



Eastern Deciduous Forest Biome
IBP Memo Report 72-70

AQUATIC MODELING, DATA ANALYSIS
AND DATA MANAGEMENT AT LAKE GEORGE, NEW YORK

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By

Richard A. Park
Department of Geology

John W. Wilkinson
Operations Research and Statistics Program

Jay A. Bloomfield
Environmental Engineering Curriculum

Robert C. Kohberger
Operations Research and Statistics Program

Claudia Sterling
Environmental Engineering Curriculum

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ABSTRACT

Modeling and data management accomplishments in 1972 are described. These include statistical consulting and the development of abstract and data retrieval systems, as well as phytoplankton-zooplankton, phytoplankton kinetic, zooplankton biomass, zooplankton resource, zooplankton vertical migration, invertebrate benthos, aquatic decomposition, mixing and sedimentation models. The philosophy and programming of the Biome aquatic ecosystem model is also discussed.

KEYWORDS

Data management, management information system, data storage and retrieval, data set abstracts, simulation analysis, statistical analysis, FORTRAN, mathematical models.

ACKNOWLEDGMENTS

Many people have contributed to this year's Lake George modeling effort. Faculty participants have included Frank DiCesare, Assistant Professor of Systems Engineering, Samuel Katz, Professor of Geology, and William A. Wallace, Associate Professor of Public Management. Graduate student participants have included Irving K. Hwang and Mitchell T. Silver. Undergraduate participants included John S. Fisher and James Nagy, who were instrumental in programming the data management systems and models, and Richard Roth, who was in charge of the LUNR programming.

Technical advice and data have been supplied by the associated members of the Lake George Study Group, particularly Nicholas L. Clesceri, site coordinator and James Ferris, research coordinator, Donald B. Aulenbach, Lenore S. Clesceri, S. Kobayashi, Edward J. LaRow, Donald C. McNaught, Ronald Stewart, and Raymond G. Stross.

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INTRODUCTION

The Lake George modeling project has made significant gains in both data management and simulation modeling during the past year. The present state of activity is encouraging: the modeling group is functioning as a well integrated team with clear responsibilities to other Lake George site investigators and Biome headquarters; and a library of interactive abstract and

data retrieval programs and simulation programs has been developed in order to provide the necessary software capabilities. It appears that the modelling effort has reached the point where it can serve as a major force in the synthesis of site and Biome data and information.

The data management system has been greatly improved during the last year; and a powerful, user-oriented time-sharing control system with its own command modules has been developed to serve as the man-machine interface. In addition to aiding other site investigators, this latter system provides an efficient control environment for the programming and evaluation of the ecosystem models. Several new, specialized ecosystem submodels have been developed, existing models have been updated, and the Biome aquatic ecosystem model is being implemented by the modeling group. This Biome model, in turn, will serve as the core for a generalized model to be used in simulations of IBP lakes from around the world; the principal work on this generalized IBP model will also be centered at the Lake George site.

Because of the re-ordering of priorities necessitated by the effort on the Biome model, development of several of the models is ahead of the schedule indicated in the PERT chart from last year's report (Park and Wilkinson, 1971) and proposal; other models have been deferred until a later date.

DATA ANALYSIS AND MANAGEMENT

Statistical Consulting

In conjunction with Dr. Raymond G. Stross, an extensive analysis was performed on hourly P_{MAX} values for the years 1969 to 1971. The factorial experiment was studied to determine the statistically significant factors influencing the spatial and temporal variability of P_{MAX} values. The results of this analysis will be available shortly in memo report form under the senior authorship of Dr. Stross.

An experimental design was formulated for the chemistry laboratory of the Fresh Water Institute to assess the variability of laboratory tests of phosphorus and nitrogen. The design will enable the laboratory to differentiate between variability of the tests with respect to technicians and concentrations as well as the inherent variability of the tests themselves. The results of the experiment will enable one to place confidence limits upon the test results found in the laboratory.

With Dr. Lenore Clesceri, the growth rate of microbial populations was estimated. Examination of the data suggests that incubation longer than 1.5 hours allows exponential growth, which is not the growth rate desired to be measured. For incubations under 1.5 hours, the relationship between the microbial biomass and time is linear, implying a constant growth rate. The desired incubation time was therefore set under 1.5 hours. To assist in the determination of this growth rate, a simple interactive linear regression program was written. The program is written in

FORTTRAN IV and designed to operate under the ALPHA teleprocessing system. A prior estimate of the variance is able to be entered and pooled with the estimate of variance determined from the regression data. This is an important feature because, although only about four points are available at one time to be used to determine the regression equation for growth rate, many samples of such sets of points are available. With each sample of four, an estimator of the variance is available with two degrees of freedom. Using the pooled estimate of the variance, the regression program permits the placement of reasonably precise confidence limits on the growth rate.

Data Management

To assist investigators at Lake George and to facilitate the transfer of information to the Biome Information Center, a data management system has been developed. ADLIB - Abstract Data Librarian is a bibliographic retrieval system which directly ties to FIND - Freshwater Institute Numeric Database. ADLIB is a series of programs which allow investigators to examine data set abstracts to determine which data are available on the database. FIND is a series of programs that store and retrieve the actual data. These systems are described in IBP Memo Report #72-61 (FIND) and IBP Memo Report #72-62 (ADLIB).

Code sheets for transcription of data to computer-compatible form have been designed and printed for chemistry and secondary production. Data format for decomposition has been designed using standard computer coding sheets.

Several specialized programs have been written. An analysis program to determine productivity and average productivity over the water column has been written for Dr. Donald McNaught's work in secondary production. Two plotting programs have been written so that day of the year and/or time of day versus an independent variable may be plotted automatically by the computer.

Numerous data sets have been keypunched and entered into the FIND system. These are in such form that they can be transmitted to the Biome Information Center as soon as data set abstracts are completed by the respective principal investigators.

Utilization of External Data Sets

The purpose of this effort was to make available data on the Lake George Basin contained in the New York State Land Use and Natural Resources Inventory (LUNR), and its con-commitant geological and soils file. In addition, data from the first three counts of the census on the basin were added to the file.

To assist in utilization, programs for listing and mapping the data (DATALIST I and PLANMAP II and III) were modified for use on the Rensselaer's IBM 360/50 computer system. As a result, we can access land-use data for any portion of the drainage basin, and maps (Figure 1) can be prepared to aid in the interpretation.

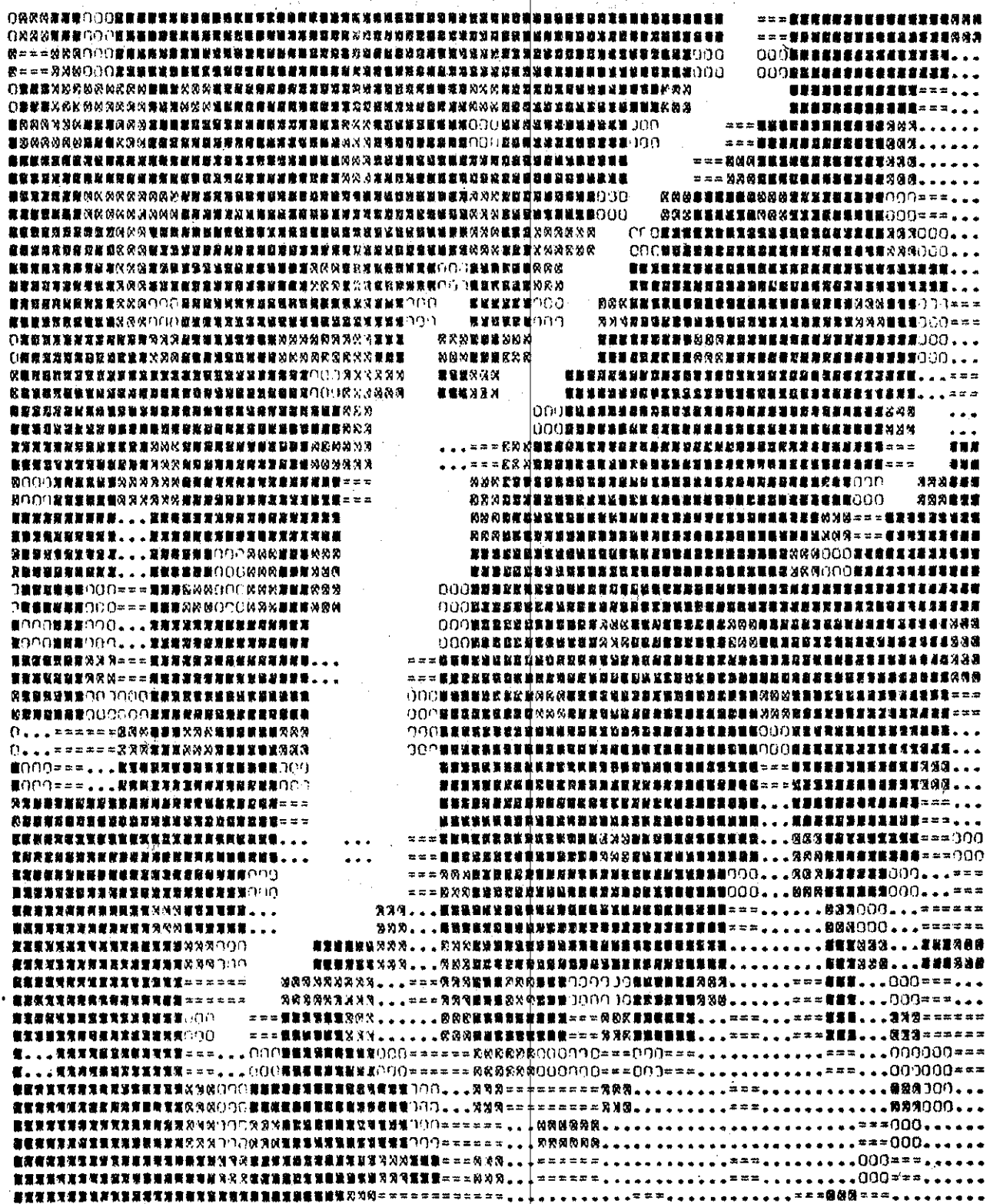


FIGURE 1 - MAP OF LAKE GEORGE NATURAL FORESTS PREPARED FROM LUNR DATA. INTENSITY OF OVERPRINTING IS PROPORTIONAL TO PERCENTAGE OF FOREST COVER.

MODELING

Modeling Status

During 1971 and 1972, the emphasis in ecological simulation shifted from system identification (conceptual modeling) to calibration of the eight mathematical models developed at the Lake George site. The modeling effort gained impetus during 1972 with the availability of ecological data on primary productivity, secondary productivity, decomposition, climatology and water chemistry.

Under the joint efforts of members of the Lake George and Lake Wingra sites and the Oak Ridge modeling staff, an aquatic ecosystem model (CLEAN) was developed utilizing process and trophic-level models developed at the two sites. CLEAN is essentially a mass balance for biomass in a one-meter square water column and the underlying sediments in open-water region of a freshwater lake.

Work progressed at Lake George on three specialized models: PHYKIN, a model of phytoplankton kinetics; ZOORES, a population dynamics model for herbivorous zooplankton; and VERMI, a model of zooplankton vertical migration. A model for sedimentation (SEDMNT) is also under development.

Programming Considerations

CLEAN and allied models employ modular programming. This method consists of creating a separate subprogram function or module for each process (such as respiration). Modular programming allows a main control program to select the subprograms required for a specific model. A user may choose to execute a specific model or link any combination of the models for primary produc-

tivity, secondary productivity, predation and decomposition.

Programming at the Lake George site is done on interactive time-sharing systems in FORTRAN. All Lake George models are available under ALPHA on Rensselaer's IBM 360 Model 50 in FORTRAN IV. In addition, CLEAN is available in FORTRAN V on the State University of New York at Albany's UNIVAC 1108. FORTRAN was chosen for its universality and because it generates efficient object code, a necessity when running large-scale simulations.

All calculations are specified with extended precision in an attempt to minimize truncation errors. All variables and parameters are "passed" in common blocks for ease in coding and to conserve core memory. Model parameters are saved from one run to the next on magnetic disk. The FORTRAN namelist feature is used for editing parameters and initial conditions.

Comprehensive Lake Ecosystem Analyzer (CLEAN)

CLEAN is an integrated set of biomass models for pelagic and benthic organisms in a one-meter square water column and the underlying sediments. CLEAN presently predicts total biomass over the entire column and does not consider vertical mixing (see "Mixing Model"). The model consists of twenty coupled differential equations. Ecosystem components that are represented in the model include macrophytes, nanno- and net phytoplankton, herbivorous copepods and cladocera, predatory zooplankton, bluegill-like fish, bass-like fish, carp-like fish, detritus-feeding benthos, pelagic decomposers, particulate organic matter, and dissolved organic matter (Figure 2). Allowances were made, when programming CLEAN,

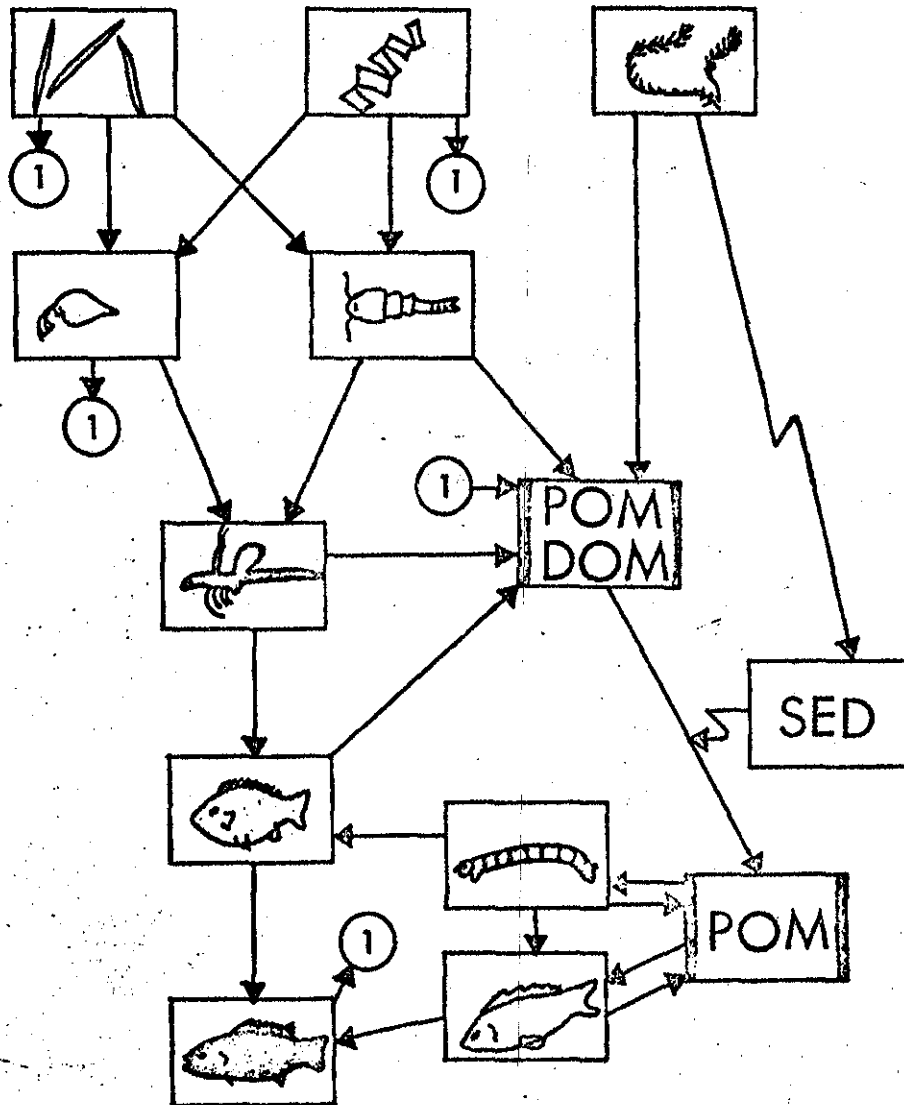


FIGURE 2 - ECOSYSTEM COMPONENTS FORMING SUBMODELS IN CLEAN, THE BIOME AQUATIC ECOSYSTEM MODEL. DECOMPOSERS ARE ASSOCIATED WITH BOTH PARTICULATE ORGANIC MATTER (POM) AND DISSOLVED ORGANIC MATTER (DOM).

to accommodate the addition of several more groups (rotifers, epiphytes, non-rooted macrophytes, protozoa, mollusks and tubificids). Figure 3 is a transfer matrix for CLEAN. Figure 4 is the programming flowchart used in designing this model.

As of this time the CLEAN program is debugged, but the lack of certain physiological and ecologic parameters as well as comprehensive data on production of several bionomic groups has hindered full calibration of the model. Adequate data are available for the driving variables in the model for both Lake Wingra and Lake George; these variables are incident solar radiation, mean water temperature, mean ammonia, nitrate, and orthophosphate concentrations and the relative inputs of particulate and dissolved organic matter. CLEAN is programmed to permit the addition of driving variables such as dissolved oxygen, silica and carbon dioxide. The pH of the sediments has recently been considered as an additional driving variable.

As a result of discussions held at the IBP/Freshwater Productivity Synthesis Conference in Reading, England, CLEAN will serve as the core of a generalized model that will be validated with data from the principal IBP lake and pond sites in the other U.S./IBP biomes and foreign countries.

A detailed documentation of the design and implementation of CLEAN will be issued as a memo report as soon as content validation is reasonably complete.

Phytoplankton-Zooplankton Model (PHYHZ)

An earlier version of PHYHZ was calibrated for the south end of Lake George for the year 1970 (Memo Report 71-117). Since then

TO FROM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	*		+	+											+	+				
2		*	+	+											+	+				
3			*		+		+	+							+	+				
4				*	+		+	+							+	+				
5					*		+	+							+	+				
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17							+													+
18							+													+
19							+													+
20																				+
0	+	+																		+

+ POSITIVE FLUX

BIOMASS KEY

- 1 NANNOPHYTOPLANKTON
- 2 NET PHYTOPLANKTON
- 3 HERBIVOROUS CLADOCERANS
- 4 HERBIVOROUS COPEPODS
- 5 PREDATORY ZOOPLANKTON
- 6 BENTHIC INVERTEBRATES
- 7 BLUEGILL-LIKE FISH
- 8 BASS-LIKE FISH
- 9 CARP-LIKE FISH
- 10 MACROPHYTE LEAVES
- 11 MACROPHYTE ROOTS
- 12 MACROPHYTE CARBOHYDRATE POOL
- 13 PELAGIC HYDROL. DECOMPOSERS
- 14 PELAGIC NON-HYD. DECOMPOSERS
- 15 PELAGIC P.O.M.
- 16 PELAGIC D.O.M.
- 17 SEDIMENT HYDROL. DECOMPOSERS
- 18 SEDIMENT NON-HYD. DECOMPOSERS
- 19 SEDIMENT P.O.M.
- 20 SEDIMENT D.O.M.
- 0 EXTERNAL POOLS (CO₂, ETC.)

FIGURE 3 - TRANSFER MATRIX FOR CLEAN

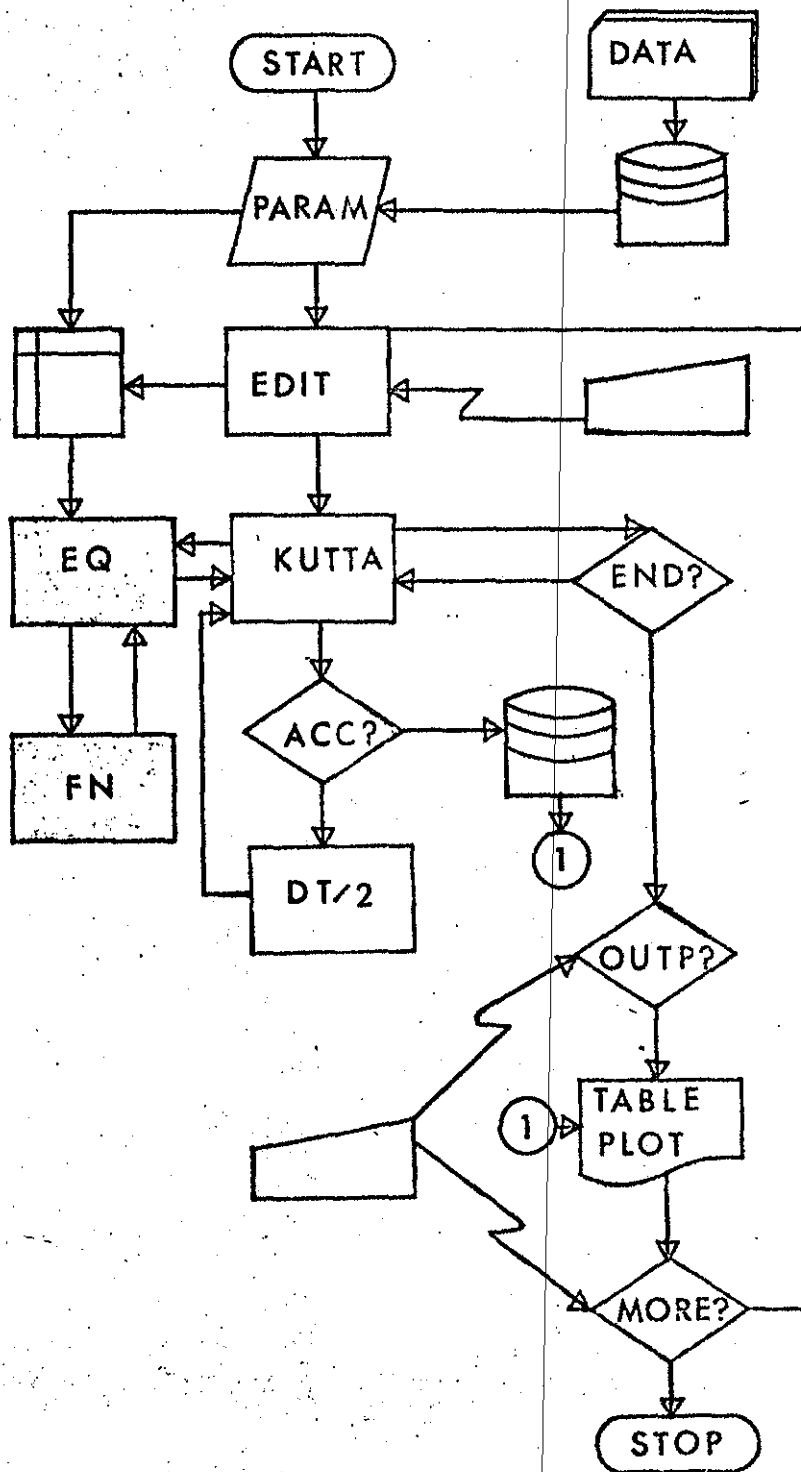


FIGURE 4 - PROGRAMMING FLOWCHART FOR CLEAN

attempts have been made to determine the concurrent validity and predictive capabilities of the revised model. The results of an attempt to validate PHYHZ for the oligotrophic north end of Lake George for the year 1970 were encouraging in that the time of the spring phytoplankton peak predicted by the model was off from the actual peak by only several days.

A number of simple perturbations were run in order to evaluate the sensitivity of the model to the various driving variables. Perturbations included halving and doubling the nitrate concentrations, doubling incident solar radiation (Figure 5), and halving and doubling the temperature for the year 1970. The results could not be used for predictive purposes; but, when compared with the calibrated model (Figure 6), they did give insight into the behavior of the model.

The revisions made in this model during the past year include:

- 1) The adaptation of a more realistic herbivorous zooplankton model (McNaught and others, 1972) that considers cladoceran and copepods separately
- 2) The addition of predatory zooplankton as a control variable
- 3) The separation of phytoplankton by size into nanno- and net phytoplankton
- 4) The consideration of total soluble nitrogen as a driving variable, rather than soluble nitrate and ammonia separately.

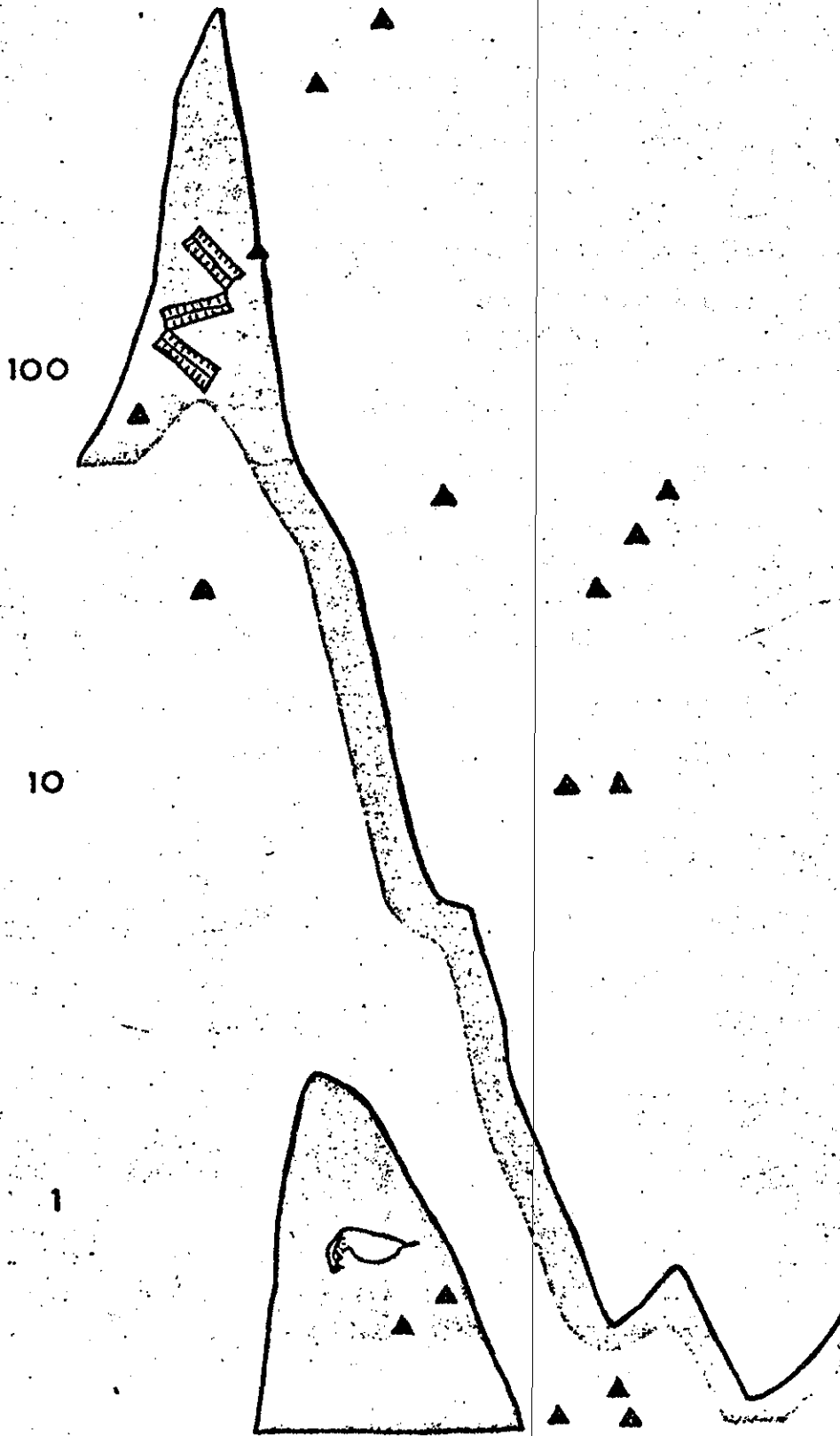
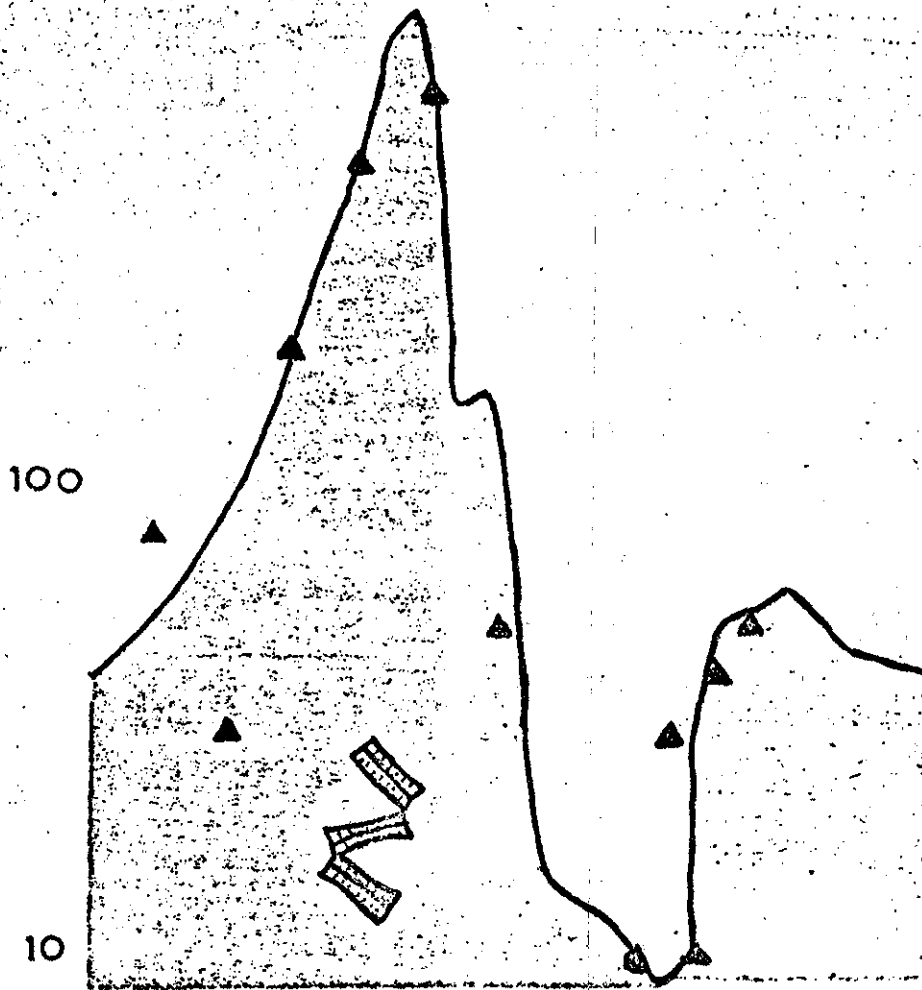
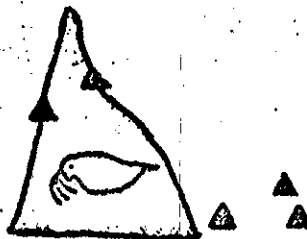


FIGURE 5 - PHYHZ WITH INCIDENT SOLAR RADIATION DOUBLED FOR THE YEAR 1970. TRIANGLES INDICATE OBSERVATIONS AND THE LINES REPRESENT PREDICTED VALUES IN MG/L



1

1



365

FIGURE 6 - PHYHIZ MODEL CALIBRATION, LEGEND SAME AS IN FIGURE 5

Zooplankton Population Resource Model (ZOORES)

A model for the population dynamics of a pelagic zooplankton community was developed by investigators from the Lake George site and the Biome modeling group at Oak Ridge. The implementation of this model is discussed by McNaught and others (1972). The basic premise of ZOORES is that the availability of food is a primary factor in determining the birth rates of freshwater copepods and cladocerans. Initially, two foods, nanno- and net phytoplankton and three zooplankton genera, Daphnia, Diaptomus and Bosmina, were considered. Presently ZOORES also includes detritus and detritivorous zooplankton.

The model was designed primarily to provide insight into the problem of describing competition by several consumers for several foods. The data being used in this simulation are primary and secondary productivity data for Lake George.

Aquatic Decomposition (DECOMP)

Research on aquatic decomposition at Lake George was advanced significantly with the development of a mathematical model in cooperation with the Biome modeling staff. The development of a mass-cycling model has given new direction and impetus to the collection of decomposition data. The model is fully operational on the Rensselaer 360/50. However, initial simulations indicate a need for more complete data on in situ hydrolysis and uptake rates. A detailed report of the simulation of aquatic decomposition can be found in Clesceri and others (1972).

Benthic Invertebrates (BENTHO)

A general model for benthic invertebrates was constructed by

members of the Lake George site and the Biome staff from Oak Ridge in early 1972. The model is an adaptation of the general consumer model of O'Neill and others (1971). The organisms considered in this initial version are chironomids, tubificids, ostracods, bivalves, gastropods and gammarids.

The model has been implemented for chironomids and concurrent studies of chironomid physiology at Lake George should provide parameter estimates for feeding and respiration rates shortly.

Phytoplankton Kinetics (PHYKIN)

A model for phytoplankton kinetics was developed to facilitate study of circadian rhythms in phytoplankton. The driving variables in the model are solar radiation, water temperature and the ambient concentrations of inorganic carbon, nitrogen, phosphorus and silica. State variables in the model consist of fixed biomass (such as the cell wall and nucleic materials) and free biomass such as the cell internal pools of nitrogen, phosphorus and organic carbon (sugars and oils). A sinusoidal component is included in the terms for nutrient uptake in order to simulate rhythmicity. A separate report on the simulation of phytoplankton kinetics is in preparation.

Zooplankton Biomass Modeling (ZOO)

A mass balance model for zooplankton was developed and implemented during 1972. Present efforts include sensitivity analysis of the various parameters in the terms for feeding and

the terms for feeding and respiration. The term for zooplankton ingestion is

$$C_j = C_{m_j} \gamma_j \left\{ \frac{\sum_{i=1}^n W_{ij} B_i}{B_j + \sum_{i=1}^n W_{ij} B_i} \right\} B_j \quad (1)$$

C_j = consumption rate of resources by the j th zooplankter (MG-Biomass/ M^2 Day)

$C_{m_j}(T)$ = maximum consumption rate as a function of water temperature (1/Day)

γ_j = a correction term for zooplankton population dynamics and behavior

W_{ij} = consumption coefficient for the j th zooplankter feeding on the i th resource

B_i = Biomass of the i th resource (MG Biomass/ M^2)

B_j = Biomass of the j th zooplankter (MG Biomass/ M^2)

Figure 7 is a 3-dimensional plot of consumption rate, C_j , versus $\sum_{i=1}^n W_{ij} B_i$ and B_j . This plot was useful in estimating the

time of the peak zooplankton consumption rate. If

$$B_j \gg \sum_{i=1}^n W_{ij} B_i \quad (2)$$

$$\text{then } C_j \propto \sum_{i=1}^n W_{ij} B_i \quad (3)$$

and the time of zooplankton peak consumption approaches the time of the peak resource concentrations. A reasonable assumption was

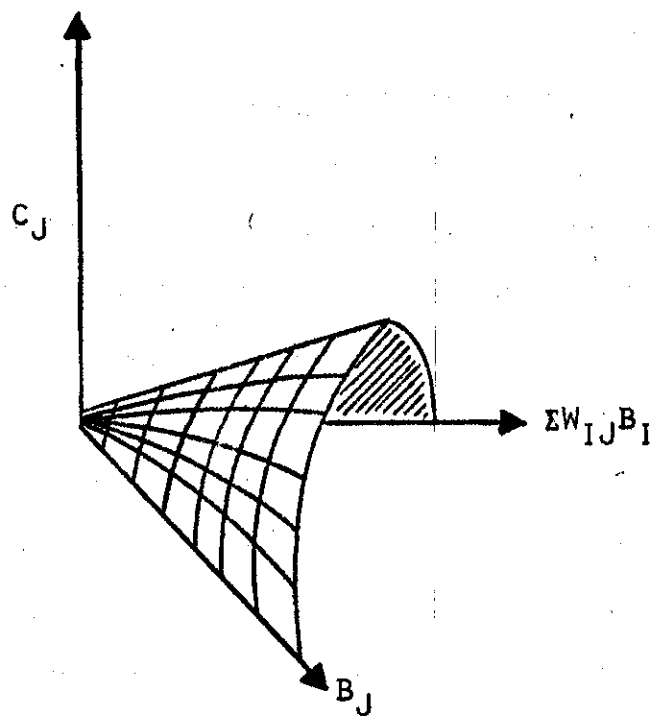


FIGURE 7 - THE SURFACE C_{IJ} GENERATED BY $\Sigma W_{IJ} B_I$ AND B_J

made that resource peaks either overlap or are sufficiently widely spaced to allow individual analysis. If

$$B_j \ll \sum_{i=1}^n W_{ij} B_i. \quad (4)$$

Then $C_j \propto B_j$ (5)

and the time of peak consumption approaches the time when the zooplankton biomass peak occurs. Since the time of peak consumption is an important factor in determining the lag time between prey and predator peaks, the relationships in equations (3) and (5) are quite significant. Figure 8 graphically describes these relationships.

McNaught and others (1972) describe in detail the design and implementation of ZOO. This report also includes sections on sensitivity analysis and on the progress in obtaining realistic feeding and respiration rates for herbivorous and predatory zooplankton.

Zooplankton Vertical Migration (VERMI)

One of the more interesting problems in limnology has been that of zooplankton vertical migration on a diurnal basis. Several explanations have been offered to describe the non-random distributions of zooplankton with depth at Lake George. Experimentation has begun on a simulation model for zooplankton vertical migration. The model consists of non-linear, one-dimensional partial differential equations for phytoplankton and zooplankton. All the equations are of the form of a general mass

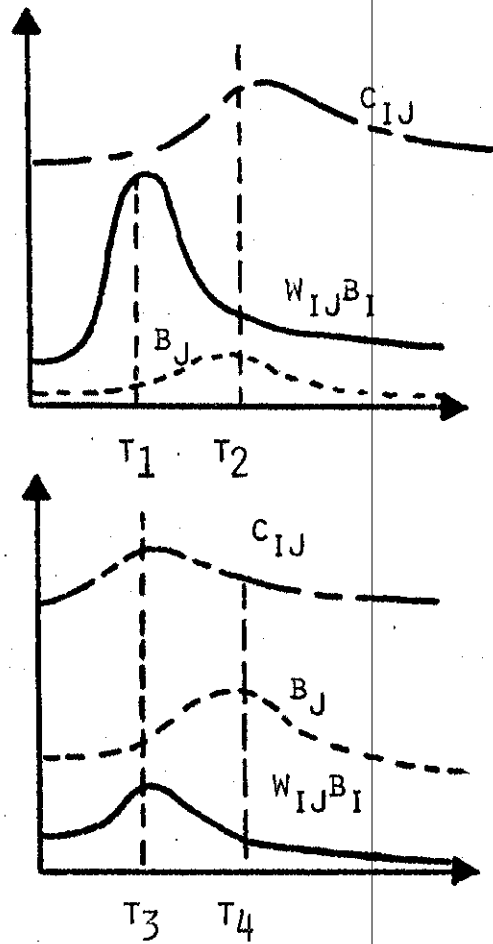


FIGURE 8 - COMPARISON OF TIMES OF PEAK PREDATOR CONSUMPTION
UNDER CONTRASTING PREDATOR-PREY RATIOS

balance:

$$\frac{\partial B_i}{\partial t} = - \frac{\partial}{\partial z} (q_{Bi}) + \sigma_{Bi} \quad (1)$$

where t = time

z = depth

B_i = biomass of the i th group

q_{Bi} = biomass flux of the i th group

σ_{Bi} = source or sink term for the i th biomass group

Assumptions were made that phytoplankton were nonmotile and that mixing could be ignored initially. Hence for phytoplankton

$$q_{Bi} = 0 \quad (2)$$

The rate of change of phytoplankton at any point was considered only as production minus grazing losses, where production was considered specifically as a function of light. Then:

$$\sigma_{Bi} = [F(I(z,t)) - k_G B_j] B_i \quad (3)$$

k_G = grazing rate constant

B_j = biomass of j th zooplankter

$I(z,t)$ = solar radiation as a function of time and depth.

For zooplankton, on an hourly basis, the growth rate of the population was assumed to be:

$$\sigma_{Bj} = k_c B_i B_j \quad (4)$$

k_c = consumption rate.

The flux rate was assumed to have three components, one for random motility:

$$q_{1j} = -\mu_j \frac{\partial B_j}{\partial z} \quad (5)$$

one component due to light:

$$q_{2j} = -\alpha_j \frac{\partial I}{\partial z} B_j \quad (6)$$

and one component due to phytoplankton concentration gradients:

$$q_{3j} = \gamma_j \frac{\partial B_i}{\partial z} B_j \quad (7)$$

Thus the equations for phytoplankton and zooplankton are:

$$\frac{\partial B_i}{\partial t} = [F(I(z,t)) - k_G B_j] B_i \quad (8)$$

$$\begin{aligned} \frac{\partial B_j}{\partial t} = - \frac{\partial}{\partial z} & \left(-\mu_j \cdot \frac{\partial B_j}{\partial z} - \alpha_j \cdot \frac{\partial I}{\partial z} \cdot B_j + \gamma_j \cdot \frac{\partial B_i}{\partial z} \cdot B_j \right) \\ & + k_c B_i B_j \end{aligned} \quad (9)$$

where α_j is probably a function of light and γ_j is probably a function of substrate concentration. Equations (8) and (9) thus represent a complex simulation model for zooplankton vertical migration. At this time, much thought must be given as to whether this system of partial differential equations has a realistic solution that is ecologically meaningful.

Mixing Model

This model simulates mixing action of particulate matter in a non-flowing body of water subject to variable wind, temperature, solar radiation, etc., over a period of one year.

The model is derived using a mass balance equation. This approach has been used by Varga and Falls (1972) for modeling dissolved oxygen dynamics.

The standard form is:

$$\frac{\partial B}{\partial t} = - \nabla q_u + \sigma_B$$

where

t = time

B = mass of particulate matter

$$\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$$

x, y = horizontal directions

z = vertical direction

q_B = mass flux

σ_B = sinks or sources

$\frac{\partial B}{\partial t}$ = mass change with time

We have chosen to simplify analysis by treating only motion in the vertical, or z , direction, thus reducing the general equation to:

$$\frac{\partial B}{\partial t} = - \frac{\partial q_B}{\partial z} + \sigma_B$$

The q_B term is assumed to have two components, one for thermal structure and fluid motion:

$$q_1 = - A \frac{\partial B}{\partial z}$$

where A is an undetermined lumped coefficient which is a function of atmospheric variables. The second coefficient represents diffusion and is treated in the sense of diffusion of heat:

$$q_2 = C \cdot B_1$$

where C is an undetermined lumped coefficient, a function of wind, temperature and water viscosity, and therefore of t and z.

σ_B represents a growth term:

$$\sigma_B = (P-R-E-U-M)B = D$$

where P = gross photosynthesis
 R = respiration
 E = grazing
 U = excretion
 M = non-grazing mortality
 B = biomass of phytoplankton

and is a function of solar radiation, nutrient concentration, temperature, depth and mass, and therefore of t, z and B.

Thus we have:

$$\frac{\partial B}{\partial t} = - \frac{\partial}{\partial z} \left(-A \cdot \frac{\partial B}{\partial z} + C \cdot B \right) + D. \quad (1)$$

In addition, we probably need a form of the Navier-Stokes equation in order to accurately specify fluid motion; however, such an equation is not included because an empirical approach to density stratification and fluid motion seems to be more productive at this time. Therefore, differentiating, rearranging and lumping coefficients, we have:

$$\begin{aligned}
\frac{\partial B}{\partial t} &= \frac{\partial A}{\partial z} \frac{\partial B}{\partial z} + A \frac{\partial^2 B}{\partial z^2} - \frac{\partial C}{\partial t} \cdot B - C \frac{\partial B}{\partial z} + D \\
&= A \frac{\partial^2 B}{\partial z^2} - \left(-\frac{\partial A}{\partial z} + C \right) \frac{\partial B}{\partial z} - \frac{\partial C}{\partial t} \cdot B + D \\
&= A \frac{\partial^2 B}{\partial z^2} - F \frac{\partial B}{\partial z} + N
\end{aligned} \tag{2}$$

$$A = A(t, z)$$

$$F = F(t, z)$$

$$N = N(t, z, B).$$

Earlier in the year we assumed that A and C were constants. Thus for numerical analysis the following equation was used:

$$\frac{\partial B}{\partial t} = A \frac{\partial^2 B}{\partial z^2} - C \frac{\partial B}{\partial z} + D \tag{1a}$$

which is derived from (1) by carrying out the differentiation by assuming A and C independent of z. In addition it was assumed that motion occurs only in the vertical direction, that the thermocline is constant at 15 meters, and that mixing only occurs in the upper 15 meters.

We are now expanding the model to treat A, C, and D as variable coefficients, where A and C are functions of time and depth, and D is a function of time, depth and mass. This makes the formulation more difficult but more accurate. For numerical analysis we then use (2). This is a second order, non-linear partial differential equation with variable coefficients. Two difference schemes have been worked out for approximating this equation for

use in the computer: a simple implicit scheme and a predictor-corrector scheme. These are currently being checked out for mathematical validity.

In addition we are also deriving an equation for mixing below the thermocline. This uses equation (1) but the coefficients A' and C' are different than for mixing above the thermocline. We are also beginning work to treat mixing between the two layers.

Determination of D , the growth term, already has been done in a separate model, PHYHZ (see "Phytoplankton - Zooplankton Model"). This has already helped in development of the mixing model.

Coefficients A and C are functions of wind, water, temperature, precipitation, evaporation, duration of atmospheric conditions, and, for C , water viscosity. To determine A and C we must first determine all these as functions of t and z , which will be done from empirical data. For an initial approximation we tried to break time and depth into blocks where A and C would be fairly constant. From observation, we have rough graphs (Figures 9a and 9b). The ordinate, $|A|$, is the degree of turbulent mixing at a given z level, horizontal positions fixed. Since mixing alternates constantly from rising to falling motion, sometimes within minutes, we have used $|A|$ to show simply the magnitude of mixing. This graph indicates that the greatest degree of mixing occurs during turnover, that summer mixing is much less than that of turnover periods but greater than that of winter, and also that the same pattern is evident for both layers of the lake, the overall magnitudes for the hypolimnion being less than for the epilimnion. From this it seems that we can divide the range of A into two depth regions with four time regions each, using as

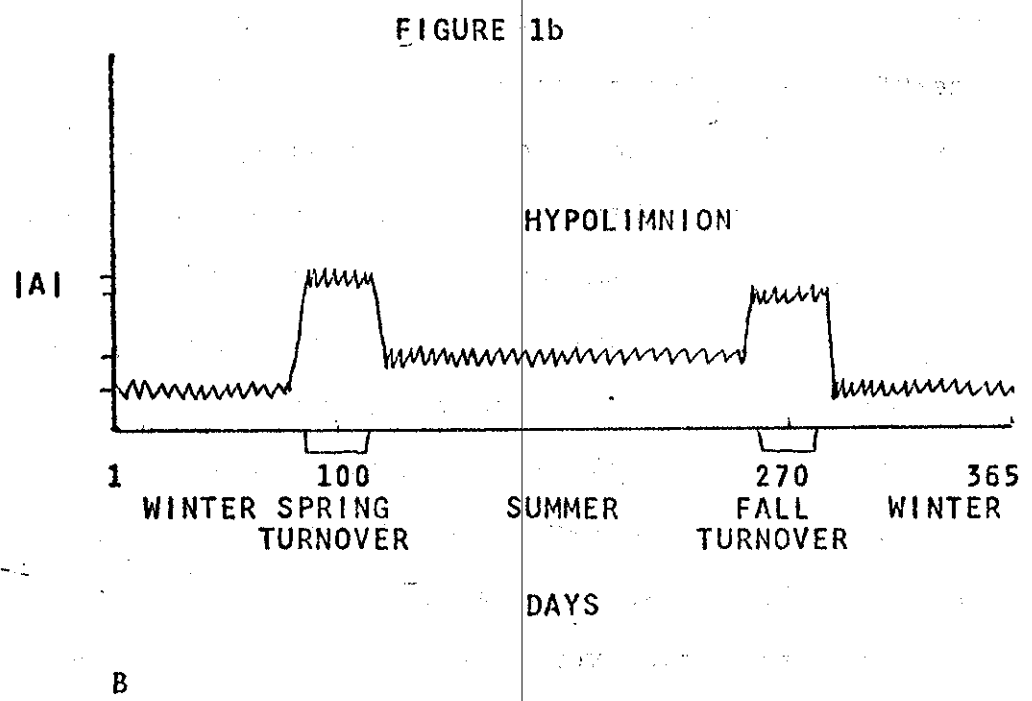
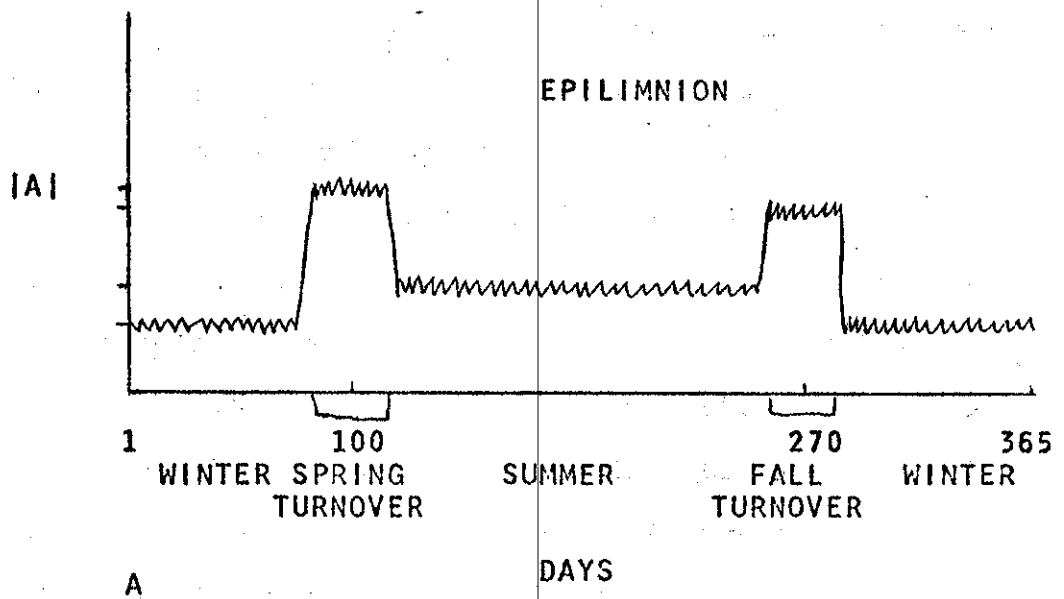


FIGURE 9 - AMPLITUDE OF TURBULENT MIXING VS. TIME

magnitude of A for each region the mean absolute value of A. Thus we can initially approximate A by some average constant for each natural time and depth region: epilimnion and hypolimnion for winter, spring turnover, summer and fall turnover.

Likewise, Figure 10 expresses the relationships for C. The sinking or sedimentation coefficient, C, is largely dependent upon water viscosity, which is inversely proportional to temperature. In warmer weather viscosity is less and sinking less hindered. The curve for the hypolimnion is lower and has a lesser range because the mean temperature is lower and the summer warming is less. Thus, we can also approximate C in eight different regions: epilimnion and hypolimnion for winter, spring, summer and fall. Here the magnitude for winter and summer are expressed as constants; and the spring and fall values are linear with time.

At present we particularly need data in order to derive accurate functionalities for A and C.

Sedimentation (SEDMNT)

It was necessary to incorporate a sedimentation model into CLEAN in order to account for the settling out and re-suspension of particulate organic matter. In effect, this model calculates the minimum diameter of the bottom sediment for the observed wave height and periodicity. The basic equation, based on an algorithm used by Fox (1967), is:

$$s = \frac{.022 V^2 + \sqrt{(.022 V^2)^2 + 329.96V}}{494.94} \quad (1)$$

s = sediment diameter in mm

V = velocity

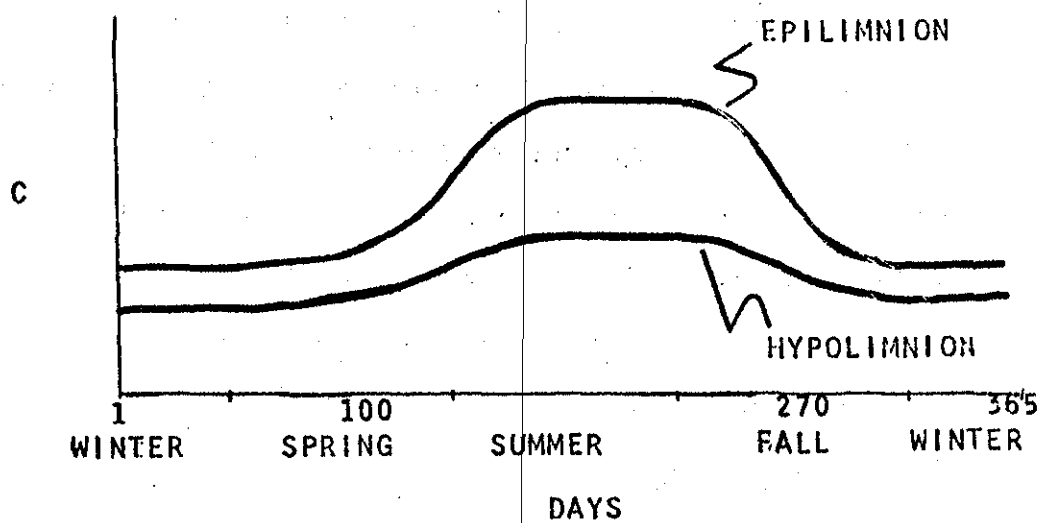


FIGURE 10 - SPEED OF SINKING VS. TIME

$$V = 707.0 V_o \quad (2)$$

V_o = orbital velocity

$$V_o = \frac{w/2 \cdot 2\pi/p}{\sinh(N \cdot z)} \quad (3)$$

w = actual wave height

p = wave period.

If the predicted sediment size is greater than that of fine silt-sized particles (.0625 mm) then the bottom surface organic sediment is transferred to the water column. If the predicted sediment size is less than that of silt then sedimentation proceeds as a function of sinking rate and water-column mixing (see "Mixing Model"). If macrophytes occur (or are predicted as the simulation proceeds) then wave agitation is symbolically "damped out" and re-suspension is not permitted.

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