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DEVELOPMENT OF AN OPERATIONAL
NORTHERN AQUATIC ECOSYSTEM MODEL

by

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Development of an operational northern aquatic ecosystem model: completion report

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INTRODUCTION

Lake management in the north is presently influenced by two dominant features. The northern lake ecosystem is characterized by low natural productivity which is very sensitive to light. Northern lakes receive relatively little use. This occurs as light recreational use, some water supply and hydropower, and low-density shoreland development. As a result, there has been little need for a lake management plan to prevent conflicting uses. However, as Alaska becomes more developed, and as the two large city areas, Anchorage and Fairbanks, become urbanized, lake and reservoir management will become an important water resource endeavor.

Resource management often waits until conflicts develop, or algae blooms or gross pollution problems occur before sufficient interest is expressed in an extensive management scheme. In Alaska, as in other areas of the north, the opportunity exists to begin studies and initiate measures to avoid such situations before they occur.

Because of the great geographic, climatic, and geologic variability of Alaska, it is difficult to draw inferences about northern lakes within the state. A traditional limnological study carried out on a particular lake in one region may not be transposable to a problem situation in another nearby region. This situation is particularly critical in the Alaska coastal zone which is dominated by very rugged terrain and great climatic extremes. Further, since only an extremely limited data base exists for Alaska, it is not known whether inference from existing data based on temperate limnological experience may be applicable to northern lakes with several unique features.

Traditional limnological studies will never be completely replaced. Nevertheless, lake management in Alaska may be assisted by use of a comprehensive lake ecosystem model which has been constructed and adapted in such a way as to account for the peculiar features of the northern lake environment. A comprehensive model would especially allow efficient use of the sparse data base and associated inferences. Validation studies would raise questions which would provide a basis for efficient planning of future limnological studies. Where a management change such as a diversion of water into a lake, a higher nutrient input, or a

drastic change concerning a fishery is anticipated, a good model may be able to assess the consequences.

Because of the complexity of aquatic ecosystems use of a comprehensive model has disadvantages. Validation of some components of the model may be difficult, especially with sparse data; therefore, user acceptance of the model may be impaired. A situation may occur in which the program becomes too complex to understand or assess problems or inaccuracies in the results.

A good northern lake ecosystem model may have two potential uses important to Alaska. Several large, very deep reservoirs behind hydropower dams are planned in southcentral Alaska. If built, they would form one of the largest hydropower projects undertaken in the United States. When the construction plan is developed, a special program of ecosystem model development would be quite useful. Another wide basis of application is the study of the use of northern lakes for fish hatchery water supply. The State of Alaska has embarked on an extensive fish hatchery program which will invest up to 50 million dollars on capital improvements.

Water supply is an important feature of fish hatchery design; particularly during the wintertime period of active egg development characteristic of many salmonoid fishes. Most salmon hatcheries will be in the coastal region of Alaska, a hydrological region of very poor winter stream flow and groundwater supply. As a result, lakes will become an important water supply alternative. However, Alaskan coastal lakes are poorly understood and the use of lakes for water suppy could result in large variations in the water quality to the fish hatchery site. A comprehensive lake model would be useful in future assessment studies of particular sites or for a more general study of the feasibility of coastal lakes for a fish hatchery water supply. As most of these facilities are yet in the design or early planning stage this is an important use of the model.

This research project has accomplished several important steps toward developing a useful tool for northern lake management. An existing aquatic ecosystem model based on temperate lake experience was examined. Its weak points have been identified and a capability to simulate ice cover developed. The adaptation of the model to explain northern phenomena is outlined and includes several suggestions for

altering the model for future use. An update of other modeling experience has been provided including a rather extensive literature survey of existing aquatic ecosystem models with an emphasis on use in the north.

OBJECTIVES

The objective of this project was to study means of suitable adaptation of an existing ecosystem model to user-oriented problems in cold regions. The project used Harding Lake as a case study and addressed system characteristics and range of variation expected in a typical northern lakes situation, the nature of general climatic conditions, model inputs and outputs, general constituent levels, and certain aspects of the lake geometry. An appropriate strategy for simulating aquatic ecosystems in cold regions was also studied.

RESEARCH RESULTS

The research effort was carried out over a two-and-one-half-year period in several stages.

The project began with the acquisition of the Chen-Orlob aquatic ecosystem model from Resource Management Associates. William Norton of Resource Management Associates provided a short seminar on the use of the model which was attended by Institute of Water Resources personnel, other University of Alaska personnel, and several people from state agencies. Mr. Norton also assisted in the installation of the model, a rather large program, on the University of Alaska, Fairbanks, IBM 360 computer. Resource Management Associates continued to provide assistance with coding problems throughout the project. The Chen-Orlob model, developed in the early 1970s, is based on a wide range of experience with temperate aquatic ecosystems (reservoirs and lakes).

Concurrent with establishment of this project, a separate project, under the sponsorship of an EPA grant, obtained information on the possible effects of increased nutrient input to Harding Lake, a rather large, deep subarctic lake 80 km southeast of Fairbanks, Alaska. As it is easily accessible and some background data existed, it provided a good source of original field data for the modeling project. A wide variety of information was used from the Harding Lake project including

measurement of physical and chemical water parameters, ice thickness, depth, and numerous biological and chemical descriptive parameters. The project also studied certain features of the watershed system and provided some climatological parameters which were useful for the modeling effort.

A literature search was conducted throughout the project in an effort to augment the information obtained from the Harding Lake sample data, to review other uses of the Chen-Orlob model, and to determine the model's relative strengths and weaknesses compared to other modeling strategies. We reviewed the general nature of other available models although we did not attempt a definitive comparison to other models. We determined the impact of specifically northern phenomena on a lake ecosystem and updated the equations for internal model relationships used to describe key lake interactions and mechanisms.

Midway through the project in the fall of 1975, the University of Alaska discontinued the IBM 360 computer system and switched to a Honeywell 88 system. The installation of the model on the Honeywell Fortran compiler brought out several program errors that were not previously observed on the IBM 360. The new system allowed use of a visual display terminal which allowed quicker manipulation of the program. Unfortunately, switching computers midway through the project absorbed a great deal of project and personnel time.

The model, although relatively well founded and widely used for temperate aquatic ecosystems, was found to have several problems which made difficult a direct adaptation to northern lake situations. The definition of input parameters is unclear; ice-related phenomena could not be simulated; and a useful radiation routine was needed in order to handle adequately the very intense ice breakup season. The large size of the program made changes difficult as errors were often shielded by internal interaction. Many of the internal functions and calculation methods were not in step with current knowledge. There were no accurate and complete model descriptions, definitions, or a list of variables; in addition, the output values gave no indication of expected error involved which made a trend response interpretation of results very difficult. A great deal of time was used in correcting these problems before the model could be evaluated and revised for use on northern lakes.

In the fall of 1976, a coinvestigator on the project, Patricia Fox attended an EPA-sponsored workshop on aquatic ecosystem modeling. The workshop brought together people from all over the United States to discuss and pool information for a summary of the state of the art of modeling as a resource tool for use in water resource planning. Much of the discussion centered around the problems mentioned above which are not merely limited to the Chen-Orlob model. Specific aims, a definition of parameters, identifying problem needs, and describing parameter values for various areas of the United States were discussed. The general consensus of the workshop was that the models were a useful tool for water resource planning and management but much remains to be done about validation and parameter definition and evaluation.

The output of this research effort included:

1. Development of a user guide to aquatic ecosystems modeling of northern lakes.
2. A closer definition and examination of the biological portion of the model with emphasis on needed adaptation to the northern climate.
3. Examination of the nature of the thermal stability during and immediately after the ice breakup period.
4. Identification of the important potential of the model for use in the study of lake water supply for an extensive salmon hatchery program.

Once the model is sufficiently revised along the lines suggested by the results of this project, it may prove to be a useful tool for a variety of lake management and other resource activities in Alaska and other northern regions.

Several papers were prepared as a result of this project:

1. The user's guide.
2. A general project description paper.
3. An examination of statistical vulnerability of modeling situations in northern lakes where the constituents have extremely low concentration.
4. Two papers which examine the adaptation of ecosystem modeling to northern lakes, one with emphasis on climatological and physical interaction and the other with emphasis on the chemical and biological components.

5. A review of the present literature pertaining to aquatic ecosystem modeling with emphasis on adaptation to the northern environment.

Several potential applications of the model were identified; these include the reservoirs of a large hydroelectric project in southcentral Alaska, the salmon hatcheries development project mentioned previously, and other lake and reservoir management schemes throughout the state.

SUMMARY

We have evaluated a model which can assist in northern lake management and have offered suggestions for an appropriate strategy for approaching the problems of simulating northern lake ecosystems.

There are a number of difficulties in using a large simulation model to study lake management problems. Spring breakup is a very important season in arctic limnology, yet it is extremely difficult to simulate because of the unstable nature of the water column during that period. The measurement of suitable parameters in sufficient quantity to provide a validation is difficult. These measurements are practically nonexistent for most applications. Nevertheless, most operational users require a validation demonstration, even one based on poor measurements. User interest in complex models seems low; and often agencies are interested in looking at a strategy for solution only after a problem occurs.

The project has resulted in the development of a suitable strategy for using the adapted model for lake management in the north. We have made numerous contacts with personnel of state and federal agencies in Alaska and have created an interest in possible adaptation of the model, particularly for study of a salmon hatchery water supply lake.

DISSEMINATION OF RESEARCH RESULTS

Six publications will result from the project work; the abstracts follow:

Northern Lake Modeling--A Literature Review

P. M. Fox, J. D. LaPerriere, and R. F. Carlson
Paper submitted to Water Resources Research

Abstract: This literature search shows that no lake simulation model has been developed specifically for northern lakes (by our definition, those above 40°N latitude with a continuous winter ice cover and large seasonal differences in daylight pattern, and which are oligotrophic). However, a number of low-latitude lake ecosystem models exist that may be modified to suit these conditions. These are summarized according to the following: philosophy of approach, physical dimensioning, water quality parameter, ice and snowcover, lake vs. reservoir, latitude, depth, and biological interaction considerations.

A difference in model sophistication exists between physical and biological/chemical considerations in many cases. Examination of both types reveal great variation in approach to modeling, and, more importantly, the general dependence on theoretically-determined biological input parameters. These existing models require modification especially before using ones specific to location or time, or in integrating new component models.

A User's Guide for a Northern Aquatic Ecosystem Model

P. M. Fox, R. F. Carlson, and C. N. Hok
In preparation as an IWR report.

Abstract: Although several versions of the Chen-Orlob model have been and are currently being used there has been a great lack in the quality of documentation available to the user. This manual attempts to fill that void, by presenting a concise description of model interactions, internal functions, and assumptions made in the model development. The manual also includes a complete variable list with definitions, a list of constants supplied by the model, and a complete input summary. The manual describes a subarctic lake ecosystem model that is still in a developmental stage. It should prove useful, however, to anyone using this or any version of the Chen-Orlob model.

Adaptation of an Aquatic Ecosystem Model to Northern Lakes: Part I - General Considerations

P. M. Fox, J. D. LaPerriere, R. F. Carlson, J. D. Fox
Paper in preparation for Water Resources Research

Abstracts: Northern lakes face the possibility of a great amount of development but with a number of handicaps for devising the appropriate solutions to resultant problems. Little limnological data is available; temperate lake understanding dominates scientific inferences; a great diversity of lake environments exists within the north; and the lake cycle is dominated by a poorly understood, abrupt ice-out process. A widely temperate aquatic ecosystem model was adapted to northern lakes for use as a management tool. Although the complexity of the lake ecosystem and the sparsity of data makes a large modeling effort very difficult, a solid foundation has been established for useful application to a variety of management problems. Some special accomplishments of the project include: a simulation of the ice-out process, adjustment of the biological components to northern conditions, a special consideration of the statistical vulnerability of low concentration measurements, and development of a user's guide to the computer program. An important application of the model is expected to be made in a study of the use of northern coastal lakes for salmon hatchery water supply.

Adaptation of an Aquatic Ecosystem Model to Northern Lakes: Part II - Climatological and Physical Components

R. F. Carlson, J. D. Fox, C. N. Hok
Paper in preparation for Water Resources Research

Abstract: As a part of a larger effort of adapting a temperate lake-based ecosystem model to the northern environment, several aspects of the climatological-physical component were considered. Some key features of the northern climate include radiation, sun angle, cloudiness, relative humidity, air temperature, and wind. All are measured only at a few locations in the north so special consideration must be given to operation of a complex model with sparse data. Other considerations of special interest include: the boundary layer with special attention to water, ice, snow and evaporation processes; the drainage basin which involved the stream runoff regime quality characteristics and the influence of bogs and marshes; and finally, the lake body itself which involves light penetration, light/temperature regulation, ice and snow cover effects, and a very critical and abrupt spring ice-out process.

Adaptation of Aquatic Ecosystem Models for Northern Lakes: Chemical and Biological Considerations

J. D. LaPerriere, P. M. Fox
Paper in preparation for Water Resource Research

Abstract: Existing aquatic ecosystem models have been found inadequate for application to northern lakes. Most are not capable of modeling for the period of ice cover, and many of the basic assumptions upon which the models are based are invalid. This paper presents the basic assumptions concerning chemical and biological cycles in northern lakes and makes suggestions for their inclusion in existing and new models. Biologically important chemical species and trophic levels up to and including secondary consumers are considered.

Statistical Vulnerability of Sampling and Defining Lake Parameters

P. M. Fox, C. N. Hok, R. F. Carlson
Paper in preparation for the Hydraulics Division Journal, ASCE

Abstract: Sampling various constituent concentrations and conditions in subarctic lake ecosystems present special problems in terms of interpretation of results. Large scale variability in time and space coupled with usual measurements errors, small sample sizes, and the importance of small magnitude values and shifts can make parameter determination using conventional sampling and statistical techniques meaningless. Examples of these problems and possible solutions are described for one physical and one biological parameter determination from sample information. Some general approaches are suggested which will reduce the vulnerability of parameter estimates to being lost in associated error.

TRAINING

The project did not directly support graduate thesis research. However, a graduate student in natural resource management worked extensively on the project in the literature review, program manipulation, data reduction, and other phases of the work. Several undergraduate and graduate students in engineering and science were also employed on the project.

This work, although informal in nature, was an important part of the students' degree programs.

COLLABORATION

There have been numerous agency contacts, including personnel of the U. S. Corps of Engineers, U. S. Army-Cold Region Research Engineering Laboratory, Alaska Department of Fish and Game, and several other agencies. We have also related closely to a study of Harding Lake conducted at this institute. In addition, we held a small workshop at the beginning of the project which was attended by university personnel and state employees.

We maintained close contact with several other more basic limnological studies at the University of Alaska, Fairbanks; and of the Freshwater Institute of Manitoba, Canada. One project participant attended a national workshop on aquatic ecosystem modeling which provided a useful two-way exchange, particularly on sampling problems.