anaerobic processes from occurring. Experience suggests an initial value of 0.5.

SEDTHK. This value defines the active sediment thickness (cm) as the depth of sediment that will contribute reduced materials or phosphate to the water column through sediment release. This value does not affect the amount of sediment decay, or the amount of oxygen utilization by the sediments during aerobic decomposition.

ANAER2 (QUAL)

TMN4ST. The settling rate for particulate (oxidized) Mn(IV), in m day^{-1}. Values near 0.1 have been used in previous studies.

TMN4RE. The reduction rate of Mn(IV) in day^{-1}. Values from 0.002 to 0.16 have been used in previous studies.

TMNREL. This value, in g m^{-2} day^{-1}, is the rate at which Mn^{+2} is released from sediments under anaerobic conditions. Values from 0.1 to 0.5 have been used in previous studies.

TMN2OX. This value, in day^{-1}, is the rate at which Mn^{+2} is oxidized to Mn(IV) under aerobic conditions. Values up to 0.35 have been used in previous modeling studies.

ANAER3 (QUAL)

TFE3ST. This is the settling rate for particulate (oxidized) Fe(III) in m day^{-1}. Values near 0.05 have been used in previous studies.

TFE3RE. This is the reduction rate for Fe(III) in units of day^{-1}. Values near 0.03 have been used in previous studies.

TFEREL. This value, in g m^{-2} day^{-1}, is the rate at which Fe^{+2} is released from sediments under anaerobic conditions. Values near 0.3 have been used in previous modeling studies.

TFE2OX. This value is the rate, in day^{-1}, at which Fe^{+2} is oxidized to Fe(III) under aerobic conditions. Values up to 0.6 have been used in previous studies.

TFESAD. This value, in day^{-1}, is the rate at which FeS in the sediments is oxidized to Fe and S under aerobic conditions. Values up to 0.4 have been used in previous studies.

TFESST. This value, in m day^{-1}, is the rate at which particulate FeS settles in the water column. Values up to 0.5 have been used in previous studies.

TFESBD. This value, in day^{-1}, is the rate at which FeS in the water column is oxidized to Fe(III) and SO_4^{-2} under aerobic conditions. Values up to 0.6 have been used in previous studies.

ANAER4 (QUAL)

TSO4RE. This value, in day^{-1}, is the rate at which SO_4^{-2} in the water column is reduced to S^{-2}. Values up to 0.04 have been used in previous studies.

TSREL. This value, in g m^{-2} day^{-1}, is the rate at which S^{-2} is released from sediments under anaerobic conditions. Values up to 0.1 have been used in previous modeling studies.

TS2OXI. This value, in day^{-1}, is the rate at which S^{-2} is oxidized to SO_4^{-2} in the water column. Values up to 0.5 have been used in previous modeling studies.

TS2DK. This value, in day^{-1}, is the rate at which S^{-2} is lost through reaction with Fe^{+2} to form FeS under anaerobic conditions. Values up to 0.05 have been used in previous studies.

TXP4RE. This value, in g m^{-2} day^{-1}, is the rate at which PO_4^{-3}-P is released from sediments under anaerobic conditions. Values up to 0.3 have been used in previous studies. Other values are listed in Table 37.

TCNREL. This value, in g m^{-2} day^{-1}, is the rate at which NH_4^+-N is released from sediments under anaerobic conditions. Values up to 0.4 have been used in previous modeling studies.

Table 37

Phosphorus Release Rates from the Sediment During Anaerobic Conditions

TXP4RE (g m^{-2} day^{-1})	Sites	Reference
0.001; 0.01-0.150	Shallow eutrophic lakes	Snow and Di Giano 1976
0.018-0.020	Lake Glaninger, Sweden	Ryding and Forsberg 1977
	Lake Ramsjon, Sweden	Ryding and Forsberg 1977
	Lake Ryssbysjon, Sweden	Ryding and Forsberg 1977
0.013	Lake Erie	Burns 1976
0.017	Lake Fureso	Kamp-Nielsen 1974

INIT0 (QUAL, THERM)

NPOINT. NPOINT indicates the number of layers for which initial conditions are specified. Initial conditions can be specified for each layer starting from the bottom. If initial conditions are not specified for each layer, CE-QUAL-R1 linearly interpolates between layers to obtain the required information. At a minimum, initial conditions must be specified for the bottom and top layers, starting from the bottom of the pool. For each layer for which initial conditions are specified in CE-QUAL-R1, a set of INIT2, INIT3, INIT4, and INIT5 records are needed. Initial conditions should be measured on the day represented by ISTART (JOB record). Because the number of variables differs between CE-THERM-R1 and CE-QUAL-R1, the user should refer to Appendix D when preparing this section.

INIT1 (QUAL)

FISH. Since fish are expressed on a kilogram per hectare basis for the entire reservoir, only one record is required for initial conditions. Initial conditions for fish can be obtained from Leidy and Jenkins (1977). One value should be in field 2.

INIT2 (QUAL, THERM)

ELEV. The elevations are specified from the bottom up to the surface in metres. The highest specified elevation cannot be greater than the midpoint of the surface layer.

DALGA1. The initial condition for the first algae compartment at this elevation is given in mg/ℓ dry weight.

DALGA2. The initial condition for the second algae compartment is given in mg/ℓ dry weight.

DALGA3. The initial condition for the third algal compartment is given in mg/ℓ dry weight.

DALKA. The initial condition for total alkalinity is given in mg/ℓ as $CaCO_3$.

DCNH3. The initial condition for ammonia is given in mg/ℓ as N.

DCNO3. The initial condition for nitrite plus nitrate is given in mg/ℓ as N.

DCRFR. This is the initial condition for refractory DOM. Units are mg/ℓ dry weight.

DCOLIF. The initial concentration of coliform bacteria is given as number of colonies/100 ml.

For CE-THERM-R1, fields 3, 4, and 5 contain initial conditions for temperature, total dissolved solids, and suspended solids, respectively.

INIT3 (QUAL)

There must be one INIT3 record following every INIT2 record.

DDETUS. The initial condition for organic detritus is given in mg/ℓ dry weight.

DDOM. The initial condition for labile DOM is given in mg/ℓ.

DOXY. The initial condition for dissolved oxygen is given in mg/ℓ.

DPO4. The initial condition for available phosphorus (orthophosphate) is given in mg/ℓ as P.

DSEDMT. The initial condition for organic sediment is given in g/m^2.

DTEMP. The initial condition for temperature is given in °C.

DTDS. The initial condition for total dissolved solids is given in mg/ℓ.

DZOO. The initial condition for the zooplankton compartment is given in mg/ℓ dry weight.

DPH. The initial condition for pH is unitless.

INIT4 (QUAL)

There must be one INIT4 record following every INIT3 record.

DSSOL is the initial condition for suspended solids (mg/ℓ).

DCMN4 is the initial condition for Mn(IV) in g/m^3.

DCMN2 is the initial condition for Mn^{+2} in g/m^3.

DFE3 is the initial condition for Fe(III) in g/m^3.

DFE2 is the initial condition for Fe^{+2} in g/m^3.

DFESB is the initial condition for FeS in the water column in g/m^3.

DSO4 is the initial condition for SO_4^{-2} in g/m^3.

DS2 is the initial condition for S^{-2} in g/m^3.

DCMN is the initial condition for Mn in sediments in g/m^3.

INIT5 (QUAL)

There must be one INIT5 record following every INIT4 record.

DFE is the initial condition for Fe in sediments in g/m^3.

DFESA is the initial condition for FeS in sediments in g/m^3.

DS is the initial condition for S is sediments in g/m^3.

DXPO4 is the initial condition for inorganic P in sediments in g/m^3.

DCN is the initial condition for inorganic N in sediments in g/m^3.

DSI is the initial condition for silica in the water column in g/m^3.

INITAB1 (QUAL, THERM, OPTIONAL)

This record can be included only if AFTERBAY was chosen for variable FTRBAY. The explanation below refers to CE-QUAL-R1. (See Appendix D for information on CE-THERM-R1.)

ABVOL. This is the total volume (m^3) of the afterbay on the first simulation day.

AB1ALG. This is the initial condition for algae 1 (mg/ℓ) in the afterbay.

AB2ALG. This is the initial condition for algae 2 (mg/ℓ) in the afterbay.

AB3ALG. This is the initial condition for algae 3 (mg/ℓ) in the afterbay.

ABALKA. This is the initial condition for alkalinity (mg/ℓ) in the afterbay.

ABDOM. This is the initial condition for labile DOM (mg/ℓ) in the afterbay.

ABCNH3. This is the initial condition for ammonia (mg/ℓ) in the afterbay.

ABCNO3. This is the initial condition for nitrite plus nitrate (mg/ℓ) in the afterbay.

ABRFR. This is the initial condition for refractory DOM (mg/ℓ) in the afterbay.

INITAB2 (QUAL, OPTIONAL)

This record can be included only if AFTERBAY was chosen for variable FTRBAY.

ABCOLIF. This is the initial condition for coliforms (number of colonies/100 ml) in the afterbay.

ABDETUS. This is the initial condition for detritus (mg/ℓ) in the afterbay.

ABOXY. This is the initial condition for oxygen (mg/ℓ) in the afterbay.

ABPO4. This is the initial condition for orthophosphate (mg/ℓ) in the afterbay.

ABSI. This is the initial condition for silica (mg/ℓ) in the afterbay.

ABTEMP. This is the initial condition for temperature (mg/ℓ) in the afterbay.

ABTDS. This is the initial condition for total dissolved solids (mg/ℓ) in the afterbay.

ABSSOL. This is the initial condition for suspended solids (mg/ℓ) in the afterbay.

ABZOO. This is the initial condition for zooplankton (mg/ℓ) in the afterbay.

INITAB3 (QUAL, OPTIONAL)

This record can be included only if AFTERBAY was chosen for variable FTRBAY.

ABCARB. This is the initial condition for inorganic carbon (mg/ℓ) in the afterbay.

ABCMN4. This is the initial condition for Mn(IV) in the afterbay (mg/ℓ).

ABCMN2. This is the initial condition for Mn^{+2} in the afterbay (mg/ℓ).

ABFE3. This is the initial condition for Fe(III) in the afterbay (mg/ℓ).

ABFE2. This is the initial condition for Fe^{+2} in the afterbay (mg/ℓ).

ABFESB. This is the initial condition for FeS in the afterbay (mg/ℓ).

ABSO4. This is the initial condition for SO_4^{-2} in the afterbay (mg/ℓ).

ABS2. This is the initial condition for S^{-2} in the afterbay (mg/ℓ).

PLANTS (QUAL)

This record contains the initial mass (g/m^2) of macrophytes. The initial mass can be specified for up to nine layers, starting from the surface. Figure 47 represents the mass growing from the sediment found in a particular layer and, as such, the mass may actually be found in other water column layers. The cells described below are those shown in Figure 47.

PLCOL(1). Plant mass (g/m^2) growing from cell (1,1).

PLCOL(2). Plant mass (g/m^2) growing from cell (2,2).

PLCOL(3). Plant mass (g/m^2) growing from cell (3,3).

PLCOL(4). Plant mass (g/m^2) growing from cell (4,4).

PLCOL(5). Plant mass (g/m^2) growing from cell (5,5).

PLCOL(6). Plant mass (g/m^2) growing from cell (6,6).

PLCOL(7). Plant mass (g/m^2) growing from cell (7,7).

PLCOL(8). Plant mass (g/m^2) growing from cell (8,8).

PLCOL(9). Plant mass (g/m^2) growing from cell (9,9).

FILES (QUAL, THERM)

This record contains the names of files that will be created as a linkage between CE-QUAL-R1 or CE-THERM-R1 and simulation utilities. The names must be left justified in their fields and may contain no more than seven characters. When CE-QUAL-R1 is operated in Monte Carlo mode, only the first file name is used and is attached to the Monte Carlo plot file. Otherwise, the file names are as designated below.

FILNAM(1). This is the name attached to the file containing predicted water column data.

FILNAM(2). This is the name attached to the file containing predicted outflow data.

FILNAM(3). This is the name attached to the file containing tributary 1 inflow data.

FILNAM(4). If a second tributary is modeled, this is the name attached to it. If only one tributary is modeled, and the user is interested in flux information (a value of 1 for NFLX on the JOB record), this name is attached to the flux file.

FILNAM(5). This is the name of the flux file if two tributaries are modeled.

CE-THERM-R1 does not contain options for Monte Carlo simulations or flux information. A maximum of two tributaries is allowed in this version of the models. Plot files are automatically stored as permanent disk files under the user's ID. Because they can be quite large, the files should be purged after use or stored off-line.

FILID (QUAL, THERM)

FILID. This record contains up to 40 characters of identification text that will be used to identify output from utilities. The information should be in columns 9 through 48.

WEATH1 (QUAL, THERM)

Meteorological data required as input to CE-QUAL-R1 include dry bulb and dew point temperatures, wind speed, barometric or station pressure, and cloud cover. These data are used in subroutine RADIATE to calculate the heat budget of the reservoir and in MIXING to calculate the wind stress and resulting mixing.

Meteorological data are available for numerous stations in the continental United States from the National Climatic Center (NCC), Environmental Data Service, National Oceanic and Atmospheric Administration, US Department of Commerce, Asheville, N. C. The NCC maintains, on magnetic tape, meteorological data collected by the National Weather Service (NWS), the US Air Force, the US Navy, and the Federal Aviation Agency. Records of most interest for modeling are those collected by the NWS at their first-order meteorological stations. Observations usually number 24 per day through 1964 and 8 per day from 1964 to date. First-order NWS stations record all the meteorological data required for model input. These data can be obtained on magnetic tape for specified years of interest. Once the meteorological data tape is obtained, it should first be examined for missing or erroneous observations.

In selecting the meteorological stations for modeling a specific reservoir, it is important to consider the comparability of site conditions at both the project and the station. First-order meteorological stations are seldom located at project sites. In many instances, they are located in large urban centers that are characterized by climatic regimes different from those of the surrounding countryside. The direct transfer of data should be made only after an evaluation of topography, elevation, and general climatic conditions. It is not unusual for an appropriate meteorological station to be located 75 to 150 km from the project site.

INTMET is the meteorological update interval. It is specified in hours and is chosen as an integral multiple of the computation interval, NHOI. In most simulations, it is recommended to use meteorological data averaged over a daily interval to provide daily model updates.

The meteorological update interval, INTMET, would then be 24. Care should be exercised in applying daily averages obtained directly from NWS. NWS considers the mean daily dry bulb temperatures to be the mean between the daily maximum and minimum temperatures rather than the arithmetic mean of eight observations.

NCARDS is the number of records containing the meteorological data. In specifying meteorological updates for CE-QUAL-R1, an update is required for one computation interval beyond what is specified on the JOB card. For example, if input data start on IFIRST = 100 and stop on ISTOP = 299 and the computation interval is 24 hr, then an update for day 300 must also be specified. NCARDS must also include this extra record.

W2 (QUAL, THERM)

One W2 record is required for each INTMET interval specified on the WEATH1 record. A total of NCARDS records must be included.

The second field (columns 9-16) on the W2 record is not used for model input but is intended for identification. It is recommended that the station and date of observation be specified in this field.

CLOUD. The cloud cover is used in subroutine RADIATE to compute the shortwave and longwave radiation. In CE-QUAL-R1, it is specified as a fraction with CLOUD = 1 indicating 100 percent cloud cover. Since NWS reports cloud cover in tenths (i.e., 10 equals 100 percent cloud cover), the values must be divided by 10. For periods when the solar or shortwave radiation dominates, it is sometimes necessary to look for diurnal variations in cloud cover and to use the cloud cover only for hours of sunlight. This value should be in the third field.

DBT. Dry bulb temperatures may be available at small airports or towns near the project site. These may be used to modify temperatures at the first-order station if significant differences in monthly or weekly averages are discerned. Comparisons should not be made on a daily basis because of possible lags in weather movements. Simple regression techniques are useful in developing temperature relationships between two stations. Since NWS currently reports temperature in °F, these must be modified to °C for CE-QUAL-R1 (°C = (°F - 32) · 5/9).

DPT. The dew point temperature is the temperature at which dew or frost condenses from air on a cooled surface. It is not equivalent to the wet bulb temperature, although relationships between the two do exist. DPT is used in CE-QUAL-R1 to compute the vapor pressure. As with DBT, NWS reports DPT in °F, which must be converted to °C. If modifications are made to dry bulb temperatures, similar modifications should be made to dew point temperatures. An appropriate difference is thus maintained between the temperatures, a factor important for thermal energy budget computations in the model.

APRES. The NWS currently reports the barometric pressure in inches of mercury. These values must be converted to millibars (mb) for

CE-QUAL-R1. The appropriate conversion factor is mb = in. of Hg × 33.86 .

WIND. Wind is one of the most important meteorological variables in energy budget computations for reservoirs. It is necessary to evaluate possible topographic differences between the project site and the meteorological station. Many NWS stations are located at airports where the surrounding terrain is flat or gently rolling. Such conditions may not be representative of the project site.

CE-QUAL-R1 requires the wind speed in kilometres per hour. Since the NWS reports the wind speed in knots or miles per hour, these values must be converted (km/hr = knots × 1.85 or km/hr = mph × 1.61). If the value of wind is recorded as zero, set value to a small number or an error will occur.

FHARV1 (QUAL)

INTFH. The fish harvest update interval must be specified in hours as an integral multiple of the computation interval, NHOI. At least two values must be specified for updates, representing the beginning and end of simulation. Linear interpolation between update values is used to obtain updates for each computational interval. Harvest values may be stated for any regular interval, but seasonal values are often sufficient.

NCARDS. The number of records containing update values must be specified so a proper count can be maintained. Fish harvest records are repeated for each update interval. There must be at least two update records.

FHARV2 (QUAL)

HARVST. This is the fish harvest value (kg ha^{-1} yr^{-1}). The fish harvest rates should reflect the composite nature of the estimate because there is only one fish compartment to represent the entire reservoir fishery. Leidy and Jenkins (1977) give regional estimates of commercial and sport fish harvest rates. Only one value per record, in the second field, is used. At least two FHARV2 records must be included in the data set.

OPSCHI (QUAL, THERM, OPTIONAL)

This record can be included only if MODE is not NORMAL.

NCARDS. This variable represents the number of records that contain information on operation schedules when the model is run in the schedule mode.

OPSCH2 (QUAL, THERM, OPTIONAL)

This record can be included only if MODE is not NORMAL.

The number of OPSCH2 records that are read must equal the value of NCARDS on the OPSCH1 record.

XDAY. The Julian day for which operation data are given. Information regarding this variable is given in the section describing subroutine OPREAD in PART III. This is an integer variable.

XTYPE. This variable describes the flow event type. A "G" in column 24 signifies a generation event. A "P" in column 24 signifies a pumpback event.

XTIME. This is the amount of time (hr) in which the above event took place.

XRATE. This is the flow rate (m^3 sec^{-1}) for the above event.

LPORTN. This is the number signifying the port used for the above event.

If a second event occurs on the same day, another set of values representing XTYPE, XTIME, XRATE, and LPORTN should be located in fields 7, 8, 9, and 10. If a third event or a third and fourth event occur on the same day, another record with the same information as this one must be included. As presently dimensioned, a maximum of four events per day is possible. This same schedule of events will be used until a new XDAY is supplied.

ROUTL1 (QUAL, THERM, OPTIONAL)

This record will be read if SPECIFY was not selected for variable CHOICE.

INTINT. This is the update interval for outflows (hr). It is chosen as an integral multiple of the computation interval, NHOI. Daily updates are recommended (24 in columns 15 and 16).

NCARDS. This variable represents the number of ROUTL2 records that are to be read. As with other updates in CE-QUAL-R1, one additional update, past the last simulation interval, is required.

ROUTL2 (QUAL, THERM, OPTIONAL)

This record will read if SPECIFY was not selected for variable CHOICE.

The first 16 columns of the ROUTL2 record contain no data and can be used for identification. In the remaining eight 8-column fields, four pairs of total outflow Q and target temperature T are specified.

Q(I). The total outflow in m^3/sec can be obtained from reservoir regulation records or from a downstream gage. If a downstream gage is used, care should be taken to ensure that no tributaries enter between the dam and the gage. CE-QUAL-R1 will distribute the flow between selective withdrawal ports to match the target temperature.

T(I). The target temperature is user specified. Often it follows a natural temperature regime or a downstream coldwater fisheries objective.

SOUTL1 (QUAL, THERM, OPTIONAL)

This record is read if NORMAL was selected for MODE, SPECIFY was selected for CHOICE, and PORT or PORTWEIR was specified for STRUCT.

INTINT. This is the update interval for outflows (hr). It is chosen as an integral multiple of the computation interval, NHOI. Daily updates are recommended (24 in columns 15 and 16).

NCARDS. The value for NCARDS represents the number of SOUTL2 records when NOUTS (OUTLET record) is less than or equal to four, or the number of pairs of SOUTL2 records when NOUTS is greater than four but less than or equal to eight. As presently dimensioned, NOUTS cannot be greater than eight.

As with other updates, one additional update, past the last simulation interval, is required. If weirs and ports are being modeled, see the description for SWRFLO records which follows SOUTL2.

SOUTL2 (QUAL, THERM, OPTIONAL)

This record is read if NORMAL was selected for MODE, SPECIFY was selected for CHOICE, and PORT or PORTWEIR was specified for STRUCT.

The first 16 columns of the SOUTL2 record contain no data and can be used for identification. In the remaining eight fields (eight more fields are available on a second record if required), the port number (LET) and outflow from that port (QOT) are specified in pairs starting from the top port. The last pair corresponds to the floodgates.

LET. The outlets are numbered from the top port down.

QOT. The flows out of each port in m^3/sec must be obtained from project regulation records.

SWRFLO (QUAL, THERM, OPTIONAL)

If NORMAL was specified for MODE, and PORTWEIR was read for variable STRUCT, then one SWRFLO record follows each SOUTL2 record or pair of records. The update interval is the same as for INTINT on the SOUTL1 record.

WRFLO. This variable represents weir flow (m^3 sec^{-1}).

WRFLOW1 (QUAL, THERM, OPTIONAL)

If only NORMAL was specified for MODE, and WEIR was specified for variable STRUCT, then WRFLOW1 and WRFLOW2 records are read.

INTINT. This is the update interval for outflows (hr). It is chosen as an integral multiple of the computation interval, NHOI. Daily updates are recommended (24 in columns 15 and 16).

NCARDS. This variable represents the number of WRFLOW2 records that are to be read.

WRFLOW2 (QUAL, THERM, OPTIONAL)

These records are read if NORMAL was specified for MODE, and WEIR was specified for STRUCT.

DATA(I). This value represents flow over the weir (m^3 sec^{-1}). There are nine such values per record.

Inflow data--general

A block of data representing flow quantities and constituent concentrations must be supplied for each tributary. Each block of data contains 25 variables or variable groups for CE-QUAL-R1 (four for CE-THERM-R1). For each variable or variable group, two types of records are needed. The first record contains two variables.

QI (QUAL, THERM)

INT--. The first variable represents the update interval (hr) that must be an integral multiple of the computation interval, NHOI. For flow quantities, daily intervals are recommended. The interval need not be the same for different constituents, but the interval must be the same for any one constituent. This can create some problems since sampling intervals are seldom constant. If the sampling interval is not constant, the data will have to be manipulated to conform to a constant update interval.

Thornton et al. (1979) investigated the sensitivity of model predictions to inflow updates. They found no significant differences between daily and weekly updates, but significant differences between weekly and biweekly or monthly updates. Based on this study, it is recommended that weekly updates be used when possible.

NCARDS. The number of records containing update values for the current variable or variable group.

The second type of record contains the update values. For each variable, nine updates are included on each record, in fields 2 through 10. The update variables must be assembled in the following order for CE-QUAL-R1 (see Appendix D concerning CE-THERM-R1):

1 Q2
2 1ALG
3 2ALG
4 3ALG
5 ALKA
6 DOML
7 CNH4

8	CNO3
9	DOMR
10	COL
11	DET
12	OXY
13	PO4
14	SI
15	TEMP
16	TDS
17	SSOL
18	PH
19	MN4
20	MN2
21	FE3
22	FE2
23	FESB
24	SO4
25	S2

Q2 (QUAL, THERM)

DATA(I). Flow, per modeled tributary, should be in units of m^3/sec. Daily update values are recommended. Values can be obtained from US Geological Service or dam-tender records.

IALG (QUAL)

DATA(I). This variable represents the inflowing concentration of the first algal compartment. In many main stem and tributary impoundments, the composition of the algae and zooplankton communities is very distinct from that occurring in the river or tributaries. In most cases, the river community will not be viable in the reservoir and should be considered an organic detrital input to the reservoir. Values are read in units of mg/ℓ.

2ALG (QUAL)

DATA(I). The same argument applies for the second algal compartment as for the first.

3ALG (QUAL)

DATA(I). The same argument applies for the third algal compartment as for the first.

ALKA (QUAL)

DATA(I). If weekly update values are not available for alkalinity, regression approaches may provide reasonable estimates of weekly update values based on flow measurements. Update units are mg/ℓ as $CaCO_3$.

DOML (QUAL)

DATA(I). Inflow concentrations for labile DOM should be as dry weight (mg/ℓ).

CNH4 (QUAL)

DATA(I). Ammonia updates should be expressed in units of mg/ℓ as N.

CNO3 (QUAL)

DATA(I). Nitrite-nitrate values should be in units of mg/ℓ as N.

DOMR (QUAL)

DATA(I). Inflow concentrations for refractory DOM should be as dry weight (mg/ℓ).

COL (QUAL)

DATA(I). Coliform updates may represent total coliforms, fecal coliforms, or fecal streptococcus, depending on the study objectives. The units should be in colonies/100 ml.

DET (QUAL)

DATA(I). Since organic detritus may have contributions from algae and zooplankton, estimates of detritus may be obtained by using particulate organic carbon concentrations and dividing by the stoichiometric equivalent (e.g., 0.45) between C and biomass. The units should be mg/ℓ dry weight.

OXY (QUAL)

DATA(I). Daily updates of dissolved oxygen would be desirable and possibly may be obtained through regression approaches incorporating temperature and percent saturation. The characteristics of the inflowing stream, its assimilative capacity, and point or nonpoint source inputs must be considered, however. Weekly updates are considered minimal. The units are mg/ℓ.

PO4 (QUAL)

DATA(I). Phosphorus entering the reservoir from its tributaries is assumed to be completely available for algal uptake and growth in the form of phosphate. Availability studies using algal bioassays indicate that for many field situations, nutrients are not in completely available forms. The availability of nutrients depends on many factors such as reservoir hydrodynamics, cation concentrations, alkalinity, season, antecedent conditions, and so forth. These factors are highly site specific. Availability studies, therefore, need to be conducted several times during the year. Algal production and standing crop values may be overestimated if availability studies are not conducted.

If the data have already been collected and it is not possible to conduct availability studies, soluble reactive phosphorus or orthophosphate values can be used as inflow updates. Soluble reactive phosphorus is roughly equivalent to the immediately available phosphorus for phytoplankton uptake. The units are mg/ℓ as P.

SI (QUAL)

DATA(I). Inflow values for silica should be in units of mg/ℓ.

TEMP (QUAL, THERM)

DATA(I). Regression approaches for developing daily stream temperatures are quite reliable and should be used. Daily inflow temperatures are important for proper placement and mixing of the inflow in the reservoir. The units are in °C.

TDS (QUAL, THERM)

DATA(I). Regression approaches for developing daily total dissolved solids updates as a function of flow generally account for a significant portion of the variance in TDS. R^2 values of 0.90 to 0.95 are reasonable. Daily TDS values are important since TDS also modifies the inflow density. TDS can also be obtained from specific conductance by assuming $TDS = 0.6 \cdot$ specific conductance (American Public Health Association 1976). The units for TDS are mg/ℓ.

SSOL (QUAL, THERM)

DATA(I). Suspended sediment transport is generally greatest during elevated flow. It may be possible to develop relations between flow and suspended solids to improve update values. The units for SS are mg/ℓ.

PH (QUAL)

DATA(I). Since flow generally accounts for very little of the variance in pH, regression approaches may not be appropriate for pH. The variable pH is dimensionless.

MN4 (QUAL)

DATA(I). This variable represents the inflowing concentration of Mn(IV) in g/m^3.

MN2 (QUAL)

DATA(I). This variable represents the inflowing concentration of Mn^{+2} in g/m^3.

FE3 (QUAL)

DATA(I). This variable represents the inflowing concentration of FE(III) in g/m^3.

FE2 (QUAL)

DATA(I). This variable represents the inflowing concentration of Fe^{+2} in g/m^3.

FESB (QUAL)

DATA(I). This variable represents the inflowing concentration of FeS in g/m^3.

SO4 (QUAL)

DATA(I). This variable represents the inflowing concentration of SO_4^{-2} in g/m^3.

S2 (QUAL)

DATA(I). This variable represents the inflowing concentration of S^{-2} in g/m^3.

ABFLO1 (QUAL, THERM, OPTIONAL)

This record is read when AFTERBAY was chosen for FTRBAY.

INTAB. This variable represents the update interval for flows out of the afterbay. Daily updates are recommended.

NCARDS. This is the number of records that contain release flows from the afterbay.

ABFLO2 (QUAL, THERM, OPTIONAL)

These records are read when AFTERBAY was chosen for FTRBAY.

DATA. This record contains nine values that represent flow (m^3/sec) out of the afterbay. The record is repeated until all updates are read.

Monte Carlo directives (QUAL, OPTIONAL)

These records are added to the data set for Monte Carlo simulations only. An example data set is included in Appendix E, as Example 3.

MCCOEF. If any coefficient is to be randomized, specify RANDOM, right justified to column 10. If RANDOM is specified, disposition for all coefficients must be specified on separate records. These coefficients are the first 59 elements in the common block, COMMON AREA08; the 52 elements of COMMON AREA8T; and the 32 elements of COMMON AREA12. These coefficients are listed in Table 38. This field can be blank if coefficients are not randomized.

Table 38

Coefficients Read for Monte Carlo Simulations

Number	Name	Number	Name	Number	Name	Number	Name
1	BIOC	37	PS2CO2(3)	73	TSETL(3)	109	TMRESP
2	BION	38	PISAT(1)	74	TZMAX	110	TMEXCR
3	BIOP	39	PISAT(2)	75	TZMORT	111	TMMORT
4	ALGAS	40	PISAT(3)	76	TZRESP	112	DOMT1
5	DMCO2	41	PS2N(1)	77	TSSETL	113	NH3T1
6	ALDIGO	42	PS2N(2)	78	TMN4ST	114	NO3T1
7	DMO2	43	PS2N(3)	79	TFE3ST	115	DETT1
8	FEFFIC	44	PS2PO4(1)	80	TFESST	116	ALG1T1
9	FPSED	45	PS2PO4(2)	81	TMN4RE	117	ALG2T1
10	FS2FSH	46	PS2PO4(3)	82	TFE3RE	118	ALG3T1
11	FPALG(1)	47	PS2SI	83	TSO4RE	119	ZOOT1
12	FPALG(2)	48	PREF(1)	84	TMN2OX	120	FSH1T1
13	FPALG(3)	49	PREF(2)	85	TFE2OX	121	PLTT1
14	FPDET	50	PREF(3)	86	TS2OXI	122	DOMT2
15	FPZOO	51	PREF(4)	87	TFESBD	123	NH3T2
16	HECTAR	52	Q10COL	88	TS2DK	124	NO3T2

(Continued)

Table 38 (Concluded)

Number	Name	Number	Name	Number	Name	Number	Name
17	O2DET	53	ZEFFIC	89	TPEXCR(1)	125	DETT2
18	O2DOM	54	ZS2P	90	TPEXCR(2)	126	ALG1T2
19	O2FAC	55	ADSRBP	91	TPEXCR(3)	127	ALG2T2
20	PLIMP	56	ADSRBN	92	TPMORT(1)	128	ALG3T2
21	PLIMC	57	ADMAXP	93	TPMORT(2)	129	ZOOT2
22	PLIMN	58	ADMAXN	94	TPMORT(3)	130	FSH1T2
23	PLFRAC	59	ZOOMIN	95	TRFRDK	131	PLTT2
24	PLITE	60	TNH3DK	96	TDOMRF	132	ALG1T3
25	PLDENS	61	TCOLDK	97	TNO3DK	133	ALG2T3
26	PLDIGO(1)	62	TDETDK	98	TSEDDK	134	ALG3T3
27	PLDIGO(2)	63	TDOMDK	99	TFMAX	135	ZOOT3
28	PLDIGO(3)	64	TDSETL	100	TFMORT	136	FSH1T3
29	TMPMAC	65	TPMAX(1)	101	TFRESP	137	PLTT3
30	O2FE2	66	TPMAX(2)	102	TMNREL	138	ALG1T4
31	O2MN2	67	TPMAX(3)	103	TFEREL	139	ALG2T4
32	O2NH3	68	TPRESP(1)	104	TSREL	140	ALG3T4
33	O2RESP	69	TPRESP(2)	105	TXP4RE	141	ZOOT4
34	O2S2	70	TPRESP(3)	106	TCNREL	142	FSH1T4
35	PS2CO2(1)	71	TSETL(1)	107	TFESAD	143	PLTT4
36	PS2CO2(2)	72	TSETL(2)	108	TPLMAX		

MCUPDT. If any inflowing water quality constituent is to be randomized, specify RANDOM, right justified to column 20. If RANDOM is specified, disposition for the water quality constituents located in common block COMMON AREA04 must be specified for each tributary. The list must include the place-holding dummy variables. This field can be blank if updates are not randomized. Variables for COMMON AREA04 are included as Table 39. The names correspond to information under the topic "Inflow data--general" in this PART.

Table 39

Inflow Variables Read for Monte Carlo Simulations

Number	Name	Number	Name	Number	Name
1	1ALG	12	PO4	23	FESB
2	2ALG	13	SI	24	SO4
3	3ALG	14	TEMP	25	S2
4	ALKA	15	TDS	26	dummy
5	DOML	16	SSOL	27	dummy
6	CNH4	17	dummy	28	dummy
7	CNO3	18	dummy	29	dummy
8	DOMR	19	MN4	30	dummy
9	COL	20	MN2	31	dummy
10	DET	21	FE3	32	dummy
11	OXY	22	FE2	33	PH

MCTIME. In Monte Carlo operation, two options are available for specifying generation of new values. If DELTA-T is specified, right justified to column 30, values will be generated for each selected coefficient or update each computation interval. If TOTAL-T is specified, also right justified to column 30, new values for coefficients and/or updates will be supplied at the beginning of each successive simulation year. An option must be specified for MCTIME.

MCPRINT. A blank field or the entry DIAGNOSTIC is the only permissible entry in this field. This option is selected only when examination of the selected random values for coefficients and updates is desired. As the entry implies, it is used in a diagnostic mode to evaluate the operation of subroutine MC and not during routine Monte Carlo simulations.

NLOOPS. Columns 47 to 50 are used to specify the number of simulation cycles to be performed by the model.

LSTART. Cumulative statistics are used by subroutine MC to evaluate conditions of convergence as a function of simulation cycles. It becomes a significant cost element to repeat the first 50 iterations of the simulation cycle in order to evaluate cycles 51 to 60. Because the same sequence of random numbers is generated during each execution, it is possible to proceed through the generation of values for the first 50 cycles, and then begin actual simulation on the 51st cycle using the LSTART parameter. The user should specify the first simulation cycle to be executed right justified to column 60.

Coefficient directives

These records are added to the data set for Monte Carlo simulations only.

IDENT. Coefficient identification that corresponds to the element names in Table 38.

VARIATION. Three options are available to the user. The first option allows the variable to return to the main program unaltered (Code 1 in column 20). The second option allows the model to select a value using the data set value as the mean of a specified probability distribution, as a nominal value as the mean of a specified probability distribution, or as a nominal value with a specified percent of deviation from that value (Code 2 in column 20). The last option allows random coefficient selection from a completely specified distribution (Code 3 in column 20).

DISTRIBUTION. If VARIATION Code 2 or 3 is selected, one of four distributions must be selected. In each case, the code is placed in column 30. The uniform distribution (Code 1) is utilized when all values of a coefficient in a given range have an equal probability of selection. A uniform distribution is selected when frequency histograms of published values for coefficients show an approximately equal distribution. This technique has been utilized to select values for half-saturation coefficients, decay rates, settling rates, and for coefficients where the distribution is not known.

The second distribution option, a normal distribution (Code 2), is used when the frequency histogram for coefficient values approximates a normal bell-shaped curve. This distribution will yield values near the mean more often than more extreme values either much greater or much smaller than the mean. Normal distributions have been utilized for growth, respiration, and mortality coefficients.

The third distribution option is the rotated log normal distribution (Code 3). It is used most effectively when the frequency histograms for the coefficient in question show profound skewness toward values greater than the median published values. This distribution has been specified most often for half-saturation coefficients.

The last distribution option is the log normal distribution (Code 4). It is appropriately specified when the frequency histogram for a particular coefficient demonstrates skewness toward values less than the median published values. This distribution has been used for half-saturation coefficients.

MINIMUM. This value is appropriately specified (right justified to column 40) when it is desired to generate values from specified distributions (VARIATION Code 3). It represents the lower bound of acceptable values. Values generated which are less than the specified minimum are set to the distribution mean.

MAXIMUM. This value is also appropriately specified (right justified to column 50) when using VARIATION Code 3. It represents the upper bound of acceptable values. Values generated which are greater than the specified maximum are set to the distribution mean.

MEAN. This value is appropriately specified (right justified to column 60) when using VARIATION Code 3.

STANDARD DEVIATION. This value is appropriately specified (right justified to column 70) when using VARIATION Code 2 or 3. It is calculated from the values comprising the frequency histogram.

PERCENT OF NOMINAL. This value is appropriately specified (right justified to column 80) when using VARIATION Code 2. It represents the percentage of the data set value which constitutes the necessary degree of coefficient perturbation from the deterministic value.

Update directives

These records are added to the data set for Monte Carlo simulations only.

Update directives are indicated using the same variables as coefficient directives. A separate record must be included for each variable listed in Table 39, although the update directives need not be included for dummy variables. It is required that each tributary be specified separately.

VERIFY1 (THERM)

For verification data for CE-THERM-R1, please refer to Appendix F.

Execution

CE-QUAL-R1 resides on the Cybernet Services interactive time-sharing computer system. A user must have his own account number and should have some knowledge of Cybernet procedures.

To execute CE-QUAL-R1, prepare a file as follows for use by the SUBMIT directive. (Names that are underlined can be changed at the user's discretion.)

```
Jobname, T720, P4.
/USER
/CHARGE
MAP, FULL.
Get, CQROBJ, Tape5 = datafile.
RFL, CM = 377700.
CQROBJ.
SAVE, Tape6.
SAVE, OUTPUT = OFILE.
DAYFILE, DFILE.
SAVE, DFILE.
EXIT.
SAVE, TAPE6.
EXIT.
SAVE, OUTPUT = OFILE.
EXIT.
DAYFILE, DFILE.
SAVE, DFILE.
```

Upon successful execution:

- file TAPE6 contains tabular output.
- plot files are created and saved with names provided in the data set.

In addition:

- file OFILE contains a load map and an error summary if pertinent.
- file DFILE contains a job activity summary.

Calibration Procedures

Calibration procedures can be simplified by initially taking the time to determine coefficients and updates and by following a logical procedure. Users must realize that both CE-QUAL-R1 and CE-THERM-R1 have been coded to represent generalized reservoirs. Changes to the code representing site-specific characteristics, both physical and ecological, may have to be made.

Even if water quality constituents are of interest, the authors recommend that CE-THERM-R1 be used first to check the water budget, and then to calibrate temperature, dissolved solids, and total dissolved solids. Once a satisfactory thermal profile has been simulated using CE-THERM-R1, CE-QUAL-R1 can be calibrated. Coliforms can be calibrated apart from other variables because they are not linked to other constituents. The remaining nonanaerobic variables must be calibrated together because the concentration of each one depends on the concentration of others (Figure 2). Variables or processes may be set to zero, but the user must realize that to do so may affect other variables. During calibration, the flux values predicted by the model should be investigated to make sure that variable concentrations are being predicted for the correct reasons. The anaerobic constituents should be calibrated only after satisfactory oxygen profiles are predicted.

Water Budget

The overall water budget of a reservoir is determined by the cumulative effects of inflows, outflows, precipitation, and evaporation. Precipitation is currently not included in the model. The budget can be checked by comparing the predicted reservoir elevation with the recorded reservoir elevation. The difference over the simulation period should be less than 0.5 m for most reservoirs.

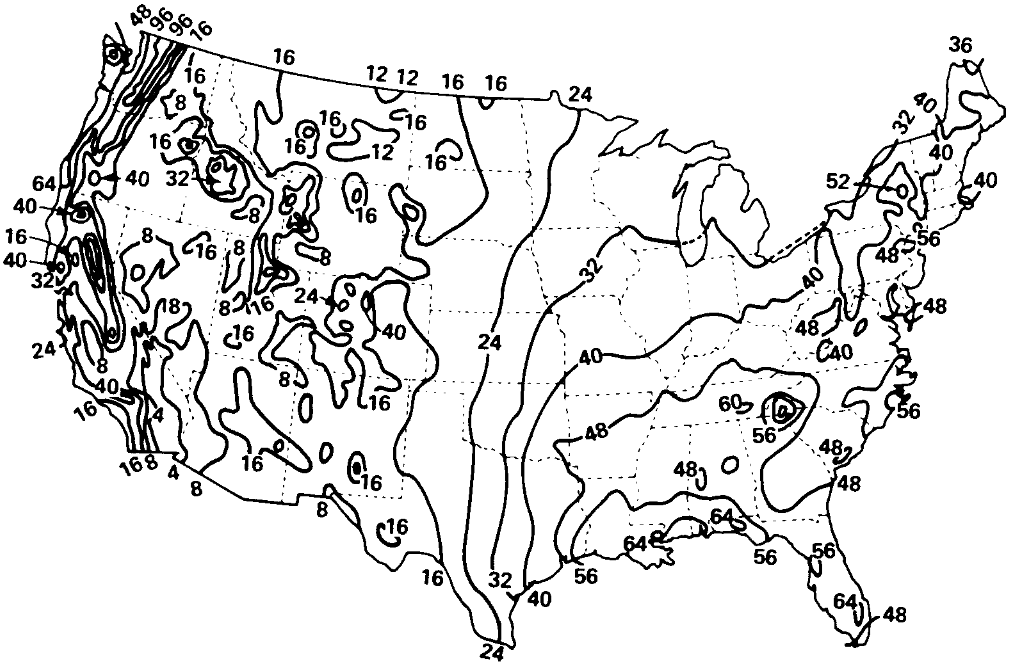
If there is an error in the water budget, it should first be determined if the difference results from storm events or is a gradual cumulative-type error. This is easily checked by comparing daily reservoir elevations to determine if discrepancies are related to storm events.

Errors in the water budget due to storm events can be traced to neglect of direct precipitation or to errors in inflow measurements. Errors made by neglecting direct precipitation to the lake can be determined by adding precipitation to the water surface and comparing the result with the recorded elevation. Direct precipitation can be added to the inflow to improve the water budget. Errors concerning inflow measurements are more complicated. They can result from an inaccurate rating curve or more likely from a gage that does not accurately measure the total inflow to a reservoir because the area of the watershed above the gage is probably less than the area above the damsite. A simple solution to this problem is to proportion the inflow by area. A better solution would be to route inflows to the reservoir by one of the many hydrologic routing models currently available.

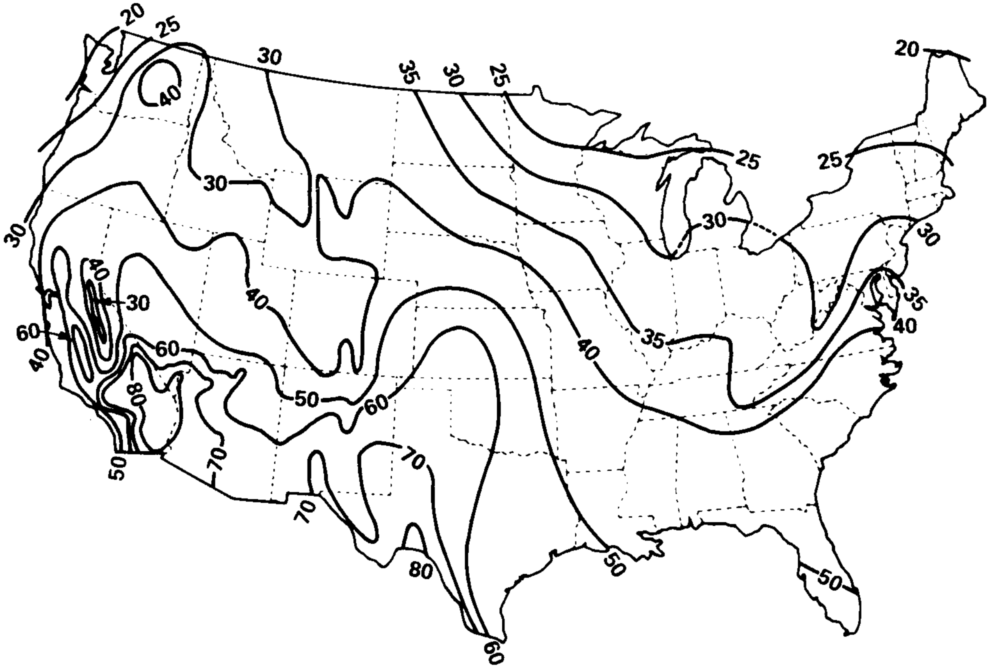
Gradual creeping-type errors in the water budget are usually attributed to evaporation, outflows, and/or seepage. Evaporation can easily be checked by comparing the predicted evaporation with the average evaporation expected for that region (Figure 81) or with pan evaporation data. The coefficients AA and BB can be used to fine tune the evaporation and water budget. Errors due to outflows and seepage need to be checked by investigating the outflow measurements.

Thermal Structure

The thermal structure is calibrated by comparing predictions with measured profiles. Emphasis should be placed on the timing of the onset of stratification, thermocline depth, gradient in the metalimnion, hypolimnetic temperatures, and time and temperature of fall overturn. Caution should be exercised due to the importance of internal absorption of solar radiation. Use of TDS data, if available, instead of temperature data to calibrate the mixing coefficients is recommended to



a. Average annual precipitation, in.



b. Average annual lake evaporation, in.

Figure 81. Isoplots of average annual precipitation and lake evaporation (from National Weather Service)

avoid confusing temperature changes due to mixing with those due to internal absorption of solar radiation.

The coefficients directly impacting the heat budget of a reservoir are TURB, AA, and BB (PHYS1 record). If the water budget and evaporation rate are correct, then AA and BB should be set and no further calibration is required. TURB affects the magnitude of the solar radiation impinging on the water surface. The value for TURB can be increased if too much heat is in the reservoir for most of the simulation. It is important to keep in mind the factors affecting thermal structure during interpretation of temperature predictions.

The internal absorption of solar radiation is determined by EXCO and SURFRAC. These two coefficients are easily estimated from Secchi disk readings (Figures 79 and 80). Modifying these coefficients should not be necessary. In general, decreasing EXCO and SURFRAC causes more heat to be distributed deeper in the reservoir.

The thermal structure is determined by the MIXING coefficients SHELCF, PEFRAC, CDIFW, and CDIFF. Initially, the sheltering coefficient, SHELCF, should be estimated using the concepts illustrated in Figure 78, and CDIFW and CDIFF should be set to 0. Then SHELCF and PEFRAC can be adjusted to match the timing and temperature of the onset of stratification and fall overturn and also to match the depth of the epilimnion. Generally, increasing SHELCF and PEFRAC will delay the onset of stratification and increase the depth of the epilimnion. Initial adjustments to SHELCF should be made in tenths during periods of heating and strong winds. Adjustments to PEFRAC should be made during periods of cooling and light winds, although the model is relatively insensitive to PEFRAC.

Once SHELCF and PEFRAC are set, CDIFW and CDIFF can be adjusted to fine tune the slope or strength of the temperature gradient in the metalimnion and hypolimnion. Other information concerning these variables can be found in the section describing the MIXING record.

Water Quality Compartments

Most of the water quality compartments are strongly coupled. Calibration of any one compartment will thereby affect the remaining compartments. Before any coefficients are adjusted, it is important to identify the cause of a particular phenomenon. For example, does a metalimnetic oxygen demand result from inflowing organic matter or from organic matter settling from above? Or, does a phytoplankton bloom crash from nutrient limitation or from zooplankton predation? Only after these types of questions are addressed can the proper coefficient be identified and adjusted. Use of the flux model can aid the user in answering these types of questions.

Output Interpretation

The actual model computations constitute a small percentage of the overall effort. The interpretation of results, however, is the culmination and climax of the modeling process. The limitations and assumptions of the water quality model, the site-specific characteristics, and the data modifications and manipulations must be thoroughly known and understood to adequately interpret the model output. This interpretation should result from the interactions of a multidisciplinary group. This is essential because the model incorporates physical, biological, and chemical considerations and their interactions in simulating reservoir water quality.

It is most important to recognize the one-dimensional assumption when interpreting any output. The model predictions theoretically represent the entire horizontal layer, but in practice the predictions are considered more representative of the reservoir in the deepest part of the pool. This is quite important to keep in mind when looking, for example, at coliform concentrations. A low value in the model simulation with high input values from the tributaries should not be interpreted to mean that coliforms would not be a problem anywhere in the reservoir. The headwater areas may still not be suitable for campsites or recreational areas although, further down the reservoir, coliform concentrations may not be a problem.

When interpreting model output, it is also important to ask the question: Are the predictions meaningful and do they make sense? For example, there must be a logical reason for the crash of a phytoplankton bloom. Are the nutrients exhausted? Did a large inflow dilute the bloom? Did zooplankton concentrations increase to a sufficient level that grazing caused the crash? There should be a logical and explainable reason for everything the model predicts.

One of the most critical factors to be considered when interpreting modeling results is the temperature profile. Temperature reflects the density distribution existing within the impoundment and, therefore, the degree of mixing that will occur among the various layers. In addition, many of the rate processes occurring in the biological and chemical compartments are temperature dependent. The temperature profile provides an indication of how slowly or rapidly various reactions may be occurring. It is important to restate that this temperature profile is considered representative of the deepest part of the impoundment. This is usually near the structure or outlet works and is not likely to be representative of the thermal distribution throughout coves, embayments, or shallower areas of the reservoir.

The predicted temperatures may not match measured temperatures exactly. Temperature variations occur on an hourly as well as a seasonal time scale. If a daily computational interval is used, it is impossible to predict diurnal changes in temperature.

Gross algal production (P) and community respiration (R) are computed by integrating over the water column. Comparisons of P/R can be made to look at seasonal patterns.

Alkalinity can provide information on the buffering capacity of the system. Low alkalinity (10 to 30 mg/ℓ) may not sufficiently buffer the system to prevent rapid changes in pH. High alkalinity values (150 to 250 mg/ℓ) indicate that the system is somewhat buffered against large changes in pH, but that some nutrients entering as inflow may precipitate and not be available for algal uptake.

The phosphorus values may provide some indication of the trophic status of the reservoir. High values of phosphorus indicate that there is probably another limiting factor such as nitrogen, carbon, or light. Low values of phosphorus may indicate phosphorus limitation of algal growth. Various management schemes that significantly affect phosphorus or nitrogen values can be expected to alter algal growth, standing crop, and production.

Coliform concentrations can represent total coliforms, fecal coliforms, or fecal streptococcus depending on the update data and decay coefficient selected for the simulation. The vertical distribution of coliforms is important in projects with water supply, body contact, and general recreation usage.

The three algal compartments represent a composite of the present or expected phytoplankton assemblage. This composite suggests that caution be exercised in drawing conclusions about the magnitude and duration of algal blooms. Unless the compartments are parameterized to represent three major species, the simulated results should be interpreted only as average conditions. The dominant species in each composite assemblage will vary from season to season and month to month, as environmental conditions vary. This succession cannot be simulated because the model has been parameterized around a fixed assemblage of species that remains invariant throughout the simulation. The results can provide information on the timing of blooms and on succession as one compartment replaces another in dominance.

The units of the biological compartments are in terms of dry weight biomass per unit volume. Values indicating low algae mass should not be interpreted to imply that algae will never be a problem in some of the coves and embayment areas. Local microhabitat conditions can be extremely conducive for an algal bloom even though one may not occur in the main part of the reservoir.

The zooplankton compartment should be parameterized by weighting the various coefficients by the expected proportion of cladocerans, copepods, rotifers, and so forth, comprising the population. Because zooplankton are represented as feeding on phytoplankton and detritus, their population dynamics can be expected to track the phytoplankton dynamics with some lag.

Detritus decays to the various forms of carbon, nitrogen, and phosphorus as it settles out of the water column. Detritus, zooplankton, and phytoplankton are particulates and modify the light extinction coefficient by decreasing light penetration throughout the water column.

Total dissolved solids represent the dynamics of conservative substances. Changes in concentration result from dilution only; rate processes are not involved.

In interpreting output, the interactions of various components should be considered along with the impact of these interactions on reservoir water quality. A single compartment or variable should not be used to indicate reservoir water quality.

PART V: MODEL UTILITIES

Interactive Graphics

The numerous plot files accessible by the graphics utility are identified at the outset of a plotting session by the establishment of a data directory. The user is responsible for knowing the NAMES and TYPES of his plot files. Once they are known by the utility, they are referred to by their file number in the directory.

File types are declared according to the following schedule:

FILE TYPE	CONTENT
1	Monte Carlo output predictions
2	Simulation input file
3	Simulation output-water column predictions
4	Simulation output-outflow predictions
11-12	Simulation output-inflow predictions "11" means tributary 1 "12" means tributary 2
21	Validation input-water column measurements
22	Validation input-outflow measurements

Interactive graphics operations

When plot data files have been successfully created by CE-QUAL-R1, the stage is set for interactive graphics using a Tektronix 4014 or equivalent graphics terminal. The graphics utility is initiated by issuing the commands

```
GET,RUNGRAF/UN=CERON1
BEGIN,,RUNGRAF
```

After a brief startup delay during which an extensive library is linked and loaded, messages and requests for input appear from the utility. All messages are intentionally terse. When a response is requested and the user is uncertain how to respond, typing a "?" produces an elaborative message and point of continuation. The user will be asked to identify data files to be accessed by the utility, to select graphics tasks, and, according to the requirements of those tasks, will be asked other questions such as constituent identification, file number, and so forth. The tasks that allow multiple graphs on a single plot permit the user to specify any legal data source for each graph. Upon completion of a task, the user specifies a disposition from among choices that include making a clean CRT copy and creation of a remote plotting file.

In general, once the user has gained familiarity with the utility and no longer needs response information, passage through the preliminaries to the plots themselves is rapid, and a swift-moving, responsive pace can be maintained.

Example Terminal Session

Prior to using the graphics utility, a list of plot file names and types should be compiled. The list need not be exhaustive, as opportunities are afforded to make additions to the data directory during execution. However, the user needs to know exactly what his data resources are.

The utility begins with a display of rules and then prompts to build its data directory. These are illustrated in Figure 82 together with example responses pertinent to the availability of two files.

The utility continues with a recapitulation of the data directory, offering the user an opportunity to correct errors. This interaction is illustrated in Figure 83, together with the response that is given to resume graphics.

A task listing, illustrated in Figure 84, corresponds exactly to the available graphics services discussed above. Task selection is made by moving the horizontal cursor of the graphics CRT (Tektronix 4014 or equivalent) so that it intersects the box depicting the service desired. The user types "c" to continue.

The utility now branches to the selected task, prompting for appropriate responses. Once again, typing "?" will provide explanatory help.

```
              — CE-QUAL-R1 GRAPHICS UTILITY —
                           NOTE
1. REQUIRES TEKTRONIX 4014 TERMINAL OR EQUIVALENT.
2. TYPE "?" FOR HELP AT ANY REQUEST FOR INPUT.
3. TYPE "C" TO CONTINUE AT ANY PAUSE.
4. MAKE MENU SELECTIONS BY ADJUSTING THE POSITION
   OF THE HORIZONTAL CURSOR SO THAT IT PASSES
   THROUGH THE BOX CONTAINING THE NUMBER OF THE
   DESIRED CHOICE. THEN TYPE "C" TO CONTINUE.
   (NOTE — NO CARRIAGE RETURN WITH MENUS)
5. MULTIPLE PLOTS HAVE THE SCALES OF THE FIRST
   GRAPH PLOTTED.

.....................................................................


— INITIAL DATA DIRECTORY —
    INITIAL NUMBER OF FILES ?
      I>2
    FILE TYPE          1 ?
     I>3
    FILE NAME          1 ?
     I>PLOT03
    FILE TYPE          2 ?
     I>4
    FILE NAME          2 ?
     I>PLOT04
```

Figure 82. Opening dialogue

```
          CURRENT CONTENTS OF
            DATA DIRECTORY-

     DATA          DATA          DATA
     FILE          FILE          FILE
    NUMBER         NAME          TYPE

       1           PLOT03          3
       2           PLOT04          4

    TYPE "A" TO ADD A FILE
           "D"   DELETE A FILE
           "N"   CHANGE A FILE NAME
           "T"   CHANGE A FILE TYPE
           "R"   RESUME GRAPHICS

    I>
```

Figure 83. Data directory

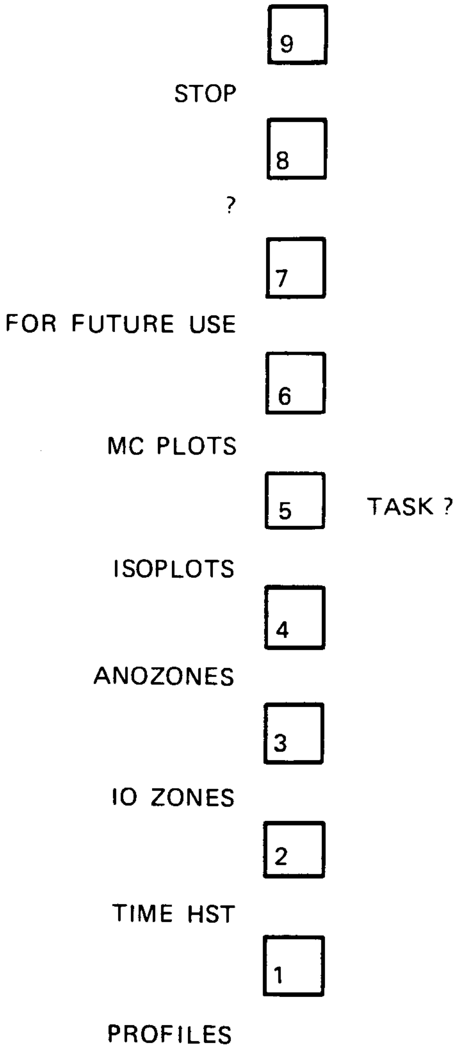


Figure 84. Graphics tasks

The following description pertains to a selection of Task 1, constituent depth profiles.

The first request for input to Task 1 involves CONSTITUENT IDENTIFICATION, a code by which the quantity to be graphed against depth is identified. To illustrate this code, the response to "?" is shown in Figure 85. Next, the user provides the number of the plot file to be used. This number was displayed earlier by the utility when the data directory was assembled.

If the pathway to the data has been correctly described and traversed, the utility now graphs the desired profile. An example is shown

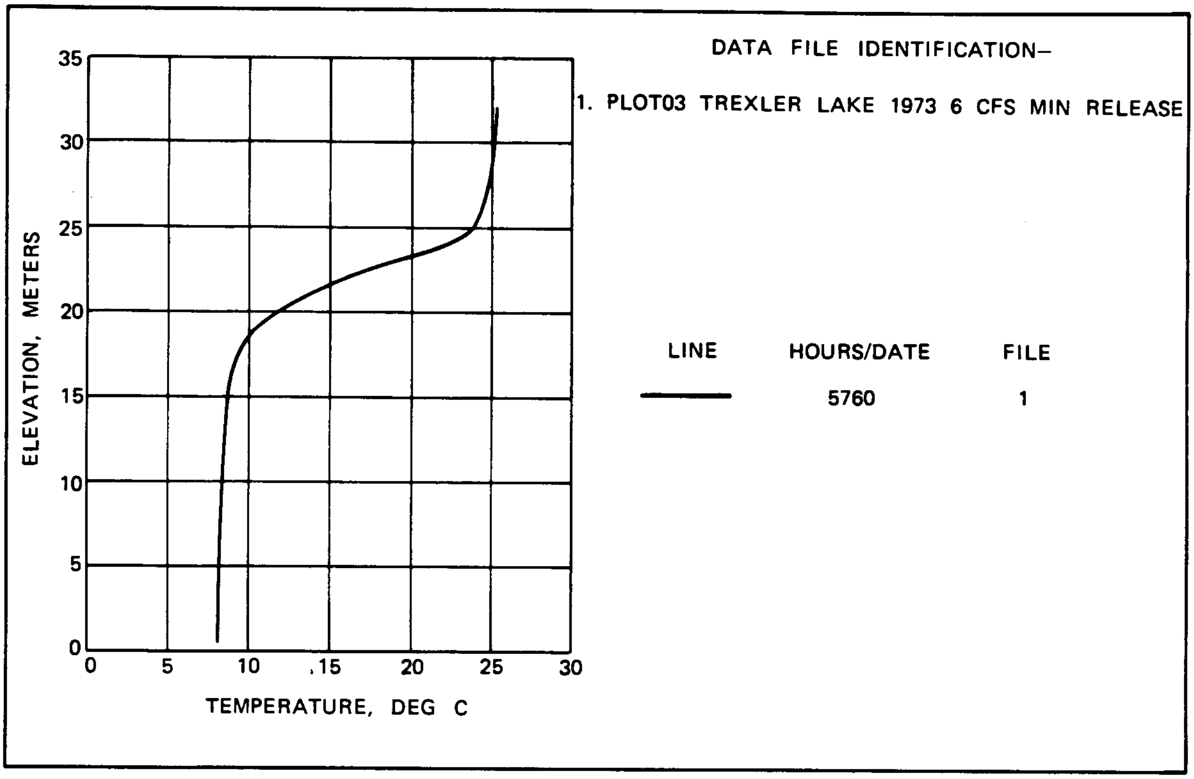
```
        HELP FOR "CONSTITUENT IDENTIFICATION ?"...
          CONSTITUENT IDENTIFICATION NUMBERS-
                ALL FILE TYPES (EXCEPT 2)
 01 TEMPERATURE                 14 DISSOLVED OXYGEN
&02 ZOOPLANKTON                 15 CARBON DIOXIDE
 03 ALGAE 1                     16 PH
 04 ALGAE 2                     17 ALKALINITY
 05 ALGAE 3                     18 TDS
 06 TOTAL MANGANESE             19 SUSPENDED SOLIDS 1
 07 DETRITUS                    20 TOTAL IRON
 08 DIS. ORGANIC MATTER         21 SULFATE
 09 PHOSPHATE                   22 REDUCED MANGANESE
 10 TOTAL CARBON                23 REDUCED IRON
 11 AMMONIA                     24 IRON SULFIDE
 12 NITRITE                     25 REDUCED SULFIDE
 13 NITRATE                     26 COLIFORM BACTERIA
           FILE TYPES 3 AND 21
27 BENTHOS               34 LAYER OUTFLOW
28 SEDIMENT              35 DIFFUSION COEFFICIENT
29 FISH 1                36 RESERVOIR ELEVATION
30 FISH 2                37 LAYER AREAS
31 FISH 3                38 LAYER WIDTHS
32 SCAM3 (TOTAL)         39 RADIATIVE FLUX
33 LAYER INFLOW

        FILE TYPES 4 AND 22
27 OUTFLOW
28 PARTICULATE ORGANIC CARBON
        FILE TYPES 11 AND 12
27 INFLOW
            FILE TYPE 2
50 CLOUD COVER FRACTION
51 DRY BULB TEMPERATURE
52 DEW POINT TEMPERATURE
53 AIR PRESSURE
54 WIND SPEED
& — UNAVAILABLE IN FILE TYPES 11 AND 12
NOW TYPE "C" TO CONTINUE.....
```

Figure 85. Constituent identification

in Figure 86, together with the continuation statement ANOTHER GRAPH ON THIS PLOT. Note that many error recovery features are built into the utility to handle inconsistent responses, file specification errors, and so forth, and to offer an opportunity for withdrawal if the situation gets out of hand.

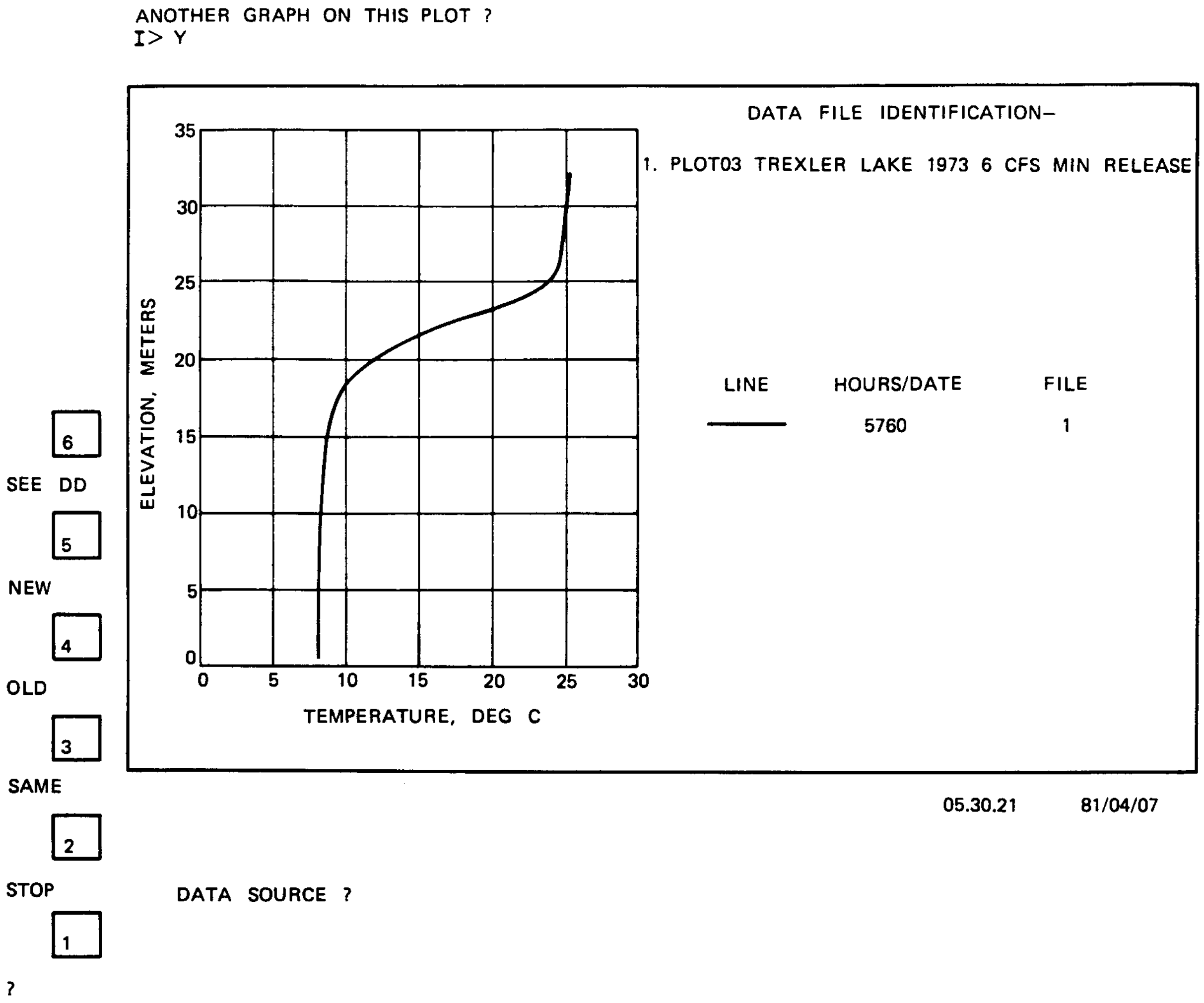
If the user chooses to place another graph on the same plot, he is presented with a DATA SOURCE listing (Figure 87), reflecting the fact that numerous files are accessible when overlaying graphs. He may choose to use the same file or another file already in the directory, or to place a new file in the directory at this time. Whatever the choice, the utility repeats the querying and graphing process.

```
 ANOTHER GRAPH ON THIS PLOT ?
I>
```



05.30.21 81/04/07

Figure 86. Example plot, task 1



```
ANOTHER GRAPH ON THIS PLOT ?
I> Y
```

```
DATA SOURCE ?
```

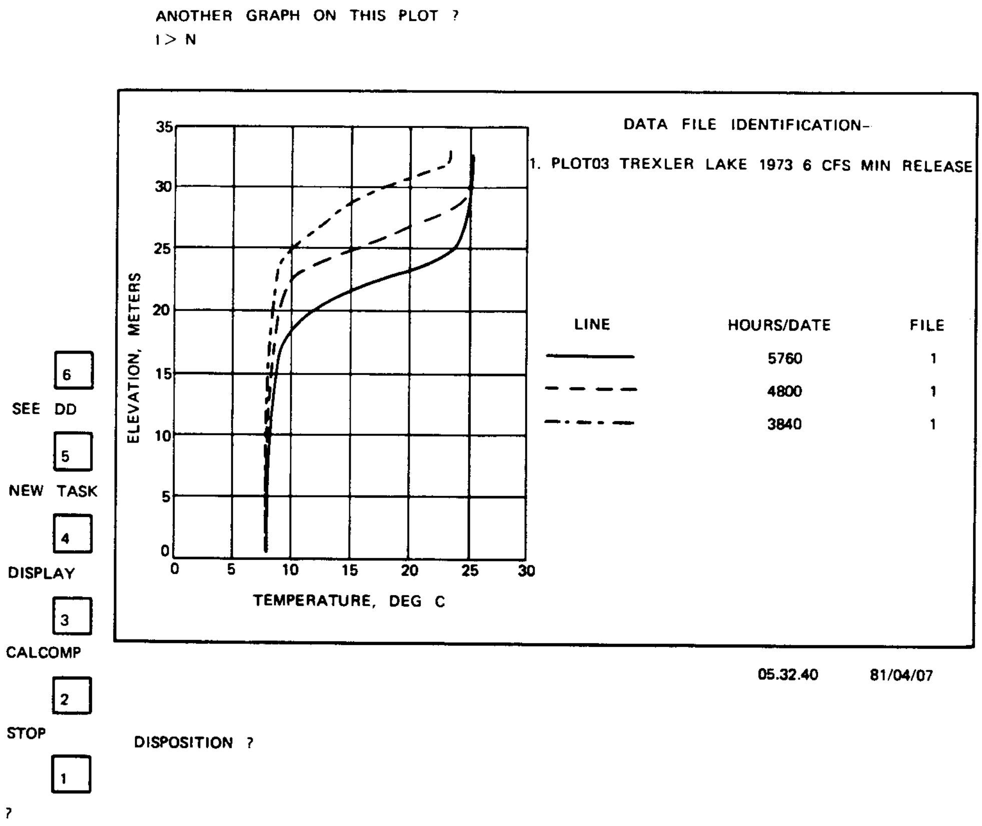
Figure 87. Data source, at left

When no more graphs are to be plotted (or when the maximum of four have been plotted), the utility requests a DISPOSITION (Figure 88). The user may choose to make a clean copy on the CRT, to create a plot file for use on a local plotter, to select another task, or to stop execution.

Representative plots for Tasks 2 to 6 are shown in Figures 89 to 93.

Preprocessors

Data set preprocessors have been developed for both CE-THERM-R1



```
ANOTHER GRAPH ON THIS PLOT ?
I> N
```

```
DISPOSITION ?
```

Figure 88. Disposition, at left

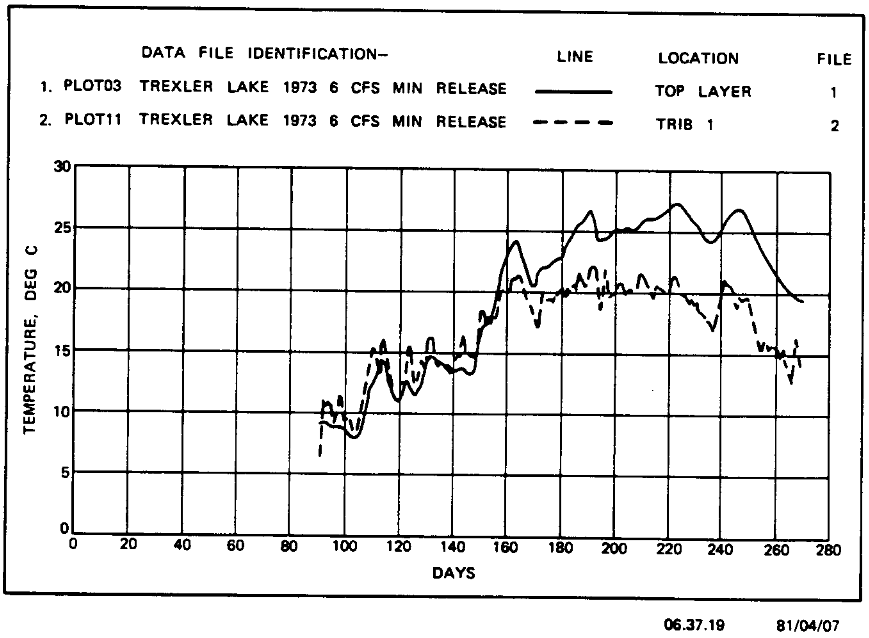
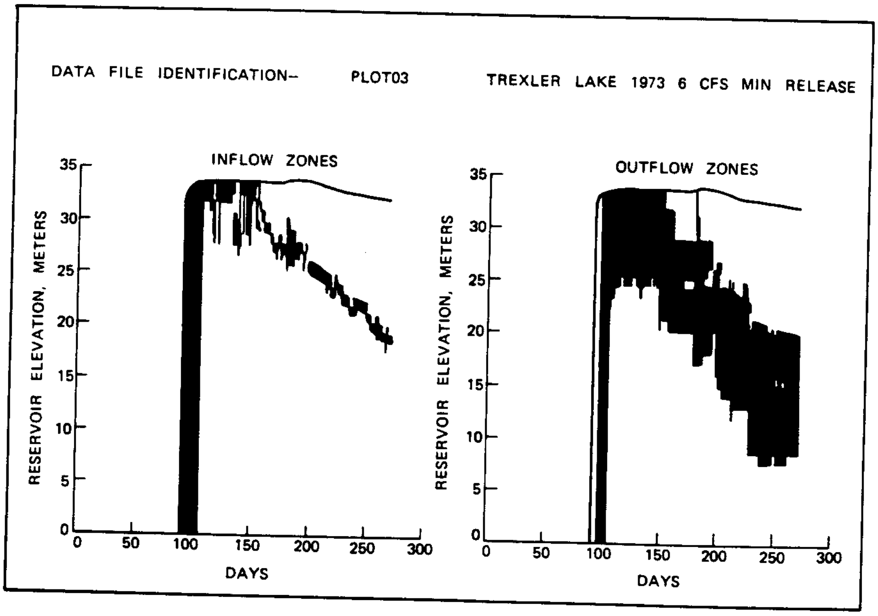
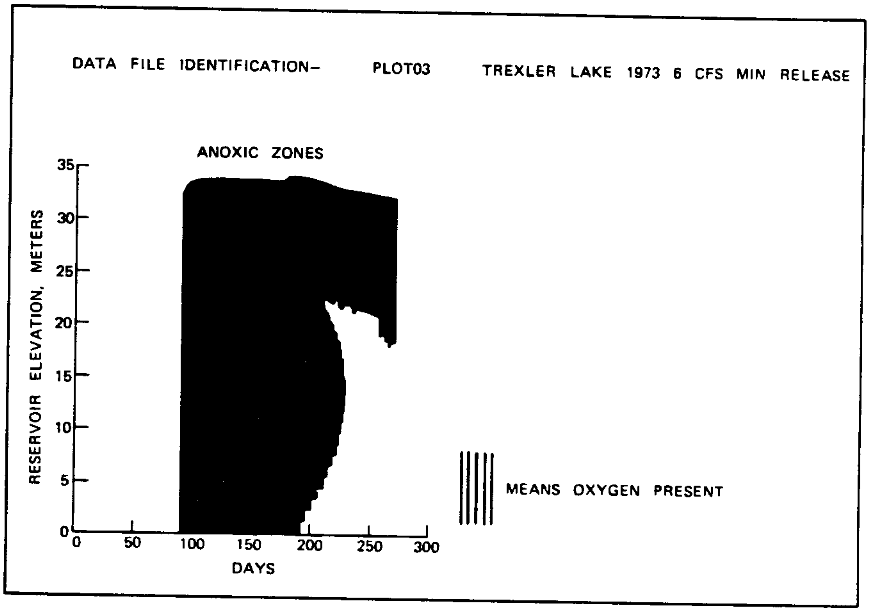


Figure 89. Example output, task 2



06.51.57 81/04/07

Figure 90. Example output, task 3



06.52.20 81/04/07

Figure 91. Example output, task 4

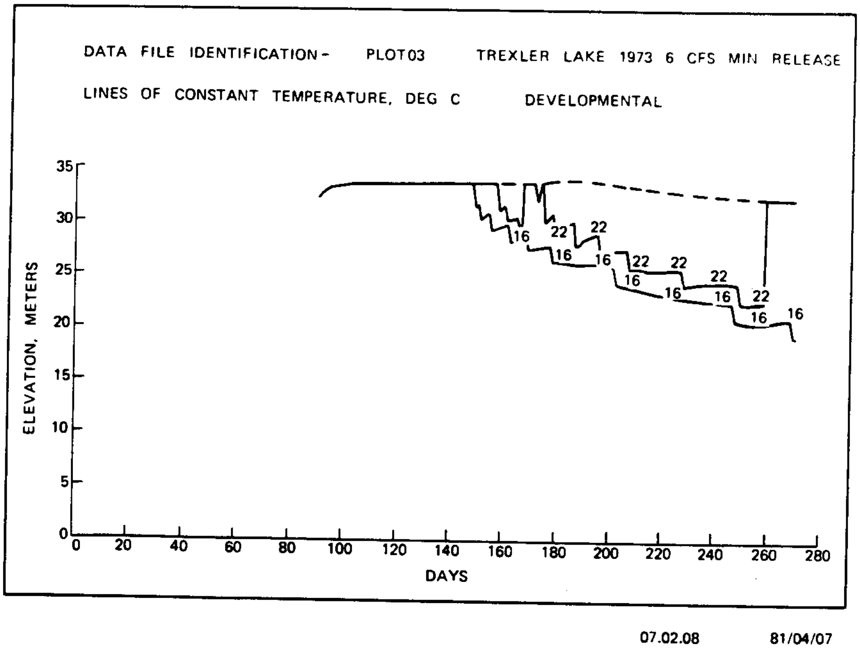


Figure 92. Example output, task 5

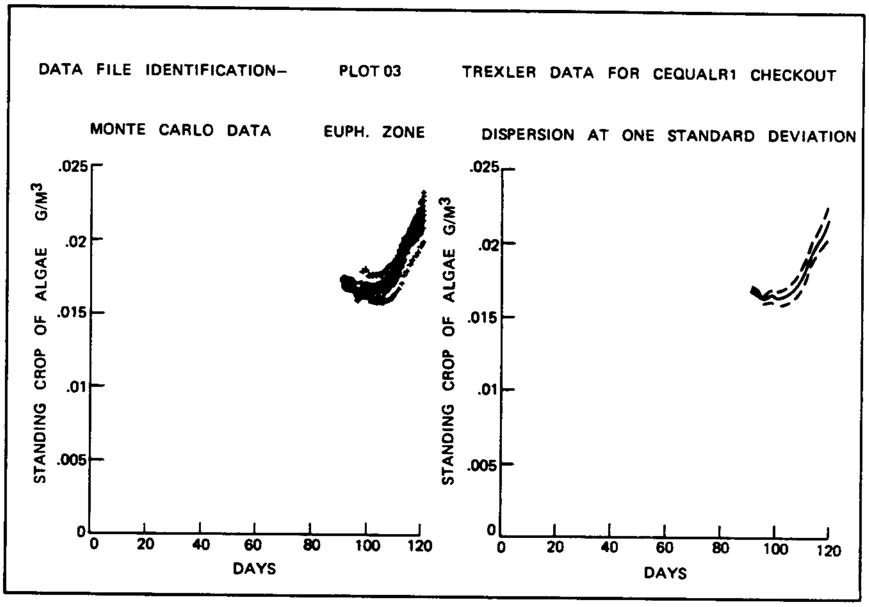


Figure 93. Example output, task 6

and CE-QUAL-R1 water quality models. The preprocessor for CE-THERM-R1 data sets will be referred to as "CQTTSM," and the preprocessor for CE-QUAL-R1 data sets will be referred to as "CQRTSM." Both are two-part preprocessors. Each preprocessor is designed to check the sequence of records required and whether each field of data on each record is the correct type of variable value expected by the model. Secondly, certain variable values and coefficients are compared with established ranges or values to see if the values fall within preestablished limitations.

Before attempting to run either preprocessor, it is recommended that the user review Appendixes C and D. Appendix C provides a dot diagram for CE-THERM-R1 and CE-QUAL-R1 data sets. These diagrams indicate precisely which records are required for any particular option the user may choose. It is correct to assume that the data set for any particular option will not include all of the records indicated in the listings for either model. The sequence in which the records appear in the dot diagram is, however, the sequencing required by the models for the data sets. The preprocessors will flag as an error any deviation from the expected sequence of required records in either model. In addition, Appendix D presents detailed information concerning the data set structure for CE-THERM-R1 and CE-QUAL-R1. A complete listing of all of the records required by any of the options available for CE-THERM-R1 or CE-QUAL-R1 is provided. The variable name for each item of data that should appear in each field of each record is also shown.

The preprocessors handle the data set as a fixed sequential listing of the records required for each option. Records are recognized by the label which appears in field 1, columns 1 through 8, left justified. This record name is used by the preprocessor to check sequencing of the records in the data set. When errors in the data set are reported by the processors, the location of each error is identified by line number and field number. Additionally, the flagged record is duplicated for the user on the same line of output.

In order to make efficient use of the preprocessor, certain data set conventions must be adopted.

a. Each record must begin with the appropriate record label. (See the dot diagram in Appendix C or Appendix D for a complete listing.)

b. Fields representing integer data must not contain a decimal point.

c. Fields representing real data must contain a decimal point.

d. No, or zero, flow from a port must be recorded as a "0." on the SOUTL2 records in the appropriate field paired with the port number.

Part I of the preprocessor is a type and sequence analysis of the data set. The preprocessor searches for missing records and incorrect data. It checks the sequence of records to verify that all required records for the particular option selected are included in the data set in the proper order. Each field of data on each successive record is compared with model expectations to verify that real data occur where real data are expected and integer data occur where integer data are expected. Error messages are produced when record labels or fields of data deviate from expected types in the model. For instance, the omission of a record would be noted by the preprocessor as an incorrect label in the first field of the flagged record. A field of data which contained a decimal point would be flagged as an error if the model expected an integer value in that particular field. It should be noted that Part I does not provide any information concerning the size or reasonableness of any particular entry in the data set. (See Figure 94 for sample output from Part I.)

Part I ceases its search for errors when 20 errors have been accumulated. This feature was installed as a safeguard since the omission of a single expected record could make an otherwise correct data set appear error ridden. All errors noted by Part I must be corrected in the data set before Part II will execute.

Part II compares certain variable values and coefficients against arbitrarily established ranges or values based on experience in working with the model. The execution of Part II involves comparing certain selected variable values and coefficients against preestablished ranges or values. Output from this part of the preprocessor is informational

```
                              TYPE AND SEQUENCE ANALYSIS OF RECORDS AND FIELDS


                                                       1       2       3       4       5       6       7       8       9       10
EXPECTING...   ...IN FIELD...   ...OF RECORD...    ********        ********        ********        ********        ********
                                                           ********        ********        ********        ********        ********


INTEGER               4                 6          JOB            1     364     24.    2400       25      79
NUMBER OF LAYERS ON PHYS2+ RECORDS EXCEEDS NUME    PHYS2+        1.      1.      1.      1.      1.      1.      1.
CURVE                 1                21          AREAC     561.81    2.79
ALPHANUMERIC          2                21          AREAC     561.81    2.79
AREAC                 1                22          WIDTHC     47.70    0.55
WIDTHC                1                23          CURVE      POWER
REAL NUMBER           2                23          CURVE      POWER
ID                    1                74          FILID   USER MANUAL MAY 7 1985
SOUTL2                1               534          OUTL3*  RA 79093      1               2               3    58.1
SOUTL2                1               575          OUTL3*  RA 79134      1               2               3    39.4
SOUTL2                1               673          OUTL3*  RA 79232      1               2               3     2.7
VERIFY2               1              1004          NVRFY         23


                              TYPE AND SEQUENCE ANALYSIS OF RECORDS AND FIELDS


                                        NUMBER OF ERRORS 11
```

Figure 94. Sample output from Part I of the preprocessor

in nature and requires judgments on the part of the user as to the need to alter data set values. The usefulness of this part of the preprocessor may be illustrated as follows. If the model expects real data in a certain field, Part I of the preprocessor will accept any number containing a decimal point as a valid entry. An entry of 314. in a field expecting real data would be just as acceptable as 3.14 to Part I of the preprocessor. It totally disregards the size of that variable value. This would pose an especially harmful situation if the sign of an exponent in an exponential expression were entered incorrectly. The following variable values or coefficients are examined in Part II of the preprocessor: IFIRST, ILAST, NHOI, IPRT, ISTART, NTRIBS, NUME, TURB, AA, BB, SDZMIN, SDZMAX, SDZ, NOUTS, BELOW, COEF, SHELCF, PEFRAC, CDENS, EXCO, SURFRAC, EXTINS, CLOUD, DBT, DPT, APRES, WIND, XDAY, XTIME, LPORTN, T(J), PLDIGO, ZEFFIC, PREF, FPS, and FEFFIC. (See Figure 95 for sample output from Part II.)

```
                   TYPE AND SEQUENCE ANALYSIS OF RECORDS AND FIELDS



                                NUMBER OF ERRORS  0




                  MAGNITUDE ANALYSIS OF JOB PARAMETERS AND COEFFICIENTS


                            INFORMATION ONLY---ACTION OPTIONAL

                                 "BTW." = BETWEEN
                                 "SG." = SUGGESTED
                                 "TP." = TYPICALLY


                                                            EXPERIENCE
      COEFFICIENT         DATASET        APPLICABLE            RANGE
                           VALUE         CONSTRAINT        MIN        MAX


       SHELCF              1.20          BETWEEN            0.0        1.0
       APRES            0.151E+04        BETWEEN          970.0     1050.0
```

Figure 95. Sample output from Part II of the preprocessor

To execute CQTTSM or CQRTSM, prepare a file as follows for use by the SUBMIT directive on the Cybernet Services interactive time-sharing computer system. (Names that are underlined can be changed at the user's discretion.)

```
JOBNAME,CM170000,T15,P6.
/USER
/CHARGE
MAP, FULL.
GET,PRTOBJ/UN=CERON1,TAPE5=data file.
CQTTSM.
SAVE,TAPE6=TOPT.
DAYFILE,DFILE.
SAVE,DFILE.
EXIT.
SAVE,TAPE6=TOPT.
EXIT.
DAYFILE,DFILE.
SAVE,DFILE.
```

Upon successful execution

- file TOPT contains error messages noted by the preprocessor.
- file DFILE contains a job activity summary.

For executing CQRTSM, the preprocessor for CE-QUAL-R1, CQTTSM must be replaced with CQRTSM in the above file. The data set named must be altered to identify the data set one wishes to check. Also, the OUTPUT file should be renamed QOPT.

Data Manipulation

Two utilities, Batch Graphics and Statistics, which are subsequently explained, need only a small fraction of the in-pool data generated and saved, on file, by the model (see FILES record, Part IV). The Data Manipulation utility chooses from that file only data which correspond to dates when measured data are available, and stores them in a manner suitable for the Batch Graphics and Statistics utilities.

Two files are needed for this utility. The first file contains data generated by CE-QUAL-R1, stored on a file with the name that was found in field 2 of the FILES record. That file is associated with this utility using device number 89. The second file uses device number 5. This file contains the following data, right justified:

Record 1

NUMB. This variable represents the number of days for which measured data are available (columns 2 through 7).

LYER. This is the last two digits in the year of simulation (columns 9 and 10). For example, "82" signifies that the simulation year was 1982.

IRUN. A "1" in column 12 signifies that this was a simulation using CE-THERM-R1. A blank or a number other than 1 in column 12 signifies that this was a simulation using CE-QUAL-R1.

Record 2

LDATE(1). The date representing the first sampling period, in columns 2 through 7. Columns 2 and 3 contain the last two digits of the year. Columns 4 and 5 represent the number of the month. Columns 6 and 7 represent the day of the month. Sampling on April 7, 1982, would be represented by "820407." LDATE(1) must be after the first simulation day (variable ISTART on the JOB record, Part IV).

LDATE(2).

●

●

●

●

LDATE(NUMB). NUMB records, similar to LDATE(1), must be read. Each contains the dates of one sampling period, in chronological order.

An example of this file is given in Figure 96. To execute the Data Manipulation program, submit the following file. (Names that are underlined can be changed at the user's discretion.)

```
  38 79 0
790206
790219
790220
790306
790319
790320
790403
790405
790417
790418
790501
790515
790516
790529
790611
790612
790626
790709
790710
790724
790806
790807
790821
790903
790904
790918
790919
791001
791002
791016
791030
791113
791115
791126
791127
791211
791226
791227
```

Figure 96. Example of the data file for device 5 for use by the Data Manipulation utility

```
JOBNAME.
/USER
/CHARGE
MAP,FULL.
GET,GRAOBJ,TAPE5=LDATE.
GET,TAPE89=PLDG14.
RFL,CM=377700.
GRAOBJ.
```

```
SAVE,TAPE6=GRADAT.
EXIT.
SAVE,OUTPUT=OFILE.
DAYFILE,DFDMP.
SAVE,DFDMP.
EXIT.
SAVE,TAPE6=GRADAT.
EXIT.
SAVE,OUTPUT=OFILE.
EXIT.
DAYFILE,DFDMP.
SAVE,DFDMP.
```

Batch Graphics

For those occasions when the user wishes to plot the same information many times, batch graphics is provided. For example, the user may wish to compare the same set of measured data to model-predicted values for each of a number of calibration simulations. Eight graphs per page are printed, using a Tektronix 4014 terminal. As an option, hardcopy output can also be printed.

A number of files are needed for batch graphics. The first file, to be read by device number 15, contains information that specifies the variables and dates that are to be graphed. File 2, to be read by device 41, contains simulation data supplied by the Data Manipulation utility. File 3, to be read by device 42, contains field-measured values. Three other files are optional. File 4, for device 43, is another simulation data file similar to file 2. Files 5 and 6, for devices 44 and 45, respectively, contain field-measured values. The first file contains the following information, right justified.

Record 1

REL. In columns 25 to 30, specify the maximum reservoir surface elevation, in metres from the reservoir bottom. This will be the setting for the Y axis for all graphs.

ICOPY. A "1" in column 35 signifies that a hardcopy plot will automatically be made after each eight graphs are plotted. Otherwise, the unit will pause after each set of graphs.

Record 2

NFD. This is the number of files that are to be plotted. Possible values for this variable, in column 8, are 1, 2, 3, 4, or 5.

IFD(1). This value, in column 16, represents the first file type. Values and file types are:

1	First simulation
2	Second simulation
3	First confirmation
4	Second confirmation
5	Third confirmation

IFD(2). This value, in column 24, represents the second file type (optional).

IFD(3). This value, in column 32, represents the third file type (optional).

IFD(4). This value, in column 40, represents the fourth file type (optional).

IFD(5). This value, in column 48, represents the fifth file type (optional).

Record 3

NC. This is the number that represents the first variable to be plotted (columns 1 through 8). Code numbers and associated variables are located in Table 40.

NDDUM. The number of dates to be plotted for this variable (columns 9 through 16). The maximum number of dates is now dimensioned at 24.

Table 40

Code Numbers, Plot Variables, Minimum Value for Statistics, and Associated Modeled Variables

Code Number	Variable	Minimum Value	Modeled Variable
1	Temperature	0.	TEMP(I)
2	Zooplankton	0.001	ZOO(I)
3	Algae1	0.001	ALGAE(I,1)
4	Algae2	0.001	ALGAE(I,2)
5	Algae3	0.001	ALGAE(I,3)
6	Total manganese	0.	CMN4(I) + CMN2(I)
7	Detritus	0.001	DETUS(I)
8	Dissolved organic matter	0.001	DOM(I) + RFR(I)
9	Phosphate phosphorus	0.0001	PO4(I)
10	Total inorganic carbon	0.0001	CARBON(I)
11	Ammonia	0.0001	CNH3(I)
12	Total algae	0.003	ALGAE(I,1) + ALGAE(I,2) + ALGAE(I,3)
13	Nitrite + nitrate nitrogen	0.0001	CNO3(I)
14	Dissolved oxygen	0.	OXY(I)
15	Carbon dioxide	0.	CO2(I)
16	pH	0.001	PH(I)
17	Alkalinity	0.001	ALKA(I)
18	Total dissolved solids	0.001	TDS(I)
19	Suspended solids	0.001	SSOL(I)
20	Total iron	0.	FE3(I) + FE2(I) + [FESB(I) * 0.6363]
21	Sulfate	0.	SO4(I)
22	Reduced manganese		CMN2(I)
23	Reduced iron	0.	FE2(I)
24	Iron sulfide	0.	FESB(I)
25	Sulfide	0.	S2(I)
26	Coliforms	0.	COLIF(I)
27	Silica	0.0001	SI(I)

The rest of this record, in eight fields of eight columns, contains the dates to be plotted. The first two columns of each field are blank. Columns 3 and 4 of each field contain the last two digits of the year. Columns 5 and 6 of each field contain the number representing the month of the year. Columns 7 and 8 represent the day of the month. If the value for NDDUM is greater than eight, then one or two more records, in 10 fields of eight, contain the rest of the dates.

After all the dates are read for the first variable, another record, similar to record 3, is read. If the dates for this variable are the same as for the previous variable, the user need only have the variable code number in the first field, and a 1 in columns 16 and 24. The same structure is continued until information for all variables to be graphed is read. An example data set is provided as Figure 97.

```
DEGRAY 1979 AUG 22 1983   60.0     1
       2       1       3
       1       8  790306  790417  790612  790724  790904  791002  791113  791227
       2       8  790306  790417  790529  790710  790807  790919  791016  791211
       3       8  790319  790418  790515  790611  790709  790806  791001  791226
       8       8  790306  790417  790612  790724  790904  791002  791113  791227
       9       1       1
      10       1       1
      11       1       1
      12       1       1
      14       1       1
      16       8  790220  790417  790612  790724  790904  791002  791113  791227
      17       8  790306  790417  790612  790724  790904  791002  791113  791227
      18       1       1
```

Figure 97. Example of data set for device 15 for use by the Batch Graphics utility

Files for field-measured data contain the following information, to be read by device 42.

Record 1

Title. The first 24 columns contain information describing the file.

Record 2

NC. Columns 5 and 6 contain the variable code identifier, found in Table 40.

ID. Columns 8 through 13 contain the date of sampling. Columns 8 and 9 are the last two digits of the year. Columns 10 and 11 represent the month of the year. Columns 12 and 13 represent the day of the month.

NR. Columns 16 and 17 contain the number of depths for which data are given. The maximum number is 72.

On the remainder of this record, and on subsequent records, four pairs of data are given. Each pair contains the depth at which a sample was collected and the value of the sample. The order of the depth-value pairs is from the deepest sampling point to the surface. Depths are in metres; concentrations are in g/m^3. The four depth-value pairs are in columns 19-22, 24-32; 34-37, 39-47; 49-52, 54-62; 64-67, 69-77. The number of depth value pairs equals the value of NR, located on Record 2. The order of the variables must be the same as listed in Table 40, although not all variables must be included. For each variable, the dates must be in chronological order. An example for this file is given in Figure 98. Please refer to the Statistics utility for more information concerning field-measured (confirmation) data.

To execute Batch Graphics, issue the commands

```
GET,GRAF8/UN=CERON1
BEGIN,,GRAF8
```

Statistics

This utility allows the user to obtain a statistical analysis of model predictions when compared to field-measured values. Statistics include (a) reliability index (Leggett and Williams 1981); (b) paired t-test for means (Sokal and Rohlf 1969); (c) normalized mean error (Gordon 1981, see also Wlosinski 1982); and (d) coefficients for the linear regression equation for plotting observed versus predicted values (Thomann 1980). Mean values for observed and predicted data are also given. The statistics are calculated for each variable over all depths for which data were collected, as well as for each variable over depths and times.

Information on these statistics is presented in Wlosinski (1984). The reliability index has been found, in past studies, to be a good statistic for comparisons because its value does not depend on whether the observed or predicted value is greater. Also, because it is scale variant, results from different variables can be aggregated and compared. The value of the reliability index would be 1.0 in the case of perfect production. If all comparisons are an average of one-half order of magnitude apart, the value of the reliability index would be 5.0.

```
DEGRAY79 ST.4
4  1 790206  47 46.0     4.300 45.0     4.300 44.0     4.300 43.0     4.300
                42.0     4.300 41.0     4.300 40.0     4.300 39.0     4.300
                38.0     4.300 37.0     4.300 36.0     4.300 35.0     4.300
                34.0     4.300 33.0     4.300 32.0     4.300 31.0     4.300
                30.0     4.300 29.0     4.300 28.0     4.300 27.0     4.300
                26.0     4.300 25.0     4.300 24.0     4.300 23.0     4.300
                22.0     4.300 21.0     4.300 20.0     4.300 19.0     4.300
                18.0     4.300 17.0     4.300 16.0     4.300 15.0     4.300
                14.0     4.300 13.0     4.300 12.0     4.300 11.0     4.300
                10.0     4.300  9.0     4.300  8.0     4.300  7.0     4.300
                 6.0     4.300  5.0     4.300  4.0     4.300  3.0     4.300
                 2.0     4.300  1.0     4.300  0.0     4.300
4  1 790220  47 46.0     4.200 45.0     4.200 44.0     4.200 43.0     4.200
                42.0     4.200 41.0     4.200 40.0     4.200 39.0     4.200
                38.0     4.200 37.0     4.200 36.0     4.200 35.0     4.300
                34.0     4.300 33.0     4.300 32.0     4.300 31.0     4.300
                30.0     4.300 29.0     4.300 28.0     4.300 27.0     4.300
                26.0     4.300 25.0     4.400 24.0     4.400 23.0     4.400
                22.0     4.400 21.0     4.400 20.0     4.400 19.0     4.400
                18.0     4.400 17.0     4.400 16.0     4.400 15.0     4.400
                14.0     4.400 13.0     4.400 12.0     4.400 11.0     4.300
                10.0     4.400  9.0     4.400  8.0     4.400  7.0     4.300
                 6.0     4.300  5.0     4.400  4.0     4.400  3.0     4.400
                 2.0     4.400  1.0     4.400  0.0     4.400
4  1 790306  49 48.0     4.500 47.0     4.500 46.0     4.600 45.0     4.600
                44.0     4.600 43.0     4.600 42.0     4.600 41.0     4.600
                40.0     4.600 39.0     4.600 38.0     4.600 37.0     4.700
                36.0     4.700 35.0     4.700 34.0     4.800 33.0     4.800
                32.0     4.900 31.0     5.000 30.0     5.100 29.0     5.200
                28.0     5.300 27.0     5.300 26.0     5.400 25.0     5.400
                24.0     5.400 23.0     5.400 22.0     5.400 21.0     5.500
                20.0     5.500 19.0     5.500 18.0     5.600 17.0     5.600
                16.0     5.700 15.0     5.700 14.0     5.800 13.0     5.900
                12.0     5.800 11.0     5.900 10.0     5.900  9.0     6.100
                 8.0     6.100  7.0     6.200  6.0     6.200  5.0     6.300
                 4.0     6.400  3.0     6.400  2.0     6.600  1.0     6.600
                 0.0     6.700
4  1 790320  47 46.0     4.900 45.0     4.900 44.0     4.900 43.0     4.900
                42.0     4.900 41.0     4.900 40.0     4.900 39.0     4.900
                38.0     4.900 37.0     4.900 36.0     4.900 35.0     4.900
                34.0     4.900 33.0     5.000 32.0     5.000 31.0     5.100
                30.0     5.100 29.0     5.100 28.0     5.100 27.0     5.100
                26.0     5.200 25.0     5.400 24.0     5.600 23.0     5.700
                22.0     5.700 21.0     5.800 20.0     5.900 19.0     6.000
                18.0     6.200 17.0     6.300 16.0     6.500 15.0     6.800
                14.0     7.300 13.0     7.600 12.0     8.200 11.0     8.500
                10.0     8.700  9.0     8.900  8.0     9.000  7.0     9.100
                 6.0     9.300  5.0     9.400  4.0     9.600  3.0    10.000
                 2.0    10.100  1.0    11.900  0.0    12.500
```

Figure 98. Example of confirmation data set for CE-QUAL-R1

Because the value of the index is based on the order of magnitude difference between measured and predicted values, results may be misleading if zero values are entered for measured data. CE-QUAL-R1 does not allow zero values to be predicted for certain variables. Instead, a small positive value, at or below normal detection limits, is maintained. This same small positive value should be used if measured data are reported as zero. Table 40 contains these small positive values. The file containing the field-measured data is the same file used for the Batch Graphics utility.

To execute the statistical package, the file given below is needed. (Names that are underlined can be changed at the user's discretion.)

```
JOBNAME.
/USER
/CHARGE
MAP,FULL.
GET,STSTOBJ.
GET,TAPE22=VD794.
GET,TAPE23=GRADAT.
GET,TAPE6=STSWICH.
RFL,CM=377700.
STSTOBJ.
SAVE,TAPE7=STSTDAT.
SAVE,OUTPUT=OFILE.
DAYFILE,DFSTAT.
SAVE,DFSTAT.
EXIT.
SAVE,TAPE7=STSTDAT.
EXIT.
SAVE,OUTPUT=OFILE.
EXIT.
DAYFILE,DFSTAT.
SAVE,DFSTAT.
```

File VD794 is the file that contains measured values. An example of this file is given in Figure 98. File GRADAT is the file that was created by the Data Manipulation utility. File STSWICH is a one-line file containing information on variables for which statistics will be performed. A "1" in a particular column will cause the statistical analysis to be performed for a particular variable. The column code for variables can be found in Table 40. An example of output from this utility is shown in Figure 99.

```
1                                         STATISTICAL PROGRAM FOR CE-QUAL-R1 COMPARING FILES
                       DEGRAY79 ST.4                             AND    DEGRAY79 JUNE 11 1985 NO.1
                                          VAX VERSION  1-16-85


         RELIABILITY INDEX  LEGGETT AND WILLIAMS ECOLOGICAL MODELLING 13(1981)303-312
         PAIRED T TEST FOR MEANS SOKAL AND ROHLF 1969 BIOMETRY W.H.FREEMAN AND COMPANY
         NORMALIZED MEAN ERROR(SUM(ABS(P-O)/O)*100.)/N,
         COEFFICIENTS FOR THE LINEAR REGRESSION EQUATION
         STATISTICS ARE UNDEFINED WHEN .999 IS PRINTED


0  VARIABLE     DATE      NUMBER OF    OBSERVED     PREDICTED        T       RELIABILITY   NORMALIZED
              YYMMDD    COMPARISONS     MEAN         MEAN        STATISTIC     INDEX       MEAN ERROR
 TEMP         790206         47       0.430E+01    0.389E+01     0.206E+02    0.111E+01    0.957E+01
 TEMP         790220         47       0.433E+01    0.375E+01     0.288E+02    0.116E+01    0.133E+02
 TEMP         790306         49       0.539E+01    0.513E+01     0.750E+01    0.107E+01    0.489E+01
 TEMP         790320         47       0.660E+01    0.626E+01     0.269E+01    0.113E+01    0.102E+02
 TEMP         790403         49       0.759E+01    0.762E+01    -0.272E+00    0.109E+01    0.590E+01
 TEMP         790417         46       0.890E+01    0.878E+01     0.138E+01    0.106E+01    0.397E+01
 TEMP         790501         49       0.890E+01    0.934E+01    -0.404E+01    0.106E+01    0.520E+01
 TEMP         790516         45       0.103E+02    0.107E+02    -0.314E+01    0.107E+01    0.491E+01
 TEMP         790529         47       0.107E+02    0.111E+02    -0.250E+01    0.109E+01    0.556E+01
 TEMP         790612         50       0.114E+02    0.116E+02    -0.928E+00    0.111E+01    0.617E+01
 TEMP         790626         47       0.119E+02    0.124E+02    -0.237E+01    0.110E+01    0.613E+01
 TEMP         790710         48       0.120E+02    0.125E+02    -0.225E+01    0.110E+01    0.613E+01
 TEMP         790724         47       0.123E+02    0.129E+02    -0.249E+01    0.112E+01    0.781E+01
 TEMP         790807         47       0.129E+02    0.134E+02    -0.185E+01    0.114E+01    0.945E+01
 TEMP         790821         46       0.128E+02    0.136E+02    -0.257E+01    0.114E+01    0.103E+02
 TEMP         790904         48       0.129E+02    0.134E+02    -0.198E+01    0.112E+01    0.809E+01
 TEMP         790918         48       0.120E+02    0.124E+02    -0.138E+01    0.113E+01    0.733E+01
 TEMP         791002         41       0.132E+02    0.134E+02    -0.889E+00    0.111E+01    0.712E+01
 TEMP         791016         45       0.117E+02    0.115E+02     0.142E+01    0.109E+01    0.480E+01
 TEMP         791030         47       0.110E+02    0.111E+02    -0.690E+00    0.109E+01    0.484E+01
 TEMP         791113         45       0.104E+02    0.987E+01     0.298E+01    0.113E+01    0.655E+01
 TEMP         791127         45       0.979E+01    0.942E+01     0.309E+01    0.108E+01    0.478E+01
 TEMP         791211         47       0.870E+01    0.820E+01     0.490E+01    0.109E+01    0.615E+01
 TEMP         791227         44       0.848E+01    0.794E+01     0.512E+01    0.110E+01    0.722E+01
0TEMP       ALL DATES       1121      0.991E+01    0.100E+02    -0.210E+01    0.111E+01    0.694E+01
 A=-.949E+00  B=0.110E+01   T FOR SLOPES=0.202E+02  T FOR INTERCEPTS=,-.156E+02   R SQUARE=0.976E+00   ST.ERROR OF EST.=0.370E+02
```

Figure 99. Example of output from the Statistics utility

Flux

To execute the flux package, prepare a file, as listed below, for use by the SUBMIT directive. (Names that are underlined can be changed at the user's discretion.)

```
FLXXEQ,CM300000,T300,P6.
/USER
/CHARGE
MAP,FULL.
GET,FLXOBJ/UN=CEROB5,TAPE61=FLUX,TAPE5=FLXIN5.
FLXOBJ.
SAVE,TAPE6=OUTPF.
SAVE,OUTPUT=PUTOUT1.
DAYFILE,DAYFX.
SAVE,DAYFX.
SAVE,TAPE6=OUTPF.
EXIT.
SAVE,OUTPUT=PUTOUT1.
EXIT.
DAYFILE,DAYFX.
REPLACE,DAYFX.
```

File FLUX is the file where information from a CE-QUAL-R1 simulation is stored. File FLXIN5 (Figure 100) is a four-line file containing information needed for output. The first line contains the

Figure 100. Example of file FLUX5
for the FLUX utility

hour of the year for which output is requested; up to 16 values can be specified in fields of five characters each. The second line contains either a blank or a "1" in the first 16 columns. A "1" signifies that information is needed for a particular variable; the 16 variables for which flux values are calculated are listed in Table 41.

Table 41

Variables for Which Flux Information Is Available

Column	Variable
1	Fish 1
2	Zooplankton
3	Algae (three compartments)
4	Silica
5	Detritus
6	Sediment
7	Labile DOM
8	Orthophosphate
9	Inorganic carbon
10	Ammonia
11	Nitrite plus nitrate
12	Oxygen
13	Refractory DOM
14	Sediment phosphorus
15	Sediment nitrogen
16	Macrophytes

The third line of FLXIN5 contains two variables. The first variable concerns how the fluxes are to be summed according to layers. It must be remembered that CE-QUAL-R1 contains a variable-layer scheme and that the layers are numbered from the bottom to the surface. Throughout the year, the number of layers may change, so that the surface layer may not always have the same layer number. If the user is interested in a particular process occurring at the surface--for example, surface aeration--he would have to look at different layer numbers during different times of the year. To make it easier to study the fluxes occurring in the epilimnion, it is possible to sum fluxes in relation to the surface by putting the word SURFACE in columns 1 through 7 of the third card. Otherwise, the fluxes will be summed from the bottom of the reservoir. The second variable concerns units of output: if the word CUBICM is specified in columns 11 through 16, fluxes will be reported in g/m^3; fluxes will be reported in units of kilograms/layer with any other specification.

The fourth line of FLXIN5 contains three variables, the first of which concerns the number of time steps for which fluxes are to be accumulated; the value is shown in columns 1 through 5, right justified. For example, if the original simulation used a 24-hr time step, a "1" in column 5 would give information on fluxes on a daily basis; a value of 30 would accumulate fluxes for periods of approximately 1 month. The second variable, in columns 6 through 10, represents hours and allows output to be specified at particular intervals (this information is printed in addition to output requested in the first line). The third variable, in columns 11 through 15, specifies the Julian date for the start of the simulation.

Upon satisfactory completion of the execution, four files will be created and permanently stored. File MAP2 contains the storage location map. File OUTPF is the normal output from the flux package; an example of output is given in Figure 101. File PUTOUT1 contains information concerning problems during execution. File DAYFX is the day file that describes the execution.

```
                              DEGRAY79 JUNE 6 1985 NO.1
                                 FLUX VERSION MAY. 7 85

SIMULATION HOUR=  1320 LOWEST NUMBER OF LAYERS=   53    LAYERS NUMBERED FROM THE SURFACE
FLUXES ARE IN KG/LAYER ACCUMULATED OVER THE LAST    31 SIMULATION TIME STEPS
                       ******************************************************************************
                       ******************************************************************************

                                          FLUX FOR REFRACTORY DOM

LAYER DECOMPOSITION  FROM LABILE       INFLOW      OUTFLOW          NET           DIFFUSION             TOTAL
                      DOM DECAY                              CONVECTION        ABOVE        BELOW
    1  -0.3012E+05   0.5896E+05   0.7533E+05  -0.9078E+04  -0.1001E+06   0.0000E+00   0.5515E+05   0.5012E+05
    2  -0.2800E+05   0.5278E+05   0.5253E+05  -0.1379E+05  -0.3541E+04  -0.5515E+05   0.7662E+05   0.8144E+05
    3  -0.2645E+05   0.4963E+05   0.3476E+05  -0.1342E+05   0.8881E+05  -0.7662E+05   0.5303E+05   0.1097E+06
    4  -0.2507E+05   0.4710E+05   0.2289E+05  -0.1319E+05   0.1196E+06  -0.5303E+05   0.3746E+05   0.1358E+06
    5  -0.2379E+05   0.4473E+05   0.2174E+05  -0.1305E+05   0.1080E+06  -0.3746E+05   0.6104E+05   0.1613E+06
    6  -0.2240E+05   0.4212E+05   0.1850E+05  -0.1280E+05   0.1104E+06  -0.6104E+05   0.3525E+05   0.1100E+06
    7  -0.2117E+05   0.3979E+05   0.1748E+05  -0.1265E+05   0.1497E+06  -0.3525E+05   0.3153E+05   0.1695E+06
    8  -0.1989E+05   0.3730E+05   0.1009E+05  -0.1240E+05   0.6293E+05  -0.3153E+05   0.2917E+05   0.7566E+05
    9  -0.1887E+05   0.3534E+05   0.9556E+04  -0.1231E+05   0.5899E+05  -0.2917E+05   0.2855E+05   0.7208E+05
   10  -0.1784E+05   0.3335E+05   0.8077E+04  -0.1219E+05   0.5191E+05  -0.2855E+05   0.2921E+05   0.6397E+05
   11  -0.1687E+05   0.3145E+05   0.7011E+04  -0.1208E+05  -0.1297E+06  -0.2921E+05   0.2659E+05  -0.1228E+06
   12  -0.1593E+05   0.2964E+05   0.5693E+04  -0.1197E+05  -0.8527E+05  -0.2659E+05   0.2441E+05  -0.8002E+05
   13  -0.1505E+05   0.2795E+05   0.5368E+04  -0.1189E+05  -0.5591E+05  -0.2441E+05   0.2257E+05  -0.5136E+05
   14  -0.1420E+05   0.2633E+05   0.5055E+04  -0.1181E+05  -0.5748E+05  -0.2257E+05   0.3973E+05  -0.3495E+05
   15  -0.1338E+05   0.2476E+05   0.4754E+04  -0.1174E+05  -0.5245E+05  -0.3973E+05   0.1983E+05  -0.6796E+05
   16  -0.1254E+05   0.2319E+05   0.3051E+04  -0.1164E+05  -0.4109E+05  -0.1983E+05   0.1487E+05  -0.4399E+05
   17  -0.1181E+05   0.2172E+05   0.1340E+04  -0.1156E+05  -0.1272E+06  -0.1487E+05   0.1282E+05  -0.1295E+06
   18  -0.1107E+05   0.2034E+05   0.1255E+04  -0.1150E+05  -0.9073E+05  -0.1282E+05   0.1122E+05  -0.9330E+05
   19  -0.1034E+05   0.1900E+05   0.6613E+03  -0.1143E+05  -0.9554E+05  -0.1122E+05   0.9916E+04  -0.9896E+05
   20  -0.9669E+04   0.1773E+05   0.6171E+03  -0.1137E+05  -0.5651E+05  -0.9916E+04   0.8339E+04  -0.6078E+05
   21  -0.9017E+04   0.1652E+05   0.5748E+03  -0.1132E+05   0.6432E+04  -0.8339E+04   0.7741E+05   0.7227E+05
   22  -0.8394E+04   0.1535E+05   0.5343E+03  -0.1126E+05   0.1367E+04  -0.7741E+05   0.1196E+05  -0.6785E+05
   23  -0.7797E+04   0.1424E+05   0.4957E+03  -0.1121E+05  -0.1467E+02  -0.1196E+05   0.1025E+05  -0.5998E+04
   24  -0.7245E+04   0.1322E+05   0.4601E+03  -0.1037E+05  -0.3198E+03  -0.1025E+05   0.2621E+05   0.1170E+05
   25  -0.6720E+04   0.1224E+05   0.4268E+03  -0.9186E+04  -0.1192E+03  -0.2621E+05   0.1540E+05  -0.1416E+05
   26  -0.6225E+04   0.1133E+05   0.3951E+03  -0.8044E+04   0.3577E+03  -0.1540E+05   0.1092E+05  -0.6672E+04
   27  -0.5730E+04   0.1042E+05   0.3633E+03  -0.8014E+04   0.5060E+04  -0.1092E+05   0.9647E+04   0.8279E+03
   28  -0.5259E+04   0.9554E+04   0.3332E+03  -0.7988E+04   0.8090E+04  -0.9647E+04   0.8473E+04   0.3557E+04
   29  -0.4809E+04   0.8734E+04   0.3047E+03  -0.7965E+04   0.9782E+04  -0.8473E+04   0.7419E+04   0.4992E+04
   30  -0.4392E+04   0.7973E+04   0.1230E+03  -0.7304E+04   0.1062E+05  -0.7419E+04   0.6975E+04   0.6574E+04
   31  -0.3999E+04   0.7243E+04   0.0000E+00  -0.6981E+04   0.1094E+05  -0.6975E+04   0.5235E+04   0.5468E+04
   32  -0.3624E+04   0.6562E+04   0.0000E+00  -0.6673E+04   0.1054E+05  -0.5235E+04   0.4136E+04   0.5710E+04
   33  -0.3299E+04   0.5973E+04   0.0000E+00  -0.6100E+04   0.1011E+05  -0.4136E+04   0.4095E+04   0.6639E+04
   34  -0.2972E+04   0.5365E+04   0.0000E+00  -0.6114E+04   0.9695E+04  -0.4095E+04   0.2844E+04   0.4724E+04
   35  -0.2652E+04   0.4801E+04   0.0000E+00  -0.5862E+04   0.8881E+04  -0.2844E+04   0.2143E+04   0.4466E+04
   36  -0.2367E+04   0.4268E+04   0.0000E+00  -0.5896E+04   0.8001E+04  -0.2143E+04   0.1481E+04   0.3345E+04
   37  -0.2093E+04   0.3772E+04   0.0000E+00  -0.5941E+04   0.7773E+04  -0.1481E+04   0.9501E+03   0.2981E+04
   38  -0.1838E+04   0.3312E+04   0.0000E+00  -0.5999E+04   0.7542E+04  -0.9501E+03  -0.3711E+02   0.2028E+04
   39  -0.1602E+04   0.2884E+04   0.0000E+00  -0.6071E+04   0.7113E+04   0.3711E+02   0.2839E+03   0.2645E+04
   40  -0.1391E+04   0.2504E+04   0.0000E+00  -0.5918E+04   0.7236E+04  -0.2839E+03  -0.5172E+03   0.1630E+04
   41  -0.1198E+04   0.2155E+04   0.0000E+00  -0.5784E+04   0.1689E+04   0.5172E+03  -0.3067E+03  -0.2928E+04
   42  -0.1012E+04   0.1818E+04   0.0000E+00  -0.5908E+04   0.3147E+04   0.3067E+03  -0.3720E+03  -0.2021E+04
   43  -0.8541E+03   0.1535E+04   0.0000E+00  -0.5622E+04   0.1905E+04   0.3720E+03  -0.7031E+03  -0.3367E+04
   44  -0.7207E+03   0.1274E+04   0.0000E+00  -0.5006E+04   0.1889E+04   0.7031E+03  -0.7546E+03  -0.2616E+04
   45  -0.5766E+03   0.1018E+04   0.0000E+00  -0.5362E+04   0.1925E+04   0.7546E+03  -0.1620E+03  -0.2403E+04
   46  -0.3144E+03   0.5507E+03   0.0000E+00  -0.4499E+04   0.1334E+04   0.1620E+03  -0.2984E+03  -0.3065E+04
   47  -0.2247E+03   0.3923E+03   0.0000E+00  -0.4089E+04   0.1065E+04   0.2984E+03  -0.1989E+03  -0.2757E+04
   48  -0.1980E+03   0.3472E+03   0.0000E+00  -0.4087E+04   0.8298E+03   0.1989E+03  -0.5111E+02  -0.2960E+04
   49  -0.1423E+03   0.2491E+03   0.0000E+00  -0.5424E+04   0.6296E+03   0.5111E+02  -0.1558E+02  -0.4652E+04
   50  -0.8482E+02   0.1478E+03   0.0000E+00  -0.5426E+04   0.5023E+03   0.1558E+02  -0.3335E+01  -0.4848E+04
   51  -0.3294E+02   0.5617E+02   0.0000E+00  -0.4209E+04   0.3855E+03   0.3335E+01  -0.1144E+01  -0.3798E+04
   52  -0.1644E+02   0.2788E+02   0.0000E+00  -0.6742E+04   0.2780E+03   0.1144E+01  -0.1957E+00  -0.6452E+04
   53  -0.8149E+01   0.1365E+02   0.0000E+00  -0.2512E+04   0.1975E+03   0.1957E+00  -0.1312E-01  -0.2309E+04
   54  -0.4075E+01   0.6756E+01   0.0000E+00  -0.3689E+04   0.1344E+03   0.1312E-01   0.0000E+00  -0.3552E+04
   55  -0.2293E+01   0.3796E+01   0.0000E+00  -0.1289E+04   0.8646E+02   0.0000E+00   0.0000E+00  -0.1201E+04
   56  -0.1272E+01   0.2108E+01   0.0000E+00  -0.3171E+03   0.5137E+02   0.0000E+00   0.0000E+00  -0.2649E+03
   57  -0.6518E+00   0.1082E+01   0.0000E+00  -0.2461E+02   0.2739E+02   0.0000E+00   0.0000E+00   0.3213E+01
   58  -0.2924E+00   0.4853E+00   0.0000E+00   0.0000E+00   0.1233E+02   0.0000E+00   0.0000E+00   0.1252E+02
   59  -0.1052E+00   0.1745E+00   0.0000E+00   0.0000E+00   0.4416E+01   0.0000E+00   0.0000E+00   0.4485E+01
   60  -0.8171E-02   0.1356E-01   0.0000E+00   0.0000E+00   0.3424E+00   0.0000E+00   0.0000E+00   0.3478E+00
TOTAL  -0.4613E+06   0.8591E+06   0.3098E+06  -0.4661E+06  -0.9430E-02  -0.8297E+06   0.8297E+06   0.2415E+06
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Figure 101. Example of output from the Flux utility

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APPENDIX A: GLOSSARY OF TERMS

Term	Units*	Explanation**	Record Where Read†
ADMAXN	g N m^{-3}/g solids m^{-3}	Maximum amount of nitrogen adsorbed	SSETL
ADMAXP	g P m^{-3}/g solids m^{-3}	Maximum amount of phosphorus adsorbed	SSETL
ADSRBN	m^3 g^{-1}	Adsorption coefficient for nitrogen	SSETL
ADSRBP	m^3 g^{-1}	Adsorption coefficient for phosphorus	SSETL
AEXCR(I,J)	hr^{-1}	Excretion of the J^{th} algal group in the I^{th} layer [TPEXCR]	ALG2,3,4 hr^{-1}
ALDIGO	dimensionless	Fraction of dead algae going to detritus	ALG1
ALGAE(I,1)	g m^{-3}	Concentration of algae 1 in the I^{th} layer [DALGA1]	INIT2
ALGAE(I,2)	g m^{-3}	Concentration of algae 2 in the I^{th} layer [DALGA2]	INIT2
ALGAE(I,3)	g m^{-3}	Concentration of algae 3 in the I^{th} layer [DALGA3]	INIT2
ALGAS	dimensionless	SE between silica and algae	ALG1
ALGT4(J)	°C	Upper lethal temperature bound for the J^{th} algal compartment [ALG(J)T4]	ALG6,7,8
ALKA(I)	g m^{-3}	Concentration of alkalinity as $CaCO_3$ [DALKA]	INIT2
ALKAIN(J)	g m^{-3}	Inflowing concentration of alkalinity in J^{th} tributary	ALKA
AMU(I,J)	hr^{-1}	TV for photosynthesis of the J^{th} algal compartment in I^{th} layer, computed	
ANPM(I,J)	hr^{-1}	TV for mortality of the J^{th} algal compartment in I^{th} layer, computed	
AREA(I)	m^2	Lower area of the I^{th} layer	AREAC
ART(I,J)	hr^{-1}	TV for respiration of the J^{th} algal compartment in the I^{th} layer, computed	
BIOC	dimensionless	SE between carbon and organic matter [BIOC]	BIO
BION	dimensionless	SE between nitrogen and organic matter [BION]	BIO
BIOP	dimensionless	SE between phosphorus and organic matter [BIOP]	BIO
CARBIN(N)	g m^{-3}	Inflowing concentration of carbon in the N^{th} tributary, computed	

(Continued)

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* Units given are those used by the computer program. Input units may be different; they are converted internally.

** Variable names in brackets correspond to the input data read in Part IV. "TV" represents temporary variable; "SE" represents stoichiometric equivalent.

† For CE-QUAL-R1; most of these variables are not used in CE-THERM-R1.

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Term	Units	Explanation	Record Where Read
CARBON(I)	g m^{-3}	Concentration of inorganic carbon in the I^{th} layer, computed	
CMN(I)	g $layer^{-1}$	Total amount of manganese in the I^{th} layer of sediments [DCMN]	INIT4
CMN2(I)	g m^{-3}	Concentration for Mn^{+2} in the I^{th} layer [DCMN2]	INIT4
CMN4(I)	g m^{-3}	Concentration of Mn(IV) in the I^{th} layer [DCMN4]	INIT4
CMN4IN(J)	g m^{-3}	Inflowing concentration of Mn(IV) in the J^{th} tributary	ANR
CNH3DK	hr^{-1}	Decay rate of ammonium [TNH3DK]	DECAY1
CNH3(I)	g m^{-3}	Concentration of ammonium in the I^{th} layer [DCNH3]	INIT2
CNH3IN(N)	g m^{-3}	Inflowing concentration of ammonium in the N^{th} layer	CNH4
CN(I)	g $layer^{-1}$	Total amount of nitrogen in the I^{th} layer of sediments [DCN]	INIT5
CNO3DK	hr^{-1}	Nitrite plus nitrate denitrification rate [TNO3DK]	DECAY1
CNO3(I)	g m^{-3}	Concentration of nitrite plus nitrate in the I^{th} layer [DCNO3]	INIT2
CNO3IN(N)	g m^{-3}	Inflowing concentration of nitrite plus nitrate in the N^{th} tributary	CNO3
CNREL	g m^{-2} hr^{-1}	Sediment release rate of nitrogen [TCNREL]	ANAER4
CNTOT(I)	g m^{-3}	Total nitrogan available for photosynthesis in the I^{th} layer, computed	
COLIDK	hr^{-1}	Maximum coliform decay rate [TCOLDK]	DECAY1
COLIF(I)	colonies/100 ml	Coliform concentration in the I^{th} layer [DCOLIF]	INIT2
COLIN(J)	colonies/100 ml	Inflowing concentration of coliforms in the J^{th} tributary	COL
CO2(NUME)	g m^{-3}	Carbon dioxide concentration in the surface layer, computed	
CSED(I)	g $layer^{-1}$	Amount of sediment in the I^{th} layer, [DSEDMT]	INIT3
DC(I)	m^2 hr^{-1}	Diffusion coefficient for the I^{th} layer, computed	

(Continued)

(Sheet 2 of 10)

Term	Units	Explanation	Record Where Read
DETUDK	hr^{-1}	Maximum detritus decay rate [TDETDK]	DECAY1
DETUIN(N)	$g\ m^{-3}$	Inflowing concentration of detritus in the N^{th} tributary	DET
DETUS(I)	$g\ m^{-3}$	Detritus concentration in the I^{th} layer [DDETUS]	INIT3
DMCO2	$m^2\ hr^{-1}$	Molecular diffusion coefficient for CO_2	DIFC
DMO2	$m^2\ hr^{-1}$	Molecular diffusion coefficient for oxygen	DIFC
DOCIN(N)	$g\ m^{-3}$	Inflowing concentration of labile dissolved organic carbon in the N^{th} tributary	DOML
DOM(I)	$g\ m^{-3}$	Concentration of labile DOM in the I^{th} layer [DDOM]	INIT3
DOMDK	hr^{-1}	Maximum decay rate of labile DOM [TDOMDK]	DECAY1
DOMRFR	hr^{-1}	Decay rate from labile to refractory DOM [TDOMRF]	DECAY1
DSETL	$m\ hr^{-1}$	Detritus settling rate [TDSETL]	DET1
DVOL(I)	m^{-3}	Volume of the I^{th} layer, computed	
EXCRM	hr^{-1}	Maximum excretion rate of macrophytes [TMEXCR]	PLANT1
FEFFIC	dimensionless	Ingestion efficiency for fish	FISH2
FE(I)	$g\ layer^{-1}$	Total amount of iron in the I^{th} sediment layer [DFE]	INIT5
FEREL	$g\ m^{-2}\ hr^{-1}$	Release rate of FE^{+2} from the sediments [TFEREL]	ANAER3
FESA(I)	$g\ layer^{-1}$	Total amount of iron sulfide in the I^{th} sediment layer [DFESA]	INIT5
FESADK	hr^{-1}	Oxidation rate of sediment iron sulfide [TFESAD]	ANAER3
FESBDK	hr^{-1}	Oxidation rate of FeS [TFESBD]	ANAER3
FESB(I)	$g\ m^{-3}$	Concentration of iron sulfide in the I^{th} layer [DFESB]	INIT4
FESBIN(J)	$g\ m^{-3}$	Inflowing concentration of iron sulfide in the J^{th} tributary	FESB
FESSTL	$m\ hr^{-1}$	Settling rate of iron sulfide [TFE3ST]	ANAER3
FE2(I)	$g\ m^{-3}$	Concentration of Fe^{+2} in the I^{th} layer [DFE2]	INIT4

(Continued)

(Sheet 3 of 10)

Term	Units	Explanation	Record Where Read
FE2IN(J)	g m^{-3}	Inflowing concentration of Fe^{+2} in the J^{th} tributary	FE2
FE2OXI	hr^{-1}	Oxidation rate of Fe^{+2} [TFE2OX]	ANAER3
FE3(I)	g m^{-3}	Concentration of FE(III) in the I^{th} layer [DFE3]	INIT4
FE3IN(J)	g m^{-3}	Inflowing concentration of Fe(III) in the J^{th} tributary	FE3
FE3RED	hr^{-1}	Reduction rate of Fe(III) [TFE3RE]	ANAER3
FE3STL	m hr^{-1}	Settling rate of Fe(III) [TFE3ST]	ANAER3
FISHB(I)	g m^{-3}	Fish concentration in the I^{th} layer [FISH]	INIT1
FMORTA	hr^{-1}	Maximum fish mortality rate [TFMORT]	FISH2
FMT(I)	hr^{-1}	TV of fish mortality in the I^{th} layer computed	
FMU(I)	hr^{-1}	TV of fish ingestion in the I^{th} layer computed	
FPALG(J)	dimensionless	Preference factor for fish for the J^{th} algal compartment	FISH1
FPDET	dimensionless	Preference factor for fish for the J^{th} detritus compartment	FISH1
FPSED	dimensionless	Preference factor for fish for the J^{th} sediment compartment	FISH1
FPZOO	dimensionless	Preference factor for fish for the J^{th} zooplankton compartment	FISH1
FRACT(I)	dimensionless	Fraction of area of the I^{th} layer with water beneath it, computed	
FRESP	hr^{-1}	Maximum fish respiration rate [TFRESP]	FISH2
FRT(I)	hr^{-1}	TV of fish respiration for the I^{th} layer, computed	
FSHEAT(I)	g	Weighted food amount for fish, computed	
FSHMAX	hr^{-1}	Maximum fish ingestion rate [TFMAX]	FISH1
FS2FSH	g m^{-3}	Half-saturation coefficient for fish ingestion	FISH1
GROLIT	dimensionless	TV limiting macrophyte photosynthesis due to light, computed	
HARVST	kg hr^{-1}	Fish harvest rate	FHARV2

(Continued)

(Sheet 4 of 10)

Term	Units	Explanation	Record Where Read
MNREL	$g\ m^{-2}\ hr^{-1}$	Mn^{+2} release rate from the sediments [TMNREL]	ANAER2
MN2OXI	hr^{-1}	Oxidation rate of Mn^{+2} [TMN2OX]	ANAER2
MN4RED	hr^{-1}	Reduction rate of Mn(IV) [TMN4RE]	ANAER2
MN4STL	$m\ hr^{-1}$	Settling rate of Mn(IV) [TMN4ST]	ANAER2
MXQUAL(J)	$g\ m^{-3}$	Pumpback concentration of the J^{th} constituent, computed	
MIN1	dimensionless	Function that selects the minimum value from a list	
OXY(I)	$g\ m^{-3}$	Oxygen concentration in the I^{th} layer [DOXY]	INIT3
OXYIN(J)	$g\ m^{-3}$	Inflowing concentration of oxygen in the J^{th} tributary	OXY
O2DET	dimensionless	SE between detritus and oxygen for decomposition	CHEM
O2DOM	dimensionless	SE between DOM and oxygen for decomposition	CHEM
O2FAC	dimensionless	SE between algae and oxygen for photosynthesis	CHEM
O2FE2	dimensionless	SE between iron and oxygen for oxidation	CHEM
O2MN2	dimensionless	SE between manganese and oxygen for oxidation	CHEM
O2NH3	dimensionless	SE between ammonia and oxygen for oxidation	CHEM
O2RESP	dimensionless	SE between biological constituents and oxygen for respiration	CHEM
O2S2	dimensionless	SE between sulfide and oxygen for oxidation	CHEM
PALGAE(I,J)	$g\ hr^{-1}$	TV for concentration independent terms for J^{th} algae in the I^{th} layer, computed	
PALK(I)	$g\ hr^{-1}$	TV for concentration independent terms for alkalinity in the I^{th} layer, computed	
PBENTR(I)	$m^3\ hr^{-1}$	Entrained water in the I^{th} layer due to pumpback, computed	
PBFLOW	m^3	Amount of pumpback plus entrained flow	
PCAR(I)	$g\ hr^{-1}$	TV for concentration independent terms for carbon in the I^{th} layer, computed	
PDET(I)	$g\ hr^{-1}$	TV for concentration independent terms for detritus in the I^{th} layer, computed	

(Continued)

(Sheet 5 of 10)

Term	Units	Explanation	Record Where Read
PDOM(I)	g hr^{-1}	TV for concentration independent terms for DOM, in the I^{th} layer, computed	
PEXCR(J)	hr^{-1}	Maximum excretion rate for the J^{th} algal group [TPEXCR(J)]	ALG2,3,4
PFE3(I)	g hr^{-1}	TV for concentration independent terms for Fe(III) in the I^{th} layer, computed	
PHOURS	hr^{-1}	Number of hours of pumpback [XTIME]	OPSCH2
PISAT(J)	Kcal m^{-2} hr^{-1}	Light at maximum photosynthesis for the J^{th} algal group	ALG2,3,4
PLDIGO(1)	dimensionless	Fraction of dead plants going to DOM	PLANT1
PLDIGO(2)	dimensionless	Fraction of dead plants going to detritus	PLANT1
PLDIGO(3)	dimensionless	Fraction of dead plants going to sediment	PLANT1
PLFLX(I,1)	g hr^{-1}	TV for macrophyte photosynthesis, computed	
PLFLX(I,2)	g hr^{-1}	TV for macrophyte photosynthesis, computed	
PLFLX(I,3)	g hr^{-1}	TV for macrophyte respiration, computed	
PLFLX(I,4)	g hr^{-1}	TV for macrophyte excretion, computed	
PLFLX(I,5)	g hr^{-1}	TV for macrophyte mortality, computed	
PLFLX(I,6)	g hr^{-1}	TV for macrophyte mortality, computed	
PLFRAC	dimensionless	Fraction of nutrients for macrophyte growth from water column	
PLMORT	hr^{-1}	Maximum mortality of macrophytes [TMMORT]	PLANT1
PLNT(J,I)	g $cell^{-1}$	Macrophyte mass in the J^{th} layer, I^{th} column	PLANTS
PLTMAX	hr^{-1}	Maximum rate for macrophyte production [TPLMAX]	PLANT1
PMAX(J)	hr^{-1}	Maximum rate for algal production of the J^{th} group [TPMAX]	ALG2,3,4
PMN2(I)	g hr^{-1}	TV for concentration independent terms for Mn^{+2} in the I^{th} layer, computed	
PMN4(I)	g hr^{-1}	TV for concentration independent terms for Mn(IV) in the I^{th} layer, computed	
PMORT(J)	hr^{-1}	Maximum rate for algal mortality of the J^{th} group [TPMORT]	ALG2,3,4

(Continued)

(Sheet 6 of 10)

Term	Units	Explanation	Record Where Read
PNH3(I)	g hr^{-1}	TV for concentration independent terms for ammonia in the I^{th} layer, computed	
PNO3(I)	g hr^{-1}	TV for concentration independent terms for nitrate plus nitrite in the I^{th} layer, computed	
POXY(I)	g hr^{-1}	TV for concentration independent terms for oxygen in the I^{th} layer, computed	
PO4(I)	g m^{-3}	Concentration of orthophosphate in the I^{th} layer [DPO4]	INIT3
PO4IN(N)	g m^{-3}	Inflowing concentration of phosphorus in the N^{th} tributary	PO4
PPO4(I)	g hr^{-1}	TV for concentration independent terms for phosphorus in the I^{th} layer, computed	
PREF(1)	dimensionless	Preference factor of zooplankton for algae 1	ZOO1
PREF(2)	dimensionless	Preference factor of zooplankton for algae 2	ZOO1
PREF(3)	dimensionless	Preference factor of zooplankton for algae 3	ZOO1
PREF(4)	dimensionless	Preference factor of zooplankton for detritus	ZOO1
PRESP(J)	hr^{-1}	Maximum respiration rate of the J^{th} algal compartment [TPRESP]	ALG2,3,4
PRFR(I)	g hr^{-1}	TV for concentration independent terms for refractory organic matter in the I^{th} layer, computed	
PSI(I)	g hr^{-1}	TV for concentration independent terms for silica in the I^{th} layer, computed	
PSO4(I)	g hr^{-1}	TV for concentration independent terms for sulfate in the I^{th} layer, computed	
PSSOL(I)	g hr^{-1}	TV for concentration independent terms for suspended solids in the I^{th} layer, computed	
PS2(I)	g hr^{-1}	TV for concentration independent terms for sulfide in the I^{th} layer, computed	
PTDS(I)	g hr^{-1}	TV for concentration independent terms for total dissolved solids in the I^{th} layer, computed	
QHI(I)	m^3 hr^{-1}	Inflow rate to the I^{th} layer, computed	
QHO(I)	m^3 hr^{-1}	Outflow rate from the I^{th} layer, computed	
Q10COL	dimensionless	Q_{10} formulation for coliform die-off	TMP

(Continued)

(Sheet 7 of 10)

Term	Units	Explanation	Record Where Read
RESPM	hr^{-1}	Maximum macrophyte respiration rate [TMRESP]	PLANT1
RFRDK	hr^{-1}	Maximum decay rate for refractory organics [TRFRDK]	DECAY1
RFR(I)	$g\ m^{-3}$	Concentration of refractory dissolved organics [DCRFR]	INIT2
RFRIN(N)	$g\ m^{-3}$	Inflowing concentration of refractory dissolved organics in the N^{th} tributary	DOMR
RTMLT1(J,I)	dimensionless	Ascending temperature rate multiplier, computed	
RTMLT2(J,I)	dimensionless	Descending temperature rate multiplier, computed	
SEDDK	hr^{-1}	Maximum sediment decay rate [TSEDDK]	DECAY1
SETL(J)	$m\ hr^{-1}$	Settling rate of the J^{th} algal compartment [TSETL(J)]	ALG2,3,4
SDZ(I)	m	Thickness of the I^{th} layer	PHYS2+
S(I)	$g\ layer^{-1}$	Total amount of sulfur in the I^{th} sediment layer [DS]	INIT5
SI(I)	$g\ m^{-3}$	Silica concentration in the I^{th} layer [DSI]	INIT5
SIIN(N)	$g\ m^{-3}$	Inflowing silica concentration in the N^{th} tributary	SI
SO4(I)	$g\ m^{-3}$	Concentration of SO_4^{-2} in the I^{th} layer [DSO4]	INIT4
SO4IN(J)	$g\ m^{-3}$	Inflowing concentration of SO_4^{-2} in the J^{th} tributary	SO4
SO4RED	hr^{-1}	Reduction rate of SO_4^{-2} [TSO4RE]	ANAER4
SREL	$g\ m^{-2}\ hr^{-1}$	Release rate of S^{-2} from the sediments [TSREL]	ANAER4
SSETL	$m\ hr^{-1}$	Settling rate of suspended solids [TSSETL]	SSETL
SSOL(I)	$g\ m^{-3}$	Concentration of suspended solids in the I^{th} layer [DDSOL]	INIT4
SSOLIN(J)	$g\ m^{-3}$	Inflowing concentration of suspended solids in the J^{th} tributary	SSOL
SUMJ	dimensionless	TV representing the number of variables that settle, computed	
SWS(I)	$Kcal\ m^{-2}\ hr^{-1}$	Shortwave radiation in the I^{th} layer, computed	

(Continued)

(Sheet 8 of 10)

Term	Units	Explanation	Record Where Read
S2DK	hr^{-1}	Reaction rate of S^{-2} to form FeS	ANAER4
S2(I)	$g\ m^{-3}$	Concentration of S^{-2} in the I^{th} layer, [DS2]	INIT4
S2OXI	hr^{-1}	Oxidation rate of S^{-2} [TS2OXI]	ANAER4
S2IN(J)	$g\ m^{-3}$	Inflowing concentration of S^{-2} in the J^{th} tributary	S2
TALGAE(I)	$g\ m^{-3}$	TV for total weighted food for zooplankton, computed	
TDS(I)	$g\ m^{-3}$	Concentration of total dissolved solids in the I^{th} layer [DTDS]	INIT3
TSDIN(J)	$g\ m^{-3}$	Inflowing concentration of total dissolved solids in the J^{th} tributary	TDS
TEMP(I)	°C	Temperature in the I^{th} layer [DTEMP]	INIT3
WIND	km/hr	Wind speed [WIND]	W2
XC	dimensionless	TV for photosynthetic limitation due to carbon, calculated	
XL	dimensionless	TV for photosynthetic limitation due to light, calculated	
XLIMC	dimensionless	TV for photosynthetic limitation due to carbon, calculated	
XLIMN	dimensionless	TV for photosynthetic limitation due to nitrogen, calculated	
XLIMP	dimensionless	TV for photosynthetic limitation due to phosphorus, calculated	
XN	dimensionless	TV for photosynthetic limitation due to nitrogen, calculated	
XP	dimensionless	TV for photosynthetic limitation due to phosphorus, calculated	
XPO4(I)	$g\ layer^{-1}$	Total phosphorus in the sediments [DXPO4]	INIT5
XP4REL	$g\ m^{-2}\ hr^{-1}$	Release rate of phosphorus from the sediments [TXP4RE]	ANAER4
XS	$g\ layer^{-1}$	Total sulfur in sediments [DS]	INIT5
ZEFFIC	dimensionless	Zooplankton ingestion efficiency [ZEFFIC]	ZOO1
ZMAX	hr^{-1}	Maximum ingestion rate for zooplankton [TZMAX]	ZOO1
ZMORTA	hr^{-1}	Maximum zooplankton mortality rate [TZMORT]	ZOO1

(Continued)

(Sheet 9 of 10)

Term	Units	Explanation	Record Where Read
ZMT(I)	hr^{-1}	TV for zooplankton mortality, calculated	
ZMU(I)	hr^{-1}	TV for zooplankton ingestion, calculated	
ZOO(I)	$g\ m^{-3}$	Zooplankton concentration in the I^{th} layer [DZOO]	INIT3
ZOOMIN	$g\ m^{-3}$	Low threshold concentration for zooplankton feeding	ZOO1
ZRESP	hr^{-1}	Maximum zooplankton respiration rate [TZRESP]	ZOO1
ZRT(I)	hr^{-1}	TV for zooplankton respiration, calculated	
ZS2P	$g\ m^{-3}$	Half-saturation coefficient for zooplankton ingestion	ZOO2

(Sheet 10 of 10)

APPENDIX B: OUTPUT EXAMPLE FROM CE-QUAL-R1

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                                     THIS IS *CE-QUAL-R1*                                                      LOOP   1

               CE-QUAL-R1 IS A RESEARCH TOOL FOR RESERVOIR ECOSYSTEM ANALYSIS USED BY THE WATER QUALITY MODELING GROUP, WATERWAYS,
                EXPERIMENT STATION.  NOTE THAT ORGANIZATIONAL AND PROCEDURAL CLARITY HAVE PRIORITY OVER COMPUTATIONAL EFFICIENCY
                  LAST UPDATE = MAY. 7,1985.

                                     DEGRAY LAKE 1979
                                  USING CE-QUAL-R1 MAY 7 1985 VERSION

                                     JUNE 11 1985,NO.1


DATA SUMMARY:
                                                                                                         START DAY                1
  INITIALIZATION DAY     25  STOP DAY                 362  COMP.INTERVAL,HRS       24  OUTPUT INTERVAL,HRS  120  NUMBER OF OUTLETS        3
  NUMBER OF TRIBUTARIES  2   LATITUDE,DEG           34.40  LONGITUDE,DEG        93.10  TURBIDITY FACTOR     2.0  EMP.WIND COEF,AA0.00E+00
  EMP.WIND COEF,BB0.12E-08   MIN.LAYER THKNS,M        0.5  MAX.LAYER THKNS,M      2.0  INIT.POOL HGT,M     60.5  EFF.RES.LENGTH,M  13000.
  MIXING PARAMETERS.......   'PEFRAC'                0.01  'SHELCF'              1.00  'CDIFW'         0.40E-04  'CDIFF'           0.80E-05
  EXTINC.COEF,1/M    0.450   INFLO CRIT(KG/M3) 2.0000  SURFACE RAD.FRACT. 0.400  PUMPBACK COEF .     0.00
  AREA COEFFICIENTS.......   ACOEF(1)             561.810  ACOEF(2)            2.790  ACOEF(3)          0.000  EXTINS,1/M-MG/L     0.010
  WIDTH COEFFICIENTS......   WCOEF(1)              47.700  WCOEF(2)            0.550  TSSETL,M/DAY        0.1


INITIAL GEOMETRIC ATTRIBUTES AND TEMPERATURE PROFILE:

  LAYER       LOWER        UPPER        LAYER       LOWER       UPPER       LAYER       TOTAL       LAYER      TEMPERATURE
  NUMBER     SURFACE      SURFACE     THICKNESS    SURFACE     SURFACE     VOLUME      VOLUME      WIDTH        DEG C
            ELEVATION    ELEVATION       M          AREA        AREA        M3         UP TO        M
                M            M                       M2          M2                    LOWER
                                                                                      SURFACE
                                                                                        M3

   60         59.50        60.50        1.00     50175510.   52563825.   51363730.   787715798.   453.42        5.50
   59         58.50        59.50        1.00     47857976.   50175510.   49010884.   738704913.   449.25        5.40
   58         57.50        58.50        1.00     45610281.   47857976.   46728348.   691976565.   445.04        5.40
   57         56.50        57.50        1.00     43431481.   45610281.   44515179.   647461386.   440.81        5.40
   56         55.50        56.50        1.00     41320626.   43431481.   42370431.   605090955.   436.54        5.30
   55         54.50        55.50        1.00     39276765.   41320626.   40293152.   564797803.   432.23        5.30
   54         53.50        54.50        1.00     37298942.   39276765.   38282390.   526515413.   427.89        5.30
   53         52.50        53.50        1.00     35386200.   37298942.   36337188.   490178225.   423.52        5.30
   52         51.50        52.50        1.00     33537573.   35386200.   34456584.   455721642.   419.10        5.30
   51         50.50        51.50        1.00     31752097.   33537573.   32639613.   423082029.   414.65        5.30
   50         49.50        50.50        1.00     30028800.   31752097.   30885307.   392196722.   410.16        5.30
   49         48.50        49.50        1.00     28366707.   30028800.   29192693.   363004028.   405.63        5.30
   48         47.50        48.50        1.00     26764839.   28366707.   27560795.   335443233.   401.05        5.30
   47         46.50        47.50        1.00     25222214.   26764839.   25988631.   309454603.   396.44        5.30
   46         45.50        46.50        1.00     23737843.   25222214.   24475215.   284979387.   391.77        5.30
   45         44.50        45.50        1.00     22310736.   23737843.   23019559.   261959828.   387.07        5.30
   44         43.50        44.50        1.00     20939895.   22310736.   21620668.   240339160.   382.31        5.30
   43         42.50        43.50        1.00     19624318.   20939895.   20277543.   220061617.   377.51        5.20
   42         41.50        42.50        1.00     18363001.   19624318.   18989180.   201072437.   372.65        5.30
   41         40.50        41.50        1.00     17154931.   18363001.   17754571.   183317866.   367.75        5.30
   40         39.50        40.50        1.00     15999093.   17154931.   16572702.   166745164.   362.79        5.30
   39         38.50        39.50        1.00     14894465.   15999093.   15442554.   151302610.   357.77        5.30
   38         37.50        38.50        1.00     13840020.   14894465.   14363103.   136939507.   352.70        5.30
   37         36.50        37.50        1.00     12834725.   13840020.   13333319.   123606188.   347.56        5.30
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 36        35.50      36.50       1.00   11877542.   12834725.   12352167.  111254020.   342.36        5.30
 35        34.50      35.50       1.00   10967427.   11877542.   11418606.   99835415.   337.10        5.30
 34        33.50      34.50       1.00   10103329.   10967427.   10531587.   89303828.   331.77        5.30
 33        32.50      33.50       1.00    9284190.   10103329.    9690057.   79613771.   326.36        5.30
 32        31.50      32.50       1.00    8508949.    9284190.    8892956.   70720815.   320.89        5.30
 31        30.50      31.50       1.00    7776533.    8508949.    8139217.   62581598.   315.33        5.30
 30        29.50      30.50       1.00    7085865.    7776533.    7427765.   55153832.   309.70        5.30
 29        28.50      29.50       1.00    6435861.    7085865.    6757520.   48396313.   303.97        5.30
 28        27.50      28.50       1.00    5825426.    6435861.    6127391.   42268921.   298.16        5.30
 27        26.50      27.50       1.00    5253460.    5825426.    5536283.   36732638.   292.26        5.20
 26        25.50      26.50       1.00    4718854.    5253460.    4983090.   31749547.   286.26        5.30
 25        24.50      25.50       1.00    4220490.    4718854.    4466699.   27282849.   280.15        5.30
 24        23.50      24.50       1.00    3757239.    4220490.    3985985.   23296863.   273.93        5.30
 23        22.50      23.50       1.00    3327965.    3757239.    3539818.   19757045.   267.59        5.30
 22        21.50      22.50       1.00    2931519.    3327965.    3127054.   16629991.   261.13        5.30
 21        20.50      21.50       1.00    2566745.    2931519.    2746542.   13883450.   254.53        5.30
 20        19.50      20.50       1.00    2232472.    2566745.    2397116.   11486334.   247.79        5.30
 19        18.50      19.50       1.00    1927519.    2232472.    2077602.    9408732.   240.90        5.30
 18        17.50      18.50       1.00    1650690.    1927519.    1786811.    7621921.   233.84        5.30
 17        16.50      17.50       1.00    1400779.    1650690.    1523542.    6098379.   226.60        5.20
 16        15.50      16.50       1.00    1176562.    1400779.    1286581.    4811798.   219.17        5.20
 15        14.50      15.50       1.00     976801.    1176562.    1074696.    3737102.   211.53        5.20
 14        13.50      14.50       1.00     800241.     976801.     886640.    2850462.   203.65        5.20
 13        12.50      13.50       1.00     645607.     800241.     721150.    2129312.   195.52        5.20
 12        11.50      12.50       1.00     511607.     645607.     576942.    1552369.   187.10        5.20
 11        10.50      11.50       1.00     396924.     511607.     452711.    1099658.   178.35        5.20
 10         9.50      10.50       1.00     300219.     396924.     347130.     752528.   169.25        5.20
  9         8.50       9.50       1.00     220124.     300219.     258845.     493683.   159.72        5.20
  8         7.50       8.50       1.00     155242.     220124.     186475.     307208.   149.70        5.20
  7         6.50       7.50       1.00     104140.     155242.     128604.     178604.   139.10        5.20
  6         5.50       6.50       1.00      65343.     104140.      83779.      94825.   127.79        5.20
  5         4.50       5.50       1.00      37330.      65343.      50503.      44323.   115.60        5.20
  4         3.50       4.50       1.00      18516.      37330.      27224.      17099.   102.25        5.20
  3         2.50       3.50       1.00       7242.      18516.      12322.       4777.    87.28        5.20
  2         1.25       2.50       1.25       1047.       7242.       4432.        345.    67.40        5.20
  1         0.00       1.25       1.25          1.       1047.        344.          1.    36.83        5.20

OUTLET STRUCTURE

            PORT NUMBER      ELEVATION,M         AREA,M2


                 1               56.4               31.1
                 2               51.8               31.1
                 3               44.4               31.1

CHEMICAL AND BIOLOGICAL PARAMETERS:

 ALGAE-
  ALGAE1 PROD.RATE,1/DAY      1.10  ALGAE2 PROD.RATE,1/DAY     0.80  ALGAE3 PROD.RATE,1/DAY     1.00
  ALGAE1 SETTLE RATE,M/DAY 0.140  ALGAE2 SETTLE RATE,M/DAY 0.140  ALGAE3 SETTLE RATE,M/DAY 0.140
  PO4 HALF-SAT,ALGAE1,MG/L 0.009  PO4 HALF-SAT,ALGAE2,MG/L 0.009  PO4 HALF-SAT,ALGAE3,MG/L 0.009
  N.HALF-SAT,ALGAE1,MG/L    0.014  N.HALF-SAT,ALGAE2,MG/L    0.010  N.HALF-SAT,ALGAE3,MG/L    0.010
  CO2 HALF-SAT,ALGAE1,MG/L 0.120  CO2 HALF-SAT,ALGAE2,MG/L 0.100  CO2 HALF-SAT,ALGAE3,MG/L 0.100

CHEMICAL CONSTITUENTS.........
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 CARBON                        0.460  NITROGEN                    0.050  PHOSPHORUS                   0.004  SILICA,                      0.010
 SIL HALF-SAT,ALGAE3,MG/L       0.1   LIGHT SAT,ALGAE1             50.0  LIGHT SAT,ALGAE2              20.0  LIGHT SAT,ALGAE3              54.0
 SELF SHADE COEF,1/M*MG/L      0.10   RESPIRATION RATE,1/DAY      0.000

ZOOPLANKTON-
 INGESTION RATE,1/DAY         0.440  MORTALITY RATE,1/DAY        0.010  FEEDING EFFICIENCY           0.500  PREFERENCE FOR ALGAE1        0.500
 PREFERENCE FOR ALGAE2        0.000  PREFERENCE FOR ALGAE3       0.000  PREFERENCE FOR DETR.         0.500
 RESPIRATION RATE,1/DAY       0.140  ALG. HALF-SAT COEF,MG/L     0.300
 CHEMICAL CONSTITUENTS.........      CARBON                      0.460  NITROGEN                     0.050  PHOSPHORUS                   0.004

MACROPHYTES-
 PROD.RATE,1/DAY               0.00  RESP.RATE,1/DAY             0.200  EXCRETION RATE,1/DAY         0.100  MORTALITY RATE,1/DAY         0.050
 SELF SHADE COEF,1/M*MG/L      0.02  PO4 HALF SAT,MG/L           0.005  N.HALF SAT,MG/L              0.010  CO2 HALF SAT,MG/L            0.050
 PLANT DENSITY,G/M3            10.0  LIGHT SAT.,KC/M2/HR          30.0  SED.NUTRIENT FRAC.            0.50
 MORTALITY FRACTION TO.........      D.O.M.                       0.40  DETRITUS                      0.30  SEDIMENT                      0.30

FISH-
 INGEST.RATE,1/DAY             0.02  ASSIM.EFFICIENCY             0.80  MORT.RATE,1/DAY              0.010  RESP.RATE,1/DAY              0.010
 FISH HALF SAT,G/RES           0.20  PREF.FOR SEDIMENT            0.03  PREF.FOR ALG 1                0.37  PREF.FOR ALG 2                0.00
 PREF.FOR ALG 3                0.00  PREF.FOR ZOOPL.              0.34  PREF.FOR DETRITUS             0.26

OTHERS-
 CHEMICAL CONSTITUENTS,DETRITUS      CARBON                      0.460  NITROGEN                     0.050  PHOSPHORUS                   0.004
 DETR.SETTLE RATE,M/DAY      0.350   DOM DECAY RATE,1/DAY        0.032  NH3 DECAY RATE,1/DAY         0.080
 DETR.DECAY RATE,1/DAY       0.009   COLIF.DECAY RATE,1/DAY      1.400  SEDM.DECAY RATE,1/DY         0.008  Q10,COLIFORM                 1.040
 STOICHIOMETRIC FACTORS.........     O2-NH3                      4.570  O2-DETRITUS                  1.400
 O2-RESPIRATION             1.100    O2-ALGAL BIOMASS            1.400  O2-DISSOLVED ORGANICS        1.400  S.S.SETTLING,M/DAY           0.050
 CHEM.CONST,DIS.ORG.MATTER.....      CARBON                      0.460  NITROGEN                     0.050  PHOSPHORUS                   0.004

ANAEROBIC-
 MN4 SETTLE RATE,M/DAY         0.05  MN4 REDUCTION RATE,1/DAY     0.02  MN(SED)REL.RATE,G/M2/DAY      0.10  MN2 OXIDATION RATE,1/DAY      0.00
 FE3 SETTLE RATE,M/DAY         0.05  FE3 REDUCTION RATE,1/DAY     0.03  FE(SED)REL.RATE,G/M2/DAY      0.10  FE2 OXIDATION RATE,1/DAY      0.00
 FE2 DECAY RATE,1/DAY          0.00  FES(SED)DECAY RATE,1/DAY     0.00  FES SETTLE RATE,M/DAY         0.90  FES DECAY RATE,1/DAY          0.50
 SO4 REDUCTION RATE,1/DAY      0.00  S(SED)REL.RATE,G/M2/DAY      0.00  S2 OXIDATION RATE,1/DAY       0.30  S2 DECAY RATE,1/DAY           0.00
 PO4(SED)REL.RATE,G/M2/DAY     0.00  N(SED)REL.RATE,G/M2/DAY      0.01  SEDIMENT THICKNESS,CM         5.00
 STOICHIOMETRIC FACTORS........      O2-MN2                       0.15  O2-FE2                        0.14  O2-S2                         2.00

TEMPERATURE RATE MULTIPLIER PARAMETERS:

                                  K1     K2     K3     K4     T1     T2     T3     T4

               DOM               0.12   0.98                 2.0   20.0
               NH3               0.10   0.98                 2.0   32.0
               NO3               0.10   0.98                 2.0   32.0
               DETR,SED          0.01   0.98                 4.0   28.0
               ALGAE1            0.10   0.98   0.98   0.10   0.0   26.0   30.0   35.0
               ALGAE2            0.10   0.98   0.98   0.10   4.0   26.0   36.0   40.0
               ALGAE3            0.10   0.98   0.98   0.10   2.0   26.0   32.0   37.0
               ZOOPLANKTON       0.10   0.98   0.98   0.10   0.0   20.0   26.0   36.0
               FISH              0.10   0.98   0.98   0.10   1.0   24.4   28.4   35.2
               MACROPHYTES       0.10   0.98   0.98   0.10   2.0   25.0   29.0   38.0

PHYSICAL QUANTITIES:
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 0    5   10   15   20   25   30   35    TEMPERATURE  S/W RADIATION  LAYER INFLOW  LAYER OUTFLOW DISSOLVED OXYGEN  ELEVATION
                                            DEG C      KCAL/M2/HR     M3/SEC        M3/SEC           G/M3              M

60     *                                     5.5         0.00          0.00          0.00             9.5             60.5
59    *                                      5.4         0.00          0.00          0.00             9.5             59.5
58    *                                      5.4         0.00          0.00          0.00             9.4             58.5
57    *                                      5.4         0.00          0.00          0.00             9.4             57.5
56    *                                      5.3         0.00          0.00          0.00             9.4             56.5
55    *                                      5.3         0.00          0.00          0.00             9.4             55.5
54    *                                      5.3         0.00          0.00          0.00             9.4             54.5
53    *                                      5.3         0.00          0.00          0.00             9.4             53.5
52    *                                      5.3         0.00          0.00          0.00             9.4             52.5
51    *                                      5.3         0.00          0.00          0.00             9.4             51.5
50    *                                      5.3         0.00          0.00          0.00             9.3             50.5
49    *                                      5.3         0.00          0.00          0.00             9.3             49.5
48    *                                      5.3         0.00          0.00          0.00             9.4             48.5
47    *                                      5.3         0.00          0.00          0.00             9.4             47.5
46    *                                      5.3         0.00          0.00          0.00             9.3             46.5
45    *                                      5.3         0.00          0.00          0.00             9.4             45.5
44    *                                      5.3         0.00          0.00          0.00             9.3             44.5
43    *                                      5.2         0.00          0.00          0.00             9.3             43.5
42    *                                      5.3         0.00          0.00          0.00             9.3             42.5
41    *                                      5.3         0.00          0.00          0.00             9.3             41.5
40    *                                      5.3         0.00          0.00          0.00             9.3             40.5
39    *                                      5.3         0.00          0.00          0.00             9.3             39.5
38    *                                      5.3         0.00          0.00          0.00             9.3             38.5
37    *                                      5.3         0.00          0.00          0.00             9.3             37.5
36    *                                      5.3         0.00          0.00          0.00             9.3             36.5
35    *                                      5.3         0.00          0.00          0.00             9.3             35.5
34    *                                      5.3         0.00          0.00          0.00             9.3             34.5
33    *                                      5.3         0.00          0.00          0.00             9.3             33.5
32    *                                      5.3         0.00          0.00          0.00             9.3             32.5
31    *                                      5.3         0.00          0.00          0.00             9.3             31.5
30    *                                      5.3         0.00          0.00          0.00             9.3             30.5
29    *                                      5.3         0.00          0.00          0.00             9.3             29.5
28    *                                      5.3         0.00          0.00          0.00             9.3             28.5
27    *                                      5.2         0.00          0.00          0.00             9.3             27.5
26    *                                      5.3         0.00          0.00          0.00             9.3             26.5
25    *                                      5.3         0.00          0.00          0.00             9.3             25.5
24    *                                      5.3         0.00          0.00          0.00             9.3             24.5
23    *                                      5.3         0.00          0.00          0.00             9.2             23.5
22    *                                      5.3         0.00          0.00          0.00             9.3             22.5
21    *                                      5.3         0.00          0.00          0.00             9.3             21.5
20    *                                      5.3         0.00          0.00          0.00             9.3             20.5
19    *                                      5.3         0.00          0.00          0.00             9.3             19.5
18    *                                      5.3         0.00          0.00          0.00             9.3             18.5
17    *                                      5.2         0.00          0.00          0.00             9.3             17.5
16    *                                      5.2         0.00          0.00          0.00             9.3             16.5
15    *                                      5.2         0.00          0.00          0.00             9.3             15.5
14    *                                      5.2         0.00          0.00          0.00             9.4             14.5
13    *                                      5.2         0.00          0.00          0.00             9.4             13.5
12    *                                      5.2         0.00          0.00          0.00             9.4             12.5
11    *                                      5.2         0.00          0.00          0.00             9.4             11.5
10    *                                      5.2         0.00          0.00          0.00             9.4             10.5
 9    *                                      5.2         0.00          0.00          0.00             9.4              9.5
 8    *                                      5.2         0.00          0.00          0.00             9.4              8.5
 7    *                                      5.2         0.00          0.00          0.00             9.4              7.5
 6    *                                      5.2         0.00          0.00          0.00             9.4              6.5
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   5     *                      5.2       0.00       0.00       0.00       9.4       5.5
   4     *                      5.2       0.00       0.00       0.00       9.4       4.5
   3     *                      5.2       0.00       0.00       0.00       9.4       3.5
   2     *                      5.2       0.00       0.00       0.00       9.4       2.5
   1     *                      5.2       0.00       0.00       0.00       9.4       1.3

BIOTA:                                                            LIMITING FACTOR
      ALGAE 1     ALGAE 2     ALGAE 3     ZOOPLANKTON    COLIFORM  ALGAE1  ALGAE2  ALGAE3
        G/M3        G/M3        G/M3         G/M3       COL/ML
60     1.4000      0.0000      0.0010       0.0070          6.     \       \       \
59     1.5000      0.0000      0.0010       0.0070          5.     \       \       \
58     0.8000      0.0000      0.0010       0.0070          4.     \       \       \
57     1.4200      0.0000      0.0010       0.0070         55.     \       \       \
56     1.4000      0.0000      0.0010       0.0070         80.     \       \       \
55     0.9400      0.0000      0.0010       0.0060        570.     \       \       \
54     1.6000      0.0000      0.0010       0.0060       1060.     \       \       \
53     0.6000      0.0000      0.0010       0.0060        545.     \       \       \
52     0.4000      0.0000      0.0010       0.0060         30.     \       \       \
51     1.2000      0.0000      0.0010       0.0060         16.     \       \       \
50     1.5000      0.0000      0.0010       0.0070          2.     \       \       \
49     0.0010      0.0000      0.0010       0.0070        231.     \       \       \
48     0.0010      0.0000      0.0010       0.0070        460.     \       \       \
47     0.0010      0.0000      0.0010       0.0070        307.     \       \       \
46     0.0010      0.0000      0.0010       0.0070        153.     \       \       \
45     0.0010      0.0000      0.0010       0.0080          0.     \       \       \
44     0.0010      0.0000      0.0010       0.0080         42.     \       \       \
43     0.0010      0.0000      0.0010       0.0080         84.     \       \       \
42     0.0010      0.0000      0.0010       0.0080        126.     \       \       \
41     0.0010      0.0000      0.0010       0.0080        168.     \       \       \
40     0.0010      0.0000      0.0010       0.0030        210.     \       \       \
39     0.0010      0.0000      0.0010       0.0030        176.     \       \       \
38     0.0010      0.0000      0.0010       0.0030        142.     \       \       \
37     0.0010      0.0000      0.0010       0.0030        108.     \       \       \
36     0.0010      0.0000      0.0010       0.0030         74.     \       \       \
35     0.0010      0.0000      0.0010       0.0030         40.     \       \       \
34     0.0010      0.0000      0.0010       0.0030         44.     \       \       \
33     0.0010      0.0000      0.0010       0.0030         48.     \       \       \
32     0.0010      0.0000      0.0010       0.0030         52.     \       \       \
31     0.0010      0.0000      0.0010       0.0030         56.     \       \       \
30     0.0010      0.0000      0.0010       0.0030         60.     \       \       \
29     0.0010      0.0000      0.0010       0.0030        178.     \       \       \
28     0.0010      0.0000      0.0010       0.0030        296.     \       \       \
27     0.0010      0.0000      0.0010       0.0030        414.     \       \       \
26     0.0010      0.0000      0.0010       0.0030        532.     \       \       \
25     0.0010      0.0000      0.0010       0.0030        650.     \       \       \
24     0.0010      0.0000      0.0010       0.0030        528.     \       \       \
23     0.0010      0.0000      0.0010       0.0030        406.     \       \       \
22     0.0010      0.0000      0.0010       0.0030        284.     \       \       \
21     0.0010      0.0000      0.0010       0.0030        162.     \       \       \
20     0.0010      0.0000      0.0010       0.0010         40.     \       \       \
19     0.0010      0.0000      0.0010       0.0010        100.     \       \       \
18     0.0010      0.0000      0.0010       0.0010         73.     \       \       \
17     0.0010      0.0000      0.0010       0.0010         47.     \       \       \
16     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
15     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
14     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
13     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
12     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
11     0.0010      0.0000      0.0010       0.0010         20.     \       \       \
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10        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 9        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 8        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 7        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 6        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 5        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 4        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 3        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 2        0.0010          0.0000          0.0010          0.0010                20.    \       \       \
 1        0.0010          0.0000          0.0010          0.0010                20.    \       \       \

MACROPHYTES,G/M2,GROWING FROM A SEDIMENT LAYER
    LAYER-    60        59        58        57        56        55        54        53        52
            0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

                              FISH  KG/HA:                          55.0

PRODUCTIVITY QUANTITIES:

                         PRIMARY PRODUCTIVITY
                                                     CARBON    OXYGEN

                                  RESERVOIR, G/M2             0.00      0.00
                                  EUPHOTIC ZONE, G/M3         0.00      0.00
                                  RESERVOIR, G/M3             0.00      0.00

                         STANDING CROP OF ALGAE
                                                     ALGAE1    ALGAE2    ALGAE3

                                  RESERVOIR, G/M2             0.00      0.00      0.00
                                  EUPHOTIC ZONE, G/M3         0.00      0.00      0.00

                         SECCHI DISK DEPTH, M                  0.0

                         COMMUNITY RESPIRATION, G/M2           0.00

NUTRITIVE QUANTITIES:
        AMMONIA          NITRATE          RFR ORG          PHOSPHATE          SILICA          DETRITUS          SEDIMENT
         G/M3             G/M3             G/M3             G/M3               G/M3            G/M3              G/M2

60        0.0080          0.2100          13.0400           0.0020          1.0000              0.00          101.10     60
59        0.0070          0.2100          10.9600           0.0020          1.0000              0.00          101.10     59
58        0.0050          0.2200           8.8000           0.0020          1.0000              0.00          101.10     58
57        0.0001          0.2200           7.9200           0.0010          1.0000              0.00          101.10     57
56        0.0001          0.2200           8.0000           0.0040          1.0000              0.00          101.10     56
55        0.0001          0.2200           8.0000           0.0010          1.0000              0.00          101.10     55
54        0.0001          0.2100           8.1600           0.0010          1.0000              0.00          101.10     54
53        0.0001          0.1500           7.9200           0.0010          1.0000              0.00          101.10     53
52        0.0001          0.0900           7.7600           0.0010          1.0000              0.00          101.10     52
51        0.0001          0.1600           7.8400           0.0010          1.0000              0.00          101.10     51
50        0.0001          0.2200           8.0000           0.0010          1.0000              0.00          101.10     50
49        0.0001          0.2200          10.8800           0.0010          1.0000              0.00          101.10     49
48        0.0001          0.2200          13.6800           0.0010          1.0000              0.00          101.10     48
47        0.0001          0.2200          14.9600           0.0010          1.0000              0.00          101.10     47
46        0.0001          0.2100          16.3200           0.0010          1.0000              0.00          101.10     46
45        0.0001          0.2100          17.6000           0.0010          1.0000              0.00          101.10     45
44        0.0001          0.2100          16.6400           0.0010          1.0000              0.00          101.10     44
43        0.0001          0.2100          15.6800           0.0010          1.0000              0.00          101.10     43
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 42     0.0001      0.2200     14.7200      0.0010      1.0000      0.00     101.10   42
 41     0.0001      0.2200     13.7600      0.0010      1.0000      0.00     101.10   41
 40     0.0001      0.2200     12.8000      0.0010      1.0000      0.00     101.10   40
 39     0.0001      0.2200     11.9200      0.0010      1.0000      0.00     101.10   39
 38     0.0001      0.2200     11.1200      0.0010      1.0000      0.00     101.10   38
 37     0.0001      0.2100     10.2400      0.0010      1.0000      0.00     101.10   37
 36     0.0001      0.2100      9.3600      0.0010      1.0000      0.00     101.10   36
 35     0.0001      0.2100      8.5600      0.0010      1.0000      0.00     101.10   35
 34     0.0001      0.2100      8.5600      0.0010      1.0000      0.00     101.10   34
 33     0.0001      0.2000      8.5600      0.0010      1.0000      0.00     101.10   33
 32     0.0001      0.2000      8.5600      0.0010      1.0000      0.00     101.10   32
 31     0.0001      0.1900      8.5600      0.0010      1.0000      0.00     101.10   31
 30     0.0001      0.1900      8.5600      0.0010      1.0000      0.00     101.10   30
 29     0.0001      0.1900      8.5600      0.0010      1.0000      0.00     101.10   29
 28     0.0001      0.2000      8.5600      0.0010      1.0000      0.00     101.10   28
 27     0.0001      0.2000      8.7200      0.0010      1.0000      0.00     101.10   27
 26     0.0001      0.2100      8.7200      0.0010      1.0000      0.00     101.10   26
 25     0.0001      0.2100      8.7200      0.0010      1.0000      0.00     101.10   25
 24     0.0001      0.2200      8.5600      0.0010      1.0000      0.00     101.10   24
 23     0.0001      0.2200      8.4000      0.0010      1.0000      0.00     101.10   23
 22     0.0001      0.2300      8.3200      0.0020      1.0000      0.00     101.10   22
 21     0.0001      0.2100      8.1600      0.0020      1.0000      0.00     101.10   21
 20     0.0001      0.2300      8.0000      0.0020      1.0000      0.00     101.10   20
 19     0.0001      0.2200      8.7200      0.0010      1.0000      0.00     101.10   19
 18     0.0001      0.2200      9.0400      0.0010      1.0000      0.00     101.10   18
 17     0.0001      0.2100      9.2800      0.0010      1.0000      0.00     101.10   17
 16     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   16
 15     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   15
 14     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   14
 13     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   13
 12     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   12
 11     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   11
 10     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10   10
  9     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    9
  8     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    8
  7     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    7
  6     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    6
  5     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    5
  4     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    4
  3     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    3
  2     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    2
  1     0.0001      0.2100      9.6000      0.0010      1.0000      0.00     101.10    1

 OTHER CHEMICAL QUANTITIES:
       ALKALINITY   TOTAL DISSLVD SOLIDS   SUS.SOL.  DISSOLVED ORGANICS   CARBON   CARBON DIOXIDE    PH
          G/M3             G/M3              G/M3          G/M3            G/M3         G/M3

 60      14.80            57.00               6.0          3.26            4.01         0.46         7.4      60
 59      15.70            63.00               6.0          2.74            4.38         0.63         7.3      59
 58      16.50            69.00               6.0          2.20            4.77         0.81         7.2      58
 57      17.00            65.50               6.0          1.98            4.91         0.84         7.2      57
 56      16.00            62.00               6.0          2.00            4.83         1.01         7.1      56
 55      15.50            64.00               6.0          2.00            4.80         1.10         7.0      55
 54      15.00            66.00               6.0          2.04            4.77         1.19         7.0      54
 53      16.50            65.50               6.0          1.98            5.25         1.31         7.0      53
 52      18.00            65.00               6.0          1.94            5.73         1.43         7.0      52
 51      17.00            66.00               6.0          1.96            5.57         1.51         6.9      51
 50      16.00            67.00               6.0          2.00            5.41         1.60         6.9      50
 49      16.50            66.50               6.0          2.72            5.58         1.65         6.9      49
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 48        17.00            66.00          6.0         3.42          5.75          1.70         6.9         48
 47        17.30            63.30          6.0         3.74          5.85          1.73         6.9         47
 46        17.70            60.70          6.0         4.08          6.44          2.22         6.8         46
 45        18.00            58.00          6.0         4.40          6.55          2.26         6.8         45
 44        17.60            58.80          6.0         4.16          6.40          2.21         6.8         44
 43        17.20            59.60          6.0         3.92          6.26          2.16         6.8         43
 42        16.80            60.40          6.0         3.68          6.11          2.11         6.8         42
 41        16.40            61.20          6.0         3.44          5.97          2.06         6.8         41
 40        16.00            62.00          6.0         3.20          5.82          2.01         6.8         40
 39        16.40            61.80          6.0         2.98          5.97          2.06         6.8         39
 38        16.80            61.60          6.0         2.78          6.11          2.11         6.8         38
 37        17.20            61.40          6.0         2.56          6.81          2.72         6.7         37
 36        17.60            61.20          6.0         2.34          6.97          2.78         6.7         36
 35        18.00            61.00          6.0         2.14          7.13          2.84         6.7         35
 34        18.00            60.40          6.0         2.14          7.13          2.84         6.7         34
 33        18.00            59.80          6.0         2.14          7.13          2.84         6.7         33
 32        18.00            59.20          6.0         2.14          7.13          2.84         6.7         32
 31        18.00            58.60          6.0         2.14          7.13          2.84         6.7         31
 30        18.00            58.00          6.0         2.14          7.13          2.84         6.7         30
 29        18.00            58.00          6.0         2.14          7.13          2.84         6.7         29
 28        18.00            58.00          6.0         2.14          7.13          2.84         6.7         28
 27        17.00            59.00          6.0         2.18          6.74          2.69         6.7         27
 26        17.00            59.00          6.0         2.18          6.73          2.69         6.7         26
 25        17.00            59.00          6.0         2.18          6.73          2.69         6.7         25
 24        17.00            59.40          6.0         2.14          6.73          2.69         6.7         24
 23        17.00            59.80          6.0         2.10          6.73          2.69         6.7         23
 22        17.00            60.20          6.0         2.08          7.42          3.38         6.6         22
 21        17.00            60.60          6.0         2.04          7.42          3.38         6.6         21
 20        17.00            61.00          6.0         2.00          7.42          3.38         6.6         20
 19        18.00            57.00          6.0         2.18          7.86          3.58         6.6         19
 18        18.70            54.30          6.0         2.26          8.16          3.71         6.6         18
 17        19.30            51.70          6.0         2.32          8.43          3.84         6.6         17
 16        20.00            49.00          6.0         2.40          8.74          3.98         6.6         16
 15        20.00            49.00          6.0         2.40          8.74          3.98         6.6         15
 14        20.00            49.00          6.0         2.40          8.74          3.98         6.6         14
 13        20.00            49.00          6.0         2.40          8.74          3.98         6.6         13
 12        20.00            49.00          6.0         2.40          8.74          3.98         6.6         12
 11        20.00            49.00          6.0         2.40          8.74          3.98         6.6         11
 10        20.00            49.00          6.0         2.40          8.74          3.98         6.6         10
  9        20.00            49.00          6.0         2.40          8.74          3.98         6.6          9
  8        20.00            49.00          6.0         2.40          8.74          3.98         6.6          8
  7        20.00            49.00          6.0         2.40          8.74          3.98         6.6          7
  6        20.00            49.00          6.0         2.40          8.74          3.98         6.6          6
  5        20.00            49.00          6.0         2.40          8.74          3.98         6.6          5
  4        20.00            49.00          6.0         2.40          8.74          3.98         6.6          4
  3        20.00            49.00          6.0         2.40          8.74          3.98         6.6          3
  2        20.00            49.00          6.0         2.40          8.74          3.98         6.6          2
  1        20.00            49.00          6.0         2.40          8.74          3.98         6.6          1

  ANAEROBIC QUANTITIES:
     MN4      MN(SED)     MN2       FE3      FE(SED)     FE2     FES(SED)  FES(W/C)    SO4     S(SED)       S2     PO4(SED)   N(SED)
     G/M3      G/M2       G/M3      G/M3      G/M2       G/M3      G/M2      G/M3      G/M3     G/M2        G/M3     G/M2      G/M2

 60  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
 59  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
 58  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
 57  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
 56  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
 55  0.10     30.00      0.00      0.00    600.00      0.00      0.00      0.00      3.00    10.00        0.00     20.00     50.00
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54  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
53  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
52  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
51  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
50  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
49  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
48  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
47  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
46  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
45  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
44  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
43  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
42  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
41  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
40  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
39  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
38  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
37  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
36  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
35  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
34  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
33  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
32  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
31  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
30  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
29  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
28  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
27  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
26  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
25  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
24  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
23  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
22  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
21  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
20  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
19  0.10   30.00   0.00   0.00   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
18  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
17  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
16  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   3.00   10.00   0.00   20.00   50.00
15  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
14  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
13  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
12  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
11  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
10  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 9  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 8  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 7  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 6  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 5  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 4  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 3  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 2  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
 1  0.10   30.00   0.00   0.10   600.00   0.00   0.00   0.00   4.00   10.00   0.00   20.00   50.00
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                                  DAILY INFORMATION
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HOUR  DAY  SIM.INT.  ELEV    INFLOW  TEMP  OUTFLOW  TEMP  IF REGULATION     PORT     FLOW    PORT     FLOW    PORT     FLOW   MORE
                       M      M3/S     M     M3/S     C    TARGET T. C.               M3/S             M3/S             M3/S

 600   25       1     60.5    17.2    2.3    21.5    5.2                       1      21.5                                    NO
 624   26       1     60.5    17.5    2.5    36.9    5.1                       1      36.9                                    NO
 648   27       1     60.4    17.5    3.1    36.9    5.0                       1      36.9                                    NO
 672   28       1     60.4    14.8    2.6    36.9    4.8                       1      36.9                                    NO
1
STATUS AT END OF SIMULATION HOUR   696                                        THIS IS JULIAN DAY  29, CALENDAR DAY 29JAN79

AVERAGE METEOROLOGICAL QUANTITIES FOR THIS COMPUTATION INTERVAL:

  CLOUD COVER          0.60  AIR PRESSURE,MB  1013.40  WIND SPEED,KPH       7.90  DRYBULB TEMP,DEGC,   -3.7  DEWPOINT TEMP,DEGC, -9.7
  S/W RAD,KC/M2/HR    85.8   L/W RAD,KC/M2/HR   179.2  VAPOR PRESSURE,MB    2.9   SAT.VAP.PRES,MB       8.6  EVAP.RATE,M/HR     0.0001

SURFACE ELEVATION,M:  60.4

INFLOWING QUANTITIES FOR THIS COMPUTATION INTERVAL:

  TRIBUTARY              1   INFLOW,M3/SEC         9.1  ALGAE 1,G/M3         0.00  ALGAE 2,G/M3         0.00   ALGAE 3,G/M3         0.00
  ALKALINITY,G/M3    16.00   DOC,G/M3              1.82  AMMONIA,G/M3         0.06  NITRATE,G/M3         0.22  REFRACT,G/M3         7.30
  COLIFORM,COL/100     18.   DETRITUS,G/M3         0.56  OXYGEN,G/M3         12.80  PHOSPHATE,G/M3       0.02  SILICA,G/M3          0.00
  TEMPERATURE,DEGC    2.20   TDS,G/M3             31.00  CO2,    G/M3         6.74  PH                    6.3  SUSP.SOL,G/M3        7.00
  MANGANESE-4,MG/L    0.00   RED.MANGANESE,MG/L  0.00  IRON-3,MG/L          0.20  REDUCED IRON,MG/L    0.00  IRON SULFIDE,MG/L    0.00
  SULFATE,MG/L        5.00   REDUCED SULFUR,MG/L 0.00

  TRIBUTARY              2   INFLOW,M3/SEC         4.3  ALGAE 1,G/M3         0.00  ALGAE 2,G/M3         0.00   ALGAE 3,G/M3         0.00
  ALKALINITY,G/M3    16.00   DOC,G/M3              1.82  AMMONIA,G/M3         0.06  NITRATE,G/M3         0.22  REFRACT,G/M3         7.30
  COLIFORM,COL/100     18.   DETRITUS,G/M3         0.56  OXYGEN,G/M3         12.80  PHOSPHATE,G/M3       0.02  SILICA,G/M3          0.00
  TEMPERATURE,DEGC    2.20   TDS,G/M3             31.00  CO2,    G/M3         6.74  PH                    6.3  SUSP.SOL,G/M3        7.00
  MANGANESE-4,MG/L    0.00   RED.MANGANESE,MG/L  0.00  IRON-3,MG/L          0.20  REDUCED IRON,MG/L    0.00  IRON SULFIDE,MG/L    0.00
  SULFATE,MG/L        5.00   REDUCED SULFUR,MG/L 0.00

OUTFLOWING QUANTITIES FOR THIS COMPUTATION INTERVAL:
                                    PORT                      LAYER                    OUTFLOW,M3/SEC

                                     1                          50                          26.80
                                     2                          45                           0.00
                                     3                          38                           0.00

                             TOTAL OUTFLOW,M3/SEC            26.80    OUTFLOW TEMPERATURE DEG C      4.66


  ALGAE 1,G/M3        0.65   ALGAE 2,G/M3          0.00  ALGAE 3,G/M3         0.00
  ALKALINITY,G/M3    16.66   DIS.ORG.MTR G/M3      2.47  AMMONIA,G/M3         0.00
  NITRATE,G/M3        0.20   REFRACT,G/M3         10.54  COLIFORM,COL/100      11.  DETRITUS,G/M3        0.01  OXYGEN,G/M3         10.60
  PHOSPHATE,G/M3      0.00   SILICA,G/M3           0.99  TDS,G/M3            62.52  SUSP.SOLIDS G/M3     5.92  ZOOPLANKTON,G/M3     0.01
  CO2,G/M3            1.22   PH                     7.0  POC,G/M3             5.20
  MANGANESE-4         0.10   RED.MANGANESE         0.00  IRON-3               0.00
  REDUCED IRON        0.00   IRON SULFIDE          0.00  SULFATE              3.34  REDUCED SULFUR       0.00


PHYSICAL QUANTITIES:

   0    5   10   15   20   25   30   35    TEMPERATURE    S/W RADIATION  LAYER INFLOW   LAYER OUTFLOW DISSOLVED OXYGEN    ELEVATION
                                              DEG C        KCAL/M2/HR      M3/SEC         M3/SEC          G/M3              M
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55   *                               4.7      40.18      1.28      0.46      10.6      60.4
54   *                               4.7      22.34      1.19      0.45      10.6      59.3
53   *                               4.7      12.41      1.14      0.45      10.6      58.3
52   *                               4.7       6.89      1.08      0.45      10.6      57.3
51   *                               4.7       3.82      1.03      0.45      10.6      56.3
50   *                               4.7       2.12      0.98      0.45      10.6      55.2
49   *                               4.7       1.18      0.92      0.45      10.6      54.2
48   *                               4.7       0.66      0.87      0.45      10.6      53.2
47   *                               4.7       0.37      0.83      0.45      10.6      52.2
46   *                               4.7       0.20      0.78      0.45      10.6      51.2
45   *                               4.7       0.11      0.74      0.45      10.6      50.2
44   *                               4.7       0.06      0.70      0.45      10.6      49.1
43   *                               4.7       0.04      0.66      0.45      10.6      48.1
42   *                               4.7       0.02      0.62      0.45      10.6      47.1
41   *                               4.7       0.01      0.58      0.45      10.6      46.1
40   *                               4.7       0.01      0.00      0.45      10.6      45.1
39   *                               4.7       0.00      0.00      0.45      10.6      44.1
38   *                               4.7       0.00      0.00      0.45      10.6      43.0
37   *                               4.7       0.00      0.00      0.45      10.6      42.0
36   *                               4.7       0.00      0.00      0.45      10.6      41.0
35   *                               4.7       0.00      0.00      0.45      10.6      40.0
34   *                               4.7       0.00      0.00      0.45      10.6      39.0
33   *                               4.7       0.00      0.00      0.45      10.6      37.9
32   *                               4.7       0.00      0.00      0.45      10.6      36.9
31   *                               4.7       0.00      0.00      0.45      10.6      35.9
30   *                               4.7       0.00      0.00      0.45      10.6      34.9
29   *                               4.7       0.00      0.00      0.45      10.6      33.8
28   *                               4.7       0.00      0.00      0.46      10.6      32.8
27   *                               4.7       0.00      0.00      0.46      10.6      31.8
26   *                               4.7       0.00      0.00      0.46      10.6      30.7
25   *                               4.7       0.00      0.00      0.46      10.6      29.7
24   *                               4.7       0.00      0.00      0.46      10.6      28.6
23   *                               4.7       0.00      0.00      0.47      10.6      27.6
22   *                               4.7       0.00      0.00      0.47      10.6      26.5
21   *                               4.7       0.00      0.00      0.47      10.6      25.5
20   *                               4.7       0.00      0.00      0.48      10.6      24.4
19   *                               4.7       0.00      0.00      0.48      10.6      23.3
18   *                               4.7       0.00      0.00      0.48      10.6      22.2
17   *                               4.7       0.00      0.00      0.49      10.6      21.1
16   *                               4.7       0.00      0.00      0.50      10.6      19.9
15   *                               4.7       0.00      0.00      0.51      10.6      18.8
14   *                               4.7       0.00      0.00      0.52      10.6      17.6
13   *                               4.7       0.00      0.00      0.54      10.6      16.4
12   *                               4.7       0.00      0.00      0.56      10.6      15.1
11   *                               4.7       0.00      0.00      0.59      10.6      13.7
10   *                               4.7       0.00      0.00      0.65      10.6      12.3
 9   *                               4.7       0.00      0.00      0.42      10.6      10.6
 8   *                               4.7       0.00      0.00      0.31      10.6       9.6
 7   *                               4.7       0.00      0.00      0.47      10.6       8.5
 6   *                               4.7       0.00      0.00      0.30      10.6       7.0
 5   *                               4.7       0.00      0.00      0.17      10.6       5.9
 4   *                               4.7       0.00      0.00      2.29      10.6       4.7
 3   *                               4.7       0.00      0.00      0.91      1C.6       3.5
 2   *                               4.7       0.00      0.00      0.23      10.6       2.4
 1   *                               4.7       0.00      0.00      0.02      10.6       1.2
BIOTA:
     ALGAE 1      ALGAE 2      ALGAE 3      ZOOPLANKTON      COLIFORM        LIMITING FACTOR
                                                                      ALGAE1   ALGAE2   ALGAE3
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```
             G/M3          G/M3          G/M3          G/M3         COL/ML
 55         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 54         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 53         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 52         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 51         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 50         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 49         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 48         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 47         0.6474        0.0000        0.0010        0.0056                    11.    P    \    \
 46         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 45         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 44         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 43         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 42         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 41         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 40         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 39         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 38         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 37         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 36         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 35         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 34         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 33         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 32         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 31         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 30         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 29         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 28         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 27         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 26         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 25         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 24         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 23         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 22         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 21         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 20         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 19         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 18         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 17         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 16         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 15         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 14         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 13         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 12         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 11         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
 10         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  9         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  8         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  7         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  6         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  5         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  4         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  3         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  2         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
  1         0.6474        0.0000        0.0010        0.0056                    11.    L    \    \
MACROPHYTES,G/M2,GROWING FROM A SEDIMENT LAYER
    LAYER-     55       54       53       52       51       50       49       48       47
             0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00     0.00
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                    FISH  KG/HA:                         54.8

PRODUCTIVITY QUANTITIES:

               PRIMARY PRODUCTIVITY
                                                   CARBON    OXYGEN

                    RESERVOIR, G/M2                -0.05     -0.14
                    EUPHOTIC ZONE, G/M3             0.00     -0.01
                    RESERVOIR, G/M3                 0.00     -0.01

               STANDING CROP OF ALGAE
                                                   ALGAE1    ALGAE2    ALGAE3

                    RESERVOIR, G/M2                10.31      0.00      0.00
                    EUPHOTIC ZONE, G/M3             0.65      0.00      0.00

               SECCHI DISK DEPTH, M                 3.1

               COMMUNITY RESPIRATION, G/M2          0.76

NUTRITIVE QUANTITIES:
        AMMONIA         NITRATE         RFR ORG         PHOSPHATE        SILICA        DETRITUS        SEDIMENT
          G/M3            G/M3            G/M3            G/M3            G/M3           G/M3            G/M2

55       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.53     55
54       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.59     54
53       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.59     53
52       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.59     52
51       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.59     51
50       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.56     50
49       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.51     49
48       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.55     48
47       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.54     47
46       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.49     46
45       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.43     45
44       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.47     44
43       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.46     43
42       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.44     42
41       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.43     41
40       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.41     40
39       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     39
38       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     38
37       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     37
36       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     36
35       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     35
34       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     34
33       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     33
32       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     32
31       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     31
30       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     30
29       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.39     29
28       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.38     28
27       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.38     27
26       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.38     26
25       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.38     25
24       0.0047          0.2027         10.5397          0.0002          0.9920          0.01           101.38     24
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23	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.38	23
22	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.33	22
21	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.38	21
20	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.38	20
19	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.37	19
18	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.37	18
17	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.37	17
16	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.37	16
15	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.36	15
14	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.36	14
13	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.36	13
12	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.35	12
11	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.34	11
10	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.33	10
9	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.33	9
8	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.32	8
7	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.31	7
6	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.30	6
5	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.28	5
4	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.26	4
3	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.23	3
2	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.19	2
1	0.0047	0.2027	10.5397	0.0002	0.9920	0.01	101.14	1

OTHER CHEMICAL QUANTITIES:

	ALKALINITY G/M3	TOTAL DISSLVD SOLIDS G/M3	SUS.SOL. G/M3	DISSOLVED ORGANICS G/M3	CARBON G/M3	CARBON DIOXIDE G/M3	PH	
55	16.66	62.52	5.9	2.47	5.20	1.20	7.0	55
54	16.66	62.52	5.9	2.47	5.20	1.20	7.0	54
53	16.66	62.52	5.9	2.47	5.20	1.20	7.0	53
52	16.66	62.52	5.9	2.47	5.20	1.20	7.0	52
51	16.66	62.52	5.9	2.47	5.20	1.20	7.0	51
50	16.66	62.52	5.9	2.47	5.20	1.20	7.0	50
49	16.66	62.52	5.9	2.47	5.20	1.20	7.0	49
48	16.66	62.52	5.9	2.47	5.20	1.20	7.0	48
47	16.66	62.52	5.9	2.47	5.20	1.20	7.0	47
46	16.66	62.52	5.9	2.47	5.20	1.20	7.0	46
45	16.66	62.52	5.9	2.47	5.20	1.20	7.0	45
44	16.66	62.52	5.9	2.47	5.20	1.20	7.0	44
43	16.66	62.52	5.9	2.47	5.20	1.20	7.0	43
42	16.66	62.52	5.9	2.47	5.20	1.20	7.0	42
41	16.66	62.52	5.9	2.47	5.20	1.20	7.0	41
40	16.66	62.52	5.9	2.47	5.20	1.22	7.0	40
39	16.66	62.52	5.9	2.47	5.20	1.22	7.0	39
38	16.66	62.52	5.9	2.47	5.20	1.22	7.0	38
37	16.66	62.52	5.9	2.47	5.20	1.22	7.0	37
36	16.66	62.52	5.9	2.47	5.20	1.22	7.0	36
35	16.66	62.52	5.9	2.47	5.20	1.22	7.0	35
34	16.66	62.52	5.9	2.47	5.20	1.22	7.0	34
33	16.66	62.52	5.9	2.47	5.20	1.22	7.0	33
32	16.66	62.52	5.9	2.47	5.20	1.22	7.0	32
31	16.66	62.52	5.9	2.47	5.20	1.22	7.0	31
30	16.66	62.52	5.9	2.47	5.20	1.22	7.0	30
29	16.66	62.52	5.9	2.47	5.20	1.22	7.0	29
28	16.66	62.52	5.9	2.47	5.20	1.22	7.0	28
27	16.66	62.52	5.9	2.47	5.20	1.22	7.0	27
26	16.66	62.52	5.9	2.47	5.20	1.22	7.0	26
25	16.66	62.52	5.9	2.47	5.20	1.22	7.0	25

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24      16.66            62.52          5.9         2.47           5.20          1.22        7.0         24
23      16.66            62.52          5.9         2.47           5.20          1.22        7.0         23
22      16.66            62.52          5.9         2.47           5.20          1.22        7.0         22
21      16.66            62.52          5.9         2.47           5.20          1.22        7.0         21
20      16.66            62.52          5.9         2.47           5.20          1.22        7.0         20
19      16.66            62.52          5.9         2.47           5.20          1.22        7.0         19
18      16.66            62.52          5.9         2.47           5.20          1.22        7.0         18
17      16.66            62.52          5.9         2.47           5.20          1.22        7.0         17
16      16.66            62.52          5.9         2.47           5.20          1.22        7.0         16
15      16.66            62.52          5.9         2.47           5.20          1.22        7.0         15
14      16.66            62.52          5.9         2.47           5.20          1.22        7.0         14
13      16.66            62.52          5.9         2.47           5.20          1.22        7.0         13
12      16.66            62.52          5.9         2.47           5.20          1.22        7.0         12
11      16.66            62.52          5.9         2.47           5.20          1.22        7.0         11
10      16.66            62.52          5.9         2.47           5.20          1.22        7.0         10
 9      16.66            62.52          5.9         2.47           5.20          1.22        7.0          9
 8      16.66            62.52          5.9         2.47           5.20          1.22        7.0          8
 7      16.66            62.52          5.9         2.47           5.20          1.22        7.0          7
 6      16.66            62.52          5.9         2.47           5.20          1.22        7.0          6
 5      16.66            62.52          5.9         2.47           5.20          1.22        7.0          5
 4      16.66            62.52          5.9         2.47           5.20          1.22        7.0          4
 3      16.66            62.52          5.9         2.47           5.20          1.22        7.0          3
 2      16.66            62.52          5.9         2.47           5.20          1.22        7.0          2
 1      16.66            62.52          5.9         2.47           5.20          1.22        7.0          1

  ANAEROBIC QUANTITIES:
     MN4     MN(SED)     MN2     FE3     FE(SED)    FE2    FES(SED)  FES(W/C)    SO4    S(SED)     S2    PO4(SED)   N(SED)
     G/M3     G/M2       G/M3    G/M3     G/M2      G/M3     G/M2      G/M3      G/M3    G/M2      G/M3    G/M2      G/M2

55   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
54   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
53   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
52   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
51   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
50   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
49   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
48   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
47   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
46   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
45   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
44   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
43   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
42   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
41   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
40   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
39   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
38   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
37   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
36   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
35   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
34   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
33   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
32   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
31   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
30   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
29   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
28   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
27   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
26   0.10     30.02      0.00    0.00    600.00     0.00     0.00      0.00      3.34   10.00      0.00   20.00     50.01
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25  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
24  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
23  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
22  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
21  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
20  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
19  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
18  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
17  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
16  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
15  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
14  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
13  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
12  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
11  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
10  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 9  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 8  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 7  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 6  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 5  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 4  0.10     30.02     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 3  0.10     30.01     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 2  0.10     30.01     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
 1  0.10     30.01     0.00     0.00   600.00     0.00     0.00     0.00     3.34    10.00     0.00    20.00    50.01
1
```

APPENDIX C: RECORDS NEEDED FOR VARIOUS OPTIONS (DOT DIAGRAM)

DOT DIAGRAM FOR CE-THERM-R1 OPTIONS

NOTE: '*' RECORD INCLUDED '-' RECORD OMITTED

	NORMAL				SCHEDULED		
	REGULATION	SPECIFIED			GENERATION ONLY		GENERATION WITH PUMPBACK
RECORD LABEL	PORT ONLY	PORT ONLY	WEIR ONLY	PORT+WEIR	AFTERBAY	NO AFTERBAY	AFTERBAY
TITLE	*	*	*	*	*	*	*
JOB	*	*	*	*	*	*	*
MODE	*	*	*	*	*	*	*
LECTRIC	-	-	-	-	*	*	*
AFTERBAY	-	-	-	-	*	-	*
PUMPBACK	-	-	-	-	-	-	*
PHYS1	*	*	*	*	*	*	*
PHYS2	*	*	*	*	*	*	*
PHYS2+	*	*	*	*	*	*	*
OUTLET	*	*	-	*	*	*	*
PHYS3	*	*	-	*	*	*	*
PHYS3+	*	-	-	-	-	-	-
WEIR	-	-	*	*	-	-	-

CURVE	*	*	*	*	*	*	*
AREAC	*	*	*	*	*	*	*
WIDTHC	*	*	*	*	*	*	*
MIXING	*	*	*	*	*	*	*
LIGHT	*	*	*	*	*	*	*
SSETL	*	*	*	*	*	*	*
INIT0	*	*	*	*	*	*	*
INIT2	*	*	*	*	*	*	*
INITAB1	-	-	-	-	*	-	*
FILES	*	*	*	*	*	*	*
FILID	*	*	*	*	*	*	*
WEATH1	*	*	*	*	*	*	*
W2	*	*	*	*	*	*	*
OPSCH1	-	-	-	-	*	*	*
OPSCH2	-	-	-	-	*	*	*
ROUTL1	*	-	-	-	-	-	-
ROUTL2	*	-	-	-	-	-	-
SOUTL1	-	*	-	*	-	-	-
SOUTL2	-	*	-	*	-	-	-
SWRFLO	-	-	-	*	-	-	-
WRFLOW1	-	-	*	-	-	-	-
WRFLOW2	-	-	*	-	-	-	-
Q1	*	*	*	*	*	*	*
Q2	*	*	*	*	*	*	*
WQ TEMP	*	*	*	*	*	*	*
TEMP	*	*	*	*	*	*	*
WQ TDS	*	*	*	*	*	*	*
TDS	*	*	*	*	*	*	*
WQ SSOL	*	*	*	*	*	*	*
SSOL	*	*	*	*	*	*	*

ABFL01	-	-	-	-	*	-	*
ABFL02	-	-	-	-	*	-	*
VERIFY1	*	*	*	*	*	*	*
(NOTE: VERIFY2 AND VERIFY3 ARE INCLUDED FOR ALL OPTIONS ONLY WHEN VERIFY1 IS 'YES')							
VERIFY2	*	*	*	*	*	*	*
VERIFY3	*	*	*	*	*	*	*

DOT DIAGRAM FOR CE-QUAL-R1 OPTIONS

NOTE: '*' RECORD INCLUDED '-' RECORD OMITTED

	NORMAL				SCHEDULED		
	REGULATION	SPECIFIED			GENERATION ONLY		GENERATION WITH PUMPBACK
RECORD LABEL	PORT ONLY	PORT ONLY	WEIR ONLY	PORT+WEIR	AFTERBAY	NO AFTERBAY	AFTERBAY
TITLE	*	*	*	*	*	*	*
JOB	*	*	*	*	*	*	*
OUTPUT	*	*	*	*	*	*	*
MODE	*	*	*	*	*	*	*
LECTRIC	-	-	-	-	*	*	*
AFTERBAY	-	-	-	-	*	-	*
PUMPBACK	-	-	-	-	-	-	*
PHYS1	*	*	*	*	*	*	*
PHYS2	*	*	*	*	*	*	*
PHYS2+	*	*	*	*	*	*	*
OUTLET	*	*	-	*	*	*	*
PHYS3	*	*	-	*	*	*	*
PHYS3+	*	-	-	-	-	-	-
WEIR	-	-	*	*	-	-	-
CURVE	*	*	*	*	*	*	*

AREAC	*			*	*	*			*	*				*
WIDTHC	*			*	*	*			*	*				*
MIXING	*			*	*	*			*	*				*
LIGHT	*			*	*	*			*	*				*
DIFC	*			*	*	*			*	*				*
BIO	*			*	*	*			*	*				*
ALG1	*			*	*	*			*	*				*
ALG2	*			*	*	*			*	*				*
ALG3	*			*	*	*			*	*				*
ALG4	*			*	*	*			*	*				*
ALG5	*			*	*	*			*	*				*
ALG6	*			*	*	*			*	*				*
ALG7	*			*	*	*			*	*				*
ALG8	*			*	*	*			*	*				*
PLANT1	*			*	*	*			*	*				*
PLANT2	*			*	*	*			*	*				*
PLANT3	*			*	*	*			*	*				*
ZOO1	*			*	*	*			*	*				*
ZOO2	*			*	*	*			*	*				*
DET1	*			*	*	*			*	*				*
FISH1	*			*	*	*			*	*				*
FISH2	*			*	*	*			*	*				*
DECAY1	*			*	*	*			*	*				*
DECAY2	*			*	*	*			*	*				*
DECAY3	*			*	*	*			*	*				*
DECAY4	*			*	*	*			*	*				*
SSETL	*			*	*	*			*	*				*
TMP	*			*	*	*			*	*				*
CHEM	*			*	*	*			*	*				*
ANAER1	*			*	*	*			*	*				*

ANAER2	*	*	*	*	*	*	*
ANAER3	*	*	*	*	*	*	*
ANAER4	*	*	*	*	*	*	*
INIT0	*	*	*	*	*	*	*
INIT1	*	*	*	*	*	*	*
INIT2	*	*	*	*	*	*	*
INIT3	*	*	*	*	*	*	*
INIT4	*	*	*	*	*	*	*
INIT5	*	*	*	*	*	*	*
INITAB1	-	-	-	-	*	-	*
INITAB2	-	-	-	-	*	-	*
INITAB3	-	-	-	-	*	-	*
PLANTS	*	*	*	*	*	*	*
FILES	*	*	*	*	*	*	*
FILID	*	*	*	*	*	*	*
WEATH1	*	*	*	*	*	*	*
W2	*	*	*	*	*	*	*
FHARV1	*	*	*	*	*	*	*
FHARV2	*	*	*	*	*	*	*
OPSCH1	-	-	-	-	*	*	*
OPSCH2	-	-	-	-	*	*	*
ROUTL1	*	-	-	-	-	-	-
ROUTL2	*	-	-	-	-	-	-
SOUTL1	-	*	-	*	-	-	-
SOUTL2	-	*	-	*	-	-	-
SWRFLO	-	-	-	*	-	-	-
WRFLOW1	-	-	*	-	-	-	-
WRFLOW2	-	-	*	-	-	-	-
Q1	*	*	*	*	*	*	*
Q2	*	*	*	*	*	*	*

WQ 1ALG	*	*	*	*	*	*	*
1ALG	*	*	*	*	*	*	*
WQ 2ALG	*	*	*	*	*	*	*
2ALG	*	*	*	*	*	*	*
WQ 3ALG	*	*	*	*	*	*	*
3ALG	*	*	*	*	*	*	*
WQ ALKA	*	*	*	*	*	*	*
ALKA	*	*	*	*	*	*	*
WQ DOML	*	*	*	*	*	*	*
DOML	*	*	*	*	*	*	*
WQ CNH4	*	*	*	*	*	*	*
CNH4	*	*	*	*	*	*	*
WQ CNO3	*	*	*	*	*	*	*
CNO3	*	*	*	*	*	*	*
WQ DOMR	*	*	*	*	*	*	*
DOMR	*	*	*	*	*	*	*
WQ COL	*	*	*	*	*	*	*
COL	*	*	*	*	*	*	*
WQ DET	*	*	*	*	*	*	*
DET	*	*	*	*	*	*	*
WQ OXY	*	*	*	*	*	*	*
OXY	*	*	*	*	*	*	*
WQ PO4	*	*	*	*	*	*	*
PO4	*	*	*	*	*	*	*
WQ SI	*	*	*	*	*	*	*
SI	*	*	*	*	*	*	*
WQ TEMP	*	*	*	*	*	*	*
TEMP	*	*	*	*	*	*	*
WQ TDS	*	*	*	*	*	*	*
TDS	*	*	*	*	*	*	*

WQ SSOL	*	*	*	*	*	*	*
SSOL	*	*	*	*	*	*	*
WQ PH	*	*	*	*	*	*	*
PH	*	*	*	*	*	*	*
WQ MN4	*	*	*	*	*	*	*
MN4	*	*	*	*	*	*	*
WQ MN2	*	*	*	*	*	*	*
MN2	*	*	*	*	*	*	*
WQ FE3	*	*	*	*	*	*	*
FE3	*	*	*	*	*	*	*
WQ FE2	*	*	*	*	*	*	*
FE2	*	*	*	*	*	*	*
WQ FESB	*	*	*	*	*	*	*
FESB	*	*	*	*	*	*	*
WQ SO4	*	*	*	*	*	*	*
SO4	*	*	*	*	*	*	*
WQ S2	*	*	*	*	*	*	*
S2	*	*	*	*	*	*	*
ABFL01	-	-	-	-	*	-	*
ABFL02	-	-	-	-	*	-	*

(FOR INFORMATION CONCERNING MONTE CARLO DIRECTIVES SEE PART IV OF THIS MANUAL)

APPENDIX D: DATA SET STRUCTURES

CE-THERM-R1

'*' INDICATES A RECORD TYPE MAY BE REPEATED

1	2	3	4	5	6	7	8	9	10
*TITLE		(UP TO 72 CHARACTERS PER RECORD -- FIVE TITLE RECORDS MUST BE PRESENT)							
JOB	IFIRST.	ILAST.	NHOI.	IPRT.	ISTART.	IYEAR.			
MODE	MODE.	STRUCT.	CHOICE.	CALBRAT.					
LECTRIC	PUMPBK.	FTRBAY.							
AFTERBAY	AFBCOF 1.	AFBCOF 2.	AFBCOF 3.	NFTRBY.					
PUMPBACK	PBCOEF.	THETAO.							
PHYS1	NTRIBS.	NUME.	XLAT.	XLON.	TURB.	AA.	BB.	ELEMSL	
PHYS2	RLEN.	SDZMIN.	SDZMAX.						
*PHYS2+	SDZ(1).	SDZ(2).	... SDZ(NUME)						
OUTLET	NOUTS.								
*PHYS3	ELOUT(I). (NWELL, FMIN, FMAX -- INCLUDED WITH REGULATION OPTION ONLY)	PVDIM(I).	PHDIM(I).	NWELL(I).	FMIN(I).	FMAX(I).	WANGLE(I)	(I=1,NOUTS)	
PHYS3+	SELMAX.	BELOW.	NUMWEL	QFLOOD	QSAME				
WEIR	WRLNG.	WRHGT.	COEF.						
CURVE	CURVE.								
AREAC	ACOEF(1).	ACOEF(2).	ACOEF(3).						
WIDTHC	WCOEF(1).	WCOEF(2).							
MIXING	SHELCF.	PEFRAC.	CDIFW.	CDIFF.	CDENS.				
LIGHT	EXCO.	SURFRAC.	EXTINS.						
SSETL	TSSETL.								
INIT0	NPOINT.					(NPOINT INIT2 RECORDS FOLLOW)			
*INIT2	ELEV.	DTEMP.	DTDS.	DSSOL.					
INITAB1	ABVOL.	ABTEMP.	ABSSOL.	ABTDS.					
FILES	FILNAM(I)	, I=1,K.	(LEFT JUSTIFIED IN FIELD-NO MORE THAN 7 CHARACTERS EACH)						

```
      FILID     .FILID(I). , I=1,5.          .(40 CHARACTERS LEFT JUSTIFIED BEGINNING IN COLUMN 9) .
      WEATH1    . INTMET. NCARDS.            .          .          .      (NCARDS W2 RECORDS FOLLOW) .
      *W2       . [ID'S].  CLOUD.      DBT.     DPT.     APRES.     WIND.         .          .         .
      OPSCH1    . NCARDS.         .          .          .          . (NCARDS OPSCH2 RECORDS FOLLOW) .
      *OPSCH2   .   XDAY. XTYPE 1. XTIME 1. XRATE 1.LPORTN 1. XTYPE 2. XTIME 2. XRATE 2.LPORTN 2.
      ROUTL1    . INTINT. NCARDS.            .          .          . (NCARDS ROUTL2 RECORDS FOLLOW) .
      *ROUTL2   . [ID'S].    Q(1).     T(1).     Q(2).     T(2).     Q(3).     T(3).     Q(4).     T(4).
      SOUTL1    . INTINT. NCARDS.            .  (NCARDS SOUTL2 OR SOUTL2 PAIRS OF RECORDS FOLLOW) .
      *SOUTL2   . [ID'S].  LET(1).   QOT(1).          .    ...    . LET(J).   QOT(J).     (J=1,NOUTS) .
      *SWRFLO   .  WRFLO.         .          .  (INTERLEAVED WITH SOUTL2 RECORDS IF WEIR PRESENT) .
      WRFLOW1   . INTINT. NCARDS.            .          .          . (NCARDS WRFLOW2 RECORDS FOLLOW) .
      *WRFLOW2  . DATA(1). DATA(2).    ...   . DATA(J).   ;  J=1,9    .          .          .         .
   [  Q1        . INTQ(I). NCARDS.           .  I=1,NTRIBS         .      (NCARDS Q2 RECORDS FOLLOW) .
 N |  *Q2[ID'S]. QIN(1).  QIN(2).     ...   . DATA(K).   ;  K=1,9    .          .          .         .
 T |  WQ TEMP   . INTWQ.  NCARDS.            .          .          .    (NCARDS TEMP RECORDS FOLLOW) .
 R |  *TEMP     . DATA(1). DATA(2).    ...   . DATA(L).   ;  L=1,9    .          .          .         .
 I |  WQ TDS    . INTWQ.  NCARDS.            .          .          .     (NCARDS TDS RECORDS FOLLOW) .
 B |  *TDS      . DATA(1). DATA(2).    ...   . DATA(L).   ;  L=1,9    .          .          .         .
 S |  WQ SSOL   . INTWQ.  NCARDS.            .          .          .    (NCARDS SSOL RECORDS FOLLOW) .
   |  *SSOL     . DATA(1). DATA(2).    ...   . DATA(L).   ;  L=1,9    .          .          .         .
 S [
 E    ABFLO1    . INTAB.  NCARDS.            .          .          .  (NCARDS ABFLO2 RECORDS FOLLOW) .
 T    *ABFLO2   . DATA(1). DATA(2).    ...   . DATA(J).   ;  J=1,9    .          .          .         .
 S    VERIFY1   . (8 CHARACTERS RIGHT JUSTIFIED IN COLUMNS 9-16)     .          .          .         .
      VERIFY2   .  NVRFY.         .          .          .          . (NVRFY VERIFY3 RECORDS FOLLOW) .
      *VERIFY3  .  NVDAY.  NVTMPS. VELEV 1 . VTEMP 1.    ...    .VELEV(J).VTEMP(J).   ;  J=1,NVTMPS .
```

CE-QUAL-R1

'*' INDICATES A RECORD TYPE MAY BE REPEATED

1	2	3	4	5	6	7	8	9	10
*TITLE		(UP TO 72 CHARACTERS PER RECORD--FIVE TITLE RECORDS MUST BE PRESENT)							
JOB	IFIRST.	ILAST.	NHOI.	IPRT.	ISTART.	IYEAR.	NFLX.	NALG.	
OUTPUT	OUTPUT.								
MODE	MODE.	STRUCT.	CHOICE.	CALBRAT.	AREATE.				
LECTRIC	PUMPBK.	FTRBAY.							
AFTERBAY	AFBCOF 1.	AFBCOF 2.	AFBCOF 3.	NFTRBY.					
PUMPBACK	PBCOEF.	THETAO.							
PHYS1	NTRIBS.	NUME.	XLAT.	XLON.	TURB.	AA.	BB.	ELEMSL	
PHYS2	RLEN.	SDZMIN.	SDZMAX.						
*PHYS2+	SDZ(1).	SDZ(2).	... SDZ(NUME)						
OUTLET	NOUTS.								
*PHYS3	ELOUT(I).	PVDIM(I).	PHDIM(I).	NWELL(I).	FMIN(I).	FMAX(I).	WANGLE(I)	(I=1,NOUTS)	
	(NWELL, FMIN, FMAX--INCLUDED WITH REGULATION OPTION ONLY)								
PHYS3+	SELMAX.	BELOW.	NUMWEL	QFLOOD	QSAME				
WEIR	WRLNG.	WRHGT.	COEF.						
CURVE	CURVE.								
AREAC	ACOEF(1).	ACOEF(2).	ACOEF(3).						
WIDTHC	WCOEF(1).	WCOEF(2).							
MIXING	SHELCF.	PEFRAC.	CDIFW.	CDIFF.	CDENS.				
LIGHT	EXCO.	SURFRAC.	EXTINS.						
DIFC	DMO2.	DMCO2.							
BIO	BIOP.	BIOC.	BION.						
ALG1	EXTINP.	ALDIGO.	ALGAS.						
ALG2	TPMAX1.	TSETL1.	PS2PO41.	PS2N1.	PS2CO21.	PISAT1.	TPEXCR1.	TPMORT1.	TPRESP1.

ALG3	TPMAX2.	TSETL2.	PS2P042.	PS2N2.	PS2C022.	PISAT2.	TPEXCR2.	TPMORT2.	TPRESP2.
ALG4	TPMAX3.	TSETL3.	PS2P043.	PS2N3.	PS2C023.	PISAT3.	TPEXCR3.	TPMORT3.	TPRESP3.
ALG5	PS2SI.								
ALG6	ALG1T1.	ALG1T2.	ALG1T3.	ALG1T4.	ALG1K1.	ALG1K4.			
ALG7	ALG2T1.	ALG2T2.	ALG2T3.	ALG2T4.	ALG2K1.	ALG2K4.			
ALG8	ALG3T1.	ALG3T2.	ALG3T3.	ALG3T4.	ALG3K1.	ALG3K4.			
PLANT1	TPLMAX.	TMRESP.	TMEXCR.	TMMORT.	PLDIG01.	PLDIG02.	PLDIG03.	TMPMAC.	
PLANT2	EXTINM.	PLIMC.	PLIMN.	PLIMP.	PLDENS.	PLITE.	PLFRAC.	PLNTDEP.	
PLANT3	PLTT1.	PLTT2.	PLTT3.	PLTT4.	PLTK1.	PLTK4.			
ZOO1	TZMAX.	TZMORT.	ZEFFIC.	PREF1.	PREF2.	PREF3.	PREF4.	TZRESP.	ZOOMIN.
ZOO2	ZS2P.	ZOOT1.	ZOOT2.	ZOOT3.	ZOOT4.	ZOOK1.	ZOOK4.		
DET1	TDSETL.	DETT1.	DETT2.	DETK1.					
FISH1	TFMAX.	FS2FSH.	FPSED.	FPALG1.	FPALG2.	FPALG3.	FPZOO.	FPDET.	
FISH2	FSH1T1.	FSH1T2.	FSH1T3.	FSH1T4.	FSH1K1.	FSH1K4.	FEFFIC.	TFMORT.	TFRESP.
DECAY1	TDOMDK.	TRFRDK.	TDOMRF.	TNH3DK.	TDETDK.	TCOLDK.	TSEDDK.	TNO3DK.	
DECAY2	DOMT1.	DOMT2.	DOMK1.						
DECAY3	NH3T1.	NH3T2.	NH3K1.						
DECAY4	NO3T1.	NO3T2.	NO3K1.						
SSETL	TSSETL.	ADSRBP.	ADSRBN.	ADMAXP.	ADMAXN.				
TMP	Q10COL.								
CHEM	O2NH3.	O2DET.	O2RESP.	O2FAC.	O2DOM.	O2MN2.	O2FE2.	O2S2.	
ANAER1	OXYLIM.	SEDTHK.							
ANAER2	TMN4ST.	TMN4RE.	TMNREL.	TMN2OX.					
ANAER3	TFE3ST.	TFE3RE.	TFEREL.	TFE2OX.	TFESAD.	TFESST.	TFESBD.		
ANAER4	TSO4RE.	TSREL.	TSOXI.	TS2DK.	TXP4RE.	TCNREL.			
INIT0	NPOINT.								
INIT1	FISH.			(NPOINT SETS OF INIT2 THRU INIT5 RECORDS FOLLOW)					
*INIT2	ELEV.	DALGA1.	DALGA2.	DALGA3.	DALKA.	DCNH3.	DCNO3.	DCRFR.	DCOLIF.
*INIT3	DDETUS.	DDOM.	DOXY.	DPO4.	DSEDMT.	DTEMP.	DTDS.	DZOO.	DPH.
*INIT4	DSSOL.	DCMN4.	DCMN2.	DFE3.	DFE2.	DFESB.	DSO4.	DS2.	DCMN.

*INIT5	DFE.	DFESA.	DS.	DXPO4.	DCN.	DSI.			
INITAB1	ABVOL.	AB1ALG.	AB2ALG.	AB3ALG.	ABALKA.	ABDOM.	ABCNH3.	ABCNO3.	ABRFR.
INITAB2	ABCOLIF.	ABDETUS.	ABOXY.	ABPO4.	ABSI.	ABTEMP.	ABTDS.	ABSSOL.	ABZOO.
INITAB3	ABCARB.	ABCMN4.	ABCMN2.	ABFE3.	ABFE2.	ABFESB.	ABSO4.	ABS2.	
PLANTS	DATA(1).	DATA(2).	...	DATA(I).I=1,NINE.	; NINE=NUME IF(NUME.GT.9)NINE=9				
FILES	FILNAM(I)	, I=1,K.	(LEFT JUSTIFIED IN FIELD-NO MORE THAN 7 CHARACTERS EACH)						
FILID	FILID(I).	, I=1,5.	(UP TO 40 CHARACTERS LEFT JUSTIFIED BEGINNING IN COLUMN 9)						
WEATH1	INTMET.	NCARDS.					(NCARDS W2 RECORDS FOLLOW)		
*W2	[ID'S].	CLOUD.	DBT.	DPT.	APRES.	WIND.			
FHARV1	INTFH.	NCARDS.				(NCARDS FHARV2 RECORDS FOLLOW)			
*FHARV2	HARVST.								
OPSCH1	NCARDS.					(NCARDS OPSCH2 RECORDS FOLLOW)			
*OPSCH2	XDAY.	XTYPE 1.	XTIME 1.	XRATE 1.	LPORTN 1.	XTYPE 2.	XTIME 2.	XRATE 2.	LPORTN 2.
ROUTL1	INTINT.	NCARDS.				(NCARDS ROUTL2 RECORDS FOLLOW)			
*ROUTL2	[ID'S].	Q(1).	T(1).	Q(2).	T(2).	Q(3).	T(3).	Q(4).	T(4).
SOUTL1	INTINT.	NCARDS.			(NCARDS SOUTL2 OR SOUTL2 PAIRS FOLLOW)				
*SOUTL2	[ID'S].	LET(1).	QOT(1).	...	...	LET(J).	QOT(J).		(J=1,NOUTS)
*SWRFLO	WRFLO.			(INTERLEAVED WITH SOUTL2 RECORDS IF WEIR PRESENT)					
WRFLOW1	INTINT.	NCARDS.				(NCARDS WRFLOW2 RECORDS FOLLOW)			
*WRFLOW2	DATA(1).	DATA(2).	...	DATA(J).	; J=1,9				
Q1	INTQ(I).	NCARDS.		I=1,NTRIBS			(NCARDS Q2 RECORDS FOLLOW)		
*Q2[ID'S].	QIN(1).	QIN(2).	...						
WQ 1ALG	INTWQ.	NCARDS.				(NCARDS 1ALG RECORDS FOLLOW)			
*1ALG	DATA(1).	DATA(2).	...	DATA(L).	; L=1,9				
WQ 2ALG	INTWQ.	NCARDS.				(NCARDS 2ALG RECORDS FOLLOW)			
*2ALG	DATA(1).	DATA(2).	...	DATA(L).	; L=1,9				
WQ 3ALG	INTWQ.	NCARDS.				(NCARDS 3ALG RECORDS FOLLOW)			
*3ALG	DATA(1).	DATA(2).	...	DATA(L).	; L=1,9				
WQ ALKA	INTWQ.	NCARDS.				(NCARDS ALKA RECORDS FOLLOW)			
*ALKA	DATA(1).	DATA(2).	...	DATA(L).	; L=1,9				

NTRIBS

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Q

R

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 WQ DOML . INTWQ . NCARDS.            .          .        . (NCARDS DOML RECORDS FOLLOW) .
*DOML    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ CNH4 . INTWQ . NCARDS.            .          .        . (NCARDS CNH4 RECORDS FOLLOW) .
*CNH4    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ CNO3 . INTWQ . NCARDS.            .          .        . (NCARDS CNO3 RECORDS FOLLOW) .
*CNO3    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ DOMR . INTWQ . NCARDS.            .          .        . (NCARDS DOMR RECORDS FOLLOW) .
*DOMR    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ COL  . INTWQ . NCARDS.            .          .        .  (NCARDS COL RECORDS FOLLOW) .
*COL     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ DET  . INTWQ . NCARDS.            .          .        .  (NCARDS DET RECORDS FOLLOW) .
*DET     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ OXY  . INTWQ . NCARDS.            .          .        .  (NCARDS OXY RECORDS FOLLOW) .
*OXY     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ PO4  . INTWQ . NCARDS.            .          .        .  (NCARDS PO4 RECORDS FOLLOW) .
*PO4     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ SI   . INTWQ . NCARDS.            .          .        .   (NCARDS SI RECORDS FOLLOW) .
*SI      . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ TEMP . INTWQ . NCARDS.            .          .        . (NCARDS TEMP RECORDS FOLLOW) .
*TEMP    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ TDS  . INTWQ . NCARDS.            .          .        .  (NCARDS TDS RECORDS FOLLOW) .
*TDS     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ SSOL . INTWQ . NCARDS.            .          .        . (NCARDS SSOL RECORDS FOLLOW) .
*SSOL    . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ PH   . INTWQ . NCARDS.            .          .        .   (NCARDS PH RECORDS FOLLOW) .
*PH      . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ MN4  . INTWQA. NCARDS.            .          .        .  (NCARDS MN4 RECORDS FOLLOW) .
*MN4     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
 WQ MN2  . INTWQA. NCARDS.            .          .        .  (NCARDS MN2 RECORDS FOLLOW) .
*MN2     . DATA(1). DATA(2).   ...    . DATA(L). ;  L=1,9                               .
```

```
E     WQ FE3   . INTWQA . NCARDS .     .         .     . (NCARDS FE3 RECORDS FOLLOW) .
C     *FE3     . DATA(1). DATA(2). ... . DATA(L).  ;  L=1,9
O     WQ FE2   . INTWQA . NCARDS .     .         .     . (NCARDS FE2 RECORDS FOLLOW) .
      *FE2     . DATA(1). DATA(2). ... . DATA(L).  ;  L=1,9
R     WQ FESB  . INTWQA . NCARDS .     .         .     . (NCARDS FESB RECORDS FOLLOW) .
      *FESB    . DATA(1). DATA(2). ... . DATA(L).  ;  L=1,9
D     WQ SO4   . INTWQA . NCARDS .     .         .     . (NCARDS SO4 RECORDS FOLLOW) .
S     *SO4     . DATA(1). DATA(2). ... . DATA(L).  ;  L=1,9
      WQ S2    . INTWQA . NCARDS .     .         .     . (NCARDS S2 RECORDS FOLLOW) .
      *S2      . DATA(1). NCARDS . ... . DATA(L).  ;  L=1,9
      ABFL01   . INTAB  . NCARDS .     .         .     . (NCARDS ABFLO2 RECORDS FOLLOW) .
      *ABFLO2  . DATA(1). DATA(2). ... . DATA(J).  ;  J=1,9
```

(FOR INFORMATION CONCERNING MONTE CARLO DIRECTIVES SEE PART IV OF THIS MANUAL)

APPENDIX E: DATA SET EXAMPLES

Data Set for CE-QUAL-RI

```
TITLE                   *** DEGRAY LAKE 1979***
TITLE
TITLE      ********                       CE-QUAL-R1                  ********
TITLE      ***************** JUNE 27 1985,NO.1 ********************
TITLE
JOB            1     362      24    4800      25      79       0       1
OUTPUT  COMPLETE
MODE      NORMAL    PORT SPECIFY     YES
PHYS1          2      60    34.4    93.1      2.      0. 1.2E-09
PHYS2      13000    0.50    2.00
PHYS2+      1.25    1.25      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.      1.      1.      1.
PHYS2+        1.      1.      1.      1.      1.      1.
OUTLET         3
PHYS3       56.4    5.58    5.58                            180.
PHYS3       51.8    5.58    5.58                            180.
PHYS3       44.4    5.58    5.58                            180.
CURVE      POWER
AREAC     561.81    2.79
WIDTHC      47.7     .55
MIXING       1.0     .01  .00004 .000008      2.
LIGHT      0.450    0.40    0.01
DIFC     2.04-09 1.63-09
BIO         .004    0.46    0.05
ALG1         .10     .25     .01
ALG2        1.10    0.14    .009    .014    0.12     50.    .010    .010     .02
ALG3         0.8    0.14    .009     .01     0.1     20.    .020    .020     .02
ALG4         1.0    0.14    .009     .01     0.1     54.    .001    .001     .02
ALG5         .05
ALG6           0      26      30      35     0.1     0.1
ALG7           4      26      36      40     0.1     0.1
ALG8           2      26      32      37     0.1     0.1
PLANT1       0.0      .2      .1     .05      .4      .3      .3
PLANT2       .02     .05     .01    .005     10.     30.      .5
PLANT3        2.     25.     29.     38.      .1      .1
ZOO1         .44    .010    0.50     0.5     0.0     0.0     0.5    0.14     .01
ZOO2         .30     0.0      20      26      36     0.1     0.1
DET1         .35     4.0      28    0.01
FISH1      .0150      .2     .03     .37      0.     0.0     .34     .26
FISH2         1.    24.4    28.4    35.2      .1      .1      .8     .01     .01
DECAY1     0.032   0.005   0.005     .08    .009     1.4    .008    .001
DECAY2         2      20     .12
DECAY3         2      32     0.1
DECAY4         2      32     0.1
SSETL        .05    150.    125.    .007    .005
TMP         1.04
CHEM        4.57     1.4     1.1     1.4     1.4    0.15    0.14     2.0
ANAER1       0.5     5.0
ANAER2      0.05    0.02      .1      .0
ANAER3       .05     .03      .1      .0      .0      .9      .5      .5
ANAER4      .001 .000012      .3      .0    .001     .01     0.1
INIT0         48
INIT1        55.
INIT2         0.    .001      0.    .001     20.   .0001     .21     9.6     20.
INIT3      .0002     2.4     9.4    .001   101.1     5.2     49.    .001     6.6
INIT4        6.0     0.1     0.0     0.1     0.0     0.0     4.0     0.0    600.
```

```
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       14.5    .001       0.     .001      20.    .0001      .21      9.6      20.
INIT3      .0002     2.4      9.4     .001    101.1      5.2      49.     .001      6.6
INIT4        6.0     0.1      0.0      0.1      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       15.5    .001       0.     .001      20.    .0001      .21      9.6      20.
INIT3      .0002     2.4      9.3     .001    101.1      5.2      49.     .001      6.6
INIT4        6.0     0.1      0.0      0.1      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       16.5    .001       0.     .001      20.    .0001      .21      9.6      20.
INIT3      .0002     2.4      9.3     .001    101.1      5.2      49.     .001      6.6
INIT4        6.0     0.1      0.0      0.1      0.0      0.0      3.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       17.5    .001       0.     .001     19.3    .0001      .21     9.28     46.7
INIT3      .0002    2.32      9.3     .001    101.1      5.2     51.7     .001      6.6
INIT4        6.0     0.1      0.0      0.1      0.0      0.0      3.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       18.5    .001       0.     .001     18.7    .0001      .22     9.04     73.3
INIT3      .0002    2.26      9.3     .001    101.1      5.3     54.3     .001      6.6
INIT4         6.     0.1      0.0      0.1      0.0      0.0      3.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       19.5    .001       0.     .001      18.    .0001      .22     8.72     100.
INIT3      .0002    2.18      9.3     .001    101.1      5.3      57.     .001      6.6
INIT4         6.     0.1      0.0      0.0      0.0      0.0      3.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       20.5    .001       0.     .001      17.    .0001      .23       8.      40.
INIT3      .0002      2.      9.3     .002    101.1      5.3      61.     .001      6.6
INIT4         6.     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       21.5    .001       0.     .001      17.    .0001      .21     8.16     162.
INIT3      .0002    2.04      9.3     .002    101.1      5.3     60.6     .003      6.6
INIT4         6.     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       22.5    .001       0.     .001      17.    .0001      .23     8.32     284.
INIT3      .0002    2.08      9.3     .002    101.1      5.3     60.2     .003      6.6
INIT4         6.     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       23.5    .001       0.     .001      17.    .0001      .22      8.4     406.
INIT3      .0002     2.1      9.2     .001    101.1      5.3     59.8     .003      6.7
INIT4         6.     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       24.5    .001       0.     .001      17.    .0001      .22     8.56     528.
INIT3      .0002    2.14      9.3     .001    101.1      5.3     59.4     .003      6.7
INIT4        6.0     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       25.5    .001       0.     .001      17.    .0001      .21     8.72     650.
INIT3      .0002    2.18      9.3     .001    101.1      5.3      59.     .003      6.7
INIT4        6.0     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       26.5    .001       0.     .001      17.    .0001      .21     8.72     532.
INIT3      .0002    2.18      9.3     .001    101.1      5.3      59.     .003      6.7
INIT4         6.     0.1      0.0      0.0      0.0      0.0      4.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       27.5    .001       0.     .001      17.    .0001      .20     8.72     414.
INIT3      .0002    2.18      9.3     .001    101.1      5.2      59.     .003      6.7
INIT4         6.     0.1      0.0      0.0      0.0      0.0      3.0      0.0     600.
INIT5     12000.     0.0     200.     400.    1000.       1.
INIT2       28.5    .001       0.     .001      18.    .0001      .20     8.56     296.
INIT3      .0002    2.14      9.3     .001    101.1      5.3      58.     .003      6.7
INIT4         6.     0.1      0.0      0.0      0.0      0.0      3.0      0.0     600.
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INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     29.5     .001     0.     .001     18.    .0001     .19    8.56    178.
INIT3    .0002     2.14    9.3     .001    101.1     5.3     58.     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     3.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     30.5     .001     0.     .001     18.    .0001     .19    8.56     60.
INIT3    .0002     2.14    9.3     .001    101.1     5.3     58.     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     3.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     31.5     .001     0.     .001     18.    .0001     .19    8.56     56.
INIT3    .0002     2.14    9.3     .001    101.1     5.3    58.6     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     3.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     32.5     .001     0.     .001     18.    .0001     .20    8.56     52.
INIT3    .0002     2.14    9.3     .001    101.1     5.3    59.2     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     33.5     .001     0.     .001     18.    .0001     .20    8.56     48.
INIT3    .0002     2.14    9.3     .001    101.1     5.3    59.8     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     34.5     .001     0.     .001     18.    .0001     .21    8.56     44.
INIT3    .0002     2.14    9.3     .001    101.1     5.3    60.4     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     35.5     .001     0.     .001     18.    .0001     .21    8.56     40.
INIT3    .0002     2.14    9.3     .001    101.1     5.3     61.     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     36.5     .001     0.     .001     17.6   .0001     .21    9.36     74.
INIT3    .0002     2.34    9.3     .001    101.1     5.3    61.2     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     37.5     .001     0.     .001     17.2   .0001     .21   10.24    108.
INIT3    .0002     2.56    9.3     .001    101.1     5.3    61.4     .003     6.7
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     38.5     .001     0.     .001     16.8   .0001     .22   11.12    142.
INIT3    .0002     2.78    9.3     .001    101.1     5.3    61.6     .003     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     39.5     .001     0.     .001     16.4   .0001     .22   11.92    176.
INIT3    .0002     2.98    9.3     .001    101.1     5.3    61.8     .003     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     40.5     .001     0.     .001     16.    .0001     .22    12.8    210.
INIT3    .0002     3.2     9.3     .001    101.1     5.3     62.     .003     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     41.5     .001     0.     .001     16.4   .0001     .22   13.76    168.
INIT3    .0002     3.44    9.3     .001    101.1     5.3    61.2     .008     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     42.5     .001     0.     .001     16.8   .0001     .22   14.72    126.
INIT3    .0002     3.68    9.3     .001    101.1     5.3    60.4     .008     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
INIT5    12000.     0.0    200.    400.    1000.      1.
INIT2     43.5     .001     0.     .001     17.2   .0001     .21   15.68     84.
INIT3    .0002     3.92    9.3     .001    101.1     5.2    59.6     .008     6.8
INIT4      6.      0.1     0.0     0.0      0.0      0.0     4.0     0.0    600.
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INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       44.5      .001        0.      .001      17.6     .0001       .21     16.64       42.
INIT3      .0002      4.16       9.3      .001     101.1       5.3      58.8      .008       6.8
INIT4         6.       0.1       0.0       0.0       0.0       0.0       4.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       45.5      .001        0.      .001       18.     .0001       .21      17.6        0.
INIT3      .0002       4.4       9.4      .001     101.1       5.3       58.      .008       6.8
INIT4         6.       0.1       0.0       0.0       0.0       0.0       4.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       46.5      .001        0.      .001      17.7     .0001       .21     16.32     153.3
INIT3      .0002      4.08       9.3      .001     101.1       5.3      60.7      .007       6.8
INIT4         6.       0.1       0.0       0.0       0.0       0.0       4.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       47.5      .001        0.      .001      17.3     .0001       .22     14.96     306.7
INIT3      .0002      3.74       9.4      .001     101.1       5.3      63.3      .007       6.9
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       48.5      .001        0.      .001       17.     .0001       .22     13.68      460.
INIT3      .0002      3.42       9.4      .001     101.1       5.3       66.      .007       6.9
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       49.5      .001        0.      .001      16.5     .0001       .22     10.88      231.
INIT3      .0002      2.72       9.3      .001     101.1       5.3      66.5      .007       6.9
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       50.5       1.5        0.      .001       16.     .0001       .22        8.        2.
INIT3      .0002        2.       9.3      .001     101.1       5.3       67.      .007       6.9
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       51.5       1.2        0.      .001       17.     .0001       .16      7.84       16.
INIT3      .0002      1.96       9.4      .001     101.1       5.3       66.      .006      6.95
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       52.5        .4        0.      .001       18.     .0001       .09      7.76       30.
INIT3      .0002      1.94       9.4      .001     101.1       5.3       65.      .006       7.0
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       53.5        .6        0.      .001      16.5     .0001       .15      7.92      545.
INIT3      .0002      1.98       9.4      .001     101.1       5.3      65.5      .006       7.0
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       54.5       1.6        0.      .001      15.0     .0001       .21      8.16     1060.
INIT3      .0002      2.04       9.4      .001     101.1       5.3      66.0      .006       7.0
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       55.5       .94        0.      .001      15.5     .0001       .22        8.      570.
INIT3      .0002        2.       9.4      .001     101.1       5.3       64.      .006      7.05
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       56.5       1.4        0.      .001       16.     .0001       .22        8.       80.
INIT3      .0002        2.       9.4      .004     101.1       5.3       62.      .007       7.1
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       57.5      1.42        0.      .001       17.     .0001       .22      7.92       55.
INIT3      .0002      1.98       9.4      .001     101.1       5.4      65.5      .007       7.2
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
INIT5     12000.       0.0      200.      400.     1000.        1.
INIT2       58.5        .8        0.      .001      16.5      .005       .22       8.8       3.8
INIT3      .0002       2.2       9.4      .002     101.1       5.4       69.      .007       7.2
INIT4         6.       0.1       0.0       0.0       0.0       0.0       3.0       0.0      600.
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INIT5     12000.     0.0    200.    400.   1000.      1.
INIT2       59.5     1.5      0.    .001    15.7    .007     .21   10.96     4.9
INIT3      .0002    2.74     9.5    .002   101.1     5.4     63.    .007     7.3
INIT4         6.     0.1     0.0     0.0     0.0     0.0     3.0     0.0    600.
INIT5     12000.     0.0    200.    400.   1000.      1.
INIT2       59.7     1.4      0.    .001    14.8    .008     .21   13.04      6.
INIT3      .0002    3.26     9.5    .002   101.1     5.5     57.    .007     7.4
INIT4         6.     0.1     0.0     0.0     0.0     0.0     3.0     0.0    600.
INIT5     12000.     0.0    200.    400.   1000.      1.
PLANTS        0.      0.      0.      0.      0.      0.      0.
FILES   PLTWC   PLDG15  PLDG16  PLDG17  FLUX
FILID    DEGRAY79 JUNE 27 1985 NO.1
WEATH1        24     365
W2 LTLRC 79 1 1      0.9    -2.0    -7.4  1013.5    19.7
W2 LTLRC 79 1 2      0.0    -7.2   -17.2  1022.9    16.2
W2 LTLRC 79 1 3      0.3    -3.3   -11.9  1027.1     5.8
W2 LTLRC 79 1 4      0.6    -0.3    -7.8  1028.3     6.3
W2 LTLRC 79 1 5      1.0     0.3    -3.5  1023.1    10.4
W2 LTLRC 79 1 6      1.0    -2.6    -6.5  1015.1    13.7
W2 LTLRC 79 1 7      0.9    -1.5    -6.3  1011.5    13.0
W2 LTLRC 79 1 8      0.1    -6.3   -13.2  1022.1     8.1
W2 LTLRC 79 1 9      0.2    -4.7    -8.8  1022.4     4.9
W2 LTLRC 79 110      0.9    -3.9    -6.7  1022.2     7.6
W2 LTLRC 79 111      0.9    -5.1   -11.0  1017.9    14.1
W2 LTLRC 79 112      0.9    -2.4    -6.8  1006.6    10.9
W2 LTLRC 79 113      0.9    -1.2    -4.3   998.8    11.3
W2 LTLRC 79 114      0.0    -7.1   -15.3  1018.2    17.8
W2 LTLRC 79 115      0.6    -4.7   -12.4  1020.5     9.0
W2 LTLRC 79 116      1.0     1.7    -3.6  1017.7     3.2
W2 LTLRC 79 117      1.0     7.0     4.1  1017.0     2.5
W2 LTLRC 79 118      0.9     4.0    -1.3  1017.2    12.0
W2 LTLRC 79 119      1.0     6.1     4.2  1004.8     5.3
W2 LTLRC 79 120      1.0     7.6     6.9   993.1    16.7
W2 LTLRC 79 121      0.7     1.0    -5.5  1000.1    19.9
W2 LTLRC 79 122      0.5     0.2    -3.3  1006.1     7.6
W2 LTLRC 79 123      1.0     2.2    -0.2   993.9    17.8
W2 LTLRC 79 124      0.0    -2.8   -11.5  1003.7    21.1
W2 LTLRC 79 125      0.7    -1.9    -7.0  1009.1     7.9
W2 LTLRC 79 126      1.0      0.    -2.4  1004.7    10.9
W2 LTLRC 79 127      0.9    -0.7    -3.8  1001.3    16.4
W2 LTLRC 79 128      0.2    -3.1    -9.6  1010.3    14.1
W2 LTLRC 79 129      0.6    -3.7    -9.7  1013.4     7.9
W2 LTLRC 79 130      1.0     0.1    -4.6  1010.5     7.9
W2 LTLRC 79 131      0.2    -3.6   -11.5  1015.5    19.2
W2 LTLRC 79 2 1      0.5    -5.3   -11.6  1018.1     6.3
W2 LTLRC 79 2 2      1.0     0.1    -4.4  1013.5     3.9
W2 LTLRC 79 2 3      1.0     3.2     0.1  1012.1     4.6
W2 LTLRC 79 2 4      0.8     0.3    -5.2  1017.0    12.0
W2 LTLRC 79 2 5      1.0    -2.2   -10.5  1016.6    14.6
W2 LTLRC 79 2 6      1.0    -0.8    -5.3  1004.8    11.6
W2 LTLRC 79 2 7      1.0     1.1    -2.6  1006.7     8.6
W2 LTLRC 79 2 8      0.9     0.4    -3.5  1012.2    14.6
W2 LTLRC 79 2 9      0.2    -8.6   -16.3  1022.8    11.1
W2 LTLRC 79 210      0.2    -4.2    -9.9  1018.9     2.1
W2 LTLRC 79 211      0.5     1.8    -2.9  1016.2     4.2
W2 LTLRC 79 212      1.0     8.8     3.9  1016.3     7.4
W2 LTLRC 79 213      1.0     1.6    -3.3  1015.4     7.9
W2 LTLRC 79 214      0.7     6.5     4.0  1006.7     1.9
W2 LTLRC 79 215      0.9    17.6    11.5  1007.5    18.5
W2 LTLRC 79 216      0.7     1.0    -6.5  1019.8    20.8
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W2 LTLRC 79 217        1.0     -3.0      -8.5  1020.4      19.2
W2 LTLRC 79 218        0.7     -0.5      -5.4  1020.2      10.6
W2 LTLRC 79 219        0.2      1.3      -3.5  1022.3       2.3
W2 LTLRC 79 220        0.8      3.9       0.3  1013.7       4.9
W2 LTLRC 79 221        1.0     10.6       6.4  1013.8       3.9
W2 LTLRC 79 222        1.0     15.7      13.8  1010.9       9.7
W2 LTLRC 79 223        1.0     17.7      15.6  1010.3       4.4
W2 LTLRC 79 224        1.0      7.8       5.7  1007.4      14.8
W2 LTLRC 79 225        0.6      4.0      -0.9  1009.0      24.3
W2 LTLRC 79 226        0.1      4.9      -5.0  1016.0       7.6
W2 LTLRC 79 227        0.4      5.6      -0.8  1011.7       5.6
W2 LTLRC 79 228        0.9     10.3       6.6  1006.4      11.3
W2 LTLRC 79 3 1        0.9      9.0       5.2  1013.8       8.1
W2 LTLRC 79 3 2        0.7      8.4       5.9  1011.9      10.2
W2 LTLRC 79 3 3        0.7     17.4      11.5  1000.7      13.9
W2 LTLRC 79 3 4        0.6      4.7      -2.8  1009.0      17.6
W2 LTLRC 79 3 5        0.1      6.3      -5.2  1016.1      11.6
W2 LTLRC 79 3 6        0.2     11.0      -1.3  1013.3       5.8
W2 LTLRC 79 3 7        0.5     12.6       0.9  1007.2      15.3
W2 LTLRC 79 3 8        0.2      7.0      -1.9  1009.0       8.8
W2 LTLRC 79 3 9        0.8     12.2       4.6  1010.5      12.5
W2 LTLRC 79 310        0.7      7.9      -0.3  1016.6      11.3
W2 LTLRC 79 311        0.       8.5      -5.5  1018.3       6.0
W2 LTLRC 79 312        0.2     14.5       0.3  1016.7       5.8
W2 LTLRC 79 313        0.6     18.7       4.8  1012.1      16.0
W2 LTLRC 79 314        0.1     13.2      -4.4  1021.3      14.6
W2 LTLRC 79 315        0.6      7.3      -2.0  1025.0      11.1
W2 LTLRC 79 316        1.0      8.8      -1.3  1024.2       9.5
W2 LTLRC 79 317        0.5     15.4       6.5  1021.2       8.8
W2 LTLRC 79 318        0.8     18.4      14.0  1015.5      13.7
W2 LTLRC 79 319        1.0     20.8      17.1  1014.4      11.8
W2 LTLRC 79 320        0.8     19.5      15.9  1013.3      12.7
W2 LTLRC 79 321        1.0     14.7      13.0  1013.4      11.8
W2 LTLRC 79 322        0.9     16.7      15.6  1004.2      10.9
W2 LTLRC 79 323        0.6     11.6       7.8   993.7      19.4
W2 LTLRC 79 324        0.3      8.0      -2.1  1000.1      23.8
W2 LTLRC 79 325        0.       8.4      -5.0  1005.9      14.6
W2 LTLRC 79 326        0.4     10.6       1.9  1011.7      11.8
W2 LTLRC 79 327        1.0     10.1       8.7  1015.8      13.2
W2 LTLRC 79 328        1.0     17.2      13.3  1016.1      11.6
W2 LTLRC 79 329        1.0     20.9      14.3  1014.3      17.6
W2 LTLRC 79 330        1.0     19.4      16.0  1013.1      16.4
W2 LTLRC 79 331        1.0     19.4      16.5  1014.0       5.6
W2 LTLRC 79 4 1        1.0     16.3      15.8  1006.4       6.5
W2 LTLRC 79 4 2        0.7     13.8       9.9  1010.6      13.7
W2 LTLRC 79 4 3        0.7     10.8       6.7  1012.5      15.5
W2 LTLRC 79 4 4        0.8     10.3       6.9  1010.6      12.7
W2 LTLRC 79 4 5        0.1     11.9       4.4  1016.1       9.3
W2 LTLRC 79 4 6        0.0     11.9       5.9  1020.6      13.2
W2 LTLRC 79 4 7        0.3     15.8       8.5  1017.4      10.6
W2 LTLRC 79 4 8        0.9     16.8      14.7  1007.2      14.1
W2 LTLRC 79 4 9        0.1     12.1       6.6  1007.5      12.0
W2 LTLRC 79 410        1.0     11.5       8.7  1005.5      17.4
W2 LTLRC 79 411        0.9     20.5      17.8   999.2      14.1
W2 LTLRC 79 412        0.7     20.8      14.9  1004.9       5.3
W2 LTLRC 79 413        0.3     17.3       8.1  1009.1       9.5
W2 LTLRC 79 414        0.0     17.6      10.3  1013.2       6.5
W2 LTLRC 79 415        0.      18.5      10.6  1016.4       5.8
W2 LTLRC 79 416        0.      20.1      10.4  1017.6       6.0
W2 LTLRC 79 417        0.7     21.3      11.7  1018.7       5.6
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W2	LTLRC	79	418	0.9	19.9	12.5	1018.9	3.5
W2	LTLRC	79	419	0.7	22.8	13.0	1017.8	10.2
W2	LTLRC	79	420	0.8	20.5	12.2	1016.1	8.3
W2	LTLRC	79	421	1.0	20.0	12.8	1017.8	10.0
W2	LTLRC	79	422	1.0	17.6	14.4	1016.4	21.8
W2	LTLRC	79	423	0.8	19.6	17.4	1009.8	19.4
W2	LTLRC	79	424	0.5	19.3	15.6	1009.1	8.1
W2	LTLRC	79	425	0.6	21.0	16.7	1006.9	8.8
W2	LTLRC	79	426	0.4	19.1	10.0	1006.3	18.1
W2	LTLRC	79	427	0.6	15.5	6.4	1011.0	12.5
W2	LTLRC	79	428	0.4	14.0	2.8	1014.8	6.0
W2	LTLRC	79	429	0.7	16.8	7.9	1014.5	7.2
W2	LTLRC	79	430	0.4	16.7	8.7	1016.0	9.7
W2	LTLRC	79	5 1	0.7	18.0	10.8	1013.9	5.8
W2	LTLRC	79	5 2	1.0	21.0	16.0	1010.3	11.6
W2	LTLRC	79	5 3	1.0	21.2	17.2	1009.7	14.1
W2	LTLRC	79	5 4	1.0	16.3	13.7	1010.5	15.0
W2	LTLRC	79	5 5	0.3	15.6	8.6	1013.0	10.4
W2	LTLRC	79	5 6	0.5	17.4	12.7	1009.0	14.1
W2	LTLRC	79	5 7	0.1	22.4	15.7	1007.4	12.7
W2	LTLRC	79	5 8	0.2	26.0	19.1	1009.1	14.6
W2	LTLRC	79	5 9	0.4	25.7	19.4	1009.3	12.5
W2	LTLRC	79	510	0.5	24.7	20.5	1009.9	9.7
W2	LTLRC	79	511	1.0	20.6	17.8	991.0	11.3
W2	LTLRC	79	512	0.8	15.8	8.2	1015.1	16.0
W2	LTLRC	79	513	0.1	18.0	8.3	1016.9	7.4
W2	LTLRC	79	514	0.0	21.5	12.7	1017.8	10.9
W2	LTLRC	79	515	0.1	22.2	15.8	1020.5	10.2
W2	LTLRC	79	516	0.4	21.2	12.3	1022.4	10.4
W2	LTLRC	79	517	0.1	21.7	12.8	1020.8	5.6
W2	LTLRC	79	518	0.6	22.5	13.8	1016.4	7.9
W2	LTLRC	79	519	0.4	25.1	17.3	1013.3	12.5
W2	LTLRC	79	520	0.8	25.6	18.3	1012.0	12.0
W2	LTLRC	79	521	1.0	20.8	17.2	1012.1	18.5
W2	LTLRC	79	522	1.0	19.7	16.5	1011.2	14.1
W2	LTLRC	79	523	0.6	22.4	14.9	1011.9	13.7
W2	LTLRC	79	524	0.2	18.9	8.3	1015.1	17.4
W2	LTLRC	79	525	0.1	18.5	6.5	1016.6	12.5
W2	LTLRC	79	526	0.7	16.9	9.9	1012.7	11.6
W2	LTLRC	79	527	0.9	19.8	15.7	1009.7	11.1
W2	LTLRC	79	528	0.9	20.5	17.3	1010.8	4.6
W2	LTLRC	79	529	1.0	21.3	17.6	1008.6	7.6
W2	LTLRC	79	530	0.9	23.5	19.2	1007.4	9.3
W2	LTLRC	79	531	0.7	25.1	19.9	1013.2	10.0
W2	LTLRC	79	6 1	0.7	24.8	19.3	1019.2	10.4
W2	LTLRC	79	6 2	1.0	21.3	18.1	1015.9	13.2
W2	LTLRC	79	6 3	1.0	20.6	16.1	1014.4	9.5
W2	LTLRC	79	6 4	0.5	23.8	17.5	1012.5	5.6
W2	LTLRC	79	6 5	0.7	24.0	18.8	1009.9	5.8
W2	LTLRC	79	6 6	1.0	24.9	20.6	1008.6	7.6
W2	LTLRC	79	6 7	0.7	27.0	22.5	1009.4	15.3
W2	LTLRC	79	6 8	0.4	28.6	22.1	1015.2	11.6
W2	LTLRC	79	6 9	0.2	28.7	21.7	1017.0	9.7
W2	LTLRC	79	610	0.4	24.6	16.4	1018.2	15.5
W2	LTLRC	79	611	0.0	22.4	10.6	1021.5	11.6
W2	LTLRC	79	612	0.1	23.8	12.6	1020.4	7.9
W2	LTLRC	79	613	0.6	24.7	14.2	1019.7	10.2
W2	LTLRC	79	614	0.2	25.7	15.8	1019.6	7.4
W2	LTLRC	79	615	0.0	25.3	14.9	1019.1	12.7
W2	LTLRC	79	616	0.1	25.6	16.8	1015.8	8.8

W2	LTLRC	79	617	0.2	26.9	17.7	1015.1	11.6
W2	LTLRC	79	618	0.3	27.1	18.1	1017.1	15.5
W2	LTLRC	79	619	0.3	28.7	21.2	1017.6	18.1
W2	LTLRC	79	620	0.5	29.8	22.2	1018.8	18.5
W2	LTLRC	79	621	0.9	24.8	21.2	1019.0	11.6
W2	LTLRC	79	622	0.6	25.8	21.3	1017.7	6.7
W2	LTLRC	79	623	0.8	26.8	22.2	1016.8	8.3
W2	LTLRC	79	624	0.9	23.8	20.1	1018.5	11.6
W2	LTLRC	79	625	0.6	22.0	15.2	1021.5	13.2
W2	LTLRC	79	626	0.2	23.4	15.1	1022.6	8.1
W2	LTLRC	79	627	0.2	24.4	16.9	1021.8	3.0
W2	LTLRC	79	628	0.6	25.6	18.5	1018.8	11.1
W2	LTLRC	79	629	0.5	28.9	20.6	1015.0	9.7
W2	LTLRC	79	630	0.6	26.4	17.4	1014.7	10.4
W2	LTLRC	79	7 1	0.9	25.0	19.9	1013.4	7.6
W2	LTLRC	79	7 2	0.6	28.6	21.6	1015.9	10.2
W2	LTLRC	79	7 3	0.1	29.0	21.7	1017.1	12.7
W2	LTLRC	79	7 4	0.5	30.0	22.4	1015.4	13.0
W2	LTLRC	79	7 5	0.6	28.9	23.4	1017.6	10.0
W2	LTLRC	79	7 6	1.0	24.1	19.5	1019.8	12.0
W2	LTLRC	79	7 7	0.9	24.9	20.6	1020.0	8.6
W2	LTLRC	79	7 8	0.8	26.9	22.8	1018.0	7.2
W2	LTLRC	79	7 9	0.8	24.0	21.3	1013.9	9.7
W2	LTLRC	79	710	0.9	24.0	20.4	1011.7	6.0
W2	LTLRC	79	711	0.9	25.2	21.4	1010.4	8.8
W2	LTLRC	79	712	0.5	26.1	21.1	1012.7	9.7
W2	LTLRC	79	713	0.4	27.0	22.2	1014.6	10.2
W2	LTLRC	79	714	0.6	26.8	23.1	1015.7	11.3
W2	LTLRC	79	715	0.4	27.0	23.4	1018.2	11.1
W2	LTLRC	79	716	0.5	28.0	23.1	1020.6	10.9
W2	LTLRC	79	717	0.9	27.5	22.8	1019.8	12.5
W2	LTLRC	79	718	0.7	25.1	18.1	1018.7	14.8
W2	LTLRC	79	719	0.6	26.2	18.4	1017.5	13.9
W2	LTLRC	79	720	0.5	26.2	17.6	1018.1	11.8
W2	LTLRC	79	721	0.4	25.5	18.2	1017.1	5.8
W2	LTLRC	79	722	0.5	25.9	19.2	1015.9	5.6
W2	LTLRC	79	723	0.6	27.0	22.1	1014.4	12.3
W2	LTLRC	79	724	0.7	26.3	23.3	1013.2	9.5
W2	LTLRC	79	725	0.8	26.7	23.5	1012.7	9.0
W2	LTLRC	79	726	1.0	25.0	23.1	1012.7	12.0
W2	LTLRC	79	727	1.0	25.1	23.3	1012.2	15.7
W2	LTLRC	79	728	0.8	27.3	23.5	1014.7	11.8
W2	LTLRC	79	729	0.4	28.8	23.9	1017.1	11.8
W2	LTLRC	79	730	0.2	28.2	22.8	1015.5	12.0
W2	LTLRC	79	731	0.5	27.6	23.0	1015.8	11.8
W2	LTLRC	79	8 1	0.6	26.9	21.4	1015.0	12.3
W2	LTLRC	79	8 2	0.7	24.9	21.9	1014.3	6.5
W2	LTLRC	79	8 3	0.9	25.2	22.0	1016.0	7.6
W2	LTLRC	79	8 4	0.4	26.7	22.6	1018.6	5.1
W2	LTLRC	79	8 5	0.2	28.2	22.1	1020.8	8.3
W2	LTLRC	79	8 6	0.1	27.9	23.0	1020.4	4.9
W2	LTLRC	79	8 7	0.1	28.0	23.3	1019.7	5.8
W2	LTLRC	79	8 8	0.2	28.1	23.4	1020.5	4.2
W2	LTLRC	79	8 9	0.4	27.1	23.2	1019.9	7.2
W2	LTLRC	79	810	0.5	26.9	23.3	1017.3	10.2
W2	LTLRC	79	811	0.7	24.2	20.0	1012.9	13.4
W2	LTLRC	79	812	0.3	21.4	17.2	1015.3	10.4
W2	LTLRC	79	813	0.3	22.2	18.1	1017.9	5.8
W2	LTLRC	79	814	0.4	25.1	20.6	1020.3	6.9
W2	LTLRC	79	815	0.5	25.2	21.7	1020.6	8.6

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W2 LTLRC 79 816     0.8    21.6    16.8  1021.3     9.7
W2 LTLRC 79 817     0.     24.0    18.3  1019.8     6.3
W2 LTLRC 79 818     0.2    26.5    20.7  1018.0     7.9
W2 LTLRC 79 819     0.4    27.6    22.6  1016.8    10.4
W2 LTLRC 79 820     0.4    26.2    21.9  1015.5    11.6
W2 LTLRC 79 821     0.4    24.2    22.1  1014.1     6.3
W2 LTLRC 79 822     0.8    22.9    21.0  1011.5     6.5
W2 LTLRC 79 823     0.6    24.9    21.1  1010.8     6.0
W2 LTLRC 79 824     1.0    24.9    21.4  1011.5    10.0
W2 LTLRC 79 825     0.8    23.8    21.3  1013.6     7.2
W2 LTLRC 79 826     0.6    25.8    21.9  1015.6     6.9
W2 LTLRC 79 827     0.6    24.5    22.2  1014.7     7.2
W2 LTLRC 79 828     0.7    24.8    22.4  1012.0    10.0
W2 LTLRC 79 829     0.2    27.8    23.3  1013.5     7.2
W2 LTLRC 79 830     0.2    27.4    23.3  1016.8     6.9
W2 LTLRC 79 831     0.4    26.7    23.1  1014.9    10.6
W2 LTLRC 79 9 1     0.8    24.7    22.0  1012.0    10.0
W2 LTLRC 79 9 2     0.8    26.1    22.4  1012.4     8.3
W2 LTLRC 79 9 3     0.5    26.6    22.8  1013.6     5.1
W2 LTLRC 79 9 4     0.3    27.4    23.4  1013.1     6.3
W2 LTLRC 79 9 5     0.4    27.2    23.1  1012.7     5.6
W2 LTLRC 79 9 6     0.5    26.5    22.1  1013.6     7.2
W2 LTLRC 79 9 7     0.1    25.6    20.3  1015.6    14.1
W2 LTLRC 79 9 8     0.     21.7    14.0  1017.4    13.7
W2 LTLRC 79 9 9     0.     20.3    14.4  1017.4    13.0
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W2 LTLRC 79 912     0.7    23.6    19.1  1012.0     8.8
W2 LTLRC 79 913     0.6    24.2    17.4  1008.3    20.6
W2 LTLRC 79 914     0.     20.2    10.7  1016.7    17.6
W2 LTLRC 79 915     0.1    18.0     8.2  1020.2    14.4
W2 LTLRC 79 916     0.1    18.2     9.7  1019.5    15.3
W2 LTLRC 79 917     0.9    20.3    16.4  1017.7    11.6
W2 LTLRC 79 918     1.0    20.8    19.7  1017.2     9.5
W2 LTLRC 79 919     1.0    21.7    20.1  1016.1     5.6
W2 LTLRC 79 920     1.0    20.1    19.5  1008.0    16.2
W2 LTLRC 79 921     0.6    21.1    16.7  1007.1    18.3
W2 LTLRC 79 922     0.1    19.4    12.8  1015.4     9.3
W2 LTLRC 79 923     0.     17.9    12.6  1017.2     7.6
W2 LTLRC 79 924     0.     17.5    12.4  1017.9     6.0
W2 LTLRC 79 925     0.2    18.7    13.5  1019.4     4.9
W2 LTLRC 79 926     0.1    19.9    15.8  1018.6     5.6
W2 LTLRC 79 927     0.1    20.8    16.0  1014.3     5.6
W2 LTLRC 79 928     0.1    21.5    17.2  1012.9     8.3
W2 LTLRC 79 929     0.2    23.4    19.0  1014.2     3.9
W2 LTLRC 79 930     0.     24.4    17.8  1014.2     6.0
W2 LTLRC 7910 1     0.1    24.4    18.1  1011.2    10.9
W2 LTLRC 7910 2     0.4    19.6     8.0  1011.5    13.2
W2 LTLRC 7910 3     0.4    19.7    12.5  1010.8    11.3
W2 LTLRC 7910 4     0.2    17.4     4.6  1015.0    15.3
W2 LTLRC 7910 5     0.3    15.0     4.5  1010.2    12.5
W2 LTLRC 7910 6     0.4    18.2     7.0  1008.7    13.7
W2 LTLRC 7910 7     0.     19.7    10.9  1012.8    10.4
W2 LTLRC 7910 8     0.3    23.2    15.6  1009.9    15.3
W2 LTLRC 7910 9     0.9    16.7    11.8  1013.3    17.1
W2 LTLRC 791010     0.6    11.2     3.3  1014.1    10.4
W2 LTLRC 791011     0.1    17.2     7.9  1024.7    16.4
W2 LTLRC 791012     0.3    21.6    12.8  1006.2    13.4
W2 LTLRC 791013     0.3    15.0     2.0  1016.6    16.4
W2 LTLRC 791014     0.2    12.1     4.6  1019.6     6.7
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W2	LTLRC	791015	0.9	16.0	5.8	1015.8	7.4
W2	LTLRC	791016	0.8	19.2	11.9	1014.2	9.3
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W2	LTLRC	791018	0.4	21.5	16.6	1017.0	7.6
W2	LTLRC	791019	0.4	21.5	16.3	1012.5	15.3
W2	LTLRC	791020	0.6	25.1	18.6	1011.0	18.3
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W2	LTLRC	791022	0.4	18.0	10.2	1010.5	18.5
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W2	LTLRC	791024	0.1	13.1	5.3	1014.8	1.9
W2	LTLRC	791025	0.0	15.3	7.4	1014.7	3.2
W2	LTLRC	791026	0.0	16.5	8.8	1015.1	6.0
W2	LTLRC	791027	0.2	18.4	11.5	1012.6	13.0
W2	LTLRC	791028	0.9	17.9	14.3	1009.3	13.2
W2	LTLRC	791029	0.8	15.5	11.9	1008.9	6.3
W2	LTLRC	791030	0.8	19.2	14.9	1005.6	18.3
W2	LTLRC	791031	0.6	16.3	9.2	1005.0	19.2
W2	LTLRC	7911 1	0.	10.8	2.4	1014.0	10.2
W2	LTLRC	7911 2	0.4	11.9	1.5	1016.6	8.8
W2	LTLRC	7911 3	0.1	11.4	1.0	1019.4	10.0
W2	LTLRC	7911 4	0.3	9.9	1.5	1019.7	8.3
W2	LTLRC	7911 5	0.4	12.3	3.5	1018.4	12.7
W2	LTLRC	7911 6	0.3	11.8	5.7	1022.6	18.3
W2	LTLRC	7911 7	0.5	7.8	3.0	1019.4	9.5
W2	LTLRC	7911 8	1.0	11.9	7.9	1007.5	6.5
W2	LTLRC	7911 9	1.0	14.3	13.3	998.7	16.4
W2	LTLRC	791110	0.2	6.4	0.3	1011.9	15.3
W2	LTLRC	791111	0.1	4.8	-1.0	1016.4	15.5
W2	LTLRC	791112	0.2	6.3	0.4	1017.1	11.1
W2	LTLRC	791113	0.1	7.4	0.8	1019.6	11.8
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W2	LTLRC	791115	0.1	10.4	2.9	1020.4	12.0
W2	LTLRC	791116	0.1	12.6	3.7	1019.4	12.0
W2	LTLRC	791117	0.5	12.3	4.3	1017.3	11.6
W2	LTLRC	791118	0.6	14.3	9.3	1014.3	10.0
W2	LTLRC	791119	0.6	19.0	15.8	1016.9	12.7
W2	LTLRC	791120	0.7	17.8	13.1	1017.7	8.6
W2	LTLRC	791121	1.0	18.4	15.8	1012.9	8.6
W2	LTLRC	791122	0.9	9.6	4.3	1012.4	13.9
W2	LTLRC	791123	0.5	6.0	0.8	1010.4	8.3
W2	LTLRC	791124	0.6	5.8	0.3	1014.0	3.7
W2	LTLRC	791125	0.9	6.3	3.6	1003.8	5.6
W2	LTLRC	791126	0.1	9.0	3.6	1007.0	6.5
W2	LTLRC	791127	0.7	14.3	8.9	1010.4	14.8
W2	LTLRC	791128	0.	5.3	-3.5	1019.7	13.9
W2	LTLRC	791129	0.1	1.2	-9.4	1020.6	15.0
W2	LTLRC	791130	0.3	0.7	-7.8	1018.0	8.8
W2	LTLRC	7912 1	0.0	4.2	-7.1	1017.4	11.6
W2	LTLRC	7912 2	0.	0.3	-8.5	1028.0	15.0
W2	LTLRC	7912 3	0.2	1.5	-5.8	1024.8	8.8
W2	LTLRC	7912 4	0.1	6.5	-2.6	1020.6	7.2
W2	LTLRC	7912 5	0.2	11.0	2.4	1024.8	11.8
W2	LTLRC	7912 6	0.4	10.1	1.2	1004.0	9.3
W2	LTLRC	7912 7	0.	10.3	-2.2	1011.2	10.4
W2	LTLRC	7912 8	0.	6.7	-6.0	1026.0	13.2
W2	LTLRC	7912 9	0.2	5.6	-4.3	1023.6	5.6
W2	LTLRC	791210	0.1	9.7	0.3	1016.3	8.6
W2	LTLRC	791211	0.9	15.8	9.7	1013.0	9.0
W2	LTLRC	791212	1.0	7.2	4.9	1014.6	8.3
W2	LTLRC	791213	0.8	6.0	0.2	1019.2	10.9

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W2 LTLRC 791214      0.1      4.6      -4.5   1023.9      14.4
W2 LTLRC 791215      0.1      4.8      -2.6   1016.8       3.7
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W2 LTLRC 791217      0.      -4.8     -15.4   1028.1      12.5
W2 LTLRC 791218      0.0      0.7     -11.4   1019.0      10.2
W2 LTLRC 791219      0.3      7.5      -4.6   1013.4       8.1
W2 LTLRC 791220      0.8     10.6       5.8   1013.8       3.9
W2 LTLRC 791221      1.0     15.3      12.6   1013.9      12.0
W2 LTLRC 791222      1.0     15.7      13.9   1007.9      13.2
W2 LTLRC 791223      1.0     16.7      15.1   1004.4      16.4
W2 LTLRC 791224      0.9      9.0       5.6   1006.2      22.2
W2 LTLRC 791225      0.0      7.8      -0.5   1015.5      12.3
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FHARV2         2.5
FHARV2         2.5
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SOUTL2 DGR79007        1    36.9
SOUTL2 DGR79008        1    36.9
SOUTL2 DGR79009        1    20.1
SOUTL2 DGR79010        1    10.0
SOUTL2 DGR79011        1    10.0
SOUTL2 DGR79012        1    10.0
SOUTL2 DGR79013        1    10.0
SOUTL2 DGR79014        1    10.0
SOUTL2 DGR79015        1    10.0
SOUTL2 DGR79016        1    10.0
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SOUTL2 DGR79018        1    10.0
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SOUTL2 DGR79020        1    10.0
SOUTL2 DGR79021        1    10.0
SOUTL2 DGR79022        1    10.0
SOUTL2 DGR79023        1    10.0
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SOUTL2 DGR79025        1    21.5
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SOUTL2 DGR79027        1    36.9
SOUTL2 DGR79028        1    36.9
SOUTL2 DGR79029        1    26.8
SOUTL2 DGR79030        1    10.0
SOUTL2 DGR79031        1    10.0
SOUTL2 DGR79032        1    10.0
SOUTL2 DGR79033        1    10.0
SOUTL2 DGR79034        1    10.0
SOUTL2 DGR79035        1    10.0
SOUTL2 DGR79036        1    10.0
SOUTL2 DGR79037        1    10.0
SOUTL2 DGR79038        1    10.0
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SOUTL2 DGR79039       1      10.0
SOUTL2 DGR79040       1      10.0
SOUTL2 DGR79041       1      10.0
SOUTL2 DGR79042       1      10.0
SOUTL2 DGR79043       1      10.0
SOUTL2 DGR79044       1      10.0
SOUTL2 DGR79045       1      10.0
SOUTL2 DGR79046       1      10.0
SOUTL2 DGR79047       1      10.0
SOUTL2 DGR79048       1      10.0
SOUTL2 DGR79049       1      10.0
SOUTL2 DGR79050       1      10.0
SOUTL2 DGR79051       1      10.0
SOUTL2 DGR79052       1      25.4
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SOUTL2 DGR79054       1      36.9
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SOUTL2 DGR79069       1     151.6
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SOUTL2 DGR79079       1                  2                3       10.0
SOUTL2 DGR79080       1                  2                3       31.0
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SOUTL2 DGR79082       1                  2                3       66.7
SOUTL2 DGR79083       1                  2                3       66.7
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SOUTL2 DGR79086       1                  2                3       66.7
SOUTL2 DGR79087       1                  2                3       31.3
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SOUTL2 DGR79093       1                  2                3       58.1
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SOUTL2 DGR79095       1                  2                3      154.2
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SOUTL2 DGR79098       1                  2                3       10.0
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Q1                  24        41
Q2 79   1        105.0      39.0      23.0      17.0      14.0      13.0      12.0      12.0      11.0
Q2 79  10         10.0       9.3       8.7       8.0       7.4       6.8       6.4       6.4       6.5
Q2 79  19         11.8      23.9      23.3      17.9      16.7      13.8      11.7      11.9      11.9
Q2 79  28         10.1       9.1       9.0       8.4       8.3       8.2       9.5       9.4       9.3
Q2 79  37          9.7      10.7      10.0       9.0       8.6       9.4      15.2      20.4      17.7
Q2 79  46         15.1      12.4      10.8      10.2      10.0      10.4      19.0      28.0      29.0
Q2 79  55         42.0      47.0      41.0      36.0      29.0      22.2      29.5     217.7      70.1
Q2 79  64         37.4      24.3      18.3      14.7      12.4      10.7       9.4       8.5       7.9
Q2 79  73          7.4       6.8       6.6       6.4       6.1      12.7     127.2      54.8      30.3
Q2 79  82         25.1      18.4      14.6      12.5      15.0      14.2      16.3     291.7     140.3
Q2 79  91        209.9     189.6      61.3      36.9      23.8      18.0      14.8      28.5      20.0
Q2 79100          16.3      27.0      59.9      28.1      18.2      14.2      11.8      10.2       8.9
Q2 79109           8.1       7.5       7.5      18.0     136.3      66.9      34.8      21.6      15.7
Q2 79118          12.6      10.9       9.5       8.0       7.6      39.6     137.2      52.2      27.8
Q2 79127          18.6      13.6      10.9       9.4      51.7      57.4      28.4      18.2      13.7
Q2*79136          11.1       9.3       8.2       7.4       6.9      69.9     320.0     130.8      54.1
Q2*79145          27.9      18.9      30.2      41.0      42.0      27.0      20.0      15.6      44.5
Q2 79154          73.0      36.3      22.5      20.2      20.1      14.5      11.6       9.7       8.4
Q2 79163           7.5       6.8       6.4       5.9       5.6       5.3       5.1       4.9       4.7
Q2 79172           4.6       4.8       4.9       6.8       9.5       6.5       5.4       4.9       4.7
Q2 79181           4.4       4.3       4.2       4.1       4.0       3.9       3.9       4.2       4.3
Q2 79190           4.2       7.6       5.2       4.5       4.6       4.1       4.0       4.1       4.4
Q2 79199           4.0       3.8       3.7       3.6       3.5       3.4       3.4       3.4       3.5
Q2 79208          14.9      54.3      16.3      10.2       7.9       7.0       6.2       8.3       8.9
Q2 79217           6.7       5.6       5.0       4.6       4.3       4.1       6.8       4.9       4.4
Q2 79226           4.1       4.0       4.7       4.5       4.1       3.9       3.7       3.6       3.6
Q2 79235           3.5       4.4       4.0       3.7       3.6       5.0       5.5       4.3       4.0
Q2 79244           5.2       5.5       4.6       4.2       4.0       3.8       3.9       4.1       3.8
Q2 79253           3.6       3.5       3.4       3.3       3.3       3.2       3.1       3.1       3.1
Q2 79262           3.3       3.9       7.4       7.8       5.7       4.8       4.3       4.0       3.8
Q2 79271           3.6       3.6       3.5       3.4       3.3       3.3       3.2       3.1       3.1
Q2 79280           3.0       3.0       3.0       3.0       3.0       3.0       3.0       2.9       3.0
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Q2 79289        3.0      3.1      3.3      3.4      3.3      3.2      3.3      3.7      3.5
Q2 79298        3.3      3.3      3.2      3.2      3.7      3.8      8.5      7.9      5.8
Q2 79307        4.9      4.4      4.1      4.0      3.8      3.7      4.1      5.9      5.1
Q2 79316        4.6      4.3      4.1      4.0      3.9      3.8      3.7      3.7      3.8
Q2 79325        6.2     14.7     10.2      8.2      7.0      6.2      5.6      5.2      4.8
Q2 79334        4.6      4.4      4.3      4.1      4.0      3.9      3.9      3.8      3.7
Q2 79343        3.7      3.6      3.6      8.1     22.9     14.4     10.6      9.0      7.7
Q2 79352        6.6      6.0      5.6      5.3      8.5     97.2    160.4     40.8     21.7
Q2 79361       16.0     12.4     10.4      9.2      8.1       0.       0.       0.       0.
WQ 1ALG        8760        1
1ALG             0.       0.
WQ 2ALG        8760        1
2ALG             0.       0.
WQ 3ALG        8760        1
3ALG             0.       0.
WQ ALKA         168        6
ALKA            13.      13.      13.      13.      16.      18.      20.      21. 17.
ALKA            13.      18.      24.      17.      10.      16.      19.      22. 24.
ALKA            23.      21.      18.      15.      21.      27.      27.      28. 29.
ALKA            30.      36.      41.      38.      34.      33.      32.      34. 35.
ALKA            38.      41.      41.      41.      46.      46.      48.      49. 42.
ALKA            45.      39.      33.      44.      37.      30.      18.      18. 18.
WQ DOML         168        6
DOML           1.91     1.91     1.91     1.91     1.82     1.73     1.42     1.11 1.42
DOML           1.73     3.80     3.77     3.24     2.66     2.53     2.35     2.84 3.29
DOML           2.26     1.24     1.86     2.49     2.40     2.35     2.26     2.18 1.91
DOML           1.64     1.33     1.07     1.29     1.51     1.82     2.09     1.78 1.47
DOML           1.11      .75      .75      .75     1.42     2.09     2.53     2.35 1.07
DOML            .98      .88     2.31     2.31     1.91     1.55     1.20     1.20 1.20
WQ CNH4         168        6
CNH4            .04      .04      .04      .04      .06      .08      .04      .00 .02
CNH4            .04      .08      .12      .06      .00      .00      .00      .00 .00
CNH4            .01      .02      .01      .00      .00      .00      .05      .00 .02
CNH4            .03      .03      .02      .03      .04      .05      .05      .04 .02
CNH4            .01      .00      .01      .02      .02      .02      .02      .00 .00
CNH4            .00      .00      .00      .01      .01      .02      .02      .05 .08
WQ CNO3         168        6
CNO3            .19      .19      .19      .19      .22      .24      .21      .18 .25
CNO3            .31      .28      .25      .28      .31      .23      .15      .11 .06
CNO3            .11      .16      .14      .11      .09      .06      .13      .20 .20
CNO3            .19      .11      .03      .05      .06      .06      .05      .06 .07
CNO3            .05      .02      .02      .01      .01      .00      .00      .00 .06
CNO3            .05      .01      .15      .08      .01      .22      .40      .40 .40
WQ DOMR         168        6
DOMR           7.65     7.65     7.65     7.65     7.30     6.94     5.70     4.45  5.70
DOMR           6.94    11.04    15.13    12.99    10.68    10.15     9.43    11.39 13.17
DOMR           9.08     4.98     7.48     9.97     9.61     9.43     9.08     8.72  7.65
DOMR           6.59     5.34     4.27     5.16     6.05     7.30     8.37     7.12  5.87
DOMR           4.45     3.03     3.03     3.03     5.70     8.37    10.15     9.43  4.27
DOMR           3.92     3.56     3.74     9.26     7.65     6.23     4.81     4.81  4.81
WQ COL          168        6
COL              4.       4.       4.       4.      18.      31.      20.       8. 30.
COL             51.    1326.    2600.    1300.       0.      31.      61.      36. 10.
COL              9.       7.     219.     430.     216.       2.     231.     460.
COL            600.     312.      23.      18.      12.       6.       0.     500.1000.
COL
COL
WQ DET          168        6
DET             .67      .67      .67      .67      .56      .44      .67      .89  .1
DET            1.11     1.00     0.88      .88      .89      .78      .67      .45 .22
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DET             .33       .44       .55      0.66       .66      0.66      1.89      .67 .66
DET             .66       .66       .67       .56       .45       .78      1.11      .95 .66
DET             .55       .45       .45       .45       .66       .66       1.1      .66 .66
DET             .66       .66       .66      .660       .66       .66       .66      .66 .66
WQ OXY          168         6
OXY            12.0      12.0      12.0      12.0      12.8      13.6      12.8     12.012.5
OXY            12.9      12.9      10.5      10.0       9.4       9.4       9.4      9.1 8.8
OXY             8.7       8.6       8.7       8.8       8.6       8.4       8.2      7.9 7.1
OXY             6.3       6.4       6.5       7.8       9.1       8.1       7.0      6.5 6.0
OXY             6.9       7.8       8.0       8.1       7.5       8.1       7.7      7.811.0
OXY            10.8       9.5      10.6      11.5      11.5      14.2      12.7     12.7 12.7
WQ PO4          168         6
PO4            .025      .025      .025      .025      .016      .007      .007     .006.012
PO4            .017      .023      .029      .024      .018      .015      .012     .009.005
PO4            .007      .009      .009      .009      .009      .009      .017     .024.016
PO4            .008      .010      .011      .013      .015      .017      .019     .021.023
PO4            .017      .011      .011      .011      .011      .010      .014     .018.012
PO4            .012      .009      .014      .009      .002      .009      .030     .030 .030
WQ  SI         8760         1
SI               .0        .0
WQ TEMP          24        41
TEMP   1        6.2       3.5       2.6       3.0       4.0       4.2       3.1      2.1  1.9
TEMP  10        2.4       2.5       2.9       2.2       1.2       1.2       2.0      3.8  4.3
TEMP  19        5.6       6.0       4.3       4.3       3.4       2.4       2.3      2.5  3.1
TEMP  28        2.6       2.2       2.4       2.2       1.4       1.6       2.6      3.2  3.1
TEMP  37        2.5       1.3       2.0       1.5       1.5       2.6       4.8      5.8  5.7
TEMP  46        7.7       7.7       4.7       3.3       3.9       4.1       5.6      7.8  9.6
TEMP  55        8.5       6.0       6.3       6.9       7.9       8.8       8.8     10.1  8.8
TEMP  64        7.8       7.8       9.3       9.1       9.2       9.0       8.7      9.6 11.5
TEMP  73       12.2      10.8       9.7      10.0      11.5      13.1      12.9     12.5 12.0
TEMP  82       11.1       9.7       9.8      10.8      11.7      11.9      12.4     12.7 13.1
TEMP  91       13.7      13.3      13.3      14.4      12.9      11.3      11.5     11.0 12.9
TEMP 100       14.0      13.1      13.1      13.1      13.9      14.3      15.1     14.9 15.5
TEMP 109       16.5      17.2      17.0      17.2      17.3      17.1      16.0     14.5 14.8
TEMP 118       15.9      17.1      15.6      14.8      15.4      15.8      15.6     15.6 15.9
TEMP 127       15.0      14.7      15.4      16.7      18.7      19.7      20.0     17.6 15.9
TEMP 136       16.4      17.0      18.1      19.1      19.7      20.1      20.6     21.2 20.0
TEMP 145       19.2      19.4      19.0      19.7      19.8      20.7      21.5     22.0 22.0
TEMP 154       21.5      21.7      22.0      22.1      23.0      23.7      24.2     24.2 23.5
TEMP 163       23.2      23.1      23.2      23.6      23.8      24.2      24.5     24.8 25.5
TEMP 172       25.3      24.6      25.2      24.5      23.9      23.8      23.9     24.0 24.8
TEMP 181       25.4      25.0      25.6      26.1      26.1      26.7      26.1     25.4 25.7
TEMP 190       25.2      24.7      25.2      25.1      25.4      25.8      25.9     26.2 26.4
TEMP 199       26.1      25.9      26.0      25.7      25.7      25.9      26.0     26.0 26.1
TEMP 208       26.1      26.6      26.9      27.0      27.3      27.7      27.8     27.9 26.8
TEMP 217       25.9      27.2      28.1      28.3      28.6      28.8      27.1     25.2 24.8
TEMP 226       25.6      26.1      26.5      26.4      27.0      27.8      28.1     27.5 27.1
TEMP 235       26.8      25.7      24.4      25.5      26.5      27.2      26.8     27.1 27.7
TEMP 244       27.4      27.4      27.1      27.4      27.4      27.2      26.8     26.0 24.4
TEMP 253       23.7      24.0      23.9      24.2      23.0      21.3      20.3     19.9 20.3
TEMP 262       20.7      20.6      20.2      20.5      20.4      20.2      20.0     20.4 20.7
TEMP 271       20.8      21.5      21.9      22.4      21.8      20.6      19.7     17.9 17.6
TEMP 280       17.7      18.7      18.6      16.4      16.0      17.0      18.0     16.5 15.8
TEMP 289       16.4      17.2      18.1      18.6      19.6      20.7      20.6     17.4 15.8
TEMP 298       15.4      15.4      15.7      16.1      16.3      16.6      16.6     14.5 13.5
TEMP 307       12.7      11.8      11.6      12.3      11.4      11.4      12.0     11.4 10.4
TEMP 316        9.3       8.6       8.3       8.4       8.7       9.1       9.5     10.8 12.2
TEMP 325       13.5      13.1      11.1       9.4       9.0       8.8       9.2      8.9  7.2
TEMP 334        5.8       5.1       4.9       4.6       4.7       5.6       6.7      6.7  6.7
TEMP 343        6.3       6.4       7.6       8.1       7.7       7.3       7.1      6.7  5.1
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TEMP 352        3.8       4.0       5.5       7.7       9.8      11.6      10.8       9.2  8.7
TEMP 361        8.9       9.1       8.6       7.8       7.5
WQ TDS          168         6
TDS             47.       47.       47.       47.       31.       15.       18.       21. 29.
TDS             36.       51.       65.       62.       59.       54.       49.       47. 45.
TDS             58.       71.       68.       65.       62.       59.       75.       91. 82.
TDS             73.       64.       55.       52.       49.       41.       32.       43. 53.
TDS             62.       71.       46.       21.       51.       51.       67.       91. 60.
TDS             29.       49.       92.       87.       67.       79.       23.       23. 23.
WQ SSOL         168         6
SSOL             7.        7.        7.        7.        7.        6.       13.       20.       13.
SSOL             6.       74.      153.       65.       24.       15.        6.        6.        6
SSOL             6.        6.        6.        6.        6.        6.        6.        6.       12.
SSOL            19.       12.        6.        8.       11.       22.       33.       20.        8.
SSOL             7.        6.        6.        7.        8.        7.        6.        6.        6
SSOL             6.        6.        8.       13.        8.        6.        6.        6.        6.
WQ PH           168         6
PH             6.30      6.30      6.30      6.30      6.30      6.30      6.30      6.306.30
PH             6.30      6.30      6.30      6.50      6.70      6.90      7.10      7.006.90
PH             6.80      6.70      6.50      6.30      6.50      6.70      6.65      6.606.65
PH             6.70      6.65      6.60      7.00      7.40      7.00      6.60      7.007.40
PH             7.25      7.10      6.85      6.60      7.30      6.80      7.15      7.106.80
PH             7.10      7.30      6.90      6.90      6.20      6.30      6.10      6.10 6.1
WQ MN4          168         6
MN4             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4             0.0       0.0       0.0       0.0       0.0       0.2       0.3       0.2       0.0
MN4             0.0       0.0       0.0       0.1       0.0       0.0       0.0       0.0       0.0
MN4             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ MN2          168         6
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ FE3          168         6
FE3             0.0       0.0       0.0       0.0       0.2       0.5       0.4       0.3       0.6
FE3             0.8       1.8       2.8       2.1       1.4       0.7       0.0       0.0       0.0
FE3             0.1       0.2       0.4       0.6       0.4       0.2       0.2       0.2       0.2
FE3             0.2       0.2       0.2       0.2       0.2       0.2       0.2       0.2       0.2
FE3             0.6       1.0       0.6       0.2       0.2       0.2       0.1       0.1       0.2
FE3             0.1       0.1       0.2       0.0       0.0       0.3       0.7       0.7
WQ FE2          168         6
FE2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2             0.0       0.2       0.0       0.0       0.0       0.0       0.0       0.0
WQ FESB         168         6
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ SO4          168         6
SO4             5.0       5.0       5.0       5.0       5.0       5.0       6.0       6.0       5.0
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S04          4.0     6.0     7.0     5.0     3.0     4.0     5.0     4.0     2.0
S04          3.0     4.0     4.0     4.0     4.0     4.0     5.0     6.0     6.0
S04          5.0     5.0     5.0     4.0     4.0     4.0     5.0     5.0     5.0
S04          9.0    13.0    12.0    10.0     9.0    10.0     8.0     5.3     6.4
S04         12.0     8.0     7.0     7.0    11.0     8.0     5.0     5.0
WQ S2        168       6
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
S2           0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
Q1            24      41
Q2 79  1    49.4    18.3    10.8     8.0     6.6     6.1     5.6     5.6     5.2
Q2 79 10     4.7     4.4     4.1     3.8     3.5     3.2     3.0     3.0     3.1
Q2 79 19     5.5    11.2    11.0     8.4     7.8     6.5     5.5     5.6     5.6
Q2 79 28     4.7     4.3     4.2     3.9     3.9     3.9     4.5     4.4     4.4
Q2 79 37     4.6     5.0     4.7     4.2     4.0     4.4     7.1     9.6     8.3
Q2 79 46     7.1     5.8     5.1     4.8     4.7     4.9     8.9    13.2    13.6
Q2 79 55    19.7    22.1    19.3    16.9    13.6    10.4    13.9   102.3    32.9
Q2 79 64    17.6    11.4     8.6     6.9     5.8     5.0     4.4     4.0     3.7
Q2 79 73     3.5     3.2     3.1     3.0     2.9     6.0    59.8    25.8    14.2
Q2 79 82    11.8     8.6     6.9     5.9     7.0     6.7     7.7   137.1    65.9
Q2 79 91    98.7    89.1    28.8    17.3    11.2     8.5     7.0    13.4     9.4
Q2 79100     7.7    12.7    28.2    13.2     8.6     6.7     5.5     4.8     4.2
Q2 79109     3.8     3.5     3.5     8.5    64.1    31.4    16.4    10.2     7.4
Q2 79118     5.9     5.1     4.5     3.8     3.6    18.6    64.5    24.5    13.1
Q2 79127     8.7     6.4     5.1     4.4    24.3    27.0    13.3     8.6     6.4
Q2*79136     5.2     4.4     3.9     3.5     3.2    32.9   150.0    61.5    25.4
Q2*79145    13.1     8.9    14.2    19.0    20.0    12.7     9.4     7.3    20.9
Q2 79154    34.3    17.1    10.6     9.5     9.4     6.8     5.5     4.6     3.9
Q2 79163     3.5     3.2     3.0     2.8     2.6     2.5     2.4     2.3     2.2
Q2 79172     2.2     2.3     2.3     3.2     4.5     3.1     2.5     2.3     2.2
Q2 79181     2.1     2.0     2.0     1.9     1.9     1.8     1.8     2.0     2.0
Q2 79190     2.0     3.6     2.4     2.1     2.2     1.9     1.9     1.9     2.1
Q2 79199     1.9     1.8     1.7     1.7     1.6     1.6     1.6     1.6     1.6
Q2 79208     7.0    25.5     7.7     4.8     3.7     3.3     2.9     3.9     4.2
Q2 79217     3.1     2.6     2.4     2.2     2.0     1.9     3.2     2.3     2.1
Q2 79226     1.9     1.9     2.2     2.1     1.9     1.8     1.7     1.7     1.7
Q2 79235     1.6     2.1     1.9     1.7     1.7     2.4     2.6     2.0     1.9
Q2 79244     2.4     2.6     2.2     2.0     1.9     1.8     1.8     1.9     1.8
Q2 79253     1.7     1.6     1.6     1.6     1.6     1.5     1.5     1.5     1.5
Q2 79262     1.6     1.8     3.5     3.7     2.7     2.3     2.0     1.9     1.8
Q2 79271     1.7     1.7     1.6     1.6     1.6     1.6     1.5     1.5     1.5
Q2 79280     1.4     1.4     1.4     1.4     1.4     1.4     1.4     1.4     1.4
Q2 79289     1.4     1.5     1.6     1.6     1.6     1.5     1.6     1.7     1.6
Q2 79298     1.6     1.6     1.5     1.5     1.7     1.8     4.0     3.7     2.7
Q2 79307     2.3     2.1     1.9     1.9     1.8     1.7     1.9     2.8     2.4
Q2 79316     2.2     2.0     1.9     1.9     1.8     1.8     1.7     1.7     1.8
Q2 79325     2.9     6.9     4.8     3.9     3.3     2.9     2.6     2.4     2.3
Q2 79334     2.2     2.1     2.0     1.9     1.9     1.8     1.8     1.8     1.7
Q2 79343     1.7     1.7     1.7     3.8    10.8     6.8     5.0     4.2     3.6
Q2 79352     3.1     2.8     2.6     2.5     4.0    45.7    75.4    19.2    10.2
Q2 79361     7.5     5.8     4.9     4.3     3.8      0.      0.      0.      0.
WQ 1ALG     8760       1
1ALG          0.      0.
WQ 2ALG     8760       1
2ALG          0.      0.
WQ 3ALG     8760       1
3ALG          .0      .0
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WQ ALKA     168       6
ALKA        13.     13.      13.      13.      16.      18.      20.      21. 17.
ALKA        13.     18.      24.      17.      10.      16.      19.      22. 24.
ALKA        23.     21.      18.      15.      21.      27.      27.      28. 29.
ALKA        30.     36.      41.      38.      34.      33.      32.      34. 35.
ALKA        38.     41.      41.      41.      46.      46.      48.      49. 42.
ALKA        45.     39.      33.      44.      37.      30.      18.      18. 18.
WQ DOML     168       6
DOML       1.91    1.91     1.91     1.91     1.82     1.73     1.42     1.11 1.42
DOML       1.73    3.80     3.77     3.24     2.66     2.53     2.35     2.84 3.29
DOML       2.26    1.24     1.86     2.49     2.40     2.35     2.26     2.18 1.91
DOML       1.64    1.33     1.07     1.29     1.51     1.82     2.09     1.78 1.47
DOML       1.11     .75      .75      .75     1.42     2.09     2.53     2.35 1.07
DOML        .98     .88     2.31     2.31     1.91     1.55     1.20     1.20 1.20
WQ CNH4     168       6
CNH4        .04     .04      .04      .04      .06      .08      .04      .00 .02
CNH4        .04     .08      .12      .06      .00      .00      .00      .00 .00
CNH4        .01     .02      .01      .00      .00      .00      .05      .00 .02
CNH4        .03     .03      .02      .03      .04      .05      .05      .04 .02
CNH4        .01     .00      .01      .02      .02      .02      .02      .00 .00
CNH4        .00     .00      .00      .01      .01      .02      .02      .05 .08
WQ CNO3     168       6
CNO3        .19     .19      .19      .19      .22      .24      .21      .18 .25
CNO3        .31     .28      .25      .28      .31      .23      .15      .11 .06
CNO3        .11     .16      .14      .11      .09      .06      .13      .20 .20
CNO3        .19     .11      .03      .05      .06      .06      .05      .06 .07
CNO3        .05     .02      .02      .01      .01      .00      .00      .00 .06
CNO3        .05     .01      .15      .08      .01      .22      .40      .40 .4
WQ DOMR     168       6
DOMR       7.65    7.65     7.65     7.65     7.30     6.94     5.70     4.45  5.70
DOMR       6.94   11.04    15.13    12.99    10.68    10.15     9.43    11.39 13.17
DOMR       9.08    4.98     7.48     9.97     9.61     9.43     9.08     8.72  7.65
DOMR       6.59    5.34     4.27     5.16     6.05     7.30     8.37     7.12  5.87
DOMR       4.45    3.03     3.03     3.03     5.70     8.37    10.15     9.43  4.27
DOMR       3.92    3.56     3.74     9.26     7.65     6.23     4.81     4.81  4.81
WQ COL      168       6
COL          4.      4.       4.       4.      18.      31.      20.       8. 30.
COL         51.   1326.    2600.    1300.       0.      31.      61.      36. 10.
COL          9.      7.     219.     430.     216.       2.     231.     460.
COL        600.    312.      23.      18.      12.       6.       0.     500.1000.
COL
COL
WQ DET      168       6
DET         .67     .67      .67      .67      .56      .44      .67      .89  .1
DET        1.11    1.00     0.88      .88      .89      .78      .67      .45 .22
DET         .33     .44      .55     0.66      .66     0.66     1.89      .67 .66
DET         .66     .66      .67      .56      .45      .78     1.11      .95 .66
DET         .55     .45      .45      .45      .66      .66      1.1      .66 .66
DET         .66     .66      .66     .660      .66      .66      .66      .66 .66
WQ OXY      168       6
OXY        12.0    12.0     12.0     12.0     12.8     13.6     12.8     12.012.5
OXY        12.9    12.9     10.5     10.0      9.4      9.4      9.4      9.1 8.8
OXY         8.7     8.6      8.7      8.8      8.6      8.4      8.2      7.9 7.1
OXY         6.3     6.4      6.5      7.8      9.1      8.1      7.0      6.5 6.0
OXY         6.9     7.8      8.0      8.1      7.5      8.1      7.7      7.811.0
OXY        10.8     9.5     10.6     11.5     11.5     14.2     12.7     12.7 12.7
WQ PO4      168       6
PO4        .025    .025     .025     .025     .016     .007     .007     .006.012
PO4        .017    .023     .029     .024     .018     .015     .012     .009.005
PO4        .007    .009     .009     .009     .009     .009     .017     .024.016
```

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PO4             .008     .010     .011     .013     .015     .017     .019     .021.023
PO4             .017     .011     .011     .011     .011     .010     .014     .018.012
PO4             .012     .009     .014     .009     .002     .009     .030     .030 .03
WQ SI           8760        1
SI                .0       .0
WQ  TEMP          24       41
TEMP   1         6.2      3.5      2.6      3.0      4.0      4.2      3.1      2.1  1.9
TEMP  10         2.4      2.5      2.9      2.2      1.2      1.2      2.0      3.8  4.3
TEMP  19         5.6      6.0      4.3      4.3      3.4      2.4      2.3      2.5  3.1
TEMP  28         2.6      2.2      2.4      2.2      1.4      1.6      2.6      3.2  3.1
TEMP  37         2.5      1.3      2.0      1.5      1.5      2.6      4.8      5.8  5.7
TEMP  46         7.7      7.7      4.7      3.3      3.9      4.1      5.6      7.8  9.6
TEMP  55         8.5      6.0      6.3      6.9      7.9      8.8      8.8     10.1  8.8
TEMP  64         7.8      7.8      9.3      9.1      9.2      9.0      8.7      9.6 11.5
TEMP  73        12.2     10.8      9.7     10.0     11.5     13.1     12.9     12.5 12.0
TEMP  82        11.1      9.7      9.8     10.8     11.7     11.9     12.4     12.7 13.1
TEMP  91        13.7     13.3     13.3     14.4     12.9     11.3     11.5     11.0 12.9
TEMP 100        14.0     13.1     13.1     13.1     13.9     14.3     15.1     14.9 15.5
TEMP 109        16.5     17.2     17.0     17.2     17.3     17.1     16.0     14.5 14.8
TEMP 118        15.9     17.1     15.6     14.8     15.4     15.8     15.6     15.6 15.9
TEMP 127        15.0     14.7     15.4     16.7     18.7     19.7     20.0     17.6 15.9
TEMP 136        16.4     17.0     18.1     19.1     19.7     20.1     20.6     21.2 20.0
TEMP 145        19.2     19.4     19.0     19.7     19.8     20.7     21.5     22.0 22.0
TEMP 154        21.5     21.7     22.0     22.1     23.0     23.7     24.2     24.2 23.5
TEMP 163        23.2     23.1     23.2     23.6     23.8     24.2     24.5     24.8 25.5
TEMP 172        25.3     24.6     25.2     24.5     23.9     23.8     23.9     24.0 24.8
TEMP 181        25.4     25.0     25.6     26.1     26.1     26.7     26.1     25.4 25.7
TEMP 190        25.2     24.7     25.2     25.1     25.4     25.8     25.9     26.2 26.4
TEMP 199        26.1     25.9     26.0     25.7     25.7     25.9     26.0     26.0 26.1
TEMP 208        26.1     26.6     26.9     27.0     27.3     27.7     27.8     27.9 26.8
TEMP 217        25.9     27.2     28.1     28.3     28.6     28.8     27.1     25.2 24.8
TEMP 226        25.6     26.1     26.5     26.4     27.0     27.8     28.1     27.5 27.1
TEMP 235        26.8     25.7     24.4     25.5     26.5     27.2     26.8     27.1 27.7
TEMP 244        27.4     27.4     27.1     27.4     27.4     27.2     26.8     26.0 24.4
TEMP 253        23.7     24.0     23.9     24.2     23.0     21.3     20.3     19.9 20.3
TEMP 262        20.7     20.6     20.2     20.5     20.4     20.2     20.0     20.4 20.7
TEMP 271        20.8     21.5     21.9     22.4     21.8     20.6     19.7     17.9 17.6
TEMP 280        17.7     18.7     18.6     16.4     16.0     17.0     18.0     16.5 15.8
TEMP 289        16.4     17.2     18.1     18.6     19.6     20.7     20.6     17.4 15.8
TEMP 298        15.4     15.4     15.7     16.1     16.3     16.6     16.6     14.5 13.5
TEMP 307        12.7     11.8     11.6     12.3     11.4     11.4     12.0     11.4 10.4
TEMP 316         9.3      8.6      8.3      8.4      8.7      9.1      9.5     10.8 12.2
TEMP 325        13.5     13.1     11.1      9.4      9.0      8.8      9.2      8.9  7.2
TEMP 334         5.8      5.1      4.9      4.6      4.7      5.6      6.7      6.7  6.7
TEMP 343         6.3      6.4      7.6      8.1      7.7      7.3      7.1      6.7  5.1
TEMP 352         3.8      4.0      5.5      7.7      9.8     11.6     10.8      9.2  8.7
TEMP 361         8.9      9.1      8.6      7.8      7.5
WQ TDS           168        6
TDS              47.      47.      47.      47.      31.      15.      18.      21. 29.
TDS              36.      51.      65.      62.      59.      54.      49.      47. 45.
TDS              58.      71.      68.      65.      62.      59.      75.      91. 82.
TDS              73.      64.      55.      52.      49.      41.      32.      43. 53.
TDS              62.      71.      46.      21.      51.      51.      67.      91. 60.
TDS              29.      49.      92.      87.      67.      79.      23.      23. 23.
WQ SSOL          168        6
SSOL              7.       7.       7.       7.       7.       6.      13.      20.        13.
SSOL              6.      74.     153.      65.      24.      15.       6.       6.         6
SSOL              6.       6.       6.       6.       6.       6.       6.       6.        12.
SSOL             19.      12.       6.       8.      11.      22.      33.      20.         8.
SSOL              7.       6.       6.       7.       8.       7.       6.       6.         6
```

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SSOL            6.        6.        8.       13.        8.        6.        6.        6.        6.
WQ PH         168         6
PH            6.30      6.30      6.30      6.30      6.30      6.30      6.30      6.306.30
PH            6.30      6.30      6.30      6.50      6.70      6.90      7.10      7.006.90
PH            6.80      6.70      6.50      6.30      6.50      6.70      6.65      6.606.65
PH            6.70      6.65      6.60      7.00      7.40      7.00      6.60      7.007.40
PH            7.25      7.10      6.85      6.60      7.30      6.80      7.15      7.106.80
PH            7.10      7.30      6.90      6.90      6.20      6.30      6.10      6.10 6.1
WQ MN4        168         6
MN4            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN4            0.0       0.0       0.0       0.0       0.0       0.2       0.3       0.2       0.0
MN4            0.0       0.0       0.0       0.1       0.0       0.0       0.0       0.0       0.0
MN4            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ MN2        168         6
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
MN2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ FE3        168         6
FE3            0.0       0.0       0.0       0.0       0.2       0.5       0.4       0.3       0.6
FE3            0.8       1.8       2.8       2.1       1.4       0.7       0.0       0.0       0.0
FE3            0.1       0.2       0.4       0.6       0.4       0.2       0.2       0.2       0.2
FE3            0.2       0.2       0.2       0.2       0.2       0.2       0.2       0.2       0.2
FE3            0.6       1.0       0.6       0.2       0.2       0.2       0.1       0.1       0.2
FE3            0.1       0.1       0.2       0.0       0.0       0.3       0.7       0.7
WQ FE2        168         6
FE2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2            0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FE2            0.0       0.2       0.0       0.0       0.0       0.0       0.0       0.0
WQ FESB       168         6
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
FESB           0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
WQ SO4        168         6
SO4            5.0       5.0       5.0       5.0       5.0       5.0       6.0       6.0       5.0
SO4            4.0       6.0       7.0       5.0       3.0       4.0       5.0       4.0       2.0
SO4            3.0       4.0       4.0       4.0       4.0       4.0       5.0       6.0       6.0
SO4            5.0       5.0       5.0       4.0       4.0       4.0       5.0       5.0       5.0
SO4            9.0      13.0      12.0      10.0       9.0      10.0       8.0       5.3       6.4
SO4           12.0       8.0       7.0       7.0      11.0       8.0       5.0       5.0
WQ S2         168         6
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
S2             0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
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Monte Carlo Data Set

```
      RANDOM      RANDOM    TOTAL-                    3          1
  BIOC               2           1                                                   .2
  BION               2           1                                                   .2
  BIOP               2           1                                                   .2
  ALGAS              2           1                                                   .2
  DMCO2              2           1                                                   .2
  ALDIGO             1           1
  DM02               2           1                                                   .2
  FEFFIC             2           1                                                   .2
  FPSED              2           1                                                   .2
  FS2FSH             2           1                                                   .2
  FPALG(1)           1           1
  FPALG(2)           1           1
  FPALG(3)           1           1
  FPDET              1           1
  FPZOO              1           1
  HECTAR             2           1                                                   .2
  O2DET              2           1                                                   .2
  O2DOM              2           1                                                   .2
  O2FAC              2           1                                                   .2
  PLIMP              2           1                                                   .2
  PLIMC              2           1                                                   .2
  PLIMN              2           1                                                   .2
  PLFRAC             2           1                                                   .2
  PLITE              2           1                                                   .2
  PLDENS             2           1                                                   .2
  PLDIGO(1)          1           1
  PLDIGO(2)          1           1
  PLDIGO(3)          1           1
  TMPMAC             2           1                                                   .2
  O2FE2              2           1                                                   .2
  O2MN2              2           1                                                   .2
  O2NH3              2           1                                                   .2
  O2RESP             2           1                                                   .2
  O2S2               2           1                                                   .2
  PS2CO2(1)          2           1                                                   .2
  PS2CO2(2)          2           1                                                   .2
  PS2CO2(3)          2           1                                                   .2
  PISAT(1)           2           1                                                   .2
  PISAT(2)           2           1                                                   .2
  PISAT(3)           2           1                                                   .2
  PS2N(1)            2           1                                                   .2
  PS2N(2)            2           1                                                   .2
  PS2N(3)            2           1                                                   .2
  PS2PO4(1)          2           1                                                   .2
  PS2PO4(2)          2           1                                                   .2
  PS2PO4(3)          2           1                                                   .2
  PS2SI              2           1                                                   .2
  PREF(1)            1           1
  PREF(2)            1           1
  PREF(3)            1           1
  PREF(4)            1           1
  Q10COL             2           1                                                   .2
  ZEFFIC             2           1                                                   .2
  ZS2P               2           1                                                   .2
  ADSRBP             2           1                                                   .2
  ADSRBN             2           1                                                   .2
  ADMAXP             2           1                                                   .2
  ADMAXN             2           1                                                   .2
  TNH3DK             2           1                                                   .2
```

```
TCOLDK                  2         1                                        .2
TDETDK                  2         1                                        .2
TDOMDK                  2         1                                        .2
TDSETL                  2         1                                        .2
TPMAX(1)                2         1                                        .2
TPMAX(2)                2         1                                        .2
TPMAX(3)                2         1                                        .2
TPRESP(1)               2         1                                        .2
TPRESP(2)               2         1                                        .2
TPRESP(3)               2         1                                        .2
TSETL(1)                2         1                                        .2
TSETL(2)                2         1                                        .2
TSETL(3)                2         1                                        .2
TZMAX                   2         1                                        .2
TZMORT                  2         1                                        .2
TZRESP                  2         1                                        .2
TSSETL                  2         1                                        .2
TMN4ST                  2         1                                        .2
TFE3ST                  2         1                                        .2
TFESST                  2         1                                        .2
TMN4RE                  2         1                                        .2
TFE3RE                  2         1                                        .2
TSO4RE                  2         1                                        .2
TMN2OX                  2         1                                        .2
TFE2OX                  2         1                                        .2
TS2OXI                  2         1                                        .2
TFESBD                  2         1                                        .2
TS2DK                   2         1                                        .2
TPEXCR(1)               2         1                                        .2
TPEXCR(2)               2         1                                        .2
TPEXCR(3)               2         1                                        .2
TPMORT(1)               2         1                                        .2
TPMORT(2)               2         1                                        .2
TPMORT(3)               2         1                                        .2
TRFRDK                  2         1                                        .2
TDOMRF                  2         1                                        .2
TNO3DK                  2         1                                        .2
TSEDDK                  2         1                                        .2
TFMAX                   2         1                                        .2
TFMORT                  2         1                                        .2
TFRESP                  2         1                                        .2
TMNREL                  2         1                                        .2
TFEREL                  2         1                                        .2
TSREL                   2         1                                        .2
TXP4RE                  2         1                                        .2
TCHREL                  2         1                                        .2
TFESAD                  2         1                                        .2
TPLMAX                  2         1                                        .2
TMRESP                  2         1                                        .2
TMEXCR                  2         1                                        .2
TMMORT                  2         1                                        .2
DOMT1                   2         1                                        .2
NH3T1                   2         1                                        .2
NO3T1                   2         1                                        .2
DETT1                   2         1                                        .2
ALG1T1                  2         1                                        .2
ALG2T1                  2         1                                        .2
ALG3T1                  2         1                                        .2
ZOOT1                   2         1                                        .2
FSH1T1                  2         1                                        .2
```

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PLTT1           2        1
DOMT2           2        1                           .2
NH3T2           2        1                           .2
NO3T2           2        1                           .2
DETT2           2        1                           .2
ALG1T2          2        1                           .2
ALG2T2          2        1                           .2
ALG3T2          2        1                           .2
ZOOT2           2        1                           .2
FSH1T2          2        1                           .2
PLTT2           2        1                           .2
ALG1T3          2        1                           .2
ALG2T3          2        1                           .2
ALG3T3          2        1                           .2
ZOOT3           2        1                           .2
FSH1T3          2        1                           .2
PLTT3           2        1                           .2
ALG1T4          2        1                           .2
ALG2T4          2        1                           .2
ALG3T4          2        1                           .2
ZOOT4           2        1                           .2
FSH1T4          2        1                           .2
PLTT4           2        1                           .2
ALGAIN(1,1      2        1                           .2
ALGAIN(1,2      2        1                           .2
ALGAIN(1,3      2        1                           .2
ALKAIN(1)       2        1                           .2
DOCIN(1)        2        1                           .2
CNH3IN(1)       2        1                           .2
CNO3IN(1)       2        1                           .2
RFRIN(1)        2        1                           .2
COLIN(1)        2        1                           .2
DETUIN(1)       2        1                           .2
OXYIN(1)        2        1                           .2
PO4IN(1)        2        1                           .2
SIIN(1)         2        1                           .2
TEMPIN(1)       2        1                           .2
TDSIN(1)        2        1                           .2
SSOLIN(1)       2        1                           .2
DUMMYA(1)       1        1                           .2
CARBIN(1)       2        1
CMH4IN(1)       2        1                           .2
CMN2IN(1)       2        1                           .2
FE3IN(1)        2        1                           .2
FE2IN(1)        2        1                           .2
FESBIN(1)       2        1                           .2
SO4IN(1)        2        1                           .2
S2IN(1)         2        1                           .2
DUMMYB(1)       1        1                           .2
DUMMYC(1)       1        1
DUMMYD(1)       1        1
DUMMYE(1)       1        1
DUMMYF(1)       1        1
DUMMYG(1)       1        1
CO2IN(1)        2        1
PHIN(1)         2        1                           .2
ALGAIN(2,1      2        1                           .2
ALGAIN(2,2      2        1                           .2
ALGAIN(2,3      2        1                           .2
ALKAIN(2)       2        1                           .2
                                                     .2
```

```
DOCIN(2)            2         1                                                 .2
CNH3IN(2)           2         1                                                 .2
CNO3IN(2)           2         1                                                 .2
RFRIN(2)            2         1                                                 .2
COLIN(2)            2         1                                                 .2
DETUIN(2)           2         1                                                 .2
OXYIN(2)            2         1                                                 .2
PO4IN(2)            2         1                                                 .2
SIIN(2)             2         1                                                 .2
TEMPIN(2)           2         1                                                 .2
TDSIN(2)            2         1                                                 .2
SSOLIN(2)           2         1                                                 .2
DUMMYA(2)           1         1
CARBIN(2)           2         1                                                 .2
CMN4IN(2)           2         1                                                 .2
CMN2IN(2)           2         1                                                 .2
FE3IN(2)            2         1                                                 .2
FE2IN(2)            2         1                                                 .2
FESBIN(2)           2         1                                                 .2
SO4IN(2)            2         1                                                 .2
S2IN(2)             2         1                                                 .2
DUMMYB(2)           1         1
DUMMYC(2)           1         1
DUMMYD(2)           1         1
DUMMYE(2)           1         1
DUMMYF(2)           1         1
DUMMYG(2)           1         1
CO2IN(2)            2         1                                                 .2
PHIN(2)             2         1                                                 .2
```

Confirmation Data Set for CE-THERM-R1

```
VERIFY1       YES
NVRFY          23
  4  1     37  47 46.0      4.300 45.0      4.300 44.0      4.300 43.0      4.300
                  42.0      4.300 41.0      4.300 40.0      4.300 39.0      4.300
                  38.0      4.300 37.0      4.300 36.0      4.300 35.0      4.300
                  34.0      4.300 33.0      4.300 32.0      4.300 31.0      4.300
                  30.0      4.300 29.0      4.300 28.0      4.300 27.0      4.300
                  26.0      4.300 25.0      4.300 24.0      4.300 23.0      4.300
                  22.0      4.300 21.0      4.300 20.0      4.300 19.0      4.300
                  18.0      4.300 17.0      4.300 16.0      4.300 15.0      4.300
                  14.0      4.300 13.0      4.300 12.0      4.300 11.0      4.300
                  10.0      4.300  9.0      4.300  8.0      4.300  7.0      4.300
                   6.0      4.300  5.0      4.300  4.0      4.300  3.0      4.300
                   2.0      4.300  1.0      4.300  0.0      4.300
  4  1     51  47 46.0      4.200 45.0      4.200 44.0      4.200 43.0      4.200
                  42.0      4.200 41.0      4.200 40.0      4.200 39.0      4.200
                  38.0      4.200 37.0      4.200 36.0      4.200 35.0      4.300
                  34.0      4.300 33.0      4.300 32.0      4.300 31.0      4.300
                  30.0      4.300 29.0      4.300 28.0      4.300 27.0      4.300
                  26.0      4.300 25.0      4.400 24.0      4.400 23.0      4.400
                  22.0      4.400 21.0      4.400 20.0      4.400 19.0      4.400
                  18.0      4.400 17.0      4.400 16.0      4.400 15.0      4.400
                  14.0      4.400 13.0      4.400 12.0      4.400 11.0      4.300
                  10.0      4.400  9.0      4.400  8.0      4.400  7.0      4.300
                   6.0      4.300  5.0      4.400  4.0      4.400  3.0      4.400
                   2.0      4.400  1.0      4.400  0.0      4.400
  4  1     65  49 48.0      4.500 47.0      4.500 46.0      4.600 45.0      4.600
                  44.0      4.600 43.0      4.600 42.0      4.600 41.0      4.600
                  40.0      4.600 39.0      4.600 38.0      4.600 37.0      4.700
                  36.0      4.700 35.0      4.700 34.0      4.800 33.0      4.800
                  32.0      4.900 31.0      5.000 30.0      5.100 29.0      5.200
                  28.0      5.300 27.0      5.300 26.0      5.400 25.0      5.400
                  24.0      5.400 23.0      5.400 22.0      5.400 21.0      5.500
                  20.0      5.500 19.0      5.500 18.0      5.600 17.0      5.600
                  16.0      5.700 15.0      5.700 14.0      5.800 13.0      5.900
                  12.0      5.800 11.0      5.900 10.0      5.900  9.0      6.100
                   8.0      6.100  7.0      6.200  6.0      6.200  5.0      6.300
                   4.0      6.400  3.0      6.400  2.0      6.600  1.0      6.600
                   0.0      6.700
  4  1     79  47 46.0      4.900 45.0      4.900 44.0      4.900 43.0      4.900
                  42.0      4.900 41.0      4.900 40.0      4.900 39.0      4.900
                  38.0      4.900 37.0      4.900 36.0      4.900 35.0      4.900
                  34.0      4.900 33.0      5.000 32.0      5.000 31.0      5.100
                  30.0      5.100 29.0      5.100 28.0      5.100 27.0      5.100
                  26.0      5.200 25.0      5.400 24.0      5.600 23.0      5.700
                  22.0      5.700 21.0      5.800 20.0      5.900 19.0      6.000
                  18.0      6.200 17.0      6.300 16.0      6.500 15.0      6.800
                  14.0      7.300 13.0      7.600 12.0      8.200 11.0      8.500
                  10.0      8.700  9.0      8.900  8.0      9.000  7.0      9.100
                   6.0      9.300  5.0      9.400  4.0      9.600  3.0     10.000
                   2.0     10.100  1.0     11.900  0.0     12.500
```

APPENDIX F: CE-THERM-R1

The thermal analysis portion of CE-QUAL-R1 has been extracted to allow for its use independent of the full model. This model (CE-THERM-R1) simulates all of the physical processes found in the parent model, but simulates only temperature, suspended solids (SS), and total dissolved solids (TDS) as opposed to the many quality parameters in CE-QUAL-R1. It is important to note that the assumptions made in CE-QUAL-R1 also apply to CE-THERM-R1.

CE-THERM-R1 has two major areas of application. First, this model can be used as a precursor to CE-QUAL-R1. Initial simulations made with the thermal model offer the advantage of reduced computer costs and data requirements when checking the water and heat budgets and calibrating the mixing coefficients. It is important to model correctly the temperature dynamics because of the many temperature-dependent quality parameters in CE-QUAL-R1. The second major application is for use in thermal studies of reservoirs and their tailwaters. These include studies to examine the stratification cycle, to determine the location of selective withdrawal ports to meet downstream temperature objectives, and to evaluate the effects on in-pool and downstream temperatures of reservoir operational changes (e.g., change in withdrawal level).

Besides the main program, the subroutines from CE-QUAL-R1 that are used are as follows:

OPREAD
PDCIDE
RADIATE
FLOWIN
CONTRL
PUMPKN
INFLOP
BUCKET
ENTRN
SBJET
RUNGS
DERIVE
LAYERS
MIXING
HEAT
ENTRAIN
TRANSPT
TMPRTR
SOLIDS
TDSOL
COMMIX
REREG
OBLOUT
OUTPT1

WBJET
OUTVEL
VPORT
VWEIR
OUTPT2
OUTPT3
INTEGR

Modifications of these programs were required to simulate only temperature, SS, and TDS.

Several of the records differ slightly in format or content from those given in the main text (see Appendix D for additional help):

a. LIGHT: In CE-THERM-R1, because particulate organic materials are not explicitly modeled, the light attenuation due to this material is handled through either EXTINS or EXCO. If the SS update and initial condition values have been incremented in the CE-THERM-R1 data set to include organic as well as inorganic particulates suspended in the water column, then EXTINS (1/m * mg/ℓ) represents the extinction coefficient for all SS, including inorganic matter, phytoplankton, zooplankton, and suspended detritus. However, if the SS update and initial condition values in the CE-THERM-R1 data set do not include organic particulates (i.e., if the magnitude of the SS update and initial condition values are identical in the CE-QUAL-R1 and CE-THERM-R1 data sets), then light attenuation by organic matter suspended in the water column cannot be handled by EXTINS. Rather, the value of EXCO must be increased to handle the extra attenuation due to phytoplankton, zooplankton, and detritus. In either case, the magnitude of EXTINS should be the same for both models.

b. INIT1: The INIT1 records contain only the initial conditions for temperature, SS, and TDS. The record name (INIT1) should be in the first field, with elevation, temperature, TDS, and SS data in successive fields.

c. WQ____: Only TEMP, SSOL, and TDS updates are used in the thermal simulation.

An additional record that is required for a thermal simulation is VERIFY1. This record enables the user to include temperature confirmation, which will be included with tabular output, as part of the simulation. If this option is chosen, YES should be typed on this record in columns 14-16. If YES, two additional record types are then required.

a. The VERIFY2 record contains the number of days, in columns 9-16, for which confirmation data are specified (NVRFY).

b. The VERIFY3 record contains several variables:

(1) NVDAY is the Julian day corresponding to a particular confirmation temperature profile. NVDAY must be specified for each temperature profile and must be right justified in columns 8-13.

(2) NVTMPS is the number of depth-temperature pairs, in columns 15-17, provided for each temperature profile.

(3) VELEV and VTEMP are the depth-temperature pairs defining the confirmation temperature profile. Up to four depth-temperature pairs are specified on each VERIFY3 record, in columns 19-22, 24-32; 34-37, 39-47; 49-52, 54-62; and 64-67, 69-77.

An example of the confirmation data set is included in Appendix E.

CE-THERM-R1 also resides on the Cybernet Services interactive time-sharing computer system. A user must have his own account number and should have some knowledge of Cybernet procedures.

To execute CE-THERM-R1, prepare a file as follows for use by the SUBMIT directive.

```
JOBNAME.
/USER
/CHARGE
MAP,FULL.
GET,CQTOBJ,TAPE5=datafile.
RFL,CM=377700.
CQTOBJ.
SAVE,TAPE6.
SAVE,OUTPUT=OFILE.
DAYFILE,DFILE.
SAVE,DFILE.
EXIT.
SAVE,TAPE6.
EXIT.
SAVE,OUTPUT=OFILE.
EXIT.
DAYFILE,DFILE.
SAVE,DFILE.
```

Upon successful execution:

- file TAPE6 contains tabular output.
- plot files are created and saved with names provided in the data set. In addition:
- file OFILE contains a load map and an error summary if pertinent.
- file DFILE contains a job activity summary.

Before attempting a thermal simulation, the user should be familiar with Parts II and IV of this manual, keeping in mind that only temperature, suspended solids, and total dissolved solids are simulated with CE-THERM-R1.

APPENDIX G: WINDOWS AND PLOTTING PACKAGE

WINDOWS AND PLOTTING PACKAGE

INTRODUCTION

The purpose of the windows package is to create a user-friendly environment to run the water quality models and utilities on a personal computer. The plotting program allows the user ease in the calibration process by being able to view the results immediately. Features such as keyboard and mouse-controlled cursor movement, dynamic menu and status bars, interactive windows for prompts and inputs, sophisticated error messages, and on-line help with searching capabilities are included for user convenience. Although still in the testing phase, all error checking has been carefully thought out and incorporated in a way that alerts the user in an informative manner. However, it is impossible to cover all details; therefore, it is essential that any bugs be reported to the WES immediately. Corrections will be made promptly, and a new version will be returned as soon as possible.

WESWIN

WESWIN is an interactive windows package designed to execute the water quality modeling programs, CE-QUAL-R1 and CE-THERM-R1, and the utilities associated with the models provided by the U.S. Army Corps of Engineers. The utilities provided are as follows:

1. CQRTSM - preprocessor for CE-QUAL-R1
2. CQTTSM - preprocessor of CE-THERM-R1
3. STSTIC - statistical analysis program
4. GRAFORM - data manipulation program
5. WESPLOT - plotting program
6. FLUX - (not working at the present)

WESWIN is run simply by typing WESWIN at the prompt. Each interactive window is activated by moving the cursor to the desired option found on the menu bar and pressing enter. Cursor movement is achieved by using the ARROW key that corresponds to the direction of movement. The available options found on the menu bar are as follow:

1. Execute
2. Plot

3. Help
4. Quit

The execute option activates an interactive window that contains the executable water quality programs and utilities. The user selects the executable program to run by using the ARROW key and pressing return. Before the selected program is executed, the directory is checked for that program's internal files (e.g., an input data file). These internal files are checked for their presence in the directory. If the internal file is an input data file, then the file must be present; if the internal file is an output file, then the file must NOT be present because the FORTRAN programs will not overwrite output files. If the output file is present, then the user has the option to rename or delete the file. An output file, if renamed, will be renamed using the original name with the extension OLD. At the present time, the program will terminate on input file errors. Future revisions of the internal file check program will support more intelligent subroutines in which messages will be echoed to the screen informing the user of which water quality programs should be executed to produce a particular input file.

The plotting option runs WESPLOT, an interactive plotting program that assists the user in comparing the predicted and observed values. The user is given the option to set axis ranges or allow the program to set them. The user also has two ways of displaying the results; 1) to the monitor or 2) to a printer.

The help option activates a topic index window that allows the user to select a topic in which help is needed. After the help document is displayed, the user can scroll up or down the page one line at a time using the ARROW keys. The PAGEUP and PAGEDOWN keys will toggle to a new screen of text. The HOME key sets the document to the first page, and the END key will move to the last page of text. At any time, the user may use ALT-S to reactivate the topic index window.

Anytime an interactive window is open, a status bar that supports that window will appear at the bottom of the screen. The status bar does more than list the available commands associated with the open window. If the user is using a mouse, then placing the mouse on the status bar command and clicking the left button will initiate that particular command. A window can be closed in one of the following ways:

1. Using the escape key
2. Clicking the left mouse button on the close box found in the upper left-hand corner of the window.
3. Clicking the right mouse button at any time.

To quit the WESWIN program and return to the DOS prompt, the user can select quit and press enter or press ATL-X.

WESPLOT

WESPLOT is an interactive graphics program that enables the user to compare measured data to values predicted by CE-QUAL-R1 or CE-THERM-R1. WESPLOT requires several files in order to execute properly. The first file is FILE15.DAT, which contains information that specifies which constituents and dates are to be plotted. FILE15 is a user-prepared data file,and the file format can be obtained from the user manual on pages 386-389. The second file, GRAOTP.DAT, contains predicted data reformatted by the data manipulation utility, GRAFORM.FOR. VER.DAT is the third file and contains field-measured data. VER.DAT is also a user-prepared data file, and information concerning the format for this file can be found on pages 389-390 in the user manual.

WESPLOT begins execution by prompting the user for the procedure to select the maximum X and Y axis values. The two procedures are as follows:

1. User selected - the user is prompted for the maximum X and Y values.
2. Program selected - the program will read GRAOTP.DAT and VER.DAT and from these files determine the maximum values.

Once the maximum values have been determined, the program will use these values for each plot. To change these values, the user must exit the plotting program and reselect the plot option from the menu bar.

The plotting program will prompt the user for the display option once the axis settings have been determined. The five display options are:

1. Print four plots per page to the screen.
2. Print one plot per page to the screen.

3. Print four plots per page to the printer.
4. Print one plot per page to the printer.
5. Print all the plot (four per page) to the printer.

If the user wants to print to a printer, the setup option should be chosen from the menu; then the user must select printer options. The user selects the printer type he or she has. The default setup for a printer is a Hewlett Packard LaserJet III. Once the display option is chosen, the plotting program will read FILE15.DAT and display the constituent and dates to an interactive window (unless option 5 is selected). The user must then select the set to plot. If option 2 is selected, then the BACKSPACE key will cycle backward through the dates and the ESC key will exit.

HELP DOCUMENT

Adding text to the help document requires any text editor, as long as the "WES.DOC" is in ACSII format. The "On-Line-Help" program is written so that the titles are automatically included within the "help index" window. The only format requirements for the titles are as follows:

- each title should be about 20 characters long
- each title must end with an end-of-title keystroke

To create the "end-of-title" keystroke, simply hold down the ALT key and at the same time key in 21.

When using software such as WordPerfect, be sure to save the document as an ASCII file and use new courier point 12 font. Using this font will ensure that the document will completely reside within the computer screen.

To move around in the "On-Line-Help" program, Table G-1 contains a list of the allowable keystrokes.

Table G-1

KEYSTROKES

ESC key	Close a window
RETURN key	Make a selection
UP key	Scroll up one line
DOWN key	Scroll down one line
PAGE UP key	Goto the previous screen
PAGE DOWN	Goto the next screen
HOME	Goto the first line of text
END	Goto the last line of text
ALT-S keys	Search for a help topic
ALT-X	Exits to the DOS prompt from WESWIN