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# GREAT LAKES ENVIRONMENTAL PLANNING USING LIMNOLOGICAL SYSTEMS ANALYSIS: MODEL SPECIFICATIONS

by

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## DISCLAIMER

# FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise, and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment requires a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The Office of Research and Development contributes to this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

This report assesses the technical feasibility and economic practicality of developing mathematical models to assist in defining and making selections among alternative management strategies and structural solutions proposed for solving water resource problems of the Great Lakes. The deliberate decision-making process reported is a milestone in preapplication analysis of modeling for natural resource management purposes.

## ABSTRACT

The report documents the deliberate decision making process used by the Great Lakes Basin Commission in concluding that rational modeling methodologies could be used to evaluate the effect of different planning alternatives on the Great Lakes and that planning for specific problems affecting the Great Lakes system can be technically and economically supported through mathematical modeling and systems analysis. It assesses the technical and economical feasibility of developing mathematical models to assist in making selections from among alternative management strategies and structural solutions proposed for solving water resource problems of the Great Lakes. The study reviews, evaluates and categorized present and future water resources problems, presently available data, problem-oriented mathematical models and the state of models and model synthesis for large lakes. A demonstration modeling framework for planning is developed and applied to western Lake Erie and the Great Lakes system. The report evaluates four widely ranging alternatives for future modeling efforts in the Great Lakes and recommends the modeling level most feasible to answer planning questions on scales ranging from the Great Lakes to regional areas. Also discussed is a proposed Commission study which will apply limnological systems analysis to the planning process.

The report consists of three volumes:

a. Summary
b. Phase I - Preliminary Model Design
c. Model Specifications

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# SECTION I

# SPECIFICATION FOR MAIN LIMNOLOGICAL SYSTEMS ANALYSIS PROGRAMS

## Background

A study has been completed and a final report issued on the technical feasibility and the economic practicality of applying a Limnological Systems Analysis (LSA) to water resources problems in the Great Lakes.(1) Specific attention was directed to an evaluation of the state of the art of modeling as it applied to interrelated water resource problems. The overall purpose of the study was to indicate the degree of understanding of limnological phenomena, as affected by both nature and man's activities, and to evaluate the degree to which these processes can be expressed in a valid mathematical form within a system analysis framework.

The overall methodology followed in the Limnological Systems Analysis of the Great Lakes is presented in Figure 1. Two parallel paths were followed. The first line of analysis evaluated the present and future water resource problems and water use interferences with their associated water resource variables. The second line of analysis evaluated presently available data, problem oriented mathematical models, and present state of the art of models and model building which are useful for a Limnological Systems Analysis. The two lines of analysis were synthesized into a problem and model ranking of priority from which feasibility recommendations were drawn. A demonstration modeling framework was constructed in order to illustrate the output of a Limnological Systems Analysis in several problem contexts.

Water resource problems in the Great Lakes were identified and grouped into seven problem categories as follows:

1. Monthly Lake Water Levels and Flows
2. Erosion, Sediment
3. Ice
4. Toxic and Harmful Substances
5. Water Quality
6. Eutrophication, Fishery
7. Public Health

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(1) Hydroscience, Inc., "Limnological Systems Analysis of the Great Lakes - Phase I," (1973).

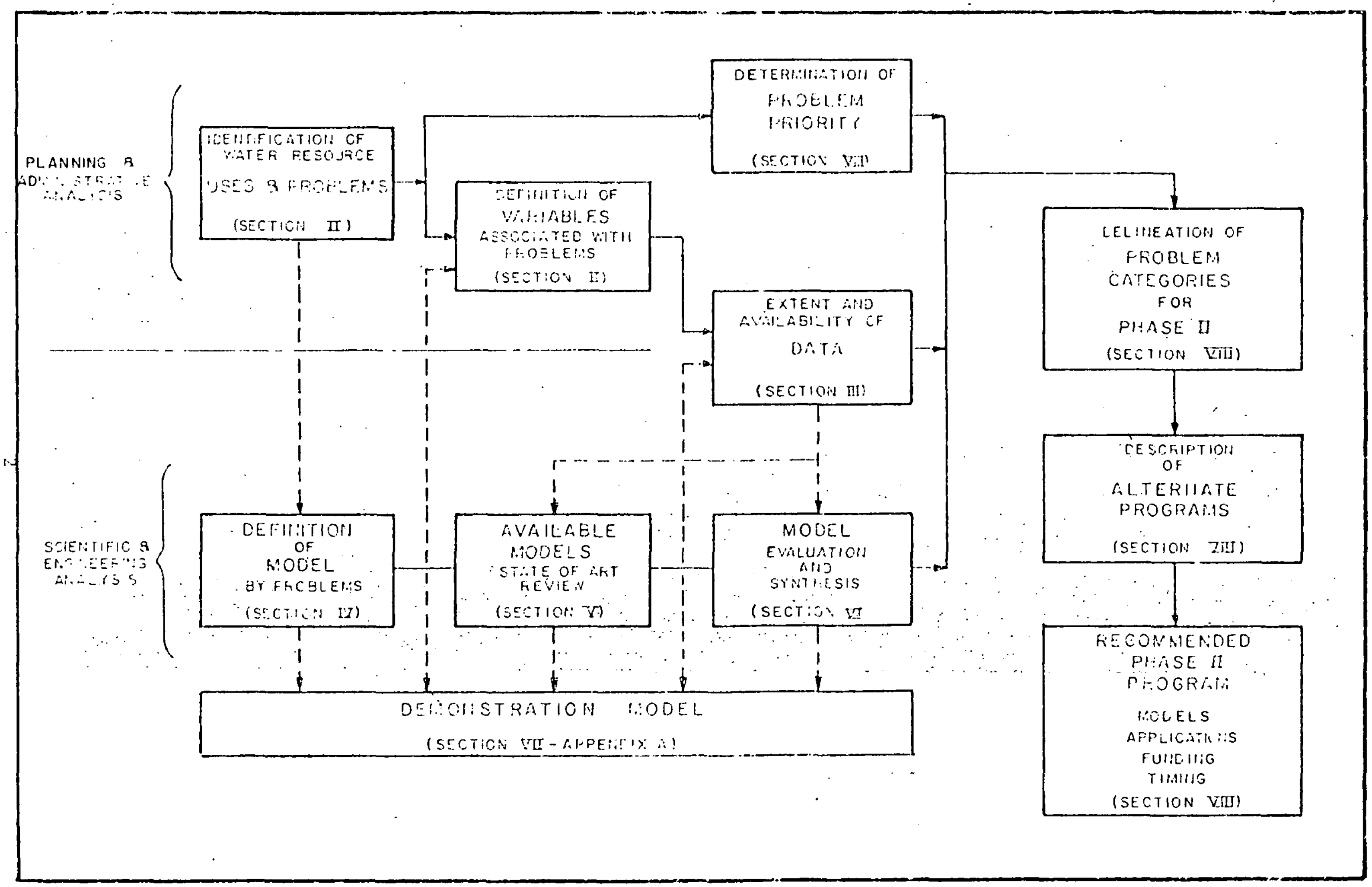


FIGURE I

METHODOLOGY FOR GREAT LAKES LIMNOLOGICAL SYSTEMS ANALYSIS

For each problem category a detailed review was made of associated water uses and water variables to provide the link to the available models.

It was concluded that of the seven problem areas, the ice category and a portion of the public health category (near shore pathogen problems) are generally not Type II planning problems. The Great Lakes problems associated with (a) lake levels and (b) erosion and sediment are being analyzed and are adequately modelled in various ways for present needs. The ranking of the four remaining Type II planning problems (which was subjectively established) is as follows:

1. Eutrophication
2. Water Quality
3. Public Health (regional and lake wide scale)
4. Concentrations of toxic or harmful substances

The formal modeling structure proposed for Phase II is composed of a broad scale framework consisting of seven integrated modeling subsystems: water balance, lake circulation and mixing, chemical, eutrophication, dissolved oxygen, pathogens, and ecological, as shown in Figure 2.

Alternate Limnological Systems Analysis programs were evaluated (1973) in order to explore varying levels of effort and cost for a Phase II study.

1. Level 1: This alternate is estimated to cost 0.7 million with a two year completion time and represents the lowest level at which a meaningful Limnological Systems Analysis can be carried out.

2. Level 2: This level is estimated at a $2 million cost with a three year completion time and represents a favorable balance between problem contexts that can be approached rapidly, given the present modeling status, and those problem categories which have high priority but for which modeling frameworks must be significantly advanced.

3. Level 3: The cost of this level is estimated at $3.9 million with a three year completion time and represents a more intensive effort than Level 2. Level 3 funding is felt to be the maximum amount that can be prudently spent for a Phase II study of the use of a Limnological Systems Analysis for the Great Lakes.

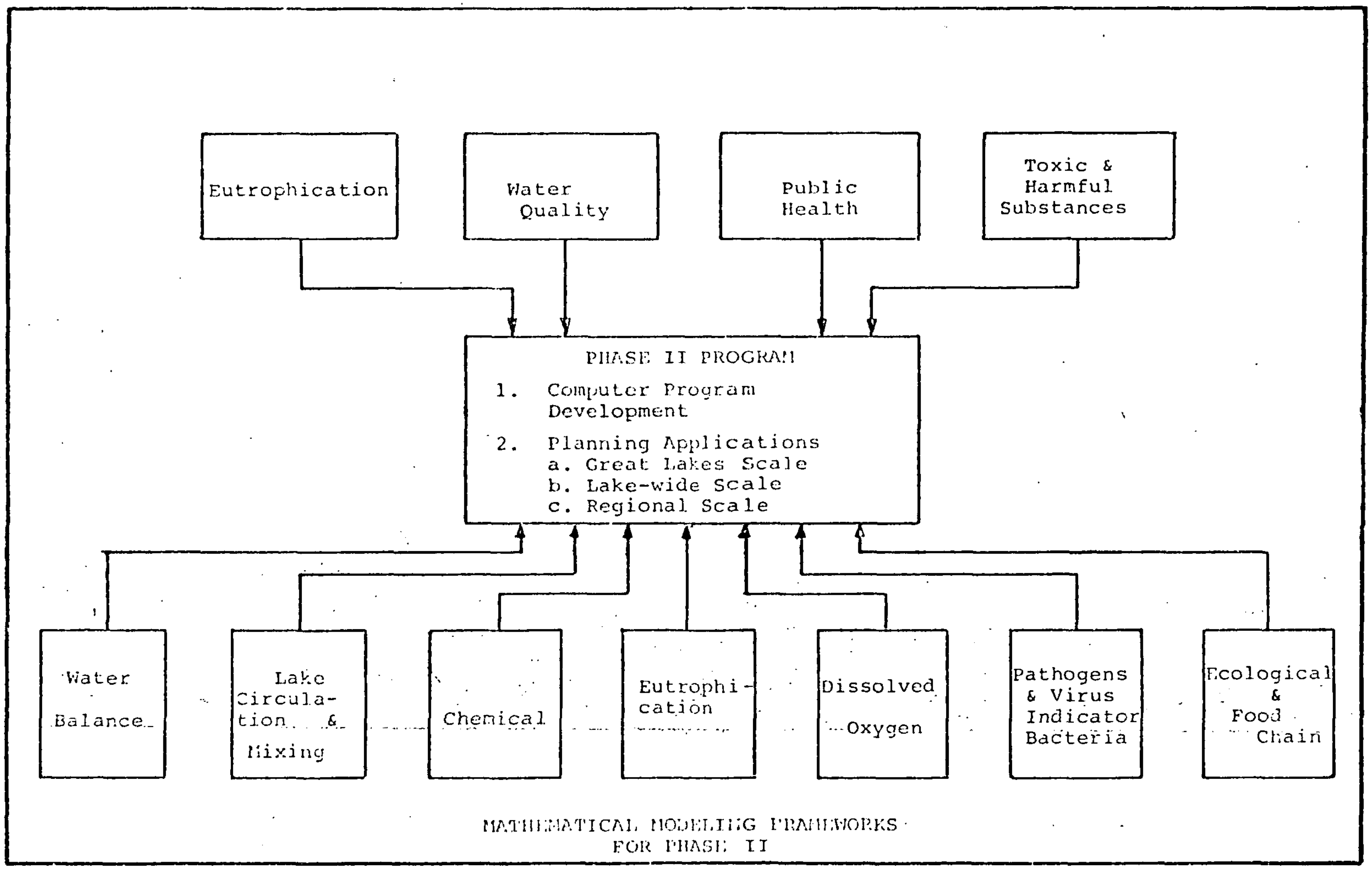


FIGURE 2

WATER RESOURCE PROBLEMS AND MATHEMATICAL MODELS INCLUDED IN PHASE II PROGRAM

## Specifications

It was recommended that a Phase II Limnological Systems Analysis study be funded at the $2.0 million level with a three-year completion time.

Within this level, it was recommeded that:

1. Existing subsystem models, parameter values, and inputs be gathered into interactive modeling frameworks.

2. Generalized computer programs be developed and modifications be made to existing models to accommodate recently evolved numerical and software techniques.

3. Applications be made of existing systems technology to those problem categories for which a reasonable degree of success for the application is assured.

The following specific problem contexts were recommended for inclusion in the Phase II study:

1. Water Quality Problems
   a. Dissolved oxygen
   b. Chemical interactions

2. Public Health

3. Eutrophication - biomass problems

4. Food chain toxicant problems

It was recommended that the Phase II study be directed toward three spatial scales:

| | | |
|---|---|---|
| 1. | Comprehensive Great Lakes scale | All lakes interconnected |
| 2. | Lake wide scale | Lakes Erie and Ontario |
| 3. | Regional scale | Duluth, Minnesota area, Southern Lake Michigan, Green Bay, Saginaw Bay, Lake St. Clair. |

Pursuant to these recommendations the following specifications have been prepared for the applicable modeling frameworks. The scope of applications for the models recommended for the various spatial scales is summarized in Table 1.

Figure 3 illustrates the primary input and output variable associated with recommended modeling frameworks. The system diagram for the eutrophication model is presented in Figure 4. The food chain modeling effort is illustrated in Figures 5, 6, and 7 which diagrammatically depict a ten-compartment model with no spatial definition, a ten-compartment model with spatial definition, and a seven-compartment food chain model. Interfacing of the eutrophication and food chain models is illustrated in Figure 8.

Specifications have been prepared in accordance with the recommended Level 2 Limnological Systems Analysis programs. The recommended level of effort and these specifications do not include certain features which were considered in the initial project statement of work to be components of the recommended program. These components are not consistent with the actual recommendations developed. For consistency with the scope of analysis and level of complexity of the recommended programs, specifications have not been prepared for the development of Administrative Models or of input data handling systems. The specifications that follow cover the modeling applications recommended for Phase II as discussed above and summarized in Table 1.

| Area and Spatial Scale | Problem Category: Water Quality a) Dissolved Oxygen | Problem Category: Water Quality b) Chemical | Problem Category: Public Health | Problem Category: Eutrophication | Problem Category: Food Chain | Analysis Framework | Time Scale: Decade | Time Scale: Annual | Time Scale: Seasonal | Time Scale: Monthly | Time Scale: Weekly | Dissolved Oxygen | Organic Carbon Cycle | Nitrogen (Organic, Ammonia, Nitrate) | Nitrogen Assoc. with Living Material | Phosphorus (Inorganic, Organic) | Phosphorus Assoc. with Living Material | Phosphorus (Inorganic) - (Availability Based on Chemical State) | Coliforms (Total and Fecal) | Phytoplankton (Cl "a") | Zooplankton | Total Dissolved Solids | Chlorides | Silica | Light Transparency | Benthic Oxygen Uptake | Carbonaceous Demand | Nitrogenous Demand | Photosynthesis and Respiration | Bottom Release | Reaeration | Coliform After Growth | Coliform Die-Away | Food Chain Compartments | Heavy Metals, Pesticides, Toxicants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Great Lakes Scale | | ● | | | | Time Variable | ● | ● | | | | | | | | | | | | | | ● | ● | | | | | | | | | | | | |
| | | | | ● | | Time Variable, Nonlinear | | ● | ● | | | | | ● | ● | ● | ● | | | ● | ● | | | | ● | | | | | | | | | | |
| Lake Erie Lakewide Scale | ● | | | | | Time Variable, Nonlinear | | | ● | | | ● | | | | | | | | | | | | | | ● | ● | ● | ● | ● | ● | | | | |
| | | ● | | | | Steady - State | | ● | | | | | | | | | | ● | | | | | | | | | | | | | | | | | |
| | | | | ● | | Time Variable, Nonlinear | | | ● | | | ▲ | ▲ | ● | ● | ● | ● | | | ● | ● | | | ▲ | ● | | | | | | | | | | |
| Diluth Area of Lake Superior Regional Scale | | | | ● | | Time Variable, Nonlinear | | | ● | | | ▲ | ▲ | ● | ● | ● | ● | | | ● | ● | | | ▲ | ● | | | | | | | | | | |
| Southern Lake Michigan Regional Scale | | | ● | | | Steady State, Linear | | | | ● | | | | | | | | | ● | | | | | | | | | | | | | ● | ● | | |
| | | | | ● | | Time Variable, Nonlinear | | | ● | | | ▲ | ▲ | ● | ● | ● | ● | | | ● | ● | | | ▲ | ● | | | | | | | | | | |
| Saginaw Bay Regional Scale | ● | | | | | Steady State, Linear | | | ● | | | ● | | | | | | | | | | | | | | ● | ● | ● | ● | ● | ● | | | | |
| | | | ● | | | Steady State, Linear | | | | ● | | | | | | | | | ● | | | | | | | | | | | | | ● | ● | | |
| Green Bay Regional Scale | ● | | | | | Steady State, Linear | | | ● | | | ● | | | | | | | | | | | | | | ● | ● | ● | ● | ● | ● | | | | |
| | | | ● | | | | | | | ● | | | | | | | | | ● | | | | | | | | | | | | | ● | ● | | |
| Food Chain Modeling Lake Ontario | | | | | ● | | | ● | | | | | | | | | | | | | | | | | | | | | | | | | | ● | ● |
| Lake St. Clair | | | | | ● | | | ● | | | | | | | | | | | | | | | | | | | | | | | | | | ● | ● |

LEGEND:
- ● VARIABLES TO BE EXAMINED
- ▲ ADDITIONAL VARIABLES TO BE EXAMINED, IF NECESSARY

TABLE I
SUMMARY OF RECOMMENDED MODELS

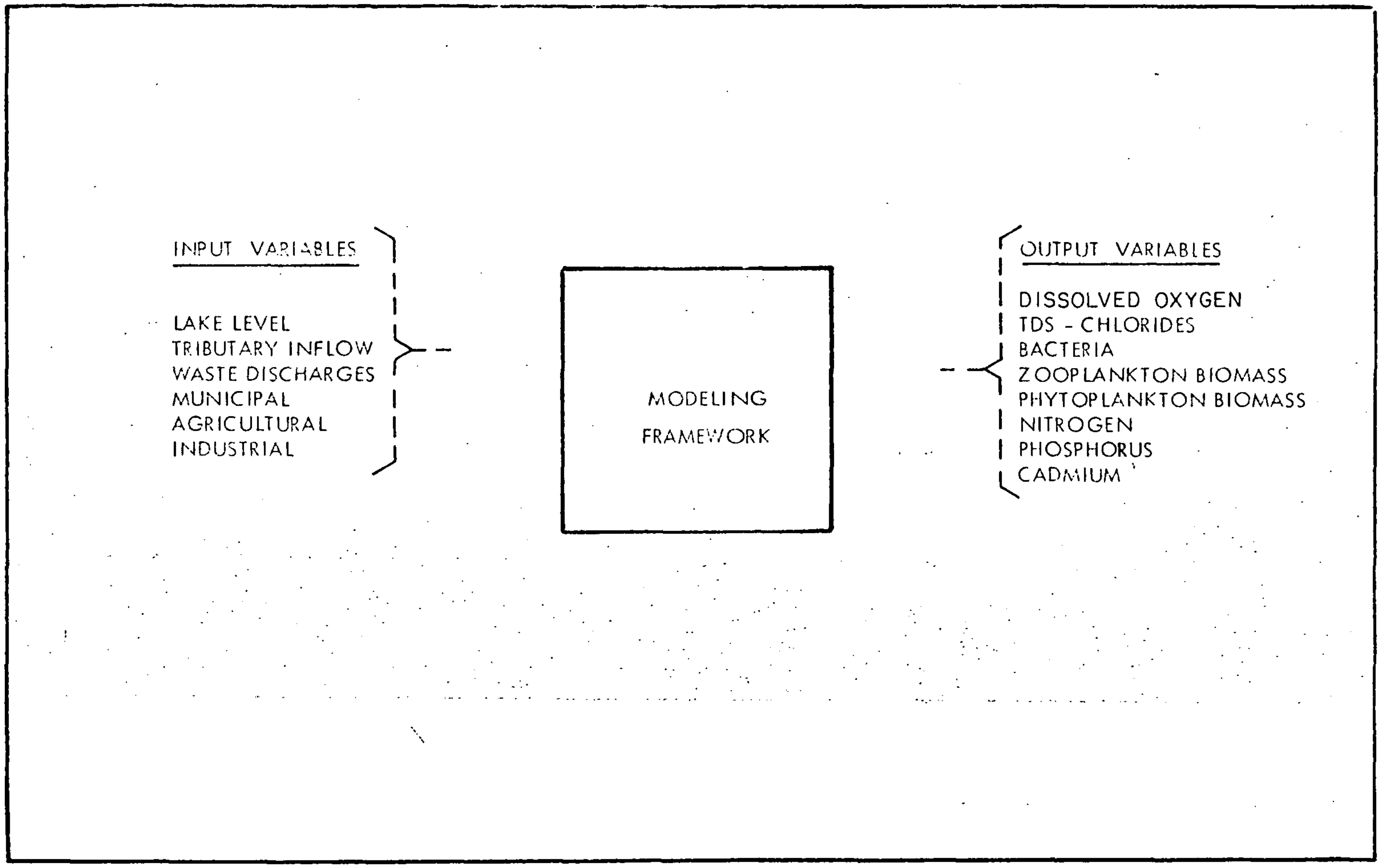


FIGURE 3
PRIMARY INPUT - OUTPUT VARIABLES

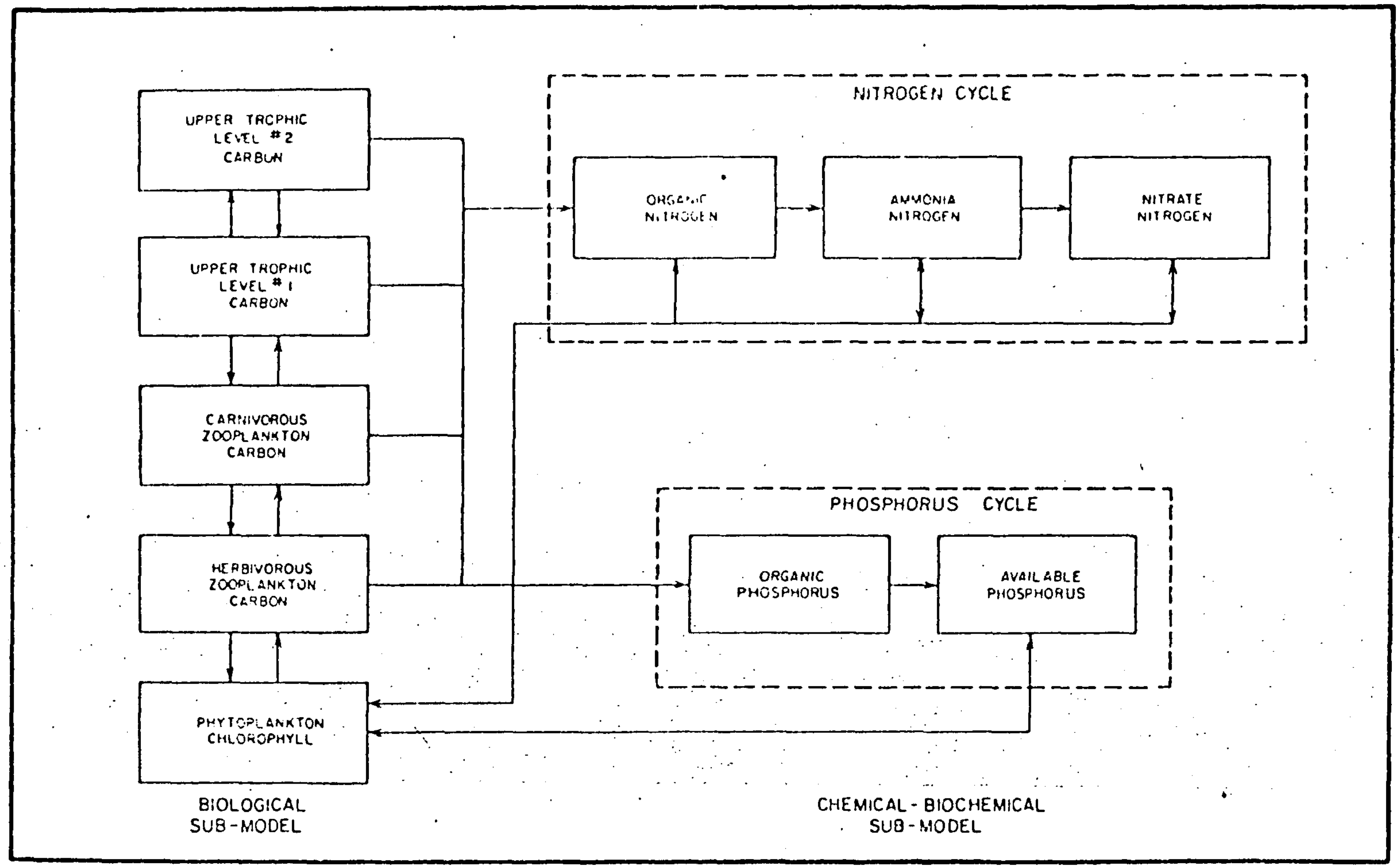


FIGURE 4
SYSTEM DIAGRAM - LAKE I MODEL

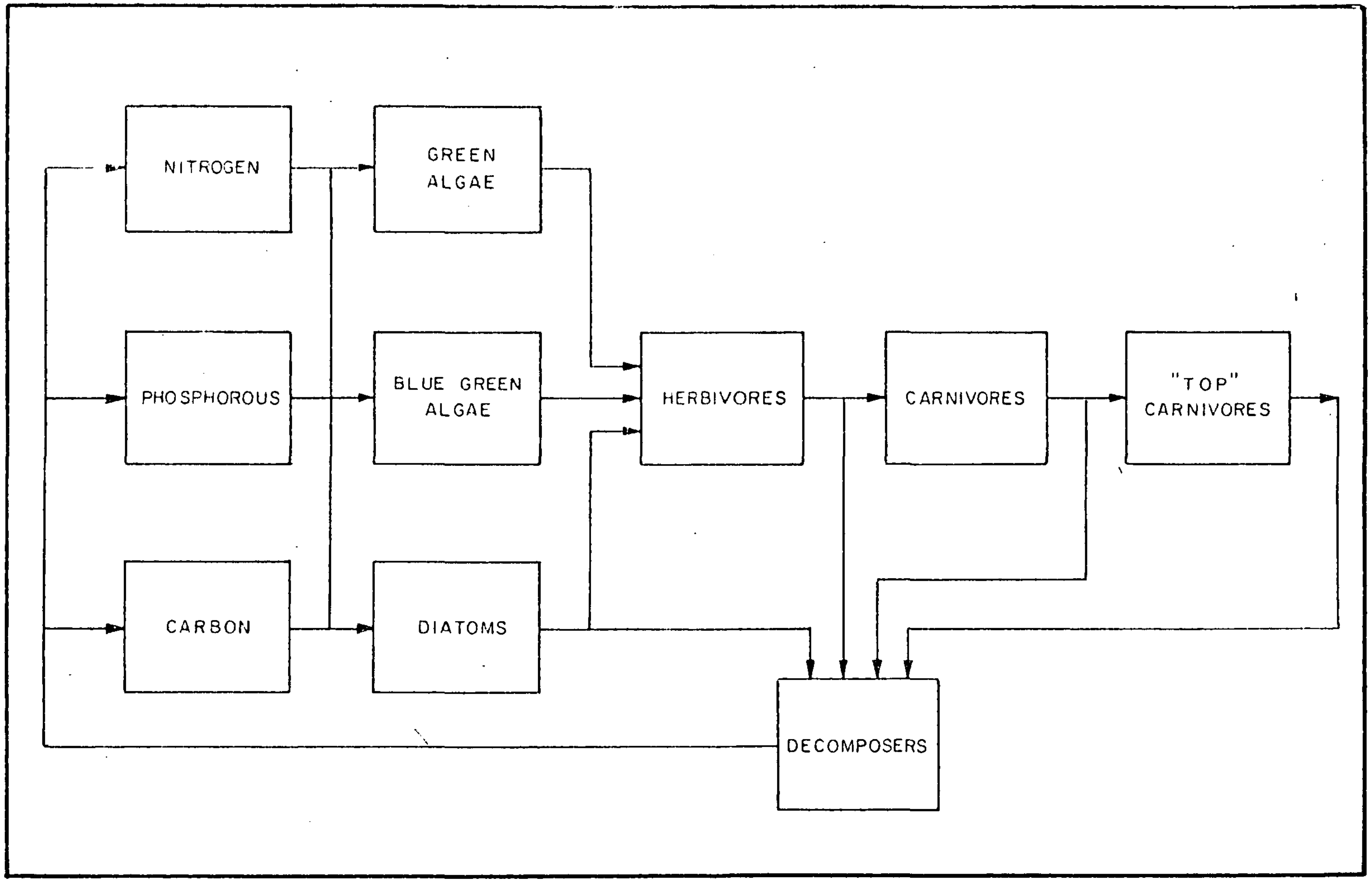


FIGURE 5

A TEN COMPARTMENT MODEL

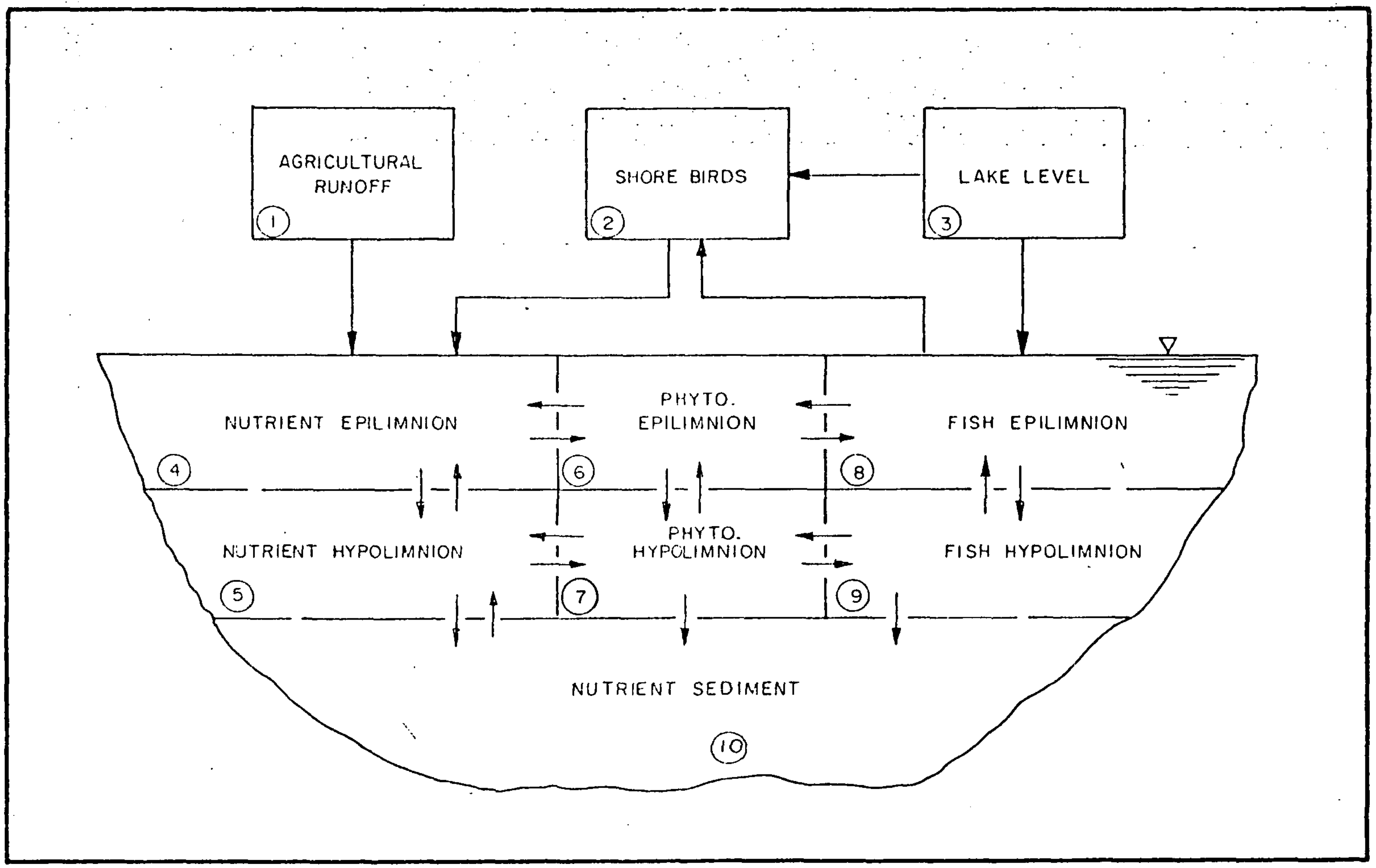


FIGURE 6

A TEN COMPARTMENT MODEL
WITH SPATIAL DEFINITION

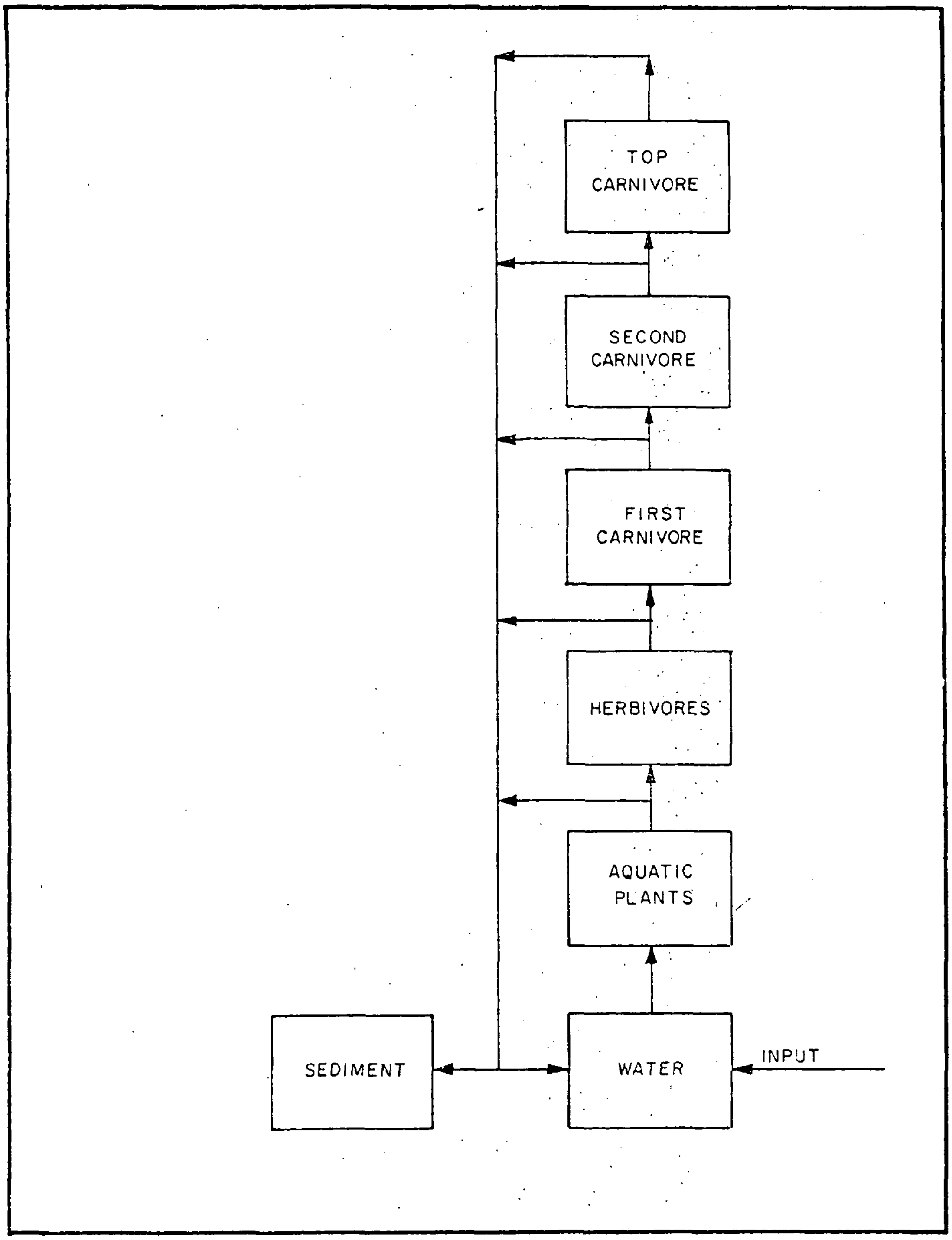


FIGURE 7

A FOOD CHAIN MODEL

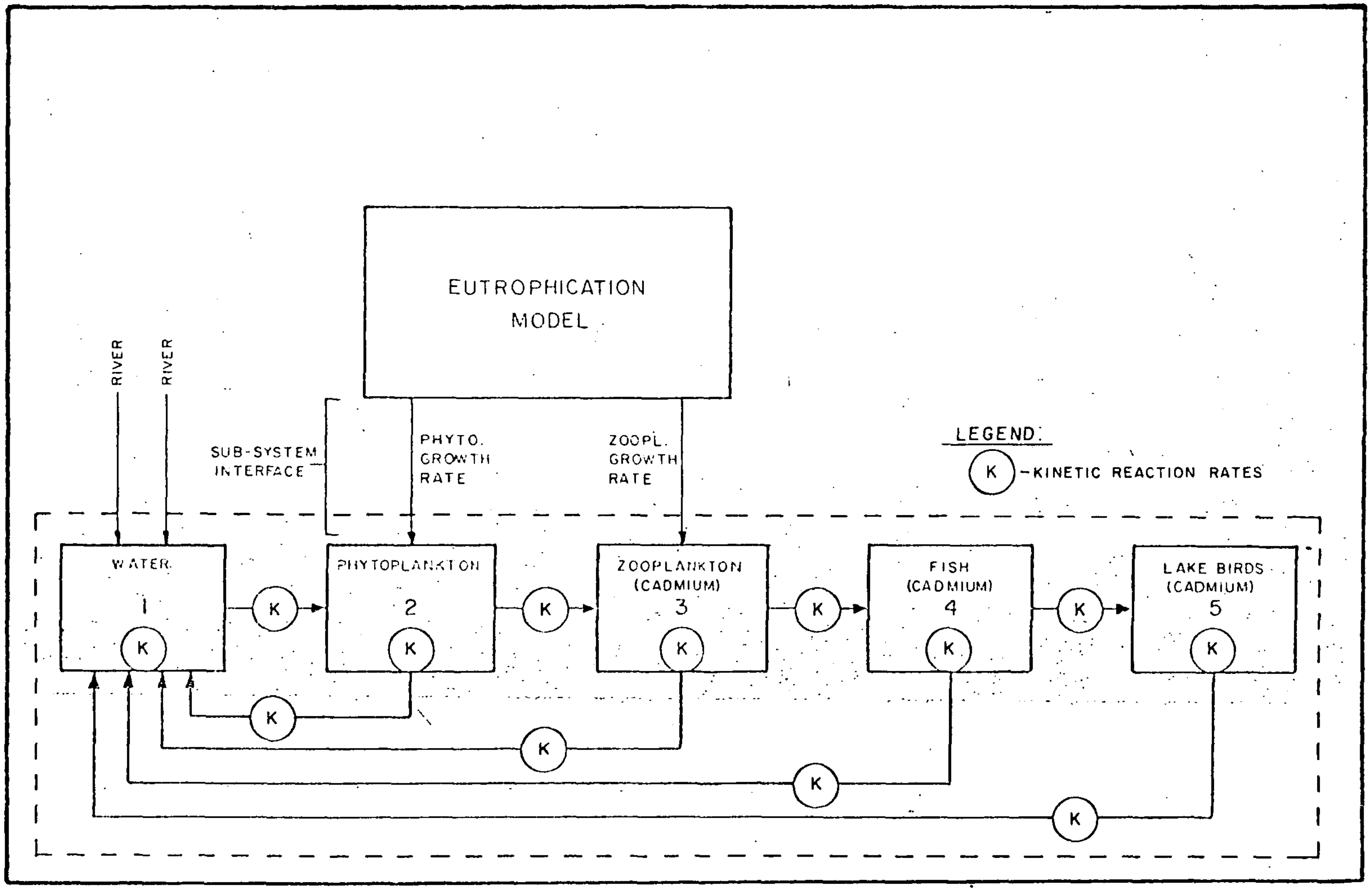


FIGURE 8

INTERFACING OF EUTROPHICATION AND FOOD CHAIN MODELS

## SECTION II

## GREAT LAKES MODELING COMPUTER PROGRAMS

### Program Purpose

These computer programs are to be used to do the computations involved in the LSA model applications discussed previously. Two general types of problem formulations are involved.

1. A set of linearly coupled, linear elliptic partial differential equations corresponding to the temporal steady state spatial distribution of water quality variables.

2. A set of nonlinearly coupled, parabolic partial differential equations corresponding to the time varying spatial distribution of water quality variables.

### Spatial Settings

The computer programs shall be quite general in terms of the spatial configurations that can be accommodated. The segments (or cells) of the finite difference scheme can be arranged into configurations that are representative of:

1. The five lakes - each lake represented as a few interacting segments and linked to each other via the tributary flow. The TDS model demonstration[1] is an example of this type of application.

2. One lake or a basin within the lake; fairly detailed segmentation in both horizontal dimensions; two layers in the vertical dimension representing the epilimnion and hypolimnion.

3. One lake or a basin within the lake; full three-dimensional segmentation with varying degrees of spatial resolution in different regions of the lake.

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(1) Hydroscience, Inc.,"Limnological Systems Analysis of the Great Lakes - Phase I,"pp. 318-327, (1973).

## Program Design Philosophy

This program is intended to be used by persons with a reasonable background in computer based modeling. Therefore, the program should not be designed in such a way that its operation is invisible to the user (as would be, for example, compilers) but rather as a generally applicable water quality modeling program with enough flexibility and features so that it can be applied to the different problem settings with comparable ease. The major difficulties to be overcome are the large size of the problems to be computed, in terms of the input required to specify the geometry, transport, kinetics, boundary conditions, and external sources; the storage required for computations; and the execution time required for solution.

## Required Program Features

The following is a series of features which appear to be necessary if the program is to be sufficiently general and useful:

1. Constant or spatially and/or temporally variable transport coefficients (dispersion coefficients and velocities) parameters, reaction kinetic coefficients, exogenous forcing functions, and boundary conditions.

2. Easily modified non-linear reaction kinetics to accommodate newly developed formulations.

3. Program code transportability. Coding in standard FORTRAN. Highly molecular design. Logically straight-forward construction so that other programmers can understand the code. Detailed documentation in the code. Execution of both IBM 360/370 and CDC 6000/7000 series computers.

4. General capabilities to print and/or plot the results on a standard line printed in the form of (a) tabular columns, (b) temporal plots at a segment, (c) printed arrays with boundary outlines, with the variables in positions corresponding to their locations in space for either horizontal or vertical planes of the three dimensional computations and, (d) contour plots of the results generated in (c).

5. Non-uniform grids, perhaps as sets of uniform blocks, to accommodate the requirements of varying spatial resolution.

## Desirable Program Features

During the design phase of the program, the following features are to be evaluated and included, if feasible:

1. Easily specified spatial configurations using the known geometrics of the lakes and reference coordinates of latitude and longitude.

2. Specifications of transport parameters at some spatial locations with the complete detailed specifications for each segment done by the program using an interpolation scheme, which, in the case of velocities, conserves fluid.

3. Efficient computations at full arithmetic speed of the machine even for large problems that exceed memory size.

4. Capabilities of generating graphics output stills and/or motion picutres, in such a way as to be as machine and installation non-specific as possible.

5. Graphical comparison of observed data and computed results for use in verification analysis.

6. Ability to compute and display various additional diagnostic results such as the reaction kinetic terms of the equations, the transport fluxes, linear combinations of variables, etc.

7. Ability to modify the differencing scheme used for the calculation in order to investigate the sensitivity of the solution to the scheme used.

8. Ability to investigate solution sensitivity to parameter variations in a convenient way.

9. Extensive error trapping capability. Overflows, underflows, indeterminate quantities produce output which aids in the debugging of the program, in addition to producing output computed up to the error.

## Phases of the Development Project

After an expenditure of 10% to 20% of project funds, the contractor shall present a preliminary program design which addresses the issues raised in these specifications as well as those which occur during the design process. Since this program is not unlike other large scale scientific computations, e.g., numerical weather codes, hydrodynamic calculations for the Great Lakes and elsewhere, the contractor shall review these and any other relevant programs in order to examine how they operate, what the experience has been during their use, what the major difficulties have been, and how this experience applies to the Great Lakes computer program. The laboratories at which such computations are performed, such as the National Center for Atmospheric Research, the Geophysical Fluid Dynamics Laboratory, and the Linermore Radiation Laboratory, should be contacted and the knowledgeable personnel consulted for relevant experience.

## Technical Specifications

Two sets of equations can be solved for the various geometrics. They are:

1. Steady state, linearly coupled elliptic partial differential equations of the form:

$$\sum_{i=1}^{3} = \frac{\partial}{\partial x_i} \left(-E_i \frac{\partial c^j}{\partial x_i} + V_i c^j\right) = \sum_{k=1}^{N} K_{jk} c^k + W^j$$

in the three coordinate variables $x_1$, $x_2$, $x_3$, with dispersion coefficients $E_i$, velocity field $V_i$, for the water quality variables $c^1$, $c^2$, ...$C^N$, interacting linearly via the reaction kinetic constants $K_{jk}$. With sources $W_{tj}$, boundary conditions of the form:

$$- E_i \frac{c^j}{x_i} + V_i c^j = J^j + K^j (C_s^j - C)$$

are to be implemented at the boundaries.

2. Time variable parabolic equations of the form:

$$\frac{c^j}{t} + {}_{L=1}^{2} - \frac{}{x_i} \left(-E_i \frac{c^j}{x_i} + V_i c^j\right) = R^j(c) + W^j$$

with transport similar to the steady state equations and non-linear kinetic coupling functions $R^j(c)$.

The contractor shall investigate the relevant finite difference schemes and solution methods for each equation, with reference to the parameter ranges for the Great Lakes applications. Stability criteria shall be evaluated in order to choose the scheme that is a balance between computational cost and programming ease. In particular, the experience of users of the various schemes investigated shall be considered, as well as a thorough literature review and evaluation. Among the issues to be addressed are: implicit and/or explicit schemes, accuracy, stability, positivity, and conservation properties (mass, quadratic).

## Contractor Requirements

The contractor shall design, code, debug, validate, and document the Great Lakes modeling computer program.

Validation shall consist of reproducing selected calculations for the Lake Erie Western Basin coliform model, the five lake TDS model, and the eutrophication model as described in the LSA feasibility study.

Documentation shall consist of two manuals: a Users Manual intended for the informed user, and a Systems Manual which describes the program in sufficient detail for a programmer to understand and implement it at an installation. In addition, a report shall be produced which documents the result of the investigations during the design phase, with regard to the numerical and programming issues raised.

A schedule with landmark requirements shall be established to aid in keeping the project on budget and schedule.

# SECTION III

# GREAT LAKES SCALE APPLICATION

## Scope of Application

The scope of this application encompasses the five Great Lakes. The basin is treated conceptually as a number of lakes in series or in parallel as appropriate. The modeling effort will employ the computer programs developed under other tasks of this project. A total of ten to twenty horizontal segments for the entire five Great Lakes will be employed. Spatial detail will, therefore, not be considered as a prime objective of this modeling effort. In addition to the horizontal segments, vertical segmentation of the Lake systems, as appropriate, will consider an additional ten to fifteen vertical segments.

Two specific problem categories will be examined in this modeling framework. The first is consideration of chemical water quality on a time variable basis with the use of a time scale of year-to-year variations. The consequence of activities on the Great Lakes over decades will be analyzed. The specific variables to be studied in this analysis are total dissolved solids and chlorides.

A second problem category to be examined deals with eutrophication within the five Great Lakes. Again, the overall planning horizon is on the order of decades. The model to be employed will consider time variable, non-linear kinetics with seasonal and year-to-year effects. The specific variables to be examined in the modeling effort are nitrogen series (organic nitrogen, organic nitrogen associated with living material, ammonia nitrogen, nitrite, nitrate nitrogen); phosphorus series (inorganic phosphorus, organic phosphorus, and phosphorus associated with living organic material); phytoplankton (as measured by chlorophyll 'a'); and zooplankton (as measured by zooplankton carbon). The objective of this application is to examine water quality in the Great Lakes resulting from long term projections for municipal and industrial development.

## Study Input Data

The geomorphology of each of the five Great Lakes will have to be inputted to the modeling framework. It will be necessary to identify the volume, depths, and thermocline locations for each of the spatial segments to be considered in the modeling effort. In addition, an averaged hydrological balance for the entire Great Lakes must be developed, and should include inflows, outflows, precipitation, evaporation, and variations in lake volume.

Input from man's activities and natural phenomena must be considered within the modeling framework. Specifically, the chemical and biological input from point and distributed sources on a lake-by-lake and segment-by-segment basis are required.

Water quality data on the total dissolved solids, chlorides, nitrogen, phosphorus, phytoplankton, and zooplankton under observed historical conditions will have to be collected and analyzed over the time scale of the modeling analysis. These data should cover the greatest possible historical span. It is not necessary to have a complete data set in all variables to provide a basis for partial verification of the model. The contractor is to collect all of the available information and to examine it for use in model verification with due consideration of the large time and space scale being considered in the model and the objective of making long-term projections of water quality in the Great Lakes.

## Modeling Framework

The chemical water quality study, considering total dissolved solids and chlorides, will employ a time variable analysis with conservative variables. The eutrophication study will employ a non-linear time variable analysis as described in, "Limnological Systems Analysis of the Great Lakes - Phase I," prepared by Hydroscience, Inc.[1]

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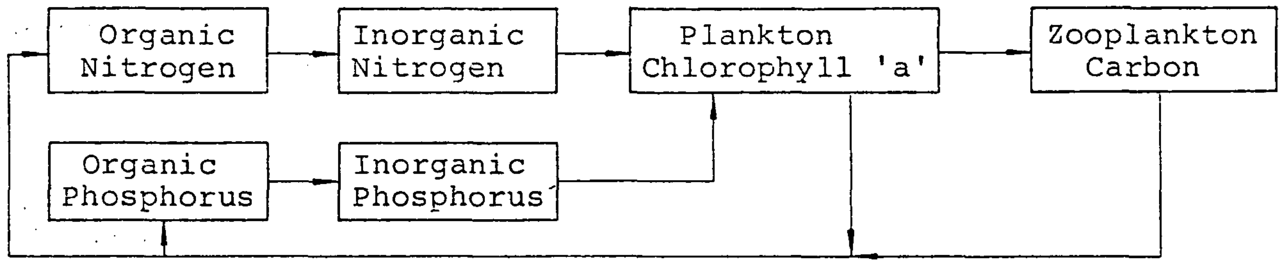
(1) Hydroscience, Inc.," Limnological Systems Analysis of the Great Lakes - Phase I," (1973).

The specific modeling framework and kinetic interactions to be included in the Great Lakes scale eutrophication modeling are those indicated by the kinetic diagram shown below:




Sources and sinks of material to be considered in the Great Lakes scale analysis should include not only those point and distributed sources from the shoreline but should also include atmospheric inputs, settling, and leaching phenomena as appropriate.

## Verification Analysis

The model output for both the conservative chemical and eutrophication models should be compared to historical data. It will not be necessary to have a consistent and continuous set of historical data in time to obtain the desired comparisons.

Because of the large time scale of the modeling effort, it is desirable to include an additional step in the verification analysis. One of the data sets available in both the total dissolved solids and eutrophication analysis should be withheld for an independent check on the verified model, following calibration of that model.

The sensitivity analysis for the Great Lakes scale models should include analysis of the sensitivity of model output to input load, to Great Lakes hydrology and coefficients, and to interrelationships employed in the analysis.

## Application of Model

A series of projections will be made under three levels of future growth of the Great Lakes area. The specific information on populations and economic levels will be provided by the GLEPS study of the Great Lakes Basin Commission. The data on population changes and industrial growth, together with alternations in land use, will be employed by the contractor to develop sequences of inputs to the lakes over time. The effect of these sequences of inputs will be examined. It will be necessary to closely coordinate these alternatives with the Great Lakes Basin Commission.

## Final Report

The contractor will prepare a final project report which will describe the modeling effort, the data base employed for model verification, the system inputs, and the results of the verification and sensitivity analyses. The final report will present the projected water quality resulting from the three levels of future development in the basin.

## SECTION IV

## LAKEWIDE SCALE - LAKE ERIE

### Scope of Application

The study area will encompass all of Lake Erie. Horizontal and vertical model segmentation will be structured so that each sub-model is upward compatible with the largest model, i.e., segment geometry will be such that segments do not overlap. The ultimate spatial resolution will be limited by computer time and memory constraints. It is anticipated that a variable grid including both horizontal and vertical segments will be employed with total segmentation ranging between fifty and two hundred segments.

The computation framework which will be developed in other tasks will consider time variable and non-linear kinetics on a seasonal time scale. The major thrust of the calculation procedures will be the evaluation of eutrophication as measured by phytoplankton biomass as a function of nutrients inputted either as point sources or as distributed sources (including the effects of nutrients returned and removed by phenomen associated with the benthos). The major water quality effect to be considered is the anoxic hypolimnion and its relation to primary production with respect to dissolved oxygen.

The variables to be examined will include the nitrogen series (organic nitrogen, organic nitrogen associated with living material, ammonia nitrogen, nitrite, nitrate nitrogen), the phosphorus series (inorganic phosphorus, organic phosphorus, and phosphorus associated with living organic material, phytoplankton (as measured by chlorophyll 'a'), and zooplankton (as measured by zooplankton carbon). In addition, the organic carbon cycle, dissolved oxygen, and silica are to be included, as necessary. Finally, chemical effects on the availability of inorganic phosphorus may also be a significant factor.

### Study Input Data

The contractor will review and gather data available on system geomorphology. Specifically, the contractor will gather information on the geometry of Lake Erie, including the depths, volumes, and location of thermoclines. The contractor will, in addition, develop a hydrologic balance for the region, gathering information as required on inflows, outflows, precipitation over the lake, evaporation and variations in lake volume. An advective-dispersive model is to be employed; therefore, the contractor must also evaluate data on lake velocities and dispersion coefficients. The major transport variables will have to be evaluated with a combination of calculated circulation patterns and observed data.

An accurate and complete quantitative assessment of all major mass inputs of the dependent variables is required. This is critical to the success of the modeling effort, both in verification and projections. Estimates, therefore, must be generated of mass inputs contributed by man's activities from point sources, such as industrial and municipal wastes, as well as those associated with runoff from urban, suburban, and undeveloped land areas. Assessments must be developed of the input of nutrients associated with bottom phenomena, particularly with anoxic conditions in the hypolimnion of central Lake Erie. Finally, information on applicable reaction and transformation rates must be obtaind for the Great Lakes literature base. The contractor is required to examine the data base and gather information on appropriate water quality variables employed in the modeling effort. The model will require verification at different spatial locations over the period of several years. It will, therefore, be necessary to select from the data base, information on a nitrogen series, phosphorus series, phytoplankton, zooplankton, organic carbon, dissolved oxygen, and silica. The data base should cover at least two annual cycles and need not extend beyong four annual cycles. Data sets may consist of information pieced together from a number of different surveys and observations carried out by interested agencies and groups on the Great Lakes.

## Modeling Frameworks

The eutrophication biomass formulation will be essentially that presented in the demonstration model(1), suitably enlarged and refined as required. The specific extensions that are to be considered in this analysis are:

1. effects of anoxic hypolimnion on nutrient recycle,
2. the possibility of nitrogen fixation and denitrification,

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(1) Hydroscience, Inc., "Limnological Systems Analysis of the Great Lakes - Phase I," pp. 337-354, (1973).

3. the vertical settling and decomposition of plankton and detritus,

4. the effect of sediment processes on the mineralization and recycle of nutrients,

5. an improved zooplankton formulation,

6. an explicit formulation of the significant inorganic chemical processes and their effect on silica and phosphorus,

7. dissolved oxygen analysis including the oxidation of organic carbon and oxygen production and respiration by plankton,

8. inclusion of dissolved carbon dioxide in the modeling framework coupled with oxidation of organic carbon and carbon dioxide transfer between the liquid and atmospheric phases.

## Verification Analysis

Model verification of the transport regime is required and should employ conservative ions as tracers and/or temperature gradients. In addition, verification and/or temperature gradients of composite variables that are primarily affected by the boundaries of the model can be made and would include total nitrogen and total phosphorus concentrations.

At least two years of data for all variables, for which data exists, should be examined. In addition, at least one year and, if possible, an additional year of data should be employed in the verification. As an example of this kind of independent check, sparse data is available on plankton counts and nutrient levels in 1930 in the western basis of Lake Erie. Comparable data from the forties, fifties, and sixties could also be used for other portions of Lake Erie. Finally, all kinetic constants and parameters should be in the range of reported literature values.

Additional model output should be obtained to determine the sensitivity of the system to variations in model coefficients and parameters.

## Application of Model

The contractor shall apply the eutrophication and dissolved oxygen models to predict the effects of man's activities and changes in natural inputs. The GLEPS program of the Great Lakes Basin Commission's studies will provide data on changes in waste loads resulting from population growth, economic developments, altered land use patterns, and environmental control procedures. These data on input waste loads will be employed in the modeling effort to predict the anticipated level of phytoplankton biomass and dissolved oxygen in the study area. Specifically, the model will be employed to develop projections for at least three levels of growth and future activities.

## Final Report

The contractor will prepare a final project report which will describe the modeling effort, the data base employed, waste loads and inputs to the system, the results of the verification, and sensitivity analysis. The report will also present the specific projected results for the three levels of future development in terms of anticipated phytoplankton biomass and dissolved oxygen responses within Lake Erie.

## SECTION V

## DULUTH AREA OF LAKE SUPERIOR - REGIONAL SCALE APPLICATION

### Scope of Application

The spatial extent of this application includes the Duluth area of Lake Superior and extends approximately twenty miles into Lake Superior proper. The modeling effort should utilize from twenty to forty spatial segments.

The application will consider the specific problem category of eutrophication. A non-linear time variable computer program developed under other tasks in this project will be used on a seasonal time scale. The variables to be included in the modeling effort are the nitrogen series (organic nitrogen associated with living material, ammonia nitrogen, nitrite, nitrate nitrogen), the phosphorus series (inorganic phosphorus, organic phosphorus, and phosphorus associated with living organic material), phytoplankton (as measured by chlorophyll 'a'), zooplankton (as measured by zooplankton carbon). In addition, the available data will be examined and appropriately evaluated to determine if silica, oxygen and organic carbon cycle should be included in the analysis. The contractor is to employ data analysis and simple calculation procedures to establish the availability of organic carbon and silica as a potential limiting nutrient for plankton populations under existing conditions and under future projected conditions.

### Study Input Data

The contractor will review data on the system geomorphology. Specifically, the contractor will gather information on the geometry of Lake Superior in the Duluth area. This will include the depths, lake volumes, and location of thermoclines.

The contractor will develop a hydrologic balance for the region of Lake Superior, gathering information as required on inflows, outflows, precipitation over the lake, evaporation, and variations in lake volume. An advective-dispersive model will be employed. Therefore, the contractor must evaluate data on lake velocities and dispersion coefficients in the Duluth area of Lake Superior. The hydrologic balance will be developed for a period when observed water quality data for the variables being modeled are available.

The contractor is required to examine the observed data base and gather information on water quality variables employed in the modeling effort. The model will require verification at different spatial locations in the Duluth area of Lake Superior over time. It will, therefore, be necessary to review the existing data base and to select from that data base water quality information on the nitrogen series, phosphorus series, phytoplankton, and zooplankton for one to two annual cycles. Information need not be available continuously over an annual cycle but can be obtained from periodic water quality survey information collected over a number of years. This relaxed data requirement is associated with the fact that growth in Duluth in recent years, has not been considered rapid in relationship to the size of the area to be modeled in Lake Superior. This phenomenon makes it possible to piece together data sets from a number of different years of observations.

The final item of input data required consists of the residual inputs from point and distributed sources of the modeling effort. Residual inputs from natural distributed sources may be obtained from existing data in the Lake Superior area or may be extrapolated from literature values for comparable land use areas. Modification of the literature values may be necessary, depending on the specifics of the study area in which the data was collected. The chemical and biochemical data from the point sources in the area should consider direct discharges to Lake Superior and tributaries as point source inputs. Checks should be made of tributary loads to insure that the observed data on the tributaries represent the sum of contributing populations(with consideration to treatment of municipal and industrial discharges), as well as land runoff.

## Modeling Framework

The contractor will employ the time variable non-linear programs developed by other tasks in this study. The modeling framework to be used by the contractor is an updated computer program which employs feedback and non-linear kinetic relationships. The major output variables and modeling variables are as identified previously and are, specifically, the nitrogen series (organic nitrogen, organic nitrogen associated with living material, ammonia nitrogen, nitrite, nitrate nitrogen); the phosphorus series (inorganic phosphorus, organic phosphorus and phosphorus associated with living organic material); phytoplankton (as measured by chlorophyll 'a'); and zooplankton (as measured by zooplankton carbon).

The contractor shall consider as input to the modeling effort, estimates of the distributed and point loads from natural weathering, erosion, and man's activities. In addition, the contractor shall consider estimates of settling and leaching of material from the bottom of Lake Superior. The contractor shall also determine the significance of atmospheric sources of material and, if appropriate, include estimates of these in the modeling effort.

## Verification Analysis

Model verification shall consist of a comparison of computed model output over an annual cycle against observed water quality data. The comparison shall be developed for all of the model variables simultaneously, with a consistent set of parameters and coefficients.

In addition, model output shall be obtained to determine the sensitivity of the system.

## Application of Model

The contractor shall apply the eutrophication model to predict the effect of man's activities and changes in natural inputs to the system. Specifically, the GLEPS program from the Great Lakes Basin Commission study will provide data on increases in population and economic development of the area and changes in land use patterns within the study area. These data on input changes will be employed in the modeling effort to predict the level of nitrogen, phosphorus, phytoplankton, and zooplankton. Specifically, the model will be employed to develop projections for at least three levels of growth and range of future activities.

## Final Report

The contractor will prepare a final project report which will describe the modeling effort, the data base, loads, and the results of the verification and sensitivity analysis. The final report will present the specific projected results for the three levels of future development in the Duluth area of Lake Superior.

# SECTION VI

# SOUTHERN LAKE MICHIGAN REGIONAL SCALE APPLICATION

## Scope of Application

The area of concern includes Southern Lake Michigan and extends approximately one hundred twenty-five miles into Lake Michigan, in a northerly direction from Gary, Indiana. The modeling effort will employ the computer programs developed under other tasks of this project and will consider from seventy-five to one hundred fifty spatial segments within Lake Michigan.

There are two specific problems which are to be addressed by the contractor. The first problem will deal with the eutrophication phenomenon in Southern Lake Michigan and will employ the time variable non-linear models for eutrophication. The analysis will consider seasonal phenomena. The variables to be included in the eutrophication model will consist of the nitrogen series (organic nitrogen, organic nitrogen associated with living materials, ammonia nitrogen, nitrite, nitrate nitrogen), the phosphorus series (inorganic phosphorus, organic phosphorus, and phosphorus associated with living organic material), phytoplankton (as measured by chlorophyll 'a'), and zooplankton (as measured by zooplankton carbon). In addition, the available data will be examined and appropriately evaluated to determine whether silica, oxygen, and organic carbon cycle should be included in the analysis. The second problem category to be examined by the contractor will deal with bacterial pollution of the nearshore region of Lake Michigan. Specifically, the spatial extent of this second modeling effort will be on the order of a ten mile band around the shoreline of Lake Michigan. This modeling effort will employ linear models and will consider steady state conditions on approximately a monthly time scale. The specific variables to be examined in this second problem category will be total and fecal coliform bacteria with consideration given to die-away and aftergrowth.

## Study Input Data

The contractor will review and gather data on the system geomorphology. Specifically, the contractor will gather information on the geometry of Southern Lake Michigan including the depths, lake volumes, and location of thermoclines.

The contractor will, in addition, develop a hydrologic balance for the region, gathering information as required on inflows, outflows, precipitation over the lake, evaporation, and variations in lake volume. An advective-dispersive model is to be employed for the calculation base in the eutrophication modeling effort. Therefore, the contractor must also evaluate data on lake velocities and dispersion coefficients. The hydrologic balance will be developed for a period when observed water quality data for the variables being modeled are available.

The contractor is required to examine the observed data base and gather information on water quality variables in the modeling effort. The model will require verification at different spatial locations over time. It will, therefore, be necessary to review the existing data base and to select from that data base, water quality information on the nitrogen series, phosphorus series, phytoplankton, and zooplankton for one to two annual cycles. Information need not be available continuously over an annual cycle, but can be obtained from periodic irregular water quality survey data collected in the area over a number of years. Data sets may consist of information pieced together from a number of different years of observation.

The final item of study input data required consists of the residual inputs from point and distributed sources of the various chemical, biochemical, and bacterial variables considered in the modeling efforts. Residual inputs from natural distributed sources may be obtained from existing data in the region or may be extrapolated from literature values for comparable land use areas throughout the continental United States. Modification of the literature values may be necessary, depending on the specifics of the study area in which the data was collected. The chemical, biochemical, and bacteriological data from the point sources in the area should consider direct discharges to Southern Lake Michigan and tributaries as point source inputs. Checks should be made of tributary loads to insure that the inputs represent the sum of contributing populations (with consideration to treatment of municipal and industrial discharges), as well as the land runoff. The information on waste inputs for the eutrophication analysis is required, preferably, on a time variable basis. If this information is not available for municipal and industrial inputs, it is adequate to use an average municipal and industrial input to the system which is constant over time. The natural load variations should be calculated in a time variable fashion, if possible. Constant monthly average inputs are adequate for the coliform analysis.

## Modeling Framework

As indicated previously, the contractor will be required to employ the time variable, non-linear eutrophication modeling framework developed elsewhere in this study. The major output variables and modeling variables are the nitrogen series (organic nitrogen, organic nitrogen associated with living material, ammonia nitrogen, nitrite, nitrate nitrogen); the phosphorus series (inorganic phosphorus, organic phosphorus, and phosphorus associated with living organic material); plankton (as measured by chlorophyll 'a'); and zooplankton (as measured by zooplankton carbon).

Specifically, the modeling framework to be used by the contractor is an updated computer program which employs the feedback and non-linear kinetic relationships.

The contractor shall consider as input to the modeling effort, estimates of the distributed and point loads from natural weathering and man's activities and, in addition, shall consider estimates of settling and leaching of material from the bottom of Lake Michigan, and shall determine the significance of atmospheric sources of material, and if appropriate, include estimates of those in the modeling effort.

The model that will be employed for the examination of bacterial pollution in the nearshore regions of Lake Michigan will be the linear steady state modeling effort developed by other tasks. The model variables will be the bacterial input of both total and fecal coliform from direct point sources, both industrial and municipal. In addition, the contractor will consider the runoff from stormwater overflow in urban, suburban, and rural areas, and finally will consider the contribution of fecal and total coliform bacteria from natural phenomena and those entering the system from tributaries to Southern Lake Michigan.

## Verification Analysis

Model verification shall consist of a comparison of computed model output over an annual cycle against observed water quality data for the eutrophication analysis. Seasonal steady state comparison shall be made for the coliform analysis. The comparisons shall be developed for all of the model variables simultaneously with consistent sets of parameters and coefficients.

In addition, model output shall be obtained to determine the sensitivity of the system.

## Application of Model

The contractor shall employ the eutrophication and coliform models to predict the effect of man's activities and changes in natural inputs to the system. Specifically, the GLEPS program from the Great Lakes Basin Commission study will provide data on waste loads resulting from increases in population and economic development of the area and changes in land use patterns. These data on input waste load changes will be employed in the modeling effort to predict the anticipated level of nitrogen, phosphorus, phytoplankton, zooplankton and coliform in the area under study. Specifically, the model will be employed to develop projections for at least three levels of growth of future activities.

## Final Report

The contractor will prepare a final project report which will describe in detail the modeling effort, the data base employed for model verification, the loads employed, and the results of the verification and sensitivity analysis. The final report will present the specific projected results for the three levels of future development in Southern Lake Michigan.

## SECTION VII

## SAGINAW BAY REGIONAL SCALE APPLICATION

### Scope of Application

The study area will encompass Saginaw Bay and extend approximately sixty miles in a northeasterly direction from Bay City, Michigan, toward Lake Huron. The modeling effort will make use of computer programs developed under other tasks of this project. The analysis will employ the linear steady state program framework. A variable spatial grid will be utilized with finer segmentation in the vicinity of major waste inputs and expanded grid sizes as Lake Huron is approached. It is anticipated that on the order of two hundred spatial segments will be employed in the modeling effort.

Two specific water quality problems will be examined by the contractor. The water quality variables associated with these problems are dissolved oxygen and coliform under seasonal steady state conditions.

The modeling effort will consider oxidation of carbonaceous and nitrogenous material (sequential oxidation of ammonia to nitrate shall be considered), algal oxygen production and respiration, oxygen utilization by bottom deposits, release of materials into the water column by bottom deposits, reaeration, aftergrowth, and die-away of total and fecal coliform bacteria. The modeling effort will consider steady state summer water quality on approximately a monthly time scale and will employ linear reactions and feedbacks as appropriate.

### Study Input Data

The contractor will review and gather data available on the system geomorphology. Specifically, the contractor will gather information on the geometry of Saginaw Bay, including the depths, volumes, and location of thermoclines.

The contractor will, in addition, develop a hydrologic balance for the region, gathering information as required on inflows, outflows, precipitation, evaporation, and variations in volume.

An advective-dispersive model will be employed. Therefore, the contractor must also evaluate data on lake velocities and dispersion coefficients. The hydrologic balance must be developed for a period when observed water quality data for the variables being modeled are available.

The contractor is required to examine the data base and gather information on water quality variables employed in the modeling effort. The model will require verification at different spatial locations. It will, therefore, be necessary to review the existing data base and to select from that data base information on the temperature, nitrogen series, BOD, dissolved oxygen, chlorophyll, and coliform during at least one and not more than three periods. Data sets may consist of information pieced together from a number of different years of observations provided that temperature, flow, and input are similar.

## Modeling Framework

As indicated previously, the contractor will be required to employ a linear steady state program as part of the modeling effort. The variables to be considered as output from the modeling effort will be the dissolved oxygen and coliform bacterial profiles in Saginaw Bay. The phenomena to be included in the dissolved oxygen model are oxidation of carbonaceous and nitrogenous material (ammonia conversion to nitrite and nitrate should be considered), algal oxygen production and respiration, bottom oxygen utilization and release of material into the overlying water column from the bottom, and atmospheric reaeration. The coliform model will consider sources of coliform bacteria aftergrowth and the subsequent die-away of the coliform organisms in the bay.

## Verification Analysis

Model verification for dissolved oxygen and coliform distributions shall consist of a comparison of computed model output under steady state conditions and observed water quality data in Saginaw Bay. Monthly or seasonally averaged information should be employed for the comparison. The comparisons shall be developed between all of the modeled variables simultaneously by use of consistent parameters and coefficients. The verification analysis shall consider at least one and no more than three steady state water quality data sets. Verification shall consider data sets obtained under different temperature, waste loading or flow conditions within Saginaw Bay.

Additional output shall be obtained to determine the sensitivity of the system to variation in the model coefficients.

## Application of Model

The contractor shall apply the dissolved oxygen and the coliform models to predict the effects of man's activities and changes in natural inputs. The GLEPS program from the Great Lakes Basin Commission's studies will provide data on changes in waste loads resulting from population growth, economic development, and changes in land use patterns. These data on input waste loads will be employed in the modeling effort to predict the anticipated level of dissolved oxygen and coliform bacteria in the study area. Specifically, the model will be employed to develop projections for at least three levels of growth and future activities.

## Final Report

The contractor will prepare a final project report which will describe the modeling effort, the data base, loads, and the results of the verification and sensitivity analysis. The final report will present the specific projected results for the three levels of future development in the Saginaw Bay area.

## SECTION VIII

## GREEN BAY REGIONAL SCALE APPLICATION

### Scope of Application

The study area encompasses Green Bay and extends approximately one hundred miles in a northeasterly direction from Green Bay, Wisconsin to Lake Michigan. The modeling effort will employ computer programs developed under other tasks of this project. The analysis will specifically employ the linear steady state program framework. A variable spatial grid will be utilized with finer segmentation in the vicinity of major waste inputs and expanded grid sizes as Lake Michigan is approached. It is anticipated that the area will be segmented into about two hundred spatial units.

Two specific water quality problems will be examined by the contractor. The water quality variables associated with these are dissolved oxygen concentration and numbers of coliform organisms under seasonal steady state conditions. The analysis will include oxidation of carbonaceous and nitrogenous material (sequential oxidation of ammonia to nitrate will be considered), algal oxygen production and respiration, oxygen utilization by bottom deposits, release of materials into the water column by bottom deposits, reaeration, aftergrowth, and die-away of total and fecal coliform bacteria. The modeling effort will consider steady state summer water quality on approximately a monthly time scale and will employ linear reactions and feedbacks as appropriate.

### Study Input Data

The contractor will review and gather data on the system geomorphology. Specifically, the contractor will gather information on the geometry of Green Bay, including the depths, volumes, and location of thermoclines.

The contractor will, in addition, develop a hydrologic balance for the region, gathering information as required on inflows, outflows, precipitation over the lake, evaporation, and variations in volume. An advective-dispersive model will be employed. Therefore, the contractor must also evaluate data on velocities and dispersion coefficients. The hydrologic balance must be developed for periods when observed water quality data for the variables being modeled are available.

The contractor is required to examine the observed data base and gather information on water quality variables employed in the modeling effort. The verification of the model at different spatial locations is required. It will, therefore, be necessary to review the existing data base and to select from that data base information on the sources of both point and distributed man-made and natural sources of BOD, nutrients, and bacteria. In addition, water quality data on the temperature, nitrogen series, BOD, dissolved oxygen, chlorophyll, and coliform during at least one and not more than three periods are required. Data sets may consist of information pieced together from a number of different years of observations provided that temperature, flow, and input are similar.

## Modeling Framework

As indicated previously, the contractor will be required to employ a linear steady state program as part of this modeling effort. The variables to be considered as output from the modeling effort will be the dissolved oxygen and coliform profiles in Green Bay. The phenomena to be included in the dissolved oxygen model are oxidation of carbonaceous and nitrogenous material (ammonia conversion to nitrite and nitrate should be considered), algal oxygen production and respiration, bottom oxygen utilization, release of material into the overlying water column from the bottom, and atmospheric reaeration. The coliform model will consider sources of coliform bacteria, aftergrowth, and subsequent die-away of the coliform organisms in the bay.

## Verification Analysis

Model verification for dissolved oxygen and coliform distributions shall consist of a comparison of computed model output under steady state conditions and observed water quality data in Green Bay. Monthly or seasonally averaged information should be employed for the comparison. The comparisons shall be developed between all of the modeled variables simultaneously with the use of consistent parameters and coefficients. The verification analysis shall consider at least one and no more than three steady state water quality data sets. Verification shall consider data sets obtained under different temperature, waste loading, or flow conditions within Green Bay.

Additional output shall be obtained to determine the sensitivity of the system to variation in the model coefficients.

## Application of Model

The contractor shall apply the dissolved oxygen and the coliform models to predict the effects of man's activities and changes in natural inputs. The GLEPS program from the Great Lakes Basin Commission's studies will provide data on changes in waste loads resulting from population growth, economic development, and changes in land use patterns. These data on input waste loads will be employed in the modeling effort to predict the anticipated level of dissolved oxygen and coliform bacteria in the study area. Specifically, the model will develop projections for at least three levels of growth and future activities.

## Final Report

The contractor will prepare a final project report which will describe in detail the modeling effort, the data base employed for model verification, the loads employed, and the results of the verification and sensitivity analysis. The final report will present the specific projected results for the three levels of future development in Southern Lake Michigan.

SECTION IX

FOOD CHAIN MODELING

## Scope of Application

The study area will consist of Lake Ontario as an illustration of Lakewide scale food chain modeling and Lake St. Clair as an illustration of regional modeling of this problem. In both cases, the emphasis is on a broad scale model to provide a basis for tracking potential toxic substances through the food web in the aquatic environment. The analysis should consider, as a minimum, two heavy metals, two organic pesticides, and two other potential toxicants. At least seven compartments in the food web should be considered as subsequently identified. In addition, the spatial segmentation should be on the order of one hundred to four hundred spatial compartments.

## Study Input Data

The contractor will review and gather data on the systems geomorphology. Specifically, the contractor will gather information on the geometry of Lakes Ontario and St. Clair, including the depths, volumes, and location of thermoclines.

The contractor will, in addition, develop a hydrologic balance for the regions, gathering information as required on inflows, outflows, precipitation over the lake, evaporation, and variations in lake volumes. An advective-dispersive model is to be employed. Therefore, the contractor must also evaluate data on lake velocities and dispersion coefficients. The hydrologic balance must be developed for periods when observed water quality data for the variables being modeled are available.

The contractor is required to examine the observed data base and gather information on the concentration of the two heavy metals, two pesticides, and two other potential toxicants in each of the food web compartments to be specified on the modeling framework. In addition, the contractor will be required to develop estimates of the biomass in each of the food web compartments so specified. Data sets and information on concentrations of toxicants and biomass estimates may be obtained by piecing together information from a number of different years of observations.

## Modeling Framework

The contractor will be required to employ a linear interactive compartment program, as previously developed under other tasks in this study. Modifications to the computer software may be necessary to provide flexibility to allow for easy rearrangement of compartment transport and dispersion phenomena as a function of the ecological variable. Any computer program modifications should be thoroughly tested for integrety of the software and to demonstrate veracity. Program modifications should be fully documented.

The ecological compartments to be considered should consist of at least the following:

1. water column
2. sediments
3. plankton (10-100 microns)
4. carnivorous zooplankton (100-1,000 microns)
5. carnivorous zooplankton (1,000-10,000 microns)
6. representative small fish (1-10 centimeters)
7. representative large fish (10 centimeters-1 meter)

(Note: Sizes given are provided as only a general quideline).

The basic modeling framework for each compartment should include the mass of toxicant/mass of compartment and the total biomass measured in convenient units (for example, carbon) of each of the compartments. Also, data on point and distributed sources of each of the toxicants are required as input to the modeling effort and may be obtained from measurements or estimates derived from the literature. For Lake Ontario, the results of the IFYGL program should be reviewed in detail and compiled for use.

Finally, for establishment of the modeling framework, specific consultation will have to be sought to determine the appropriate food web so as to delineate the interactions between the various compartments in the system.

The final step required in the analysis will be a literature survey and review to identify threshold levels of each of the potential toxicants and the effects such levels will have on the ecological compartment.

## Verification Analysis

Verification analysis shall consist, in part, of comparisons of computed model output and observed water quality and biological data. Specifically, a single tracer in the food web should be selected and the model applied to Lake Ontario to determine the magnitude of the linear transfer coefficients. With the same tracer, a verification analysis should be conducted with available data from Lake St. Clair. This will provide one check on the veracity of the linear transfer coefficients. Hydrodynamic transport regimes would be externally supplied information from existing computer programs and models. This verification procedure will then be repeated for each of the potential toxicants to be studied. Additional model output shall be obtained to determine the sensitivity of the system to variations in the model coefficients and linear transfer parameters.

## Application of the Model

The contractor shall apply the food chain model to predict the effect of man's activities on the distribution of toxicants in the two lakes. Specifically, examination of increases and decreases in point and distributed sources of the toxicants should be evaluated. The GLEPS program from the Great Lakes Basin Commission studies will provide data on changes in waste loads resulting from population growth, economic development, and changes in land use patterns or legal regulations. In addition, the contractor will examine the effect of potential changes in growth rates of the various ecological compartments on the distribution and concentration of toxicants. Specifically, the food chain modeling will be employed to develop projections for at least three levels of future activities in the Great Lakes Basin.

## TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The report documents the deliberate decision making process used by the Great Lakes Basin Commission in concluding that rational modeling methodologies could be used to evaluate the effect of different planning alternatives on the Great Lakes and that planning for specific problems affecting the Great Lakes system can be technically and economically supported through mathematical modeling and systems analysis. It assesses the technical and economical feasibility of developing mathematical models to assist in making selections from among alternative management strategies and structural solutions proposed for solving water resource problems of the Great Lakes. The study reviews, evaluates and categorizes present and future water resources problems, presently available data, problem-oriented mathematical models and the state of models and model synthesis for large lakes. A demonstration modeling framework for planning is developed and applied to western Lake Erie and the Great Lakes system. The report evaluates four widely ranging alternatives for future modeling efforts in the Great Lakes and recommends the modeling level most feasible to answer planning questions on scales ranging from the Great Lakes to regional areas. Also discussed is a proposed Commission study which will apply limnological systems analysis to the planning process.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
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