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Eutrophication has several direct and indirect effects on reservoir water quality and uses. The report documents assessment procedures which have been developed for application to Corps of Engineer reservoirs. Study phases include problem identification, data gathering, data reduction, and model implementation. Three computer programs are designed to assist in the last two phases:

a. FLUX - estimation of tributary nutrient loadings from grab-sample concentration data and continuous flow records using a variety of calculation methods which permit quantification of potential errors and evaluation of alternative sampling program designs.

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b. PROFILE - display and reduction of pool water quality data, including calculation of hypolimnetic oxygen depletion rates, characterization of spatial and temporal variability, and robust statistical summary of mixed-layer concentration data.

c. BATHTUB - implementation of nutrient balance models and eutrophication response models in a spatially segmented hydraulic network which accounts for advective transport, diffusive transport, and nutrient sedimentation.

Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll-a, transparency, organic nitrogen, particulate phosphorus, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships which have been calibrated and tested for reservoir applications. Based upon research using several independent data sets, previous "northern-lake-based" empirical modeling approaches have been modified to account for effects of: (a) nonlinear nutrient sedimentation kinetics; (b) algae growth limitation by phosphorus, nitrogen, light, and flushing rate; (c) inflow nutrient partitioning (bioavailability of dissolved versus particulate loadings); (d) seasonal variations in loadings and morphometry; and (e) spatial variations in nutrients and related trophic state indicators.

To reflect input data limitations and inherent model errors, inputs and outputs can be expressed in probabilistic terms. The segmented model can be applied to single reservoirs (mixed or spatially segmented), partial reservoirs (embayments, separate tributary arms), networks of reservoirs (hydrologically linked), or collections of reservoirs (hydrologically independent). The last type of application permits regional comparative assessments of reservoir conditions, controlling factors, and model performance. This report follows Reports 1-3 of this series, which document data base development, model testing, and model refinements, respectively.

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PREFACE

This report was prepared by Dr. William W. Walker, Jr., Environmental Engineer, Concord, Mass., for the US Army Engineer Waterways Experiment Station (WES) under Contract No. DACW39-78-C-0053-P006, dated 7 June 1978. Previous reports in this series, entitled "Empirical Methods for Predicting Eutrophication in Impoundments," include "Report 1, Phase I: Data Base Development," "Report 2, Phase II: Model Testing," and "Report 3, Phase II: Model Refinements." The study forms part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Work Unit IE, Simplified Techniques for Predicting Reservoir Water Quality and Eutrophication Potential. The EWQOS Program is sponsored by the Office, Chief of Engineers (OCE), US Army, and is assigned to the WES under the purview of the Environmental Laboratory (EL). The OCE Technical Monitors for EWQOS were Dr. John Bushman, Mr. Earl Eiker, and Mr. James L. Gottesman.

The study was conducted under the direct WES supervision of Dr. Robert F. Gaugush and under the general supervision of Dr. Thomas L. Hart, Chief, Aquatic Processes and Effects Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, EL. Dr. J. L. Mahloch was Program Manager of EWQOS. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

COL Dwayne G. Lee, CE, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONTENTS

CONVERSION FACTOR TABLE

Multiply values expressed in	By
Concentration (Units, milligrams/cubic meter)*	
grams/cubic meter	1.000×10^{3}
micrograms/liter	1.000
milligrams/liter	1.000×10^{3}
parts/billion	1.000
parts/million	1.000×10^{3}
pounds/gallon	1.198×10^{8}
Flow (Units, cubic hectometers/year)*	
acre-feet/day	4.502×10^{-1}
cubic feet/second	8.931×10^{-1}
cubic meters/second	3.154×10^{1}
million gallons/day	1.382
Area (Units, square kilometers)*	
acres	4.047×10^{-3}
hectares	1.000×10^{-2}
square feet	9.294×10^{-8}
square meters	1.000×10^{-6}
square miles	2.590
Depth (meters)*	
feet	3.048×10^{-1}
inches	2.540×10^{-2}

* Use of conversion factors will provide values expressed in units given in parentheses.

EMPIRICAL METHODS FOR PREDICTING EUTROPHICATION IN IMPOUNDMENTS

PHASE III: APPLICATIONS MANUAL

PART I: INTRODUCTION AND BACKGROUND

This report describes simplified procedures for assessment and prediction of eutrophication-related water quality conditions in Corps of Engineer (CE) reservoirs. The techniques below are based upon research described in previous reports in this series: Report 1, Data Base Development (Walker 1981); Report 2, Model Testing (Walker 1982); and Report 3, Model Refinement (Walker 1985).

Three computer programs have been written to facilitate data reduction and model implementation. While the assessment procedures and programs can be "run" based upon the information contained in this report, their intelligent "use" requires an understanding of basic modeling concepts and familiarity with the supporting research. Review of the above research reports and related references on this topic (see References and Bibliography) will facilitate proper use of the techniques described below.

Eutrophication can be defined as the nutritional enrichment of water bodies leading to an excessive production of organic materials by algae and/or aquatic plants. This process has several direct and indirect impacts on reservoir water quality and beneficial uses. Common measures of eutrophication include total nutrient concentrations (phosphorus and nitrogen), chlorophyll-a (a measure of algal density), Secchi depth (a measure of transparency), organic nutrient forms (nitrogen and carbon), and hypolimnetic dissolved oxygen depletion.

The basis of the modeling approach described below is to relate eutrophication symptoms to external nutrient loadings, hydrology, and reservoir morphometry using statistical models derived from a representative cross section of reservoirs. For existing reservoirs, the relationships provide a framework for interpreting water quality monitoring data and predicting effects of future changes in external nutrient loadings. The models can also be used to predict water quality conditions in a proposed reservoir.

Three basic phases are involved in applying the methodology to an existing or proposed reservoir:

a. Analysis and reduction of tributary water quality data.

b. Analysis and reduction of pool water quality data.

c. Model implementation.

A separate computer program has been developed for each phase. The data-reduction phases are critical steps in the modeling process. Potential program applications spill over into other aspects of reservoir operation and management, including monitoring program design and generalized data analysis. The model implementation program is designed so that it can be applied to a single reservoir (mixed or spatially segmented), networks of reservoirs (hydrologically linked), or collections of reservoirs (hydrologically independent). The last type of application can support regional (district- or division-wide) comparative assessments of reservoir conditions and controlling factors.

The report is organized in four parts. Part I reviews basic empirical modeling concepts, presents an overview of the assessment procedures which have been developed for reservoir application, and summarizes basic data requirements and recommended monitoring strategies. Part II describes the FLUX program, which is designed for analysis and reduction of tributary monitoring data. Part III describes PROFILE, a program designed for analysis and reduction of pool monitoring data. Part IV describes BATHTUB, a program designed for model implementation.

Several levels of involvement are offered to potential users of this methodology. The following steps are suggested:

Step 1: Review summary information (Part I).

Step 2: Review supporting research and basic reference documents.

Step 3: Review program documentation (Parts II, III, and IV).

Step 4: Review documented output listings.

Step 5: Acquire and install programs on accessible computer system. Assistance in the acquisition and implementation of the software is available. Contact:

Dr. Robert F. Gaugush, WESES-A
USAE Waterways Experiment Station
PO Box 631
Vicksburg, MS 39180-0631

Phone: (601) 634-3626
FTS 542-3626

Step 6: Run programs using several sample input files provided.

Step 7: Apply program to user-defined problems.

The above procedures provide a gradual and logical introduction of the techniques and a foundation for their application in a reservoir management context.

EUTROPHICATION MODELING TECHNIQUES

Modeling approaches for reservoir eutrophication can be broadly classified as theoretical or empirical. While one might argue that all models are empirical, the approaches are distinguished by their levels of empiricism. General characteristics and limitations of these model types are discussed below.

Theoretical models generally involve direct simulation of physical, chemical, and biological processes superimposed upon a simulation of reservoir hydrodynamics. These methods generally have extensive resource requirements in terms of input data, computing facilities, and user expertise. They can be useful for problems requiring high spatial and temporal resolution and/or simulation of cause-effect relationships which cannot be represented using simpler models. Their relative complexity does not guarantee that simulation models are more accurate or more reliable than simplified models for certain types of applications.

Although based upon theoretical concepts (such as mass balance and nutrient limitation of algal growth) empirical models do not attempt explicit simulation of biochemical processes and use simplified hydrodynamic representations. They generally deal with spatially and temporally averaged conditions. The simple structures, low resolution, limited number of input variables, and initial calibration to data from groups of impoundments result in relatively low data requirements. At the same time, the above characteristics limit model applicability. In one sense, empirical models attempt to "interpolate" the gross responses of a given impoundment, based upon observed responses of other impoundments and levels of certain controlling variables. They also provide a quantitative framework for interpreting monitoring data from a given impoundment and describing eutrophication-related water quality conditions and controlling factors both in absolute and relative terms.

Empirical Model Structures and Evolution

Empirical prediction of reservoir eutrophication can be described as a two-stage procedure involving the following types of models:

a. Nutrient balance models. These relate pool or discharge nutrient levels to external nutrient loadings, morphometry, and hydrology.

b. Eutrophication response models. These describe relationships among eutrophication indicators within the reservoir pool, including nutrient levels, chlorophyll-a, transparency, and hypolimnetic oxygen depletion.

Generally, models of each type must be linked to relate external nutrient loadings to reservoir water quality responses. In the absence of loading information, however, application of eutrophication response models alone can provide useful diagnostic information on existing water quality conditions and controlling factors.

The literature contains a wide array of empirical eutrophication models which have been calibrated and tested using data from various lake and/or reservoir data sets. Many of these models, particularly the early ones, were based primarily upon data from northern, natural lakes. While the equations and coefficients vary considerably among the lake models, they share the same sets of variables and basic assumptions, as depicted in Figure I-1. Inputs to these models can be summarized in three terms:

a. Inflow total phosphorus concentration. External loading/discharge rate, a nutrient supply factor.

b. Mean depth. Reservoir volume/surface area, a morphometric factor.

c. Hydraulic residence time. Reservoir volume/discharge rate, a hydrologic factor.

Empirical nutrient balance models have generally evolved from a simplistic "black-box" model which treats the impoundment as a continuous stirred-tank reactor at steady state and the sedimentation of phosphorus as a first-order

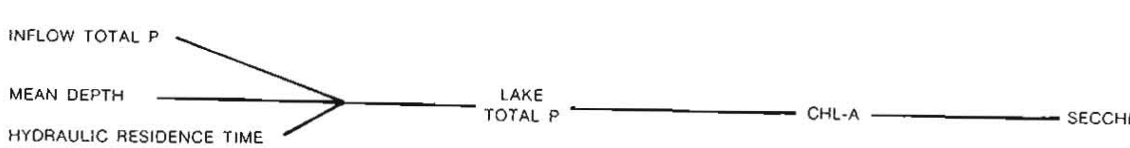


Figure I-1. Control pathways in empirical eutrophication models developed for northern lake applications reaction. Phosphorus is assumed to control algal growth and other eutrophication-related water quality conditions. Response models generally consist of bivariate regression equations relating each pair of response measurements (e.g., phosphorus/ chlorophyll, chlorophyll/transparency, etc.).

In adapting these models for use in CE and other reservoirs (Walker 1981, 1982, 1985), they have been modified to include additional input variables, controlling factors, and response variables, as depicted in Figure I-2. Table I-1 compares the variables and assumptions of the reservoir models documented in this manual. The reservoir modifications are designed to improve generality by incorporating additional independent variables and controlling factors found to be important in model testing. Refinements are focused in the following areas:

a. Effects of nonlinear sedimentation kinetics on nutrient balances. A second-order kinetic model appears to be more general than a first-order model for predicting both among-reservoir, spatially averaged variations and within-reservoir, spatial variations.

b. Effects of inflow nutrient partitioning (dissolved versus particulate or organic versus inorganic) on nutrient balances and chlorophyll-a levels. Because of differences in biological availability and sedimentation rates, reservoir responses appear to be much more sensitive to the ortho-phosphorus loading component than to the nonortho (total - ortho) component.

c. Effects of seasonal variations in nutrient loadings, morphometry, and hydrology on nutrient balances. Pool water quality conditions are related more directly to seasonal than to annual nutrient balances in impoundments with relatively high flushing rates.

d. Effects of algal growth limitation by phosphorus, nitrogen, light, and flushing rate on chlorophyll-a concentrations. Simple phosphorus/chlorophyll-a relationships are of limited use in

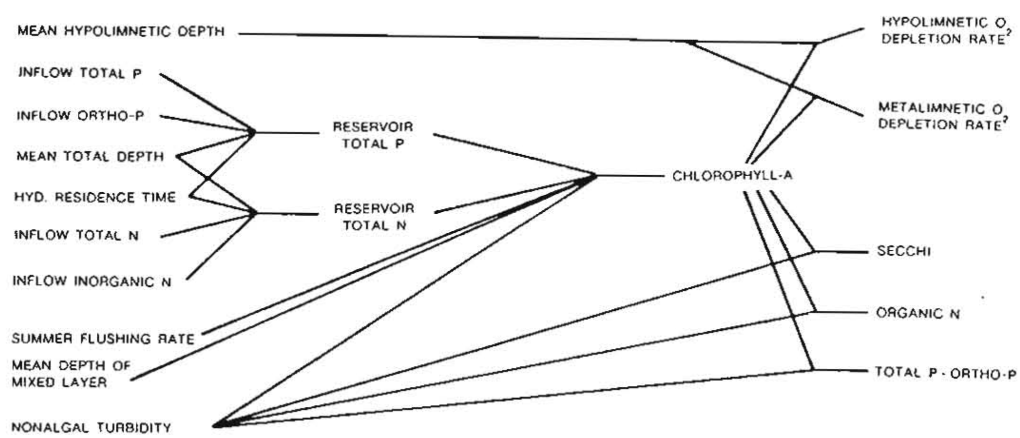


Figure I-2. Control pathways in empirical eutrophication models developed for CE reservoir applications

Table I-1

Comparison of Lake and Reservoir Empirical Eutrophication Models

Model Characteristics	Lake Models	Reservoir Models
Input variables	Inflow total P concentration Mean depth Annual hydraulic residence time Mean hypolimnetic depth	Inflow total P concentration Inflow ortho-P concentration Inflow total N concentration Inflow inorganic N concentration Mean depth Mean hypolimnetic depth Mean depth of mixed layer Seasonal hydraulic residence time Nonalgal turbidity
Spatial variability	Mixed	Mixed or spatially segmented
Temporal variability	Steady state	Steady state
Nutrient sedimentation kinetics	Linear (first-order)	Nonlinear (second-order)
Factors controlling algal growth	Phosphorus	Phosphorus Nitrogen Light Flushing rate
Output variables	Total phosphorus Chlorophyll-a Transparency Hypolimnetic oxygen depletion	Total phosphorus Total nitrogen Chlorophyll-a Transparency Nonortho-phosphorus Organic nitrogen Hypolimnetic oxygen depletion Metalimnetic oxygen depletion

reservoirs because nitrogen, light, and/or flushing rate may also regulate algal growth, depending upon site-specific conditions.

e. Effects of spatial variations in nutrients and related variables, as controlled by reservoir morphometric, hydrologic, and nutrient loading characteristics. Nutrient balance models can be implemented in a spatially segmented framework which accounts for advection, dispersion, and sedimentation to predict spatial water quality variations among and within major tributary arms.

Model structures have been tested against several independent reservoir data sets. Details on model development and testing are given elsewhere (Walker 1982, 1983).

Applications

Potential model applications can be classified into two general categories: diagnostic and predictive. Characteristics and limitations of these applications are described below.

In a diagnostic mode, the models provide a framework for analysis and interpretation of monitoring data from a given reservoir. This yields perspective on eutrophication-related water quality conditions and controlling factors. Assessments can be expressed in absolute terms (e.g., with respect to water quality objectives, criteria, or standards) and/or relative terms (e.g., comparisons with other impoundments, nationwide or regionally). The data bases used in model development permit ranking conditions in a given impoundment in relation to other CE reservoirs. Diagnostic applications are limited to existing reservoirs with appropriate water quality, morphometric, and hydrologic data.

In a predictive mode, the models are used to project future conditions in either existing or planned reservoirs. The distinction between the two types of predictive applications is important. In the first case, monitoring data from an existing reservoir can be used, in combination with the models and diagnostic analyses, as a "starting point" for "extrapolation" to future conditions. Because of the opportunity for site-specific calibration, projections of future conditions in an existing reservoir are generally subject to less uncertainty than projections of water quality conditions in a proposed reservoir.

In a predictive mode, the models can be used to project the long-term, steady-state responses of a reservoir to changes in controlling variables which are explicitly represented. These can be applied to impact assessments and evaluations of water quality control strategies. For example, future scenarios involving changes in seasonal or annual mean values of the following factors can be evaluated:

- a. Inflow nutrient concentrations, particularly total and ortho-phosphorus and total and inorganic nitrogen.
- b. Pool elevation, as it affects mean depth, mixed-layer depth, mean hypolimnetic depth, and hydraulic residence time.
- c. Inflow volume and changes in hydraulic residence time.
- d. Pool segmentation and its effect on longitudinal nutrient transport and sedimentation processes, and the spatial distribution of water quality conditions.

Applications of the first type are of primary importance because control strategies for reservoir eutrophication are usually focused on external nutrient (especially, phosphorus) supplies.

Examples of impacts and control strategies which cannot be explicitly evaluated with these models include:

- a. High-frequency pool level fluctuations.
- b. Changes in outlet levels.
- c. Structural modifications, such as the construction of weirs.
- d. Hypolimnetic aeration of destratification.
- e. Other in-reservoir management techniques, including dredging and chemical treatment.

In such cases, implementation of the models in a diagnostic mode can provide useful baseline water quality perspectives; however, simulation or other approaches must be used for predictive purposes.

Error and Sensitivity Analysis Concepts

The distinction between "error" and "variability" is important. Error refers to a difference between an observed and a predicted mean value. Variability refers to spatial or temporal fluctuations in concentration about the mean. Prediction of temporal variability is generally beyond the scope of empirical modeling efforts, although such variability is important because it influences the precision of observed mean values calculated from limited monitoring data.

Because both measurement and model errors tend to increase with concentration scale, errors are most conveniently expressed on normalized or logarithmic scales. This stabilizes variance over the ranges of concentration encountered, an important requirement for application of common statistical techniques (e.g., regression). This report frequently uses the mean coefficient of variation (CV) as a measure of error. The CV equals the standard error of the estimate expressed as a fraction of the predicted value. For example, a CV of 0.2 indicates that the standard error is 20 percent of the mean predicted value. Assuming that the errors are log-normally distributed about the predicted value, 95-percent confidence limits can be estimated from the following equation:

$$Y_m \exp(-2CV) < Y < Y_m \exp(2CV)$$

where

Y_m = predicted mean value

CV = error mean coefficient of variation

Y = 95-percent confidence range for the mean value

Magnitudes, sources, and interpretations of error are discussed below.

Error CV's for the reservoir model network (Figure I-2) are on the order of 0.27 for predicting total phosphorus and 0.35 for predicting mean chlorophyll-a. According to the above equation, these statistics translate into 95-percent confidence factors of 1.72 and 2.00, respectively. In applying these models in a reservoir management context, limitations imposed by errors of this magnitude are less severe than immediately apparent because of the following factors:

a. Despite the relatively wide confidence bands, the models explain 91 percent and 79 percent of the observed variances in total phosphorus and chlorophyll-a across reservoirs, respectively. This reflects the relatively wide ranges of conditions encountered and suggests that the models are adequate for broad comparative analyses of reservoir conditions (i.e., ranking).

b. Error statistics are calculated from "imperfect" data sets. Errors are partially attributed to random sampling, measurement, and estimation errors in the input and output (i.e., observed) conditions, which inflate the total error but do not reflect model performance.

c. Error magnitudes refer to a-priori predictions which are made without the benefit of site-specific water quality information. In applications to existing reservoirs, prediction errors can be reduced by carefully "tuning" certain coefficients based upon site-specific monitoring data.

d. Year-to-year water quality variations induced by climate, hydrology, loading, and other random factors are substantial in many reservoirs. It would be difficult to detect modest errors in predicting average conditions without several years of intensive monitoring.

e. Ability to define objective criteria or standards is limited. The "penalty" or "risk" associated with modest errors in predicting average responses may be low when expressed in terms of impacts on water uses. The measured and modeled variables (chlorophyll-a, etc.) are reasonable and practical, but imperfect, surrogates for potential water use impacts.

f. Ability to predict changes in loading resulting from adoption of specific management strategies is limited. This applies particularly to implementation of nonpoint source loading controls with performances evaluated using watershed simulation models. In such situations, errors associated with predicting reservoir response may be swamped by errors associated with predicting loadings; i.e., the reservoir response model may not be the limiting factor in the analysis.

Error analysis concepts discussed below provide additional perspectives on the above points.

Differences between observed and predicted reservoir conditions can be attributed to the combined effects of a number of error sources, as described below.

a. Independent variable error. These are errors in the estimates of model input variables, including external nutrient loadings, flows, and reservoir morphometry.

b. Dependent variable error. These are errors in the estimates of mean observed reservoir water quality conditions, based upon limited monitoring data.

c. Parameter error. These errors are attributed to biases or random errors in the model coefficients estimated from cross-sectional data sets.

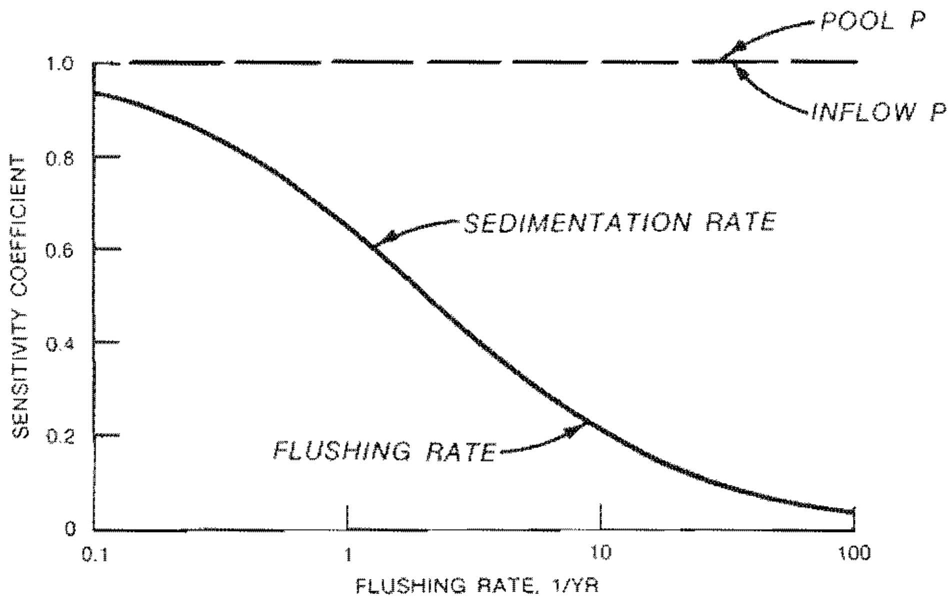
d. Model error. These errors are attributed to errors in model structure or effects of factors which are not explicitly represented.

The user has direct control over the first two error sources (i.e., independent and dependent variable error), primarily through design and implementation of appropriate monitoring programs and use of proper data reduction techniques. The last two sources (i.e., parameter and model error) are also under user control to the extent that the user selects the model(s) deemed appropriate for specific application. Research (Walker 1981, 1982, 1985) has been directed at reducing the last two error sources by reviewing, screening, refining, calibrating, and testing arrays of models which are appropriate for reservoir applications under specific conditions.

The impacts of errors in specifying model input variables or coefficients depend upon the sensitivities of model predictions to those inputs. Sensitivities, in turn, reflect model structure and variable ranges. A sensitivity coefficient can be conveniently expressed as a normalized first derivative, or as the percent change in a model output variable induced by a 1-percent change in a model input. For example, a sensitivity coefficient of 1.0 would indicate that the output is proportional to the input; in this situation, for example, a 5-percent error in specifying the input would propagate through the model and cause a 5-percent error in the predicted output. For a sensitivity coefficient of 0.2, however, a 5-percent input error would cause only a 1-percent output error. Sensitivity coefficients provide insights into which model variables and coefficients are the most important to measure or estimate accurately.

Figures I-3 and I-4 display sensitivity coefficients for models predicting mean phosphorus concentrations in reservoirs assuming first- and second-order sedimentation reactions, respectively. In both cases, the output variable is the error term or the ratio of the observed to the predicted mean phosphorus concentration. Input variables used to calculate this ratio include the observed pool concentration, inflow concentration (flow-weighted over all sources), flushing rate (outflow/ volume), and sedimentation coefficient.

Sensitivities vary as a function of flushing rate over the approximate range encountered in CE impoundments (median value for reservoirs used in model testing = 7/yr. At low flushing rates (or long hydraulic residence times), sensitivities to the sedimentation coefficient and flushing rate are relatively high (approaching 1.0 for the first-order model and 0.5 for the second-order model). This reflects the relative importance of the sedimentation term in the overall phosphorus balance of the reservoir. At high flushing rates, sensitivities to the sedimentation coefficient and flushing rate approach zero for both models. In this situation, the sedimentation process is relatively unimportant, and modest errors in the specified flushing rate and/or sedimentation coefficient can be tolerated without having major impacts on the predicted pool concentration or error ratio. Because the sedimentation coefficient is estimated from highly simplified empirical models



$$\text{SENSITIVITY COEF} = \frac{|\%\ \text{CHANGE IN ERROR}|}{|\%\ \text{CHANGE IN FACTOR}|}$$

$$\text{ERROR} = \frac{\text{OBSERVED POOL P}}{\text{PREDICTED POOL P}}$$

$$\text{PREDICTED POOL P} = \frac{P_i F}{F + K_1}$$

WHERE: P_i = INFLOW TOTAL PHOSPHORUS CONCENTRATION (mg/m^3)

F = FLUSHING RATE (1/yr)

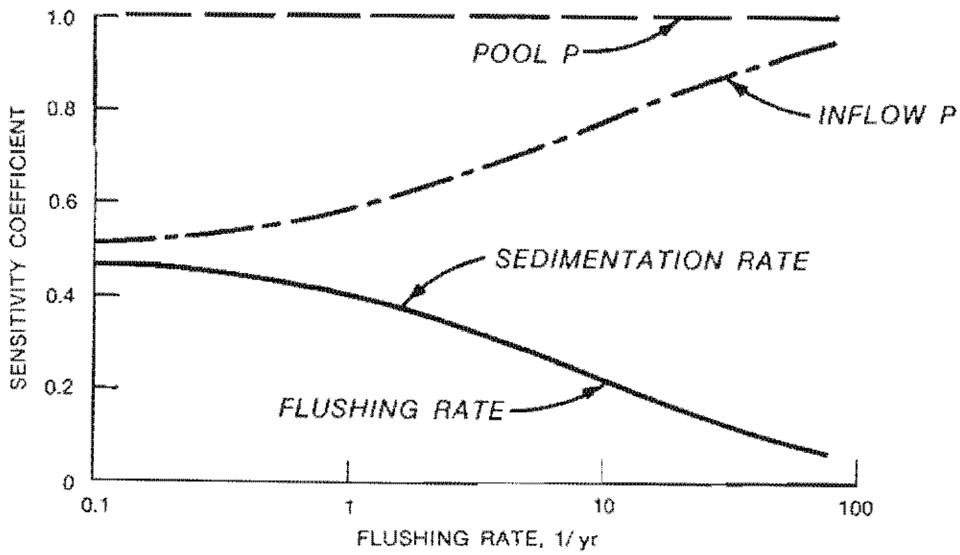
K_1 = FIRST-ORDER SEDIMENTATION COEFFICIENT = 2.5 1/yr

Figure I-3. Sensitivity analysis of first-order phosphorus sedimentation model

(whereas the other input terms can be directly measured), its sensitivity characteristics have a strong influence on model performance and uncertainty over the range of flushing rates.

Figures I-3 and I-4 are intended primarily to demonstrate sensitivity analysis concepts. They also illustrate some important basic characteristics of empirical nutrient balance models:

a. Sensitivities are highest for inflow and pool phosphorus concentrations over the entire range of flushing rates. This emphasizes the importance of monitoring programs (tributary and pool) and data reduction procedures to modeling efforts.



$$\text{SENSITIVITY COEF} = \frac{|\%\ \text{CHANGE IN ERROR}|}{|\%\ \text{CHANGE IN FACTOR}|}.$$

$$\text{ERROR} = \frac{\text{OBSERVED POOL P}}{\text{PREDICTED POOL P}}$$

$$\text{PREDICTED POOL P} = \frac{-F + \sqrt{F + 4\,P_i\,K_2}}{2\,K_2}$$

WHERE: F = FLUSHING RATE (1/yr)

P_i = INFLOW TOTAL PHOSPHORUS CONCENTRATION = 50 mg/m^3

K_2 = SECOND-ORDER SEDIMENTATION COEFFICIENT = .1 $m^3/mg\text{-}yr$

Figure I-4. Sensitivity analysis of second-order phosphorus sedimentation model

b. Because of a higher sensitivity to phosphorus sedimentation, potential prediction errors are greater for reservoirs with lower flushing rates.

While pool nutrient concentrations can be predicted relatively easily from inflow concentrations in reservoirs with high flushing rates, predictions of biological responses (as measured by chlorophyll-a) may be more difficult because of temporal variability in nutrient levels (induced by storm events, for example) and/or controlling effects of turbidity and flushing rate. The importance of obtaining accurate inflow and pool concentration estimates for model implementation has led to the development of computer programs described in subsequent sections. FLUX and PROFILE are designed to make efficient use of tributary and pool monitoring data, respectively, in calculating the required summary statistics.

SUMMARY OF ASSESSMENT PROCEDURES

Figure I-5 depicts the basic steps involved in applying the eutrophication assessment procedures described in this and subsequent sections. The "pathway" comprises four general stages:

a. Problem identification.

b. Data compilation.

c. Data reduction.

d. Model implementation.

Once the user has developed a working understanding of the model structures, assumptions, and limitations by reviewing basic references and supporting research (see References and Bibliography), most of the effort and cost would typically be involved in the data compilation and data reduction stages. Three computer programs have been written to assist at various stages of the analysis. The functions of these programs are outlined below:

a. FLUX - estimation of tributary mass discharges (loadings) from grab-sample concentration data and continuous flow records.

b. PROFILE - display and reduction of pool water quality data.

c. BATHTUB - implementation of nutrient balance and eutrophication response models in a spatially segmented hydraulic network.

Figure I-5 summarizes the basic inputs, functions, and outputs of each supporting program. This section provides an overview of each analytical stage. Details are given in subsequent chapters, along with examples and guidance for use of the computer software.

Problem Identification

The problem identification stage defines the scope of the modeling effort. The following factors are specified:

a. The reservoir, watershed, and water uses.

b. Water quality standards and management objectives.

Figure I-5. Assessment pathways

c. Whether the reservoir is existing or planned.

d. Specific management strategies or impacts to be evaluated.

e. Types of evaluations to be performed.

(1) Diagnostic.

(2) Predictive.

f. Classes of models to be used.

(1) Nutrient balance.

(2) Eutrophication response.

If the analysis is not directed toward evaluating specific management strategies or impacts, the general objective may be to develop perspectives on reservoir water quality conditions and controlling factors as part of a "diagnostic" study. This may lead, in turn, to future evaluations of specific management strategies designed for water quality control.

Two general types of evaluations may be performed. In a diagnostic mode, the models are used as a framework for interpreting monitoring data from the reservoir and/or its tributaries. A diagnostic study provides insights into factors controlling algal productivity and rankings of trophic state indicators versus water quality criteria and/or data from other CE reservoirs. In a predictive mode, the models are applied to predict future conditions in a planned reservoir or in an existing reservoir undergoing changes in nutrient loading regime and/or other controlling factors.

Model classes are determined by the types of analyses to be performed. Both nutrient balance and eutrophication response models are required for a predictive analysis. Diagnostic studies of existing reservoirs can be based exclusively upon response models and pool water quality data; this provides a basis for defining existing conditions and controlling factors, but not for evaluating watershed/reservoir or load/response relationships. Monitoring requirements are generally more stringent for implementing nutrient balance models than for implementing eutrophication response models.

Response models and pool monitoring data may be used in preliminary diagnostic studies and, depending upon results, may be followed by more elaborate nutrient balance monitoring and modeling of priority projects. Priorities can be established based upon the severities of existing eutrophication-related problems (if any), intensities and types of water use, and potential for future improvement or degradation owing to changes in loading regime.

Data Compilation

As shown in Figure I-5, data compilation occurs in two general areas. The reservoir data required for implementation of eutrophication response models include morphometric characteristics, outflow hydrology, and pool water quality obtained over at least one complete growing season (three preferred). The watershed data required for implementation of nutrient balance models include basic watershed characteristics (e.g., subwatershed delineations, topography, geology, land uses, point source inventories) and tributary flow and nutrient concentration data taken at reservoir entry points over at least one full water year (three preferred). Details on data requirements and suggested monitoring designs are given later in this Part.

Data Reduction

In the data reduction phase, pool and tributary water quality data are reduced or summarized in forms which can serve as model input. Since the models generally deal with conditions averaged over a growing season within defined reservoir areas (segments), data reduction involves the averaging or integration of individual measurements, sometimes with appropriate weighting factors.

The FLUX program is designed to facilitate reduction of tributary inflow monitoring data and reservoir discharge monitoring data. Using a variety of calculation techniques, FLUX estimates the average mass discharge or loading that passes a given tributary monitoring station, based upon grab-sample concentration data and a continuous flow record. Potential errors in the estimates are also quantified and can be used to: (a) select the "best" or least-error loading estimate, (b) assess data adequacy, and (c) improve future tributary monitoring efficiency via optimal allocation of sampling effort among seasons and/or flow regimes. Graphic displays of concentration, flow, and loading data are also provided for diagnostic purposes.

The PROFILE program facilitates analysis and reduction of pool water quality data from existing reservoirs. A variety of display formats are provided to assist the user in developing perspectives on spatial and temporal water quality variations within a given reservoir. Algorithms are included for calculation of hypolimnetic oxygen depletion rates and for robust estimation of area-weighted, surface-layer mean concentrations of nutrients, and other response measurements used in subsequent modeling steps. Future versions of PROFILE will incorporate methods for evaluating and optimizing sample allocation for pool monitoring efforts.

Model Implementation

The BATHTUB program permits application of empirical eutrophication models to morphometrically complex reservoirs or to collections of reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network which accounts for advective transport, diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll-a, transparency, organic nitrogen, particulate phosphorus, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships previously developed and tested for reservoir applications (Walker 1983).

To reflect data limitations or other sources of uncertainty, key inputs to the model can be specified in probabilistic terms (mean and CV). Outputs are expressed in terms of a mean value and CV for each mass balance term and response variable. Output CV's are based upon a first-order error analysis which accounts for input variable uncertainty and inherent model error.

As shown in Figure I-5, applications of BATHTUB would normally follow use of the FLUX program for reducing tributary monitoring data and use of the PROFILE program for reducing pool monitoring data. Use of the data reduction programs is optional if independent estimates of tributary loadings and/or average pool water quality conditions are used.

DATA REQUIREMENTS

This section outlines general information requirements for model implementation. Needs are described in the following areas:

- a. Watershed characteristics.
- b. Water and nutrient loadings.
- c. Reservoir morphometry.
- d. Pool water quality and hydrology.

Before describing each area in detail, it is appropriate to discuss some general concepts and guidelines that may be helpful in the design of a reservoir study.

In a typical program, most of the effort and cost would be expended in the critical data-gathering phase. Information sources would generally include project design memoranda, basin planning reports, historical hydrologic and water quality data, and water quality data gathered specifically for the study. Data requirements can be given rather explicitly, as determined by the list of model input variables. Specific data sources and monitoring program designs cannot be dictated, however, because they are influenced by unique aspects of each reservoir and its watersheds, the extent of existing data, logistic considerations, and study resources.

Compilation and review of existing data are important initial steps in conducting a reservoir study. Preliminary application of models using existing data (even if inadequate) can highlight data strengths and weaknesses and help to focus future monitoring activities. In some cases, existing data may be adequate to support modeling efforts. When existing data are inadequate or unavailable, a phased monitoring program is generally indicated. The first phase involves a small-scale program designed to obtain preliminary data for use in designing efficient monitoring programs for subsequent years. A phased study can be a relatively cost-effective means of data acquisition.

Given specific objectives (e.g., estimated annual total phosphorus loading or growing-season mean chlorophyll-a concentration in an existing reservoir), statistical methods can be applied to improve monitoring efficiency, subject to logistic and economic constraints measured by the amount of uncertainty (variance) in the desired summary statistic (e.g., loading or reservoir-mean concentration) for a given level of effort (cost or number of samples). Monitoring efficiency may be improved by optimizing the allocation of sampling effort. Examples of such optimization procedures include:

a. Allocation of samples among flow regimes to estimate loadings from a given tributary.

b. Allocation of samples among tributaries to estimate total reservoir loading.

c. Allocation of samples among stations, depths, and dates to estimate reservoir-mean concentrations.

Phased studies or useful existing data bases are required to implement these optimization procedures. Because of logistic constraints, multiple monitoring objectives, and other factors, "optimal" designs are rarely implemented; instead, they can be used to indicate appropriate directions for adjusting existing sampling designs.

Watershed Characteristics

Basic watershed information is used in the development and interpretation of nutrient loading and hydrologic data, in the design of tributary monitoring programs, and in the assessment of problem sources and control strategies. Maps (US Geological Survey topographic or other) are the most useful formats for this type of information. Separate maps (or a series of transparent overlays) can be used to summarize the following types of watershed information:

- *a*. Elevation contours.
- *b*. Subwatershed delineations.
- *c*. Dominant land uses.
- *d*. Soil types.
  - (1) Hydrologic soil groups.
  - (2) Erosion potential.
- *e*. Point sources.
- *f*. Monitoring station locations.

Aerial photos, regional planning agencies, design memoranda, and/or published basin reports are generally useful sources of watershed information. Soils information would also be available from the Soil Conservation Service. The information should be summarized in a tabular form by subwatershed.

Land uses, soil types, topography, and point sources are important factors in determining runoff and nutrient export from a given subwatershed. This type of information is used to:

- *a*. Design tributary monitoring programs (place stations).
- *b*. Interpret watershed monitoring data (compare monitored runoff and loads from different subwatersheds to develop perspectives on regional land use/nutrient-export relationships).
- *c*. Estimate loadings from unmonitored watersheds (use land use/nutrient-export factors or proportion monitored loads from a nearby watershed with similar land uses and soil types, based upon drainage area).

Projected future land use and point source distributions are also required for model applications involving predictions of future development or reservoir management scenarios.

Water and Nutrient Loadings

The formulation of water and nutrient balances for the reservoir is a critical step in the empirical modeling process. The following components are of concern:

a. Water.
b. Total phosphorus.
c. Dissolved ortho-phosphorus.
d. Total nitrogen.
e. Total inorganic nitrogen.

While nitrogen balances are desirable, they may be bypassed if monitoring data and/or preliminary mass balance calculations indicate that the reservoir is clearly not nitrogen-limited under existing and future loading conditions. The ortho-phosphorus and inorganic nitrogen (ammonia, nitrate, and nitrite) loading components are required for (optional) implementation of nutrient sedimentation models which account for the "availability" or partitioning of total nutrient loads between dissolved and particulate (or inorganic and organic) fractions.

The nutrient species listed above correspond to those monitored by the US Environmental Protection Agency (EPA) National Eutrophication Survey, the primary data source used in model development and testing. Monitoring of other species (particularly, total dissolved phosphorus) may be desirable for defining inflow nutrient partitioning and availability. Because of existing data constraints, however, the models are based upon the above species.

Generally, balances should be formulated over both annual and seasonal (May-September) time periods. Annual balances should be calculated on a water year (versus calendar year) basis. While traditional nutrient loading models deal with annual time scales, seasonal loadings are better predictors of trophic status in many reservoirs. The methodologies presented in subsequent sections can be applied separately to annual and seasonal nutrient balance data. Nutrient residence time criteria are used to assess the appropriate time scale for each reservoir.

The nominal definition of seasonal (May-September) can be adjusted in specific applications, depending upon seasonal variations in inflow hydrology and, especially, pool level. For example, if a full recreational pool were maintained June through August and much lower elevations were maintained during other months for flood control purposes, then a June-August time scale may be more appropriate for seasonal nutrient balances. Generally, seasonal balances are unimportant in projects with little or no inflow or outflow during the summer months. The formulation of both seasonal and annual balances is generally recommended for all applications and does not substantially increase monitoring requirements, since both sets of loading estimates can be derived from the same monitoring program.

For each component and time scale, a control volume is drawn around the reservoir (or reservoir segment) and the following mass balance terms are quantified:

a. Total inputs.

b. Total outputs.

c. Increase in storage.

d. Net loss.

Table I-2 outlines the specific elements of each term and general data sources. Since water is conservative, the net loss term in the water balance (estimated by difference) reflects errors in the estimates of the other water balance terms. For nutrients, the net loss term can be estimated by difference or, in a predictive mode, by using empirical nutrient sedimentation models which have been calibrated and tested for reservoir applications.

In general, direct monitoring is recommended to quantify major flow and nutrient sources. Table I-3 summarizes "minimal" and "desirable" designs for tributary monitoring programs and methods for quantifying other loading components. These are intended as general guidelines to be modified based upon site-specific conditions. The basic design for major tributaries and outflows consists of continuous flow monitoring and a combination of periodic grab-sampling and event monitoring for concentration. A sampling program weighted toward high-flow regimes is generally desirable for estimation of loadings. The multiple objectives of estimating both annual and seasonal loadings should be considered in designing surveys. The FLUX program can be applied to historical and/or preliminary monitoring data to assist in sampling design.

Table I-2

Mass Balance Terms and Data Sources

Mass Balance Terms	General Data Sources
Inputs	
Gauged tributaries	Direct monitoring
Ungauged tributaries	Drainage area approximations Watershed models
Direct point sources	Direct monitoring Per capita loading factors
Shoreline septic systems	Per capita loading factors Hydrogeologic studies
Direct ground-water inputs	Hydrogeologic studies
Atmospheric	Local precipitation data Regional atmospheric loading rates
Outputs	
Outflows and withdrawals	Direct monitoring
Evaporation	Local climatologic data
Increase in storage	Pool elevation and morphometry data
Net loss	Calculated by difference Represents error in water balance Empirical nutrient sedimentation models

Table I-3

Minimal and Desirable Designs for Tributary Monitoring Programs

FEATURE	MINIMAL DESIGN	DESIRABLE DESIGN	COMMENTS
DURATION OF WATER AND NUTRIENT BALANCE MONITORING	ONE WATER YEAR (OCTOBER - SEPTEMBER) COUPLED WITH POOL MONITORING	THREE WATER YEARS	DETERMINED PARTIALLY BY EXTENT OF YEAR-TO-YEAR VARIABILITY IN HYDROLOGY AND NUTRIENT LOADINGS
TRIBUTARY DISCHARGE LOCATIONS	MAJOR FLOW SOURCES AND OUTFLOWS	ALL TRIBUTARIES AND OUTFLOWS	PRIORITIZE BASED UPON WATERSHED SIZE
TRIBUTARY DISCHARGE FREQUENCY	DAILY/EVENT-BASED	CONTINUOUS MONITORING	
TRIBUTARY WATER QUALITY LOCATIONS	MAJOR LOAD SOURCES AND OUTFLOWS; AS CLOSE TO RESERVOIR AS POSSIBLE	ALL TRIBUTARIES AND OUTFLOWS	MONITOR AT LEAST 75% OF TOTAL LOAD PRIORITIZE TRIBUTARIES WITH. LARGE WATERSHEDS, HIGH LAND USE INTENSITY, AND/OR SIGNIFICANT POINT SOURCES
TRIBUTARY WATER QUALITY COMPONENTS	INSTANTANEOUS FLOW TOTAL AND ORTHO-PHOSPHORUS ORGANIC AND INORGANIC NITROGEN	ADD: TOTAL DISSOLVED PHOSPHORUS SUSPENDED SOLIDS	NITROGEN SPECIES PASSED OR SAMPLED LESS FREQUENTLY, IF CLEARLY NOT LIMITING BASED UPON POOL MONITORING AND/OR PRELIMINARY NUTRIENT BALANCES
TRIBUTARY WATER QUALITY FREQUENCY	BIWEEKLY (NOMINAL) SUPPLEMENTED WITH EVENT SAMPLING MONTHLY FOR MINOR LOAD SOURCES	WEEKLY (NOMINAL) CONTINUOUS STORM EVENT MONITORING BIWEEKLY FOR MINOR LOAD SOURCES	CHARACTERIZE ANNUAL AND SEASONAL LOADINGS ADJUST FREQUENCIES ACCORDING TO: RELATIVE MAGNITUDE (IMPORTANCE) OF LOAD, TEMPORAL VARIABILITY IN LOAD AND FLOW, FLOW/CONCENTRATION DYNAMICS, GUIDANCE FROM FLUX PROGRAM
UNGAUGED WATERSHEDS/ LOCAL DIRECT RUNOFF FLOWS AND LOADINGS	ACCOUNT FOR LESS THAN 25% OF TOTAL LOAD ESTIMATE BY DRAINAGE AREA PROPORTIONING USING MONITORED EXPORT RATES FROM REGIONAL WATERSHEDS WITH SIMILAR LAND USES AND GEOLOGY	ACCOUNT FOR LESS THAN 10% OF TOTAL LOAD SUPPLEMENT WITH DIRECT RUNOFF MONITORING AND/OR INDEPENDENT WATERSHED MODELING	DEVELOP PERSPECTIVES ON RUNOFF RATES AND CONCENTRATIONS THROUGH REGIONAL DATA BASES
DIRECT POINT SOURCES	ESTIMATE FROM TYPE OF SOURCE, PLANT SIZE, TREATMENT PROCESS, AND LITERATURE VALUES FOR EFFLUENT CONCENTRATIONS OR PER-CAPITA LOADING FACTORS	SOURCE-SPECIFIC 24-HR. FLOW-WEIGHTED COMPOSITES SUFFICIENT SAMPLES TO CHARACTERIZE SEASONAL AND ANNUAL LOADS	SAMPLING DESIGN SHOULD CONSIDER EFFECTS OF OF DAILY, WEEKLY, SEASONAL VARIATIONS IN LOAD FROM MUNICIPAL/INDUSTRIAL DISCHARGES MONITOR DIRECTLY IF SIGNIFICANT PORTION OF TOTAL LOAD
SHORELINE SEPTIC TANKS	ESTIMATE FROM USE INTENSITY AND TYPICAL PER CAPITA LOADING FACTORS ADJUST ACCORDING TO SOIL CHARACTERISTICS DESIGN, AND MAINTENANCE PRACTICES	DIRECT MONITORING	USUALLY UNIMPORTANT
ATMOSPHERIC LOADING	USE LITERATURE VALUES, REGIONAL IF AVAILABLE	MONITOR DIRECTLY OVER ANNUAL PERIOD CAPTURE DRY-FALL AND WET-FALL	USUALLY UNIMPORTANT, EXCEPT IN PROJECTS WITH LOW SURFACE OVERFLOW RATES AND LOW TRIBUTARY INFLOW CONCENTRATIONS
GROUND-WATER LOADINGS	SITE-SPECIFIC	SITE-SPECIFIC HYDROGEOLOGIC STUDIES	USUALLY UNIMPORTANT POSSIBLE SIGNIFICANCE INDICATED BY ERRORS IN WATER BALANCE
PRECIPITATION AND EVAPORATION	USE SEASONAL AND ANNUAL PRECIPITATION DATA FROM NEARBY WEATHER STATION LITERATURE VALUES FOR SEASONAL AND ANNUAL EVAPORATION RATES	ONSITE MONITORING LOCAL PAN EVAPORATION STUDIES AND AND PRECIPITATION GAUGES	USED IN DEVELOPING WATER BALANCE USUALLY INSENSITIVE, EXCEPT IN PROJECTS WITH LOW SURFACE OVERFLOW RATES

While balances are formulated for the study (monitored) period, a historical hydrologic record is desirable to provide perspective on study conditions in relation to long-term averages and extremes. Long-term hydrologic records are usually available for reservoir discharge sites and major tributary inflows. If not, records from a nearby, long-term station, possibly outside the watershed(s), can be correlated with monitoring data from study sites and used to extrapolate the record.

Reservoir Morphometry

Reservoir morphometric information is required for nutrient balance and eutrophication response models. It is usually readily available from project design memoranda and other sources. A map indicating the following basic information is useful:

- a. Distance scale.
- b. Shoreline for typical and extreme pool levels.
- c. Bottom elevation contours or soundings.
- d. Tributary inflows and any direct point sources.
- e. Pool and tributary monitoring station locations.

The following morphometric data should also be compiled in tabular form:

- a. Elevation/area volume table.
- b. Typical operating pool elevations (rule curve).
- c. Reservoir bottom elevation at each pool sampling station.
- d. Volumes, surface areas, and lengths of major reservoir segments at typical operating elevations.

This information is used in data reduction (PROFILE) and modeling (BATHTUB).

Pool Water Quality and Hydrology

In studies of existing reservoirs, pool water quality and hydrologic data are used for the following purposes:

- a. Assessment of existing trophic status, related water quality conditions, and controlling factors.
- b. Model testing and calibration.

Expressed in terms of model variables, the primary objectives of the monitoring program are to obtain the data required for calculation of growing-season, mixed-layer, mean concentrations of the following variables:

- a. Total phosphorus.
- b. Dissolved ortho-phosphorus.
- c. Total nitrogen.
- d. Total inorganic nitrogen.
- e. Organic nitrogen.
- f. Chlorophyll-a (corrected for phaeophytin).
- g. Transparency (Secchi depth).

In stratified reservoirs, another primary objective is to estimate hypolimnetic and metalimnetic oxygen depletion rates. Secondary objectives are to develop perspectives on spatial variations, vertical stratification, basic water chemistry, and other variables which are directly or indirectly related to eutrophication.

General guidelines for designing pool monitoring programs are outlined in Table I-4. Basic design features include component coverage, station locations, sample depths, temporal frequency, and duration. An appreciation for spatial and temporal variability of conditions within the reservoir may be obtainable from historical data and can be very useful in designing future surveys.

The objectives of identifying spatial gradients and calculating reservoir-mean conditions suggest somewhat different emphasis for station placement. Generally, horizontal variations parallel to the net advective flow along the main axis of a major tributary arm are much more important than variations perpendicular to the flow. If they exist, longitudinal gradients in nutrients, algal biomass, and transparency are usually steepest in upper pool areas; this suggests that stations should be more closely spaced in upper pool areas to permit adequate resolution of gradients. Most of the reservoir volume, however, is usually located in the lower pool areas, where width and depth tend to be greater and spatial gradients tend to be less pronounced; this suggests a greater emphasis on lower pool stations for the purposes of calculating reservoir means. Because of these trade-offs, it is difficult to use a statistical approach for optimizing station placement within a given reservoir.

Table I-4

General Guidelines for Designing Reservoir Pool Monitoring Programs

FEATURE	MINIMAL DESIGN	DESIRABLE DESIGN
WATER QUALITY COMPONENTS	TEMPERATURE DISSOLVED OXYGEN TOTAL P ORTHO-P ORGANIC N AMMONIA N NITRITE+NITRATE N TRANSPARENCY ALKALINITY pH CONDUCTIVITY TURBIDITY CHLOROPHYLL-a (CORRECTED FOR PHAEOPHYTIN) DOMINANT ALGAL TYPES	ADD: TOTAL SILICA TOTAL ORGANIC CARBON TOTAL IRON TOTAL MANGANESE TRUE COLOR SULFIDES SUSPENDED SOLIDS (TOTAL AND ORGANIC) OXIDATION REDUCTION POTENTIAL ALGAL CELL COUNTS (ASU) BY TYPE
STATION LOCATIONS	MINIMUM OF THREE STATIONS/RESERVOIR (NEAR-DAM, MID-POOL, UPPER-POOL) DISTRIBUTED ALONG THALWEG OF EACH MAJOR TRIBUTARY ARM WITHIN POOL IN REPRESENTATIVE AREAS MAXIMUM DISTANCE BETWEEN STATIONS ALONG THALWEG = 20 KM	ADD STATIONS IN SMALLER TRIBUTARY ARMS AND EMBAYMENTS CRITICAL RESERVOIR USE AREAS ABOVE AND BELOW JUNCTIONS OF MAJOR TRIBUTARY ARMS MAXIMUM DISTANCE BETWEEN STATIONS ALONG THALWEG = 10 KM
DURATION OF SAMPLING	ONE GROWING SEASON (TYPICALLY APRIL - OCTOBER) BRACKET STRATIFIED PERIOD, INCLUDING 1 ROUND EACH DURING SPRING AND FALL ISOTHERMAL PERIODS	THREE GROWING SEASONS
FREQUENCY - LAB SAMPLES	MONTHLY OR BIWEEKLY	BIWEEKLY OR WEEKLY
DEPTHS - LAB SAMPLES	MIXED-LAYER COMPOSITE DEPTH-INTEGRATED HOSE SAMPLING	UNSTRATIFIED RESERVOIRS: SURFACE, MID-DEPTH, 1 METER OFF BOTTOM STRATIFIED RESERVOIRS: 3 SAMPLES IN MIXED LAYER 1 SAMPLE IN THERMOCLINE 3 SAMPLES IN HYPOLIMNION 1 METER FROM TOP OF. HYPOL. MID-DEPTH 1 METER OFF BOTTOM
FREQUENCY - FIELD PROFILES UNSTRATIFIED RESERVOIRS. TEMPERATURE DISSOLVED OXYGEN	UNSTRATIFIED RESERVOIRS: SAME AS LAB SAMPLES STRATIFIED RESERVOIRS: BIWEEKLY IN SPRING TO EARLY SUMMER (UNTIL ONSET OF ANOXIA), THEN MONTHLY	UNSTRATIFIED RESERVOIRS: SAME AS LAB SAMPLES STRATIFIED RESERVOIRS: WEEKLY IN SPRING TO EARLY SUMMER (UNTIL ONSET OF ANOXIA), THEN BIWEEKLY
DEPTHS - FIELD PROFILES TEMPERATURE DISSOLVED OXYGEN	1-METER INTERVALS TOP TO BOTTOM	INCREASE SPATIAL FREQUENCY IN THERMOCLINE AND OTHER ZONES WITH STEEP GRADIENTS
RESERVOIR HYDROLOGY SURFACE ELEVATION OUTFLOW VOLUMES	MONTH-END VALUES MONTHLY TOTALS	DAILY VALUES DAILY TOTALS

Given multiple sampling objectives, a reasonable design rule is to distribute stations throughout representative areas of the reservoir. The size, morphometric complexity, and loading distribution of a reservoir largely determine the required number of stations. A minimum of three stations (upper-pool, midpool, and near-dam) are recommended for small projects with simple morphometry. Based upon reservoir morphometric information, weighting factors can be applied to data from each station in calculating area-weighted reservoir means (see PROFILE).

To provide bases for characterizing variability and developing robust statistical summaries, surveys should be designed to provide replication (some overlap in information content) of measurements made in each reservoir area or segment during each sampling round. There are several ways in which replication can be built into survey designs, including:

a. Multiple sampling at a given date, station, and depth.

b. Multiple sampling with depth within the mixed layer at a given date and station.

c. Multiple sampling stations within a given reservoir segment or area.

d. High temporal sampling frequencies, permitting aggregation of data from adjacent sampling dates.

In designing surveys, combinations of the above strategies can be employed to provide data which include at least three measurements for each reservoir segment and sampling round. In the "desirable" design (see Table I-4), three samples are suggested within the mixed layer for each station and date. Since the stratum is mixed, on the average, the three samples can be treated as replicates. Other strategies listed above can be used in conjunction with depth sampling to provide replication. Another monitoring objective is to sample each station on each sampling round; this greatly simplifies reduction of the data and error analysis, as implemented in the PROFILE program.

Assuming representative station distribution and proper sampling and analytical techniques, the "precision" of a mean, surface-layer, growing-season value depends largely upon the number of sampling rounds and the inherent temporal variabilities of water quality components in the reservoir being studied. For sampling periods of roughly a week or longer, the variance of the mean is roughly inversely proportional to the number of rounds. Based upon analyses of variance applied to model development data sets (Walker 1980, 1981), temporal variance components of phosphorus, transparency, and chlorophyll-a are typically 0.31, 0.33, and 0.62, respectively, expressed as CV's. Figure I-6 shows the estimated accuracies of reservoir mean concentrations computed from sampling designs with between 1 and 30 sampling rounds over a range of temporal CV's. The "value" of each additional round, as measured by the reduction in the mean CV, decreases as the total number of rounds increases. This table provides a rough perspective on design sensitivity and a basis for interpreting the reliability of data from historical monitoring activities, provided the sampling regimes were both specified and representative.

The "adequacy" of a given monitoring program is partially determined by the precision of the mean concentration estimates calculated from the data. Because of the limited pool sampling schedule employed by the EPA National Eutrophication Survey (3 to 4 sampling rounds per growing season), typical error CV's were on the order of 0.18 for mean total phosphorus, 0.18 for mean transparency, and 0.28 for mean chlorophyll-a. More precise estimates (e.g., mean CV's less than 0.10 for nutrients and transparency and 0.15 for mean

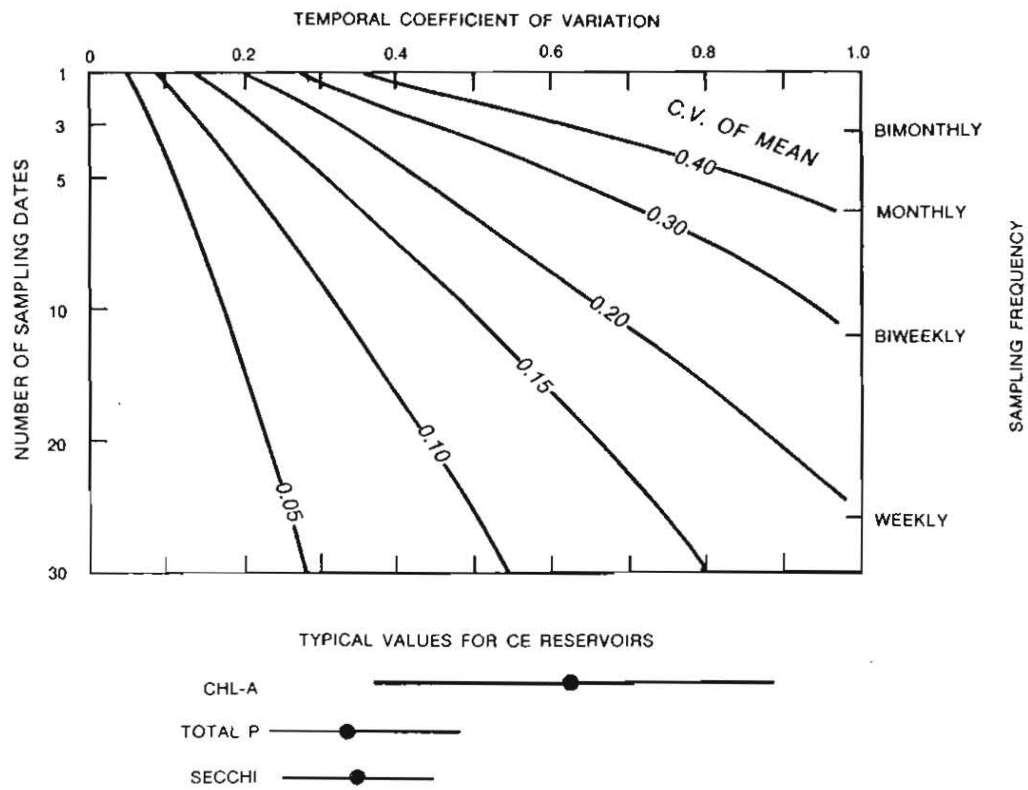


Figure I-6. Estimated accuracy of reservoir mean concentration computed from sampling designs with between 1 and 30 sampling rounds over a range of temporal CV's chlorophyll-a) are desirable for model applications in a reservoir management context.

The purpose of sampling in and below the thermocline (Table I-4) is to provide information on vertical stratification and the accumulation and transformation of nutrients within the hypolimnion. Many important secondary water quality effects of eutrophication are expressed in bottom waters, including oxygen depletion, development of reducing conditions, nutrient accumulation, iron and manganese releases, and sulfide and ammonia generation. While nutrient data from the hypolimnion are not used exclusively in the models, they are important for developing an understanding of nutrient cycling and reservoir processes. Since metalimnetic and hypolimnetic samples are less important for trophic state assessment and model implementation, however, sampling frequencies in and below the thermocline can be lower than those used for the mixed layer.

PART II: FLUX - REDUCTION OF TRIBUTARY MONITORING DATA

FLUX is an interactive program for estimating loadings or mass discharges passing a tributary or outflow monitoring station over a given period. These estimates can be used in formulating reservoir nutrient balances over annual or seasonal averaging periods appropriate for application of empirical eutrophication models. The function of the program is to interpret water quality and flow information derived from intermittent grab or event sampling to estimate mean (or total) loading over the complete flow record between two dates.

Since the appropriate loading calculation method depends partially upon the concentration/flow/seasonal dynamics which are characteristic of a given station and component and upon the sampling program design, five alternative calculation methods are provided. An option to stratify the samples into groups based upon flow and/or date is also included. In many cases, stratifying the sample increases accuracy and reduces potential biases in loading estimates. The variances of the estimated mean loadings are calculated to provide relative indications of error. A variety of graphic and statistical diagnostics are included to assist the user in evaluating data adequacy and in selecting the most appropriate calculation method and stratification scheme for each loading estimate. The program can also be used to improve the efficiencies of monitoring programs designed to provide data for calculating loadings and reservoir mass balances.

Program structure is illustrated in Figure II-1. The user directs the analysis and reduction of a given set of flow and concentration data in response to prompts generated by the program. Calculations are structured around a main procedure menu and three submenus, as illustrated in Figure II-2. Input data requirements, underlying theory, and suggested application procedures are described in the following sections.

INPUT DATA REQUIREMENTS

Coding forms (located in the section titled Input Coding Forms) contain detailed information on input file contents and formats. Input data are specified in four groups:

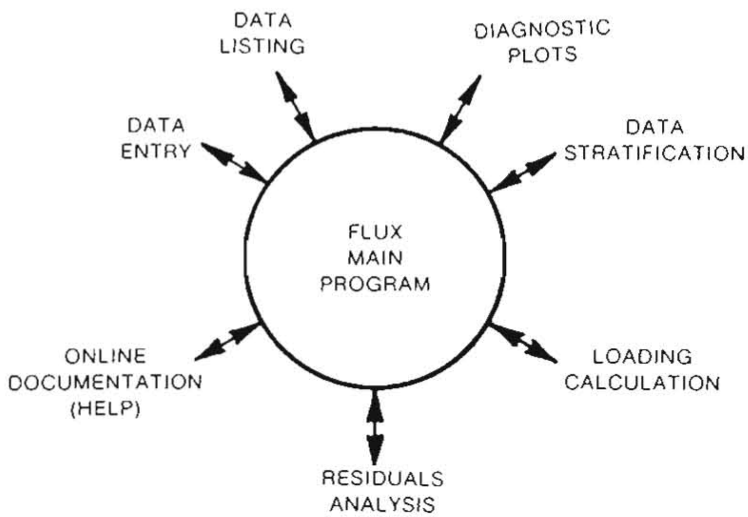


Figure II-1. FLUX schematic

Group 1: Title - describing reservoir, tributary, date ranges, etc.

Group 2: Variable Index - flow and water quality variable labels; unit conversion factors.

Group 3: Water Quality Records - date, stratum, and instantaneous flows; concentrations.

Group 4: Flow Distribution Records - date, stratum, and mean daily flow.

The function of the program is to use the water quality information in Group 3 to estimate the mean (or total) loading which corresponds to the complete flow distribution (Group 4) over the period of interest. The "stratum" input for Groups 3 and 4 provides an optional means of grouping the data for load calculations, as described in detail below. Input files can be generated from existing data bases, punched on cards, or entered using a terminal editor.

All program calculations and output are in metric units, with flows expressed in million cubic meters (= cubic hectometers, hm^3) per year, concentration in milligrams per cubic meter, and loading in kilograms per year. In Group 2, the user specifies factors to convert input flow and concentration units to program units. For a typical nutrient balance study, Group 2 would index the following components: instantaneous flow, total phosphorus, ortho-phosphorus, total nitrogen, and inorganic nitrogen. Potential applications of the program are not restricted to nutrients, however.

F L U X PROCEDURES:	*MAIN MENU*
1. = READ NEW DATA	
2. = LIST SAMPLE RECORD	
3. = LIST FLOW RECORD	
4. = PLOT DATA	*SUBMENU A*
5. = DEFINE STRATA	*SUBMENU B*
6. = CALCULATE LOADINGS	
7. = ANALYZE RESIDUALS	
8. = DELETE A SAMPLE	
9. = HELP	*SUBMENU C*
99. = END	

F L U X PLOTTING PROCEDURES:	*SUBMENU A*
1. = SET PLOT WIDTH AND HEIGHT	
2. = PLOT CONCENTRATION VS. FLOW	
3. = PLOT SAMPLED LOAD VS. FLOW	
4. = PLOT CONCENTRATION VS. DATE	
5. = PLOT SAMPLED LOAD VS. DATE	
6. = PLOT SAMPLED FLOWS VS. DATE	
7. = PLOT ALL FLOWS VS. DATE	
8. = HISTOGRAM OF CONCENTRATIONS	
9. = PLOT CUMULATIVE FLOW FREQUENCIES	
10. = COMPARE FLOW MEANS BY STRATUM	
99. = RETURN TO MAIN MENU	

F L U X OPTIONS FOR DEFINING STRATA:	*SUBMENU B*
1. = USE FLOWS - SEARCH FOR BOUNDS	
2. = USE FLOWS - ENTER BOUNDS DIRECTLY	
3. = USE DATES - ENTER BOUNDS DIRECTLY	
4. = DO NOT STRATIFY	
99. = RETURN TO MAIN MENU	

F L U X HELP MENU:	*SUBMENU C*
1. = GENERAL PROGRAM DESCRIPTION	
2. = PROCEDURE DESCRIPTIONS	
3. = GLOSSARY	
4. = TERMINAL CONVENTIONS	
99. = RETURN TO MAIN MENU	

Figure II-2. FLUX menus

The water quality data (Group 3) are normally derived from periodic grab-sampling. Flow measurements stored with the water quality data should correspond to the times of sampling; daily mean flows can be used in the absence of instantaneous flow measurements, but with some loss of accuracy. Generally, the samples are taken periodically over a year and over a range of flow regimes. If intensive storm-event sampling has also been done, the event data can be summarized prior to entry; in this case, each entry includes the event-mean flow and a flow-weighted-mean concentration for each component. If continuously sampled events represent a significant fraction of the total loading over the estimation period, the program will tend to overestimate error variance because a finite sample correction is not included.

The reliabilities of loading estimates strongly reflect monitoring program designs. Water quality samples should be taken over the ranges of flow regime and season which are represented in the complete flow record. For a given number of concentration samples, loading estimates will usually be of greater precision if the sampling schedule is weighted toward high-flow seasons and storm events, which usually account for a high percentage of the annual or seasonal loading. While the calculation methods described below are designed to make efficient use of the available data, they cannot work miracles. If the basin dynamics are such that annual loadings are dominated strongly by a few extreme events, no calculation procedure will give an acceptable answer without representative samples from at least some of the major events.

The water quality records (Group 3) can include measurements of up to seven components, but loading calculations are performed for only one component at a time. Concentrations which are entered as zero or negative values are assumed to be missing. Water quality records with zero or negative flow values are treated as missing values and are not used in the calculations. Specific sample or flow records can be excluded from analysis by entering a negative number in the "stratum" input field.

Group 4 data specify the complete flow distribution, which is generally derived from continuous stage measurements made at or near the water quality monitoring site. Typically, the entries consist of a mean flow for each day in the period of interest. In the absence of daily measurements, other averaging periods can also be used (weekly, monthly), but with some loss of accuracy. If a continuous flow record is not available for a particular site, one might be constructed using simulation techniques or correlating available flow measurements with simultaneous data from a nearby benchmark station with a continuous flow record and similar watershed. Missing values are not permitted in the flow distribution file; zero flow values are legal to permit consideration of intermittent streams.

It is convenient to define the time period represented in Group 3 as the "sampling period" and that represented in Group 4 as the "averaging period." Normally, these two periods correspond, i.e., Group 4 contains a mean daily flow value for each day in the year of water quality sampling (Group 3). If the sampling and averaging periods do not correspond (e.g., Group 3 might contain water quality samples from 1978 through 1981 and Group 4 might contain daily flows for 1981), then the user is making the assumption that the flow/concentration dynamics of the stream are stable, i.e., that concentrations measured between 1979 and 1980 are also representative of those measured in 1981. In some cases, using samples from outside the averaging period can increase the accuracy of the loading estimates (by increasing the number of samples and improving the coverage of flow regimes) but may introduce biases if watershed conditions are unstable. In each program run, the user specifies date ranges to be considered for Group 3 and 4; this permits estimation of both annual and seasonal loadings from a single file containing data from one or more years of monitoring.

The flow distribution group can include daily flows from the year(s) of water quality monitoring, as well as "low-flow," "average," and "high-flow" years. Provided that a sufficiently wide range of flow regimes are sampled, this permits extrapolation of the sample record, i.e., estimation of year-to-year variations in loadings based upon sample data from a specific year or years.

The current version of FLUX can handle problems with the following maximum dimensions:

Number of water quality samples	= 500	(Group 3)
Number of mean daily flows	= 2,000	(Group 4)
Number of strata	= 5	

The above constraints apply to data read into computer memory at the start of program execution, not the size of the input data file. Since the user is prompted for the ranges of sample and flow dates to be used in a given run, the input data file can be much larger than indicated above. A warning statement is printed if the problem size constraints are violated. Size limitations can be modified by changing the appropriate array dimension statements and recompiling the program. Users should check the online documentation file (accessed through the program menu) for maximum problem dimensions and other program changes in updated versions of FLUX.

LOADING CALCULATION METHODS

Table II-1 lists the equations used to estimate the mean and variance according to each of five calculation methods. Method applicability depends upon flow/concentration/seasonal dynamics and sampling design in each application. Results of Monte-Carlo simulations designed to test each method over a range of flow/concentration relationships are summarized in Table II-2. The primary objective of the simulations is to assess potential biases in the estimates of the means and variances derived from each method.

Desired properties of the loading estimates include minimum bias and minimum variance. The distinction between <u>bias</u> and <u>variance</u> (analogous to "accuracy" and "precision") is important. A biased procedure will give the wrong answer, even for an infinite number of samples, whereas variance in the mean can generally be reduced by increasing the number of independent random samples. The seriousness of bias depends upon its size relative to the variance of the mean or the standard error of estimate. Biases less than 10 percent of the standard error account for less than 1 percent of the total mean squared error and are generally considered negligible (Cochran 1977). Bias in a loading estimate can come from two sources: unrepresentative sampling, or the use of an inappropriate calculation method. These sources are discussed below.

Consistent problems with sample collection, handling, and analytical procedures can lead to one type of unrepresentative sampling; there is little that can be done about these sources of error at the calculation stage. Another, more subtle, but generally more common type of unrepresentative sampling results from differences in the distributions of flows between the sampling dates and the entire averaging period. Sampled flows may tend to be higher or lower, on the average, than the complete distribution of flows, or contain a higher or lower percentage of extreme flows. This can lead to bias in the estimate, if the calculation procedure does not take the relative flow

Table II-1

Estimation Algorithms Used in FLUX Program

Method 1 - Direct Mean Loading

$$W_1 = \text{Mean}(w)$$

Method 2 - Flow-Weighted Concentration (Ratio Estimate)

$$W_2 = \text{Mean}(w)\ \text{Mean}(Q)/\text{Mean}(q)$$

Method 3 - Modified Ratio Estimate (Bodo and Unny 1983)

$$W_3 = W_2(1 + F_{wq}/n)/(1 + F_q/n)$$

Method 4 - Regression, First-Order (Walker 1981)

$$W_4 = \text{Mean}(w)[\text{Mean}(Q)/\text{Mean}(q)]^{b+1}$$

Method 5 - Regression, Second-Order

$$W_5 = W_4(1 + r\ F_Q)/(1 + r\ F_q)$$

where

c_i = measured concentration in sample i (mg/m^3)

q_i = measured flow during sample i (hm^3/yr)

b = slope of log (c) versus log (q) regression

w_i = measured flux during sample i = $q_i c_i$ (kg/yr)

wq_i = product of flux and flow for sample i ($kg * hm^3/yr^2$)

F_{wq} = Var(wq)/[Mean(w) Mean(q)]

F_q = Var(q)/[Mean(q) Mean(q)]

F_Q = Var(Q)/[Mean(Q) Mean(Q)]

Q_j = mean flow on day j (hm^3/yr)

n = number of samples (i)

(Continued)

N = number of daily flows (j)

W_m = estimated mean flux over N days, method m (kg/yr)

V_m = variance of estimated mean flux, method m $(kg/yr)^2$

r = 0.5 b(b + 1)

Mean(x) = mean of vector x

Var(x) = variance of vector x

Variance Estimates - All Methods - Jackknife (Mosteller and Tukey 1978)

$$V_m = Var(W_{m,i})/n$$

where

$$W_{m,i} = n\ W_m - (n - 1)\ W_{m,-i}$$

$W_{m,-i}$ = mean flux calculated by method m, excluding sample i

Table II-2

Simulation Results - FLUX Estimation Methods

METH	VRATIO	BIAS/SE	BIAS/M	CV	Comments
		Slope = 0.75			
1	1.093	0.000	0.000	1.214	Simulation algorithm:
2	1.175	0.155	0.105	0.679	
3	1.099	0.076	0.058	0.764	5 years of daily values
4	1.197	0.246	0.126	0.511	360 days/year
5	0.875	0.057	0.016	0.278	24 samples/trial/year
		Slope = 0.50			15-day sampling interval
1	1.074	0.000	0.000	0.831	120 total trials
2	1.0.67	0.149	0.065	0.439	
3	1.009	0.066	0.033	0.494	"Observed" fluxes calculated from
4	0.995	0.193	0.067	0.347	unsampled days in given year
5	0.757	-0.088	-0.021	0.241	
		Slope = 0.25			"Estimated" fluxes calculated
1	1.033	0.000	0.000	0.547	from sampled days in given year
2	0.912	0.120	0.031	0.258	using each of five methods
3	0.880	0.047	0.013	0.289	
4	0.804	0.113	0.025	0.226	
5	0.699	-0.097	-0.020	0.206	
		Slope = 0.0			Daily flows (q) and concentra-
1	0.974	0.000	0.000	0.353	tions (c) generated from:
2	0.809	0.015	0.002	0.159	
3	0.795	0.001	0.000	0.173	ln(q) = N(0,1)
4	0.704	0.002	0.000	0.158	
5	0.645	0.013	0.002	0.171	ln(c) = b ln(q) + 0.5 N(0,0.5)
		Slope = 0.25			
1	0.922	0.000	0.000	0.230	Where:
2	1.001	-1.30	-0.021	0.160	N(M,S) = normal pseudo-random
3	0.984	-0.050	-0.008	0.165	number with mean M and
4	0.763	-0.084	-0.011	0.136	standard deviation S
5	0.694	0.112	0.020	0.176	
		Slope = -0.50			b = SLOPE
1	0.923	0.000	0.000	0.159	
2	1.112	-0.188	-0.039	0.209	
3	1.091	-0.062	-0.013	0.210	
4	0.881	-0.105	-0.014	0.129	
5	0.587	0.097	0.020	0.204	
		Slope = -0.75			
1	1.000	0.000	0.000	0.122	
2	1.072	-0.207	-0.054	0.259	
3	1.043	-0.059	-0.015	0.257	
4	0.942	-0.078	-0.009	0.120	
5	0.547	0.103	0.015	0.145	

METH = calculation method (see Table II-1).
VRATIO = observed/estimated mean squared error.
BIAS = mean observed load - mean estimated load.
BIAS/SE = bias as a fraction of the observed standard error.
BIAS/M = bias as a fraction of the mean observed load.
CV = observed coefficient of variation, or the
square root of mean squared error/mean observed flux.
SLOPE = slope of log concentration versus log flow regression.

distributions into consideration by directly representing the flow/concentration relationship and/or by stratifying the sample, as described below.

Even if the sampled and averaging flow distributions are equivalent, bias can be introduced as a result of the calculation method. For example, loading calculated as the product of the sample concentration and the mean flow over the averaging period would be badly biased if flow and concentration are (even weakly) correlated (Walker 1981). Because of the potential bias associated with this method, it is not included in the program. The five included methods have been selected and tested so that, for representative samples, they should not introduce significant bias, except under special conditions discussed below for each method.

Method 1 (direct load averaging) is the simplest of the calculation schemes but gives unbiased results only if the samples are taken randomly with respect to flow regime. This method completely ignores the unsampled flow record and generally has higher variance than the other methods because the flow record on the unsampled days is not considered. Simulations (Table II-2) indicate that this method is most appropriate for situations in which concentration tends to be inversely related to flow (i.e., loading does not vary with flow). This might occur, for example, at a station which is below a major point source and the flow/concentration relationship is controlled by dilution.

Method 2 bases the loading estimate on the flow-weighted-average concentration times the mean flow over the averaging period. This amounts to a "ratio estimate" according to classical sampling theory (Cochran 1977). This method performs best when flow and concentration are unrelated or weakly related. Some bias may occur for extreme flow/concentration relationships. For example, in trial simulations at a log (c) versus log (q) slope of 0.75, the method overestimated loadings by an average of 10 percent (Table II-2). Bias can be reduced by stratifying the samples into groups of relatively homogeneous concentration and applying the method separately to each group, as described in more detail below. This is perhaps the most robust and widely applicable method, especially when applied to stratified data sets.

Method 3 modifies the Method 2 estimate by a factor that is designed to adjust for potential bias in situations where concentration varies with flow. The factor was developed by Beale (1962) and applied in a load estimation method developed by the International Joint Commission (IJC) (1977), as described by Bodo and Unny (1983, 1984). Simulations indicate that, compared with Method 2, this procedure is moderately successful at reducing bias but tends to have slightly higher mean squared error for log (c) versus log (q) slopes equal to and exceeding zero.

Method 4 is the regression method developed and tested by Walker (1981). This method performs well over a range of log (c) versus log (q) slopes. Some bias is introduced at high slopes. At a slope of 0.75, for example, the simulated bias is 13 percent of the mean loading and 25 percent of the standard error. At this level, the bias accounts for 6.3 percent of the total mean squared error. Additional simulations indicate that bias also occurs if the log (c) versus log (q) relationship is highly nonlinear (i.e., quadratic or higher order polynomial). This problem can be resolved by stratifying the sample so that the relationship is approximately linear within each group.

Method 5 modifies the Method 4 estimate by a factor designed to account for differences in variance between the sampled and total flow distributions. The derivation of the method (Table II-3) is based upon expected value theory (Benjamin and Cornell 1970). The factor eliminates bias at high slopes and significantly reduces the error variance for log (c) versus log (q) slopes exceeding 0.25. As for Method 4, bias resulting from nonlinearity in the log (c) versus log (q) relationship can be reduced by stratification.

An alternative calculation procedure would treat the sample data as a time series and interpolate between sampling dates to estimate concentrations on the unsampled dates. This approach would be appropriate in situations where there is a significant trend or seasonal component of the concentration variance which is independent of flow. It would require relatively intensive monitoring data covering all major events over the period of interest. If concentration were even weakly flow dependent and if a major event were to occur between sampling dates, then the procedure would tend to underestimate loadings, in much the same way that averaging concentration independently of flow can lead to biased loading estimates. In general, to be valid statistically, interpolation methods would require construction of elaborate time series models and seem more useful for developing high-frequency loading estimates (for input to dynamic models, for example) than for developing the relatively low-frequency estimates (seasonal or annual) which are required for empirical eutrophication models. For this reason, interpolation methods

Table II-3

Derivation of Regression Estimator Used in Method 5

Method 4 Estimate (variables defined in Table V-1):

$$W_4 = \text{Mean}(w)\ [\text{Mean}(Q)/\text{Mean}(q)]^{b+1}$$

According to the underlying regression, loading is proportional to the b+1 power of flow. The refinement bases the adjustment factor on the expected values of Q^{b+1} and q^{b+1} .

From expected value theory (Benjamin and Cornell 1970):

$$E(f(x)) = f(\text{Mean}(x)) + 0.5\ \ (d\ f^2/d\ x^2)\ \ \text{Var}(x)$$

where

$$E(f(x)) = \text{expected value of function } f(x)$$

for

$$f(q) = q^{b+1}$$

$$E(f(q)) = \text{Mean}(q)^{b+1} + 0.5\ b\ (b+1)\ \text{Mean}(q)^{b-1}\ \text{Var}(q)$$

$$= \text{Mean}(q)^{b+1}[1 + 0.5\ b\ (b+1)\ \text{Var}(q)/\text{Mean}(q)^2]$$

A similar expression can be derived for the total flow distribution (Q). The refined estimate of loading is based upon the ratios of the expected values:

$$W_5 = E(w) \ = \ \text{Mean}(w)\ E\ (Q^{b+1})/E\ (q^{b+1})$$

or,

$$W_5 = W_4\ [1 + 0.5\ b\ (b+1)\ F_Q]/[1 + 0.5\ b\ (b+1)\ F_q]$$

where

$$F_q = \text{Var}(q)/\text{Mean}(q)^2$$
$$F_q = \text{Var}(Q)/\text{Mean}(Q)^2$$

---

are not included in this version of the program. The methods used in FLUX assume that flow is the major determining factor for loading.

For each method, the jackknife procedure (Mosteller and Tukey 1978) is used to estimate error variance. This involves excluding each concentration sample, one a time, and recalculating loadings, as described in Table II-1. While alternative, direct estimators of variance are available from classical sampling theory for most of the methods (Cochran 1977; Walker 1981; Bodo and Unny 1983, 1984), such formulas tend to rely upon distributional assumptions. The direct estimators are generally applicable to large samples and normal distributions, neither of which is typical of this application. As described by Cochran (1977), the jackknife has improved properties for ratio estimators derived from small, skewed samples. Use of the jackknife procedure also provides a uniform basis for comparing calculation methods with respect to estimated variance.

The variance ratios presented in Table II-2 indicate that jackknifing provides a reasonably unbiased estimate for error variance under the test conditions. Variances are overpredicted for Method 5, by amounts ranging from 13 to 45 percent. Two important factors should be considered in interpreting the variance estimates. First, the estimates are themselves subject to error and are of limited accuracy in small sample sizes, particularly if the sampled flow distribution is not representative. Second, the variance estimates do not reflect effects of biases associated with some calculation methods under certain conditions, as discussed above. Thus, while the estimated variances are probably the most important factors to consider in selecting the "best" loading estimation method, the sample characteristics and bias potential should also be considered. FLUX diagnostic procedures assist in this process, as described below.

DATA STRATIFICATION

FLUX includes an option to divide the input flow and concentration data into a series of groups and calculate loadings separately within each group using the methods described above. Using formulas derived from classical sampling theory (Cochran 1977), the mean and variance estimates within each group are subsequently combined across groups using weighting factors which are proportional to the frequency of each group in the total flow distribution (see Table II-4). The groups, or "strata," can be defined based upon flow, time, or any other variable which seems to influence the loading dynamics. Stratification can serve three basic functions:

a. Adjust for differences in the frequency distributions of sampled and unsampled flow regimes.

b. Reduce potential biases associated with some calculation methods and/or sampling program designs.

c. Reduce the error variance of the mean loading estimate.

When the data are adequate, stratification can offer significant advantages over the direct methods and provide insights that can be used to improve sampling efficiency in future years.

In most applications, the groups are defined based upon flow. The "flow-interval" method was developed by the US Army Engineer District, Buffalo (1975) for use in the Lake Erie Wastewater Management Study and is described by Verhoff, Yaksich, and Melfi (1980) and Westerdahl et al. (1981). This procedure applies the direct load averaging (Method 1) separately to different data groups, defined based upon flow regimes. Since loading usually increases with flow, grouping the data based upon flow reduces the loading variance within each group and results in lower variance for the total loading estimate. A flow-stratified version of Method 2 written in SAS (Statistical Analysis System) was developed and applied to estimate phosphorus loadings in a Vermont lake study (Walker 1983). The IJC method described by Bodo and Unny (1983, 1984) is a flow-stratified version of Method 3.

The program provides four options for defining groups of strata:

a. Flow range.

b. Date range.

c. Other (direct input).

d. None.

Generally, flow ranges would be used and the data would be stratified into two or three groups based upon flow. In some situations, however, it may be desirable to stratify based upon sampling date or some other characteristic, such as event flows versus base flows or measured flows versus estimated flows (Bodo and Unny 1983). Dates are expressed in days from 1 January of the first year represented in the sampled and total flow data groups. Stratification based upon date may be useful in situations where there is a strong seasonal variation in concentration which is independent of flow or for streams with

Table II-4

Stratified Sample Algorithm

(Cochran 1977, Bodo and Unny 1983)

Definitions:

s	=	subscript indicating stratum
m	=	subscript indicating estimation method
N_s	=	number of daily flows in stratum s
N_t	=	total number of daily flows
n_s	=	number of sampled concentrations in stratum s
$n_{s,*}$	=	optimal number of samples in stratum s, given n_t
n_t	=	total number of sampled concentrations
$W_{m,s}$	=	mean flux in stratum s estimated by method m
$V_{m,s}$	=	variance of mean flux in stratum s estimated by method m
$S_{m,s}$	=	effective standard deviation within stratum s for method m
$W_{m,t}$	=	mean flux over all strata estimated by method m
$V_{m,t}$	=	variance of mean flux over all strata estimated by method m
$V_{m,t}*$	=	variance of mean flux over all strata estimated by method m for optimal allocation of n_t samples according to $n_{s,*}$
Sum(s)	=	sum of expression x over all strata (s)

Equations:

$$N_t = \text{Sum}\ (N_s)$$

$$n_t = \text{Sum}\ (n_s)$$

$$W_{m,t} = \text{Sum}\ (W_{m,s} N_s)/N_t$$

$$V_{m,t} = \text{Sum}\ (V_{m,s} N_s^2)/N_t^2$$

$$S_{m,s} = [n_s V_{m,s}]^{0.5}$$

$$n_{s,*} = n_t N_s S_{m,s}/\text{Sum}\ (N_s S_{m,s})$$

$$V_{m,t*} = \text{Sum}\ (V_{m,s} N_s^2 n_s / n_{s,*})/N_t^2$$

---

highly regulated flows, such as a reservoir discharge station (particularly when intake levels are varied seasonally). Flow-independent, seasonal variance components are more likely to be detected in analysis of dissolved or inorganic nutrient concentrations (particularly nitrate) than in analysis of particulate or total nutrient concentrations. Option c is included for special circumstances, but is more difficult to implement than the other methods because a stratum value must be entered for each flow and concentration sample in the input data file.

In defining strata, one objective is to isolate homogeneous subgroups, based upon the flow/concentration relationship assumed by the calculation method (constant loading for Method 1, constant concentration for Methods 2 and 3, and log-linear flow/concentration relationship for Methods 4 and 5). A second objective is to set stratum boundaries so that the sampled and total flow distributions are equivalent within each stratum. This protects against bias in the loading estimates and applies particularly to high-flow strata. As described above, the method used to estimate error variance does not detect bias. If the flow distributions are not equivalent within each stratum, then minimum variance is less reliable as a criterion for selecting the "best" calculation method and loading estimate. Statistical and graphical tests are provided to compare flow distributions within each stratum.

FLUX includes a search procedure to assist the user in identifying flow stratum boundaries and calculation methods yielding loading estimates with minimum variance. Scatter plots generated by the program can also be useful for defining stratum boundaries. Sensitivity of the loading estimates to alternative flow boundaries for the strata can be easily tested. A minimum of three concentration samples and daily flows are required in each stratum.

For each calculation method, FLUX generates a breakdown of the flow, load, and variance components within each stratum, as well as for the total strata, as demonstrated in Table II-5 for the DeGray Reservoir inflow (Caddo River). Figure II-3 illustrates the flow/concentration relationship at this station. Samples have been divided into two flow intervals based upon application of the search procedure described above. Complete output for this example is given at the end of this Part.

Typically, most of the load and error variance is in the high-flow stratum. Since the variance component is roughly inversely related to sampling frequency within each stratum, the "BREAKDOWN BY STRATUM" listed in Table II-5

Table II-5

Sample FLUX Output - Load Estimates and Breakdown by Stratum

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STRAT	BOUND	NQ	NC	NQ%	NC%	QMEAN-T	QMEAN-S	C/Q SLOPE
1	500.0	320	44	87.7	83.0	182.8	167.5	-0.131
2	5647.2	45	9	12.3	17.0	1109.0	1351.3	0.390
ALL		365	53	100.0	100.0	297.0	368.6	0.263

LOADING TABLE-UNSTRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	53	365	297.03	21067.5	0.9427E+08	70.93	0.461
2 Q WTD C	53	365	297.03	16978.7	0.1853E+08	57.16	0.254
3 IJC	53	365	297.03	17795.9	0.2142E+08	59.91	0.260
4 REGRES-1	53	365	297.03	16042.8	0.9846E+07	54.01	0.196
5 REGRES-2	53	365	297.03	13594.6	0.1606E+07	45.77	0.093

LOADING TABLE - STRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	53	365	297.03	16421.6	0.3169E+08	55.29	0.343
2 Q WTD C	53	365	297.03	14452.4	0.3200E+07	48.66	0.124
3 IJC	53	365	297.03	14904.8	0.3178E+07	50.18	0.120
4 REGRES-1	53	365	297.03	13627.1	0.4846E+06	45.88	0.051
5 REGRES-2	53	365	297.03	12765.0	0.1365E+07	42.98	0.092

BREAKDOWN BY STRATUM FOR METHOD = 4 REGRES-1

STRAT	BOUND	NQ	NC	NC%	OPT%	FLOW-C	FLUX-C	VARIANCE-C	CONC	CV
1	500.0	320	44	83.02	45.21	160.3	3887.7	0.5924E+05	24.3	0.063
2	5647.2	45	9	16.98	54.79	136.7	9739.5	0.4254E+06	71.2	0.067
TOTAL		365	53	100.00	100.00	297.0	13627.1	0.4846E+06	45.9	0.051
OPTIMAL(OPT%)			53					0.2400E+06		0.036

NOTE: DeGray Reservoir inflow total P, 1980. Stratified into two groups at flow = 500 hm^3/year.
STRAT = flow stratum.
C/Q SLOPE = slope of log(c) versus log(q) regression in stratum.
QMEAN-S = mean sampled flow in stratum (hm^3/yr).
QMEAN-T = mean total flow in stratum (hm^3/yr).
NC = number of concentration samples.
NC% = number of concentration samples as percent of total.
NQ = number of daily flows.
NQ% = number of daily flows as percent of total.
OPT% = sample allocation yielding minimum variance in flux estimate.
OPTIMAL(OPT%) = estimated variance and CV of mean load if concentration samples (53) were distributed optimally (according to OPT%).
FLOW-C = contribution of stratum to total flow (hm^3/yr).
FLUX-C = contribution of stratum to total load (kg/yr).
VARIANCE-C = contribution of stratum to total flux variance $(kg/yr)^2$.
CONC = estimated flow-weighted mean concentration in stratum (mg/m^3).
CV = coefficient of variation of mean concentration and mean load estimate.

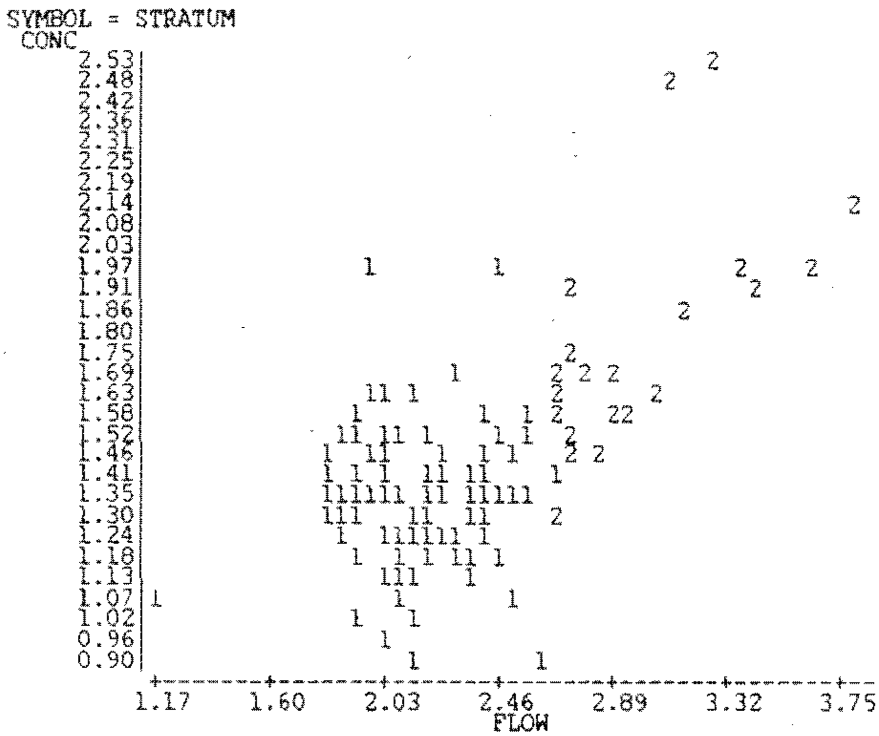


Figure II-3. Flow/concentration relationship for DeGray inflow total P, 1980. Flow units are $\log_{10}$ (flow, hm^3/yr) and concentration units are $\log_{10}$ (total P, mg/m^3)

is useful for evaluating sampling strategies. The low-flow stratum accounts for 83 percent of the total concentration samples but only 29 percent of the total estimated loading and 12 percent of the variance in the total loading estimate. In future sampling, moving some of the samples from the low-flow to the high-flow stratum would reduce the variance of the total loading estimate. Alternatively, to reduce monitoring costs, the low-flow sampling frequencies could be reduced without substantially increasing the variance of the total loading estimate. The program also provides an estimate of the "optimal" sample distribution (expressed as percent of the total sampling effort allocated to each stratum, "OPT%" in Table II-5) which would minimize the variance of the total loading estimate for a given total number of independent samples, using the equations specified in Table II-4. Comparing the observed variance with the optimal variance provides an approximate indication of the potential benefits of optimizing the sample design.

As described by Bodo and Unny (1983, 1984), stratum breakdowns can be used to refine monitoring program designs for future years, subject to practical limitations in sample scheduling and total budget and to requirements imposed by other monitoring objectives. The "optimal" distribution of sampling effort indicated by the program may be difficult to achieve without automated equipment. An important statistical limitation is that the "optimal" allocation assumes that the samples are serially independent and it may be impossible to take the recommended number of independent samples from intensively monitored strata. Five samples taken from different storm events would tend to be less serially dependent than five samples taken within one event, for example. Because of these limitations, the "optimal" design should not be viewed as an absolute objective, but as a general direction for adjusting previous survey designs within practical constraints.

DIAGNOSTICS

FLUX includes several routines for generating scatter plots and histograms of flow, concentration, loading, and sample dates, as illustrated in the documented session. The relationship between flow and concentration partially determines the appropriate calculation method and should be reviewed in each application. Flow frequency distributions (sampled versus total) can also be graphically compared. These displays characterize the flow and concentration distributions and can assist the user in assessing data adequacy, identifying appropriate stratification schemes, and evaluating calculation methods.

The calculation methods differ with respect to the schemes used to estimate the loadings on the unsampled days or periods. For a given method, observed and predicted fluxes can be compared for each water quality sample. This provides one measure of performance. Ideally, the flux residuals (observed minus predicted) should be random and independent of flow and season. In practice, this independence is sometimes difficult to achieve with the relatively simplistic models upon which the calculation methods are based. The residuals analysis procedure generates plots of observed versus predicted loadings, residuals versus flow, and residuals versus date. Alternative stratification schemes can be investigated to reduce the flow-dependence and/or time-dependence of the residuals. Listings of residuals and jackknife loading estimates (derived from excluding each sample individually) are useful for identifying outliers and determining sensitivity of total loading estimates to individual samples.

FLUX is designed to be used interactively from a CRT or hard-copy terminal. Input data files can be generated according to the format specified at the end of this Part. The user directs the flow of the program in response to prompts and linked menus, as outlined in Figure II-2. Also provided at the end of this Part is a sample session along with comments to assist in output interpretation. The program starts by reading in the concentration and flow data, using the data file, water quality component, and date ranges specified by the user. Strata specified in the input file can be redefined at any time, based upon flow or date ranges. The analysis is subsequently directed from the main program menu, which includes nine optional procedures and three submenus. After executing a given procedure, the program returns to the main menu or a submenu for another selection.

Because each loading estimation problem is unique, it is impossible to specify a "universal" pathway for the analysis. In some cases, a few iterations (mainly involving alternative strata definitions) would be required before arriving at an acceptable loading estimate. Generally, however, program applications would involve the following steps, as outlined in Table II-6:

Step	Analytical Activity
1	Data entry
2	Data verification
3	Diagnostic plots
4	Data stratification
5	Diagnostic plots - stratification
6	Load calculation
7	Residuals analysis
8	Sensitivity analysis

In Step 1, the flow and concentration data for a specific station, component, and date range are read from the input data file. In Step 2, the data are listed and checked for coding errors. A series of diagnostic plots are generated in Step 3 in order to describe data distributions, flow/concentration/load relationships, and trends or seasonal variations in the data. The

Table II-6

FLUX Application Procedures

Step	User Action	Program Action
1	---------- DATA ENTRY ----------	
A	Run Program	
B	Specify Input Data File Name	
C		Read and Print Title, Component Index
D	Specify Flow Index	
E	Specify Concentration Index	
F	Specify Minimum and Maximum Sample Dates (year-month-day, e.g., 840902)	
G		Read Sample Data and Print Number of Entries
H	Specify Minimum and Maximum Flow Dates	
I		Read Flow Data and Print Number of Entries
J		Check for >2 Samples? (YES - >K, NO - >B)
K		Set Strata to Input Values
L		Compare Sampled and Total Flow Distributions by Stratum
M		Ask Whether Strata Are to Be Redefined?
N	Respond NO "0" (Use Input Strata Initially)	
O		Print Main Program Menu
2	---------- DATA VERIFICATION ----------	
A	Request Listing of Sample Data (PROC 2)	
B		List Sample Data
C	Review Sample Data; Coding Error Found? (YES - >D, NO - >E)	
D	End Program Execution (PROC 99); Edit Data File; Repeat DATA ENTRY	
E	Request Listing of Flow Data (PROC 3)	
F		List Flow Data
G	Review Flow Data; Coding Error Found? (YES - >H, NO - >I)	
H	End Program Execution (PROC 99); Edit Data File; Repeat DATA ENTRY	
I		Print Main Program Menu

(Continued)

(Sheet 1 of 4)

Table II-6 (Continued)

Step	User Action	Program Action
3	---------- DIAGNOSTIC PLOTS ----------	
A	Request Plot Menu (PROC 4)	
B		Print Plot Menu
C	Request Diagnostic Plots (PROC 2-10)	
D		Print Requested Plots: Concentration vs. Flow (PROC 2) Load vs. Flow (PROC 3) etc. Cumulative Flow Frequencies (PROC 9) Compare Flow Dist. by Stratum (PROC 10)
E	Review Diagnostic Plots	
F		Print Plot Menu
G	Request Main Menu (PROC 99)	
H		Print Main Program Menu
4	---------- DATA STRATIFICATION ----------	
A		Print Main Program Menu
B	Request Define Strata (PROC 5)	
C		Print Stratum Options Menu
D	Request Flow Sensitivity Analysis (PROC 1)	
E		Print Default Flow Increment (= MaxFlow/50)
F	Specify Flow Increment (Normally, Round off Default Value)	
G		Conduct Sensitivity Analysis: Test Alternative Flow Boundary Values for Dividing Data into Two Groups Test Boundaries from 0. to MaxFlow by Increment Specified in STEP F If >3 Samples/Stratum: Calculate and Print Means and Variance of Loading Estimates for Each Method

(Continued)

(Sheet 2 of 4)

Table II-6 (Continued)

Step	User Action	Program Action
4	---------- DATA STRATIFICATION (Continued) ----------	
H		Print Diagnostic Plots (Symbol=Method): Mean Load vs. Stratum Boundary; Variance vs. Stratum Boundary; Variance vs. Mean
I		Print Stratum Boundary Yielding Minimum Variance for Each Calculation Method
J	Review Sensitivity Analysis Results and Diagnostic Plots Note Optimal Method Number and Boundary	
K		Print Stratum Options Menu
L	Request PROC 2: Flow - Enter Bounds Directly	
M		Request Flow Boundary Value(s)
N	Set Flow Boundary to Optimal Value Noted in Step L	
O		Print Data Inventory and Flow Statistics
P	Review Flow Statistics	
Q		Print Main Program Menu
5	---------- DIAGNOSTIC PLOTS - STRATIFICATION ----------	
A	Request Plot Menu (PROC 4)	
B		Print Plot Menu
C	Request Diagnostic Plots (PROCS 2, 10, etc.)	
D		Print Requested Plots: Flow vs. Concentration (PROC 2); Compare Flow Distributions (PROC 10); Other
E	Review Diagnostic Plots	
F		Print Plot Menu
G	Request Main Menu (PROC 99)	
H		Print Main Program Menu
6	---------- LOAD CALCULATION ----------	
A		Print Main Menu
B	Request Calculate Loadings (PROC 6)	
C		Print Data Inventories and Flow Statistics

(Continued)

(Sheet 3 of 4)

Table II-6 (Concluded)

Step	User Action	Program Action
6	---------------------- LOAD CALCULATION	(Continued) ------------------------
D		Print Unstratified Load Estimates for Each Calculation Method
		If Number of Strata >1:
E		Print Stratified Load Estimates for Each Calculation Method
F		* Print Load Estimates and Optimal Sample Allocations by Stratum for Each Method
G	Review Results	
H		Print Main Program Menu
7	------------------------- RESIDUALS ANALYSIS	-----------------------------
A	Request Residuals Analysis (PROC 7)	
B	Specify Calculation Method (1-5)	
C	Specify Stratified (1) or Unstratified (0) Estimates	
D		Calculate Observed, Predicted, and Residual Fluxes for Each Sample
E		Plot Observed vs. Predicted Fluxes
F		Print Regression of Observed vs. Predicted Fluxes
G		Plot Residuals vs. Flow
H		Plot Residuals vs. Date
I		* List Residuals
J		* Calculate and Print Jackknifed Loads
K		* Print Histogram of Jackknifed Estimates
L	Review Residuals Analysis Results	
M		Print Main Program Menu

* Optional STEP (user-prompted).

(Sheet 4 of 4)

stratification scheme is defined in Step 4, typically based upon flows and using the boundary search procedure. Additional diagnostic plots are generated in Step 5, mainly to compare sampled and total flow distributions within each stratum and to examine flow/concentration/season relationships in light of the stratification scheme. Loading calculations are performed in Step 6, and residuals are analyzed in Step 7. Step 8 involves testing the effects of alternative stratification schemes on the calculated loadings.

The selection of the "best" loading estimate to be used in subsequent modeling efforts is up to the user, based upon the following criteria:

a. Calculation method and stratification scheme yielding minimum estimated variance in the mean loading estimate.

b. Sensitivity of the loading estimate to alternative calculation methods, stratification schemes, and individual samples.

c. Residuals analysis results.

The selection can be based primarily upon minimum estimated variance (first criterion above), provided that the following conditions are met:

a. Sampling is representative (date and flow ranges reasonably well covered).

b. Sampled and total flow means are equal within each stratum (tests for equality included in the stratification procedure).

c. Residuals are reasonably independent of date and flow.

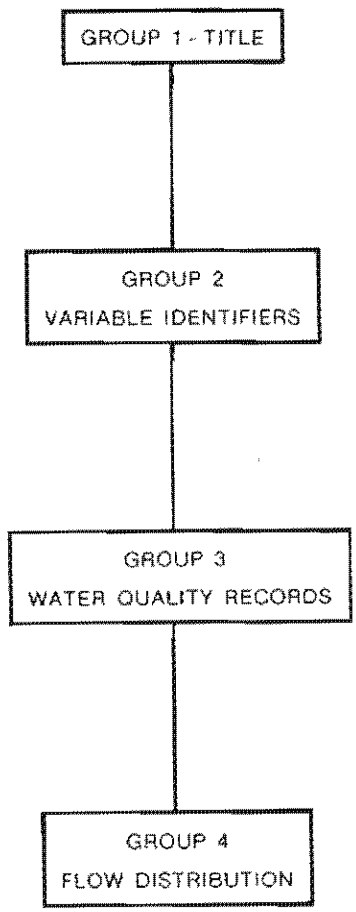
d. Samples are serially independent (event data are summarized prior to entry, rather than entered as individual data points).

If the above conditions are marginal or cannot be met because of existing data limitations, factors other than minimum variance (sensitivity and residuals analyses) should be given greater weight. Further sampling may be indicated, particularly if the tributary accounts for a major portion of the total reservoir loading.

Differences among the various calculation methods should be interpreted in relation to the estimated variances. For example, a range of 45 to 50 kg/yr in the mean loading estimate is of little significance if the estimated coefficients of variation are on the order of 0.1 or greater. Provided that flow regimes are adequately sampled, limited variation among calculation methods suggests robust results. Calculation methods 2 or 3 are generally the most robust and should be used (typically with flow stratification into two groups with the boundary set near the mean flow) if load estimates must be generated from limited data not conforming rigidly to the above criteria.

In a reservoir eutrophication study, FLUX can be used to estimate annual (October-September) and seasonal (May-September) loadings of total phosphorus, ortho-phosphorus, total nitrogen, and inorganic nitrogen for each sampled tributary and outflow. For annual calculations, water-year loadings are generally more appropriate than calendar-year loadings for use in predicting growing-season water quality in the reservoir pool. Unless flow/concentration/seasonal dynamics differ markedly among the nutrient components, it is a good idea to use the same stratification scheme for each component. The stratification scheme can be optimized for calculating total phosphorus loading (usually the most important) and subsequently used in calculating other component loadings.

ORGANIZATION OF FLUX INPUT FILES



FLUX DATA GROUP 1 - TITLE

FORMAT (6A8)

MAXIMUM 48 CHARACTERS

FLUX DATA GROUP 2 - VARIABLE IDENTIFIERS

FORMAT (I2,1X,A8,F8.0)

INCLUDE ONE RECORD FOR EACH MEASUREMENT IN SAMPLE FILE (DATA GROUP 3).

ID = SUBSCRIPT (MAXIMUM = 7)
LABEL = 8-CHARACTER VARIABLE IDENTIFIER (e.g., TOTAL P, FLOW)
C.F. = CONVERSION FACTOR TO CONVERT INPUT FLOW UNITS TO MILLION M^3/YR AND INPUT CONCENTRATION UNITS TO MG/M^3 (INCLUDE DECIMAL POINT)

ORDER OF VARIABLES CORRESPONDS TO THAT OF DATA GROUP 3.

PROJECT: ____________________

STATION: ____________________

FLUX DATA GROUP 1 — TITLE

FLUX DATA GROUP 2 — VARIABLE IDENTIFIERS

ID		LABEL	CF
01			
02			
03			
04			
05			
06			
07			
000			

FLUX DATA GROUP 3 - WATER QUALITY RECORDS

FORMAT (F6.0,I2,7F8.0)

INCLUDE ONE RECORD FOR EACH SAMPLE, MAXIMUM NUMBER OF SAMPLES = 500.

DATE = DATE IN YEAR-MONTH-DAY FORMAT (e.g., 840126)
S = INPUT STRATUM (MAXIMUM = 5, OPTIONAL, IF S < 0, RECORD IS SKIPPED)
C# = COMPONENT VALUE (INCLUDE DECIMAL POINTS OR RIGHT-JUSTIFY IN FIELD)

ENTRIES THAT ARE BLANK, ZERO, OR NEGATIVE ARE ASSUMED TO BE MISSING.

LAST RECORD IN DATA GROUP 3 - "000000"

PROJECT: ____________________

STATION: ____________________

FLUX DATA GROUP 3 — WATER QUALITY RECORDS

DATE	S	C1	C2	C3	C4	C5	C6	C7

PAGE OF PAGES

FLUX DATA GROUP 4 - FLOW DISTRIBUTION

FORMAT (F6.0,I2,F8.0)

```
DATE = DATE IN YEAR-MONTH-DAY FORMAT, MAXIMUM 2,000 RECORDS
   S = INPUT STRATUM (MAXIMUM = 5, OPTIONAL, IF S < 0, RECORD IS
       SKIPPED)
FLOW = FLOW, SAME UNITS AS WATER QUALITY SAMPLE RECORDS (DATA GROUP 3)
       INCLUDE DECIMAL POINT OR RIGHT-JUSTIFY IN FIELD
       ZERO ENTRIES ARE VALID, NEGATIVE VALUES ASSUMED TO BE MISSING
```

LAST RECORD IN DATA GROUP 4 - "000000"

FLUX DATA GROUP 4 — FLOW DISTRIBUTION

PROJECT: ____________________

STATION: ____________________

D	A	T	E			S		F	L	O	W				

PAGE OF PAGES

FLUX - EXAMPLE INPUT FILE

```
DECRAY INFLOW 1978-1980                          DATA GROUP 1: TITLE
ID-LABEL----CF------
01 FLOW      31.54
02 TOTAL P   1.                                  DATA GROUP 2: VARIABLE IDENTIFIERS
03 TOTAL DP  1.
04 ORTHO P   1.
00
DATE--S-C1------C2------C3------C4------
780102 0    0.47   12.00    4.00    4.00
780109 0    4.39   11.00   10.00    4.00
780117 0   47.00   71.00    0.00    4.00
  "    "     "       "       "       "           DATA GROUP 3: WATER QUALITY RECORDS
801216 0    9.07   31.00   28.00   22.00
801223 0    5.22   17.00   12.00   12.00
801230 0    4.32   34.00   29.00    8.00
000000
DATE--S-FLOW----
780101 0    5.09
780102 0    4.66
780103 0    4.66
  "    "     "                                   DATA GROUP 4: FLOW DISTRIBUTION
801229 0    4.35
801230 0    4.25
801231 0    4.13
000000
(END OF FILE)
```

FLUX - DOCUMENTED SESSION

```
F L U X  - VERSION 2.0
DEGRAY INFLOW 1980          < DESCRIPTIVE TITLE AT TOP OF INPUT FILE
1 FLOW          31.5400     < INPUT FLOW UNITS ARE IN M3/SEC, CONVERTED
2 TOTAL P        1.0000     < TO HM3/YR BY FACTOR OF 31.54
3 TOTAL DP       1.0000
4 ORTHO P        1.0000     < ALL INPUT CONCENTRATIONS UNITS ARE MG/M3

FLOW SUBSCRIPT <N.> ?  1
CONC SUBSCRIPT <N.> ?  2
MINIMUM DATE FOR CONCS <YYMMDD.> ?  800101 < DATE RANGE FOR CONCENTRATIONS
MAXIMUM DATE FOR CONCS <YYMMDD.> ?  801231
NUMBER OF CONC SAMPLES =    53             < PROGRAM READS SAMPLE RECORDS

MINIMUM DATE FOR FLOWS <YYMMDD.> ?  800101 <  DATE RANGE FOR FLOW RECORD
MAXIMUM DATE FOR FLOWS <YYMMDD.> ?  801231
NUMBER OF FLOW ENTRIES = 365               < PROGRAM READS FLOW RECORDS
   MEAN =     297.88,   MAXIMUM =   5663.32 < FLOW STATISTICS

<H>  "<H>" PROMPT OCCURS FREQUENTLY DURING SESSION TO PREVENT OUTPUT
      <     FROM SCROLLING; USER PRESSES CARRIAGE RETURN TO CONTINUE

SAMPLE DISTRIBUTIONS                                 < SAMPLE INVENTORY
STRATUM         BOUND    CONC SAMPLES    FLOW SAMPLES < INITIALLY UNSTRATIFIED
   1            0.000              53             365
TOTALS                             53             365

< STATISTICAL COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTION

NOTE:    5.21% OF TOTAL FLOW VOLUME EXCEEDS  MAXIMUM SAMPLED FLOW

COMPARISON OF FLOW DISTRIBUTIONS
      ------ SAMPLED -----    ------- TOTAL ------
STRAT   N     MEAN  STD DEV    N     MEAN  STD DEV    DIFF      T   PROB(>T)
 1      53   369.6    737.3  365    297.9    466.5    71.7   0.689    0.501
ALL     53   369.6    737.3  365    297.9    466.5    71.7   0.689    0.501

REDEFINE STRATA <0.=NO,1.=YES>?   0
<H>

F L U X  PROCEDURES:            < MAIN PROGRAM MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END
```

FLUX - DOCUMENTED SESSION

```
ENTER CODE <NN.>?   2      < LIST AND CHECK SAMPLE RECORD

DEGRAY INFLOW 1980                              TOTAL P

 SAMPLE  JULIAN STRATUM      FLOW    TOTAL P
     1       2       1     217.31     16.00
     2       8       1     165.90     17.00
< ETC. LIST ENTIRE SAMPLE RECORD
    52     357       1     164.64     17.00
    53     364       1     136.25     34.00
<H>
F L U X  PROCEDURES:           < MAIN MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END

ENTER CODE <NN.>?   3           < LIST AND CHECK ENTIRE FLOW RECORD

FLOW DISTRIBUTION:
 SAMPLE  JULIAN STRATUM      FLOW
     1       1       1     236.55
     2       2       1     212.90

< ETC. FOR ENTIRE FLOW RECORD OF 365 DAYS

< IF CODING ERRORS ARE FOUND IN SAMPLE OR FLOW RECORDS:
<             END PROGRAM EXECUTION
<             CORRECT INPUT FILE
<             REPEAT ABOVE PROCEDURE
<H>
F L U X  PROCEDURES:

 1. = READ NEW DATA
< ETC. MAIN MENU
99. = END

ENTER CODE <NN.>?   4           < GENERATE DIAGNOSTIC PLOTS
```

FLUX – DOCUMENTED SESSION

```
F L U X  PLOTTING PROCEDURES:  < PLOT SUBMENU

 1. = SET PLOT WIDTH AND HEIGHT
 2. = PLOT CONCENTRATION VS. FLOW
 3. = PLOT SAMPLED LOAD  VS. FLOW
 4. = PLOT CONCENTRATION VS. DATE
 5. = PLOT SAMPLED LOAD  VS. DATE
 6. = PLOT SAMPLED FLOWS VS. DATE
 7. = PLOT ALL FLOWS     VS. DATE
 8. = HISTOGRAM OF CONCENTRATIONS
 9. = PLOT CUMULATIVE FLOW FREQUENCIES
10. = COMPARE FLOW DISTRIBUTIONS BY STRATUM
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   2            < CONC. VS. FLOW

Y VARIABLE =  CONC
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1      < REQUEST LOG SCALES

X VARIABLE =  FLOW
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1      < REQUEST LOG SCALES
COMPUTE REGRESSION <0.=NO, 1.=YES> ?  1    < CALCULATE REGRESSION

BIVARIATE REGRESSION:  Y VS. X        < REGRESSION STATISTICS
 INTERCEPT          =      0.8236  SLOPE              =       0.2628
 R-SQUARED          =      0.2257  MEAN SQUARED ERROR =       0.0391
 STD ERROR OF SLOPE =      0.0683  T STATISTIC        =       3.8561
 DEGREES OF FREEDOM =          51  PROBABILITY(>|T|)  =       0.0006
 Y MEAN             =      1.4282  Y STD DEVIATION    =       0.2225
 X MEAN             =      2.3008  X STD DEVIATION    =       0.0000
<H>

SYMBOL = STRATUM, + = REGRESSION
 CONC
     2.00|                                        1        1
     1.92|    1                   1
     1.84|
     1.76|                                           +    +
     1.68|                          1           +
     1.61|   1  1         1      1   +1   1
     1.53| 1      1       1   1+ 11
     1.45|1    1    + 1  1+
     1.37|1   1+    1 1  111  1          < "+" INDICATES REGRESSION LINE
     1.29|11      1 1  1
     1.22|          1 11  1
     1.14|      1 1      1
     1.06|       1
     0.98|
     0.90|         1
          +-------+-------+-------+-------+-------+-------+--
         1.82    2.12    2.43    2.74    3.04    3.35    3.65
                                  FLOW
```

FLUX - DOCUMENTED SESSION

```
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC. PLOTTING MENU
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   3           < PLOT LOAD VS. FLOW


Y VARIABLE =  LOAD
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1

X VARIABLE =  FLOW
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1
COMPUTE REGRESSION <0.=NO, 1.=YES> ?  1

BIVARIATE REGRESSION:  Y VS. X
 INTERCEPT          =      0.8235  SLOPE               =       1.2628
 R-SQUARED          =      0.8707  MEAN SQUARED ERROR  =       0.0391
 STD ERROR OF SLOPE =      0.0681  T STATISTIC         =      18.5300
 DEGREES OF FREEDOM =          51  PROBABILITY(>|T|)   =       0.0000
 Y MEAN             =      3.7290  Y STD DEVIATION     =       0.5444
 X MEAN             =      2.3008  X STD DEVIATION     =       0.0000
<H>

SYMBOL = STRATUM, + = REGRESSION
 LOAD
     5.68|                                                  1
     5.49|                                                 +
     5.31|                                         1  +
     5.12|
     4.94|                                       +
     4.75|                         1       1
     4.57|                           1 1
     4.38|                        1   +
     4.19|                      + 11
     4.01|     1           1   1
     3.82|             1  111
     3.64|       1 1 1 11  1
     3.45| 1 1 +  1 1 11 1
     3.27|1    1 111
     3.08|11        1
          +-------+-------+-------+-------+-------+-------+-------+--
         1.82    2.12    2.43    2.74    3.04    3.35    3.65
                                  FLOW
<H>
```

```
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   4          < CONCENTRATION VS. DATE

Y VARIABLE =  CONC
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1
COMPUTE REGRESSION <0.=NO, 1.=YES> ?  1

BIVARIATE REGRESSION:  Y VS. X
 INTERCEPT          =     1.3634  SLOPE               =      0.0004
 R-SQUARED          =     0.0297  MEAN SQUARED ERROR  =      0.0490
 STD ERROR OF SLOPE =     0.0003  T STATISTIC         =      1.2501
 DEGREES OF FREEDOM =         51  PROBABILITY(>|T|)   =      0.2146
 Y MEAN             =     1.4282  Y STD DEVIATION     =      0.2225
 X MEAN             =   182.1887  X STD DEVIATION     =      0.0000
<H>

SYMBOL = STRATUM, + = REGRESSION
 CONC
     2.00|  1                                           1
     1.92|                 1          1
     1.84|
     1.76|
     1.68|          1
     1.61|             1         11           1   1  1
     1.53|     1     1      1  1   11                    11+
     1.45|            1       1+1    1  111 1   +    +
     1.37|+    +    +   111  1             1   111    1
     1.29|            1                1     1     1   1
     1.22|1  11  1                                        1
     1.14| 1    1                                   1
     1.06|         1
     0.98|
     0.90|        1
          +--------+--------+--------+--------+--------+--------+--
         2.00   61.10  120.20  179.31  238.41  297.51  356.61
                                  DATE
<H>
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU
```

```
ENTER CODE <NN.>?   7           < PLOT ALL FLOWS VS. DATE

Y VARIABLE =  FLOW
LOG10 TRANSFORM <0.=NO, 1.=YES> ?   1
ALL FLOWS VS. DATE, SYMBOL = STRATUM
 FLOW
     3.75|                                                     1
     3.62|                                                    1
     3.48|
     3.34|  1                 1
     3.21|             1 1                            1 1        1
     3.07|  1  1       11   1                            1
     2.94|  1       11   1  11                        1          1
     2.80|   1 1   111  111 1                                    1
     2.66|   1 11   111 111111                        1  1   1   1
     2.53|   1  1   11111111111                       1  1  11   1
     2.39|1  11 11 1  1 1111 11                        1 11  1  11
     2.26|111 1  1 1   1   1  1 1                      1 11   11 11
     2.12| 1      111            111   11              1 1111  1  11
     1.98|                        111   1   11  1 1
     1.85|                           11111111111
         +--------+--------+--------+--------+--------+--------+--
        1.00    60.43  119.86  179.29  238.71  298.14  357.57
                                  DATE
<H>

< DATE IN DAYS FROM JANUARY 1 IN YEAR OF FIRST SAMPLE OR FLOW RECORD
< DATE COMPUTATIONS DO NOT REFLECT LEAP YEARS
<       I.E., DATE (FEB 29) = DATE (MAR 1),
<       THIS DOES NOT AFFECT LOAD CALCULATIONS

F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU
```

```
ENTER CODE <NN.>?   8           < HISTOGRAM OF CONCENTRATIONS

SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1
CONCS : SYMBOL = STRATUM
INTERVAL MINIMUM - GEOMETRIC SCALE
        99.00 1
        81.58 111
        67.23
        55.40
        45.65 1
        37.62 11111
        31.00 11111111
        25.55 1111111111
        21.05 111111111
        17.35 11111
        14.30 111111
        11.78 1111
         9.71
         8.00
         0.00 1
<H>
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   9           < PLOT CUMULATIVE FLOW FREQUENCIES

LOG10 TRANSFORM FLOWS <0.=NO,1.=YES> ?  1

FLOW CUMULATIVE FREQ. O=SAMPLED X=ALL
 CUM FREQ
     1.00|                              XXXXXXX O      XO X
     0.93|                      XXOXXOXXO
     0.86|                   XXOO
     0.78|               OXXXO
     0.71|             XOXX
     0.64|           XOOO
     0.57|          OX
     0.50|        XXX           < Y AXIS GIVES FRACTION OF SAMPLED (O)
     0.43|       XOO            < OR TOTAL (X) FLOW RECORD BELOW FLOW
     0.36|      XX              < SPECIFIED ON X AXIS
     0.29|   XXXX
     0.22| XXXX
     0.14|OX
     0.07|XX
     0.00|X
         +-------+-------+-------+-------+-------+-------+--
        1.82    2.13    2.45    2.77    3.08    3.40    3.71
                                 FLOW
<H>
```

```
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   10           < COMPARE FLOW DISTRIBUTIONS

SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1
0 = SAMPLED FLOWS, X = ALL FLOWS
ALL STRATA
INTERVAL MINIMUM - GEOMETRIC SCALE
      5663.32                          X
      4020.66 0                        X    < DEPICTS COVERAGE OF
      2854.45                               < FLOW REGIMES
      2026.51 0                        X
      1438.72                          XXXXXX
      1021.41 0                        XXXXXX
       725.15 0                        XXXXXXXXXXX
       514.82 000                      XXXXXXXXXXXXXXXX
       365.49 0000                     XXXXXXXXXXXXXXXXXXXXXXXX>
       259.48 00000000                 XXXXXXXXXXXXXXXXXXXXXXXX>
       184.22 000000                   XXXXXXXXXXXXXXXXXXXXXXXX>
       130.78 0000000000               XXXXXXXXXXXXXXXXXXXXXXXX>
        92.85 000000                   XXXXXXXXXXXXXXXXXXXXXXXX>
        65.92 000000000000             XXXXXXXXXXXXXXXXXXXXXXXX>
         0.00
                                       < ">" MEANS ROW IS TRUNCATED
<H>

F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   99           < RETURN TO MAIN MENU
<H>
F L U X  PROCEDURES:             < MAIN MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END
```

FLUX - DOCUMENTED SESSION

```
ENTER CODE <NN.>?   5           < DEFINE STRATA

DEGRAY INFLOW 1980                              TOTAL P

CURRENT STRATA BOUNDS:      0.00

OPTIONS FOR DEFINING STRATA:
 1. = USE FLOWS - SEARCH FOR BOUNDS
 2. = USE FLOWS - ENTER BOUNDS DIRECTLY
 3. = USE DATES - ENTER BOUNDS DIRECTLY
 4. = DO NOT STRATIFY
99. = RETURN TO MAIN MENU

ENTER CODE <N.>?  1           < SEARCH FOR OPTIMUM FLOW BOUND

SAMPLES ARE DIVIDED INTO TWO STRATA BASED UPON FLOW.
SEARCH FOR OPTIMUM STRATUM BOUNDARY FOLLOWS.
OBJECTIVE IS TO FIND BOUNDARY AND CALCULATION METHOD
      YIELDING MINIMUM VARIANCE IN LOAD ESTIMATE.

MAXIMUM FLOW FOR ALL DATES =     5663.32
DEFINE FLOW INCREMENT                   < INCREMENT USED IN SEARCH
INCREMNT  OLD VALUE =      113.266  < DEFAULT = MAX FLOW/50
NEW VALUE ?   100                   < ROUND OF TO CONVENIENT VALUE

< FOR EACH FLOW BOUND, SAMPLES ARE STRATIFIED INTO TWO GROUPS

< LOADINGS AND VARIANCES ARE COMPUTED FOR EACH BOUNDARY AND METHOD

< INCREASES FLOW INCREMENT UNTIL NUMBER OF SAMPLES IN UPPER FLOW
<       STRATUM DROPS BELOW 3

< SEARCH OUTPUT:

                 < CALCULATION METHODS

METHOD:       1=AV LOAD  2=Q WTD C  3=IJC       4=REGRES-1 5=REGRES-2

BOUND =       100.00       < FIRST FLOW BOUNDARY
FLUX MEANS:  0.2150E+05 0.1695E+05 0.1777E+05 0.1513E+05 0.1227E+05
 VARIANCES:  0.9555E+08 0.1729E+08 0.1985E+08 0.4252E+07 0.9347E+07

BOUND =       200.00
FLUX MEANS:  0.2083E+05 0.1642E+05 0.1716E+05 0.1435E+05 0.1210E+05
 VARIANCES:  0.8077E+08 0.1184E+08 0.1322E+08 0.1133E+07 0.1071E+08
```

```
BOUND =      300.00
FLUX MEANS:  0.2436E+05 0.1660E+05 0.1726E+05 0.1391E+05 0.1291E+05
 VARIANCES:  0.9780E+08 0.7570E+07 0.7915E+07 0.5734E+06 0.4881E+07

BOUND =      400.00
FLUX MEANS:  0.2066E+05 0.1564E+05 0.1620E+05 0.1386E+05 0.1295E+05
 VARIANCES:  0.6059E+08 0.5014E+07 0.5087E+07 0.5701E+06 0.3065E+07

BOUND =      500.00
FLUX MEANS:  0.1647E+05 0.1449E+05 0.1495E+05 0.1367E+05 0.1280E+05
 VARIANCES:  0.3187E+08 0.3218E+07 0.3196E+07 0.4874E+06 0.1372E+07

BOUND =      600.00
FLUX MEANS:  0.2138E+05 0.1540E+05 0.1586E+05 0.1332E+05 0.1308E+05
 VARIANCES:  0.4027E+08 0.2157E+07 0.1788E+07 0.7660E+06 0.1904E+07

BOUND =      700.00
FLUX MEANS:  0.2084E+05 0.1514E+05 0.1556E+05 0.1288E+05 0.1280E+05
 VARIANCES:  0.2742E+08 0.1389E+07 0.1060E+07 0.7065E+06 0.2127E+07

BOUND =      800.00
FLUX MEANS:  0.1818E+05 0.1459E+05 0.1497E+05 0.1296E+05 0.1278E+05
 VARIANCES:  0.1865E+08 0.1272E+07 0.1008E+07 0.8876E+06 0.2283E+07

BOUND =      900.00
FLUX MEANS:  0.2000E+05 0.1475E+05 0.1504E+05 0.1263E+05 0.1278E+05
 VARIANCES:  0.1190E+08 0.6964E+06 0.5508E+06 0.1471E+07 0.2062E+07

BOUND =     1000.00
FLUX MEANS:  0.1795E+05 0.1431E+05 0.1459E+05 0.1269E+05 0.1276E+05
 VARIANCES:  0.8887E+07 0.6963E+06 0.5763E+06 0.1197E+07 0.1985E+07

BOUND =     1100.00
FLUX MEANS:  0.1659E+05 0.1399E+05 0.1425E+05 0.1271E+05 0.1274E+05
 VARIANCES:  0.7170E+07 0.6991E+06 0.5969E+06 0.1092E+07 0.1981E+07
```

< *RUNS OUT OF SAMPLES IN HIGH FLOW STRATUM FOR BOUND > 1100*

< *GRAPHICAL OUTPUT FROM SEARCH PROCEDURE:*

< FIRST PLOT DEPICTS SENSITIVITY OF MEAN LOADING ESTIMATE TO
< STRATUM BOUNDARY AND CALCULATION METHOD

```
LOG10 MEAN FLUX ESTIMATES VS. FLOW BOUND SYMBOL=METHOD
 LOAD
     4.39|        1
     4.37|
     4.34|1
     4.32|   1        1        1   1
     4.30|                               1
     4.28|
     4.26|3                           1        1
     4.23|2  3     3
     4.21|   2     2  3     1                        1
     4.19|            2        2   3
     4.17|4               2        2  2  2  3
     4.15|   4     4  4                       2  2
     4.13|                4    5
     4.10|         5  5   5        5  5  4  4  4
     4.08|5  5
         +--------+--------+--------+--------+--------+--------+--
      100.00  263.27  426.53  589.80  753.06  916.33 1079.59
                                 BOUND
<H>
```

< NEXT PLOT DEPICTS SENSITIVITY OF VARIANCE IN MEAN LOADING ESTIMATE TO
< STRATUM BOUNDARY AND CALCULATION METHOD

< MINIMUM VARIANCES SHOWN FOR METHOD 4 AT BOUNDARIES OF 300-500
< AND METHOD 3 AT BOUNDARY OF 900

```
LOG10 VARIANCE OF FLUX ESTIMATE VS. FLOW BOUND, SYMBOL=METHOD
 VARIANCE
     7.99|1       1
     7.83|   1        1
     7.66|                     1
     7.50|                1        1
     7.33|3                           1
     7.17|2  3
     7.00|5  5                           1  1
     6.84|         2                           1
     6.67|4        5  2
     6.51|            5   3
     6.35|                     5   5  5  5  5  5
     6.18|                5    3   2  2  4
     6.02|   4                     3  4     4  4
     5.85|                     4   4     2  2  3
     5.69|         4  4   4              3  3
         +--------+--------+--------+--------+--------+--------+--
      100.00  263.27  426.53  589.80  753.06  916.33 1079.59
                                 BOUND
<H>
```

< *LAST PLOT SHOWS RELATIONSHIP BETWEEN VARIANCE AND MEAN*
< *FOR EACH METHOD AND BOUNDARY*

```
LOG10 VARIANCE OF MEAN FLUX VS. LOG10 MEAN FLUX, SYMBOL=METHOD
 VARIANCE
     7.99|                                        1        1
     7.83|                                     11
     7.66|                                       1
     7.50|                     1                1
     7.33|                          3 1
     7.17|                       23
     7.00|5                    2     1       1
     6.84|                      1 3
     6.67|    5          4 2  3
     6.51|    5       2 3
     6.35|   5 5          2
     6.18|   5         2 2  3
     6.02|   44      4  3  3     < MIN VARIANCE FOR METHODS 2-4
     5.85|    4 4   23 2         < IN RANGE OF 4.13 TO 4.18 LOG UNITS
     5.69|        44   3 3
          +-------+-------+-------+-------+-------+-------+-------+--
         4.08    4.13    4.18    4.23    4.28    4.33    4.38
                                  LOAD
```

<H>

< *FINAL OUTPUT FROM SEARCH PROCEDURE LISTS FLOW BOUNDARY*
< *YIELDING MINIMUM VARIANCE FOR EACH CALCULATION METHOD*

BOUND YIELDING MINIMUM VARIANCE FOR EACH CALC METHOD:

METHOD	FLOW BOUND	FLUX	VARIANCE
1 AV LOAD	1100.0	16589.0	0.7170E+07
2 Q WTD C	1000.0	14314.1	0.6963E+06
3 IJC	900.0	15043.9	0.5508E+06
4 REGRES-1	500.0	13666.2	0.4874E+06
5 REGRES-2	500.0	12801.6	0.1372E+07

< *BASED ON ABOVE RESULTS, WE CAN DEFINE FLOW STRATA*

< *A BOUNDARY OF 500 YIELDS MINIMUM VARIANCE FOR METHOD 4*

CURRENT STRATA BOUNDS: 0.00

OPTIONS FOR DEFINING STRATA: < *STATUM DEFINITION MENU*

```
 1. = USE FLOWS - SEARCH FOR BOUNDS
 2. = USE FLOWS - ENTER BOUNDS DIRECTLY
 3. = USE DATES - ENTER BOUNDS DIRECTLY
 4. = DO NOT STRATIFY
99. = RETURN TO MAIN MENU
```

FLUX - DOCUMENTED SESSION

```
ENTER CODE <N.>?  2           < ENTER FLOW BOUNDS

MAX FLOW FOR ALL DATES =  5663.322
ENTER MAX FLOW IN EACH INTERVAL, ONE AT A TIME, RETURN TO STOP

MAX FLOW?   500           < FLOW BOUNDARY OF 500
MAX FLOW?                 < PRESS RETURN TO END FLOW ENTRIES

SAMPLE DISTRIBUTIONS
STRATUM         BOUND    CONC SAMPLES   FLOW SAMPLES
   3         100.000              53            365
TOTALS                            53            365

< STATISTICAL COMPARISON OF SAMPLED AND TOTAL FLOWS

NOTE:     5.21% OF TOTAL FLOW VOLUME EXCEEDS  MAXIMUM SAMPLED FLOW

COMPARISON OF FLOW DISTRIBUTIONS
      ------ SAMPLED -----   ------- TOTAL ------
STRAT   N      MEAN  STD DEV    N      MEAN  STD DEV     DIFF       T   PROB(>T)
 1     44     168.0     92.3  320     183.4    110.6    -15.3  -1.008     0.318
 2      9    1355.2   1473.6   45    1112.2    968.5    243.0   0.475     0.648
ALL    53     369.6    737.3  365     297.9    466.5     71.7   0.689     0.501

< DESIRABLE TO HAVE SAMPLED FLOW MEAN = TOTAL FLOW MEAN IN EACH STRATUM,
<          PARTICULARLY IN THE HIGH FLOW STRATUM

< IF PROB (> T) IS LOW (E.G., < 0.10 - 0.05), CAUTION SHOULD BE EXERCISED IN
<          USING MINIMUM VARIANCE ALONE AS THE CRITERION FOR SELECTING THE
<          BEST LOADING ESTIMATE

REDEFINE STRATA <0.=NO,1.=YES>?    0       < RETURN TO STRATUM MENU IF > 0

< SAMPLES ARE NOW STRATIFIED

< READY FOR FINAL DIAGNOSTIC PLOTS AND LOADING CALCULATIONS

<H>
F L U X  PROCEDURES:           < MAIN MENU

 1. = READ NEW DATA
< ECT. MAIN MENU
99. = END

ENTER CODE <NN.>?   4          < DIAGNOSTIC PLOTS
```

```
F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC. PLOT MENU
99. = RETURN TO MAIN MENU

ENTER CODE <NN.>?   10            < COMPARE FLOW DISTRIBUTIONS BY STRATUM

SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1
O = SAMPLED FLOWS, X = ALL FLOWS
STRATUM = 1                          < LOW-FLOW STRATUM COMPARISON
INTERVAL MINIMUM - GEOMETRIC SCALE
       494.23                          X
       423.28                          XXXXXXXXXXXXXXXXXX
       362.52 OO                       XXXXXXXXXXXX
       310.47 O                        XXXXXXXXXXXXXXXXXXX
       265.90 OOOOOO                   XXXXXXXXXXXXXXX
       227.73 OO                       XXXXXXXXXXXXXXXXXXX
       195.04 OOOO                     XXXXXXXXXXXXXXXXXXXXXXXX>
       167.04 OOO                      XXXXXXXXXXXXXXXXXXXXXXXX>
       143.06 OOOO                     XXXXXXXXXXXXXXXXXXXXXXXX>
       122.52 OOOOO                    XXXXXXXXXXXXXXXXXXXXXXXX>
       104.93 OO                       XXXXXXXXXXXXXXXXXX
        89.87 OOO                      XXXXXXXXXXXXXXX
        76.97 OO                       XXXXXXXXXXXXXXXXXXX
        65.92 OOOOOOOOOO               XXXXXXXXXXXXXXXXXXXXXXXX>
         0.00
<H>

O = SAMPLED FLOWS, X = ALL FLOWS
STRATUM =   2                          < HIGH-FLOW STRATUM COMPARISON
INTERVAL MINIMUM - GEOMETRIC SCALE
      5663.32                          X
      4700.55 O
      3901.45                          X
      3238.20
      2687.70
      2230.79 O                        X
      1851.55                          X
      1536.78                          XXX
      1275.53                          XX
      1058.69 O                        XXXXX
       878.71                          XXXXXX
       729.33 O                        XXXXXX
       605.34 O                        XXXXXXXXX
       502.43 OOOO                     XXXXXXXXXX
         0.00
<H>
```

FLUX – DOCUMENTED SESSION

```
0 = SAMPLED FLOWS, X = ALL FLOWS
ALL STRATA
INTERVAL MINIMUM - GEOMETRIC SCALE
      5663.32                         X
      4020.66 0                       X
      2854.45
      2026.51 0                       X
      1438.72                         XXXXXX
      1021.41 0                       XXXXXX
       725.15 0                       XXXXXXXXXXX
       514.82 000                     XXXXXXXXXXXXXXXX
       365.49 0000                    XXXXXXXXXXXXXXXXXXXXXXXX>
       259.48 00000000                XXXXXXXXXXXXXXXXXXXXXXXX>
       184.22 000000                  XXXXXXXXXXXXXXXXXXXXXXXX>
       130.78 0000000000              XXXXXXXXXXXXXXXXXXXXXXXX>
        92.85 000000                  XXXXXXXXXXXXXXXXXXXXXXXX>
        65.92 000000000000            XXXXXXXXXXXXXXXXXXXXXXXX>
         0.00
<H>

< EACH FLOW STRATUM IS REASONABLY SAMPLED

< PROCEED WITH FINAL LOAD CALCULATIONS

F L U X  PLOTTING PROCEDURES:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC. PLOT MENU
99. = RETURN TO MAIN MENU
ENTER CODE <NN.>?   99         < RETURN TO MAIN MENU
<H>

F L U X  PROCEDURES:

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END

ENTER CODE <NN.>?   6          < CALCULATE LOADINGS
```

FLUX - DOCUMENTED SESSION

DEGRAY INFLOW 1980 TOTAL P

COMPARISON OF SAMPLED AND TOTAL FLOW DISTRIBUTIONS

STRATUM	BOUND	NQ	NC	NQ%	NC%	QMEAN-T	QMEAN-S	C/Q SLOPE
1	500.0	320	44	87.7	83.0	183.4	168.0	-0.131
2	5663.3	45	9	12.3	17.0	1112.2	1355.2	0.390
ALL		365	53	100.0	100.0	297.9	369.6	0.263

<H>

< NQ = NUMBER OF DAILY FLOWS IN STRATUM
< NQ% = NUMBER OF DAILY FLOWS, AS PERCENT OF TOTAL FLOW RECORD
< NC = NUMBER OF CONCENTRATION SAMPLED IN STRATUM
< NC% = NUMBER OF CONCENTRATION SAMPLES, AS PERCENT OF TOTAL SAMPLES
< QMEAN-T = MEAN TOTAL FLOW
< QMEAN-S = MEAN SAMPLED FLOW
< C/Q SLOPE = SLOPE OF LONG (CONC) VS LOG (FLOW) REGRESSION IN STRATUM

< SUMMARIZE LOADINGS

LOADING TABLE - UNSTRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	53	365	297.88	21127.7	0.9481E+08	70.93	0.461
2 Q WTD C	53	365	297.88	17027.3	0.1863E+08	57.16	0.254
3 IJC	53	365	297.88	17846.9	0.2154E+08	59.91	0.260
4 REGRES-1	53	365	297.88	16088.6	0.9902E+07	54.01	0.196
5 REGRES-2	53	365	297.88	13633.5	0.1615E+07	45.77	0.093

LOADING TABLE - STRATIFIED ESTIMATES

METHOD	NC	NQ	FLOW	FLUX	VARIANCE	CONC	CV
1 AV LOAD	53	365	297.88	16468.6	0.3187E+08	55.29	0.343
2 Q WTD C	53	365	297.88	14493.7	0.3218E+07	48.66	0.124
3 IJC	53	365	297.88	14947.5	0.3196E+07	50.18	0.120
4 REGRES-1	53	365	297.88	13666.2	0.4874E+06	45.88	0.051
5 REGRES-2	53	365	297.88	12801.6	0.1372E+07	42.98	0.092

<H>

< FLOW = MEAN TOTAL FLOW
< FLUX = MEAN LOADING ESTIMATE (KG/YR)
< VARIANCE = VARIANCE OF MEAN LOADING ESTIMATE
< CONC = FLOW-WEIGHTED CONCENTRATION = FLUX/FLOW (PPB OR MG/M3)
< CV = COEFFICIENT OF VARIATION OF FLUX AND CONC ESTIMATES
< = STANDARD ERROR OF THE MEAN/MEAN

FLUX – DOCUMENTED SESSION

```
< STRATUM BREAKDOWN USEFUL FOR EVALUATING MONITORING EFFICIENCY

LIST STRATUM BREAKDOWNS <0.=NO,1.=YES>?   1       < PRINT BREAKDOWN

BREAKDOWN BY STRATUM FOR METHOD =  1 AV LOAD
STRAT BOUND  NQ  NC     NC%   OPT%  FLOW-C      FLUX-C      VARIANCE-C    CONC    CV
  1   500.0 320  44  83.02  12.24   160.8      3613.6      0.1264E+06    22.5 0.098
  2  5663.3  45   9  16.98  87.76   137.1     12854.9      0.3174E+08    93.7 0.438
TOTAL        365  53 100.00 100.00   297.9     16468.6      0.3187E+08    55.3 0.343
OPTIMAL( OPT% )  53                                         0.6999E+07         0.161

BREAKDOWN BY STRATUM FOR METHOD =  2 Q WTD C
STRAT BOUND  NQ  NC     NC%   OPT%  FLOW-C      FLUX-C      VARIANCE-C    CONC    CV
  1   500.0 320  44  83.02  22.64   160.8      3943.7      0.5540E+05    24.5 0.060
  2  5663.3  45   9  16.98  77.36   137.1     10550.0      0.3163E+07    76.9 0.169
TOTAL        365  53 100.00 100.00   297.9     14493.7      0.3218E+07    48.7 0.124
OPTIMAL( OPT% )  53                                         0.8974E+06         0.065

BREAKDOWN BY STRATUM FOR METHOD =  3 IJC
STRAT BOUND  NQ  NC     NC%   OPT%  FLOW-C      FLUX-C      VARIANCE-C    CONC    CV
  1   500.0 320  44  83.02  22.62   160.8      3942.9      0.5493E+05    24.5 0.059
  2  5663.3  45   9  16.98  77.38   137.1     11004.6      0.3141E+07    80.3 0.161
TOTAL        365  53 100.00 100.00   297.9     14947.5      0.3196E+07    50.2 0.120
OPTIMAL( OPT% )  53                                         0.8910E+06         0.063

BREAKDOWN BY STRATUM FOR METHOD =  4 REGRES-1
STRAT BOUND  NQ  NC     NC%   OPT%  FLOW-C      FLUX-C      VARIANCE-C    CONC    CV
  1   500.0 320  44  83.02  45.21   160.8      3898.8      0.5958E+05    24.3 0.063
  2  5663.3  45   9  16.98  54.79   137.1      9767.4      0.4278E+06    71.2 0.067
TOTAL        365  53 100.00 100.00   297.9     13666.2      0.4874E+06    45.9 0.051
OPTIMAL( OPT% )  53                                         0.2420E+06         0.036

BREAKDOWN BY STRATUM FOR METHOD =  5 REGRES-2
STRAT BOUND  NQ  NC     NC%   OPT%  FLOW-C      FLUX-C      VARIANCE-C    CONC    CV
  1   500.0 320  44  83.02  32.42   160.8      3884.8      0.6169E+05    24.2 0.064
  2  5663.3  45   9  16.98  67.58   137.1      8916.9      0.1311E+07    65.0 0.128
TOTAL        365  53 100.00 100.00   297.9     12801.6      0.1372E+07    43.0 0.092
OPTIMAL( OPT% )  53                                         0.4873E+06         0.055
<H>

< FLOW-C = CONTRIBUTION OF STRATUM TO TOTAL FLOW
< FLUX-C = CONTRIBUTION OF STRATUM TO TOTAL FLUX
< OPT% = PERCENT OF SAMPLES YIELDING MINIMUM VARIANCE IN TOTAL FLUX
<        = OPTIMAL VALUES OF NC% FOR OBSERVED VARIANCE DISTRIBUTION
< OPTIMAL (OPT%) = ESTIMATED VARIANCE AND CV OF MEAN IF NC (53 TOTAL)
<                  WERE DISTRIBUTED OPTIMALLY AMONG STRATA ACCORDING TO
<                  OPT%
```

FLUX - DOCUMENTED SESSION

```
< THE OPT% COLUMN PROVIDES INFORMATION USEFUL FOR REFINING SURVEY DESIGNS

< FOR METHOD 4, THE OPTIMAL SAMPLE SPLIT IS 45% LOW-FLOW/55% HIGH-FLOW
<                  AS COMPARED WITH THE 83% / 17% SPLIT IN THE DATA SET

< IN FUTURE MONITORING, MORE PRECISE FLUX ESTIMATES CAN BE DERIVED BY
<                  SHIFTING SOME OF THE SAMPLED FROM THE LOW-FLOW TO THE
<                  HIGH FLOW STRATUM

< OBJECTIVES FOR ESTIMATING LOADING FOR OTHER COMPONENTS AND/OR SEASONS
<                  SHOULD ALSO BE CONSIDERED IN REFINING SAMPLE ALLOCATION

F L U X  PROCEDURES:          < MAIN MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END

ENTER CODE <NN.>?   7         < RESIDUALS ANALYSIS

METHOD NUMBER <N.> ?  4                < CALCULATION METHOD 4
STRATIFIED <1.> OR NOT <0.> ?  1       < STRATIFIED

RESIDUALS ANALYSIS FOR METHOD: 4 REGRES-1     < PLOT OBS VS EST LOADS
OBS VS. EST FLUXES (LOG SCALES), + Y=X
 OBSERVED
    5.80|                                                 +
    5.60|                                           +    2
    5.41|                                        2
    5.21|                                      +
    5.02|                                +
    4.83|
    4.63|                       2   +    2
    4.44|                     +   2  2
    4.24|                      22
    4.05|          1 11  +
    3.86|  1    1  +1
    3.66|    11111 1
    3.47|1111 11111
    3.27|1 1 11
    3.08|11  1 1
         +-------+-------+-------+-------+-------+-------+--
        3.26    3.68    4.09    4.50    4.92    5.33    5.75
                                ESTIMATE
<H>
```

< REGRESS OBSERVED VS. ESTIMATED LOADS

```
BIVARIATE REGRESSION:  Y VS. X
 INTERCEPT           =      0.1304  SLOPE                =      0.9541
 R-SQUARED           =      0.9050  MEAN SQUARED ERROR   =      0.0287
 STD ERROR OF SLOPE  =      0.0433  T STATISTIC          =     22.0437
 DEGREES OF FREEDOM  =          51  PROBABILITY(>|T|)    =      0.0000
 Y MEAN              =      3.7290  Y STD DEVIATION      =      0.5444
 X MEAN              =      3.7716  X STD DEVIATION      =      0.0000
<H>
RESIDUAL = LOG(OBS/EST FLUX)      < PLOT RESIDUALS AGAINST FLOW
 RESIDUAL
     0.53|   1
     0.46|
     0.39|
     0.31|
     0.24|     1         1
     0.17|  1            1   1   2      < + RESIDUAL = 0
     0.09| 1   1  1   1  1
     0.02|1    +    + 1  1+1 1+      +    +     + 2  +    +
    -0.05|1   1     1
    -0.13|11      1 1 11  1      2  2                       2
    -0.20|          1  1         22   2
    -0.27|      1 1      1                2
    -0.35|       1
    -0.42|
    -0.49|         1
         +-------+-------+--------+-------+-------+--------+--
       1.82    2.12    2.43     2.74    3.04    3.35     3.65
                                 FLOW

<H>
 RESIDUAL                         < PLOT RESIDUALS AGAINST DATE
     0.53|                            1
     0.46|
     0.39|
     0.31|
     0.24|                       1                1
     0.17|                21      1                      1
     0.09|           1       111  11
     0.02|+ 2  +    +   111  1 +       +  11+     +1    +1     +
    -0.05|                            1    111  11
    -0.13|1  11     2 1                 1     1     1 2 12 1
    -0.20|1    2 1   2                         2
    -0.27| 1    1      2                             1
    -0.35|         1
    -0.42|
    -0.49|        1
         +-------+-------+--------+-------+-------+--------+--
       3.00   61.10  120.20  179.31  238.41  297.51  356.61
                                 DATE
<H>
```

< *LIST OBSERVED AND PREDICTED FLUXES FOR EACH SAMPLE DATE*

LIST OBS. AND PRED. FLUXES <0.=NO,1.=YES>? 1

DEGRAY INFLOW 1980 TOTAL P METHOD= 4 REGRES-1

OBS	DATE	STRATUM	FLOW	O-CONC	E-CONC	O-FLUX	E-FLUX	LOG(RATIO)
1	2	1	217.31	16.00	23.72	3477.0	5154.2	-0.171
2	8	1	165.90	17.00	24.57	2820.3	4076.5	-0.160
3	15	1	141.93	14.00	25.08	1987.0	3559.6	-0.253
< *ETC FOR EACH SAMPLE*								
51	350	1	286.07	31.00	23.88	8868.1	6544.9	0.132
52	357	1	164.64	17.00	24.60	2798.9	4049.6	-0.160
53	364	1	136.25	34.00	25.21	4632.6	3435.5	0.130

<H>

< *O-CONC, E-CONC = OBSERVED AND ESTIMATED CONCENTRATIONS*
< *O-FLUX, E-FLUX = OBSERVED AND ESTIMATED LOADS*
< *LOG (RATIO) = RESIDUAL = LOG10 (O-FLUX / E-FLUX)*

< *JACKKNIFED ESTIMATES*

LIST JACKKNIFED LOADS <0.=NO,1.=YES>? 1

< *PROGRAM EXCLUDES EACH SAMPLE, ONE AT A TIME, AND RECALCULATES LOADS*
< *USING SPECIFIED CALCULATION METHOD (4 IN THIS CASE) WITH STRATIFIED*
< *AND UNSTRATIFIED SAMPLES*

< *OUTPUT ILLUSTRATES SENSITIVITY OF LOAD ESTIMATE TO EACH SAMPLE*

DEGRAY INFLOW 1980 TOTAL P METHOD= 4 REGRES-1
JACKKNIFED LOADING ESTIMATES

-------- SAMPLE EXCLUDED	---------				-- UNSTRATIFIED --		--- STRATIFIED ---	
OBS	DATE	STRATUM	FLOW	CONC	LOAD	%CHANGE	LOAD	%CHANGE
NONE					16088.7		13666.2	
1	2	1	217.31	16.00	16181.3	0.58	13707.6	0.30
2	8	1	165.90	17.00	16146.7	0.36	13694.9	0.21
3	15	1	141.93	14.00	16143.5	0.34	13700.5	0.25
< *ETC FOR EACH SAMPLE*								
50	343	2	4926.23	97.00	13198.9	-17.96	13346.1	-2.34
51	350	1	286.07	31.00	16180.9	0.57	13608.3	-0.42
52	357	1	164.64	17.00	16146.0	0.36	13694.7	0.21
53	364	1	136.25	34.00	16072.4	-0.10	13640.7	-0.19

<H>

< *OBS = SAMPLE EXCLUDED*
< *% CHANGE = PERCENT INCREASE OR DECREASE IN LOAD ESTIMATE WHEN GIVEN*
< *= SAMPLE IS EXCLUDED*

< HISTOGRAM OF JACKKNIFED LOAD ESTIMATES

```
JACKKNIFED LOADS, SYMBOL=STRATUM
INTERVAL MINIMUM - LINEAR SCALE
     14000.30 2
     13937.90
     13875.49                                 < WIDER SPREAD OF VALUES FOR
     13813.09 2                               < HIGH-FLOW STRATUM (2) REFLECTS
     13750.68                                 < GREATER SENSITIVITY
     13688.28 2111111111111
     13625.88 1111111111111111111212111111
     13563.47 11211
     13501.07 1
     13438.67                                 < ESTIMATE IS REASONABLY ROBUST
     13376.26 2                               < BECAUSE RANGE OF JACKKNIFED
     13313.86 2                               < VALUES IS LIMITED
     13251.45                                 < (MAXIMUM/MINIMUM) = 1.07
     13189.05
     13126.65 2
<H>
```

< END OF RESIDUALS ANALYSIS

```
F L U X   PROCEDURES:          < MAIN MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END

ENTER CODE <NN.>?    8          < DELETE A SAMPLE
```

< USE THIS PROCEDURE TO DELETE A SAMPLE FROM THE DATE READ INTO MEMORY

< DOES NOT MODIFY SOURCE DATA FILE

FLUX - DOCUMENTED SESSION

< PROGRAM AUTOMATICALLY LISTS SAMPLE RECORD

SAMPLE	JULIAN	STRATUM	FLOW	TOTAL P
1	2	1	217.31	16.00
2	8	1	165.90	17.00
3	15	1	141.93	14.00
< ETC FOR EACH SAMPLE				
50	343	2	4926.23	97.00
51	350	1	286.07	31.00
52	357	1	164.64	17.00
53	364	1	136.25	34.00

```
ENTER SAMPLE NUMBER TO BE DELETED <0.=NONE>?  0
<H>
```

< IF VALUE BETWEEN 1 AND 53 IS ENTERED, CORRESPONDING SAMPLE IS DELETED AND SAMPLES ARE RELISTED

< ENTER "0" TO QUIT AND RETURN TO MENU

```
F L U X  PROCEDURES:          < MAIN MENU

 1. = READ NEW DATA
 2. = LIST SAMPLE RECORD
 3. = LIST FLOW RECORD
 4. = PLOT DATA
 5. = DEFINE STRATA
 6. = CALCULATE LOADINGS
 7. = ANALYZE RESIDUALS
 8. = DELETE A SAMPLE
 9. = HELP
99. = END

ENTER CODE <NN.>?   9          < HELP MENU
```

< LIST ONLINE DOCUMENTATION

```
********************************************************
**                                                    **
**      FFFFFF    L          U     U     X     X      **
**      F         L          U     U      X   X       **
**      FFFF      L          U     U       XX         **
**      F         L          U     U      X   X       **
**      F         LLLLLL     UUUUUUU     X     X      **
**                                                    **
********************************************************
** ONLINE DOCUMENTATION FOR -- F L U X -- VERSION 2.0 **
********************************************************

CONTENTS:                                    < HELP MENU
           1. - GENERAL PROGRAM DESCRIPTION
           2. - PROCEDURE DESCRIPTIONS
           3. - GLOSSARY
```

```
          4. - TERMINAL CONVENTIONS
         99. - RETURN TO PROGRAM

     ENTER SELECTION ?   1    < REQUEST GENERAL PROGRAM DESCRIPTION

FLUX IS AN INTERACTIVE PROGRAM DESIGNED TO ASSIST IN ESTIMATING THE
LOADINGS OF NUTRIENTS OR OTHER WATER QUALITY COMPONENTS PASSING A
TRIBUTARY SAMPLING STATION OVER A GIVEN PERIOD OF TIME.

THE FLUX PROGRAM REQUIRES:
   1 - INSTANANEOUS CONCENTRATION AND FLOW DATA DERIVED FROM GRAB SAMPLING
   2 - A CONTINUOUS FLOW RECORD, TYPICALLY MEAN FLOWS FOR EACH OF 365 DAYS

USING 5 ALTERNATIVE METHODS, THE PROGRAM INTERPRETS THE GRAB SAMPLING DATA
IN ORDER TO ESTIMATE THE TOTAL LOADING CORRESPONDING TO THE CONTINUOUS FLOW
RECORD.

THE LOADING ESTIMATES CAN BE USED IN FORMULATING RESERVOIR NUTRIENT
       BALANCES OVER ANNUAL OR SEASONAL AVERAGING PERIODS.

< ETC.
< HELP FILE WILL CONTAIN INFORMATION ON PROGRAM UPDATES AND OTHER
<      BASIC INFORMATION

< RETURNS TO HELP MENU

*******************************************************
** ONLINE DOCUMENTATION FOR -- F L U X -- VERSION 2.0 **
*******************************************************

CONTENTS:
          1. - GENERAL PROGRAM DESCRIPTION
          2. - PROCEDURE DESCRIPTIONS
          3. - GLOSSARY
          4. - TERMINAL CONVENTIONS
         99. - RETURN TO PROGRAM

ENTER SELECTION ?   99    < RETURN TO MAIN MENU

F L U X  PROCEDURES:

  1. = READ NEW DATA
< ETC. MAIN MENU
 99. = END

ENTER CODE <NN.>?   99    < END PROGRAM EXECUTION
```

PART III: PROFILE - REDUCTION OF POOL WATER QUALITY DATA

PROFILE is designed to assist in the analysis and reduction of pool water quality measurements. Program structure is illustrated in Figure III-1. The user supplies a data file containing basic information on the morphometry of the reservoir, monitoring station locations, surface elevation record, and water quality monitoring data referenced by station, date, and depth. The program's functions are in three general areas:

a. Display of concentrations as a function of elevation, location, and/or date.

b. Robust calculation of mixed-layer summary statistics and standard errors.

c. Calculation of hypolimnetic and metalimnetic oxygen depletion rates from temperature and oxygen profiles.

These applications are introduced in the following paragraphs. Details are given in subsequent sections.

Several display formats are available for depicting the spatial and temporal variability of water quality conditions within the reservoir. In the interest of maintaining hardware independence and transportability, the displays are designed to be "functional" rather than "fancy." Since most of the graphics are routed through a single plotting subroutine, the program could be easily modified to provide high-resolution graphics and/or scaling options compatible with specific hardware.

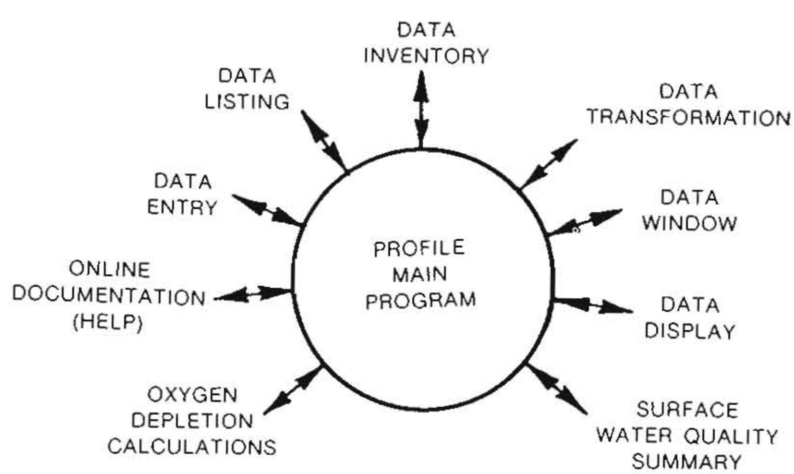


Figure III-1. PROFILE schematic

Mixed-layer water quality data can be summarized in a two-way table format which depicts variations as a function of space (station or reservoir segment) and time (sampling date) over date, depth, and station ranges specified by the user. In the two-way analysis, filtering and weighting algorithms are used to generate robust summary statistics (median, mean, and coefficient of variation of the mean) for characterization of reservoir trophic status, evaluations of data adequacy and monitoring program designs, and application of empirical models.

Hypolimnetic oxygen depletion rates are important symptoms of eutrophication in stratified reservoirs. Using input oxygen and temperature profiles, the program applies interpolation and area-weighting procedures to calculate depletion rates. Graphic and tabular outputs assist the user in selecting appropriate sampling dates and thermocline boundaries for oxygen depletion calculations.

PROFILE is interactive; the user directs the flow of the calculations through a series of linked menus, as shown in Figure III-2. The section at the end of this Part, entitled PROFILE Documented Session, presents a documented terminal session which demonstrates each procedure and output format. The following sections describe input data requirements and suggested application procedures for use of the program in each of the areas mentioned above.

INPUT DATA REQUIREMENTS

PROFILE requires an input data file as described below and illustrated in the section, Input Coding Forms. Inputs are specified in the following general groups:

Group 1: Title - reservoir name, etc.

Group 2: Parameters and Unit Conversion Factors.

Group 3: Reservoir Hypsiographic Curve - surface area versus elevation.

Group 4: Component Key - identifies types of measurements in file.

Group 5: Station Key - station number, user code, description, river kilometer, bottom elevation, segment number, area weighting factor.

Group 6: Date Key - reservoir surface elevations on each sampled date.

P R O F I L E PROCEDURES: *MAIN MENU*

1. = READ DATA FILE
2. = DEFINE WINDOW *SUBMENU A*
3. = LIST STATION, DATE, AND COMPONENT KEYS
4. = LIST PROFILE DATA
5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
6. = DISPLAY MENU *SUBMENU B*
7. = TRANSFORMATION MENU *SUBMENU C*
8. = CALCULATE OXYGEN DEPLETION RATES
9. = CALCULATE MIXED LAYER WATER QUALITY SUMMARIES
10. = HELP *SUBMENU D*
99. = END

P R O F I L E WINDOW, SAMPLES = 169 *SUBMENU A*
CURRENT PARAMETER VALUES:

1. = STATION RANGE = 1 TO 6
2. = ROUND RANGE = 1 TO 4
3. = DEPTH RANGE = 0.0 TO 999.0
4. = COMPONENT RANGE = 1 TO 2
5. = RESET WINDOW TO INCLUDE ALL DATA
6. = EDIT ALL PARAMETERS
0. = KEEP CURRENT WINDOW

P R O F I L E — DISPLAY MENU: *SUBMENU B*

1. = SET PLOT WIDTH AND HEIGHT

		PLOT FORMATS		
	Y-VARIABLE	X-VARIABLE	SYMBOL	BY
2. =	ELEVATION	CONC	DATE	STATION
3. =	ELEVATION	CONC	STATION	DATE
4. =	ELEVATION	DATE	CONC	STATION
5. =	ELEVATION	RKM	CONC	DATE
6. =	CONC	RKM	DATE	
7. =	CONC	DATE	STATION	

8. = HISTOGRAMS
9. = BOX PLOTS
99. = RETURN TO MAIN MENU

Figure III-2. PROFILE menus (Continued)

P R O F I L E TRANSFORMATION MENU: *SUBMENU C*

1. = ADD C(N) = C(I) + C(J)

2. = SUBTRACT C(N) = C(I) - C(J)

3. = MULTIPLY C(N) = C(I) * C(J)

4. = DIVIDE C(N) = C(I) / C(J)

5. = TURBIDITY CALC C(N) = 1/SECCHI(I) - .025*CHLA(J)

0. = RETURN TO MAIN MENU

P R O F I L E HELP MENU: *SUBMENU D*

1. = GENERAL PROGRAM DESCRIPTION

2. = PROCEDURE DESCRIPTIONS

3. = GLOSSARY

4. = TERMINAL CONVENTIONS

99. = RETURN TO MAIN MENU

Figure III-2. (Concluded)

Group 7: Profile Data - station, date, depth, concentration measurements.

The data file can contain measurements of up to 10 different water quality components. For eutrophication studies, the input file would normally contain measurements of oxygen, temperature, total phosphorus, ortho-phosphorus, inorganic nitrogen, organic nitrogen, total nitrogen, chlorophyll-a, and Secchi depth. Output is formatted to provide one place to the right of the decimal point; thus, input units should be milligrams per cubic meter (or parts per billion) for nutrients and chlorophyll-a and meters for Secchi depth. Other components should be scaled accordingly.

Group 2 contains scale factors to convert input area, elevation, and depth units to metric units used by the program (square kilometers for area and meters for elevation and depth). Missing concentration values are flagged with a special code specified in Group 2. A "date grouping factor" can be defined to combine data for summary purposes. In large reservoirs, it may be difficult to sample all pool monitoring stations in 1 day. If a grouping factor of two is specified, for example, sampling dates in Group 7 will be associated with the sampling rounds identified in Group 6 if the sampling date and round date differ by 2 days or less.

Integers (range 01-15) are used to identify sampling stations and are cross-referenced to user-defined station codes and descriptions in Group 5. To facilitate interpretation of data displays and tables, station numbers should be assigned in a logical order (e.g., upstream or downstream order within each tributary arm). The "river kilometer" input for each station would normally represent the distance along the thalweg from the reservoir inflow; since the river kilometer index is used only for spatial display purposes, any frame of reference can be used.

In computing summary statistics, "segment numbers" specified in Group 5 can be used to combine data from specific stations based upon their relative proximities, major tributary arms, horizontal mixing characteristics, etc. For example, if the file contains two adjacent stations (or two stations with similar observed water quality), data from these stations can be grouped by assigning them the same segment number. Segment numbers can refer directly to the spatial segments used in reservoir modeling (see BATHTUB). If oxygen depletion calculations are not desired, it is also possible to use segment numbers to refer to stations in different reservoirs.

"Areal weights" are used in calculating area-weighted summary statistics over the entire reservoir and should reflect the approximate surface area represented by each station. These can be estimated by plotting stations on a reservoir map and allocating a given area to each station, based upon relative station locations and bisecting lines between adjacent stations. Since they are rescaled in calculations, the weighting factors do not have to sum to 1.0.

PROFILE can handle problems with the following maximum dimensions:

Number of stations	=	50
Number of sampling rounds	=	100
Number of water quality components	=	10
Number of samples	=	1,000

Note that limitations on sample numbers, sampling rounds, and number of water quality components apply only to data read into the computer memory at the time of program execution, not to the data file itself. Since the user is prompted for the ranges of station numbers, sample years, and water quality components to be considered in a given run, the data file can be much larger than indicated above (except for the maximum number of stations). A warning statement is printed if problem size limitations are violated. Size limitations can be modified, by changing the appropriate array dimension statements and recompiling the program. Users should check the online documentation file (accessed through the HELP menu) for maximum problem dimensions or other program changes in updated versions of PROFILE.

DATA ENTRY AND REVIEW

Once an input data file has been generated for a particular reservoir, Table III-1 outlines procedures for initial data input and review using PROFILE. This process would normally consist of three steps:

- a. Reading of data for specific components, stations, and years into computer memory.
- b. Listing of data and editing of any input coding errors.
- c. Diagnostic plotting as a function of elevation, river kilometer, and/or date.

Display formats are illustrated later in this Part. Plots are generated through the display menu (Figure III-2) and are characterized by four dimensions:

- a. X-variable (horizontal scale).
- b. Y-variable (vertical scale).
- c. Symbol variable (symbols defined by variable values, i.e., contours).
- d. Variable (separate display generated for each variable value).

Variables potentially used in these dimensions include concentration, river kilometer, elevation, date, and station. Six combinations are available from the Display Menu (Procedures 2-7 in Figure III-2). Histograms (Procedure 8) or box plots (Procedure 9) can be generated using symbols or groups defined by station, segment, or date. Displays are repeated for each water quality component specified in the current data window (see below). Plot size (rows and columns) can be modified using Procedure 1. Plot scaling is done automatically based upon variable ranges, and linear, geometric, or logarithmic scales can be specified.

The "data window" can be set to restrict the observations to certain stations, dates, depths, and components. This applies both to the display routines and to the data summary routine described below. For example, to

Table III-1

Application Steps for PROFILE: 1 - Data Input and Review

Step	User Action	Program Action
1	---------------------------- DATA INPUT	---------------------------------
A	Run Program	
B	Specify Input Data File Name	
C		Read Parameters and Conversion Factors
		Read Area/Elevation Table
		Read and Print Component Key
D	Specify Component Subscripts to be Used (maximum 8)	
E	Specify Minimum and Maximum Station Number (0-99. for all)	
F		Read Station Key
G	Specify Minimum and Maximum Year (last two digits, 0-99. for all)	
H		Read Date Key and Profiles
		Print Error Message if Sample is Not Indexed in Station or Date Keys
I		If No Samples: End Program Execution
J		Print Numbers of Stations, Dates, Samples, and Components Read
K		Set Window to Include All Data
L		Sort Profiles by Station/Date/Depth
M		Enter Routine to List Keys:
		Print Area/Elevation Table
		Print Station Index
		Print Component Index and Plot Symbols
		Print Date Index
N		Print Main Program Menu
2	---------------------------- DATA REVIEW	------------------------------
A	Request Listing of Profile Data (PROC 4)	
B		Print Sorted Profile Data
C	Review Profile and Key Listings	
D	If Coding Error Found: End Program, Edit Data File, Repeat DATA INPUT	
E		Print Main Program Menu
3	------------------------------- DATA DISPLAY	----------------------------
A	Request Display Menu (PROC 6)	
B		Print Current Data Window
C	Edit Current Window (Optional)	
	Specify Station Range, Date Range, Depth Range, Subscript Range	
D		Print Display Menu
E	Request Diagnostic Plots Appropriate for Particular Problem	
F		Print Requested Plots
G	Review Plots	
H		Print Plot Menu
I	Request Main Menu (PROC 99)	
J		Print Main Program Menu

display mixed-layer water quality conditions, the window should be set to include the mixed-layer depth range (e.g., 0 to 5 m) prior to entering the plot routines, and samples outside of the specified depth range will not be used. Note that window parameters refer to data read into computer memory during a given run, not to the entire data file contents. After the data entry routine, the window is initialized to include all values but can be reset at any time.

The transformation routine can be called from the main menu (Procedure 7) to add, subtract, multiply, or divide two components or to compute nonalgal turbidity from chlorophyll-a and Secchi depth (see Part IV, BATHTUB). This routine can be used to compute total nitrogen from inorganic and organic nitrogen measurements or to compute nitrogen/phosphorus ratios, for example. One restriction is that the output variable must replace an existing variable. This routine is applied only to data read into memory (source data file contents are not modified).

MIXED-LAYER WATER QUALITY DATA SUMMARY

The second major function of PROFILE is the calculation of mixed-layer, summary statistics for characterization of reservoir trophic status, evaluations of data adequacy and monitoring program designs, and application of empirical models. Calculation steps (outlined in Table III-2) include the following:

a. Setting the data window to include mixed-layer samples.

b. Generating box plots to depict spatial and temporal variations.

c. Summarizing the data in a two-way table format.

These steps are described below.

The data window defines the ranges of stations, dates, and depths to be included in displays and statistical summaries. For characterization of reservoir trophic status, the window would normally be set to include all stations, dates in the growing season (e.g., April-October), and depths in the mixed layer. In model development research, a mixed-layer depth of 15 ft (4.6 m) was used for data summary purposes; this value should be adjusted in specific applications, based on review of midsummer temperature profile data. Because the data-summary procedure does not apply weighting factors with

Table III-2

Application Steps for PROFILE: 2 - Surface Water Quality Data Summary

Step	User Action	Program Action
1	------------ SET DATA WINDOW TO INCLUDE MIXED LAYER AND GROWING SEASON ------------	
A		Print Main Program Menu
B	Request Display Menu (PROC 6)	
C		Print Window
D	Edit Window in Response to Prompts Station Range (normally, all) Date Range (normally, growing season, April-October) Depth Range (normally, mixed-layer depth, e.g., 0-5 m) Variable Subscript Range (normally, all except temperature, oxygen)	
E		Print Modified Window
F	Specify Keep Current Window (Proc 0)	
2	------------ SPATIAL AND TEMPORAL BOX PLOTS ------------	
A		Print Display Menu
B	Request Box Plots (PROC 9)	
C	Request Groups by Station (or Segment)	
D		Generate Box Plots of Spatial Variations
E		Print Display Menu
F	Request Box Plots (PROC 9)	
G	Request Groups by Date	
H		Generate Box Plots of Temporal Variations
I		Print Display Menu
J	Request Main Menu	
K		Print Main Menu
3	------------ SURFACE WATER QUALITY SUMMARY ------------	
A	Request Surface Water Quality Summaries (PROC 9)	
B		Print Current Window
C	Use Current Window (as Defined in STEP 1 Above)	
D		Enter Data Summary Routine
E	Specify Column Grouping Variable (station or segment)	
F	Specify Date (Row) Blocking Factor (normally, 1)	
G	Specify Cell Summary Method (means or medians, medians recommended)	
H		Computations: Summary Value for Each Cell (row/column combination) Area-Weighted Reservoir Means Over Columns (stations) for Each Row (date) Summary Statistics Across Rows (dates) for Each column (station) and for Entire Reservoir (last column)
I		Print Table of Sample Frequencies
J		Print Table of Summary Values
K		Repeat STEPS H-J for Each Component
L		Print Main Program Menu

depth, use outside of the mixed layer (or in nonhomogenous depth layers) is not recommended.

Figure III-2 illustrates the use of box plots for a robust summary of spatial and temporal variations in mixed-layer total phosphorus concentrations in Beaver Reservoir, Arkansas. Percentiles (10, 25, 50, 75, 90) can be calculated and displayed for data grouped by station, segment, or date. The number of observations and median value are printed for each data group. As shown in Figure III-3, spatial variations are significant in Beaver Reservoir; station-median total phosphorus concentrations range from 59 to 10 mg/m^3.

The data-summary routine (Procedure 9) organizes the data in a two-way table depicting spatial (columns) and temporal (rows) variations. This is illustrated in Table III-3 using Beaver Reservoir data. Spatial groups can be defined by station or reservoir segment. Temporal groups can be defined by

```
COMPONENT:  3 total p
STATION  NOBS  MEDIAN  PERCENTILES:  10 25 50 75 90
    1.00   35   11.00 ---|*|||-------
    2.00   33   13.00 ---||||*|||||-----------
    3.00   28   20.50     ------|||||*||||||||||||-----
    4.00   29   32.00                 |||||||*||||||||||---------
    5.00   23   53.00                         ----||||*|||||||||--------
    6.00   20   62.00                             ---||||*||------

                      +--------+--------+--------+--------+--------+--------+--
total p  -->        8.40    13.21    20.78    32.69    51.41    80.87   127.19
GEOMETRIC SCALE
```

```
COMPONENT:  3 total p
D A T E  NOBS  MEDIAN  PERCENTILES:  10 25 50 75 90
   95.00   36   40.50    --------|||||||||||||||||*||||||----
  169.00   48   22.00 -----||||||||||||*||||||||||||||||||||------
  242.00   39   19.00    --|||||||||*||||||||||||||-------------------
  282.00   45   17.00   ||||||||||*||||||||||||||||----------

                      +--------+--------+--------+--------+--------+--------+--
total p  -->        9.00    13.68    20.80    31.61    48.05    73.04   111.03
GEOMETRIC SCALE
```

Figure III-3. Sample PROFILE output: box plots by station and date

Table III-3

Sample PROFILE Output: Surface Water Quality Summary

COMPONENT: TOTAL P , DEPTHS: 0.0 TO 5.0 M
RESERVOIR WEIGHTED MEANS LISTED IN LAST COLUMN
TOTAL P SAMPLE FREQUENCIES:

STATION	1	2	3	4	5	6	
DATE	WTS>0.200	0.250	0.250	0.150	0.100	0.050	
74 4 5	3	3	3	3	3	3	18
74 618	3	3	3	4	3	3	19
74 830	2	2	2	2	2	3	13
7410 9	3	3	3	3	3	3	18
TOTALS	11	11	11	12	11	12	68

TOTAL P SUMMARY VALUES:

STATION	1	2	3	4	5	6	
DATE	WTS>0.200	0.250	0.250	0.150	0.100	0.050	
74 4 5	9.0	16.0	36.0	37.0	46.0	68.0	28.3
74 618	9.0	9.0	16.0	27.0	88.0	63.0	24.0
74 830	13.0	11.5	18.5	21.0	36.5	44.0	19.1
7410 9	10.0	11.0	11.0	21.0	40.0	47.0	17.0
MEDIANS	9.5	11.3	17.3	24.0	43.0	55.0	21.6
MEANS	10.3	11.9	20.4	26.5	52.6	55.5	22.1
CV	0.185	0.249	0.534	0.285	0.454	0.212	0.230
CV(MEAN)	0.092	0.124	0.267	0.142	0.227	0.106	0.115

sampling dates or blocks of consecutive sampling dates. The purposes of date blocking are discussed below. A summary value (mean or median) is computed for each cell (row/column combination). For each row (sampling date), summary values are weighted by surface area and averaged across columns (stations or segments) to compute a reservoir-mean concentration. Values are subsequently analyzed vertically to estimate a median, mean, coefficient of variation (CV, standard deviation/mean), and coefficient of variation of the mean (CV(MEAN), standard error/mean). Because the procedure summarizes data in two stages (within dates followed by across dates), station-median values will not necessarily equal those generated by the box plot routine (Figure III-3), which employs a one-stage data summary.

The distinction between the last two statistics (CV and CV(MEAN)) is important. CV is a measure of temporal variability in conditions at a given station (standard deviation expressed as a fraction of the mean). CV(MEAN) is a measure of potential error in the estimate of the MEAN value. From classical sampling theory (Snedecor and Cochran 1972), CV(MEAN) is calculated from the CV divided by the square root of the number of nonmissing rows (sample dates). This assumes that the rows are statistically independent. The calculation of CV(MEANS) for the entire reservoir (last column in Table III-3) considers only temporal and random variance components and assumes that the stations are distributed throughout representative areas of the reservoir.

Estimates of "mean" conditions are generally required for trophic state assessment and empirical modeling. Direct calculation of arithmetic mean concentrations from all mixed-layer data would be one way of computing desired summary statistics. However, this approach is undesirable for two reasons:

a. Lack of robustness (a single errant value can have a major impact on the computed mean).

b. Nonrandomness in samples (multiple samples taken within the mixed layer on the same date would tend to be highly correlated).

The PROFILE data summary algorithm has been designed to provide more robust estimates of the mean and coefficient of variation than would be derived from blind averaging.

"Robustness" can be introduced by using medians to compute summary values within each cell. Cells may contain more than one observation as a result of:

a. Replicate sampling at a given station, date, and depth.

b. Sampling with depth within the mixed layer (e.g., 0, 2, 4 m).

c. Including more than one station per segment (if segments are used to define columns).

d. Blocking of adjacent sampling dates (specifying date-blocking factors greater than 1).

In the Beaver Reservoir example (Table III-3), cells contain between two and four observations as a result of sampling with depth. Use of the median in computing a summary value provides some protection against "errant" observations and yields summary statistics (across stations and across dates) which are less sensitive to outliers. For example, a cell containing five observations (10, 20, 15, 12, 100) would be summarized by a mean of 31 and a median of 15. The median is less dramatically influenced by the single high value.

Medians provide "filtering" of outliers only in cells containing at least three observations, which may be achieved by replicate sampling, sampling with depth, including more than one station per reservoir segment, and/or blocking of adjacent dates. Generally, date blocking should not be used unless the sampling frequency is at least biweekly and the resulting number of rows is at least three. In such cases, date blocking may also improve the CV and CV(MEAN) estimates by reducing serial dependence in the rows.

While the calculation procedure accounts for missing values in the two-way table, the usefulness and reliability of the surface water quality summary are enhanced by complete sampling designs (i.e., each station sampled on each date). Based upon review of box plots and two-way tables, monitoring programs can be refined by reducing excessive redundancy across stations, improving characterization of spatial gradients, and modifying temporal sampling frequency to achieve the desired precision in summary statistics.

OXYGEN DEPLETION CALCULATIONS

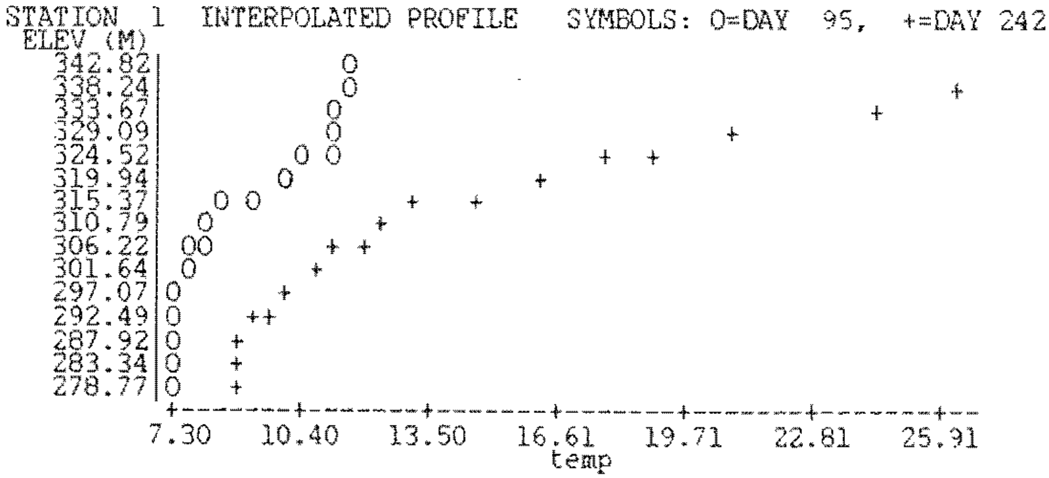
This section presents an overview of the procedures for calculating oxygen depletion rates using PROFILE. Calculations are outlined in Table III-4. Typical program output is presented in Figure III-4. The calculations are applied to vertical oxygen profiles at a given station; simultaneous measurements of temperature are also required to characterize thermal stratification. Empirical models have been developed for relating near-dam oxygen depletion

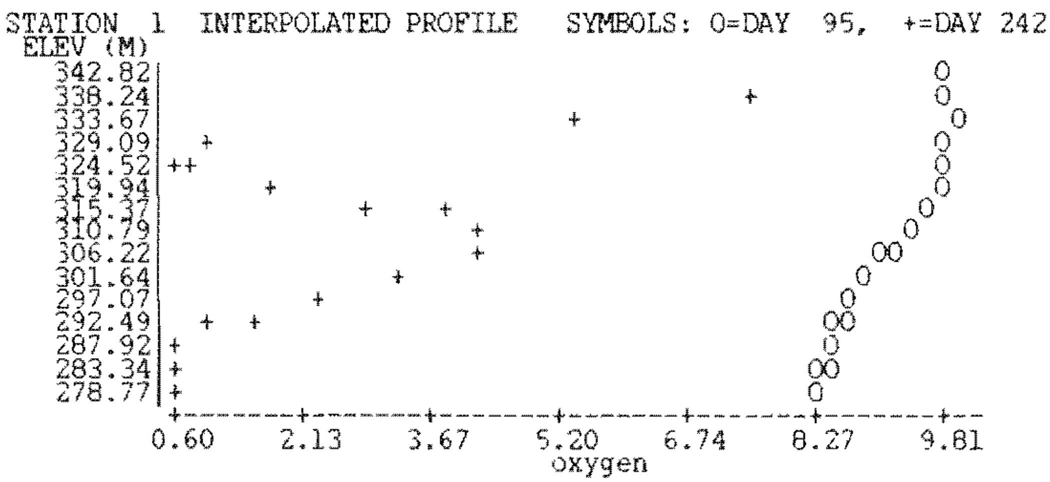
Table III-4

Application Steps for PROFILE: 3 - Calculate Oxygen Depletion Rates

Step	User Action	Program Action
A		Print Main Program Menu
B	Request Calculate Oxygen Depletion Rates (PROC 8)	
C		Set Window to Include All Data
D		Print Component Subscripts and Labels
E	Specify Temperature and Oxygen Subscripts	
F	Specify Near-Dam Station Number	
G		Print Nominal Elevation Increment for Calculations
H	Specify Elevation Increment to Be Used (round off nominal value)	
I		Calculate and Print Morphometric Table
J		Print Data Inventories for Temperature and Oxygen
K	Specify First and Last Sampling Rounds for HOD Calculations	
L		Process Temperature Profiles: Interpolate Temperature Profiles at Uniform Elevation Increment Print Summary Table Plot Interpolated Temperature Profiles
M		Process Oxygen Profiles: Interpolate Oxygen Profiles at Uniform Elevation Increment Print Summary Table Integrate Oxygen Profiles Over Depth Print Summary Table of Integrated Values Plot Interpolated Oxygen Profiles
N		Plot Areal Oxygen Depletion Rate vs. Elevation
O		Plot Volumetric Oxygen Depletion Rate vs. Elevation
P	Review Temperature and Oxygen Profiles and Identify Thermocline Boundaries	
Q	Specify Thermocline Boundaries (top of hypolimnion, top of metalimnion)	
R		Calculate Average Depletion Rates in Hypolimnion, Metalimnion, and Both for Given Thermocline Definition
S		Print Summary Table
T		*Repeat Steps Q-S for Alternative Thermocline Bounds
U		*Calculate Volume-Weighted Hypolimnetic and Metalimnetic Oxygen Concentrations and Depletion Rates for All Sampling Rounds
V		*Print Summary Table
W		*Plot Mean Hypolimnetic and Metalimnetic Oxygen Concentration vs. Time
X		Print Main Program Menu

* Optional STEPS (user-prompted).





Oxygen Depletion Calculation Summary:

STATISTIC		HYPOLIMNION	METALIMNION	BOTH
ELEVATION	M	300.00	330.00	330.00
SURFACE AREA	KM2	8.76	68.11	68.11
VOLUME	HM3	66.73	1008.95	1075.68
MEAN DEPTH	M	7.61	14.81	15.79
MAXIMUM DEPTH	M	21.23	30.00	51.23
INITIAL CONC	G/M3	8.79	9.75	9.69
FINAL CONC	G/M3	1.94	2.33	2.31
AREAL DEPL. RATE	MG/M2-DAY	354.54	747.09	792.71
VOL. DEPL. RATE	MG/M3-DAY	46.56	50.44	50.20

Figure III-4. Sample PROFILE output: oxygen depletion calculations rates to surface-layer chlorophyll-a concentrations (Walker 1985). Accordingly, the procedure would normally be applied to data from near-dam stations.

For the present purposes, the areal hypolimnetic oxygen depletion rate (HODa, mg/m^2-day) is defined as the rate of decrease of dissolved oxygen mass (mg/day) in the reservoir hypolimnion divided by the surface area of the hypolimnion (m^2). The rate is also expressed on a volumetric basis (HODv, mg/m^3-day), which is essentially the rate of decrease of the volume-weighted-average dissolved oxygen concentration in the hypolimnion between two dates, or HODa divided by the mean depth of the hypolimnion (m). These rates are symptoms of eutrophication because they partially reflect the decay of organic loadings resulting from surface algal growth and sedimentation.

The initial oxygen concentration at the onset of stratification (usually on the order of 10 to 12 g/m^3) and HODv determine the days of oxygen supply. Subtracting the days of oxygen supply from the length of the stratified period (typically 120 to 200 days) provides an estimate of the duration of anaerobic conditions. While HODv is of more immediate concern for water quality management purposes, HODa is a more direct measure of surface productivity because it is relatively independent of reservoir morphometric characteristics. For a given surface productivity and HODa, HODv is inversely related to mean hypolimnetic depth. Thus, the morphometry of the reservoir has a major impact on the severity of hypolimnetic oxygen depletion at a given surface water quality condition.

In a given stratified season, the areal and volumetric depletion rates are calculated between two monitored dates, the selection of which is important. The following criteria are suggested for selection of appropriate dates:

- a. Reasonable top-to-bottom distribution of oxygen and temperature measurements.
- b. Vertically stratified conditions, defined as top-to-bottom temperature difference of at least 4° C.
- c. Mean hypolimnetic oxygen concentrations in excess of 2 g/m^3.

The first criterion provides adequate data for characterizing thermal stratification and volume-weighting (estimation of total oxygen mass and volume-weighted concentration) within the hypolimnion on each sampling date. The second criterion is based upon the concept that HODa is valid as a measure of productivity only in water bodies that have stable vertical stratification.

The calculation is meaningless in unstratified or intermittently stratified reservoirs because of oxygen transport into bottom waters. The 4° C temperature difference is an operational criterion employed in developing data sets for model calibration and testing (Walker 1985). Special consideration must be given to water bodies with density stratification that is not related to temperature. The third criterion is designed to minimize negative biases caused by calculating HODa values under oxygen-limited conditions. The underlying model assumes that the depletion rate is limited by the organic supply, not the oxygen supply.

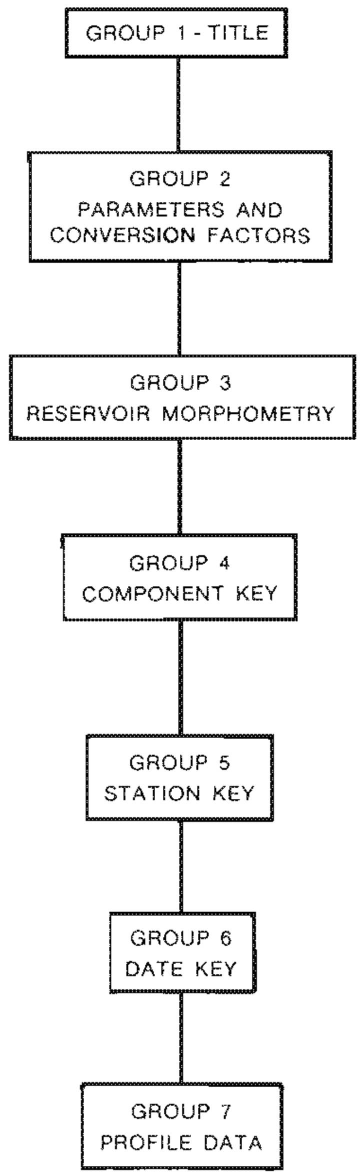
The first date generally corresponds to the first profile taken after the onset of stratification. The last date corresponds to the last profile taken before the end of August, the loss of stratification, or the loss of hypolimnetic dissolved oxygen (mean $<2 g/m^3$), whichever occurs first. Due to existing data limitations, it is sometimes difficult to conform to all of the above criteria in selecting dates. Small deviations may be acceptable, but should be noted and considered in interpreting subsequent modeling results.

To permit calculation of hypolimnetic and metalimnetic depletion rates between two dates, fixed thermocline boundaries (top and bottom) must be specified. Temperature profile displays can assist in the selection of appropriate boundaries, as illustrated in Figure III-4. The bottom of the thermocline (metalimnetic/hypolimnetic boundary) is set at the intersection of one line tangent to the region of maximum temperature gradient and another line tangent to the bottom of the profile. The top of the thermocline (epilimnetic/metalimnetic boundary) is set at the intersection of one line tangent to the region of maximum temperature gradient and another line tangent to the top of the profile. If significant thermocline migration has occurred between the two sampling dates, calculations should be based upon the thermocline levels at the last sampling date. A degree of subjective judgment must be exercised in interpreting temperature profiles and setting thermocline boundaries. Program output provides perspective on the sensitivity of the calculated depletion rates to the dates and thermocline boundaries employed.

Basic calculation steps are outlined in Table III-4. In response to program prompts, the user specifies temperature and oxygen subscripts, near-dam station number, elevation increment (meters), first and last sampling rounds, and thermocline boundaries. Profiles are interpolated and integrated at the specified elevation increment from the bottom of the reservoir to the top of the water column. At elevations below the deepest sampling point, concentrations and temperatures are set equal to those measured at the deepest sampling point. Results are most reliable when the profiles are complete and the morphometric table (Input Data Group 3) has been specified in detail.

Procedure output is in the form of several tables and plots which are useful for tracking the calculations and evaluating sensitivity to sampling date and thermocline selections. Figure III-4 shows interpolated profiles and a summary table for Beaver Reservoir. The summary table can be considered the "bottom line" in the calculations. The Beaver Reservoir example illustrates a pronounced metalimnetic oxygen depletion, which is often found in relatively deep reservoirs.

ORGANIZATION OF PROFILE INPUT FILES



PROFILE DATA GROUP 1 - TITLE

FORMAT (5A8)

PROFILE DATA GROUP 2 - PARAMETERS AND CONVERSION FACTORS

FORMAT (F8.4)

CONVERSION FACTORS ARE MULTIPLIED BY INPUT UNITS TO GET PROGRAM UNITS (METRIC) (E.G., PROGRAM UNITS FOR SAMPLE DEPTHS ARE METERS, IF INPUT UNITS ARE FEET, THEN CONVERSION FACTOR = 0.305)

PROJECT: ____________________

PROFILE DATA GROUP 1 — TITLE

PROFILE DATA GROUP 2 — PARAMETERS AND CONVERSION FACTORS

COMMENTS

Reservoir Length (km or Miles)

Missing Value Code (Suggest -9)

Conversion Factor - Elevations to Meters

Conversion Factor - Surface Areas to km^2

Conversion Factor - Distance to km

Conversion Factor - Sample Depths to Meters

Date Grouping Factor, Days (Normally = 1)

PROFILE DATA GROUP 3 - RESERVOIR MORPHOMETRY

FORMAT (2F8.0)

FIRST ENTRY MUST BE BOTTOM OF RESERVOIR (INVERT, AREA = 0.)

ELEV = SURFACE ELEVATION, IN INCREASING ORDER, MAXIMUM OF 29 ENTRIES
AREA = SURFACE AREA

UNITS CONSISTENT WITH CONVERSION FACTORS IN DATA GROUP 2
DECIMAL POINTS SHOULD BE INCLUDED OR RIGHT-JUSTIFIED

PROJECT: ____________________

PROFILE DATA GROUP 3 — RESERVOIR MORPHOMETRY

E	L	E	V					A	R	E	A				
											0		0		

0	0

PROFILE DATA GROUP 4 - COMPONENT KEY

FORMAT (I2,IX,A8,10F5.0)

IC = COMPONENT SEQUENCE NUMBER IN DATA GROUP 7
LABEL = 8-CHARACTER VARIABLE NAME (TEMP, OXYGEN, TOTAL P, ETC.)
V# = CUTPOINTS TO BE USED TO DEFINE PLOT SYMBOLS, MAXIMUM OF 10, E.G., IF V5 < VALUE ≤ V6, THEN PLOT SYMBOL = "6," ETC.

MAXIMUM OF 10 COMPONENTS

INCLUDE DECIMAL POINTS IN V1-V10 FIELDS, OR RIGHT-JUSTIFY ENTRIES

PROJECT: ____________________

PROFILE DATA GROUP 4 — COMPONENT KEY

I	C	LABEL	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
0	1											
0	2											
0	3											
0	4											
0	5											
0	6											
0	7											
0	8											
0	9											
1	0											
0	0											

PROFILE DATA GROUP 5 - STATION KEY

FORMAT (I2,1X,A8,3F8.0,I4,1X,2A8)

INCLUDE ONE RECORD FOR EACH STATION IN DATA GROUP 8, MAXIMUM OF 50

```
    ST = STATION NUMBER USED SAMPLE RECORDS, INCREASING ORDER
  CODE = 8-CHARACTER USER STATION CODE (FOR GENERAL REFERENCE)
  ELEV = ELEVATION OF RESERVOIR BOTTOM AT STATION (FT OR M)
RINDEX = DISTANCE ALONG THALWEG FROM MAJOR INFLOW (MAINSTEM STATIONS)
         RINDEX USED ONLY FOR PLOTTING PURPOSES, IGNORED IF < 0
         UNITS ARE KM OR MILES, CONSISTENT WITH CONVERSION FACTOR
          SPECIFIED IN DATA GROUP 2
WEIGHT = FACTORS USED IN AREA-WEIGHTED-AVERAGING ACROSS STATIONS
         RELATIVE SURFACE AREA REPRESENTED BY STATION (ESTIMATED FROM
          MAPS)
         WEIGHTS ARE RESCALED BY PROGRAM AND DO NOT HAVE TO SUM TO 1.0
   SEG = SEGMENT NUMBER, INTEGER, USED FOR GROUPING STATIONS BY
          RESERVOIR AREA
DESCRIPTION = 16-CHARACTER STATION LOCATION DESCRIPTION
```

INCLUDE DECIMAL POINT IN ELEV, RINDEX, WEIGHT FIELDS, OR RIGHT-JUSTIFY

LAST RECORD IN DATA GROUP 5 - "00"

PROJECT:________________

PROFILE DATA GROUP 5 — STATION KEY

ST	CODE	ELEV	RINDEX	WEIGHT	SEG	DESCRIPTION

PAGE OF PAGES

PROFILE DATA GROUP 6 - DATE KEY

FORMAT (3I2,F10.0)

MUST INCLUDE ONE RECORD FOR EACH SAMPLE DATE IN RECORD GROUP 7

MAXIMUM OF 100 DATES, IN CHRONOLOGICAL ORDER, CAN BE READ INTO PROGRAM

DATE = SAMPLE DATE IN YEAR-MONTH-DAY FORMAT (E.G., 840126)
SELEV = SURFACE ELEVATION OF RESERVOIR AT DAM ON SAMPLE DATE
UNITS CONSISTENT WITH ELEVATION CONVERSION FACTOR IN DATA GROUP 2

LAST RECORD OF DATA GROUP 6 - "00"

PROJECT: ____________________

PROFILE DATA GROUP 6 — DATE KEY

D	A	T	E			S	E	L	E	V					

PAGE OF PAGES

PROFILE DATA GROUP 7 - PROFILE DATA

FORMAT (I2,1X,3I2,11F5.0)

STATION NUMBERS INDEXED IN DATA GROUP 5, DATES INDEXED IN DATA GROUP 6

RECORDS CAN BE IN ANY ORDER

ST = STATION NUMBER
DATE = SAMPLE DATE, YEAR-MONTH-DAY FORMAT
DEPTH = SAMPLE DEPTH (FEET OR METERS, CONSISTENT WITH SCALE FACTOR IN DATA GROUP 2
C1-C10 = COMPONENT CONCENTRATIONS, INDEXED IN DATA GROUP 5 (IC VALUE)

INCLUDED DECIMAL POINT IN DEPTH AND C1-C10, OR RIGHT-JUSTIFY ENTRIES

LAST RECORD IN DATA GROUP 7 - "00"

PROJECT: ____________

PROFILE DATA GROUP 7 — PROFILE DATA

ST	DATE	DEPTH	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10

PAGE OF PAGES

PROFILE - EXAMPLE INPUT FILE

```
BEAVER RESERVOIR, ARKANSAS
```

DATA GROUP 1: TITLE

```
120.
-9.
.305
.00405
1.0
.305
2.
```

DATA GROUP 2: PARAMETERS AND CONVERSION FACTORS

```
ELEV----AREA----
 914.        0.
 938.      240.
 982.     1830.
  "         "
1130.    31700.
1137.    35860.
1142.    36260.
00
```

DATA GROUP 3: RESERVOIR MORPHOMETRY

```
IC LABEL---V1---V2---V3---V4---V5---V6---V7---V8---V9---V10--
01 Temp    4.   7.   10.  13.  16.  19.  22.  25.
02 Oxygen  2.   4.   6.   8.   10.  12.  14.
03 Secchi  .1   .2   .4   .8   1.6  3.2  6.4
 "   "     "    "    "    "    "    "    "
08 Total P 10.  20.  40.  80.  160. 320. 640. 1200.
09 Ortho P 5.   10.  20.  40.  80.  160. 320. 640.
10 Chla    1.   2.   4.   8.   16.  32.  64.  128.
00
```

DATA GROUP 4: COMPONENT KEY

(CONTINUED)

PROFILE - EXAMPLE INPUT FILE

```
ST CODE----ELEV----RINDEX--WEIGHT--SEG- DESCRIPTION-----
01 050101      916.   119.0     .20  12 above dam
02 050102      951.   100.0     .25  10 Big City
03 050103      999.    76.0     .25  08 below Rogers             DATA GROUP 5: STATION KEY
04 050104     1018.    51.8     .15  06 above Rogers
05 050105     1054.    32.0     .10  04 below War Eagle
06 050106     1073.     5.7     .05  01 headwater
00
DATE--SELEV-----
740405   1124.
740618   1124.                                                   DATA GROUP 6: DATE KEY
740830   1118.
741009   1119.
00
ST DATE--DEPTHC1---C2---C3---C4---C5---C6---C7---C8---C9---C10--
 1 740405  0.0 11.7 -9.0  2.3   60  200  140  440    9    4  1.7
 1 740405  5.0 11.6 10.0 -9.0   30  200  170  410    9    6 -9.0
 1 740405 15.0 11.6 10.0 -9.0   40  200  160  420   16   10 -9.0
 "   "       "    "    "    "    "    "    "    "    "    "    "   DATA GROUP 7: PROFILE DATA
 6 741009 15.0 17.7  6.4 -9.0  130  300  170  720   60   28 -9.0
 6 741009 30.0 17.6  6.8 -9.0  120  300  180  720   49   14 -9.0
 6 741009 39.0 17.5  6.2 -9.0  140  400  260  800   89    9 -9.0
00
```

(END OF FILE)

PROFILE - DOCUMENTED SESSION

```
P R O F I L E - VERSION 2.0

BEAVER RESERVOIR - EPA/NES DATA          < DATA FILE TITLE
READING MORPHOMETRY...                < READS MORPHOMETRIC DATA

SUBSCRIPT  VARIABLE                   < VARIABLES STORED IN FILE
      1      TEMP
      2      OXYGEN
      3      SECCHI
      4      NH3N
      5      TKN
      6      ORG N
      7      TOTAL N
      8      TOTAL P
      9      ORTHO P
     10      CHLA

SUBSCRIPT TO BE USED <  .> ?  1     < DEFINE SUBSCRIPTS TO BE USED,
SUBSCRIPT TO BE USED <  .> ?  2     <    ONE AT A TIME IN ANY ORDER
SUBSCRIPT TO BE USED <  .> ?  8
SUBSCRIPT TO BE USED <  .> ?  7
SUBSCRIPT TO BE USED <  .> ?  9
SUBSCRIPT TO BE USED <  .> ?  3
SUBSCRIPT TO BE USED <  .> ?  10
SUBSCRIPT TO BE USED <  .> ?        < PRESS RETURN OR 0 TO STOP

< DEFINE STATIONS TO BE READ

MINIMUM STATION NUMBER <  .>?   0
MAXIMUM STATION NUMBER <  .>?   99 < 0,99 WILL INCLUDE ALL STATIONS IN FILE
READING STATION KEY...

< DEFINE YEARS TO BE USED
< e.g., TO READ DATA FROM 1978 ONLY, SPECIFY MIN = 78, MAX = 78, ETC.

MINIMUM SAMPLING YEAR <  .> ?   0
MAXIMUM SAMPLING YEAR <  .> ?   99 < 0,99 WILL INCLUDE ALL YEARS

READING DATE KEY...           < READS DATES

READING PROFILES...           < READS PROFILES

< WARNING MESSAGE PRINTED IF PROFILE RECORDS INCLUDE STATIONS OR DATES
<          NOT INDEXED IN THE STATION OR DATE KEYS, RESPECTIVELY
< WARNING MESSAGE PRINTED IF NUMBER OR SAMPLES READ EXCEEDS MAXIMUM (250)

< WINDOW IS SET TO INCLUDE ALL DATA
< DATA ARE SORTED BY STATION/DATE/DEPTH
```

PROFILE - DOCUMENTED SESSION

< *INVENTORY OF DATA READ INTO MEMORY*

```
  6 STATIONS   169 SAMPLES    4 DATES  7 COMPONENTS LOADED
```

<H> < *SCREEN HOLD MESSAGE*

< *PRINTS MORPHOMETRIC TABLE, STATION, DATE, AND COMPONENT KEYS*
< *USER REVIEWS THE FOLLOWING TO CHECK FOR CODING ERRORS*

```
BEAVER RESERVOIR - EPA/NES DATA

LENGTH =   120.00 KM  BASE ELEVATION =   278.77 M
 ELEV (M)     AREA (KM2)
    278.8          0.00
    286.1          0.97
    299.5          7.41
    320.3         39.49
    328.5         62.94
    329.4         65.65
    332.5         76.14
    333.4         79.74
    335.5         88.41
    338.6        101.05
    341.6        114.29
    344.6        128.39
    346.8        145.23
    348.3        146.85
```

< *RESERVOIR HYPSOGRAPHIC CURVE*
< *FIRST ENTRY MUST BE ELEVATION*
< *AT WHICH AREA = 0*

< *STATION INDEX*

STA	CODE	ELEVATION	RKM	WEIGHT	SEGMENT	DESCRIPTION
1	050101	279.4	119.0	0.200	8	ABOVE DAM
2	050102	290.1	100.0	0.250	7	BIG CITY
3	050103	304.7	76.0	0.250	6	BELOW ROGERS
4	050104	310.5	51.8	0.150	5	ABOVE ROGERS
5	050105	321.5	32.0	0.100	4	BELOW WAR EAGLE
6	050106	327.3	5.7	0.050	2	HEADWATER

< *WATER QUALITY COMPONENTS AND VALUES USED TO DEFINE PLOT SYMBOLS*

PLOT	MAXIMUM CONCENTRATION						
SYMBOL	TEMP	OXYGEN	TOTAL P	TOTAL N	ORTHO P	SECCHI	CHLA
1	4.0	2.0	10.0	200.0	5.0	0.1	1.0
2	7.0	4.0	20.0	400.0	10.0	0.2	2.0
3	10.0	6.0	40.0	600.0	20.0	0.4	4.0
4	13.0	8.0	80.0	800.0	40.0	0.8	8.0
5	16.0	10.0	160.0	1000.0	80.0	1.6	16.0
6	19.0	12.0	320.0	1200.0	160.0	3.2	32.0
7	22.0	0.0	640.0	1400.0	320.0	6.4	64.0
8	25.0	0.0	1200.0	1600.0	640.0	0.0	128.0
9	28.0	0.0	2400.0	0.0	1200.0	0.0	0.0

PROFILE - DOCUMENTED SESSION

< *SAMPLE ROUND (DATE) INDEX AND POOL ELEVATION*

```
ROUND YR MO DY JULIAN  SURFACE ELEVATION
   1  74  4  5     95            342.8
   2  74  6 18    169            342.8
   3  74  8 30    242            341.0
   4  74 10  9    282            341.3
```

< *JULIAN = DAYS FROM JAN 1 OF FIRST SAMPLE YEAR*
< *JULIAN CALCULATION WILL BE OFF BY 1 DAY AFTER FEB 29 OF LEAP YEAR*

<H>
P R O F I L E - PROCEDURES: < MAIN MENU

```
  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END
```

OPTION < .>?   4 < *LIST PROFILE DATA*

< *LISTS DATA DEFINED BY WINDOW SORTED BY STATION/DATE/DEPTH*

BEAVER RESERVOIR - EPA/NES DATA

ST	DATE	DEPTH	TEMP	OXYGEN	TOTAL P	TOTAL N	ORTHO P	SECCHI	CHLA
1	74 4 5	0.0	11.7	-9.0	9.0	440.0	4.0	2.3	1.7
1	74 4 5	1.5	11.6	10.0	9.0	410.0	6.0	-9.0	-9.0
1	74 4 5	4.6	11.6	10.0	16.0	420.0	10.0	-9.0	-9.0
< *ETC.*									
6	7410 9	4.6	17.7	6.4	60.0	720.0	28.0	-9.0	-9.0
6	7410 9	9.2	17.6	6.8	49.0	720.0	14.0	-9.0	-9.0
6	7410 9	11.9	17.5	6.2	89.0	800.0	9.0	-9.0	-9.0

< *NOTE "-9." IS MISSING VALUE CODE DEFINED IN INPUT FILE*

<H>

PROFILE - DOCUMENTED SESSION

```
P R O F I L E  -  PROCEDURES:

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END

OPTION <  .>?   5   < REQUEST DATA INVENTORIES BY STATION, COMPONENT, AND DATE

< INVENTORIES ALL DATA DEFINED IN CURRENT WINDOW

DATA INVENTORY FOR COMPONENT:  1 TEMP      STATION: 1 ABOVE DAM
ROUND  DATE  JULIAN  SELEV  SAMPLES   ZMIN   ZMAX   CMIN   CMAX
                       M                M      M     CU     CU
   1  74 4 5    95   342.8        7    0.0   61.0    7.3   11.7
   2  74 618   169   342.8        9    0.0   52.2    8.5   24.5
   3  74 830   242   341.0        9    0.0   51.9    9.2   26.3
   4  7410 9   282   341.3       10    0.0   53.4    9.5   19.6
<H>

< SELEV   = SURFACE ELEVATION
< SAMPLES = NUMBER OF SAMPLES
< ZMIN    = MINIMUM DEPTH AT WHICH A SAMPLE WAS TAKEN
< ZMAX    = MAXIMUM DEPTH AT WHICH A SAMPLE WAS TAKEN
< CMIN    = MINIMUM CONCENTRATION (OR TEMPERATURE)
< CMAX    = MAXIMUM CONCENTRATION (OR TEMPERATURE)

< OUTPUT CONTINUES FOR ALL STATIONS AND COMPONENTS

DATA INVENTORY FOR COMPONENT:  2 OXYGEN    STATION: 1 ABOVE DAM
ROUND  DATE  JULIAN  SELEV  SAMPLES   ZMIN   ZMAX   CMIN   CMAX
                       M                M      M     CU     CU
   1  74 4 5    95   342.8        6    1.5   61.0    8.4   10.0
   2  74 618   169   342.8        8    1.5   52.2    5.4    9.0
   3  74 830   242   341.0        9    0.0   51.9    0.4    7.8
   4  7410 9   282   341.3       10    0.0   53.4    0.2    7.6

<H>   9   < ENTER POSITIVE NUMBER IN RESPONSE TO <H> TO END DATA
          <         INVENTORY AND RETURN TO MAIN MENU
```

PROFILE - DOCUMENTED SESSION

```
P R O F I L E  -  PROCEDURES:
  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END

OPTION <  .>?    7    < DEMONSTRATE TRANSFORMATION PROCEDURES

< TRANSFORMATIONS OPERATE ON ALL DATA STORED IN MEMORY,
<          REGARDLESS OF CURRENT WINDOW
< VARIABLES CAN BE RESCALED (MULTIPLIED BY A CONSTANT)
< TWO VARIABLES CAN BE COMBINED VIA SIMPLE ARITHMETIC OPERATIONS
< NON-ALGAL TURBIDITY CAN BE CALCULATED FROM CHL-A AND SECCHI DATA

P R O F I L E  TRANSFORMATION MENU:

 1. = SCALE FACTOR     C(N) = C(N) * CONSTANT
 2. = ADD              C(N) = C(I) + C(J)
 3. = SUBTRACT         C(N) = C(I) - C(J)
 4. = MULTIPLY         C(N) = C(I) * C(J)
 5. = DIVIDE           C(N) = C(I) / C(J)

 6. = TURBIDITY CALC   C(N) = 1/SECCHI(I) - .026*CHLA(J)

 0. = RETURN TO MENU

< DEMONSTRATE TRANSFORMATION BY COMPUTING TOTAL N/TOTAL P RATIO

CODE < .>?  5             < DIVIDE TWO COMPONENTS

SUBSCRIPT   LABEL         < PRINT CURRENT VARIABLE DEFINITIONS
     1      TEMP
     2      OXYGEN
     3      TOTAL P
     4      TOTAL N
     5      ORTHO P
     6      SECCHI
     7      CHLA

< ACCORDING TO ABOVE FORMULA FOR DIVISION, WILL COMPUTE C(N) = C(I)/C(J)
< NOW DEFINE SUBSCRIPTS I,J, AND N
< OUTPUT SUBSCRIPT (N) MUST REPLACE  EXISTING VARIABLE ( 1 <= N <= 7)
< ENTER A NONSENSE VALUE (E.G., -6, 0, 8) IN RESPONSE TO ANY OF THE FOLLOWING
<       PROMPTS TO BAIL OUT AND RETURN TO TRANSFORMATION MENU
```

PROFILE - DOCUMENTED SESSION

```
I SUBSCRIPT < .>?   4              < TOTAL NITROGEN        (NUMERATOR)
J SUBSCRIPT < .>?   3              < TOTAL PHOSPHORUS      (DENOMINATOR)
N (OUTPUT) SUBSCRIPT < .>?  5      < OUTPUT SUBSCRIPT      (REPLACE PDIS)
NEW 8-CHARACTER LABEL ?   TN/TP    < NEW LABEL

< TRANSFORMATIONS COMPUTED
< VARIABLE 5 IS NOW THE RATIO OF TOTAL N/TOTAL P

< TRANSFORMATIONS CAN BE USED FOR THE FOLLOWING PURPOSES:
<    * CALCULATE DIAGNOSTIC VARIABLES, TN/TP, CHLA/TP, CHLA*SECCHI, TURBIDITY
<    * COMBINE NUTRIENT SPECIES (E.G., COMPUTE INORGANIC-N FROM
<                    INPUT AMMONIA-N AND NO23-N VALUES)
<    * RESCALE VALUES TO IMPROVE NUMBER OF SIGNIFICANT DIGITS IN OUTPUT
<            (E.G., OUTPUT FROM MIXED-LAYER SUMMARY PROCEDURE PROVIDES 1 DIGIT TO
<            RIGHT OF DECIMAL POINT;
<            FOR VARIABLES LIKE CHLA/TP, SECCHI, TURBIDITY, ETC., RESOLUTION
<            CAN BE IMPROVED BY MULTIPLYING BY 10

<H>
P R O F I L E  TRANSFORMATION MENU:      < RETURN TO TRANSFORMATION MENU

 1. = SCALE FACTOR    C(N) = C(N) * CONSTANT
< ETC. TRANSFORMATION MENU
 0. = RETURN TO MENU

CODE < .>?  0              < RETURN TO MAIN MENU


< DEMONSTRATE PLOTTING PROCEDURES

P R O F I L E  -  PROCEDURES:      < MAIN MENU

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END

OPTION <  .>?   6        < REQUEST PLOT MENU

< PROGRAM AUTOMATICALLY JUMPS TO WINDOW PROCEDURE BEFORE PLOT
```

PROFILE - DOCUMENTED SESSION

```
P R O F I L E   WINDOW, SAMPLES =      169  < NUMBER OF SAMPLES IN WINDOW,
                                            < WHICH IS CURRENTLY SET TO
CURRENT PARAMETER VALUES:                   < INCLUDE ALL VALUES
  1. =  STATION RANGE   =     1 TO     6
  2. =  ROUND RANGE     =     1 TO     4
  3. =  DEPTH RANGE     =   0.0 TO 999.0
  4. =  COMPONENT RANGE =     1 TO     7

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>?  4          < DEFINE RANGE OF COMPONENTS

COMPONENTS:
      1 = TEMP
      2 = OXYGEN
      3 = TOTAL P
      4 = TOTAL N
      5 = TN/TP
      6 = SECCHI
      7 = CHLA

FIRST COMPONENT <  .>?  2     < SET WINDOW TO INCLUDE OXYGEN DATA ONLY
LAST COMPONENT <  .>?  2

< RESET WINDOW ACCORDINGLY AND RETURN TO WINDOW MENU

P R O F I L E   WINDOW, SAMPLES =      157  < 157 NON-MISSING VALUES FOR OXYGEN

CURRENT PARAMETER VALUES:
  1. =  STATION RANGE   =     1 TO     6
  2. =  ROUND RANGE     =     1 TO     4
  3. =  DEPTH RANGE     =   0.0 TO 999.0
  4. =  COMPONENT RANGE =     2 TO     2

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>?  0            < KEEP CURRENT WINDOW SETTING AND MOVE ON
                           < TO PLOT PROCEDURES
```

```
P R O F I L E -  DISPLAY MENU:        < PLOTTING MENU

 1. = SET PLOT WIDTH AND HEIGHT       < CAN BE USED TO RESET PLOT SIZE

      --------  P L O T   F O R M A T S  --------
      Y-VARIABLE  X-VARIABLE     SYMBOL      BY

 2. = ELEVATION      CONC         DATE     STATION     < PLOTTING OPTIONS
 3. = ELEVATION      CONC       STATION      DATE
 4. = ELEVATION      DATE         CONC     STATION
 5. = ELEVATION      RKM          CONC       DATE
 6. =   CONC         RKM          DATE
 7. =   CONC         DATE       STATION

 8. = HISTOGRAMS
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

< DEMONSTRATES PLOT FORMATS 2,3,4,5 ON OXYGEN DATA FROM BEAVER RESERVOIR

< VARIABLE DEFINITIONS:
<   Y-VARIABLE =        DEFINES VERTICAL AXIS
<   X-VARIABLE =        DEFINES HORIZONTAL AXIS
<   SYMBOL     = PLOT SYMBOL IS DATE, STATION, OR CONCENTRATION
<   BY         = SEPARATE PLOT GENERATED FOR EACH STATION OR DATE

CODE <NN.> ?  2          < PLOT PROCEDURE 2

LOG-TRANSFORM CONCENTRATION <0.=NO,1.=YES>?   0      < DO NOT TRANSFORM

DATES SEPARATE <0.> OR COMBINED <1.>?   1
<  IF = 0, SEPARATE PLOT WILL BE GENERATED FOR EACH DATE
<  IF = 1, DATES COMBINED ON ONE PLOT USING DIFFERENT SYMBOLS
```

```
BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
STATION:  1 ABOVE DAM        RKM:  119.0  BASE ELEV:  279.4
SYMBOL = JULIAN DAY:
1= 95  2=169  3=242  4=282
 ELEV (M)
   341.30|                                  4 3       2    1
   337.58|                                 4 3        2    1
   333.86|                        4              3
   330.14| 3                          2
   326.43|                               2   4             1
   322.71|    3                          4
   318.99|
   315.27|        4          3                   2
   311.56|                                               1
   307.84|
   304.12|            4        3                2
   300.41|
   296.69|4        3                                   1
   292.97|
   289.25| 43                       2
   285.54|
   281.82|                                           1
         +-------+-------+-------+-------+-------+-------+--
        0.20    1.80    3.40    5.00    6.60    8.20    9.80
                                 OXYGEN
```

<H>

< *ETC. FOR EACH STATION AND COMPONENT DEFINED IN WINDOW*

<H>

```
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT

      --------  P L O T   F O R M A T S  --------
      Y-VARIABLE  X-VARIABLE     SYMBOL      BY

 2. = ELEVATION      CONC         DATE    STATION
 3. = ELEVATION      CONC       STATION    DATE
 4. = ELEVATION      DATE         CONC    STATION
 5. = ELEVATION      RKM          CONC     DATE
 6. =   CONC         RKM          DATE
 7. =   CONC         DATE       STATION

 8. = HISTOGRAMS
 9. = BOX PLOTS

99. = RETURN TO MAIN MENU

CODE <NN.> ?  3
```

< *DEMONSTRATE PROCEDURE 3*

```
LOG-TRANSFORM CONCENTRATION <0.=NO,1.=YES>?   0
```

< *PLOT ELEVATION VS. OXYGEN CONCENTRATION USING SYMBOLS TO DEFINE STATIONS*

```
BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
ROUND= 1  JULIAN DATE= 95  CALENDAR DATE=74 4 5
SYMBOL = STATION:
1= 1  2= 2  3= 3  4= 4  5= 5  6= 6
 ELEV (M)
   341.30|                        5  6           4  3
   337.58|                     6  5     4        1      2
   333.86|                        5
   330.14|          5             6        4
   326.43|                                    2  1
   322.71|             5
   318.99|                   4                3
   315.27|4
   311.56|                        2        1
   307.84|                        3
   304.12|
   300.41|
   296.69|                     1
   292.97|                  2
   289.25|
   285.54|
   281.82|               1
         +-------+-------+-------+-------+-------+-------+--
        7.20    7.72    8.24    8.77    9.29    9.81   10.33
                                 OXYGEN
<H>
```

< *ETC., PLOTS GENERATED FOR EACH SAMPLING DATE AND COMPONENT IN WINDOW*

```
<H>

P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT

      --------  P L O T   F O R M A T S  --------
      Y-VARIABLE  X-VARIABLE     SYMBOL      BY

 2. = ELEVATION      CONC         DATE    STATION
 3. = ELEVATION      CONC        STATION    DATE
 4. = ELEVATION      DATE         CONC    STATION
 5. = ELEVATION      RKM          CONC      DATE
 6. =   CONC         RKM          DATE
 7. =   CONC         DATE        STATION

 8. = HISTOGRAMS
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU
```

PROFILE - DOCUMENTED SESSION

```
CODE <NN.> ?  4   < DEMONSTRATE PROCEDURE 4

< PLOT ELEVATION VS DATE USING SYMBOLS TO DEFINE CONCENTRATION LEVELS
<                SIMILAR TO CONTOUR PLOT
< CONTOURS CAN BE SKETCHED IN BY HAND
< HIGHER SAMPLE DENSITY THAN BELOW DESIRABLE FOR CONTOUR PLOTTING

BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
STATION:  1 ABOVE DAM        RKM:  119.0  BASE ELEV:  279.4
SYMBOL = MAXIMUM VALUE:
1=   2.0  2=   4.0  3=   6.0  4=   8.0  5=  10.0  6=  12.0
 ELEV (M)
   341.30|5              5                   4          4
   337.58|5              5                   4          4
   333.86|               4                   4          3
   330.14|               3                   1
   326.43|5              4                              4
   322.71|                                   1          4
   318.99|
   315.27|               4                   3          1
   311.56|5
   307.84|
   304.12|               4                   3          2
   300.41|
   296.69|5                                  1          1
   292.97|
   289.25|               3                   1          1
   285.54|
   281.82|5
         +-------+-------+-------+-------+-------+-------+--
       95.00  125.53  156.06  186.59  217.12  247.65  278.18
                                D A T E

< ETC.
< PLOT REPEATED FOR EACH STATION AND COMPONENT IN CURRENT WINDOW

P R O F I L E -  DISPLAY MENU:

 1. SET PLOT WIDTH AND HEIGHT

< ETC.

 8. = HISTOGRAMS
 9. = BOX PLOTS

99. = RETURN TO MAIN MENU
```

```
CODE <NN.> ?  5  < DEMONSTRATE PROCEDURE 5

< PLOT ELEVATION VS RIVER KILOMETER USING SYMBOLS TO DEFINE CONCENTRATION

BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
ROUND= 1  JULIAN DATE= 95  CALENDAR DATE=74 4 5
SYMBOL = MAXIMUM VALUE:
1=   2.0  2=   4.0  3=   6.0  4=   8.0  5=  10.0  6=  12.0
 ELEV (M)
   341.30I5          5       5          6         6        5
   337.58I5          5       5          5         6        5
   333.86I5          5
   330.14I5          4       5
   326.43I                              5         5        5
   322.71I           5
   318.99I                   5          5
   315.27I                   4
   311.56I                                        5        5
   307.84I                              5
   304.12I
   300.41I
   296.69I        DOWNSTREAM --->                          5
   292.97I                                        5
   289.25I
   285.54I
   281.82I                                                 5
          +-------+-------+-------+-------+-------+-------+--
         5.70   24.20   42.70   61.19   79.69   98.19  116.69
                                  R K M
<H>
```

PROFILE - DOCUMENTED SESSION

```
BEAVER RESERVOIR - EPA/NES DATA           COMPONENT:  2 OXYGEN
ROUND= 2  JULIAN DATE=169  CALENDAR DATE=74 618
SYMBOL = MAXIMUM VALUE:
I=   2.0  2=   4.0  3=   6.0  4=   8.0  5=  10.0  6=  12.0
 ELEV (M)
   341.30|5           3       4          5         5        5
   338.13|3           3       3          5         5        5
   334.97|3                   3                    4        4
   331.80|                    3          3         3        3
   328.64|3           2
   325.47|                    3          3         3        4
   322.31|            2       2          3
   319.14|                    3                    4
   315.98|                                                  4
   312.82|                    2          3
   309.65|                                         4
   306.49|                               2
   303.32|                                                  4
   300.16|                                         3
   296.99|
   293.83|                                         3
   290.67|                                                  3
          +-------+-------+-------+-------+-------+-------+--
        5.70    24.20   42.70   61.19   79.69   98.19  116.69
                                  R K M

<H>
BEAVER RESERVOIR - EPA/NES DATA           COMPONENT:  2 OXYGEN
ROUND= 3  JULIAN DATE=242  CALENDAR DATE=74 830
SYMBOL = MAXIMUM VALUE:
1=   2.0  2=   4.0  3=   6.0  4=   8.0  5=  10.0  6=  12.0
 ELEV (M)
   340.99|3           3       4          4         4        4
   337.75|3                   3          4         4        4
   334.51|1           2       2                    4        4
   331.27|1           1       1          3         2
   328.03|            1                                     1< INDICATION OF
   324.79|                    1                    1         < METALIMNETIC
   321.55|                               1                  1< OXYGEN DEMAND
   318.31|                               1
   315.06|                    1                    2        3
   311.82|
   308.58|                               1
   305.34|                                         1        3< INDICATION OF
   302.10|                                                   < HYPOLIMNETIC
   298.86|                                                   < OXYGEN DEMAND
   295.62|                                         1        1
   292.38|
   289.14|                                                  1
          +-------+-------+-------+-------+-------+-------+--
        5.70    24.20   42.70   61.19   79.69   98.19  116.69
                                  R K M
<H>
```

```
BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
ROUND= 4  JULIAN DATE=282  CALENDAR DATE=7410 9
SYMBOL = MAXIMUM VALUE:
1=   2.0  2=   4.0  3=   6.0  4=   8.0  5=  10.0  6=  12.0
 ELEV (M)
   341.30I4          4       3          4         4        4
   337.96I4          3       3          4         4        4
   334.62I
   331.29I4          3       3          4         4        3
   327.95I4          3       3          4         4        4
   324.62I           3                  3         4        4
   321.28I                   1
   317.94I                              1
   314.61I                   1          1         1        1
   311.27I
   307.94I
   304.60I                                        1        2
   301.26I
   297.93I
   294.59I                                        1        1
   291.26I
   287.92I                                                 1
         +-------+-------+-------+-------+-------+-------+--
        5.70   24.20   42.70   61.19   79.69   98.19  116.69
                                 R K M
<H>

P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
      --------  P L O T   F O R M A T S  --------
      Y-VARIABLE  X-VARIABLE    SYMBOL      BY

 2. = ELEVATION      CONC         DATE    STATION
 3. = ELEVATION      CONC       STATION     DATE
 4. = ELEVATION      DATE         CONC    STATION
 5. = ELEVATION      RKM          CONC      DATE
 6. =   CONC         RKM          DATE
 7. =   CONC         DATE       STATION

 8. = HISTOGRAMS
 9. = BOX PLOTS

99. = RETURN TO MAIN MENU

CODE <NN.> ?  99
```
< RETURN TO MAIN MENU

< FURTHER PLOT DEMONSTRATIONS

PROFILE - DOCUMENTED SESSION

```
P R O F I L E  -  PROCEDURES:       MAIN MENU

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END

OPTION < .>?  6      < REQUEST DISPLAY MENU

P R O F I L E   WINDOW, SAMPLES =     157   < FIRST CHECK WINDOW AUTOMATICALLY

CURRENT PARAMETER VALUES:

  1. =  STATION RANGE   =    1 TO     6
  2. =  ROUND RANGE     =    1 TO     4
  3. =  DEPTH RANGE     =  0.0 TO 999.0
  4. =  COMPONENT RANGE =    2 TO     2

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>?  4      < SET COMPONENT RANGE

COMPONENTS:
      1 = TEMP
      2 = OXYGEN
      3 = TOTAL P
      4 = TOTAL N
      5 = TN/TP
      6 = SECCHI
      7 = CHLA

FIRST COMPONENT <  .>?  3    < INCLUDE ONLY TOTAL P DATA FOR THIS EXAMPLE
LAST COMPONENT <  .>?  3
```

```
P R O F I L E   WINDOW, SAMPLES =      168

CURRENT PARAMETER VALUES:

  1. =  STATION RANGE    =      1 TO      6
  2. =  ROUND RANGE      =      1 TO      4
  3. =  DEPTH RANGE      =    0.0 TO 999.0
  4. =  COMPONENT RANGE =       3 TO      3

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>?  3                  < SET DEPTH RANGE

DEFINE SAMPLE DEPTH RANGES:
MINIMUM DEPTH (M) ?   0       < INCLUDE ONLY 0 - 5 METER SAMPLES FOR EXAMPLE
MAXIMUM DEPTH (M) ?   5

P R O F I L E   WINDOW, SAMPLES =       68  < 68 TOTAL P SAMPLES BETWEEN 0-5 M

CURRENT PARAMETER VALUES:

  1. =  STATION RANGE    =      1 TO      6
  2. =  ROUND RANGE      =      1 TO      4
  3. =  DEPTH RANGE      =    0.0 TO   5.0
  4. =  COMPONENT RANGE =       3 TO      3

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>? 0   < KEEP CURRENT WINDOW AND MOVE ON TO DISPLAY MENU

<  NOW DEMONSTRATE PLOT PROCEDURES 6-9 USING 0-5 METER SAMPLES FOR TOTAL P

P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
      --------  P L O T   F O R M A T S  --------
      Y-VARIABLE  X-VARIABLE     SYMBOL       BY

 2. = ELEVATION      CONC          DATE    STATION
 3. = ELEVATION      CONC        STATION     DATE
 4. = ELEVATION      DATE          CONC    STATION
 5. = ELEVATION      RKM           CONC      DATE
 6. =   CONC         RKM           DATE
 7. =   CONC         DATE        STATION

 8. = HISTOGRAMS
 9. = BOX PLOTS

99. = RETURN TO MAIN MENU
```

PROFILE - DOCUMENTED SESSION

```
CODE <NN.> ?  6
```

< PROCEDURE 6

< PLOT CONCENTRATION VS. RIVER KILOMETER, USING SYMBOLS TO DEFINE DATES

```
LOG-TRANSFORM CONCENTRATION <0.=NO,1.=YES>?   0
DATES SEPARATE <0.> OR COMBINED <1.>?   1
```

< IF = 0 SEPARATE PLOT GENERATED FOR EACH DATE
< IF = 1 DATES COMBINED ON ONE PLOT

```
BEAVER RESERVOIR - EPA/NES DATA           COMPONENT:  3 TOTAL P
SYMBOL = JULIAN DAY:
1= 95  2=169  3=242  4=282
 TOTAL P
    98.00I2          2
    92.38I
    86.75I           2
    81.13I
    75.50I           2          DOWNSTREAM DIRECTION --->
    69.88I1
    64.25I2
    58.63I2
    53.00I3          1
    47.38I4          1
    41.75I4          4       1          1
    36.13I                   1          1
    30.50I           4       4
    24.88I                              2
    19.25I                   4          3         1
    13.63I                              4         4        3
     8.00I                                        2        2
          +-------+-------+-------+-------+-------+-------+--
         5.70   24.20   42.70   61.19   79.69   98.19  116.69
                                  R K M
```

< PLOT REPEATED FOR EACH COMPONENT IN CURRENT WINDOW

< USE LOG TRANSFORMATION TO GET BETTER RESOLUTION AT LOW SCALE VALUES
< RKM'S DEFINED IN INPUT FILE CAN BE ANY CONVENIENT FRAME OF REFERENCE
< VALUES NOT PLOTTED IF RKM < 0

PROFILE - DOCUMENTED SESSION

```
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT

< ETC.

 8. = HISTOGRAMS
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

CODE <NN.> ?  7      < DEMONSTRATE PROCEDURE 7

< PLOT CONCENTRATION VS. DATE WITH SYMBOLS DEFINING STATIONS

LOG-TRANSFORM CONCENTRATION <0.=NO,1.=YES>?   1     < LOG10 SCALES
STATIONS SEPARATE <0.> OR COMBINED <1.>?  0
<  IF = 0 SEPARATE PLOT GENERATED FOR EACH STATION
<  IF = 1 STATIONS COMBINED ON ONE PLOT

BEAVER RESERVOIR - EPA/NES DATA           COMPONENT:  3 TOTAL P
STATION:  1 ABOVE DAM        RKM:  119.0  BASE ELEV:  279.4
SYMBOL = STATION
 TOTAL P
     1.20|1                                                1
     1.19|
     1.17|
     1.15|                                      1
     1.13|
     1.11|
     1.09|
     1.07|                                      1
     1.05|
     1.03|
     1.02|
     1.00|                   1                             1
     0.98|
     0.96|1                  1
     0.94|
     0.92|
     0.90|                   1
          +-------+-------+-------+-------+-------+-------+--
        95.00  125.53  156.06  186.59  217.12  247.65  278.18
                                  D A T E
<H>


<  DATE = DAYS FROM JAN 1 OF FIRST SAMPLE YEAR
<  ETC. FOR EACH STATION AND COMPONENT IN WINDOW
```

PROFILE – DOCUMENTED SESSION

```
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
 8. = HISTOGRAMS
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

CODE <NN.> ?  8      < DEMONSTRATE PROCEDURE 8

< VERTICAL HISTOGRAMS OF CONCENTRATION

GROUPS: STATION<1.>, SEGMENT<2.>, OR DATE<3.> ?   1
< ABOVE DEFINES SYMBOLS USED IN HISTOGRAMS

SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1     < GEOMETRIC SCALE

< LINEAR SCALE INCREASES BY FIXED INCREMENT
< GEOMETRIC SCALE INCREASES BY FIXED FACTOR (USUALLY NORMALIZES NUTRIENT DATA)

COMPONENT:  3 TOTAL P
SYMBOL = STATION
INTERVAL MINIMUM - GEOMETRIC SCALE
        98.00 5
        82.92 65            < DEPICTS GENERAL RANGE AND DISTRIBUTION OF VALUES
        70.17 5
        59.37 66666
        50.24 665
        42.51 65556
        35.97 4645536443    < VALUES BETWEEN 35.97 AND 42.51
        30.44 3544
        25.76 5
        21.79 343
        18.44 44444
        15.60 232311
        13.20 33221
        11.17 21
         9.45 32322111
         8.00 2112121           < VALUES < 9.45
         0.00

<H>
```

PROFILE - DOCUMENTED SESSION

```
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

CODE <NN.> ?  9        < DEMONSTRATE PROCEDURE 9

< BOX PLOTS DESIGNED TO COMPARE DISTRIBUTIONS OF DATA GROUPED
<           IN CATEGORIES DEFINED BY STATION, SEGMENT, DATE
< NOTE: SEGMENT IS A GROUP OF STATIONS (RESERVOIR AREA) DEFINED IN INPUT FILE

GROUPS: STATION<1.>, SEGMENT<2.>, OR DATE<3.> ?   1  < BOX PLOTS BY STATION
< ABOVE DEFINES GROUPING METHOD

SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1   < GEOMETRIC SCALE

COMPONENT:  3 TOTAL P
STATION  NOBS  MEDIAN  PERCENTILES:  10 25 50 75 90

    1.00   11    10.00 -||*||||||||---

    2.00   11    11.00 -||||*||||||||---

    3.00   11    16.00      -------|*|||||||||||||||||---

    4.00   12    26.50                  ||||||*|||||||---

    5.00   11    46.00                         ------|||*||||||||||||------

    6.00   12    58.50                               --||||||*||------

                       +--------+--------+--------+--------+--------+--------+--
TOTAL P  -->          8.20     12.25    18.31    27.36    40.89    61.10    91.30
GEOMETRIC SCALE


< NOBS = NUMBER OF OBSERVATIONS IN GROUP
< MEDIAN = MEDIAN VALUE IN GROUP
< PERCENTILES:     10  25    50  75   90
< SYMBOL:             ----||||||*|||||-----
< REPEAT FOR EACH COMPONENT IN WINDOW
< BOX PLOTS USUALLY EFFECTIVE FOR EVALUATING SPATIAL OR TEMPORAL VARIATIONS IN
<           MIXED-LAYER WATER QUALITY CONDITIONS
```

```
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
 8. = HISTOGRAMS
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

CODE <NN.> ?  9      < DEMONSTRATE PROCEDURE 9
< REPEAT BOX PLOTS WITH GROUPS DEFINED BY SAMPLE DATE

GROUPS: STATION<1.>, SEGMENT<2.>, OR DATE<3.> ?   3    < GROUP ON DATE
SCALE LINEAR <0.> OR GEOMETRIC <1.> ?   1

COMPONENT:  3 TOTAL P
D A T E  NOBS  MEDIAN  PERCENTILES:  10 25 50 75 90

   95.00   18   36.50    -----------|||||||||||||||*||||||-------

  169.00   19   22.00  --||||||||||||||||||*|||||||||||||||||||||---------

  242.00   13   21.00       -----||||||||*||||||||||||||-----

  282.00   18   18.00      --|||||||||*||||||||||||||||||----

                        +--------+--------+--------+--------+--------+--------+--
TOTAL P  -->          8.00    12.02    18.07    27.16    40.81    61.34    92.18
GEOMETRIC SCALE

<  HIGH SPATIAL VARIABILITY IS DEPICTED BY WIDE RANGE OF MEASUREMENTS
<          ON EACH DATE
<  REPEAT FOR EACH COMPONENT IN WINDOW
<H>
P R O F I L E -  DISPLAY MENU:

 1. = SET PLOT WIDTH AND HEIGHT
< ETC.
 9. = BOX PLOTS
99. = RETURN TO MAIN MENU

CODE <NN.> ?  99    <  RETURN TO MAIN MENU
< DEMONSTRATE MIXED-LAYER SUMMARIES
```

PROFILE - DOCUMENTED SESSION

```
P R O F I L E  -  PROCEDURES:        < MAIN MENU

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END

OPTION <  .>?   9      < PROC 9, MIXED LAYER SUMMARY

< FIRST CHECK WINDOW, CURRENTLY SET FOR TOTAL P, 0-5 METERS

P R O F I L E   WINDOW, SAMPLES =      68

CURRENT PARAMETER VALUES:

  1. =  STATION RANGE   =     1 TO     6
  2. =  ROUND RANGE     =     1 TO     4
  3. =  DEPTH RANGE     =   0.0 TO   5.0
  4. =  COMPONENT RANGE =     3 TO     3

  5. =  RESET WINDOW TO INCLUDE ALL DATA
  6. =  EDIT ALL PARAMETERS
  0. =  KEEP CURRENT WINDOW

OPTION < .>?  0         < KEEP CURRENT WINDOW

AREA-WEIGHTED SUMMARIES

< PROCEDURE DESIGNED FOR ROBUST SUMMARY OF MIXED-LAYER WATER QUALITY
< WINDOW SHOULD BE SET TO INCLUDE MIXED-LAYER, GROWING-SEASON VALUES
< SUMMARIES GENERATED IN A TWO-WAY-TABLE FORMAT
<        COLUMNS DEPICT SPATIAL VARIATIONS (DEFINED BY STATION OR SEGMENT)
<        ROWS DEPICT TEMPORAL VARIATIONS (DEFINED BY DATES OR GROUPS OF DATES)
< "CELL" = ROW/COLUMN COMBINATION

< DEFINE ROW AND COLUMN FACTORS:

GROUP BY STATION<1.> OR SEGMENT<2.> ?   1     < COLUMNS = STATION

DATE BLOCKING FACTOR< .> ?  1                 < 1 DATE PER ROW
< IF = 2, FOR EXAMPLE, CONSECUTIVE DATES WOULD BE PAIRED IN ROWS
```

PROFILE - DOCUMENTED SESSION

```
CELL SUMMARIES <1.=MEANS,2.=MEDIANS> ?  2      < USE MEDIANS
< ABOVE DEFINES METHOD FOR COMPUTING SUMMARY VALUES WITH EACH CELL
< MEDIANS RECOMMENDED BECAUSE THEY PROVIDE FILTERING OF ERRANT
<       VALUES IF NUMBER OF OBSERVATIONS PER CELL IS 3 OR GREATER
< FOR ROBUST SUMMARY, GENERAL OBJECTIVE IS TO PROVIDE AT LEAST
<       THREE VALUES PER CELL

< ENTER INVALID VALUES (E.G. 0) FOR ANY OF ABOVE PROMPTS TO RETURN TO MENU

< PROGRAM SETS UP TABLE AND PRINTS INVENTORY OF SAMPLE FREQUENCIES:

BEAVER RESERVOIR - EPA/NES DATA
COMPONENT: TOTAL P , DEPTHS:    0.0 TO    5.0 M       < CURRENT WINDOW
RESERVOIR WEIGHTED MEANS LISTED IN LAST COLUMN
TOTAL P  SAMPLE FREQUENCIES:
STATION        1       2       3       4       5       6
DATE  WTS>0.200   0.250   0.250   0.150   0.100   0.050        < SPATIAL WEIGHTS
-----------------------------------------------------------------
74 4 5         3       3       3       3       3       3      18
74 618         3       3       3       4       3       3      19
74 830         2       2       2       2       2       3      13
7410 9         3       3       3       3       3       3      18
-----------------------------------------------------------------
TOTALS        11      11      11      12      11      12      68

< PROGRAM COMPUTES AREA-WEIGHTED MEANS ACROSS ALL STATIONS
<         FOR EACH ROW (SAMPLING DATE) AND STORES RESULT IN LAST COLUMN
< COLUMNS ARE THEN SUMMARIZED VERTICALLY

< CALCULATION SUMMARY:

TOTAL P  SUMMARY VALUES:
STATION        1       2       3       4       5       6
DATE  WTS>0.200   0.250   0.250   0.150   0.100   0.050
-----------------------------------------------------------------
74 4 5       9.0    16.0    36.0    37.0    46.0    68.0    28.3 < RESERVOIR SUMMARY
74 618       9.0     9.0    16.0    27.0    88.0    63.0    24.0 < VALUES IN LAST
74 830      13.0    11.5    18.5    21.0    36.5    44.0    19.1 < COLUMN
7410 9      10.0    11.0    11.0    21.0    40.0    47.0    17.0
-----------------------------------------------------------------
MEDIANS      9.5    11.3    17.3    24.0    43.0    55.0    21.6
MEANS       10.3    11.9    20.4    26.5    52.6    55.5    22.1
CV         0.185   0.249   0.534   0.285   0.454   0.212   0.230
CV(MEAN)   0.092   0.124   0.267   0.142   0.227   0.106   0.115
```

```
< CV =        COEFFICIENT OF VARIATION = STANDARD DEVIATION/MEAN
<             REFLECTS TEMPORAL VARIABILITY
< CV (MEAN)=  COEFFICIENT OF VARIATION OF THE MEAN = STANDARD ERROR/MEAN
<             REFLECTS PRECISION OF CALCULATED MEAN VALUE

< THE MIXED-LAYER MEAN CONCENTRATION FOR THE ENTIRE RESERVOIR IS
<         ESTIMATED AT 22.1 MG/M3 (CV(MEAN) = 0.115)

< MEAN AND CV(MEAN) FOR EACH STATION (OR SEGMENT) ARE USED IN BATHTUB PROGRAM

< PROCEDURE CAN HANDLE MISSING CELLS, BUT RESULTS ARE LESS RELIABLE
< PROCEDURE REPEATED FOR EACH COMPONENT IN WINDOW

< MIXED-LAYER SUMMARY CALCULATIONS COMPLETED, RETURN TO MAIN MENU

<H>

< DEMONSTRATE OXYGEN DEPLETION CALCULATIONS

P R O F I L E  -  PROCEDURES:

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARIES
 10. = HELP
 99. = END

OPTION <  .>?   8        < CALCULATE OXYGEN DEPLETION RATES

< OBJECTIVE IS TO CALCULATE THE RATE OF OXYGEN DEPLETION IN THE
<       RESERVOIR HYPOLIMNION AND METALIMNION, BOTH OF WHICH ARE
<       IMPORTANT SYMPTOMS OF EUTROPHICATION IN STRATIFIED RESERVOIRS
< DEPLETION RATES ARE EXPRESSED ON AN AREAL BASIS (HODa MG/M2-DAY)
<                              AND VOLUMETRIC BASIS (HODv MG/M3-DAY)
```

PROFILE - DOCUMENTED SESSION

HYPOLIMNETIC OXYGEN DEPLETION (HOD) CALCULATIONS FOR NEAR-DAM STATIONS

COMPONENTS: < *INDEX OF COMPONENTS CURRENTLY IN MEMORY*
1 = TEMP < *WINDOW AUTOMATICALLY RESET TO INCLUDE ALL COMPONENTS*
2 = OXYGEN
3 = TOTAL P
4 = TOTAL N
5 = TN/TP
6 = SECCHI
7 = CHLA

TEMPERATURE SUBSCRIPT < .>? 1 < *SPECIFY TEMPERATURE SUBSCRIPT*
OXYGEN SUBSCRIPT < .>? 2 < *SPECIFY OXYGEN SUBSCRIPT*
STATION NUMBER FOR HOD CALCULATIONS? 1 < *NEAR-DAM STATION NUMBER*

< *INVALID VALUES FOR ABOVE WILL CAUSE RETURN TO MAIN MENU*

< *DEFINE ELEVATION INCREMENT FOR INTERPOLATION AND INTEGRATION OF PROFILES*

TOTAL ELEVATION RANGE = 278.8 342.8 METERS
NOMINAL ELEVATION INCREMENT = 3.20 METERS

ELEVATION INCREMENT? 5 < *PROGRAM WILL ADJUST THIS VALUE, IF NECESSARY*
< *TO GIVE A MAXIMUM OF 30 DEPTH SLICES*

< *PROGRAM INTERPOLATES AND INTEGRATES INPUT AREA/ELEVATION TABLE AT*
< *UNIFORM ELEVATION INCREMENT, STARTING AT RESERVOIR*
< *BOTTOM (IE AREA = 0)*

BEAVER RESERVOIR - EPA/NES DATA - MORPHOMETRIC TABLE

ELEV M,MSL	DEPTH M	AREA KM2	ZMEAN M	ZMAX M	VOLUME HM3
342.82	0.00	119.93	18.80	64.05	2255.09
338.77	4.05	102.00	17.71	60.00	1806.17
333.77	9.05	81.39	16.57	55.00	1348.66
328.77	14.05	63.78	15.47	50.00	986.62
323.77	19.05	49.51	14.22	45.00	704.14
318.77	24.05	37.20	13.12	40.00	488.10
313.77	29.05	29.47	10.92	35.00	321.82
308.77	34.05	21.73	8.94	30.00	194.31
303.77	39.05	14.00	7.55	25.00	105.68
298.77	44.05	7.06	7.66	20.00	54.02
293.77	49.05	4.66	5.36	15.00	24.95
288.77	54.05	2.26	3.55	10.00	8.02
283.77	59.05	0.66	1.67	5.00	1.11
278.77	64.05	0.00	0.00	0.00	0.00

< *DEPTH = DISTANCE FROM SURFACE*
< *ZMAX = DISTANCE FROM BOTTOM*
< *ZMEAN = MEAN DEPTH*

PROFILE - DOCUMENTED SESSION

< *PRINT DATA INVENTORIES FOR TEMPERATURE AND OXYGEN AT SPECIFIED STATION*

DATA INVENTORY FOR COMPONENT: 1 TEMP STATION: 1 ABOVE DAM

ROUND	DATE	JULIAN	SELEV	SAMPLES	ZMIN	ZMAX	CMIN	CMAX
			M		M	M	CU	CU
1	74 4 5	95	342.8	7	0.0	61.0	7.3	11.7
2	74 618	169	342.8	9	0.0	52.2	8.5	24.5
3	74 830	242	341.0	9	0.0	51.9	9.2	26.3
4	7410 9	282	341.3	10	0.0	53.4	9.5	19.6

DATA INVENTORY FOR COMPONENT: 2 OXYGEN STATION: 1 ABOVE DAM

ROUND	DATE	JULIAN	SELEV	SAMPLES	ZMIN	ZMAX	CMIN	CMAX
			M		M	M	CU	CU
1	74 4 5	95	342.8	6	1.5	61.0	8.4	10.0
2	74 618	169	342.8	8	1.5	52.2	5.4	9.0
3	74 830	242	341.0	9	0.0	51.9	0.4	7.8
4	7410 9	282	341.3	10	0.0	53.4	0.2	7.6

< *CMIN, CMAX = MINIMUM, MAXIMUM VALUES*
< *CU = COMPONENT UNITS (DEG-C FOR TEMP, MG/L FOR OXYGEN)*
< *ZMIN, ZMAX = DEPTH RANGE FOR NON-MISSING VALUES*

DEFINE SAMPLING ROUNDS FOR HOD CALCS
FIRST SAMPLING ROUND <NN.>? 1 < *ENTER FIRST ROUND*
LAST SAMPLING ROUND <NN.>? 3 < *ENTER LAST ROUND*

< *FOR VALID HOD CALCULATIONS, USER SELECTS ROUNDS BASED UPON FOLLOWING:*
< *1-WATER COLUMN STRATIFIED (TOP-TO-BOTTOM TEMPERATURE DIFFERENCE > 4 DEG C)*
< *2-MEAN HYPOLIMNETIC DISSOLVED OXYGEN > 2 MG/LITER*

< *"FIRST SAMPLING ROUND" IS FIRST ROUND IN SEASON SATISFYING BOTH CRITERIA*
< *"LAST SAMPLING ROUND" IS LAST ROUND SATISFYING BOTH CRITERIA*

< *PROGRAM INTERPOLATES TEMPERATURE PROFILES FROM*
< *BOTTOM OF RESERVOIR TO SURFACE ON EACH SPECIFIED ROUND*

< *SUMMARY OF TEMPERATURE CALCULATIONS:*

BEAVER RESERVOIR - EPA/NES DATA COMPONENT: 1 temp
STATION: 1 ABOVE DAM RKM: 119.0 BASE ELEV: 279.4

	ROUND	JULIAN	SAMPLES	SURF. ELEV
FIRST:	1	95	7	342.8
LAST:	3	242	9	341.0

PROFILE - DOCUMENTED SESSION

ELEV	AREA	--- DEPTHS --- FIRST	LAST	CONCENTRATIONS FIRST	LAST	DC/DT	VERT GRADIENTS FIRST	LAST
M	KM2	METERS		CONC UNITS (CU)		CU/DAY	CU/M X 1000	
338.8	102.00	4.0	2.2	11.60	26.30	100.0	15.7	133.0
333.8	81.39	9.0	7.2	11.56	25.10	92.1	8.9	616.3
328.8	63.78	14.0	12.2	11.51	20.14	58.7	83.1	704.6
323.8	49.51	19.0	17.2	10.73	18.05	49.8	180.0	437.9
318.8	37.20	24.0	22.2	9.71	15.76	41.1	203.3	464.3
313.8	29.47	29.0	27.2	8.69	13.41	32.1	152.1	350.0
308.8	21.73	34.0	32.2	8.19	12.26	27.7	79.9	220.6
303.8	14.00	39.0	37.2	7.90	11.20	22.5	59.0	184.2
298.8	7.06	44.0	42.2	7.60	10.42	19.2	43.9	145.6
293.8	4.66	49.0	47.2	7.46	9.75	15.6	20.9	121.6
288.8	2.26	54.0	52.2	7.39	9.20	12.3	13.1	54.6
283.8	0.66	59.0	57.2	7.33	9.20	12.8	9.1	0.0
278.8	0.00	64.0	62.2	7.30	9.20	12.9	0.0	0.0

< DEPTHS = DISTANCES FROM SURFACE AT TOP OF EACH STRATA
< CONCENTRATIONS = INTERPOLATED VALUES (IN THIS CASE, TEMPERATURES)
< CU = COMPONENT UNITS
< DC/DT = TIME DERIVATIVE (CHANGE IN COMPONENT UNITS PER DAY)
< BETWEEN TWO DATES
< VERT GRADIENTS = VERTICAL TEMPERATURE GRADIENTS

< PLOT INTERPOLATED TEMPERATURE PROFILES
< REVIEW AND ESTIMATE THERMOCLINE BOUNDARIES

```
STATION  1   INTERPOLATED PROFILE   SYMBOLS: 0=DAY  95,  +=DAY 242
 ELEV (M)
   342.82|          0
   338.82|          0                                          +
   334.81|         0                                       +
   330.81|                                              <
   326.81|         0                          +         <  TOP OF METALIMNION ABOUT HERE
   322.80|       0                      +               <
   318.80|     0                  +
   314.80|  0               +
   310.80|
   306.79| 0          +                                 <
   302.79| 0        +                                   <  TOP OF HYPOLIMNION ABOUT HERE
   298.79|0       +                                     <
   294.78|0     +
   290.78|
   286.78|0   +
   282.77|0   +
   278.77|0   +
          +-------+-------+-------+-------+-------+-------+--
        7.30   10.40   13.50   16.61   19.71   22.81   25.91
                                TEMP
```

PROFILE - DOCUMENTED SESSION

< *PROGRAM INTERPOLATES OXYGEN PROFILES AT UNIFORM INCREMENTS*
< *AND PRINTS SUMMARY TABLE ANALOGOUS TO ABOVE TABLE FOR TEMPERATURE*

```
BEAVER RESERVOIR - EPA/NES DATA          COMPONENT:  2 OXYGEN
STATION:  1 ABOVE DAM        RKM:  119.0  BASE ELEV:  279.4
```

	ROUND	JULIAN	SAMPLES	SURF. ELEV
FIRST:	1	95	6	342.8
LAST:	3	242	9	341.0

		--- DEPTHS ---		CONCENTRATIONS			VERT GRADIENTS	
ELEV	AREA	FIRST	LAST	FIRST	LAST	DC/DT	FIRST	LAST
M	KM2	METERS		CONC UNITS	(CU)	CU/DAY	CU/M X 1000	
338.8	102.00	4.0	2.2	10.00	7.53	-16.8	0.0	144.7
333.8	81.39	9.0	7.2	10.00	6.29	-25.2	0.0	707.1
328.8	63.78	14.0	12.2	10.00	0.46	-64.9	10.0	538.7
323.8	49.51	19.0	17.2	9.90	0.90	-61.2	23.1	-191.5
318.8	37.20	24.0	22.2	9.77	2.37	-50.3	26.2	-321.6
313.8	29.47	29.0	27.2	9.64	4.12	-37.5	35.5	-193.3
308.8	21.73	34.0	32.2	9.41	4.30	-34.8	48.7	-8.5
303.8	14.00	39.0	37.2	9.15	4.20	-33.7	52.5	167.3
298.8	7.06	44.0	42.2	8.89	2.63	-42.6	43.8	275.5
293.8	4.66	49.0	47.2	8.71	1.45	-49.4	30.7	203.1
288.8	2.26	54.0	52.2	8.58	0.60	-54.3	26.2	85.0
283.8	0.66	59.0	57.2	8.45	0.60	-53.4	18.2	0.0
278.8	0.00	64.0	62.2	8.40	0.60	-53.1	0.0	0.0

< *DC/DT SHOWS THAT VOLUMETRIC OXYGEN DEPLETION RATE VARIED BETWEEN*
< *33 AND 65 G/M3-DAY BETWEEN ELEVATIONS 278 AND 329*

< *INTERPOLATED OXYGEN PROFILES ARE NOW INTEGRATED OVER DEPTH*
< *AND WEIGHTED ACCORDING TO SURFACE AREA AT EACH ELEVATION*
< *TABLE SUMMARIZES VOLUME-WEIGHTED CONCENTRATIONS AT EACH ELEV*

INTEGRALS OVER DEPTH

		MEAN CONC		DERIV	MASS/AREA		DERIV
ELEV	ZMEAN	FIRST	LAST	DCM/DT	FIRST	LAST	DCMA/DT
M	M	G/M3	G/M3	MG/M3-D	G/M2	G/M2	MG/M2-D
338.8	17.71	9.81	3.60	-42.30	173.8	63.7	-749.0
333.8	16.57	9.75	2.46	-49.60	161.6	40.8	-821.9
328.8	15.47	9.66	2.24	-50.46	149.4	34.7	-780.6
323.8	14.22	9.54	2.88	-45.31	135.7	41.0	-644.4
318.8	13.12	9.41	3.49	-40.28	123.5	45.8	-528.5
313.8	10.92	9.26	3.67	-37.99	101.1	40.1	-414.9
308.8	8.94	9.07	3.32	-39.11	81.1	29.7	-349.7
303.8	7.55	8.88	2.54	-43.15	67.1	19.2	-325.8
298.8	7.66	8.72	1.56	-48.74	66.8	11.9	-373.2
293.8	5.36	8.62	0.94	-52.27	46.2	5.0	-280.0
288.8	3.55	8.53	0.60	-53.94	30.3	2.1	-191.5
283.8	1.67	8.45	0.60	-53.41	14.1	1.0	-89.0
278.8	0.00	0.00	0.00	0.00	0.0	0.0	0.0

PROFILE - DOCUMENTED SESSION

```
< DCM/DT = TIME DERIVATIVE OF MEAN CONCENTRATION BELOW ELEVATION (HODv)
< DCMA/DT = TIME DERIVATIVE OF MASS PER UNIT AREA BELOW ELEVATION (HODa)
<            SHOWS SENSITIVITY OF HODa TO LOWER THERMOCLINE BOUNDARY
<            E.G., FOR BOUNDARIES BETWEEN 298.8 AND 308.8, HODa VARIES
<            BETWEEN 326 AND 373 MG/M2-DAY
< TABLE SUMMARIZES VOLUME-WEIGHTED CONCENTRATIONS BELOW EACH ELEV

< PLOT INTERPOLATED OXYGEN PROFILES

STATION  1  INTERPOLATED PROFILE   SYMBOLS: O=DAY  95,  +=DAY 242
 ELEV (M)
   342.82|                                                   O
   338.82|                                    +              O
   334.81|                             +                     O
   330.81|
   326.81|+              < METALIMNETIC DEPLETION            O
   322.80|  +                                               O
   318.80|         +                                       O
   314.80|                  +                              O
   310.80|
   306.79|                   +                           O
   302.79|                   +                          O
   298.79|           +                                 O
   294.78|     +           < HYPOLIMNETIC DEPLETION   O
   290.78|
   286.78|+                                          O
   282.77|+                                          O
   278.77|+                                         O
         +-------+-------+-------+-------+-------+-------+--
        0.46    2.01    3.57    5.13    6.69    8.25    9.81
                                OXYGEN
```

PROFILE – DOCUMENTED SESSION

< *TIME DERIVATIVE OF MASS PER UNIT AREA (HOD-a)*

```
STATION  1  AREAL DEPLETION RATE (MG/M2-DAY) BETWEEN DAYS   95 AND 242
 ELEV (M)
   338.77|                                             +
   335.33|                                                  +
   331.90|
   328.46|                                               +
   325.02|                                       +
   321.58|
   318.15|                                +
   314.71|                         +
   311.27|
   307.83|                     +
   304.40|                    +
   300.96|
   297.52|                       +
   294.08|                 +
   290.65|
   287.21|            +
   283.77|      +
          +-------+-------+-------+-------+-------+-------+-------+--
         0.00  134.19  268.38  402.57  536.77  670.96  805.15
                                  OXYGEN
```

< *TIME DERIVATIVE OF MASS PER UNIT VOLUME (HODv)*

```
STATION  1 VOLUMETRIC DEPLETION RATES (MG/M3-DAY) BETWEEN DAYS  95 AND 242
         0= AT ELEV,  += VOLUME WTD. BELOW ELEV
 ELEV (M)
   338.77|             0                  +
   335.02|                    0                 +
   331.27|
   327.52|                                       +          0
   323.77|                                   +           0
   320.02|                               +      0
   316.27|
   312.52|                             +
   308.77|                           0  +
   305.02|                          0      +
   301.27|
   297.52|                                 0   +
   293.77|                                      0 +
   290.02|                                         +
   286.27|
   282.52|                                         0
   278.77|                                         0
          +-------+-------+-------+-------+-------+-------+-------+--
         0.00   10.60   21.20   31.80   42.40   53.00   63.60
                                  OXYGEN
```

PROFILE – DOCUMENTED SESSION

< *NOW SPECIFY THERMOCLINE BOUNDARIES AND PRINT SUMMARY TABLE*
< *THERMOCLINE BOUNDARIES DO NOT HAVE TO CORRESPOND TO UNIFORM*
< *ELEVATION SLICES IN ABOVE TABLES*

```
ENTER THERMOCLINE BOUNDARIES BETWEEN   278.8 AND   342.8 METERS, MSL
ELEV AT TOP OF HYPOLIMNION?   300
ELEV AT TOP OF METALIMNION?   330
```

< *ENTER LOWER THERMOCLINE BOUNDARY*
< *ENTER UPPER THERMOCLINE BOUNDARY*

< *PRINT SUMMARY TABLE*

```
BEAVER RESERVOIR - EPA/NES DATA            COMPONENT:  2 OXYGEN
STATION:  1 ABOVE DAM        RKM:  119.0  BASE ELEV:  279.4
JULIAN DAYS:   95 TO  242
```

STATISTIC		HYPOLIMNION	METALIMNION	BOTH
ELEVATION	M	300.00	330.00	330.00
SURFACE AREA	KM2	8.76	68.11	68.11
VOLUME	HM3	66.73	1008.95	1075.68
MEAN DEPTH	M	7.61	14.81	15.79
MAXIMUM DEPTH	M	21.23	30.00	51.23
INITIAL CONC	G/M3	8.79	9.75	9.69
FINAL CONC	G/M3	1.94	2.33	2.31
AREAL DEPL. RATE	MG/M2-DAY	354.54	747.09	792.71
VOL. DEPL. RATE	MG/M3-DAY	46.56	50.44	50.30

< *VOLUMETRIC DEPLETION RATES FOR HYPOLIMNION (46.56 MG/M3-DAY) AND*
< *METALIMNION (50.44 MG/M3-DAY) AND MEAN DEPTH OF HYPOLIMNION (7.6)*
< *ARE INPUT TO BATHTUB PROGRAM*

```
TRY OTHER BOUNDARIES <0.=NO,1.=YES>?  0

LIST/PLOT TIME SERIES <0.=NO,1.=YES>?   1
```

< *FOR SPECIFIED THERMOCLINE BOUNDARIES, COMPUTE VOLUME-WEIGHTED*
< *OXYGEN CONCENTRATIONS ON EACH SAMPLING DATE AND PLOT*

THERMOCLINE BOUNDARIES: 300.0   330.0

			CONCENTRATIONS (G/M3)			DEPL. RATES (MG/M3-DAY)		
ROUND	JULIAN DATE	SAMPLES	HYPOL.	METAL.	TOTAL	HYPOL.	METAL.	TOTAL
1	95	6	8.79	9.75	9.69			
						33.58	36.67	36.48
2	169	8	6.30	7.04	6.99			
						59.73	64.39	64.10
3	242	9	1.94	2.33	2.31			
						28.75	-56.78	-51.48
4	282	10	0.79	4.61	4.37			

< *DEPL. RATES ARE COMPUTED BETWEEN EACH PAIR OF SAMPLING ROUNDS*

```
VOLUME-WTD CONCENTRATIONS:   +=HYPOL., O=METAL.
 OXYGEN
     9.751O
     9.141
     8.531+                     < SLOPE OF HYPOLIMNETIC VALUES ESTIMATES
     7.921                      <       ESTIMATES THE AVERAGE HODv
     7.311                 O    < BECAUSE OF THERMOCLINE EROSION, METALIMNETIC
     6.701                      <       CONCENTRATION (O) INCREASES ON LAST DATE
     6.091                 +
     5.481
     4.871                                               O
     4.261
     3.661
     3.051
     2.441                                     O
     1.831                                     +
     1.221
     0.611                                               +
     0.001
          +-------+-------+-------+-------+-------+-------+--
        95.00  125.53  156.06  186.59  217.12  247.65  278.18
                                D A T E

< END OF OXYGEN DEPLETION CALCULATIONS
< CAN REPEAT TO TEST SENSITIVITY TO ELEVATION INCREMENT, ETC.

P R O F I L E  -  PROCEDURES:        < MAIN MENU

  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END
OPTION <  .>?   10        < DEMONSTRATE ONLINE DOCUMENTATION (HELP)

******************************************************************
**                                                              **
**   PPPPPP   RRRRRR    OOOOOO    FFFFFF   I    L       EEEEEE  **
**   P    P   R    R    O    O    F        I    L       E       **
**   PPPPPP   RRRRRR    O    O    FFFF     I    L       EEE     **
**   P        R   R     O    O    F        I    L       E       **
**   P        R    R    OOOOOO    F        I    LLLLLL  EEEEEE  **
**                                                              **
******************************************************************
**   ONLINE DOCUMENTATION FOR -- P R O F I L E -- VERSION 2.0   **
******************************************************************
```

PROFILE - DOCUMENTED SESSION

```
CONTENTS:
           1. - GENERAL PROGRAM DESCRIPTION
           2. - PROCEDURE DESCRIPTIONS
           3. - GLOSSARY
           4.-  TERMINAL CONVENTIONS
          99. - RETURN TO PROGRAM

ENTER SELECTION ?   1                 < GENERAL DESCRIPTION

P R O F I L E - GENERAL DESCRIPTION:

PROFILE IS AN INTERACTIVE PROGRAM DESIGNED TO ASSIST IN THE ANALYSIS AND
REDUCTION OF RESERVOIR POOL WATER QUALITY DATA.

A VARIETY OF DISPLAY FORMATS PROVIDE PERSPECTIVES ON WATER QUALITY
SPATIAL (VERTICAL, HORIZONTAL) AND TEMPORAL WATER QUALITY VARIATIONS.

ALGORITHMS FOR CALCULATION OF OXYGEN DEPLETION RATES AND COMPUTATION
  OF AREA-WEIGHTED, SURFACE-LAYER MEAN CONCENTRATIONS ARE ALSO PROVIDED.

PROFILE REQUIRES AND INPUT FILE CONTAINING THE FOLLOWING TYPES OF DATA:
    - RESERVOIR MORPHOMETRY (AREA VS. ELEVATION TABLE, POOL LENGTH)
    - POOL LEVEL RECORD     (ELEVATIONS ON SAMPLING DATES)
    - WATER QUALITY STATION INDEX (LOCATION, BOTTOM ELEVATION, AREA)
    - WATER QUALITY PROFILES (STATION, DATE, DEPTH, AND CONCENTRATIONS OF
          UP TO 10 USER-SPECIFIED WATER QUALITY COMPONENTS)

< ETC.
< HELP FILE CONTAINS INFORMATION ON PROGRAM UPDATES AND OTHER BASICS

< RETURNS TO HELP MENU AFTER LISTING GENERAL DESCRIPTION

*****************************************************************
**   ONLINE DOCUMENTATION FOR -- P R O F I L E -- VERSION 2.0  **
*****************************************************************

CONTENTS:
           1. - GENERAL PROGRAM DESCRIPTION
           2. - PROCEDURE DESCRIPTIONS
           3. - GLOSSARY
           4. - TERMINAL CONVENTIONS
          99. - RETURN TO PROGRAM

ENTER SELECTION ?   99              < RETURN TO MAIN PROGRAM MENU
```

PROFILE - DOCUMENTED SESSION

P R O F I L E - PROCEDURES: *< MAIN MENU*

```
  1. = READ DATA FILE
  2. = DEFINE WINDOW
  3. = LIST STATION, DATE, AND COMPONENT KEYS
  4. = LIST PROFILE DATA
  5. = INVENTORY DATA BY STATION, COMPONENT, AND DATE
  6. = DISPLAY MENU
  7. = TRANSFORMATION MENU
  8. = CALCULATE OXYGEN DEPLETION RATES
  9. = CALCULATE MIXED-LAYER WATER QUALITY SUMMARY
 10. = HELP
 99. = END
```

ENTER SELECTION ? 99 *< END PROGRAM*

PART IV: BATHTUB - MODEL IMPLEMENTATION

BATHTUB is designed to facilitate application of empirical eutrophication models to morphometrically complex reservoirs. The program performs water and nutrient balance calculations in a steady-state, spatially segmented hydraulic network which accounts for advective transport, diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (expressed in terms of total phosphorus, total nitrogen, chlorophyll-a, transparency, organic nitrogen, nonortho-phosphorus, and hypolimnetic oxygen depletion rate) are predicted using empirical relationships previously developed and tested for reservoir applications (Walker 1985). To provide regional perspectives on reservoir water quality, controlling factors, and model performance, BATHTUB can also be configured for simultaneous application to collections or networks of reservoirs. As described in Part I, applications of the program would normally follow use of the FLUX program for reducing tributary monitoring data and use of the PROFILE program for reducing pool monitoring data, although use of the data reduction programs is optional if independent estimates of tributary loadings and/or average pool water quality conditions are used.

The functions of the program can be broadly classified as diagnostic or predictive. Typical applications would include:

a. Diagnostic.
   (1) Formulation of water and nutrient balances, including identification and ranking of potential error sources.
   (2) Ranking of trophic state indicators in relation to user-defined reservoir groups and/or the CE reservoir data base.
   (3) Identification of factors controlling algal production.

b. Predictive.
   (1) Assessing impacts of changes in water and/or nutrient loadings.
   (2) Assessing impacts of changes in mean pool level or morphometry.
   (3) Estimating nutrient loadings consistent with given water quality management objectives.

The program operates in a batch mode (noninteractive) and generates output in various formats, as appropriate for specific applications. Predicted confidence limits can be calculated for each output variable using a first-order error analysis scheme which incorporates effects of uncertainty in model input values (e.g., tributary flows and loadings, reservoir morphometry, monitored water quality) and inherent model errors.

Input formats and output listings are described at the end of this Part. The following sections review underlying theory, input data specifications, output formats, and suggested application procedures.

THEORY

Introduction

A flow diagram for BATHTUB calculations is given in Figure IV-1. The model core consists of the following procedures:

a. Water balance.

b. Nutrient balance.

c. Eutrophication response.

Using a first-order error analysis procedure (Walker 1982), the model core is executed repeatedly in order to estimate output sensitivity to each input variable and submodel and to develop variance estimates and confidence limits for each output variable. The remainder of the program consists of output routines designed for various purposes.

Control pathways for predicting nutrient levels and eutrophication response in a given model segment are illustrated in Figure IV-2. Predictions are based upon a network of models which has been empirically calibrated and tested for reservoir applications (Walker 1985). Model features are documented as follows: symbol definitions (Table IV-1), model options (Table IV-2), guidance for selecting model options (Table IV-3), supplementary response models (Table IV-4), error statistics (Table IV-5), and diagnostic variables and interpretations (Table IV-6).

As listed in Table IV-2, several options are provided for modeling nutrient sedimentation, chlorophyll-a, and transparency. In each case, Models 1 and 2 are the most general (and most accurate) formulations, based upon model testing results. Alternative models are included to permit sensitivity analyses and application of the program under various data constraints (see Table IV-3). Table IV-4 specifies submodels for predicting supplementary response variables (organic nitrogen, particulate phosphorus, principal

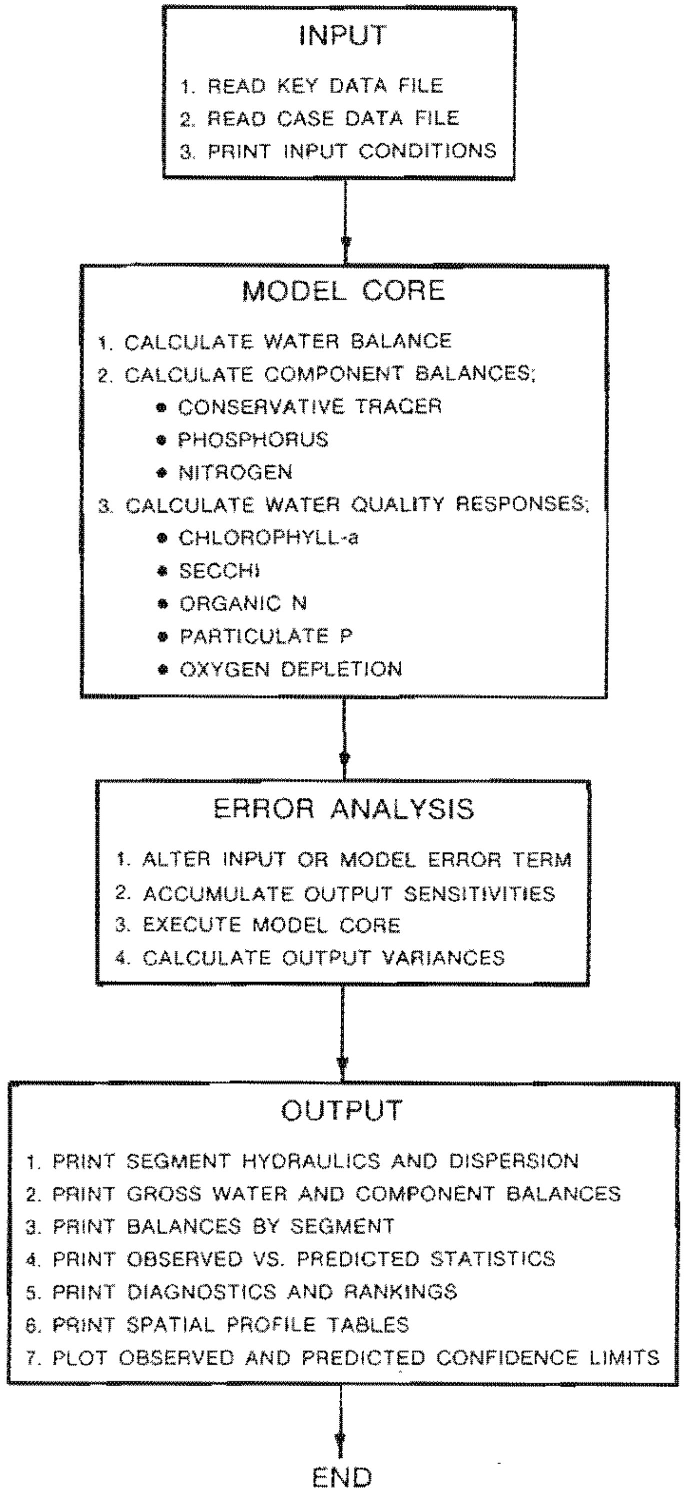


Figure IV-1. Schematic of BATHTUB calculations

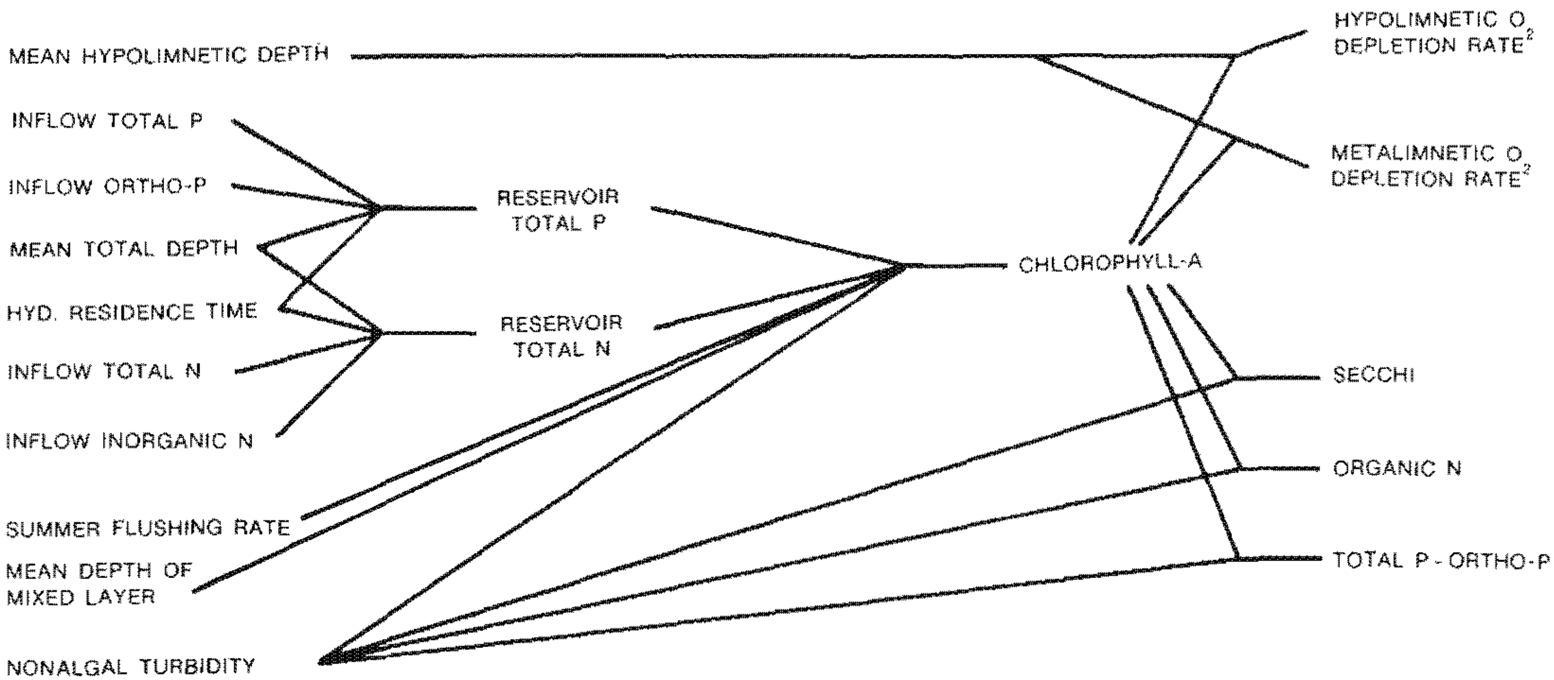


Figure IV-2. Control pathways in empirical eutrophication models developed for CE reservoir applications

Table IV-1

Symbol Definitions

a	=	Nonalgal Turbidity (1/m) = 1/S - 0.025 B
As	=	Surface Area of Segment (km^2)
Ac	=	Cross-Sectional Area of Segment (km*m)
A1	=	Intercept of Phosphorus Sedimentation Term
A2	=	Exponent of Phosphorus Sedimentation Term
B1	=	Intercept of Nitrogen Sedimentation Term
B2	=	Exponent of Nitrogen Sedimentation Term
B	=	Chlorophyll-a Concentration (mg/m^3)
Bm	=	Reservoir Area-Weighted Mean Chlorophyll-a Concentration (mg/m^3)
Bp	=	Phosphorus-Potential Chlorophyll-a Concentration (mg/m^3)
Bx	=	Nutrient-Potential Chlorophyll-a Concentration (mg/m^3)
CB	=	Calibration Factor for Chlorophyll-a (segment-specific)
CD	=	Calibration Factor for Dispersion (segment-specific)
CN	=	Calibration Factor for N Decay Rate (segment-specific)
CO	=	Calibration Factor for Oxygen Depletion (segment-specific)
CP	=	Calibration Factor for P Decay Rate (segment-specific)
CS	=	Calibration Factor for Secchi Depth (segment-specific)
D	=	Dispersion Rate (km^2/yr)
Dn	=	Numeric Dispersion Rate (km^2/yr)
E	=	Diffusive Exchange Rate between Adjacent Segments (hm^3/yr)
Fs	=	Summer Flushing Rate = (Inflow-Evaporation)/Volume (yr^{-1})
Fin	=	Tributary Inorganic N Load/Tributary Total N Load
Fot	=	Tributary Ortho-P Load/Tributary Total P Load
FD	=	Dispersion Calibration Factor (applied to all segments)
G	=	Kinetic Factor Used in Chlorophyll-a Model
HODv	=	Near-Dam Hypolimnetic Oxygen Depletion Rate (mg/m^3-day)
L	=	Segment Length (km)
MODv	=	Near-Dam Metalimnetic Oxygen Depletion Rate (mg/m^3-day)

(Continued)

Table IV-1 (Concluded)

N	=	Total Nitrogen Concentration (mg/m^3)
Ni	=	Inflow Total N Concentration (mg/m^3)
Nin	=	Inflow Inorganic N Concentration (mg/m^3)
Nia	=	Inflow Available N Concentration (mg/m^3)
Ninorg	=	Inorganic Nitrogen Concentration (mg/m^3)
Norg	=	Organic Nitrogen Concentration (mg/m^3)
P	=	Total Phosphorus Concentration (mg/m^3)
Pi	=	Inflow Total P Concentration (mg/m^3)
Pio	=	Inflow Ortho-P Concentration (mg/m^3)
Pia	=	Inflow Available P Concentration (mg/m^3)
Portho	=	Ortho-Phosphorus Concentration (mg/m^3)
PC-1	=	First Principal Component of Response Measurements
PC-2	=	Second Principal Component of Response Measurements
Q	=	Segment Total Outflow (hm^3/yr)
Qs	=	Surface Overflow Rate (m/yr)
S	=	Secchi Depth (m)
T	=	Hydraulic Residence Time (years)
U	=	Mean Advective Velocity (km/yr)
V	=	Total Volume (hm^3)
W	=	Mean Segment Width (km)
Wp	=	Total Phosphorus Loading (kg/yr)
Wn	=	Total Nitrogen Loading (kg/yr)
Xpn	=	Composite Nutrient Concentration (mg/m^3)
Z	=	Mean Total Depth (m)
Zx	=	Maximum Total Depth (m)
Zh	=	Mean Hypolimnetic Depth of Entire Reservoir (m)
Zmix	=	Mean Depth of Mixed Layer (m)

Table IV-2

BATHTUB Model Options

OPTION 1 - Conservative Substance Balance

Model 0: Do Not Compute (Set Predicted = Observed)
Model 1: Compute Mass Balances

OPTION 2 - Phosphorus Sedimentation

Unit P Sedimentation Rate (mg/m^3-yr) = $CP\ A1\ P^{A2}$
Solution for Mixed Segment:
Second-Order (A2 = 2)
$$P = [-1 + (1 + 4\ CP\ A1\ Pi\ T)^{0.5}]/(2\ CP\ A1\ T)$$
First-Order (A2 = 1)
$$P = Pi/(1 + CP\ A1\ T)$$

Model	A1	A2
0 - Do Not Compute (Set Predicted = Observed)	--	-
1 - Second-Order, Available P	0.17 Qs/(Qs + 13.3)	2
Qs = MAX(Z/T,4)		
Inflow Available P = 0.33 Pi + 1.93 Pio		
2 - Second-Order Decay Rate Function	$0.056\ Fot^{-1} Qs/(Qs + 13.3)$	
3 - Second-Order	0.10	2
4 - Canfield and Bachman (1981)	$0.11\ (Wp/V)^{0.59}$	1
5 - Vollenweider (1976)	$T^{-0.5}$	1
6 - Simple First-Order	1	1
7 - First-Order Settling	1/Z	1

(Continued)

Note: For purposes of computing effective rate coefficients (A1), Qs, Wp, Fot, T, and V are evaluated separately for each segment group based upon external loadings and segment hydraulics.

(Sheet 1 of 5)

Table IV-2 (Continued)

Model	A1	A2
OPTION 3 - Nitrogen Sedimentation		
Unit N Sedimentation Rate (mg/m^3-yr) = CN B1 N^{B2}		
Solutions for Mixed Segment:		
Second-Order (B2 = 2):		
$N = [-1 + (1 + 4\ CN\ B1\ Ni\ T)^{0.5}]/(2\ CN\ B1\ T)$		
First-Order (B2 = 1):		
$N = Ni/(1 + CN\ B1\ T)$		

Model	B1	B2
0 - Do Not Compute (Set Predicted = Observed	--	-
1 - Second-Order, Available N	0.0045 Qs/(Qs + 7.2)	2
Qs = Maximum (Z/T,4)		
Inflow Available N = 0.59 Ni + 0.70 Nin		
2 - Second-Order Decay Rate Function	0.0035 Fin$^{-0.59}$Qs/(Qs + 17.3)	2

(Continued)

Notes: For purposes of computing effective rate coefficients (B1), Qs, Wn, Fin, T, and V are evaluated separately for each segment group based upon external loadings and segment hydraulics.

Nitrogen Model 1 differs slightly from that developed in Walker (1985). The coefficients have been adjusted so that predictions will be unbiased if inflow inorganic nitrogen data are not available (inflow available N = inflow total N). These adjustments have negligible influence on model error statistics.

(Sheet 2 of 5)

Table IV-2 (Continued)

Model	B1	B2
$Qs = \text{Maximum}(Z/T, 4)$		
Fin = Tributary Inorganic N/Total N Load		
3 - Second-Order	0.00315	2
4 - Bachman (1980)/Volumetric Load	$0.0159\ (Wn/V)^{0.59}$	1
5 - Bachman (1980)/Flushing Rate	$0.693\ T^{-0.55}$	1
6 - Simple First-Order	1	1
7 - First-Order Settling	1/Z	1

OPTION 4 - Mean Chlorophyll-a	Applicability
Model 0: Do Not Compute	
Model 1: N, P, Light, Flushing Rate	General
$Xpn = [P^{-2} + ((N-150)/12)^{-2}]^{-0.5}$	
$Bx = Xpn^{1.33}/4.31$	
$G = Zmix\ (0.14 + 0.0039\ Fs)$	
$B = CB\ Bx/[(1 + 0.025\ Bx\ G)\ (1 + Ga)]$	
Model 2: P, Light, Flushing Rate	Ninorg/Portho > 7 (N-150)/P > 12
$Bp = p^{1.37}/4.88$	
$G = Zmix\ (0.19 + 0.0042\ Fs)$	
$B = CB\ Bp/[(1 + 0.025\ Bp\ G)\ (1 + Ga)]$	
Model 3: P, N, Low-Turbidity	a < 0.4 1/m Fs < 25 1/yr
$B = CB\ 0.2\ Xpn^{1.25}$	
Model 4: P, Linear	a < 0.9 1/m Ninorg/Portho > 7 (N-150)/P > 12 Fs < 25 1/yr
$B = CB\ 0.28\ P$	

(Continued)

(Sheet 3 of 5)

Table IV-2 (Continued)

Model 5: Jones and Bachman (1976)	$A < 0.4$ 1/m
$B = CB\ 0.081\ P^{1.46}$	Ninorg/Portho > 7
	$(N-150)/P > 12$
	$Fs < 25$ 1/yr
OPTION 5: Secchi Depth	Applicability
Model 0: Do Not Compute	
Model 1: Secchi vs. Chl-a and Turbidity	General
$S = CS/(a + 0.025\ B)$	
Model 2: Secchi vs. Composite Nutrient	General
$S = CS\ 16.2\ Xpn^{-0.79}$	
Model 3: Secchi vs. Total P	Ninorg/Portho > 7
$S = CS\ 17.8\ P^{-0.76}$	

OPTION 6: Exchange Flows Between Adjacent Model Segments

Model 0: Do Not Compute

$E = 0.$

Model 1: Fischer et al. (1979) Dispersion Equation, Walker (1985)

Width	$W = As/L$
Cross-Section	$Ac = W\ Z$
Velocity	$U = Q/Ac$
Dispersion	$D = CD\ FD\ 100\ W^2\ Z^{-0.84}$ Maximum (U, 1)
Numeric Dispersion	$Dn = U\ L/2$
Exchange	$E = MAX(D-Dn,\ 0)\ Ac/L$

(Continued)

(Sheet 4 of 5)

Table IV-2 (Concluded)

Model 2: Fixed Dispersion Rate

Same as Model 1, except with fixed dispersion rate of 1,000 km^2/yr

$D = 1{,}000\ CD\ FD$

Model 3: Input Exchange Rates Directly

$E = CD\ FD$

Note: For all options, E = 0. always for last (near-dam) segment and for segments discharging out of network (outflow segment number = 0).

OPTION 7: Phosphorus Calibration Method

Model 1: Multiply Estimated Decay Rates by Calibration Factors
Model 2: Multiply Estimated Concentrations by Calibration Factors

OPTION 8: Nitrogen Calibration Method

Model 1: Multiply Estimated Decay Rates by Calibration Factors
Model 2: Multiply Estimated Concentrations by Calibration Factors

OPTION 9: Error Analysis

Model 0: Do Not Compute, Set Output Coefficients of Variation to 0.
Model 1: Compute Using Input Data Error and Model Error Terms
Model 2: Compute Using Input Data Error Terms Only

(Sheet 5 of 5)

Table IV-3

Guidance for Selecting Model Options

		Model Options					Availability Factors			
		Conserv.				Secchi	Phosphorus		Nitrogen	
Application	Condition	Substance	P	N	Chla	Depth	Total	Ortho	Total	Inorg.
General case	Typical cases									
	Sedimentation Model 1	0	1	1	1	1	0.33	1.93	0.59	0.79
	Sedimentation Model 2	0	2	2	1	1	1.00	0.00	1.00	0.00
	Test other sedimentation models	-	3-5*	3-5*	-	-	1.00	0.00	1.00	0.00
	Conservative tracer data	1	-	-	-	-	-	-	-	-
Loading	No nutrient loading data	-	0	0	-	-	-	-	-	-
	No ortho-P loading data	-	1*	-	-	-	1.00	.00	-	-
	No inorganic N loading data	-	-	1*	-	-	-	-	1.00	0.00
Hydrology	Outside data set range**	-	1*	1*	-	-	0.33	1.93	0.59	0.79
		-	2*	2*	-	-	1.00	0	1.00	0

(Continued)

* Calibrate.

** Q_s < 4m/yr, T > 2 yr, or Z > 30 m.

Table IV-3 (Concluded)

Application	Condition	Model Options: Conserv. Substance	P	N	Chla	Secchi Depth	Availability Factors: Phosphorus Total	Phosphorus Ortho	Nitrogen Total	Nitrogen Inorg.
Nitrogen limitation	No nitrogen loading data - nitrogen not limiting	-	-	0	2	1	-	-	-	-
	No pool nitrogen data - nitrogen not limiting	-	-	-	2	1	-	-	-	-
Turbidity	Turbidity data qualitative									
	Nitrogen possibly limiting	-	-	-	3*	2*	-	-	-	-
	Nitrogen not limiting	-	-	-	4,5*	3*	-	-	-	-

* Calibrate.

Table IV-4

Nutrient Partitioning, Principal Components, and Oxygen Depletion Models

---

Organic Nitrogen:

$$Norg = 157 + 22.8\ B + 75.3\ a$$

Particulate Phosphorus (Total P - Ortho-P):

$$P - Portho = -4.1 + 1.78B + 23.7a \quad (\text{minimum} = 1.)$$

Hypolimnetic Oxygen Depletion Rate (Near-Dam): (for Zh > 2 m)

$$HODv = 240\ CO\ B_m^{0.5}/Z_h$$

Metalimnetic Oxygen Depletion Rate (Near-Dam):

$$MOD_v = 0.4\ HOD_v Z_h^{0.38}$$

Principal Components:

With chla-a, Secchi, nutrient, and organic nitrogen data:

$$PC\text{-}1 = 0.554 \log (B) + 0.359 \log (Norg) + 0.583 \log (Xpn) - 0.474 \log (S)$$

$$PC\text{-}2 = 0.689 \log (B) + 0.162 \log (Norg) - 0.205 \log (Xpn) + 0.676 \log (S)$$

With chl-a and Secchi data only:

$$PC\text{-}1 = 1.47 + 0.949 \log (B) - 0.932 \log (S)$$

$$PC\text{-}2 = 0.13 + 0.673 \log (B) + 0.779 \log (S)$$

Table IV-5

Error Statistics for Model Network Applied to Spatially Averaged CE Reservoir Data

Variable	Error CV Total*	Error CV Model**	R^2 †	Comment
Total phosphorus	0.27	0.45††	0.91	Models 1, 2
Total nitrogen	0.22	0.55††	0.88	Models 1, 2
Chlorophyll-a	0.35	0.26	0.79	Models 1, 2
	0.47	0.37	-	Models 3-6
Secchi depth	0.28	0.10	0.89	Model 1
	0.29	0.19	-	Model 2
Organic nitrogen	0.25	0.12	0.75	
Total P - Ortho-P	0.37	0.15	0.87	
Hypolimnetic oxygen depletion	0.20	0.15	0.90	‡
Metalimnetic oxygen depletion	0.33	0.22	0.76	‡

NOTE: Error statistics for CE model development data set (n = 40).
* Total = total error (model + data components)
** Model = Estimated Model Error Component.
† R^2 = percent of observed variance explained.
†† Model error CV applied to nutrient sedimentation rates (versus concentrations).
‡ Volumetric oxygen depletion (n = 16).

Table IV-6

Diagnostic Variables and Their Interpretation

Variable	Units	Explanation
TOTAL P	mg/m^3	Total phosphorus concentration CE distribution (MEAN = 48, CV = 0.90, MIN = 9.9, MAX = 274) Measure of nutrient supply under P-limited conditions
TOTAL N	mg/m^3	Total nitrogen concentration CE distribution (MEAN = 1002, CV = 0.64, MIN = 243, MAX = 4306) Measure of nutrient supply under N-limited conditions
C.NUTRIENT	mg/m^3	Composite nutrient concentration CE distribution (MEAN = 36, CV = 0.80, MIN = 6.6, MAX = 142) Measure of nutrient supply independent of N vs. P limitation; equals total P at high nitrogen/phosphorus ratios
CHL-A	mg/m^3	Mean chlorophyll-a concentration CE distribution (MEAN = 9.4, CV = 0.77, MIN = 2, MAX = 64) Measure of algal standing crop based upon photosynthetic pigment
SECCHI	m	Secchi depth CE distribution (MEAN = 1.1, CV = 0.76, MIN = 0.19, MAX = 4.6) Measure of water transparency as influenced by algae and nonalgal turbidity
ORGANIC N	mg/m^3	Organic nitrogen concentration CE distribution (MEAN = 474, CV = 0.51, MIN = 186, MAX = 1510) Portion of nitrogen pool in organic forms; generally correlated with chlorophyll-a concentration

(Continued)

Notes: CE distribution based upon 41 reservoirs used in development and testing of the model network (MEAN, CV = geometric mean and coefficient of variation). Low and high values are typical benchmarks for interpretation.

(Sheet 1 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
TP-ORTHO-P	mg/m^3	Total minus ortho-phosphorus CE distribution (MEAN = 30, CV = 0.95, MIN = 4, MAX = 148) Portion of phosphorus pool in organic/particulate forms; correlated with chlorophyll-a and nonalgal turbidity
HOD-V	mg/m^3-day	Hypolimnetic oxygen depletion rate CE distribution (MEAN = 77, CV = 0.75, MIN = 36, MAX = 443) Rate of oxygen depletion below thermocline; related to organic supply from settling of surface-layer algae, external organic sediment loads, and mean hypolimnetic depth For HOD-V > 100, hypolimnetic oxygen supply depleted within 120 days after onset of stratification
MOD-V	mg/m^3-day	Metalimnetic oxygen depletion rate CE distribution (MEAN = 68, CV = 0.71, MIN = 25, MAX = 286) Rate of oxygen depletion within thermocline; generally more important than HOD-V in deeper reservoirs (i.e., mean hypolimnetic depth >20 m)
ANTILOG PC-1	--	First principal component of reservoir response variables(i.e., chlorophyll-a, Secchi, organic N, composite nutrient) CE distribution (MEAN = 245, CV = 1.3, MIN = 18, MAX = 2,460) Measure of nutrient supply: Low: PC-1 < 50 = low nutrient supply = low eutrophication potential High: PC-1 > 500 = high nutrient supply = high eutrophication potential

(Continued)

(Sheet 2 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
ANTILOG PC-2	--	Second principal component of reservoir response variables (i.e., chlorophyll-a, Secchi, organic N, composite nutrient) CE distribution (MEAN = 6.4, CV = 0.53, MIN = 1.6, MAX = 13.4) Measure of nutrient expression in organic vs. inorganic forms Measure of light-limited productivity: Low: PC-2 < 4 = turbidity-dominated = light-limited = low nutrient response High: PC-2 > 10 = algae-dominated = light unimportant = high nutrient response
(N-150)/P	--	(Total nitrogen - 150)/Total phosphorus ratio CE Distribution (MEAN = 17, CV = 0.68, MIN = 4.7, MAX = 73) Indicator of limiting nutrients based upon total nutrients: Low: (N-150)/P < 10-12 = nitrogen-limited High: (N-150)/P > 12-15 = phosphorus-limited
INORGANIC N/P Ratio	--	Inorganic nitrogen/ortho-phosphorus ratio CE distribution (MEAN = 30, CV = 0.99, MIN = 1.6, MAX = 127) Indicator of limiting nutrient based upon inorganic nutrients: Low: N/P < 7-10 = nitrogen-limited High: N/P > 7-10 = phosphorus-limited
TURBIDITY	1/m	Nonalgal turbidity (1/SECCHI - 0.025 × CHL-A) CE distribution (MEAN = 0.61, CV = 0.88, MIN = 0.13, MAX = 5.2) Inverse Secchi corrected for light extinction by chlorophyll-a Reflects color and inorganic suspended solids

(Continued)

(Sheet 3 of 5)

Table IV-6 (Continued)

Variable	Units	Explanation
		Influences algal response to nutrients: Low: Turbidity < 0.4 = low turbidity = allochthonous particulates unimportant = high algal response to nutrients High: Turbidity > 1 = high turbidity = allochthonous particulates unimportant = low algal response to nutrients
ZMIX * TURBIDITY		Mixed-layer depth × turbidity (dimensionless) CE distribution (MEAN = 3.2, CV = 0.78, MIN = 1.0, MAX = 17) Effect of turbidity on mean light intensity in mixed layer: Low: Value < 3 = light availability high = turbidity unimportant = high algal response to nutrients High: Value > 6 = light availability low = turbidity important = low algal response to nutrients
ZMIX/SECCHI		Mixed-layer depth/Secchi depth (dimensionless) CE distribution (MEAN = 4.8, CV = 0.58, MIN = 1.5, MAX = 19) Inversely proportional to mean light intensity in mixed layer for a given surface light intensity: Low: Value < 3 = light availability high = high algal response to nutrients High: Value > 6 = light availability low = low algal response to nutrients

(Continued)

(Sheet 4 of 5)

Table IV-6 (Concluded)

Variable	Units	Explanation
CHL-A * SECCHI		Chlorophyll-a × transparency (mg/m^2) CE distribution (MEAN = 10, CV = 0.71, MIN = 1.8, MAX = 31) Partitioning of light extinction between algae and turbidity Measure of light-limited productivity Correlated with PC-2 (second principal component): Low: Value < 6 = turbidity-dominated = light-limited = low nutrient response High: Value > 16 = algae-dominated = nutrient-limited = high nutrient response
CHL-A/ TOTAL P	--	Mean chlorophyll-a/total P CE distribution (MEAN = 0.20, CV = 0.64, MIN = 0.04, MAX = 0.60) Measure of algal use of phosphorus supply Related to nitrogen-limited and light-limitation factors: Low: Value < 0.13 = low phosphorus response = N, light, or flushing limited High: Value > 0.40 = high phosphorus response = N, light, and flushing unimportant = P limited (e.g., northern lakes)

(Sheet 5 of 5)

components, oxygen depletion rates). Error statistics for applications of the network to predict spatially averaged conditions are summarized in Table IV-5.

The following sections review fundamental concepts, including segmentation, mass balances, nutrient sedimentation models, nutrient residence time and turnover, solution algorithms, and eutrophication response models. The development and testing of the network equations are described elsewhere (Walker 1985) and should be reviewed prior to using the program.

Segmentation

Through appropriate configuration of model segments, BATHTUB can be applied to a wide range of reservoir morphometries and management problems. Figure IV-3 depicts segmentation schemes in six general categories:

a. Single reservoir, spatially averaged.

b. Single reservoir, segmented.

c. Partial reservoir or embayment, segmented.

d. Single reservoir, spatially averaged, multiple scenario.

e. Collection of reservoirs, spatially averaged.

f. Network of reservoirs, spatially averaged

Segments can be modeled independently or linked in a network. Multiple external sources and/or withdrawals can be specified for each segment. With certain limitations, combinations of the above schemes are also possible. Characteristics and applications of each segmentation scheme are discussed below.

Scheme 1 (Figure IV-3) is the simplest configuration. It is applicable to reservoirs in which spatial variations in nutrient concentrations and related trophic state indicators are relatively unimportant. It can also be applied to predict area-weighted mean conditions in reservoirs with significant spatial variations. This is the simplest type of application, primarily because transport characteristics within the reservoir (particularly, longitudinal dispersion) are not considered. The development of submodels for nutrient sedimentation and eutrophication response has been based primarily upon application of this segmentation scheme to spatially averaged data from 41 CE reservoirs (Walker 1985).

Scheme 2 involves dividing the reservoir into a network of segments for predicting spatial variations in water quality. Nutrient profiles are

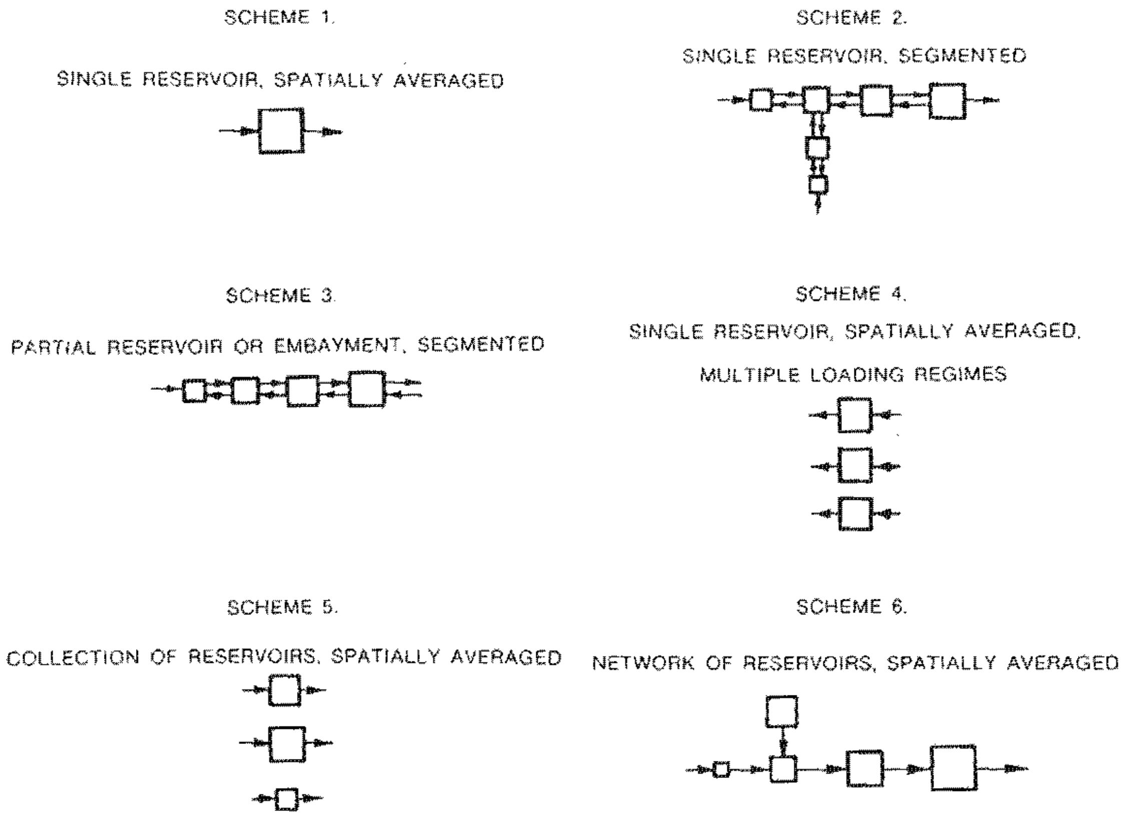


Figure IV-3. BATHTUB segmentation schemes

predicted based upon simulations of advective transport, diffusive transport, and nutrient sedimentation. Reversed arrows in Figure IV-3 reflect simulation of longitudinal dispersion. Branches in the segmentation scheme reflect major tributary arms or embayments. Multiple and higher order branches are also permitted. Segment boundaries can be defined based upon consideration of the following:

a. Reservoir morphometry.

b. Locations of major inflows and nutrient sources.

c. Observed spatial variations in water quality.

d. Locations of critical reservoir use areas.

e. Numeric dispersion potential (calculated by the program).

If pool monitoring data are available, spatial displays generated by PROFILE can be useful for identifying appropriate model segmentation. A degree of subjective judgment is normally involved in specifying segment boundaries, and sensitivity to alternative segmentation schemes should be investigated. Sensitivity to assumed segmentation should be low if longitudinal transport characteristics are adequately represented. Experience with the program indicates that segment lengths on the order of 5 to 20 km are generally appropriate. Segmentation should be done conservatively (i.e., use the minimum number required for each application).

Scheme 3 illustrates the use of BATHTUB for modeling partial reservoirs or embayments. This is similar to Scheme 2, except the entire reservoir is not being simulated and the downstream water quality boundary condition is fixed. Diffusive exchange with the downstream water body is represented by the bidirectional arrows attached to the last (most downstream) segment.

Scheme 4 involves modeling multiple loading scenarios for a single reservoir in a spatially averaged mode. Each "segment" represents the same reservoir, but under a different "condition," as defined by external nutrient loading, reservoir morphometry, or other input variables. This scheme is useful primarily in a predictive mode for evaluation and rapid comparison of alternative management plans or loading scenarios. For example, Segment 1 might reflect existing conditions, Segment 2 might reflect projected future loadings as a result of land development, and Segment 3 might reflect projected future loadings with specific control options. By defining segments to reflect a wide range of loading conditions, loadings consistent with specific water quality objectives (expressed in terms of mean phosphorus concentration, chlorophyll-a, and/or transparency) can be identified.

Scheme 5 involves modeling a collection of reservoirs in a spatially averaged mode. Each segment represents a different reservoir. This is useful for regional assessments of reservoir conditions (i.e., rankings) and evaluations of model performance. Using this scheme, a single file can be set up to include input conditions (water and nutrient loadings, morphometry, etc.) and observed water quality conditions for each reservoir in a given region (e.g., CE District or Division).

Scheme 6 represents a network of reservoirs in which flow and nutrients can be routed from one impoundment to another. Each reservoir is modeled in a spatially averaged mode. For example, this scheme could be used to represent a network of tributary and main stem impoundments. This type of application is feasible in theory but has been less extensively tested than those described above. One limitation is that nutrient losses in streams linking the reservoirs are not directly represented. Such losses may be important in some systems, depending upon such factors as stream segment length and time of travel. In practice, losses in transport could be approximately handled by defining "stream segments," provided that field data are available for calibration of sedimentation coefficients (particularly in the case of nitrogen). Networking of reservoirs is most reliable for mass balances formulated on a seasonal basis and for reservoirs that are unstratified or have surface outlets.

As illustrated in Figure IV-3, a high degree of flexibility is available for specifying model segments. Combinations of schemes are also possible within one input file. While each segment is modeled as vertically mixed, BATHTUB is applicable to stratified systems because the formulations have been empirically calibrated to data from a wide variety of reservoir types, including well-mixed and vertically stratified systems. Effects of vertical variations are incorporated in the model parameter estimates and error terms.

Mass Balances

The mass balance concept is fundamental to reservoir eutrophication modeling. BATHTUB formulates water and nutrient balances by establishing a control volume around each segment and evaluating the following terms:

INFLOWS	=	OUTFLOWS	+	INCREASE-IN-STORAGE	+	NET LOSS
(External)		(Discharge)				
(Advective)		(Advective)				
(Diffusive)		(Diffusive)				
(Atmospheric)		(Evaporation)				

The external, atmospheric, discharge, evaporation, and increase-in-storage terms are calculated directly from information provided in the input file. The remaining are discussed below.

Advective terms reflect net discharge from one segment into another and are derived from water balance calculations. Diffusive transport terms are applicable only to problems involving simulation of spatial variations within reservoirs. They reflect eddy diffusion (as driven by random currents and wind mixing) and are represented by bulk exchange flows between adjacent segment pairs. Chapra and Reckhow (1983) present examples of lake/embayment models which consider diffusive transport.

As outlined in Table IV-2, three methods are available for estimating diffusive transport rates. Each leads to the calculation of bulk exchange flows which occur in both directions at each segment interface. Dispersion coefficients, calculated from the Fischer et al. (1979) equation (Model 1) or from a fixed longitudinal dispersion coefficient (Model 2), are adjusted to account for effects of numeric dispersion ("artificial" dispersion or mixing which is a consequence of model segmentation). Model 3 can be used for direct input of bulk exchange flows.

Despite its calibration to river systems, the applicability of the Fischer et al. equation for estimating longitudinal dispersion rates in reservoirs has been demonstrated previously (Walker 1985). For a given segment width, mean depth, and outflow, numeric dispersion is proportional to segment length. By selecting segment lengths to keep numeric dispersion rates less than the estimated values, the effects of numeric dispersion on the calculations can be approximately controlled. Based upon Fischer's dispersion equation, the numeric dispersion rate will be less than the calculated dispersion rate if the following condition holds:

$$L < 200W^2Z^{-0.84}$$

where

L = segment length, km

W = mean top width = surface area/length, km

Z = mean depth, m

The above equation can be applied to reservoir-average conditions in order to estimate an upper bound for the appropriate segment length. In most cases, simulated nutrient profiles are relatively insensitive to longitudinal dispersion rates. Fine-tuning of exchange flows can be achieved via the use of segment-specific calibration factors.

While, in theory, the increase-in-storage term should reflect both changes in pool volume and concentration, only the volume change is considered in mass balance calculations, and concentrations are assumed to be at steady state. The increase-in-storage term is used primarily in verifying the overall water balance. Predictions are more reliable under steady pool levels or when changes in pool volume are small in relation to total inflow and outflow.

Nutrient Sedimentation Models

For a water balance or conservative substance balance, the net sedimentation term is zero. Nutrient retention submodels are used to estimate net sedimentation of phosphorus or nitrogen in each segment according to the equations specified in Table IV-2. Based upon research results, a second-order decay model is the most generally applicable formulation for representing phosphorus and nitrogen sedimentation in reservoirs:

$$W_s = K_2 C^2$$

where

W_s = nutrient sedimentation rate, mg/m^3-yr

K_2 = effective second-order decay rate, m^3/mg-yr

C = pool nutrient concentration, mg/m^3

Other options are provided for users interested in testing alternative models (see Table IV-2). The model error coefficients used by the program, however, have been estimated from the model development data set using the second-order sedimentation formulations. Accordingly, error analysis results (predicted coefficients of variation) will be invalid for other formulations (i.e., model codes 3 through 7 for phosphorus or nitrogen).

Effective second-order sedimentation coefficients are on the order of 0.1 m^3/mg-yr for total phosphorus and 0.0032 m^3/mg-yr for total nitrogen, as specified under "Model 3" in Table IV-2. With these coefficients, nutrient sedimentation models explain 83 and 84 percent of the between-reservoir variance in average phosphorus and nitrogen concentrations, respectively. Residuals from these models are systematically related to inflow nutrient partitioning (dissolved versus particulate or inorganic versus organic) and to surface overflow rate over the data set range of 4 to 1,000 m/yr. Effective rate coefficients tend to be lower in systems with high ortho-P/total P (and high inorganic N/total N) loading ratios or with low overflow rates (4 to 10 m/yr). Refinements to the second-order formulations (Models 1 and 2) are designed to account for these dependencies (Walker 1985).

As indicated in Table IV-2, Sedimentation Models 1 and 2 use different schemes to account for effects of inflow nutrient partitioning. In the case of phosphorus, Model 1 performs mass balance calculations on "available P," a weighted sum of ortho-P and nonortho-P which places a heavier emphasis on the ortho-P (more biologically available) component. Model 2 uses total phosphorus concentrations but represents the effective sedimentation rate as inversely related to the tributary ortho-P/ total P ratio, so that predicted sedimentation rates are higher in systems dominated by nonortho (particulate or organic) P loadings and lower in systems dominated by ortho-P or dissolved P loadings. The nitrogen models are structured similarly, although nitrogen balances are much less sensitive to inflow nutrient partitioning than are phosphorus balances, probably because inflow nitrogen tends to be less strongly associated with suspended sediments.

Thus, Model 1 accounts for inflow nutrient partitioning by adjusting the inflow concentrations and Model 2 accounts for inflow nutrient partitioning by adjusting the effective sedimentation rate coefficient. While Model 2 seems physically reasonable, Model 1 has advantages in reservoirs with complex loading patterns because a fixed sedimentation coefficient can be used and effects of inflow partitioning are incorporated prior to the mass balance calculations. Because existing data sets do not permit "global" discrimination between these two approaches, each method should be tested for applicability to a particular case. In most situations, predictions will be relatively insensitive to the particular sedimentation model employed, especially if the ortho-P/total P loading ratio is in a moderate range (roughly 0.25 to 0.60). Additional model application experiences suggest that Method 2 may have an edge over Model 1 in systems with relatively long hydraulic residence times (roughly, exceeding 1 year), although further testing is needed. Because the coefficients are concentration or load dependent and because the models do not predict nutrient partitioning in reservoir outflows, Sedimentation Models 2 and 4 cannot be applied to simulations of reservoir networks (Scheme 6 in Figure IV-3).

Based upon error analysis calculations, the models discussed above provide estimates of second-order sedimentation coefficients which are generally accurate to within a factor of 2 for phosphorus and a factor of 3 for nitrogen. In many applications, especially reservoirs with low hydraulic residence times, this level of accuracy is adequate because the nutrient balances are dominated by other terms (especially, inflow and outflow). In applications to existing reservoirs, sedimentation coefficients estimated from the above models can be adjusted within certain ranges (roughly a factor of 2 for P, factor of 3 for N) to improve agreement between observed and predicted nutrient concentrations. Such "tuning" of sedimentation coefficients should be approached cautiously because differences between observed and predicted nutrient levels may be attributed to factors other than errors in the estimated sedimentation rates, particularly if external loadings and pool concentrations are not at steady state.

Figure IV-4 shows the relationship between hydraulic residence time and mean depth in the reservoirs used in model development. Predictions of nutrient sedimentation rates are less reliable in reservoirs lying outside the data set range. This applies primarily to reservoirs with residence times exceeding 2 years, mean depths greater than 30 m, or overflow rates less than 4 m/year. Tests based upon independent data sets indicate that the sedimentation models are unbiased under these conditions but have higher error variances. In such situations, the modeling exercise should include a sensitivity analysis to model selection and, if possible, calibration of sedimentation coefficients to match observed concentration data. Deviations at the other extremes (reservoirs with lower residence times or higher overflow rates than those represented in the model development data set) are of less concern because the sedimentation term is generally an insignificant portion of the total nutrient budget in such systems (i.e., predicted pool concentrations are highly insensitive to estimated sedimentation rate).

Because the sedimentation models have been empirically calibrated, effects of "internal loading" or phosphorus recycling from bottom sediments are inherently reflected in the model parameter values and error statistics. Generally, internal recycling potential is enhanced in reservoirs with the following characteristics:

a. High concentrations of ortho-phosphorus (or high ortho-P/total P ratios) in nonpoint-source tributary drainage (indicative of natural sediments which are phosphorus-rich and have high equilibrium phosphorus concentrations).

b. Low summer surface overflow rates, typically <10 m/yr (indicative of low dilution potential for internal loadings generated on a mass per unit area basis and low external sediment loadings which may promote phosphorus sedimentation and inhibit recycling).

c. Intermittent periods of stratification and anoxic conditions at the sediment/water interface (contribute to periodic releases of soluble phosphorus from bottom sediments and transport into the mixed layer).

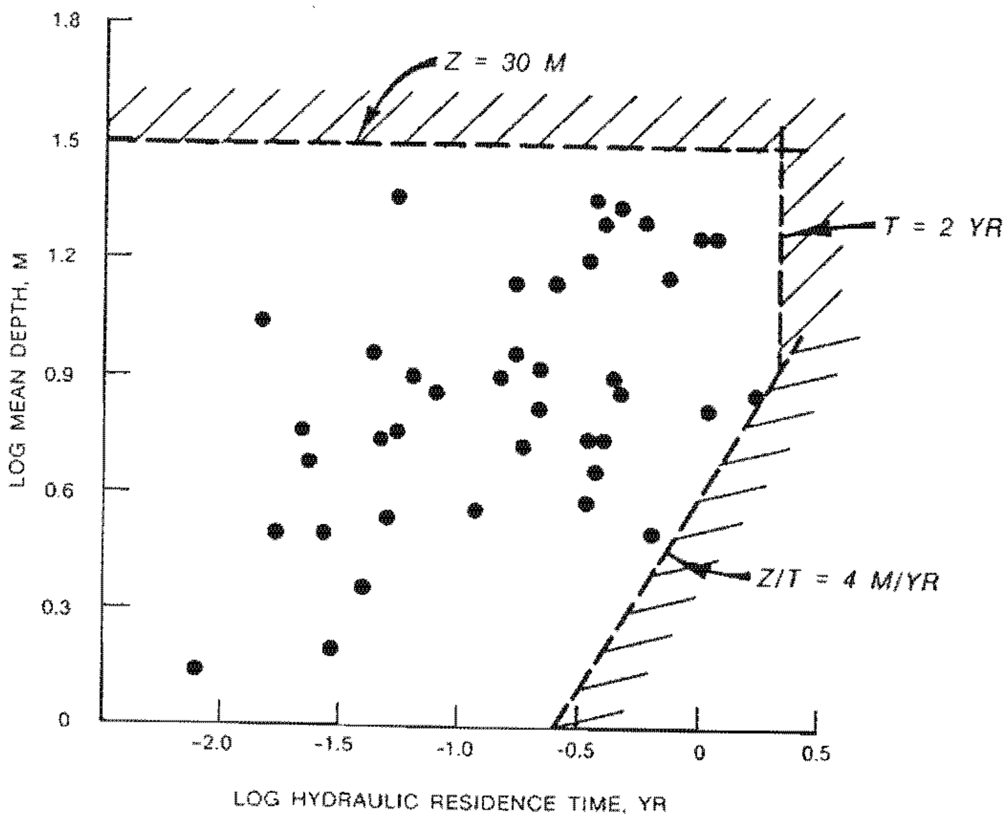


Figure IV-4. Mean depth (Z) versus hydraulic residence time (T) for CE model development data set (LOG_{10} scales)

d. Low iron/phosphorus ratios (typically <3 on a mass basis) in sediment interstitial waters or anaerobic bottom waters (permits migration of phosphorus into aerobic zones without iron phosphate precipitation).

The above conditions are often found in relatively shallow prairie reservoirs; Lake Ashtabula (US Army Engineer District, St. Paul) is an example included in the CE reservoir data set. In such situations, empirical sedimentation models will underpredict reservoir phosphorus concentrations. Depending upon the efficiency of the internal recycling process, steady-state phosphorus responses can be approximately simulated by reducing the effective sedimentation coefficient (e.g., roughly to 0. in the case of Ashtabula).

Nutrient Residence Time and Turnover Ratio

The "averaging period" is defined as the period of time over which water and mass balance calculations are performed. The selection of an appropriate averaging period is an important step in applying this type of model to reservoirs. Two variables must be considered in this process:

$$\text{Mass residence time, yr} = \frac{\text{Nutrient mass in reservoir, kg}}{\text{External nutrient loading, kg/yr}}$$

$$\text{Turnover ratio} = \frac{\text{Length of averaging period, yr}}{\text{Mass residence time, yr}}$$

The estimates of reservoir nutrient mass and external loading correspond to the averaging period. The turnover ratio approximates the number of times that the nutrient mass in the reservoir is displaced during the averaging period. Ideally, the turnover ratio should exceed 2.0. If the ratio is too low, then pool and outflow water quality measurements would increasingly reflect loading conditions experienced prior to the start of the averaging period, which would be especially problematical if there were substantial year-to-year variations in loadings.

At extremely high turnover ratios and low nutrient residence times (e.g., less than 2 weeks), the variability of loading conditions within the averaging period (as attributed to storm events, etc.) would be increasingly reflected in the pool and outflow water quality measurements. In such cases, pool measurement variability may be relatively high and the biological response (e.g., chlorophyll-a production) may not be in equilibrium with ambient nutrient levels, particularly immediately following storm events.

Figure IV-5 shows that the hydraulic residence time is an important factor in determining phosphorus and nitrogen residence times, based upon annual mass balances from 40 CE reservoirs used in model development. For a conservative substance, the mass and hydraulic residence times would be equal at steady state. The envelopes in Figure IV-5 show that the spread of nutrient residence times increases with hydraulic residence time; this reflects the increasing importance of sedimentation as a component of the overall nutrient balance. At low hydraulic residence times, there is relatively little opportunity for nutrient sedimentation, and pool nutrient concentrations and

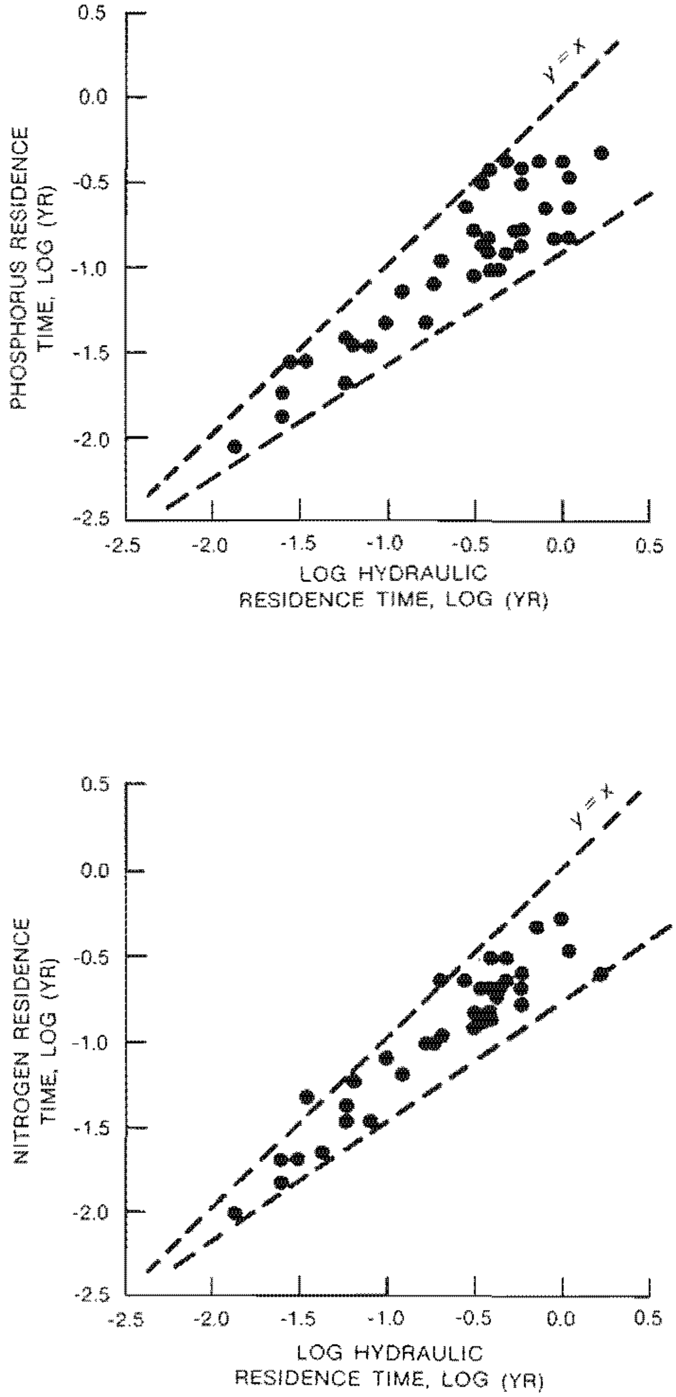


Figure IV-5. Relationships between nutrient residence times and hydraulic residence times in CE model development data set residence times can be predicted relatively easily from inflow concentrations. At high hydraulic residence times, predicted pool nutrient concentrations and residence times become increasingly dependent upon the empirical formulations used to represent nutrient sedimentation. This behavior is reflected in the sensitivity curves discussed in Part I.

Normally, the appropriate averaging period for water and mass balance calculations would be 1 year for reservoirs with relatively long nutrient residence times or seasonal (May-September) for reservoirs with relatively short nutrient residence times. As shown in Figure IV-5, most of the reservoirs in the model development data set had phosphorus residence times less than 0.2 year, which corresponds roughly to a nutrient turnover ratio of 2 for a 5-month seasonal averaging period. Thus, assuming that the reservoirs used in model development are representative, seasonal balances would be appropriate for most CE reservoir studies. BATHTUB calculates mass residence times and turnover ratios using observed or predicted pool concentration data. Results can be used to select an appropriate averaging period for each application.

Solution Algorithms

The water balances are expressed as a system of simultaneous linear equations which are solved via matrix inversion to estimate the advective outflow from each model segment. The mass balances are expressed as a system of simultaneous nonlinear equations which are solved iteratively via Newton's Method (Burden, Faires, and Reynolds 1981). Total phosphorus and total nitrogen concentrations are subsequently input to the model network (Figure IV-2) to estimate eutrophication responses in each segment.

Eutrophication Response Models

Eutrophication response models relate observed or predicted pool nutrient levels to measures of algal production and related water quality conditions. Table IV-6 lists diagnostic variables included in BATHTUB output and guidelines for their interpretation. They may be categorized as follows:

a. Basic network variables.

(1) Total P, total N.

(2) Chlorophyll-a, Secchi depth.

(3) Organic nitrogen, Total P - Ortho-P.

(4) Hypolimnetic and metalimnetic oxygen depletion rates.

b. Principal components of network variables: first and second principal components.

c. Indicators of nitrogen versus phosphorus limitation (total N-150)/total P, and inorganic N/P ratios.

d. Indicators of light limitation.

(1) Nonalgal turbidity, mixed depth × turbidity.

(2) Mixed depth/Secchi depth, and chlorophyll-a × Secchi Depth.

e. Chlorophyll-a response to phosphorus: chlorophyll-a/total P.

Statistical summaries derived from the CE model development data set provide one frame of reference. Low and high ranges given for specific variables provide approximate bases for assessing controlling processes and factors, including growth limitation by light, nitrogen, and phosphorus.

The ranges of conditions under which the empirical models have been developed should be considered in each application. Figure IV-6 depicts relationships among three key variables determining eutrophication responses (total phosphorus, total nitrogen, and nonalgal turbidity) in the CE model development data set. Figure IV-7 depicts relationships among phosphorus, chlorophyll-a, and transparency. Plotting data from a given application on each of these figures permits comparative assessment of reservoir conditions and evaluations of model applicability. If reservoir data fall outside the clusters in Figure IV-5, IV-6, or IV-7, potential model errors are greater than indicated by the statistics in Table IV-5.

The prediction of mean chlorophyll-a from observed or predicted nutrient concentrations can be based on one of the five models listed in Table IV-2. This is a critical step in the modeling process. Error analyses indicate that it is generally more difficult to predict chlorophyll-a from nutrient concentrations and other controlling factors than to predict nutrient concentrations from external loadings and morphometry. Chlorophyll-a models can be described according to limiting factors:

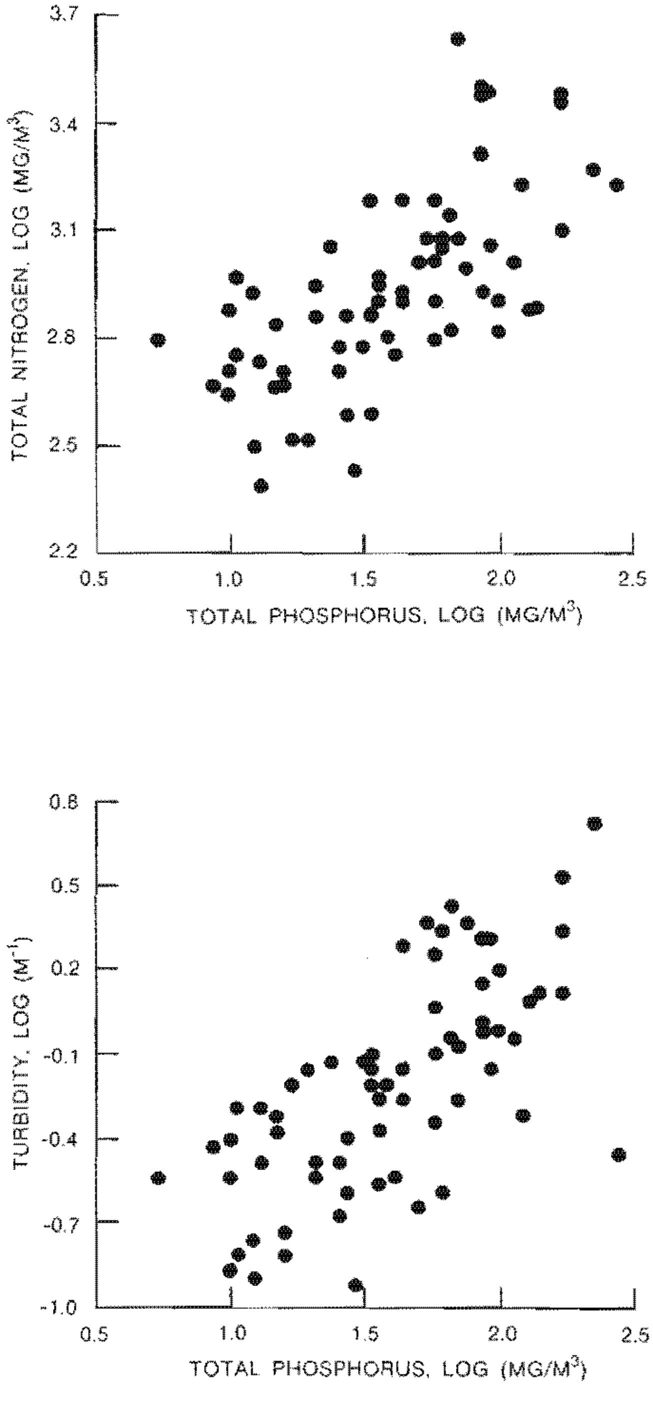


Figure IV-6. Phosphorus, nitrogen, turbidity relationships for CE reservoirs. Nonalgal turbidity calculated as 1/Secchi (m) - 0.025 Chl-a (mg/m^3)

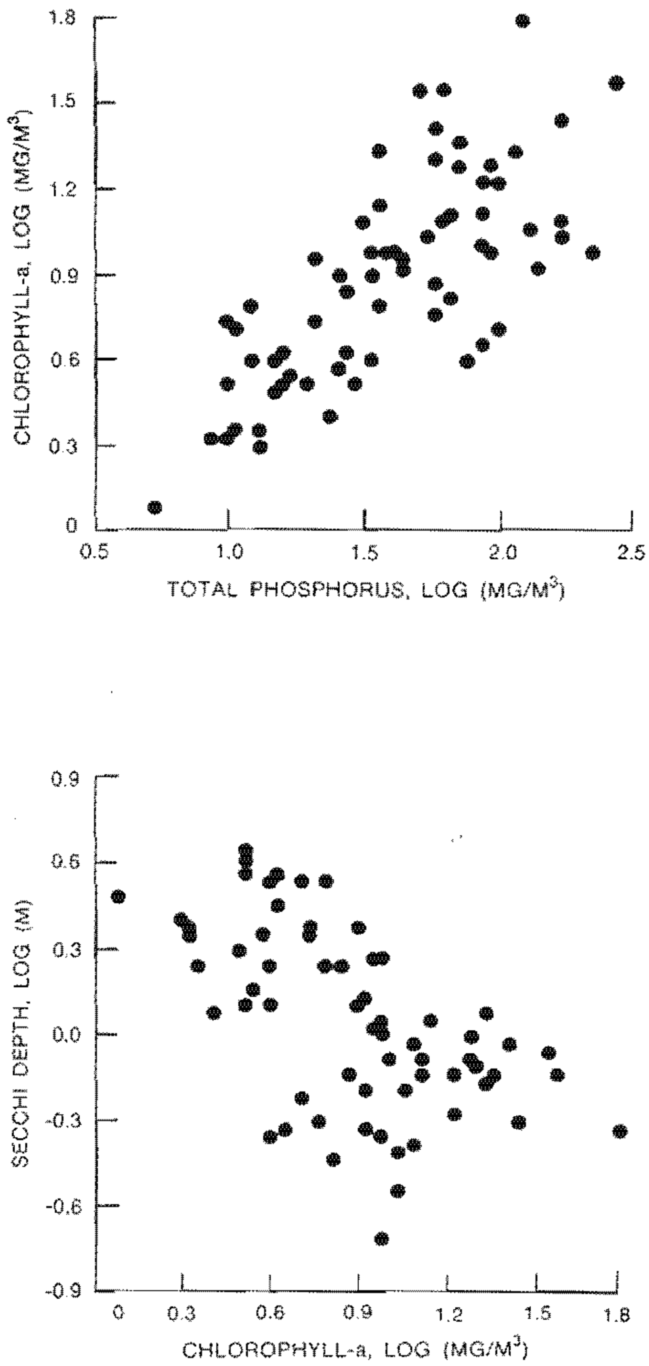


Figure IV-7. Phosphorus, chlorophyll-a, and transparency relationships for CE reservoirs

Model	Limiting Factors
1	P, N, light, flushing
2	P, light, flushing
3	P, N
4	P, linear
5	P, exponential

Approximate applicability constraints are given in Table IV-2. "Northern lake" eutrophication models are based upon phosphorus/chlorophyll regressions (similar to Models 4 and 5). Research objectives (Walker 1985) have been to define the approximate ranges of conditions under which simple phosphorus/chlorophyll relationships are appropriate and to develop more elaborate models (Models 1-3) which explicitly account for additional controlling factors (nitrogen, light, flushing rate).

While model refinements have been successful in reducing the error variance associated with simple phosphorus/chlorophyll relationships by approximately 58 percent, a "penalty" is paid in terms of increased data requirements (e.g., nonalgal turbidity, mixed-layer depths, nitrogen, and flushing rate). For existing reservoirs, these additional data requirements can be satisfied from pool monitoring and nutrient loading information. Otherwise, estimates must be based upon subjective estimates, independent hydrodynamic models, and/or regional data from similar reservoirs. Empirical models for developing independent estimates of turbidity, mixed-layer depth, and mean hypolimnetic depth are summarized in Table IV-7. These should be used only in the absence of site-specific measurements.

Since mechanistic models for predicting nonalgal turbidity levels as a function of deterministic factors (e.g., suspended solids loadings and the sedimentation process) have not been developed, it is possible to predict chlorophyll-a responses to changes in nutrient loading in light-limited reservoirs only under stable turbidity conditions. Projections of chlorophyll-a concentrations should include a sensitivity analysis over a reasonable range of turbidity levels.

Model calibration and testing have been based primarily upon data sets describing reservoir-average conditions (Walker 1985). Of the above options, Model 4 (linear phosphorus/chlorophyll-a relationship) has been most extensively tested for use in predicting spatial variations within reservoirs. The

Table IV-7

Equations for Estimating Nonalgal Turbidity, Mixed Depth, and Hypolimnetic Depths in Absence of Direct Measurements

Nonalgal turbidity

Based upon measured chlorophyll-a and Secchi depth:

$$a = 1/S - 0.025\ B \text{ (minimum value = 0.08 1/m)}$$

where

s = Secchi depth, m

B = chlorophyll-a, mg/m^3

Multivariate turbidity model:

$$\log (a) = 0.23 - 0.28 \log (Z) + 0.20 \log (FS) + 0.36 \log (P) - 0.027\ LAT + 0.35\ du \quad (R^2 = 0.75,\ SE^2 = 0.037)$$

where

LAT = dam latitude, deg N

du = regional dummy variable, (1 for USAE Divisions North Pacific, South Pacific, Missouri River, and Southwest (except USAE District, Little Rock) and USAE District, Vicksburg, and 0 for other locations)

F_s = summer flushing rate (yr^{-1}) or 0.2, whichever is greater

Z = mean total depth, m

P = total phosphorus concentration, mg/m^3

Mean depth of mixed layer (entire reservoir, for Z < 40 m):

$$\log (Zmix) = -0.06 + 1.36 \log (Z) - 0.47 [\log (Z)]^2 \quad (R^2 = 0.93,\ SE^2 = 0.0026)$$

Mean depth of hypolimnion (entire reservoir):

$$\log (Zh) = -0.58 + 0.57 \log (Zx) + 0.50 \log (Z) \quad (R^2 = 0.85,\ SE^2 = 0.0076)$$

chlorophyll/phosphorus ratio is systematically related to measures of light limitation, including the chlorophyll-a and transparency product, and the product of mixed-layer depth and turbidity. If nitrogen is not limiting, then light-limitation effects may be approximately considered by calibrating the chlorophyll/phosphorus ratio to field data; this is an alternative to using the direct models (i.e., Models 1 and 2) which require estimates of turbidity and mixed-layer depth in each segment. The relationships depicted in Figure IV-8 may be used to obtain approximate estimates of reservoir-average calibration coefficients for use in Model 4 based upon observed monitoring data or independent estimates of turbidity and mixed-layer depth (Table IV-7).

INPUT DATA REQUIREMENTS

BATHTUB requires two input files: (a) a KEY file containing data that are normally constant from one application to another, and (b) a CASE file defining a particular application. The KEY file contains variable definitions and summary statistics derived from the data set used in model development. The KEY file should be considered part of the program and should not be modified. Input coding forms for BATHTUB files are given at the end of this Part. Inputs are specified in the following groups:

Group 1: Title.

Group 2: Output Format Options.

Group 3: Model Options.

Group 4: Atmospheric Loading and Nutrient Availability Factors.

Group 5: Miscellaneous Parameters.

Group 6: Summary Discharge Information: Tributaries, Point Sources, and Outflows.

Group 7: Summary Concentration Information: Tributaries, Point Sources, and Outflows.

Group 8: Model Segments and Calibration Factors.

Group 9: Model Segment Morphometry.

Group 10: Pool Water Quality Data Summaries.

A global convention in the input CASE file is that all input coefficients of variation (CV's) are optional and may be left blank or set to 0.0 if they are not to be considered in error analysis calculations. Other missing values can be left blank, although certain variables must be specified.

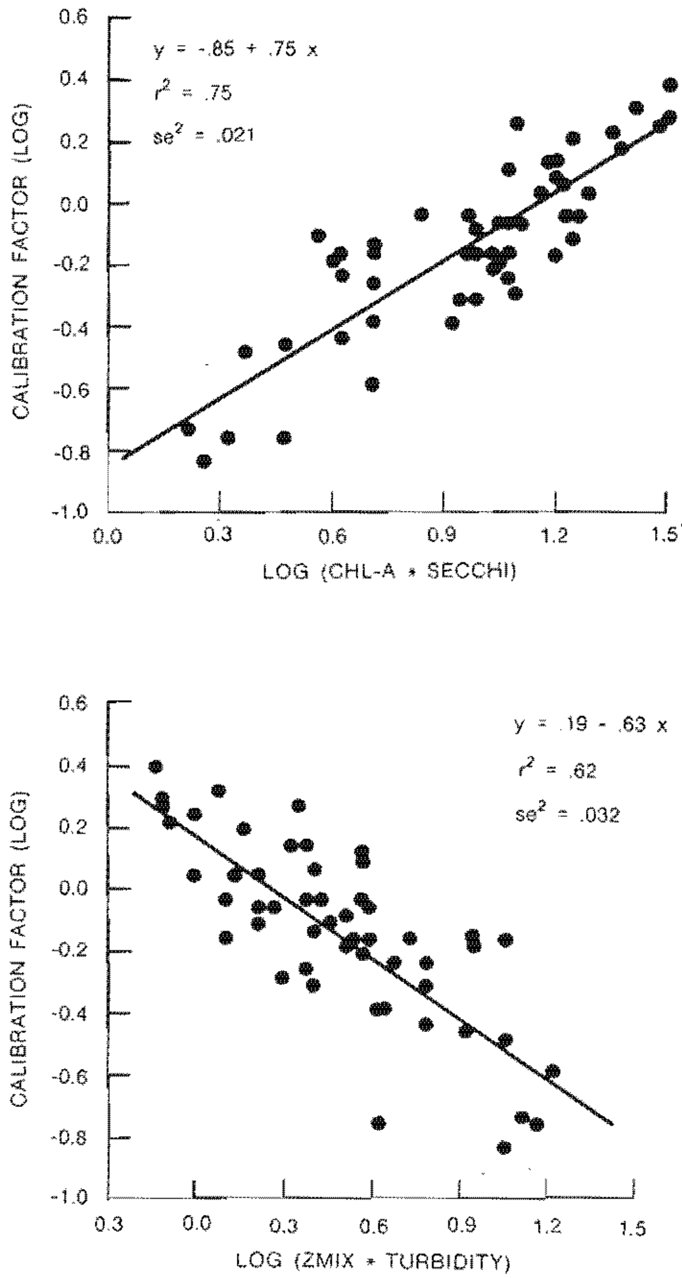


Figure IV-8. Calibration factor for linear phosphorus/chlorophyll model versus light limitation factors

Group 1 consists of an alphanumeric title (reservoir name, etc.) used to label output. Group 2 selects the output formats to be generated in the following categories:

a. List of input conditions.

b. Hydraulic and dispersion parameters.

c. Gross water and mass balances.

d. Detailed water and mass balances by segment.

e. Water and mass balance summary by segment.

f. Comparison of observed and predicted values.

g. Diagnostics.

h. Spatial profile summary.

i. Plot of segment values and confidence limits.

j. Sensitivity analysis.

A single-digit code is entered for each option. A value of zero suppresses printing of the corresponding output format. Nonzero values have particular meanings for each format, as discussed below (see section Output Formats).

Nine model and calculation options are defined in Group 3.

a. Conservative substance balance.

b. Phosphorus sedimentation model.

c. Nitrogen sedimentation model.

d. Chlorophyll model.

e. Secchi model.

f. Dispersion model.

g. Phosphorus calibration model.

h. Nitrogen calibration method.

i. Error analysis.

Option settings are summarized in Table IV-2. For each option, a setting of zero will bypass the corresponding calculations. Conservative substance (e.g., chloride) balances may be useful for verifying water balances and calibrating diffusive transport coefficients. For the phosphorus, nitrogen, and chlorophyll models, settings of 1 or 2 correspond to the most general formulations identified in model testing. If the conservative substance, phosphorus, or nitrogen sedimentation model is set to 0, corresponding mass balance calculations are bypassed, and predicted concentrations are set equal to observed values in each segment. This feature is useful for assessing pool nutrient/ chlorophyll relationships and controlling factors in the absence of nutrient loading information. For preliminary runs, error analysis calculations can be bypassed by setting option 9 to 0 to conserve computer time, which may be a factor for cases involving large numbers of segments.

Group 4 contains atmospheric loading rates and availability factors for the following water quality components:

a. Conservative substance.

b. Total phosphorus.

c. Total nitrogen.

d. Ortho-phosphorus.

e. Inorganic nitrogen.

Mass balance calculations may be computed for the first three components, according to the models specified in Group 3. Atmospheric loading rates are specified on an areal basis (kg/km^2-yr) and reflect precipitation and dustfall. Note that the availability factors should be adjusted to reflect the phosphorus and nitrogen sedimentation models employed (see Tables IV-2 and IV-3).

Group 5 defines variables which are used in mass balance and response calculations:

a. Length of averaging period, yr.

b. Precipitation, m.

c. Evaporation, m.

d. Increase in pool elevation, m.

e. Flow scale factor, unitless.

f. Dispersion factor, unitless.

g. Total area, km^2.

h. Total volume, km^3.

The averaging period equals the duration of the water and mass balance calculations, normally annual (1.0) or seasonal (May-September or 0.42 yr). Nutrient residence time and turnover criteria can be used to decide whether annual or seasonal balances are appropriate for a particular application. Estimates of precipitation, evaporation, increase in elevation, and tributary flows (Group 6) and tributary concentrations (Group 7) must correspond to this averaging period.

In order to permit application to more than one reservoir and/or loading scenario simultaneously, the first four input items in Group 5 are multiplied by segment-specific factors given in Group 9. Thus, there are two methods of specifying the averaging period, precipitation, evaporation, and increase in elevation. According to the first method (generally applied to simulations of one reservoir), the appropriate values are entered in Group 5 and the segment-specific factors in Group 9 are set to 1.0. According to the second method (generally applied to simulations of multiple reservoirs), segment-specific values are entered in Group 9 and the "global" factors in Group 5 are set to 1.0. The CV's specified in Group 5 apply to both methods.

The flow scale factor in Group 5 is applied to all tributary and discharge flows specified in Group 6, except direct point sources (type = 3). Normally, the scale factor equals 1. Other values can be specified to test prediction sensitivity to alternative flow regimes, under the assumption that inflow concentrations are approximately independent of mean flows. If the latter assumption is invalid, separate input files must be set up to reflect inflows and loadings under alternative hydrologic regimes.

The dispersion factor specified in Group 5 (normally set to a value of 1.0) is multiplied by all exchange flows in the hydraulic network. This factor can be used, along with the segment-specific dispersion factors specified in Group 7, in calibrating dispersion rates to conservative tracer and/or nutrient profile data.

If the total surface area and volume specified in Group 5 are nonzero, the segment surface areas and mean depths specified in Group 8 (see below) are rescaled to correspond with the specified total area and volume. This rescaling is generally convenient for defining segment morphometries in simulations of spatial variations within a single reservoir.

Group 6 defines external inputs, discharges, and withdrawals:

a. Stream ID number.

b. Type Code:

   (1) 1 = Measured inflow.

   (2) 2 = Estimated (ungauged) inflow.

   (3) 3 = Point source discharging directly into pond.

   (4) 4 = Discharge/withdrawal.

c. Segment reference number.

d. Name (description).

e. Drainage area.

f. Mean flow.

g. Mean flow coefficient of variation.

Stream identification numbers are specified sequentially up to a maximum value of 29. The segment reference number identifies the model segment associated with a given input stream or withdrawal. Specified gauged outflows (type = 4) are used only for verifying the pool water balance and for computing observed nutrient retention coefficients. Predicted nutrient mass balances are based upon external inflows, precipitation, and evaporation. Thus, outflow terms do not have to be specified if verification of the water balance is not desired.

Ungauged inflows include direct drainage from shoreline areas, ground-water inputs, and unmonitored tributaries to each model segment. Unmonitored tributaries and direct drainage are estimated by drainage area proportioning using monitored unit runoff rates from regional watersheds with similar land use and geologic characteristics. Adjustment of estimated ungauged flow rates is normally done by the user to establish a water balance around the reservoir prior to implementation of nutrient balance models. BATHTUB treats measured (type = 1) and estimated (type = 2) inflows equally.

The CV of the mean flow estimate (standard error/mean) is used in error analysis and reflects limitations in flow gauging methodology (for gauged streams) or limitations in models, subjective assessment, or other flow estimation methods (for ungauged streams). LaBaugh and Winter (1981) and Winter (1981) discuss potential errors in tributary flow measurements and their effects on lake water and nutrient balances. For gauged streams, mean flow CV's are typically on the order of 0.05 to 0.10. Other components, such as ground-water inflows, ungauged runoff, direct precipitation, and evaporation (specified in Group 4) may have higher error coefficients, depending upon site-specific conditions.

Group 7 defines flow-weighted mean concentrations (loading/flow) for each tributary, source, or discharge specified in Group 6.

a. Stream identification number.

b. Conservative substance.

c. Total phosphorus.

d. Total nitrogen.

e. Ortho-phosphorus.

f. Inorganic nitrogen.

For gauged streams, the estimated mean concentrations and their CV's are normally derived from FLUX program output (see Part II). For ungauged areas, concentration estimates are based upon regional data from gauged streams with similar land use and geologic characteristics. The CV's tend to be higher for ungauged streams because of the uncertainty associated with extrapolating concentration measurements from one watershed to another.

Group 8 defines the model segment linkage and calibration factors, as outlined below:

a. Segment identification number.

b. Downstream segment number.

c. Segment group number.

d. Segment name.

e. Calibration factor - phosphorus sedimentation.

f. Calibration factor - nitrogen sedimentation.

g. Calibration factor - chlorophyll-a.

h. Calibration factor - Secchi depth.

i. Calibration factor - hypolimnetic oxygen depletion.

j. Calibration factor - bulk exchange rate.

Segments are numbered sequentially up to a maximum of 14. The spatial sequence of segments is arbitrary, except that the most downstream segment (near dam) must be given the highest identification number if spatial variations or reservoir networks are being simulated. To facilitate output interpretation, segment numbers are normally assigned in increasing order moving downstream in each tributary arm.

In formulating water and mass balances, BATHTUB routes segment outflow to the downstream segment number, while accounting for external inflows and withdrawals specified in Group 5 and other balance terms. The downstream segment number of the last segment (near-dam) should be set to zero. Diffusive exchanges can occur only between adjacent segments. For independent segments (Schemes 4 and 5 in Figure IV-3), all downstream segment numbers should be set to zero.

Simulations of reservoir networks (Scheme 6 in Figure IV-3) can be achieved by specifying the appropriate downstream segment numbers and setting dispersion calibration factors to zero (to eliminate backmixing across dam interfaces). For Scheme 6, outflow streams should not be specified in Groups 6 and 7, unless they are permanent withdrawals (removed from system and not returned to downstream segments) or they refer to the last (most downstream) reservoir.

The segment group number specified in Group 8 determines the aggregation of segments for the purpose of computing effective sedimentation rate coefficients (A1 and B1 in Table IV-2). Rate coefficient computations are based upon the following variables summarized by segment group:

a. Surface overflow rate.

b. Flushing rate (or residence time).

c. Total external nutrient load.

d. Tributary total nutrient load.

e. Tributary ortho or inorganic nutrient load.

The flushing rate is also used in chlorophyll-a Models 1 and 2. Area-weighted mean chlorophyll-a concentrations are computed for each segment group and used in the computation of hypolimnetic oxygen depletion rates (see Table IV-4).

Generally, segment group numbers reflect different reservoir/loading scenario combinations. For segmentation schemes 1, 4, 5, and 6 in Figure IV-3, for example, the segment group numbers equal the segment identification numbers. For Schemes 2 and 3, all segments are located in the same reservoir, so that all segment group numbers are set to 1.

Calibration factors are used to modify estimated nutrient concentrations, chlorophyll-a concentrations, Secchi depths, oxygen depletion rates, and dispersion coefficients. Their purpose is to provide a means of adjusting model predictions to match observed concentration profiles. Normally, calibration factors are set to 1.0 for each segment and model. Given reliable monitoring data from a reservoir under study, it may be desirable to calibrate the model in some applications. In a predictive mode, calibration provides a common set of observed and predicted values for comparative evaluation of future scenarios. Calibration essentially tunes the model predictions to account for site-specific characteristics. Generally, calibration should be attempted only if the observations are made under reasonably steady-state conditions (i.e., adequate turnover ratios, etc.) and observed mean concentrations are significantly different from predicted values, considering the potential errors associated with the observations. Program output includes statistical tests to assist the user in assessing whether calibration is appropriate. Procedures for calibrating the model are described in more detail in the section Application Procedures.

The calibration factor for dispersion refers to the interface between the model segment and the next downstream segment. The factor can be used to reduce bulk exchange flows between segments with limited interchange because of separation by narrow channels, bridges, or weirs or to increase bulk exchange flows between segments with high interchange because of wind fetch or other factors. If Dispersion Model 3 is selected, the bulk exchange flows are set equal to the calibration factors (with units of cubic hectometers per year). Dispersion calibration factors are automatically set to zero for segments with outflow segment numbers of zero.

Input Group 9 defines segment morphometry:

a. Segment identification number.

b. Length of averaging period, yr.

c. Precipitation, m.

d. Evaporation, m.

e. Increase in elevation, m.

f. Length, km.

g. Surface area, km^2.

h. Mean depth, m.

i. Mean depth of mixed layer and CV, m.

j. Mean hypolimnetic depth and CV, m.

Entries for averaging period, precipitation, evaporation, and increase in elevation are multiplied by the corresponding entries in Group 5. Lengths, surface areas, and mean depths correspond to average growing-season conditions and can be estimated from maps and morphometric data. As discussed above, if the total surface area and volume specified in Group 5 are nonzero, the segment surface areas and mean depths specified in Group 8 are rescaled. Because of this rescaling, input areas and mean depths can be relative values (i.e., units can be arbitrary).

Midsummer temperature profile data and reservoir morphometric curves can be used to estimate the mean depth of the mixed-layer (volume/surface area) in each model segment. If the input field for mixed-layer depth is left blank, a value is automatically estimated from mean total depth according to the empirical equation given in Table IV-7. Mixed-layer depths are required only if chlorophyll-a Models 1 or 2 are used.

If the reservoir is stratified and oxygen depletion calculations are desired, temperature profile data taken from the period of depletion measurements (typically late spring to early summer) are used to estimate the mean depth of the hypolimnion. If mean hypolimnetic depth is blank or zero, the reservoir is assumed to be unstratified and oxygen depletion calculations are bypassed. The oxygen depletion models are based upon data from near-dam stations. Accordingly, mean hypolimnetic depths should be specified only for near-dam segments, based upon the morphometry of the entire reservoir (not the individual segment). In modeling collections or networks of reservoirs (Schemes 5 and 6 in Figure IV-3), a mean hypolimnetic depth can be specified separately for each segment (i.e., each reservoir). Table IV-7 gives an empirical relationship that can be used to estimate mean hypolimnetic depth in the absence of direct measurements.

Input Group 10 summarizes observed water quality data from each model segment. Means and CV's can be specified for the following variables:

a. Segment identification number.
b. Nonalgal turbidity.
c. Conservative substance.
d. Total phosphorus.
e. Total nitrogen.
f. Chlorophyll-a.
g. Secchi depth.
h. Organic nitrogen.
i. Total P - ortho-P.
j. Hypolimnetic oxygen depletion rate.
k. Metalimnetic oxygen depletion rate.

The program uses the observed data to test model applicability by comparing observed and predicted values. Missing values may be left blank. For the first eight components, summary statistics (mean and CV of mean) are derived from mixed-layer, growing season measurements within each segment. The PROFILE program (see Part III) includes algorithms for calculating the summary statistics by model segment and for calculating depletion rates from oxygen and temperature profile data. Oxygen depletion rates should be specified only for near-dam segments and left blank if the reservoir is unstratified.

Estimates of nonalgal turbidity (minimum = 0.08 m^{-1}) are required for chlorophyll-a Models 1 and 2, Secchi Model 1 (Table IV-2), and Nutrient Partitioning Models (Table IV-4). Ideally, turbidity is calculated from observed Secchi and chlorophyll-a data in each segment. If the turbidity input field is left blank, the program calculates turbidity values automatically from observed chlorophyll-a and Secchi values (if specified). An error message is printed, and program execution is terminated if all of the following conditions hold:

a. Turbidity value missing or zero.

b. Observed chlorophyll-a or Secchi missing or zero.

c. Chlorophyll-a Models 1, 2 or Secchi Model 1 used.

In the absence of direct turbidity measurements, the multivariate regression equation specified in Table IV-7 can be used to estimate a reservoir-average value. Such estimates can be modified based upon regional data bases. As discussed earlier (see subsection Eutrophication response models), existing models do not permit a priori estimation of within-reservoir, spatial variations in nonalgal turbidity.

Table IV-8 lists the error messages that may be generated if an invalid condition is encountered as the CASE file is read or as mass balance calculations are performed. Probable error sources are also indicated. The probable locations of coding errors in the input file can be identified by requesting a listing of input conditions (Output Format 1) and matching error message location with the input file structure. Execution of the program terminates if an error condition is detected.

OUTPUT FORMATS

Ten optional output formats have been designed for various purposes, as documented at the end of this Part. This section discusses the contents and uses of each format using data from Keystone Reservoir (located on the Arkansas and Cimarron Rivers in Oklahoma). The subsequent section describes stepwise procedures for using the model and interpreting output in typical reservoir applications.

Model segmentation for the Keystone application is illustrated in Figure IV-9. Pool and tributary water quality data were derived from measurements made in 1974 and 1975 by the EPA National Eutrophication Survey (NES) (USEPA 1975). The Keystone pool was sampled by the EPA/NES four times between April and October 1975. The role of light limitation in Keystone has been previously discussed (Walker 1985). Because of the relatively low summer hydraulic residence time of the reservoir (0.08 yr), seasonal nutrient turnover ratios are high, and water and mass balance calculations are based on May through September conditions during the pool monitoring year. Point sources

Table IV-8

BATHTUB Error Messages and Possible Causes

*** INVALID NONALGAL TURBIDITY
Turbidity specified < 0.08 1/m
Observed turbidity, chlorophyll-a, and Secchi missing
and chlorophyll-a Model 1 or 2 specified

*** INPUT CASE FILE ERROR
Records out of order
Too many tributaries or segments
Invalid segmentation scheme (outflow segment number, segment group number)
Missing segment length, area, mean depth, or averaging period
Invalid value specified

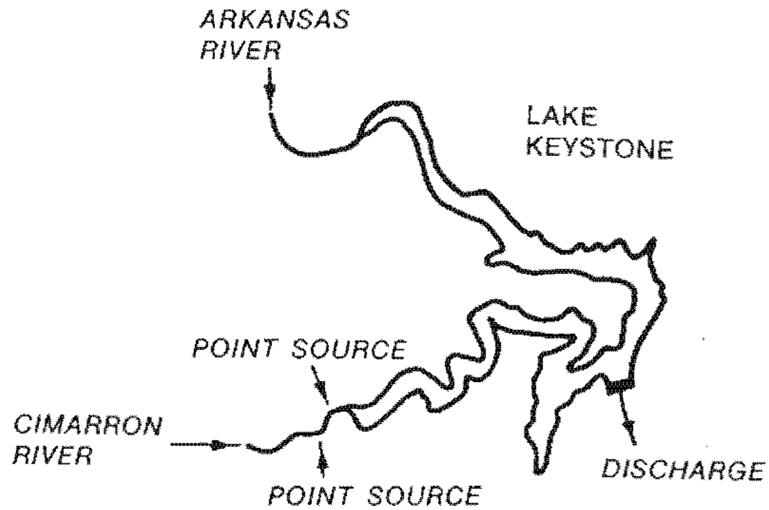
*** INPUT KEY FILE ERROR
Key file records out of order or otherwise modified

*** CHLOROPHYLL SUBMODEL ERROR
Nitrogen data not provided but required for specified chlorophyll-a model

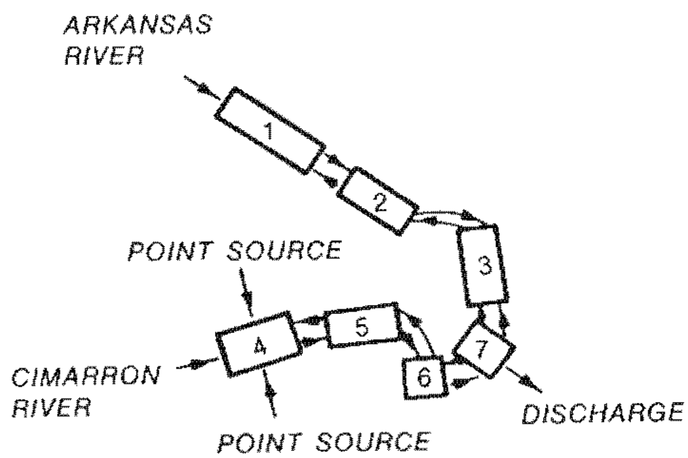
*** INVALID RATE COEFFICIENT
Missing tributary ortho-P/total P or inorganic N/total N loading
ratio for segment group, nutrient sedimentation Model 2
Missing total nutrient load for segment group, nutrient Model 4

*** INVALID SOLUTION FOR COMPONENT
Invalid segmentation scheme
Concentration solution negative
No loadings specified
Attempt to solve for conservative substance in segmentation scheme
with zero or negative net inflow (inflow-evaporation)

*** DOWN THE DRAIN
Program execution ends abnormally (follows one or more of above messages)



a. Morphologic features



b. Segmentation scheme

Figure IV-9. Model segmentation for Lake Keystone, Oklahoma, application include three sets of municipal sewage effluents which have been aggregated by reservoir segment. Since the EPA/NES estimated nutrient loadings but not flows for these effluents, a flow of 1 hm^3/yr has been assumed for each source (insignificant in relation to reservoir water balance) and the nutrient concentrations have been adjusted to correspond with the reported loadings. Table IV-9 summarizes output formats and options. Input and output files for this example are presented later in this Part.

Output Format 1 lists input conditions. This is intended to verify and document the input case file. The listing should be reviewed to check for errors in input file coding.

Output Format 2 summarizes hydraulic and dispersion calculations. The total outflow (advection plus withdrawals) is listed for each segment. Dispersion and exchange rates are calculated according to the specified dispersion model (see Table IV-2). Numeric dispersion rates are subtracted from estimated dispersion rates before calculating exchange flows. Model segmentation should be designed so that estimated dispersion exceeds numeric dispersion in each segment. Numeric dispersion rates can be reduced by reducing segment lengths.

Output Formats 3, 4, and 5 summarize water and mass balances. If an Optional Code of 1 is specified for any of these formats, mass balances (including outflow, increase in storage, and retention) are estimated from observed pool and outflow concentrations. In this case, the mass balances are essentially descriptive and do not rely on a particular sedimentation model. This is a useful option for examining the magnitude and spatial distribution of nutrient sedimentation in a reservoir, given reliable loading and outflow estimates and pool monitoring data. If an Option Code of 2 is specified, balances are based upon predicted pool concentrations, and the outflow and pool concentrations specified in the CASE file are ignored. Option 2 is used in a predictive mode.

Output Format 3 summarizes the water and mass balance calculations over the entire reservoir. Results are reviewed to ensure that an accurate water balance has been established and that all drainage areas have been accounted for before proceeding to subsequent modeling steps. The output includes a mean, variance, and CV for each water and mass balance term. In the case of the mass balance, loading means and variances are also expressed as percentages of the total inflow mean and variance, respectively. These provide

Table IV-9

BATHTUB Output Format Options

FORMAT 1 - LIST INPUT CONDITIONS

0 = Print Model Options Only
1 = Print All Input Conditions

FORMAT 2 - HYDRAULICS AND DISPERSION

0 = Do Not Print
1 = Print

FORMAT 3 - GROSS WATER AND MASS BALANCES

0 = Do Not Print
1 = Use Observed Pool and Outflow Concentrations to Compute Discharge, Change in Storage, Retention, and Mass Residence Times
2 = Use Estimated Pool Concentrations

FORMAT 4 - DETAILED WATER AND MASS BALANCES BY SEGMENT

0 = Do Not Print
1 = Use Observed Pool and Outflow Concentrations to Compute Discharge, Change in Storage, and Retention
2 = Use Estimated Pool Concentrations

FORMAT 5 - WATER AND MASS BALANCE SUMMARY BY SEGMENT

0 = Do Not Print
1 = Use Observed Pool and Outflow Concentrations to Compute Discharge, Change in Storage, and Retention
2 = Use Estimated Pool Concentrations

FORMAT 6 - COMPARE OBSERVED AND PREDICTED VALUES

0 = Do Not Print
1 = Print for Each Segment and Area-Weighted Means
2 = Print Area-Weighted Means Only

FORMAT 7 - DIAGNOSTICS

0 = Do Not Print
1 = Print for Each Segment and Area-Weighted Means
2 = Print Area-Weighted Means Only

FORMAT 8 - SPATIAL PROFILE SUMMARY

0 = Do Not Print
1 = Print Predicted Profiles Only
2 = Print Predicted, Observed, and Observed/Predicted Ratios

(Continued)

FORMAT 9 - PLOT SEGMENT VALUES AND CONFIDENCE LIMITS

0 = Do Not Print
1 = Use Linear Scales
2 = Use Geometric Scales

FORMAT 10 - SENSITIVITY ANALYSIS

0 - Do Not Print
1 = Print for Conservative Substance
2 = Print for Phosphorus
3 = Print for Nitrogen

perspectives on predominant loading and error sources. The variance distribution can be used to prioritize future data collection efforts by keying on the major sources of error (e.g., by increasing sampling frequencies).

Output Format 3 also includes hydrologic summary statistics (surface overflow rate and hydraulic residence time) and mass balance statistics (mass residence time, turnover ratio, and retention coefficient). As discussed above, the mass residence time and turnover ratio are used in selecting an appropriate averaging period for water and mass balance calculations.

In the case of the Keystone phosphorus balance, the turnover ratio is 13.4, which means that phosphorus stored in the water column was displaced approximately 13.4 times during the 5-month balance period based upon observed pool phosphorus concentrations. This is a relatively favorable ratio for mass balance modeling because it indicates that pool nutrient levels are not likely to reflect loading conditions experienced prior to the mass balance period. As discussed above, a turnover ratio of 2 or more is desirable for modeling purposes.

Output Format 4 presents detailed water and mass balances by segment. The summary includes flow, load, and mean concentration for each external source, discharge, and computed summary term. The summary terms include internal transfers (attributed to advection and exchange with neighboring segments) as well as external inputs, outflows, and retention. The advective outflow term for each segment is derived from the flow balance.

Output Format 5 is a condensed version of the water and mass balances by segment. Summary terms are presented in tables that depict the routing of water and nutrient mass through the reservoir segments. Inflow terms include external watershed loadings, atmospheric loadings, and advection from upstream segments. Outflow terms include advection to downstream segments and specified withdrawals or discharges. The water balance also includes storage, evaporation, and gross diffusive exchange with downstream segments, although the latter is not a factor in the water balance calculation because it occurs in both directions. The mass balance tables also include storage, retention, and net exchange with adjacent (upstream and downstream) segments. The net exchange term is formulated as an input (i.e., it will be positive or negative), depending upon whether dispersion causes net transport of mass into or out of the segment, respectively.

Note that the advective outflow from each segment is calculated from the water balance. If the computed advective outflow from any segment (except those segments which discharge out of the system) is less than zero, the water and balances are satisfied by backflow from downstream segments (i.e., the direction of the advective flow at the corresponding segment interface is reversed). This might occur, for example, for a segment in which the evaporation rate exceeds the sum of external inflow and precipitation. The program handles this condition by reversing the flow direction.

In the last (near-dam) segment, the advective outflow term of the water balance table represents the cumulative water balance error if the reservoir discharge rate is specified. In the Keystone example, a residual water balance error of -0.2 hm^3/yr is indicated. Since this is small relative to the gauged outflow (10,556 hm^3/yr), the impact on the water and nutrient balance calculations is negligible. This water balance has been achieved by adjusting flow rates from ungauged drainage areas.

Output Format 6 compares observed and predicted water quality conditions in each model segment. This format can be used to test model applicability to reservoirs with adequate water quality monitoring data. Area-weighted means are also calculated and compared. T-statistics compare observed and predicted means on logarithmic scales using three alternative measures of error:

a. The first test considers error in the observed value only, as specified in Input Group 10. If the absolute value of the T(1) is less than 2.0, the observed mean is not significantly different from the predicted mean at the 95-percent confidence level, given the precision in the observed mean value, which reflects variability in the monitoring data and sampling program design.

b. The second test (supplementary to the third) compares the error with the standard error estimated from the model development data set and is independent of the observed and estimated CV's.

c. The third test considers observed and predicted CV's for each case, variable, and segment. If the absolute value of T(3) exceeds 2.0, the difference between the observed and predicted means is greater than expected (at the 95-percent confidence level), given potential errors in the observed water quality data, model input data, and inherent model errors.

Since deviations would be expected to occur by chance in 5 percent of the tests applied to reservoirs conforming to the models, results of the T-tests should be interpreted cautiously. Error terms used in calculating T(2) and T(3) have been calibrated for predicting area-weighted mean conditions; observed versus predicted deviations may be greater for station-mean or segment-mean values. In calculating the CV's for area-weighted-mean observed conditions, the program attributes the major source of error to temporal variance and assumes that the errors are correlated across stations. Note that comparisons of area-weighted-mean conditions are to be accurate only if sampling stations are distributed throughout the reservoir. If existing data limitations preclude adequate spatial coverage, the observed/predicted comparisons must be based upon data from individual segments.

Output Format 7 lists observed values, estimated values, and error ratios and ranks them against the model development data set. Approximate rankings are computed from the geometric mean and geometric standard deviation of area-weighted-mean observed values in the model development data set assuming a log-normal distribution. The variable list includes the basic network variables plus nine composite variables that are useful for diagnostic purposes. Diagnostic variables are used to assess the relative importance of phosphorus, nitrogen, and light as controlling factors, as outlined in Table IV-6.

Output Format 8 presents observed values, predicted values, and observed/predicted ratios in a series of tables which facilitate comparisons among segments. This abbreviated format does not include error analysis results.

Output Format 9 provides a graphic comparison of observed and predicted concentration distributions by model segment. Dashed lines reflect approximate 95-percent confidence limits (mean ±2 standard errors). This plot is useful for identifying spatial trends. Scales are linear or geometric for option codes 1 and 2, respectively.

Output Format 10 provides a sensitivity analysis of predicted conservative substance, phosphorus, or nitrogen profiles as a function of dispersion and decay rates. This format is useful for examining sensitivity to the two major processes controlling the development of spatial concentration gradients. Dispersion rates are varied by a factor of 4, and decay rates, by a factor of 2, in rough proportion to expected error magnitudes for nutrient sedimentation options 1 or 2 and dispersion option 1 (Walker 1985). Generally, concentrations tend to be more sensitive to dispersion in upper-pool segments, where dispersion accounts for dilution of major inflows. Sensitivity to decay rate is usually greater in near-dam segments, as compared with upper-pool segments.

APPLICATION PROCEDURES

Three application scenarios can be defined, based upon reservoir status and data availability:

Scenario	Reservoir	Data Availability: Water/Nutrient Balance Data	Data Availability: Pool Water Quality Data
A	Existing	Yes	Yes
B	Existing	No	Yes
C	Existing or proposed	Yes	No

Scenario A normally applies to an existing reservoir with nutrient balance data and pool water quality data. Under Scenario B, nutrient balance (loading) information is lacking; in this case, the program can be used for diagnostic purposes (e.g., assessing pool nutrient/chlorophyll relationships and regional ranking). Scenario C is distinguished by lack of pool water quality data, which would otherwise be used for preliminary testing and calibration.

For each scenario, application procedures can be summarized in terms of the following basic steps:

Step	Procedure
1	Watershed data reduction
2	Reservoir data reduction
3	Data entry and verification
4	Water balances
5	Nutrient turnover
6	Diffusive transport
7	Nutrient balances
8	Chlorophyll-a and Secchi responses
9	Verification
10	Diagnostics
11	Predictions

These steps are designed to be executed sequentially, although reiteration of previous steps may be required under certain conditions. Not all steps are applicable to each scenario, as outlined in Table IV-10, IV-11, and IV-12 for

Table IV-10

Application Procedures for Scenario A: Existing Reservoir with Nutrient Balance and Pool Water Quality Data

1. WATERSHED DATA REDUCTION
   - Formulate drainage area balance
   - Gauged tributaries and sources:
     - Describe watershed or source
     - Compile flow and water quality data
     - Set up FLUX input file for each tributary or source
     - Assess flow/concentration/loading relationships
     - Calculate annual and seasonal flows and loadings
   - Ungauged tributaries and sources:
     - Describe watershed or source
     - Select appropriate estimation method
     - Estimate annual and seasonal flows and loadings

2. RESERVOIR DATA REDUCTION
   - Compile pool water quality, elevation, and morphometry data
   - Set up PROFILE input file
   - Reduce mixed-layer water quality data:
     - Assess spatial and temporal variations (box plots)
     - Select appropriate spatial segmentation
     - Calculate summary statistics by segment
   - If reservoir is stratified:
     - Calculate oxygen depletion rates for near-dam station

3. DATA ENTRY
   - Define segmentation and hydraulic network
   - Code two input files:
     - Annual averaging period
     - Seasonal averaging period
   - Set output format: 1(1)
   - Run model and review output
   - Correct any errors in input data files

4. WATER BALANCES
   - Set output format: 3(1)
   - For each averaging period:
     - Run model and review output
     - Assess magnitude and most likely source of water balance errors
     - Adjust inflows and/or outflows to establish water balance

(Continued)

(Sheet 1 of 4)

5. NUTRIENT TURNOVER
   Set output format: 3(1)
   Run model and review output for each averaging period
   Select averaging period for subsequent analyses:
      If seasonal phosphorus turnover ratio >2, use seasonal; otherwise, use annual

6. DIFFUSIVE TRANSPORT
   Select dispersion model option
   Initialize dispersion calibration factors = 1.0
   Adjust segment dispersion factors to account for backflow restrictions (dams, weirs, bridges, channels, etc.)
   Set output format: 2(1)
   Run model and review output
   If numeric dispersion exceeds estimated dispersion in any model segment:
      Increase number of segments
      Repeat until numeric dispersion < estimated dispersion or predicted profiles insensitive to segmentation
   If conservative tracer data are available:
      Set model options: 1(1)
      Set output formats: 2(1), 3(1), 5(2), 6(1), 9(2), 10(1)
      Run model and review output
      If overall tracer mass balance error >5 percent
         Assess most likely source of error(s)
         Modify input data file accordingly
         Run model and review output
         Repeat until tracer mass balance established
      If number of segments >1 and tracer mass balance successful:
         Compare observed and predicted tracer profiles
         Adjust transport factors:
            Global dispersion calibration factor (Input Group 5)
            Segment dispersion calibration factors (Input Group 8)
         Run model and review output
         Recheck numeric dispersion criteria
         Repeat until tracer calibration established

7. NUTRIENT BALANCES
   Set sedimentation model options and availability factors
   Initialize nutrient calibration factors = 1
   Set output formats: 3(1), 5(2), 6(1), 9(2), 10(2 or 3)
   Run model and review output

(Continued)

7. NUTRIENT BALANCES (Continued)
If conservative substance data not available and segments >1:
Compare nutrient profile shapes (gradients)

Adjust dispersion parameters accordingly:
Global dispersion calibration factor (Input Group 5)
Segment dispersion calibration factors (Input Group 8)
Run model and review output
Recheck numeric dispersion criteria
Repeat until shapes match
Compare observed and predicted nutrients (Output Format 6),
Especially area-weighted means:
If observed <> predicted $|T(3)| > 2$ and $|T(2)| > 2$:
Question model applicability
Review data and assumptions
Test alternative nutrient sedimentation model(s)
If observed <> predicted $|T(1)| > 2$:
Select nutrient calibration option (normally 1)
Adjust nutrient calibration factors
Run model and review output
Repeat until observed and predicted nutrient levels match

8. EUTROPHICATION RESPONSES
For chlorophyll-a, Secchi, and HOD models (in order):
Select model option
Set output formats 6(1), 7(1), 9(2)
Set calibration factors = 1.0
Run model and review output
Compare observed and predicted values (Output Format 6)
Especially area-weighted means:
If observed <> predicted $|T(3)| > 2$ and $|T(2)| > 2$:
Question model applicability
Review data and assumptions
Test alternative submodels
If observed <> predicted $|T(1)| > 2$:
Adjust calibration factors
Run model and review output
Repeat until observed and predicted levels match
Check diagnostics (Output Format 7) for model
applicability

9. VERIFICATION
Repeat Steps 1-4 using data from different year(s)
Keep model options, segmentation, and calibration factors constant

(Continued)

(Sheet 3 of 4)

Table IV-10 (Concluded)

9. VERIFICATION (Continued)
   Set output formats: 2(1), 3(1), 6(1), 9(2)
   Run model and review output
   Compare observed and predicted responses

10. DIAGNOSTICS
   Select output formats: 7(1)
   Run model and review output
      Rankings
      Factors controlling productivity

11. PREDICTIONS
   Select output formats: all
   Define impact or control strategies to be evaluated
   Modify input case file accordingly
   Run model and review output
   Recheck diagnostics (Output Format 7) for model applicability
   Compare with base case(s)
   Run sensitivity analyses on key assumptions:
      Submodel selection
      Segmentation
      Dispersion
      Averaging periods

(Sheet 4 of 4)

Table IV-11

Application Procedures for Scenario B: Existing Reservoir with Pool Water Quality but Without Nutrient Balance Data

---

1. WATERSHED DATA REDUCTION (not applicable)

2. RESERVOIR DATA REDUCTION
   - Compile pool water quality, elevation, and morphometry data
   - Set up PROFILE input file
   - Reduce surface water quality data
     - Assess spatial and temporal variations (box plots)
     - Select appropriate spatial segmentation
     - Calculate summary statistics by segment
   - If reservoir is stratified: calculate oxygen depletion rates for near-dam station

3. DATA ENTRY
   - Define segmentation and hydraulic network
   - Set output format: 1(1)
   - Run model and review output
   - Correct any errors in input data files

4. WATER BALANCES (not applicable)

5. NUTRIENT TURNOVER (not applicable)

6. DIFFUSIVE TRANSPORT (not applicable)

7. NUTRIENT BALANCES
   - Set sedimentation model options: 1(0), 2(0), 3(0)

8. EUTROPHICATION RESPONSES
   - Review diagnostic variables
   - For chlorophyll-a, Secchi, and HOD models (in order):
     - Select model option
     - Set output formats 6(1), 7(1), 9(2)
     - Set calibration factors = 1.0
     - Run model and review output
     - Compare observed and predicted values (Output Format 6), especially area-weighted means:
       - If observed <> predicted $|T(3)| > 2$ and $|T(2)| > 2$:
         - Question model applicability
         - Review data and assumptions
         - Test alternative submodels
       - If observed <> predicted $|T(1)| > 2$:
         - Adjust calibration factors
         - Run model and review output

(Continued)

Table IV-11 (Concluded)

Repeat until observed and predicted levels match
Check diagnostics (Output Format 7) for model applicability

9. VERIFICATION
   Repeat Steps 1-4 using data from different year(s)
   Keep model options, segmentation, and calibration factors constant
   Set output formats: 6(1), 7(1), 9(2)
   Run model and review output
   Compare observed and predicted responses

10. DIAGNOSTICS
    Select output formats: 7(1)
    Run model and review output
      Rankings
      Factors controlling productivity

11. PREDICTIONS (not applicable)

Table IV-12

<u>Application Procedures for Scenario C: Proposed or Existing</u>

<u>Reservoir Without Pool Water Quality Data</u>

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1. WATERSHED DATA REDUCTION
   - Formulate drainage area balance
   - Gauged tributaries and sources:
     - Describe watershed or source
     - Compile flow and water quality data
     - Set up FLUX input file for each tributary or source
     - Assess flow/concentration/loading relationships
     - Calculate annual and seasonal flows and loadings
   - Ungauged tributaries and sources:
     - Describe watershed or source
     - Select appropriate estimation method
     - Estimate annual and seasonal flows and loadings

2. RESERVOIR DATA REDUCTION
   - Compile morphometric and pool elevation data
   - Define segmentation and hydraulic network
   - Estimate model input variables:
     - Mean hypolimnetic depth
     - Mean depth of mixed layer
     - Nonalgal turbidity

3. DATA ENTRY
   - Set model options
   - Set output format: 1(1)
   - Code two input files:
     - Annual averaging period
     - Seasonal averaging period
   - Set observed water quality conditions to 0
   - Run model and review output
   - Correct any errors in input data files

4. WATER BALANCES
   - Set output format: 3(2)
   - Specify reservoir discharge rate to give water balance
   - Run model and review output
   - Repeat until water balance is established

5. NUTRIENT TURNOVER
   - Set nutrient sedimentation model and availability factors
   - Initialize nutrient calibration factors = 1
   - Set output format: 3(2)

(Continued)

(Sheet 1 of 3)

Table IV-12 (Continued)

5. NUTRIENT TURNOVER (Continued)
   Run model and review output for each averaging period
   Select averaging period for subsequent analyses:
      If seasonal phosphorus turnover ratio >2, use seasonal;
        otherwise, use annual

6. DIFFUSIVE TRANSPORT
   Select dispersion model option
   Initialize dispersion calibration factors = 1.0
   Adjust segment dispersion factors to account for backflow
      restrictions (dams, weirs, bridges, channels, etc.)
   Set output format: 2(1)
   Run model and review output
   If numeric dispersion exceeds estimated dispersion in any model
      segment:
      Increase number of segments
      Repeat until numeric dispersion < estimated dispersion or
        predicted profiles insensitive to segmentation

7. NUTRIENT BALANCES
   Select nutrient sedimentation models
   Initialize nutrient calibration factors = 1.0

8. EUTROPHICATION RESPONSES
   Estimate nonalgal turbidity, mixed-layer depth, hypolimnetic depth
   Review diagnostic variables
   Select chlorophyll-a and Secchi models
   Set chl-a, Secchi, and HOD calibration factors
   Set output formats: 6(1), 7(1), 9(2)
   Run model and review output
   Check diagnostics (Output Format 7) for model applicability

9. VERIFICATION (not applicable)

10. DIAGNOSTICS
   Set output formats: 7(1)
   Run model and review output
      Rankings
      Factors controlling productivity

11. PREDICTIONS
   Select output formats: (all)
   Define impact of control strategies to be evaluated

(Continued)

(Sheet 2 of 3)

Table IV-12 (Concluded)

11. PREDICTIONS (Continued)
    - Modify input case file accordingly
    - Run model and review output
    - Check diagnostics (Output Format 7) for model applicability
    - Compare with base case
    - Run sensitivity analyses on key assumptions
        - Submodel selection
        - Segmentation
        - Dispersion
        - Averaging periods

(Sheet 3 of 3)

Scenarios A, B, and C, respectively. The procedures are intended to provide general indications of factors to be considered during the modeling process. User judgment must be exercised to account for unique aspects of each application.

Scenario A - Existing Reservoir with Loading and Pool Water Quality Data

Application procedures for Scenario A (Table IV-10) are more detailed than the procedures for Scenario B or C. Step 1 involves reduction of watershed data used in modeling. Formulation of a drainage area "balance" is an important first step in summarizing watershed characteristics. The FLUX program (Part II) is used for estimation of seasonal and annual loadings for gauged tributaries, point sources, and discharges. As described in Part I, ungauged flows and loadings are estimated using a variety of methods, including drainage area proportioning, regional export coefficients, or watershed modeling.

Step 2 involves reduction of reservoir morphometric and water quality data. Morphometric information can be estimated from contour maps and/or sediment accumulation surveys. PROFILE (Part III) is used to identify appropriate segmentation, summarize observed water quality conditions by segment, and calculate oxygen depletion rates in stratified reservoirs.

In Step 3, an input coding form is completed and a CASE file is generated for each averaging period (seasonal and annual). If the appropriate averaging period is initially apparent (based upon the hydraulic residence time and/or data constraints), only one input file may be required. Input data file coding can be checked by reviewing Output Format 1.

Water balances are formulated for each averaging period in Step 4 using Output Format 3. This involves adjusting inflow, outflow, and/or increase-in-storage terms until balances are established. The appropriate terms to adjust may vary from case to case, depending upon watershed characteristics and flow monitoring networks. Based upon familiarity with the flow data sources, the user must assess the most likely source(s) of water balance error and adjust the appropriate value(s) in the CASE file. Normally, flow balance errors would be attributed to the estimated flows from ungauged watersheds, although adjustments of ungauged flows should be restricted to "reasonable" values, based upon regional hydrologic information. If a water balance cannot be established with reasonable adjustments, additional monitoring with refinements to flow gauging networks may be required.

Nutrient turnover ratios are calculated in Step 5 using Output Format 3. The appropriate averaging period is determined, based upon the observed turnover ratio of the limiting nutrient (usually phosphorus). As discussed above, a seasonal averaging period can be used if the turnover ratio exceeds 2.0 under seasonal loading conditions; an annual averaging period can be used otherwise. The turnover ratio criterion is an approximate guideline, which may be adjusted from case to case. Other considerations (such as comparisons of observed and predicted nutrient levels) can also be used as a basis for selecting an appropriate averaging period, particularly if the turnover ratio is near 2.0. Note that if the reservoir is vertically stratified and significant hypolimnetic accumulations of phosphorus occur during the growing season, seasonal phosphorus turnover ratios calculated from mixed-layer concentrations will be overestimated; both annual and seasonal balances should be tested in this situation.

Step 6 involves calculation and possible calibration of diffusive transport terms using Output Format 2. If numeric dispersion exceeds the estimated dispersion in a given segment, the user should consider revising the segmentation scheme (e.g., increasing segment numbers and thus decreasing segment lengths) until this criterion is satisfied. In some cases, this may be difficult to achieve with a reasonable number of segments, particularly in upper-pool segments, where advective velocities tend to be greater. The criterion may be waived if the sensitivity of predicted nutrient profiles to alternative segmentation schemes is shown to be minimal.

Conservative tracer data, if available (e.g., chloride), may be used to calibrate diffusive transport terms in problems involving more than one segment. A tracer mass balance is established (Output Format 3) prior to calibrating transport terms. Calibration involves adjusting the global (Input Group 5) and/or segment (Input Group 8) dispersion factors to match observed tracer profiles. Generally, predicted concentration gradients will decrease with increasing dispersion rates. The global calibration factor is to be used, where possible, because it involves fewer degrees of freedom. For Dispersion Model 1, this factor should be in the range of 0.25 to 4.0, the approximate 95-percent confidence limit for dispersion estimated from

Fischer's equation. If adjustment outside this range is required, Dispersion Model 2 and/or alternative segmentation schemes should be investigated. The segment factor can be used to reflect local dispersion restrictions caused by weirs, bridges, etc. Calibration of dispersion rates based upon tracer data is feasible only if significant tracer gradients are detected in the reservoir as a result of tracer loading distributions.

Step 7 involves selection, testing, and possible calibration of nutrient sedimentation models using Output Formats 6 and 9. Calibration of dispersion rates to match observed nutrient gradients is also feasible at this stage, provided that tracer data are not available in Step 6. Differences between observed and predicted nutrient profiles can be attributed to one or more of the following sources:

a. Errors in specification of input conditions (tributary loadings, flows, morphometry, observed water quality).

b. Errors in estimated dispersion rates.

c. Errors in estimated nutrient sedimentation rates.

d. Errors in the observed nutrient profiles.

These potential sources should be considered in judging model performance in Step 7.

T-statistics included in Output Format 6 provide approximate statistical comparisons of observed and predicted concentrations. As described above, these are computed using three alternative measures of error: observed error only, T(1); error typical of model development data set, T(2); and observed and predicted error, T(3). Interpretations of these statistics in Step 7 are discussed below.

Tests of model applicability are normally based upon T(2) and T(3). If their absolute values exceed 2 for the comparison of area-weighted mean concentrations, there is less than a 5-percent chance that nutrient sedimentation dynamics in the reservoir are typical of those in the model development data set, assuming that input conditions have been specified in an unbiased manner. The applicability of the models would be an issue in this case. If the discrepancy cannot be attributed to possible errors in the input data file (particularly, inflow concentrations), alternative sedimentation models should be investigated.

Lack of fit may also result from unsteady-state loading conditions, particularly if the nutrient turnover ratio is less than 2 based upon annual loadings. In such cases, averaging periods longer than a year may be required to establish a valid load/response relationship. This situation is more likely to occur for nitrogen than phosphorus because unit sedimentation rates tend to be lower for nitrogen.

Once an appropriate sedimentation model is selected, T(1) can be used as a basis for deciding whether calibration is appropriate. If the absolute value of T(1) exceeds 2, then there is less than a 5-percent change that the observed and predicted means are equal, given the error in the observed mean. In this situation, it may be desirable to calibrate the model so that observed and predicted nutrient concentrations match.

Two calibration methods are provided for phosphorus and nitrogen (Model Options 7 and 8, respectively): Method 1 - calibrate decay rates and Method 2 - calibrate concentrations. In the first case, segment-specific calibration factors (Input Group 8) are applied to estimated decay rates in computing nutrient balances. In the second case, the factors are applied to estimated concentrations. The first case (default) assumes that the error is attributed primarily to the sedimentation model. In the second case, the error source is unspecified (some combination of input error, dispersion error, and sedimentation model error). The latter may be used when predicted nutrient profiles are insensitive to errors in predicted sedimentation rate because the mass balance is dominated by inflow and outflow terms (i.e., low hydraulic residence times). Under calibration Method 1, adjustments in the effective decay rates will have greater influences on predicted nutrient concentrations in lower pool segments, as compared with upper pool segments. If observed and predicted nutrient profiles differ by a constant factor, calibration Method 2 will generally be more successful.

Nutrient Sedimentation Models 1 and 2 have been empirically calibrated and tested for predicting reservoir-mean conditions. Error analysis calculations indicate that sedimentation rates predicted by these models are generally accurate to within a factor of 2 for phosphorus and a factor of 3 for nitrogen (Walker 1985). To account for this error, nutrient calibration factors (Input Group 8) can be adjusted within the nominal ranges of 0.5 to 2.0 and 0.33 to 3 for phosphorus and nitrogen, respectively. To minimize degrees of freedom, calibration factors should be the same in each segment. A conservative approach to calibration is suggested.

Once nutrient balances have been established, eutrophication responses (as measured by chlorophyll-a, transparency, and hypolimnetic oxygen depletion rate) are developed in Step 8. This involves model selection, testing, and possible calibration. As outlined in Tables IV-2 and IV-3, several options are available for predicting chlorophyll-a concentrations and Secchi depths as a function of nutrient levels and other controlling factors. The interpretation and use of t-statistics (Output Format 6) in testing and calibrating the chlorophyll-a and Secchi submodels follow the above discussion for nutrients (Step 7).

With the completion of Step 8, the model has been set up and possibly calibrated using pool and tributary data from a particular year or growing season. Step 9 involves optional verification of the model based upon an independent data set derived from a different monitoring period. Model options and calibration factors are held constant, and performance is judged based upon a comparison of observed and predicted nutrient, chlorophyll-a, and transparency profiles. This procedure is especially recommended in systems with significant year-to-year variations in hydrology, loading, and pool water quality conditions or in cases where extensive calibration is necessary. Reiteration of previous steps may be required to improve model performance over the range of monitored conditions.

Step 10 involves application of the model for diagnostic purposes, based primarily upon Output Format 7. Observed and predicted concentrations and diagnostic variables are listed and ranked against the model development data set. Diagnostic variables (Table IV-6) reflect the relative importance of phosphorus, nitrogen, and light as factors controlling algal productivity. Results are reviewed to ensure that controlling factors are consistent with the chlorophyll-a and transparency submodels employed.

The model is applied to predict the impacts of alternative loading conditions or management strategies in Step 11. This involves modifying the CASE file to reflect a particular set of conditions, running the model, and comparing predicted and existing conditions. To facilitate the latter comparison, multiple loading scenarios can be specified within a single file (see Segment Scheme 4 in Figure IV-3). Alternatively, separate CASE files can be generated for each loading condition to be evaluated.

In applying the model to predict future conditions, diagnostic variables are checked to ensure that controlling factors are consistent with the chlorophyll-a and transparency submodels. For example, if a phosphorus-limited chlorophyll-a submodel (e.g., 4 or 5 in Table IV-2) is applied to existing conditions in Step 8, model predictions will be invalid for a future loading condition, which causes a switch from phosphorus- to nitrogen-limited conditions. Similarly, if the phosphorus sedimentation model does not account for inflow phosphorus availability (i.e., differences in response to ortho-P versus nonortho-P loadings) predictions of future conditions involving a significant change in the ortho-P/total P load ratio will be invalid.

Scenario B - Existing Reservoir with Pool Water Quality Data Only

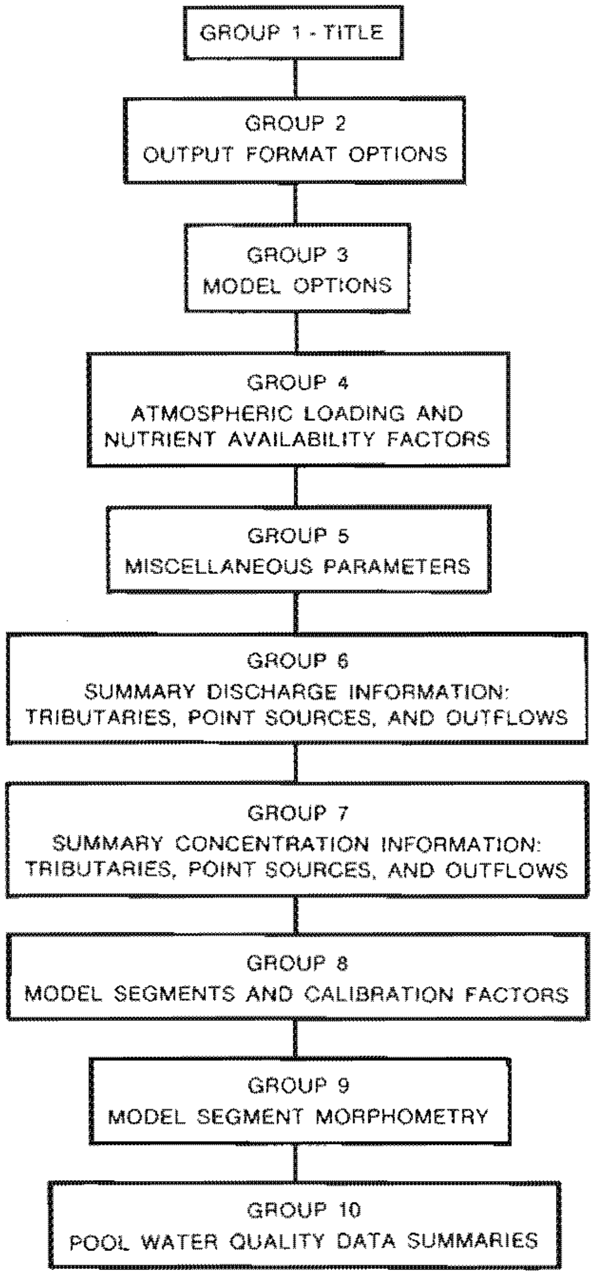
Under Application Scenario B, BATHTUB is used to summarize and rank water quality conditions and controlling factors in spatial segments representing different reservoirs or different areas within one reservoir. Comparisons are based upon observed water quality conditions and reservoir morphometric characteristics. The performance of various nutrient/chlorophyll-a and other eutrophication response models can be tested. This type of analysis can be applied in the absence of nutrient loading and water balance information. It is essentially descriptive or diagnostic in nature and does not provide a predictive basis. Calculations are outlined in Table IV-11, according to the same general outline used for Scenario A. Because water and nutrient balance calculations are not performed, Steps 4-7 and 11 are not involved.

Scenario C - Existing or Proposed Reservoir with Loading Data Only

Under Application Scenario C, BATHTUB is used to predict water quality conditions in a future reservoir or in an existing reservoir lacking observed water quality data. Steps are outlined in Table IV-12. Lack of observed water quality data precludes calibration and testing of diffusive transport, nutrient sedimentation, and eutrophication response models. Accordingly, certain steps are missing or abbreviated, as compared with Scenario A.

Note that model predictions for future reservoir refer to steady-state conditions and do not apply to the initial "reservoir aging" period, during which significant "internal" loadings may occur as a result of nutrient releases from inundated soils and vegetation. The reservoir aging period is inherently dynamic and not suited for direct simulation via the steady-state algorithms used in BATHTUB. Approximate estimates of conditions during the reservoir aging period may be derived by specifying additional nutrient sources (treated as external) of the appropriate magnitudes, based upon literature reviews and/or field data.

ORGANIZATION OF BATHTUB INPUT FILE



BATHTUB DATA GROUP 1 - TITLE

FORMAT (8A8)

BATHTUB DATA GROUP 2 - OUTPUT FORMATS

FORMAT (I2,1X,I1)

PO = PRINT OPTION NUMBER
S = SELECTION (0 = DO NOT PRINT, OTHERS GIVEN BELOW)

PO	OUTPUT FORMAT	SELECTION CODES
01	LIST INPUT CONDITIONS	1=YES
02	HYDRAULICS AND DISPERSION	1=YES
03	GROSS WATER AND MASS BALANCES	1=OBSERVED CONCS, 2=ESTIMATED
04	DETAILED BALANCES BY SEGMENT	1=OBSERVED CONCS, 2=ESTIMATED
05	BALANCE SUMMARY BY SEGMENT	1=OBSERVED CONCS, 2=ESTIMATED
06	COMPARE OBSERVED AND PREDICTED	1=ALL, 2=AREA-WTD MEANS ONLY
07	DIAGNOSTICS	1=ALL, 2=AREA-WTD MEANS ONLY
08	SPATIAL PROFILE SUMMARY	1=ESTIMATED, 2=ESTIMATED & OBSERVED
09	PLOT OBS. AND PREDICTED VALUES	1=LINEAR SCALE, 2=GEOMETRIC SCALE
10	SENSITIVITY ANALYSIS	1=CONSERV, 2=TOTAL P, 3=TOTAL N

PROJECT: ______________________

BATHTUB DATA GROUP 1 — TITLE

BATHTUB DATA GROUP 2 — OUTPUT FORMAT OPTIONS

P0	S	OUTPUT FORMAT OPTIONS
01		LIST INPUT CONDITIONS
02		HYDRAULICS AND DISPERSION
03		GROSS WATER AND MASS BALANCES
04		DETAILED BALANCES BY SEGMENT
05		BALANCE SUMMARY BY SEGMENT
06		COMPARE OBSERVED AND PREDICTED
07		DIAGNOSTICS
08		SPATIAL PROFILE SUMMARY
09		PLOT OBS. AND PREDICTED VALUES
10		SENSITIVITY ANALYSIS
00		

BATHTUB DATA GROUP 3 - MODEL OPTIONS

FORMAT(I2,1X,I1)

MO = MODEL OPTION NUMBER
S = SELECTION (0 = DO NOT CALCULATE, OTHERS GIVEN BELOW)

MO	MODEL OPTIONS	SELECTIONS
01	CONSERVATIVE TRACER	1=COMPUTE MASS BALANCES
02	P SEDIMENTATION MODEL	1=SECOND ORDER, AVAILABLE P
		2=SECOND ORDER DECAY RATE FUNCTION
		3=SECOND ORDER
		4=CANFIELD AND BACHMAN
		5=VOLLENWEIDER
		6=SIMPLE FIRST ORDER
		7=FIRST ORDER SETTLING
03	N SEDIMENTATION MODEL	1=SECOND ORDER, AVAILABLE N
		2=SECOND ORDER DECAY RATE FUNCTION
		3=SECOND ORDER
		4=BACHMAN - VOLUMETRIC LOAD
		5=BACHMAN - FLUSHING RATE
		6=SIMPLE FIRST ORDER
		7=FIRST ORDER SETTLING
04	CHLOROPHYLL A MODEL	1=N, P, LIGHT, FLUSHING RATE
		2=P, LIGHT, FLUSHING RATE
		3=P, N, LOW-TURBIDITY
		4=P, LINEAR
		5=JONES AND BACHMAN
05	SECCHI MODEL	1=SECCHI VS. CHLA AND TURBIDITY
		2=SECCHI VS. COMPOSITE NUTRIENT
		3=SECCHI VS. TOTAL P
06	DISPERSION MODEL	1=FISCHER'S DISPERSION EQUATION
		2=FIXED DISPERSION RATE
		3=INPUT EXCHANGE RATES DIRECTLY
07	P CALIBRATION METHOD	1=(DECAY RATES) x (CALIBRATION FACTORS)
		2=(CONCENTRATIONS) x (CALIBRATION FACTORS)
08	N CALIBRATION METHOD	1=(DECAY RATES) x (CALIBRATION FACTORS)
		2=(CONCENTRATIONS) x (CALIBRATION FACTORS)
09	ERROR ANALYSIS	1=COMPUTE USING INPUT DATA ERROR AND MODEL ERROR
		2=COMPUTE USING INPUT DATA ERROR ONLY

PROJECT: ____________________

BATHTUB DATA GROUP 3 — MODEL OPTIONS

MO	S	MODEL OPTIONS
01		CONSERVATIVE TRACER
02		P SEDIMENTATION MODEL
03		N SEDIMENTATION MODEL
04		CHLOROPHYLL-A MODEL
05		SECCHI MODEL
06		DISPERSION MODEL
07		P CALIBRATION METHOD
08		N CALIBRATION METHOD
09		ERROR ANALYSIS
00		

BATHTUB DATA GROUP 4 - VARIABLES

FORMAT (I2,1X,A8,3F7.0)

IV = VARIABLE SUBSCRIPT NUMBER
NAME = VARIABLE NAME
ATM = ATMOSPHERIC LOADING (KG/KM^2-YR)
CV = COEFFICIENT OF VARIATION OF ATMOSPHERIC LOADING RATE
AVAIL = AVAILABILITY FACTOR USED TO COMPUTE INFLOW AVAILABLE P AND N FROM INFLOW TOTAL P, ORTHO-P, TOTAL N, AND INORGANIC N

SUGGESTED AVAILABILITY FACTORS

	P, N MODEL 1	OTHER MODELS
TOTAL P	0.33	1.0
TOTAL N	0.59	1.0
ORTHO P	1.93	0.0
INORG N	0.79	0.0

PROJECT: ______________________

BATHTUB DATA GROUP 4 — ATMOSPHERIC LOADING AND NUTRIENT AVAILABILITY FACTORS

I	V	LABEL	ATM	CV	AVAIL
0	1	CONSERV			
0	2	TOTAL P			
0	3	TOTAL N			
0	4	ORTHO P			
0	5	INORG N			
0	0				

BATHTUB DATA GROUP 5 - MISCELLANEOUS PARAMETERS

FORMAT (I2,25X,F10.0,F7.0)

ID = PARAMETER SUBSCRIPT
LABEL = PARAMETER LABEL
MEAN = MEAN ESTIMATE
CV = COEFFICIENT OF VARIATION

ENTRIES 1-4 MULTIPLIED BY SEGMENT-SPECIFIC VALUES IN DATA GROUP 9

PROJECT: ____________________

BATHTUB DATA GROUP 5 — MISCELLANEOUS PARAMETERS

ID	LABEL	MEAN	CV
01	AVERAGING PERIOD-YRS		
02	PRECIPITATION-METERS		
03	EVAPORATION-METERS		
04	STORAGE INCREASE-METERS		
05	FLOW FACTOR		
06	DISPERSION FACTOR		
07	TOTAL AREA-KM2		0.
08	TOTAL VOLUME-HM3		0.
00			

BATHTUB DATA GROUP 6 - SUMMARY DISCHARGE INFORMATION FOR TRIBUTARIES, SOURCES, AND OUTFLOWS

FORMAT (2I2,I3,1X,2A8,3F10.0)

INCLUDE ONE RECORD FOR EACH TRIBUTARY, DISCHARGE, WITHDRAWAL, OR ESTIMATED GROUND-WATER INPUT (MAXIMUM OF 29 RECORDS)

```
ID    = IDENTIFICATION NUMBER, IN INCREASING ORDER
T     = TYPE CODE:  1 = GAUGED TRIBUTARY
                    2 = UNGAUGED TRIBUTARY, DIRECT RUNOFF, GROUND WATER
                    3 = POINT-SOURCE DISCHARGING DIRECTLY INTO RESERVOIR
                        POOL
                    4 = RESERVOIR OUTFLOW OR WITHDRAWAL
IS    = MODEL SEGMENT NUMBER (REFERS TO DATA GROUP 8)
NAME  = 16-CHARACTER NAME
DAREA = CONTRIBUTING DRAINAGE AREA (KM^2)
FLOW  = MEAN FLOW RATE OVER BALANCE PERIOD (HM^3/YR)
CV    = COEFFICIENT OF VARIATION OF MEAN FLOW ESTIMATE
```

PROJECT: ____________________

BATHTUB DATA GROUP 6 — SUMMARY DISCHARGE INFORMATION
FOR TRIBUTARIES, POINT-SOURCES, AND OUTFLOWS

ID	T	IS	NAME	DAREA	FLOW	CV
01						
02						
03						
04						
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						

(CONTINUED)

PAGE 1 OF 2 PAGES

PROJECT: ____________________

BATHTUB DATA GROUP 6 — SUMMARY DISCHARGE INFORMATION

FOR TRIBUTARIES, POINT-SOURCES, AND OUTFLOWS

ID	T	IS	NAME	DAREA	FLOW	CV
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
00						

PAGE 2 OF 2 PAGES

BATHTUB DATA GROUP 7 - SUMMARY CONCENTRATION INFORMATION FOR TRIBUTARIES, SOURCES, AND OUTFLOWS

FORMAT (I2,1X,5(F7.0,F5.0)

INCLUDE ONE RECORD FOR EACH RECORD IN DATA GROUP 6

ID = IDENTIFICATION NUMBER, IN INCREASING ORDER (REFERS TO DATA GROUP 6)
CONS = CONSERVATIVE SUBSTANCE
TOTALP = TOTAL PHOSPHORUS
TOTALN = TOTAL NITROGEN
ORTHOP = ORTHO-PHOSPHORUS
INORGN = INORGANIC NITROGEN
CV = COEFFICIENT OF VARIATION OF PRECEDING CONCENTRATION

PROJECT: ____________

BATHTUB DATA GROUP 7 — SUMMARY CONCENTRATION INFORMATION
FOR TRIBUTARIES, POINT-SOURCES, AND OUTFLOWS

ID	CONS	CV	TOTALP	CV	TOTALN	CV	ORTHOP	CV	INORGN	CV
01										
02										
03										
04										
05										
06										
07										
08										
09										
10										
11										
12										
13										
14										

PAGE 1 OF 2 PAGES

PROJECT: ____________________

BATHTUB DATA GROUP 7 — SUMMARY CONCENTRATION INFORMATION FOR TRIBUTARIES, POINT-SOURCES, AND OUTFLOWS

ID	CONS	CV	TOTALP	CV	TOTALN	CV	ORTHOP	CV	INORGN	CV
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
00										

PAGE 2 OF 2 PAGES

BATHTUB DATA GROUP 8 - MODEL SEGMENTS AND CALIBRATION FACTORS

FORMAT (I2,2I3,1X,2A8,6F5.0)

INCLUDE ONE RECORD FOR EACH MODEL SEGMENT, MAXIMUM OF 14

```
IS   = SEGMENT IDENTIFICATION NUMBER, IN INCREASING ORDER
JO   = DOWNSTREAM SEGMENT NUMBER (RECEIVES ADVECTIVE OUTFLOW FROM
       SEGMENT IS)
     = 0, IF ADVECTIVE OUTFLOW GOES OUT OF THE SYSTEM
JG   = SEGMENT GROUP NUMBER, IDENTIFIES DIFFERENT RESERVOIRS
     = IS, IF EACH SEGMENT REPRESENTS A DIFFERENT RESERVOIR
     = 1, IF ALL SEGMENTS ARE IN THE SAME RESERVOIR
NAME = SEGMENT NAME
```

CALIBRATION FACTORS (NORMALLY = 1.0)

```
KP = PHOSPHORUS
KN = NITROGEN
KC = CHLOROPHYLL A
KS = SECCHI
KO = HYPOLIMNETIC OXYGEN DEPLETION
KD = DISPERSION
```

PROJECT: ____________________

BATHTUB DATA GROUP 8 — MODEL SEGMENTS AND CALIBRATION FACTORS

IS	JO	JG	NAME	KP	KN	KC	KS	KO	KD
01									
02									
03									
04									
05									
06									
07									
08									
09									
10									
11									
12									
13									
14									
00									

BATHTUB DATA GROUP 9 - MODEL SEGMENT MORPHOMETRY

FORMAT (I2,1X,4F5.0,7F6.0)

INCLUDE ONE RECORD FOR EACH SEGMENT IDENTIFIED IN DATA GROUP 8

IS = SEGMENT IDENTIFICATION NUMBER, IN INCREASING ORDER
PERD = LENGTH OF AVERAGING PERIOD
PREC = PRECIPITATION
EVAP = TOTAL EVAPORATION
STOR = INCREASE IN POOL ELEVATION
LENG = SEGMENT LENGTH
AREA = SURFACE AREA
ZMN = MEAN DEPTH
ZMIX = MEAN DEPTH OF MIXED LAYER = VOLUME/SURFACE AREA
ZHYP = MEAN DEPTH OF HYPOLIMNION
CV = COEFFICIENT OF VARIATION FOR PRECEDING VALUE

PROJECT: ____________________

BATHTUB DATA GROUP 9 — MODEL SEGMENT MORPHOMETRY

IS	PERD	PREC	EVAP	STOR	LENG	AREA	ZMEAN	ZMIX	CV	ZHYP	CV
01											
02											
03											
04											
05											
06											
07											
08											
09											
10											
11											
12											
13											
14											
00											

BATHTUB DATA GROUP 10 - POOL WATER QUALITY SUMMARIES

FORMAT (I2,1X,10F6.0)

INCLUDE TWO RECORDS FOR EACH SEGMENT IDENTIFIED IN DATA GROUP 8

RECORDS ARE PAIRED (MEAN FOLLOWED BY CV OF MEAN)

IS = SEGMENT IDENTIFICATION NUMBER, IN INCREASING ORDER
TURB = NONALGAL TURBIDITY
CONS = CONSERVATIVE SUBSTANCE
TP = TOTAL PHOSPHORUS
TN = TOTAL NITROGEN
CHLA = CHLOROPHYLL A
SEC = SECCHI DEPTH
ORGN = ORGANIC NITROGEN
PP = TOTAL P - ORTHO-P
HODV = HYPOLIMNETIC OXYGEN DEPLETION RATE, NEAR-DAM
MODV = METALIMNETIC OXYGEN DEPLETION RATE, NEAR-DAM

PROJECT: ____________________

BATHTUB DATA GROUP 10 — POOL WATER QUALITY
SUMMARIES

I	S	TURB	CONS	TP	TN	CHLA	SEC	ORGN	PP	HODV	MODV	
0	1											MEAN
0	1											CV
0	2											MEAN
0	2											CV
0	3											MEAN
0	3											CV
0	4											MEAN
0	4											CV
0	5											MEAN
0	5											CV
0	6											MEAN
0	6											CV
0	7											MEAN
0	7											CV

(CONTINUED)

PROJECT: ____________________

BATHTUB DATA GROUP 10 — POOL WATER QUALITY SUMMARIES

IS	TURB	CONS	TP	TN	CHLA	SEC	ORGN	PP	HODV	MODV	
08											MEAN
08											CV
09											MEAN
09											CV
10											MEAN
10											CV
11											MEAN
11											CV
12											MEAN
12											CV
13											MEAN
13											CV
14											MEAN
14											CV
00											

PAGE 2 OF 2 PAGES

BATHTUB - EXAMPLE INPUT FILE

```
Keystone Reservoir, Oklahoma                 GROUP 1 - TITLE
PO S OUTPUT FORMAT OPTIONS----------
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 1 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT
05 2 BALANCE SUMMARY BY SEGMENT              GROUP 2 - OUTPUT FORMAT OPTIONS
06 2 COMPARE OBSERVED AND PREDICTED
07 1 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOT OBS. AND PREDICTED VALUES
10 1 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS--------
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL
03 1 N SEDIMENTATION MODEL
04 1 CHLOROPHYLL-A MODEL
05 1 SECCHI MODEL                            GROUP 3 - MODEL OPTIONS
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 1 ERROR ANALYSIS
00
IV LABEL---ATM----CV-----AVAIL----
01 CONSERV 0.     0.     0.
02 TOTAL P 30.    .5     .33
03 TOTAL N 1000.  .5     .59                 GROUP 4 - ATMOSPHERIC LOADING AND
04 ORTHO P 15.    .5     1.93                          NUTRIENT AVAILABILITY FACTORS
05 INORG N 500.   .5     .79
00
```

(CONTINUED)

BATHTUB - EXAMPLE INPUT FILE

```
IS JO JG NAME------------KP---KN---KC---KS---KO---KD---
01 02 01 ARKANSAS UPPER  1.0  1.0  1.0  1.0  1.0  1.0
02 03 01 ARKANSAS MID    1.0  1.0  1.0  1.0  1.0  1.0
03 07 01 ARKANSAS LOWER  1.0  1.0  1.0  1.0  1.0  1.0
04 05 01 CIMARRON UPPER  1.0  1.0  1.0  1.0  1.0  1.0
05 06 01 CIMARRON MID    1.0  1.0  1.0  1.0  1.0  1.0
06 07 01 CIMARRON LOWER  1.0  1.0  1.0  1.0  1.0  1.0
07 00 01 DAM AREA        1.0  1.0  1.0  1.0  1.0  1.0
00
IS PERD-PREC-EVAP-STOR-LENG--AREA--ZMEAN-ZMIX--CV----ZHYP--CV----
01 1.0  1.0  1.0  1.0  15.0  8.4   1.2
02 1.0  1.0  1.0  1.0  15.0  25.2  7.2
03 1.0  1.0  1.0  1.0  15.0  25.2  8.8
04 1.0  1.0  1.0  1.0  15.0  8.4   2.6
05 1.0  1.0  1.0  1.0  15.0  12.6  7.2
06 1.0  1.0  1.0  1.0  15.0  21.0  10.5
07 1.0  1.0  1.0  1.0  4.0   8.4   13.1
00
IS TURB--CONS--TP----TN----CHLA--SEC---ORGN--PP----HODV--MODV--
01             367.  1575. 62.   0.2   856.  250.
01             .09   .15   .62   .19   .14   .16
02  2.6
02  .4
03             149.  1303. 2.8   0.4   523.  48.
03             .14   .06   .48   .30   .09   .22
04             234.  1077. 23.7  0.2   700.  148.
04             .11   .12   .53   .580  .06   .24
05             130.  1099. 7.2   0.4   573.  51.
05             .15   .09   .61   .230  .05   .16
06             99.   1079. 8.7   0.6   508.  37.
06             .13   .10   .44   .250  .07   .15
07             145.  1277. 3.6   0.5   453.  34.
07             .18   .05   .57   .290  .02   .50
00
```

(END OF FILE)

GROUP 8 - MODEL SEGMENTS AND CALIBRATION FACTORS

GROUP 9 - MODEL SEGMENT MORPHOMETRY

GROUP 10 - POOL WATER QUALITY DATA SUMMARIES

OUTPUT FORMAT 1 - LIST INPUT CONDITIONS

```
B A T H T U B  - VERSION 2.0

KEYSTONE RESERVOIR, OKLAHOMA

PRINT OPTION CODES:  1  1  1  2  2  2  2  1  2  2

MODEL OPTIONS:
OPTION:  1 SELECTION: 0 conserv substance not computed
OPTION:  2 SELECTION: 1 p decay - 2nd order,avail p
OPTION:  3 SELECTION: 1 n decay - 2nd order, avail n
OPTION:  4 SELECTION: 1 chla - p, n, light, t
OPTION:  5 SELECTION: 1 secchi - vs. chla and turbidity
OPTION:  6 SELECTION: 1 dispersion - fischer-numeric
OPTION:  7 SELECTION: 1 p calibration - decay rates
OPTION:  8 SELECTION: 1 n calibration - decay rates
OPTION:  9 SELECTION: 1 error analysis - model and data

             ATMOSPHERIC LOADINGS AVAILABILITY
VARIABLE       KG/KM2-YR      CV       FACTOR
 1 CONSERV          0.00     0.00        0.00
 2 TOTAL P         30.00     0.50        0.33
 3 TOTAL N       1000.00     0.50        0.59
 4 ORTHO P         15.00     0.50        1.93
 5 INORG N        500.00     0.50        0.79

PARAMETER                           MEAN    CV
 1 PERIOD         YRS              0.420  0.000
 2 PRECIPITATION M                 0.530  0.200
 3 EVAPORATION    M                0.900  0.300
 4 INCREASE IN STORAGE M           0.000  0.000
 5 FLOW FACTOR                     1.000  0.000
 6 DISPERSION FACTOR               1.000  0.700
 7 AREA           KM2            109.200  0.000
 8 VOLUME         HM3            853.000  0.000
```

OUTPUT FORMAT 1 - LIST INPUT CONDITIONS (CONTINUED)

TRIBUTARY DRAINAGE AREAS AND FLOWS:

ID	TYPE	SEG	NAME	DRAINAGE AREA	MEAN FLOW	CV OF MEAN FLOW
1	4	7	ARKANSAS OUTFLOW	162804.0	10556.0	0.100
2	1	1	ARKANSAS INFLOW	123625.0	6770.0	0.100
3	1	1	HELLROARING	27.7	10.0	0.100
4	1	4	CIMARRON	34929.0	2572.0	0.100
5	1	4	LAGOON	123.0	37.0	0.100
6	2	1	UNGAUGED-SEG 1	600.0	216.0	0.200
7	2	2	UNGAUGED-SEG 2	400.0	143.0	0.200
8	2	4	UNGAUGED-SEG 4	2440.0	736.0	0.200
9	2	5	UNGAUGED-SEG 5	150.0	45.0	0.200
10	2	6	UNGAUGED-SEG 6	400.0	120.0	0.200
11	3	1	CLEVELAND STPS	0.0	1.0	0.200
12	3	4	CIMARRON STPS	0.0	1.0	0.200
13	3	6	MANNFORD STP`	0.0	1.0	0.200

TRIBUTARY CONCENTRATIONS: MEAN/CV

ID	CONSERV	TOTAL P	TOTAL N	ORTHO P	INORG N
1	0.0/0.00	109.0/0.04	1464.0/0.10	86.0/0.10	771.0/0.33
2	0.0/0.00	570.0/0.20	2467.0/0.15	158.0/0.09	500.0/0.30
3	0.0/0.00	72.0/0.22	1639.0/0.06	12.0/0.09	268.0/0.06
4	0.0/0.00	364.0/0.11	1884.0/0.09	133.0/0.07	285.0/0.17
5	0.0/0.00	150.0/0.19	1940.0/0.06	22.0/0.16	431.0/0.13
6	0.0/0.00	72.0/0.30	1639.0/0.30	12.0/0.30	268.0/0.30
7	0.0/0.00	72.0/0.30	1639.0/0.30	12.0/0.30	268.0/0.30
8	0.0/0.00	150.0/0.30	1940.0/0.30	22.0/0.30	431.0/0.30
9	0.0/0.00	150.0/0.30	1940.0/0.30	22.0/0.30	431.0/0.30
10	0.0/0.00	150.0/0.30	1940.0/0.30	22.0/0.30	431.0/0.30
11	0.0/0.00	4535.0/0.00	13605.0/0.00	4535.0/0.00	13605.0/0.00
12	0.0/0.00	14261.0/0.00	38456.0/0.00	14261.0/0.00	38456.0/0.00
13	0.0/0.00	1135.0/0.00	3400.0/0.00	1135.0/0.00	3400.0/0.00

MODEL SEGMENTS:

				------- CALIBRATION FACTORS -------					
SEG	OUTFLOW	GROUP	NAME	P SED	N SED	CHL-A	SECCHI	HOD	DISPERS
1	2	1	ARKANSAS UPPER	1.00	1.00	1.00	1.00	1.00	1.00
2	3	1	ARKANSAS MID	1.00	1.00	1.00	1.00	1.00	1.00
3	7	1	ARKANSAS LOWER	1.00	1.00	1.00	1.00	1.00	1.00
4	5	1	CIMARRON UPPER	1.00	1.00	1.00	1.00	1.00	1.00
5	6	1	CIMARRON MID	1.00	1.00	1.00	1.00	1.00	1.00
6	7	1	CIMARRON LOWER	1.00	1.00	1.00	1.00	1.00	1.00
7	0	1	DAM AREA	1.00	1.00	1.00	1.00	1.00	1.00

AREA SCALE FACTOR = 1.000, DEPTH SCALE FACTOR = 0.996

OUTPUT FORMAT 1 - LIST INPUT CONDITIONS (CONCLUDED)

SEGMENT MORPHOMETRY: MEAN/CV

ID	PERIOD LENGTH YEARS	PRECIP METERS	EVAP METERS	STORAGE INCREA METERS	LENGTH KM	AREA KM2	ZMEAN M	ZMIX M	ZHYP M
1	0.42	0.53	0.90	0.00	15.00	8.40	1.20	1.10/0.12	0.00/0.00
2	0.42	0.53	0.90	0.00	15.00	25.20	7.17	5.75/0.12	0.00/0.00
3	0.42	0.53	0.90	0.00	15.00	25.20	8.77	6.37/0.12	0.00/0.00
4	0.42	0.53	0.90	0.00	15.00	8.40	2.59	2.64/0.12	0.00/0.00
5	0.42	0.53	0.90	0.00	15.00	12.60	7.17	5.75/0.12	0.00/0.00
6	0.42	0.53	0.90	0.00	15.00	21.00	10.46	6.89/0.12	0.00/0.00
7	0.42	0.53	0.90	0.00	4.00	8.40	13.05	7.45/0.12	0.00/0.00

TOTAL AREA (KM2) = 109.20 TOTAL VOLUME (HM3) = 853.00

OBSERVED WATER QUALITY:

SEGMENT		TURBID	CONSER	TOTALP	TOTALN	CHL-A	SECCHI	ORG-N	TP-OP	HODV	MODV
1	MEAN:	3.45	0.0	367.0	1575.0	62.0	0.2	856.0	250.0	0.0	0.0
	CV:	0.39	0.00	0.09	0.15	0.62	0.19	0.14	0.16	0.00	0.00
2	MEAN:	2.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CV:	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	MEAN:	2.43	0.0	149.0	1303.0	2.8	0.4	523.0	48.0	0.0	0.0
	CV:	0.31	0.00	0.14	0.06	0.48	0.30	0.09	0.22	0.00	0.00
4	MEAN:	4.41	0.0	234.0	1077.0	23.7	0.2	700.0	148.0	0.0	0.0
	CV:	0.66	0.00	0.11	0.12	0.53	0.58	0.06	0.24	0.00	0.00
5	MEAN:	2.32	0.0	130.0	1099.0	7.2	0.4	573.0	51.0	0.0	0.0
	CV:	0.25	0.00	0.15	0.09	0.61	0.23	0.05	0.16	0.00	0.00
6	MEAN:	1.45	0.0	99.0	1079.0	8.7	0.6	508.0	37.0	0.0	0.0
	CV:	0.30	0.00	0.13	0.10	0.44	0.25	0.07	0.15	0.00	0.00
7	MEAN:	1.91	0.0	145.0	1277.0	3.6	0.5	453.0	34.0	0.0	0.0
	CV:	0.30	0.00	0.18	0.05	0.57	0.29	0.02	0.50	0.00	0.00

OPTION CODES FOR OUTPUT FORMAT 1: (1 SHOWN ABOVE)
0 = PRINT MODEL OPTIONS ONLY
1 = PRINT ALL INPUT CONDITIONS

OUTPUT FORMAT 2 - HYDRAULICS AND DISPERSION

KEYSTONE RESERVOIR
HYDRAULIC AND DISPERSION PARAMETERS:

SEG	NET INFLOW HM3/YR	RESIDENCE TIME YRS	CROSS SECTION M*KM	MEAN VELOCITY KM/YR	----DISPERSION----- ESTIMATED KM2/YR	NUMERIC KM2/YR	EXCHANGE RATE HM3/YR
1	6989.60	0.00144	0.669	10442.4	281908.	78318.	9085.
2	7110.40	0.02542	12.048	590.2	31833.	4426.	23013.
3	7088.20	0.03116	14.726	481.4	21936.	3610.	17991.
4	3338.60	0.00652	1.450	2302.1	32461.	17266.	1469.
5	3372.50	0.02679	6.024	559.8	7549.	4199.	1346.
6	3475.00	0.06320	14.642	237.3	6475.	1780.	4583.
7	10555.80	0.01038	27.401	385.2	19638.	770.	0.

NOTES:
SOLUTION TO FLOW BALANCE INDICATED IN OUTFLOW COLUMN
RESIDENCE TIME = SEGMENT VOLUME/SEGMENT OUTFLOW
CROSS SECTION = MEAN DEPTH x SURFACE AREA/LENGTH
MEAN VELOCITY = SEGMENT LENGTH/RESIDENCE TIME = OUTFLOW/CROSS-SECTION
DISPERSION ESTIMATED ACCORDING TO MODEL OPTION 6
NUMERIC DISPERSION = LENGTH x MEAN VELOCITY/2
EXCHANGE RATE = BULK EXCHANGE WITH DOWNSTREAM SEGMENT,
= (EST. DISP. - NUM. DISP.) x CROSS-SECTION/LENGTH

OPTION CODES FOR OUTPUT FORMAT 2: (1 SHOWN ABOVE)
0 = DO NOT PRINT
1 = PRINT

OUTPUT FORMAT 3 - GROSS WATER AND MASS BALANCES

GROSS WATER BALANCE:

ID	T	LOCATION	DRAINAGE AREA KM2	---- FLOW (HM3/YR) ---- MEAN	VARIANCE	CV	RUNOFF M/YR
1	4	ARKANSAS OUTFLOW	162804.0	10556.0	0.111E+07	0.100	0.065
2	1	ARKANSAS INFLOW	123625.0	6770.0	0.458E+06	0.100	0.055
3	1	HELLROARING	27.7	10.0	0.100E+01	0.100	0.361
4	1	CIMARRON	34929.0	2572.0	0.662E+05	0.100	0.074
5	1	LAGOON	123.0	37.0	0.137E+02	0.100	0.301
6	2	UNGAUGED-SEG 1	600.0	216.0	0.187E+04	0.200	0.360
7	2	UNGAUGED-SEG 2	400.0	143.0	0.818E+03	0.200	0.357
8	2	UNGAUGED-SEG 4	2440.0	736.0	0.217E+05	0.200	0.302
9	2	UNGAUGED-SEG 5	150.0	45.0	0.810E+02	0.200	0.300
10	2	UNGAUGED-SEG 6	400.0	120.0	0.576E+03	0.200	0.300
11	3	CLEVELAND STPS	0.0	1.0	0.400E-01	0.200	0.000
12	3	CIMARRON STPS	0.0	1.0	0.400E-01	0.200	0.000
13	3	MANNFORD STP	0.0	1.0	0.400E-01	0.200	0.000
PRECIPITATION			109.2	137.8	0.760E+03	0.200	1.262
EXTERNAL INFLOW			162694.7	10652.0	0.550E+06	0.070	0.065
***TOTAL INFLOW			162803.9	10789.8	0.550E+06	0.069	0.066
***TOTAL OUTFLOW			162804.0	10556.0	0.111E+07	0.100	0.065
***EVAPORATION			0.0	234.0	0.493E+04	0.300	0.000
***STORAGE INCREASE			0.0	0.0	0.000E+01	0.000	0.000
***WATER BALANCE ERROR			-0.1	-0.2	0.167E+07	0.000	0.000

OUTPUT FORMAT 3 - GROSS WATER AND MASS BALANCES (CONTINUED)

GROSS MASS BALANCE BASED UPON OBSERVED CONCENTRATIONS
COMPONENT: TOTAL P

ID	T	LOCATION	LOADING KG/YR	LOADING %(I)	VARIANCE KG/YR**2	VARIANCE %(I)	CV	CONC MG/M3	EXPORT KG/KM2
1	4	ARKANSAS OUTFLOW	1150604.0	25.8	0.154E+11	4.8	0.108	109.0	7.1
2	1	ARKANSAS INFLOW	3337880.5	74.8	0.305E+12	94.9	0.166	493.0	27.0
3	1	HELLROARING	469.3	0.0	0.755E+04	0.0	0.185	46.9	16.9
4	1	CIMARRON	969155.1	21.7	0.158E+11	4.9	0.130	376.8	27.7
5	1	LAGOON	3403.5	0.1	0.475E+06	0.0	0.203	92.0	27.7
6	2	UNGAUGED-SEG 1	10134.7	0.2	0.134E+08	0.0	0.361	46.9	16.9
7	2	UNGAUGED-SEG 2	6709.6	0.2	0.585E+07	0.0	0.361	46.9	16.8
8	2	UNGAUGED-SEG 4	67682.5	1.5	0.596E+09	0.2	0.361	92.0	27.7
9	2	UNGAUGED-SEG 5	4138.2	0.1	0.223E+07	0.0	0.361	92.0	27.6
10	2	UNGAUGED-SEG 6	11035.2	0.2	0.158E+08	0.0	0.361	92.0	27.6
11	3	CLEVELAND STPS	10249.1	0.2	0.420E+07	0.0	0.200	10249.1	0.0
12	3	CIMARRON STPS	32229.9	0.7	0.416E+08	0.0	0.200	32229.9	0.0
13	3	MANNFORD STP	2565.1	0.1	0.263E+06	0.0	0.200	2565.1	0.0
		PRECIPITATION	4242.4	0.1	0.450E+07	0.0	0.500	30.8	38.8
		EXTERNAL INFLOW	4455650.0	99.9	0.322E+12	100.0	0.127	418.3	27.4
		***TOTAL INFLOW	4459892.0	100.0	0.322E+12	100.0	0.127	413.3	27.4
		***TOTAL OUTFLOW	1150604.0	25.8	0.154E+11	4.8	0.108	109.0	7.1
		***STORAGE INCREASE	0.0	0.0	0.000E+01	0.0	0.000	0.0	0.0
		***NET RETENTION	3309288.0	74.2	0.337E+12	104.8	0.176	0.0	0.0

OVERFLOW RATE M/YR	HYDRAULIC RESIDENCE TIME YRS	TOTAL P POOL CONC MG/M3	TOTAL P RESIDENCE TIME YRS	TOTAL P TURNOVER RATIO -	TOTAL P RETENTION COEF -
96.66	0.0808	163.6	0.0313	13.4269	0.6139

OUTPUT FORMAT 3 - GROSS WATER AND MASS BALANCES (CONCLUDED)

NOTES:

TABLE REPEATED FOR EACH COMPONENT
ID = TRIBUTARY IDENTIFICATION NUMBER
T = TRIBUTARY TYPE CODE (1=GAUGED, 2=UNGAUGED, 3=POINT SOURCE, 4=DISCHARGE)
CV = COEFFICIENT OF VARIATION
RUNOFF = WATER EXPORT FROM WATERSHED = FLOW/DRAINAGE AREA
EXTERNAL INFLOW = SUM OF EXTERNAL INFLOWS (TYPES 1, 2, OR 3)
TOTAL INFLOW = PRECIPITATION + EXTERNAL INFLOW
TOTAL OUTFLOW = SUM OF DISCHARGE/WITHDRAWAL FLOWS (TYPE 4)
WATER BALANCE ERROR = TOTAL INFLOW - TOTAL OUTFLOW - STORAGE INCREASE - EVAP

% (I) = PERCENT OF TOTAL INFLOW LOAD OR TOTAL INFLOW VARIANCE
EXPORT = MASS EXPORT FROM DRAINAGE AREA = LOAD/DRAINAGE AREA
CONC = FLOW-WEIGHTED MEAN CONCENTRATION = LOAD/FLOW

OVERFLOW RATE = (TOTAL INFLOW - EVAPORATION) / SURFACE AREA
HYDRAULIC RESIDENCE TIME = TOTAL VOLUME/ (TOTAL INFLOW - EVAPORATION)
POOL CONC = AREA-WEIGHTED MEAN CONCENTRATION OVER ALL SEGMENTS
TOTAL P RESIDENCE TIME = TOTAL P MASS IN RESERVOIR/TOTAL LOADING
TURNOVER RATIO = LENGTH OF AVERAGING PERIOD/TOTAL P RESIDENCE TIME
RETENTION COEF = 1 - P RESIDENCE TIME/HYDRAULIC RESIDENCE TIME

OPTION CODES OUTPUT FORMAT 3: (1 SHOWN ABOVE)
0 = DO NOT PRINT
1 = USE OBSERVED POOL AND OUTFLOW CONCENTRATIONS TO COMPUTE DISCHARGE, CHANGE IN STORAGE, AND MASS RESIDENCE TIMES
2 = USE ESTIMATED POOL CONCENTRATIONS

OUTPUT FORMAT 4 - DETAILED MASS BALANCE BY SEGMENT

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P   SEGMENT: 1 ARKANSAS UPPER

ID	T	LOCATION	--- FLOW --- HM3/YR	%	--- LOAD --- KG/YR	%	CONC MG/M3
2	1	ARKANSAS INFLOW	6770.0	42.1	3337880.5	65.4	493.0
3	1	HELLROARING	10.0	0.1	469.2	0.0	46.9
6	2	UNGAUGED-SEG 1	216.0	1.3	10134.7	0.2	46.9
11	3	CLEVELAND STPS	1.0	0.0	10249.1	0.2	10249.1
		PRECIPITATION	10.6	0.1	326.3	0.0	30.8
		EXTERNAL INFLOW	6997.0	43.5	3358733.0	65.8	480.0
		ADVECTIVE INFLOW	0.0	0.0	0.0	0.0	0.0
		DIFFUSIVE INFLOW	9084.8	56.5	1747060.5	34.2	192.3
		***TOTAL INFLOW	16092.4	100.0	5106119.5	100.0	317.3
		GAUGED OUTFLOW	0.0	0.0	0.0	0.0	0.0
		ADVECTIVE OUTFLOW	6989.6	43.4	2158271.7	42.3	308.8
		DIFFUSIVE OUTFLOW	9084.8	56.5	2805239.0	54.9	308.8
		***TOTAL OUTFLOW	16074.4	99.9	4963510.5	97.2	308.8
		***EVAPORATION	18.0	0.1	0.0	0.0	0.0
		***STORAGE INCREASE	0.0	0.0	0.0	0.0	0.0
		***NET RETENTION	0.0	0.0	142609.0	2.8	0.0

NOTES:

TABLE REPEATED FOR EACH SEGMENT AND COMPONENT
% = PERCENT OF TOTAL INFLOW TO SEGMENT (FLOW OR LOAD)
ADVECTIVE INFLOW = ADVECTION FROM UPSTREAM SEGMENT
ADVECTIVE OUTFLOW = DISCHARGE TO DOWNSTREAM SEGMENT
DIFFUSIVE INFLOW = DIFFUSIVE TRANSPORT INTO SEGMENT
DIFFUSIVE OUTFLOW = DIFFUSIVE TRANSPORT OUT OF SEGMENT
TOTAL INFLOW = PRECIP + EXTERNAL + ADVECTIVE INFLOW + DIFFUSIVE INFLOW
TOTAL OUTFLOW = GAUGED OUTFLOW + ADVECTIVE OUTFLOW + DIFFUSIVE OUTFLOW
NET RETENTION = NET LOSS DUE TO NON-CONSERVATIVE BEHAVIOR

OPTION CODES OUTPUT FORMAT 4: (2 USED ABOVE)
0 = DO NOT PRINT
1 = USE OBSERVED POOL AND OUTFLOW CONCENTRATIONS TO COMPUTE DISCHARGE, CHANGE IN STORAGE, AND RETENTION
2 = USE ESTIMATED POOL CONCENTRATIONS

OUTPUT FORMAT 5 - WATER AND MASS BALANCE SUMMARY BY SEGMENT

WATER BALANCE (HM3/YR):

	-------- INFLOWS	--------		STORAGE	--- OUTFLOWS	---	DOWNSTR	
SEG	EXTERNAL	PRECIP	ADVECT	INCREASE	ADVECT	DISCH	EXCHANGE	EVAP
1	0.70E+04	0.11E+02	0.00E+00	0.00E+00	0.70E+04	0.00E+00	0.91E+04	0.18E+02
2	0.14E+03	0.32E+02	0.70E+04	0.00E+00	0.71E+04	0.00E+00	0.22E+05	0.54E+02
3	0.00E+00	0.32E+02	0.71E+04	0.00E+00	0.71E+04	0.00E+00	0.18E+05	0.54E+02
4	0.33E+04	0.11E+02	0.00E+00	0.00E+00	0.33E+04	0.00E+00	0.15E+04	0.18E+02
5	0.45E+02	0.16E+02	0.33E+04	0.00E+00	0.34E+04	0.00E+00	0.13E+04	0.27E+02
6	0.12E+03	0.26E+02	0.34E+04	0.00E+00	0.35E+04	0.00E+00	0.46E+04	0.45E+02
7	0.00E+00	0.11E+02	0.11E+05	0.00E+00	-0.20E+00	0.11E+05	0.00E+00	0.18E+02
NET	0.11E+05	0.14E+03	0.00E+00	0.00E+00	-0.20E+00	0.11E+05	0.00E+00	0.23E+03

MASS BALANCE TERMS (KG/YR) FOR: TOTAL P BASED UPON ESTIMATED CONCS:

	--------- INFLOWS	--------		STORAGE	---- OUTFLOWS----		NET	NET
SEG	EXTERNAL	ATMOSP	ADVECT	INCREASE	ADVECT	DISCH	EXCHANGE	RETENT
1	0.34E+07	0.33E+03	0.00E+00	0.00E+00	0.22E+07	0.00E+00	-0.11E+07	0.14E+06
2	0.67E+04	0.98E+03	0.22E+07	0.00E+00	0.14E+07	0.00E+00	0.20E+06	0.10E+07
3	0.00E+00	0.98E+03	0.14E+07	0.00E+00	0.11E+07	0.00E+00	0.49E+06	0.77E+06
4	0.11E+07	0.33E+03	0.00E+00	0.00E+00	0.78E+06	0.00E+00	-0.12E+06	0.18E+06
5	0.41E+04	0.49E+03	0.78E+06	0.00E+00	0.52E+06	0.00E+00	0.52E+05	0.32E+06
6	0.14E+05	0.82E+03	0.52E+06	0.00E+00	0.36E+06	0.00E+00	0.19E+06	0.36E+06
7	0.00E+00	0.33E+03	0.14E+07	0.00E+00	-0.27E+02	0.14E+07	0.24E+06	0.29E+06
NET	0.45E+07	0.42E+04	0.00E+00	0.00E+00	-0.27E+02	0.14E+07	0.00E+00	0.31E+07

OUTPUT FORMAT 5 - WATER AND MASS BALANCE SUMMARY BY SEGMENT (CONCLUDED)

MASS BALANCE TERMS (KG/YR) FOR: TOTAL N BASED UPON ESTIMATED CONCS:

	INFLOWS			STORAGE	OUTFLOWS		NET	NET
SEG	EXTERNAL	ATMOSP	ADVECT	INCREASE	ADVECT	DISCH	EXCHANGE	RETENT
1	0.13E+08	0.83E+04	0.00E+00	0.00E+00	0.11E+08	0.00E+00	-0.19E+07	0.10E+06
2	0.17E+06	0.25E+05	0.11E+08	0.00E+00	0.96E+07	0.00E+00	-0.83E+05	0.14E+07
3	0.00E+00	0.25E+05	0.96E+07	0.00E+00	0.89E+07	0.00E+00	0.79E+06	0.15E+07
4	0.46E+07	0.83E+04	0.00E+00	0.00E+00	0.43E+07	0.00E+00	-0.18E+06	0.15E+06
5	0.67E+05	0.12E+05	0.43E+07	0.00E+00	0.39E+07	0.00E+00	0.61E+05	0.52E+06
6	0.18E+06	0.21E+05	0.39E+07	0.00E+00	0.37E+07	0.00E+00	0.67E+06	0.11E+07
7	0.00E+00	0.83E+04	0.13E+08	0.00E+00	-0.24E+03	0.13E+08	0.60E+06	0.66E+06
NET	0.18E+08	0.11E+06	0.00E+00	0.00E+00	-0.24E+03	0.13E+08	0.00E+00	0.53E+07

NOTES:

TERMS OF WATER AND MASS BALANCES ARE SHOWN.
NET EXCHANGE = DIFFUSIVE INFLOW - DIFFUSIVE OUTFLOW
= NET TRANSPORT INTO SEGMENT ATTRIBUTED TO DISPERSION
NET (LAST LINE) = BALANCE AROUND ENTIRE RESERVOIR
WATER BALANCE ERROR IS LISTED AS ADVECTIVE OUTFLOW FROM LAST SEGMENT.

OPTION CODES OUTPUT FORMAT 5: (2 USED ABOVE)

0 = DO NOT PRINT
1 = USE OBSERVED POOL AND OUTFLOW CONCENTRATIONS TO COMPUTE DISCHARGE, CHANGE IN STORAGE, AND RETENTION
2 = USE ESTIMATED POOL CONCENTRATIONS

OUTPUT FORMAT 6 - COMPARE OBSERVED AND PREDICTED VALUES

```
KEYSTONE RESERVOIR

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
 1 = OBSERVED ERROR ONLY
 2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
 3 = OBSERVED AND PREDICTED ERROR
```

VARIABLE		OBSERVED MEAN	CV	ESTIMATED MEAN	CV	RATIO	T STATISTICS 1	2	3
SEGMENT: 8 AREA-WTD MEAN									
TOTAL P	MG/M3	163.6	0.13	169.5	0.17	0.97	-0.28	-0.13	-0.16
TOTAL N	MG/M3	1218.4	0.09	1255.2	0.14	0.97	-0.34	-0.14	-0.18
C.NUTRIENT	MG/M3	76.1	0.11	80.1	0.13	0.95	-0.47	-0.25	-0.30
CHL-A	MG/M3	13.0	0.56	9.8	0.29	1.32	0.50	0.81	0.44
SECCHI	M	0.4	0.28	0.4	0.16	1.03	0.10	0.10	0.09
ORGANIC N	MG/M3	570.8	0.08	566.6	0.16	1.01	0.09	0.03	0.04
TP-ORTHO-P	MG/M3	74.5	0.20	71.7	0.20	1.04	0.19	0.11	0.14

NOTES:

OBSERVED MEAN AND CV SPECIFIED IN INPUT FILE (ESTIMATED FROM MONITORING)
ESTIMATED MEAN AND CV CALCULATED FROM MODEL NETWORK AND ERROR ANALYSIS
RATIO = OBSERVED MEAN/ESTIMATED MEAN
T STATISTICS TEST FOR SIGNIFICANT DIFFERENCE BETWEEN OBSERVED AND ESTIMATED MEAN VALUES USING ALTERNATIVE ERROR TERMS
T = IN (RATIO)/ERROR

1: OBSERVED ERROR ONLY (ERROR = OBSERVED CV)
2: TYPICAL ERROR (ERROR DERIVED FROM MODEL DEVELOPMENT DATA SET, INDEPENDENT OF OBSERVED AND ESTIMATED CV)
3: OBSERVED AND PREDICTED ERROR
ERROR = (OBS CV **2 + EST CV **2) ** 0.5)

OPTION CODES FOR OUTPUT FORMAT 6: (2 SHOWN ABOVE)

0 = DO NOT PRINT
1 = PRINT FOR EACH SEGMENT AND AREA-WEIGHTED MEANS
2 = PRINT AREA-WEIGHTED MEANS ONLY

OUTPUT FORMAT 7 - DIAGNOSTICS

OBSERVED AND PREDICTED DIAGNOSTIC VARIABLES
RANKED AGAINST CE MODEL DEVELOPMENT DATA SET

SEGMENT: 8 AREA-WTD MEAN

VARIABLE		VALUES OBSERVED	VALUES ESTIMATED	RANKS (%) OBSERVED	RANKS (%) ESTIMATED
TOTAL P	MG/M3	163.55	169.46	91.4	92.0
TOTAL N	MG/M3	1218.40	1255.19	62.0	63.8
C.NUTRIENT	MG/M3	76.12	80.07	82.8	84.4
CHL-A	MG/M3	13.02	9.85	66.5	52.5
SECCHI	M	0.42	0.41	10.7	10.0
ORGANIC N	MG/M3	570.75	566.59	64.2	63.7
TP-ORTHO-P	MG/M3	74.50	71.69	83.1	82.0
ANTILOG PC-1		763.22	680.39	80.7	78.2
ANTILOG PC-2		3.75	3.00	15.3	7.4
(N - 150) / P		6.53	6.52	8.0	8.0
INORGANIC N / P		7.27	7.04	7.8	7.4
TURBIDITY	1/M	2.46	2.46	94.4	94.4
ZMIX * TURBIDITY		13.88	13.88	97.2	97.2
ZMIX / SECCHI		13.44	13.83	96.2	96.6
CHL-A * SECCHI		5.47	4.02	18.9	9.4
CHL-A / TOTAL P		0.08	0.06	7.8	2.8

NOTES:
RANKS (%) = APPROXIMATE PERCENTILE FOR OBSERVED OR PREDICTED VALUE RANKED AGAINST CE MODEL DEVELOPMENT DATA SET, ASSUMING LOG-NORMAL DISTRIBUTION
OPTION CODES FOR OUTPUT FORMAT 7: (2 USED ABOVE)
0 = DO NOT PRINT
1 = PRINT FOR EACH SEGMENT AND AREA-WEIGHTED MEANS
2 = PRINT AREA-WEIGHTED MEANS ONLY

OUTPUT FORMAT 8 - PROFILE SUMMARY

PREDICTED CONCENTRATIONS:

VARIABLE	SEGMENT-->	1	2	3	4	5	6	7	8
TOTAL P	MG/M3	308.7	192.2	153.2	233.2	153.4	104.8	132.7	169.5
TOTAL N	MG/M3	1553.9	1349.2	1261.0	1291.8	1167.5	1077.3	1197.0	1255.2
C.NUTRIENT	MG/M3	109.4	88.7	79.2	88.1	74.2	62.2	72.9	80.1
CHL-A	MG/M3	43.0	6.9	6.0	13.3	6.9	6.9	5.5	9.8
SECCHI	M	0.2	0.4	0.4	0.2	0.4	0.6	0.5	0.4
ORGANIC N	MG/M3	1396.5	509.6	475.8	791.7	489.8	424.1	426.2	566.6
TP-ORTHO-P	MG/M3	154.2	69.8	64.1	124.0	63.2	42.6	51.0	71.7

NOTES:

AREA-WEIGHTED MEANS GIVEN LAST SEGMENT (8)

OPTIONS FOR OUTPUT FORMAT 8: (1 SHOWN ABOVE)

0 = DO NOT PRINT

1 = PRINT PREDICTED PROFILES ONLY

2 = PRINT PREDICTED, OBSERVED, AND OBSERVED/PREDICTED PROFILES

OUTPUT FORMAT 9 - PLOT OBSERVED AND PREDICTED CONFIDENCE LIMITS

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CONFIDENCE LIMITS FOR OBSERVED(O) AND ESTIMATED(E) VALUES ( 2.0 STD ERRORS )

                                           TOTAL P     MG/M3
                             59.40    85.69  123.61  178.31  257.22  371.04  535.24
 SEGMENT                   MEAN+--------+--------+--------+--------+--------+--------+
  1 ARKANSAS UPPER         367.0                                             ----O----
  1 ARKANSAS UPPER         308.7                                  -----------E-----------

  2 ARKANSAS MID           192.2                          --------E--------

  3 ARKANSAS LOWER         149.0                     -------O------
  3 ARKANSAS LOWER         153.2                   ---------E---------

  4 CIMARRON UPPER         234.0                                      ----O-----
  4 CIMARRON UPPER         233.2                                  -------E-------

  5 CIMARRON MID           130.0                  -------O------
  5 CIMARRON MID           153.4                    --------E--------

  6 CIMARRON LOWER          99.0            ------O-----
  6 CIMARRON LOWER         104.8------------E-----------

  7 DAM AREA               145.0                   --------O--------
  7 DAM AREA               132.7              ----------E----------

  8 AREA-WTD MEAN          163.6                         ------O-----
  8 AREA-WTD MEAN          169.5                        -------E--------
```

(ETC.)

NOTES:

DASHED LINE INDICATES 95% CONFIDENCE LIMITS (2 STD ERRORS) FOR OBSERVED (O) AND ESTIMATED (E) MEAN VALUES FOR EACH SEGMENT.

LAST PAIR (8) CONTAINS AREA-WEIGHTED-MEAN VALUES OVER ALL 7 SEGMENTS.

PLOT REPEATED FOR EACH RESPONSE VARIABLE.

OPTION CODES FOR OUTPUT FORMAT 9: ***(2 SHOWN ABOVE)***

0 = DO NOT PRINT
1 = USE LINEAR SCALES
2 = USE GEOMETRIC SCALES

OUTPUT FORMAT 10 - SENSITIVITY ANALYSIS

PROFILE SENSITIVITY ANALYSIS FOR: TOTAL P

DECAY FACTOR	DISPERSION FACTOR	SEGMENT 1	2	3	4	5	6	7	8
0.50	0.25	458.1	276.5	202.1	282.5	200.5	125.0	163.0	227.1
0.50	1.00	339.0	239.6	203.2	259.6	193.8	148.8	181.9	213.2
0.50	4.00	245.8	211.7	199.5	214.6	188.8	176.8	191.7	200.8
1.00	0.25	439.2	219.6	144.6	257.0	157.0	86.3	111.8	180.9
1.00	1.00	308.7	192.2	153.2	233.2	153.4	104.8	132.7	169.5
1.00	4.00	207.0	167.6	153.8	181.3	148.2	131.5	145.7	157.6
2.00	0.25	408.8	166.1	98.0	223.8	115.7	56.4	72.5	139.4
2.00	1.00	279.0	149.7	110.7	202.8	115.4	70.2	92.4	131.1
2.00	4.00	173.7	129.9	115.3	151.5	113.2	94.0	107.1	121.0
OBSERVED:		367.0	0.0	149.0	234.0	130.0	99.0	145.0	163.6

NOTES:

PREDICTED CONCENTRATION PROFILES ARE SHOWN AS A FUNCTION OF RELATIVE DECAY AND DISPERSION RATES. A "DECAY FACTOR" OF 0.5 MEANS THAT ALL DECAY RATES ARE 50% OF THOSE SPECIFIED IN THE INPUT FILE; SIMILARLY FOR DISPERSION. DECAY RATES ARE VARIED BY A FACTOR OF 2, DISPERSION RATES BY A FACTOR OF 4, IN ROUGH PROPORTION TO THEIR EXPECTED ERROR MAGNITUDES.

THE LAST SEGMENT (8) CONTAINS THE AREA-WEIGHTED MEAN VALUE OVER ALL SEGMENTS.

OPTION CODES FOR OUTPUT FORMAT 10: (2 SHOWN ABOVE)

0 = DO NOT PRINT
1 = PRINT FOR CONSERVATIVE SUBSTANCE
2 = PRINT FOR PHOSPHORUS
3 = PRINT FOR NITROGEN

BATHTUB: INSTRUCTIONAL CASES

The following hypothetical case studies illustrate BATHTUB applications to predict among-reservoir or within-reservoir (spatial or temporal) variations in trophic state indicators. Each case study is described by the following materials:

a. Basic data sheet.

(1) Illustration of segmentation scheme.

(2) Mass balance period.

(3) Basic morphometric/hydrologic characteristics.

b. BATHTUB input file.

The following procedure is suggested:

a. Select application of interest from listing below.

b. Review basic data sheet.

c. Review input file.

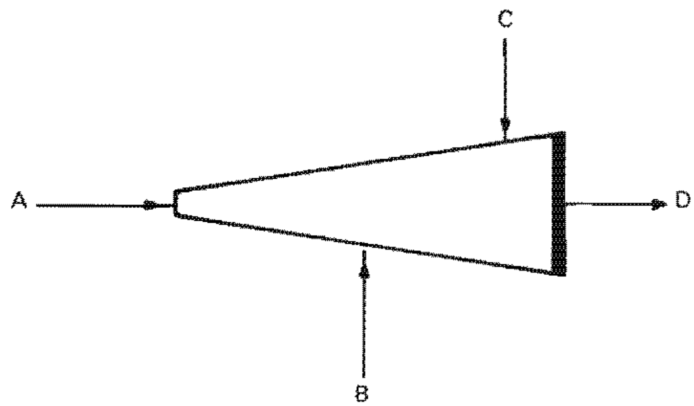
d. Execute model.

e. Review output listing.

f. Try modifying the input file and rerunning the model to evaluate sensitivity to loadings or other input parameters of interest.

Case	Segmentation Scheme
1	Single reservoir, spatially averaged
2	Single reservoir, spatially segmented
3	Reservoir embayment, spatially segmented
4	Single reservoir, spatially averaged, multiple scenario
5	Collection of reservoirs, spatially averaged
6	Network of reservoirs, spatially averaged
7	Collection of reservoirs, loading and pool data
8	Collection of reservoirs, pool data only

BASIC DATA SHEET FOR CASE 1
Single reservoir, spatially averaged



Mass Balance Period: 1 October 1979 - 1 October 1980

Stream Monitoring Data:

Stream	Drainage Area km^2	Mean Flow hm^3/yr	Flow-Weighted Total P Concentration ppb
A	380	1,014	60
B	100	300	167
C*	50	(Ungauged)	
D	570	1,430	Ungauged

* Land use and soil types in watershed C similar to watershed B.

Atmospheric total P load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir total volume = 704 hm^3
Reservoir total surface area = 40 km^2
Reservoir total length = 30 km
Reservoir surface elevation 1 Oct 1979 = 180.0 m
Reservoir surface elevation 1 Oct 1980 = 179.5 m
Observed pool water quality data: None

```
CASE 1: Single Reservoir, Spatially Averaged                                  **GROUP 1
PO S OUPUT OPTIONS                                                            **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT     * BASED UPON PREDICTED CONCS
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 1 PLOT OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                            **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                                **GROUP 4
01 CONSERV               0.
02 TOTAL P 30.           1.      * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                   MEAN       CV                                      **GROUP 5
01 AVERAGING PERIOD     YRS  1.              * MULTIPLIED BY FACTORS IN GROUP 9
02 PRECIPITATION     METERS  .7              *
03 EVAPORATION       METERS  1.              *
04 STORAGE INCREASE  METERS  -.5             *
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.
07 TOTAL AREA           KM2  40.             * RESCALE SEGMENT VALUES
08 TOTAL VOLUME         HM3  704.            *
00
ID T IS NAME            DAREA      FLOW      CV                               **GROUP 6
01 1  1 Stream A        380.       1014.
02 1  1 Stream B        100.        300.
03 2  1 Stream C         50.        150.               * PROP TO B ON DR. AREA
04 4  1 Stream D        570.       1430.
00
ID CONS    CV    TP      CV   TN      CV   ORTHOP CV    INORGN CV             **GROUP 7
01               60.                                                   * STREAM A
02               167.                                                  * STREAM B
03               167.                                                  * STREAM C
04                                                                     * STREAM D UNKNOWN
00
```

```
IS JO JG NAME           KP   KN   KC   KS   KO   KD                 **GROUP 8
01  0  1 Case 1         1.   1.   1.   1.   1.   1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV       **GROUP 9
01 1.   1.   1.   1.   30.   1.    1.
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV       **GROUP 10
01                                                                  *NO OBS WQ
01
00
```

END OF BATHTUB INPUT FILE

NOTES:

THIS IS THE SIMPLEST SEGMENTATION SCHEME.

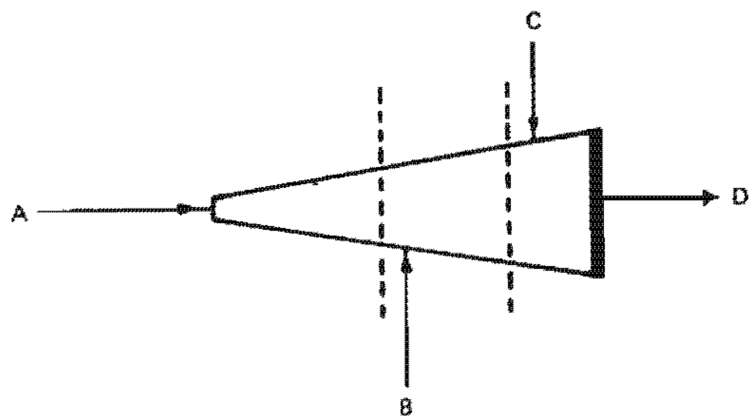
SINCE ORTHO P LOADING INFORMATION IS NOT GIVEN, THE AVAILABILITY FACTOR FOR TOTAL P MUST BE SET TO 1.0 IN GROUP 4.

STREAM C FLOW AND LOADING ESTIMATED BY DRAINAGE AREA PROPORTIONING TO STREAM B, SINCE B AND C WATERSHEDS ARE SIMILAR. THIS GIVES A REASONABLE WATER BALANCE.

NOTE THAT THE VALUES USED FOR PERIOD LENGTH, PRECIPITATION, EVAPORATION, AND INCREASE IN STORAGE ARE COMPUTED AS THE PRODUCTS OF THE ENTRIES IN GROUPS 5 AND 9. GROUP 5 ENTRIES APPLY TO ALL SEGMENTS, WHEREAS GROUP 9 VALUES ARE SEGMENT-SPECIFIC. IN THIS EXAMPLE, THE SEGMENT-SPECIFIC FACTORS ARE SET TO 1.0 AND ACTUAL VALUES ARE SPECIFIED IN GROUP 5 ALTERNATIVELY, THE GROUP 5 AND GROUP 9 ENTRIES COULD BE SWITCHED.

SINCE NON-ZERO VALUES ARE GIVEN FOR AREA AND VOLUME IN GROUP 5, SEGMENT AREA AND MEAN DEPTH (1) IN GROUP 9 ARE RESCALED TO CORRESPOND TO THE GROUP 5 AREA AND VOLUME VALUES (SEE OUTPUT LISTING).

BASIC DATA SHEET FOR CASE 2
Single reservoir, spatially segmented



Mass Balance Period: 1 October 1979 - 1 October 1980

Stream Monitoring Data: Same as CASE 1

Segment Morphometry:

Segment	Surface Area km^2	Volume hm^3	Length km
Upper	8	64	10
Middle	16	256	10
Lower	16	384	10

Atmospheric total P load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir surface elevation 1 Oct 1979 = 180.0 m
Reservoir surface elevation 1 Oct 1980 = 179.5 m
Observed pool water quality data: None

```
CASE 2: Single Reservoir, Spatially Segmented                                   **GROUP 1
PO S OUPUT OPTIONS                                                              **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT     * BASED UPON PREDICTED CONCS
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOTS OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                              **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                                  **GROUP 4
01 CONSERV               0.
02 TOTAL P 30.           1.      * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                  MEAN       CV                                         **GROUP 5
01 AVERAGING PERIOD     YRS  1.             * MULTIPLIED BY FACTORS IN GROUP 9
02 PRECIPITATION     METERS  .7             *
03 EVAPORATION       METERS  1.             *
04 STORAGE INCREASE  METERS  -.5            *
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.
07 TOTAL AREA           KM2                  * NO RESCALING
08 TOTAL VOLUME         HM3                  *
00
ID T IS NAME            DAREA     FLOW       CV                                 **GROUP 6
01 1  1 Stream A        380.      1014.
02 1  2 Stream B        100.       300.
03 2  3 Stream C         50.       150.              * PROP TO B ON DR. AREA
04 4  3 Stream D        570.      1430.
00
ID CONS   CV   TP     CV   TN     CV   ORTHOP CV   INORGN CV                    **GROUP 7
01             60.                                                              * STREAM A
02             167.                                                             * STREAM B
03             167.                                                             * STREAM C
04                                                                              * UNKNOWN
00
```

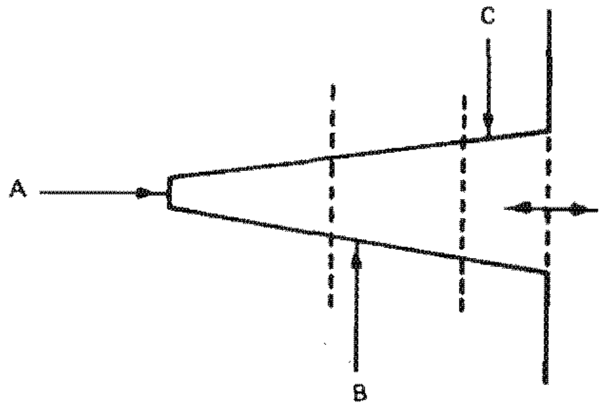
```
IS JO JG NAME            KP   KN   KC   KS   KO   KD              **GROUP 8
01 02  1 Upper Pool      1.   1.   1.   1.   1.   1.
02 03  1 Mid Pool        1.   1.   1.   1.   1.   1.
03 00  1 Near Dam        1.   1.   1.   1.   1.   1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV     **GROUP 9
01 1.   1.   1.   1.   10.   8.    8.
02 1.   1.   1.   1.   10.   16.   16.
03 1.   1.   1.   1.   10.   16.   24.
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV     **GROUP 10
01                                                                * NO OBS WQ
01
02
02
03
03
00
```

END OF BATHTUB INPUT FILE

NOTES:

SEGMENT AREAS AND MEAN DEPTHS ARE SPECIFIED IN GROUP 9; RESCALING NOT PERFORMED. (SEE CASE 1 COMMENTS).

BASIC DATA SHEET FOR CASE 3
Reservoir embayment, spatially segmented



Mass Balance Period: 1 October 1979 - 1 October 1980

Stream Monitoring Data: Same as CASE 1

Segment Morphometry:

Segment	Surface Area km^2	Volume hm^3	Length km
Upper	8	64	10
Middle	16	256	10
Lower	16	384	10

Estimated diffusive exchange with main reservoir = 2,000 hm^3/yr
Total P concentration in main reservoir = 15 mg/m^3

Atmospheric total P load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir surface elevation 1 Oct 1979 = 180.0 m
Reservoir surface elevation 1 Oct 1980 = 179.5 m
Observed pool water quality data: None

```
CASE 3: Reservoir Embayment, Spatially Segmented                    **GROUP 1
PO S OUPUT OPTIONS                                                  **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT     * BASED UPON PREDICTED CONCS
05 2 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOTS OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                  **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                      **GROUP 4
01 CONSERV               0.
02 TOTAL P 30.           1.       * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                   MEAN       CV                            **GROUP 5
01 AVERAGING PERIOD     YRS  1.
02 PRECIPITATION     METERS  .7              * TOTAL PRECIP OVER PERIOD
03 EVAPORATION       METERS  1.              * TOTAL EVAP OVER PERIOD
04 STORAGE INCREASE  METERS  -.5             * POOL DROPS 0.5 METERS
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.
07 TOTAL AREA           KM2
08 TOTAL VOLUME         HM3
00
ID T IS NAME            DAREA     FLOW      CV                      **GROUP 6
01 1  1 Stream A        380.      1014.
02 1  2 Stream B        100.       300.
03 2  3 Stream C         50.       150.         * PROP TO B ON DR. AREA
04 4  3 Stream D        570.      1430.
05 1  3 Exchange- In      0.      2000.         * DOWNSTREAM EXCH - INPUT
06 4  3 Exchange- Out     0.      2000.         * DOWNSTREAM EXCH - OUTPUT
00
```

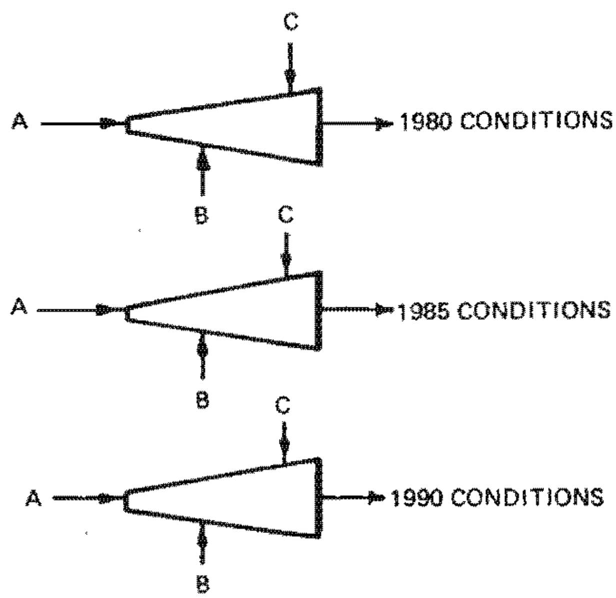
```
ID CONS    CV    TP       CV    TN       CV    ORTHOP CV    INORGN CV        **GROUP 7
01                60.                                                         * STREAM A
02                167.                                                        * STREAM B
03                167.                                                        * STREAM C
04                                                                            * UNKNOWN
05                15.                                                         * DOWNSTREAM CONC
06                                                                            * UNKNOWN
00
IS JO JG NAME                KP    KN    KC    KS    KO    KD                  **GROUP 8
01 02  1 Upper Pool          1.    1.    1.    1.    1.    1.
02 03  1 Mid Pool            1.    1.    1.    1.    1.    1.
03 00  1 Near Dam            1.    1.    1.    1.    1.    1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV     ZHYP  CV              **GROUP 9
01 1.   1.   1.   1.   10.   8.    8.
02 1.   1.   1.   1.   10.   16.   16.
03 1.   1.   1.   1.   10.   16.   24.
00
ID TURB  CONS  TP     TN     CHLA  SEC   ORGN  PP     HODV  MODV            **GROUP 10
01                                                                           * NO OBS WQ
01
02
02
03
03
00
END OF BATHTUB INPUT FILE
```

NOTES:

IN ORDER TO MODEL EMBAYMENTS (OPEN-ENDED SYSTEMS), THE EXCHANGE FLOW WITH THE DOWNSTREAM WATER BODY MUST BE SPECIFIED AS AN INPUT STREAM (TRIBUTARY ID NUMBER 05) WITH THE CONCENTRATION OF THE DOWNSTREAM WATER BODY (TP=15). OTHER EXCHANGE FLOWS (AMONG SEGMENTS WITHIN THE EMBAYMENT) ARE CALCULATED VIA DISPERSION OPTION 1.

OUTPUT STREAMS (ID'S 04 AND 06) ARE USED TO ESTABLISH WATER BALANCE, BUT PREDICTED SEGMENT CONCENTRATIONS ARE DEPENDENT ONLY UPON EXTERNAL LOADING AND NET INFLOW TERMS (TRIBUTARY+PRECIP-EVAP).

BASIC DATA SHEET FOR CASE 4
Single reservoir, spatially averaged, multiple load scenario



Mass Balance Period: 1 yr

Stream Loading Data:

Stream	Drainage Area km^2	Mean Flow hm^3/yr	Flow-Weighted Total P Concentration ppb	Scenario
A	380	1,014	60	1980 conditions
A	380	1,014	120	1985 conditions
A	380	1,014	180	1990 conditions
B	100	300	167	1980, 1985, 1990 conditions
C*	50	(Ungauged)		1980, 1985, 1990 conditions

* Land use and soil types in watershed C similar to watershed B.

Atmospheric total P Load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir total volume = 704 hm^3
Reservoir total surface area = 40 km^2
Reservoir total length = 30 km
Reservoir surface elevations constant

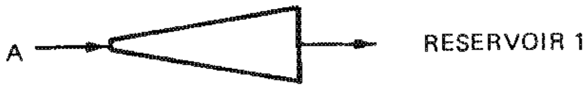
```
CASE 4: Single Reservoir, Spatially Averaged, Mult Scenario        **GROUP 1
PO S OUPUT OPTIONS                                                 **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT    * BASED UPON PRED CONC
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOTS OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                 **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                     **GROUP 4
01 CONSERV               0.
02 TOTAL P 30.    0.     1.      * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                   MEAN      CV                            **GROUP 5
01 AVERAGING PERIOD     YRS  1.
02 PRECIPITATION     METERS  1.            * SEG VALUES ENTERED IN GROUP 9
03 EVAPORATION       METERS  1.            * SEG VALUES ENTERED IN GROUP 9
04 STORAGE INCREASE  METERS  1.            * SEG VALUES ENTERED IN GROUP 9
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.
07 TOTAL AREA           KM2
08 TOTAL VOLUME         HM3
00
ID T IS NAME            DAREA     FLOW      CV                     **GROUP 6
01 1  1 Stream A 1980   380.      1014.
02 1  1 Stream B 1980   100.       300.
03 2  1 Stream C 1980   50.       150.             * PROP. TO B ON DR. AREA
04 1  2 Stream A 1985   380.      1014.
05 1  2 Stream B 1985   100.       300.
06 2  2 Stream C 1985   50.       150.             * PROP. TO B ON DR. AREA
07 1  3 Stream A 1990   380.      1014.
08 1  3 Stream B 1990   100.       300.
09 2  3 Stream C 1990   50.       150.             * PEOP. TO B ON DR. AREA
00
```

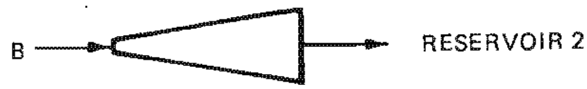
```
ID CONS    CV    TP      CV    TN       CV    ORTHOP CV    INORGN CV        **GROUP 7
01               60.
02               167.
03               167.
04               120.
05               167.
06               167.
07               180.
08               167.
09               167.
00
IS JO JG NAME             KP    KN    KC    KS    KO    KD                  **GROUP 8
01  0  1 1980 Conditions 1.    1.    1.    1.    1.    1.
02  0  2 1985 Conditions 1.    1.    1.    1.    1.    1.
03  0  3 1990 Conditions 1.    1.    1.    1.    1.    1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV     ZHYP  CV          **GROUP 9
01 1.   .7   1.   0.   30.   40.   17.6
02 1.   .7   1.   0.   30.   40.   17.6
03 1.   .7   1.   0.   30.   40.   17.6
00
ID TURB  CONS  TP    TN     CHLA  SEC   ORGN  PP     HODV  MODV          **GROUP 10
01                                                                       * NO OBS WQ
01
02
02
03
03
00
```

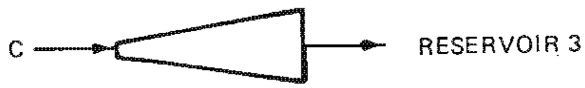
END OF BATHTUB INPUT FILE

NOTES:
THREE LOADING SCENARIOS ARE BEING MODELLED IN PARALLEL.
INFLOW STREAMS A,B,C ARE REPEATED FOR EACH SCENARIO (SEGMENT).
EACH SEGMENT (GROUP 8) DISCHARGES OUT OF NETWORK (JO=0).
DIFFERENT SEGMENT GROUP NUMBERS (IG) ARE SPECIFIED FOR EACH SCENARIO.
OUTFLOW STREAMS ARE OPTIONAL AND IGNORED IN THIS EXAMPLE.

BASIC DATA SHEET FOR CASE 5
Collection of reservoirs, spatially averaged







Mass Balance Period: 1 yr

Stream Monitoring Data:

Stream	Drainage Area km^2	Mean Flow hm^3/yr	Flow-Weighted Total P Concentration ppb
A	380	1,014	60
B	100	300	167
C*	50	(Ungauged)	

* Land use and soil types in watershed C similar to watershed B.

Reservoir Morphometry:

Segment-Reservoir	Surface Area km^2	Volume hm^3	Length km
1	8	64	10
2	16	256	10
3	16	384	10

Atmospheric total P load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir surface elevations constant

```
CASE 5: Collection of Reservoirs, Spatially Averaged                  **GROUP 1
PO S OUPUT OPTIONS                                                    **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT   * BALS BASED UPON PREDICTED CONCS
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOTS OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                    **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                        **GROUP 4
01 CONSERV               0.
02 TOTAL P 30.           1.      * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                     MEAN      CV                             **GROUP 5
01 AVERAGING PERIOD     YRS  1.
02 PRECIPITATION     METERS  1.                * PRECIP FACTOR
03 EVAPORATION       METERS  1.                * EVAP FACTOR
04 STORAGE INCREASE  METERS  1.                * STORAGE FACTOR
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.
07 TOTAL AREA           KM2                    * DO NOT RE-SCALE VALUES IN GROUP 9
08 TOTAL VOLUME         HM3
00
ID T IS NAME            DAREA    FLOW     CV                          **GROUP 6
01 1  1 Stream A        380.     1014.
02 1  2 Stream B        100.      300.
03 2  3 Stream C         50.      150.              * PROP TO B ON DR. AREA
00
ID CONS   CV   TP     CV   TN     CV   ORTHOP CV   INORGN CV          **GROUP 7
01             60.                                                   * STREAM A
02             167.                                                  * STREAM B
03             167.                                                  * STREAM C
00
```

```
IS JO JG NAME              KP    KN    KC    KS    KO    KD            **GROUP 8
01 00  1 Reservoir 1       1.    1.    1.    1.    1.    1.      *SEGS INDEPENDENT
02 00  2 Reservoir 2       1.    1.    1.    1.    1.    1.
03 00  3 Reservoir 3       1.    1.    1.    1.    1.    1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV      **GROUP 9
01 1.   .7   1.   0.   10.   8.    8.
02 1.   .7   1.   0.   10.   16.   16.
03 1.   .7   1.   0.   10.   16.   24.
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV      **GROUP 10
01                                                                 *NO OBS WQ
01
02
02
03
03
00
END OF BATHTUB INPUT FILE
```

NOTES:

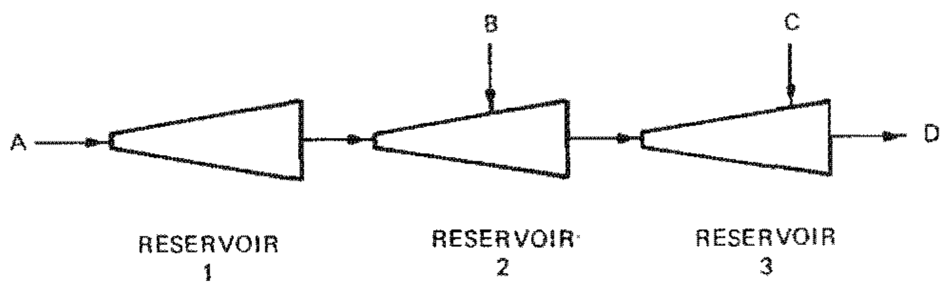
THREE RESERVOIRS ARE MODELLED IN PARALLEL.

EACH INPUT STREAM IS ASSOCIATED WITH A DIFFERENT RESERVOIR (SEGMENT).

EACH SEGMENT HAS DISCHARGES OUT OF NETWORK (JO=0) AND HAS A DIFFERENT SEGMENT GROUP NUMBER (JG).

OUTFLOW STREAMS (OPTIONAL) ARE IGNORED.

BASIC DATA SHEET FOR CASE 6
Network of reservoirs, spatially averaged



Mass Balance Period: 1 yr

Stream Monitoring Data: Same as CASE 1

Reservoir Morphometry:

Segment-Reservoir	Surface Area km^2	Volume hm^3	Length km
1	8	64	10
2	16	256	10
3	16	384	10

Atmospheric total P load = 30 kg/km^2-yr
Precipitation rate = 0.7 m/yr
Evaporation rate = 1.0 m/yr
Reservoir surface elevations constant

```
CASE 6: Network of Reservoirs, Spatially Averaged                     **GROUP 1
PO S OUPUT OPTIONS                                                    **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT    * BASED UPON PREDICTED CONCS
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 0 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOTS OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                    **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL          * P BALANCE ONLY, SED MODEL 1
03 0 N SEDIMENTATION MODEL
04 0 CHLOROPHYLL-A MODEL
05 0 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL    ATM     CV      AVAIL                                     **GROUP 4
01 CONSERV                  0.
02 TOTAL P 30.              1.       * SET AVAIL FACTOR TO 1 (NO ORTHO P LOADS)
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                      MEAN       CV                           **GROUP 5
01 AVERAGING PERIOD      YRS  1.
02 PRECIPITATION      METERS  1.             * PRECIP FACTOR
03 EVAPORATION        METERS  1.             * EVAP FACTOR
04 STORAGE INCREASE   METERS  1.             * STORAGE FACTOR.
05 FLOW FACTOR                1.
06 DISPERSION FACTOR          1.
07 TOTAL AREA               KM2              * DO NOT RE-SCALE VALUES IN GROUP 9
08 TOTAL VOLUME             HM3
00
ID T IS NAME                DAREA     FLOW       CV                   **GROUP 6
01 1  1 Stream A            380.      1014.
02 1  2 Stream B            100.       300.
03 2  3 Stream C             50.       150.             * PROP TO B ON DR. AREA
04 4  3 Stream D            570.      1430.
00
ID CONS    CV    TP      CV    TN      CV    ORTHOP CV    INORGN CV    **GROUP 7
01               60.                                                  * STREAM A
02               167.                                                 * STREAM B
03               167.                                                 * STREAM C
04                                                                    * UNKNOWN
00
```

```
IS JO JG NAME              KP    KN    KC    KS    KO    KD             **GROUP 8
01 02  1 Reservoir 1       1.    1.    1.    1.    1.    0.      * SET KD TO 0, NO
02 03  2 Reservoir 2       1.    1.    1.    1.    1.    0.      * BACK-MIXING ACROSS DAM
03 00  3 Reservoir 3       1.    1.    1.    1.    1.    0.      * KD AUTOMATICALLY 0
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV     **GROUP 9
01 1.   .7   1.   0.   10.   8.    8.
02 1.   .7   1.   0.   10.   16.   16.
03 1.   .7   1.   0.   10.   16.   24.
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV     **GROUP 10
01                                                                * NO OBS WQ
01
02
02
03
03
00
```

END OF BATHTUB INPUT FILE

NOTES:

THREE RESERVOIRS ARE MODELLED IN SERIES, AS REFLECTED IN OUTFLOW SEGMENT VALUES (JO IN GROUP 8).

EACH RESERVOIR IS SEPARATE (IG VALUES).

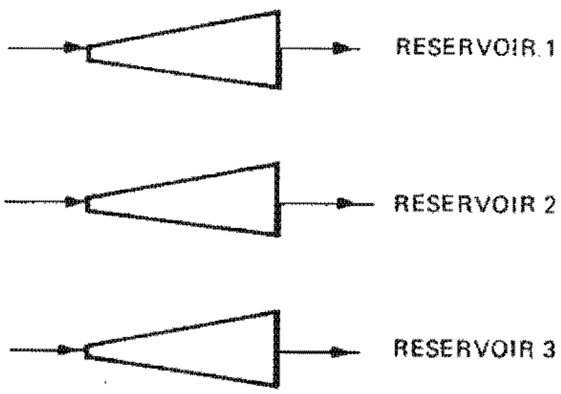
TO PREVENT LONGITUDINAL DISPERSION ACROSS DAM INTERFACES, CALIBRATION FACTORS FOR DISPERSION (KD) ARE SET TO 0 FOR EACH SEGMENT IN GROUP 8. (NOTE: PROGRAM AUTOMATICALLY SETS KD=0 FOR LAST SEGMENT (IS=3) IN ALL APPLICATIONS.)

DISCHARGE FROM ONE RESERVOIR INTO ANOTHER IS CALCULATED FROM WATER BALANCE (CANNOT BE SPECIFIED DIRECTLY IN INPUT FILE).

BATHTUB APPLICATIONS TO NETWORKS OF RESERVOIRS HAVE NOT BEEN EXTENSIVELY TESTED.

BASIC DATA SHEET FOR CASE 7

Collection of reservoirs, spatially averaged with observed water quality and nutrient loading data



Total Tributary Inflow Data (Monitored):

Stream-Reservoir	Drainage Area km^2	Mean Flow hm^3/yr	Flow and Load Averaging Period		Pool Level m		Period	
			Start	End	Start	End	Precip. m	Evap. m
1	90	35.7	5/1/79	10/1/79	89.0	89.1	0.4	0.8
2	440	201.0	5/1/79	10/1/79	45.0	44.7	0.4	0.8
3	2,200	1,157.	10/1/78	10/1/79	103.0	103.4	0.7	1.0

Tributary Inflow Concentrations (ppb):

Stream-Reservoir	Total P	Ortho-P	Total N	Inorganic N
1	123	23	2,400	1,451
2	170	51	3,118	1,970
3	22	7	732	709
Atmospheric Load (kg/km^2-yr)	30	15	1,000	500

(Continued)

BASIC DATA SHEET FOR CASE 7 (Continued)

Stream-Reservoir	Total P ppb	Ortho-P ppb	Total N ppb	Organic N ppb	Chl-a ppb	Secchi m	Oxygen Depletion Rates mg/m^3-day Hypolimnion	Metalimnion
1	35	5	882	441	13.8	Missing	Unstratified	
2	120	12	1,722	1,200	63.6	0.48	Unstratified	
3	13	6	839	235	6.3	3.55	43	35

Reservoir Morphometry:

Stream-Reservoir	Surface Area km^2	Pool Length km	Mean Depth m	Mean Depth of Mixed layer m	Mean Hypolimnetic Depth,m
1	6.5	13.6	4.5	Unknown	Assume unstratified
2	5.5	15.1	1.6	Unstratified	Unstratified
3	10.3	22.1	22.4	7.8	15.7

Assumed error analysis parameters (coefficients of variation):

Inflow volumes = 0.05
Inflow concentrations = 0.10
Observed water quality = 0.15
Mixed depth, hypolimnion depth = 0.05
Precipitation = 0.20
Evaporation = 0.50
Atmospheric loads = 0.50

```
CASE 7: Collection of Reservoirs, Averaged                                      **GROUP 1
PO 5 OUPUT OPTIONS                                                              **GROUP 2
01 1 LIST INPUT CONDITIONS
02 1 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 2 DETAILED BALANCES BY SEGMENT
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 1 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOT OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO 5 MODEL OPTIONS                                                              **GROUP 3
01 0 CONSERVATIVE TRACER
02 1 P SEDIMENTATION MODEL
03 1 N SEDIMENTATION MODEL
04 1 CHLOROPHYLL-A MODEL
05 1 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 1 ERROR ANALYSIS
00
IV LABEL   ATM     CV      AVAIL                                                **GROUP 4
01 CONSERV                 0.
02 TOTAL P 30.     .5      .33          * RESET TO CALIBRATED VALUES
03 TOTAL N 1000.   .5      .59
04 ORTHO P 15.     .5      1.93
05 INORG N 500.    .5      .79
00
ID LABEL                     MEAN      CV                                       **GROUP 5
01 AVERAGING PERIOD     YRS  1.                *VALUES SPECIFIED IN GROUP 9
02 PRECIPITATION     METERS  1.        .2      *
03 EVAPORATION       METERS  1.        .5      *
04 STORAGE INCREASE  METERS  1.                *
05 FLOW FACTOR               1.
06 DISPERSION FACTOR         1.        .7
07 TOTAL AREA           KM2                    *
08 TOTAL VOLUME         HM3                    *
00
ID T IS NAME            DAREA     FLOW      CV                                  **GROUP 6
01 1  1 Stream A        90.       35.7      .05
02 1  2 Stream B        400.      201.      .05
03 1  3 Stream C        2200.     1157.     .05
00
ID CONS   CV   TP     CV   TN     CV   ORTHOP CV   INORGN CV                    **GROUP 7
01             123.   .1   2400.  .1   23.    .1   1451.  .1
02             170.   .1   3118.  .1   51.    .1   1970.  .1
03             22.    .1   732.   .1   7.     .1   709.   .1
00
```

```
IS JO JG NAME            KP    KN    KC    KS    KO    KD                   **GROUP 8
01 00  1 Reservoir 1     1.    1.    1.    1.    1.    1.
02 00  2 Reservoir 2     1.    1.    1.    1.    1.    1.
03 00  3 Reservoir 3     1.    1.    1.    1.    1.    1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV             **GROUP 9
01 .42  .4   .8   .1   13.6  6.5   4.5
02 .42  .4   .8   -.3  15.1  5.5   1.6   1.6   .05
03 1.   .7   1.   .4   22.1  10.3  22.4  7.8   .05   15.7  .05
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV             **GROUP 10
01 .50         35.   882.  13.8        441.  30.                        * SECCHI MISSING
01 .3          .15   .15   .15         .15   .15                        * MUST EST TURBID
02             120.  1722. 63.6  .48   1200. 108.
02             .15   .15   .15   .15   .15   .15
03             13.   839.  6.3   3.55  235.  7.    43.   35.
03             .15   .15   .15   .15   .15   .15   .15   .15
00
END OF BATHTUB INPUT FILE
```

NOTES:

COLLECTION OF INDEPENDENT RESERVOIRS, AVERAGED, WITH OBSERVED WATER QUALITY.

AVAILABILITY FACTORS (GROUP 4) ARE SET TO CALIBRATED VALUES, SINCE ORTHO P AND INORGANIC N LOADING DATA ARE PROVIDED FOR ALL STREAMS.

DIFFERENT AVERAGING PERIODS, PRECIP, EVAP, STORAGE REFLECTED IN GROUP 9.

SINCE ZMIX IS MISSING FOR SEGMENT 1, PROGRAM ESTIMATES IT AUTOMATICALLY FROM SPECIFIED ZMN (MEAN DEPTH) VALUE USING REGRESSION EQUATION.

OXYGEN DEPLETION CALCULATIONS BYPASSED FOR UNSTRATIFIED SEGMENTS (ZHYP BLANK).

IF CHLOROPHYLL-A OPTION 1 OR 2 IS USED, EITHER A TURBIDITY VALUE (TURB) OR AN OBSERVED CHLA/SEC (CHLOROPHYLL, SECCHI DEPTH) PAIR MUST BE SPECIFIED FOR EACH SEGMENT. IF TURB IS BLANK, PROGRAM CALCULATES TURB FROM CHLA AND SEC. IF TURB AND (CHLA OR SEC) ARE BLANK, ERROR CONDITION IS DETECTED AND PROGRAM TERMINATES. INDEPENDENT ESTIMATES OF TURBIDITY (>= 0.08 1/M) CAN BE DERIVED FROM REGIONAL DATA SETS OR MULTIPLE REGRESSION EQUATION (SEE MANUAL).

BASIC DATA SHEET FOR CASE 8

Collection of reservoirs, spatially averaged with observed water quality data only

(Note: illustrates use of BATHTUB for diagnostic purposes/
interpretation and ranking of pool water quality data
assessment of pool nutrient/chlorophyll relationships
in absence of loading information)

Basic data are same as those given for CASE 7, except tributary inflow concentrations are missing.

```
CASE 8: Collection of Reservoirs, No Mass Balance Data                          **GROUP 1
PO S OUPUT OPTIONS                                                              **GROUP 2
01 1 LIST INPUT CONDITIONS
02 0 HYDRAULICS AND DISPERSION
03 0 GROSS WATER AND MASS BALANCES
04 0 DETAILED BALANCES BY SEGMENT
05 0 BALANCE SUMMARY BY SEGMENT
06 0 COMPARE OBSERVED AND PREDICTED
07 1 DIAGNOSTICS
08 1 SPATIAL PROFILE SUMMARY
09 2 PLOT OBS. AND PREDICTED VALUES
10 0 SENSITIVITY ANALYSIS
00
MO S MODEL OPTIONS                                                              **GROUP 3
01 0 CONSERVATIVE TRACER
02 0 P SEDIMENTATION MODEL     * SET OBS P = PREDICTED
03 0 N SEDIMENTATION MODEL     * SET OBS N = PREDICTED
04 1 CHLOROPHYLL-A MODEL
05 1 SECCHI MODEL
06 1 DISPERSION MODEL
07 1 P CALIBRATION METHOD
08 1 N CALIBRATION METHOD
09 0 ERROR ANALYSIS
00
IV LABEL   ATM    CV     AVAIL                                                  **GROUP 4
01 CONSERV                             * GROUP 4 DATA NOT NEEDED
02 TOTAL P                             * SINCE MASS BALANCES NOT DONE
03 TOTAL N
04 ORTHO P
05 INORG N
00
ID LABEL                      MEAN      CV                                      **GROUP 5
01 AVERAGING PERIOD     YRS   1.                   * VALUES SPECIFIED IN GROUP 9
02 PRECIPITATION     METERS   1.        .2         *
03 EVAPORATION       METERS   1.        .5         *
04 STORAGE INCREASE  METERS   1.                   *
05 FLOW FACTOR                1.
06 DISPERSION FACTOR          1.        .7
07 TOTAL AREA           KM2                        *
08 TOTAL VOLUME         HM3                        *
00
ID T IS NAME            DAREA     FLOW      CV                                  **GROUP 6
01 1  1 Stream A        90.       35.7      .05
02 1  2 Stream B        400.      201.      .05
03 1  3 Stream C        2200.     1157.     .05
00
ID CONS   CV   TP     CV   TN     CV   ORTHOP CV   INORGN CV                    **GROUP 7
01                                                                              * INFLOW CONC
02                                                                              * UNKNOWN
03
00
```

```
IS JO JG NAME              KP    KN    KC    KS    KO    KD                 **GROUP 8
01 00  1 Reservoir 1       1.    1.    1.    1.    1.    1.
02 00  2 Reservoir 2       1.    1.    1.    1.    1.    1.
03 00  3 Reservoir 3       1.    1.    1.    1.    1.    1.
00
IS PERD PREC EVAP STOR LENG  AREA  ZMN   ZMIX  CV    ZHYP  CV            **GROUP 9
01 .42  .4   .8   .1   13.6  6.5   4.5
02 .42  .4   .8   -.3  15.1  5.5   1.6   1.6   .05
03 1.   .7   1.   .4   22.1  10.3  22.4  7.8   .05   15.7  .05
00
ID TURB  CONS  TP    TN    CHLA  SEC   ORGN  PP    HODV  MODV            **GROUP 10
01 .5          35.   882.  13.8        441.  30.
01 .3          .15   .15   .15         .15   .15
02             120.  1722. 63.6  .48   1200. 108.
02             .15   .15   .15   .15   .15   .15
03             13.   839.  6.3   3.55  235.  7.    43.   35.
03             .15   .15   .15   .15   .15   .15   .15   .15
00
```

END OF BATHTUB INPUT FILE

NOTES:

SETUP SIMILAR TO CASE 7, EXCEPT INFLOW CONCENTRATIONS MISSING.

ALTHOUGH NUTRIENT BUDGET CALCULATIONS ARE NOT PERFORMED, TRIBUTARY STREAMS AND FLOWS STILL SPECIFIED FOR CALCULATION OF EFFECTS OF FLUSHING RATE ON CHLOROPHYLL-A PRODUCTION. TRIB STREAMS CAN BE IGNORED IN THIS TYPE OF APPLICATION IF RESERVOIRS HAVE LONG RESIDENCE TIMES (APPROX > 0.04 1/YRS, FLUSHING UNIMPORTANT CHLOROPHYLL CONTROL).

SINCE NUTRIENT BALANCES ARE NOT DONE (P AND N SEDIMENTATION OPTIONS = 0), PROGRAM SETS PREDICTED = OBSERVED NUTRIENT CONCS. PREDICTED CHLOROPHYLL-A AND OTHER RESPONSE VARIABLES ARE BASED UPON OBSERVED NUTRIENT LEVELS.

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