


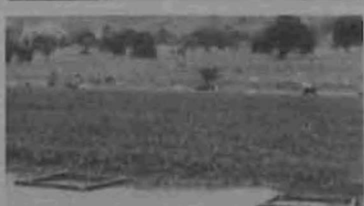

MISCELLANEOUS PAPER A-81-1

WORKSHOP ON MODELING OF AQUATIC MACROPHYTES

By Joseph H. Wlosinski

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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20. ABSTRACT (Continued).

The workshop objectives were to: (1) determine which environmental problems could be addressed by models, (2) determine what type of models could best address the questions, and (3) determine what information would be needed for those models.

The workshop participants concluded that all of the environmental problems presented could theoretically be addressed by models. The models would range from simple regression to mechanistic models, including two-dimensional, coupled, hydrodynamic-biological/chemical models. The use of a particular model would be based on the questions asked and the information available. Many of the models are not now available and would have to be developed. Field and laboratory studies will be required as input to the modeling effort.

PREFACE

This report summarizes the results of the Workshop on Modeling of Aquatic Macrophytes held at the U. S. Army Engineer Waterways Experiment Station (WES) on 19-20 February 1980. The workshop was sponsored by the Aquatic Plant Control Research Program (APCRP) under Work Unit 31702 entitled "Predictive Techniques for Evaluating Aquatic Plant Control Strategies."

The workshop was organized, conducted, and the report prepared by Dr. Joseph H. Wlosinski under the direct supervision of Mr. D. L. Robey, Chief, Water Quality Modeling Group, and under the general supervision of Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division, and Dr. J. Harrison, Chief, Environmental Laboratory. Mr. J. L. Decell was the APCRP Manager.

The Commander and Director of the WES during this period was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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WORKSHOP ON MODELING OF AQUATIC MACROPHYTES

PART I: INTRODUCTION

1. Numerous lakes, reservoirs, rivers, and canals in the United States have an overabundance of aquatic plants. The control of these plants is the goal of the Aquatic Plant Control Research Program (APCRP). This goal must take into account factors, such as environmental considerations, that are integral parts of each management plan (Sanders and Decell 1977). Techniques to enhance the management plans for aquatic plant control are needed that will aid in predicting the response of the environment to various control strategies. One such technique being considered within the APCRP is the use of mathematical models.

2. A workshop held at the U. S. Army Engineer Waterways Experiment Station (WES) 19-20 February 1980 addressed the use of mathematical models for predicting the environmental impact of various management and control strategies being developed in the APCRP. The workshop was attended by personnel from the Environmental Laboratory, WES, and by selected consultants with experience in modeling and/or aquatic macrophyte biology (Appendix A). Drs. Carpenter, Fontaine, Godshalk, Park, and Titus, in addition to being participants in the workshop, submitted letter reports that were comments on modeling within the APCRP.

3. Workshop participants were asked to address a matrix of topics including: (a) aquatic problem species (Table 1); (b) types of control (Table 2); (c) environmental conditions where the species occur (Table 3); and (d) a list of expected environmental problems attributable to the management action (Table 4). The workshop objectives were to:

- *a*. Determine which environmental problems could be addressed by models.
- *b*. Determine what type of models could best answer the questions.
- *c*. Determine what information would be needed for those models.

The participants were also instructed that the models were to be used as management tools, and as such should require as few field measurements and coefficients as possible.

4. The objective of this report is to summarize the results of the workshop and the letter reports, which have been paraphrased or quoted. The views and opinions expressed may not necessarily be ones that were agreed upon by all the participants; however, the recommendations represent a consensus.

PART II: MACROPHYTE WORKSHOP SUMMARY

Environmental Problems Addressed by Models

5. In response to which environmental problems (Table 4) could be addressed by models, the participants answered that all the problems could be--with reservations. The reservations concerned the fact that although mathematical models can theoretically address all the questions, some of the information needed for the construction of models is not available at the present time. Because of the lack of data concerning some questions, field and laboratory research studies and experiments would probably be needed before models could be developed and applied with a fair degree of success. One example concerned the much-studied Lake Wingra where a population of *Myriophyllum spicatum* exploded and suddenly crashed without investigators knowing how or why these events took place. Similar situations occurred with *Hydrilla* in the Lochloosa and Orange lakes in Florida. The comment was made that until it was known how or why these events occurred, no predictions could be made for when such events would take place.

6. A number of comments concerning the initial list of environmental problems were made by workshop participants: (a) fish spawning requirements should be included when the impact of habitat elimination is being considered; (b) the buildup of toxic substances should include the buildup in the sediments and the water column as well as bioaccumulation; (c) toxic substances should include the control agent as well as the toxics resulting from the application of control measures; and (d) the degradation of aesthetic qualities are actually the way the other nine problems listed in Table 4 are perceived. Problems not addressed during the workshop but submitted in the reports included possible perturbations to ecosystem properties described as changes in community structure, ecosystem metabolism, complexity and stability, species diversity, simplification of trophic relationships, and impact on succession. It was also mentioned that ecologists do not agree on these conceptual ecosystem properties, which may make modeling very

difficult. Nevertheless, the properties do represent possible changes that result from the control of aquatic macrophytes, and, therefore, should be considered.

Types of Models Needed to Address Problems

7. All participants agreed that more than one model would be needed to address the entire problem matrix. The models mentioned would range from simple regression models to two-dimensional, horizontal or vertically averaged, coupled hydrodynamic-biological/chemical models, and their use would be based on the questions asked and the information available. Participants also agreed that if a simple model could answer the question, a complex model need not be developed for the same problem. This same idea has been voiced by a number of authors (Alonzo 1968; Caswell et al. 1972; Crissey and Phillips 1974; Innis 1975; and O'Neill 1970).

8. Most participants supported the concept of developing mechanistic models of the ecological process in aquatic ecosystems, although a good deal of skepticism was voiced concerning the application of such models as accurate predictors during the early developmental stages. Some of the support for mechanistic models was due to their heuristic role, so that a better understanding could be gained concerning those processes that regulate macrophytes as well as other components of aquatic ecosystems. Part of the skepticism dealt with the ambitious goal of addressing the entire problem matrix with the use of mechanistic models that should require few measurements and parameters, be realistic in the representation of processes, be applicable to a wide range of systems, and be relatively precise in its predictions for a specific situation. This may be difficult, if not impossible, for, according to Levins (1966), there is a trade-off among realism, generality, and precision for a particular model. Problems dealing with the lack of information, a good data base, and accurate conceptual models led the group to recommend that mechanistic models are needed; however, development of the models should be a continuing effort to keep pace with the science.

This disciplined approach would require that deterministic model development be coupled with a strong experimental program aimed at studying the critical ecological relationships involved. Such a program would keep pace with and would stimulate the increasing body of knowledge concerning macrophytes and their environment.

9. Besides recommending the development of mechanistic models, the participants strongly recommended the development of simple models for immediate use within the APCRP. These would be empirical, curve-fit, or regression models and would mainly be used for short-term (10-90 days) predictions. For example, oxygen or nutrient concentrations in an area where macrophytes were mechanically cut without removal could be regressed against time. Much of the compiled information could eventually be used in mechanistic models, with incorporation in a number of steps. For example, an empirical term could be used for the dependence of plant growth on substrate type, and a mechanistic term could be used for the light-photosynthesis relationship. As information became available on the relationship between plant growth and substrate type, the empirical term could be replaced with a mechanistic algorithm.

10. Participants also discussed what dimensions a model would need to address APCRP problems. The consensus was that the range of APCRP problems was too great to be answered by a single-dimensional scheme. For example, if the question dealt with herbicide concentrations down and across river from an application site, a two-dimensional, vertically averaged model might be appropriate. On the other hand, if the question dealt with the effect of decaying macrophytes on the oxygen concentrations in the hypolimnion of a reservoir, the two-dimensional, vertically averaged model might be of little use. The best alternative may be to maintain the flexibility and the capability of modeling ecosystems with a combination of models, depending on the questions asked. Since the experience of many of the invited participants was in the biological fields, the workshop proceeded under the assumption that the hydrodynamics for one- and two-dimensional models would be available to predict transport and dispersion, and that biological algorithms could be coupled to them. The possibility of developing a coupled

three-dimensional model was not recommended.

11. Questions dealing with the time step for modeling were also raised. Most of the participants agreed that most of the problems could be handled using a one-day time step interval. The comment was made that fish do not respond to the average daily oxygen concentration but to the lowest concentration encountered. The recommendation was to use statistical analysis about the mean concentration rather than incur the added costs of simulations with shorter time steps. For those situations where the analysis showed possible oxygen depletion problems for parts of a day, additional simulations might be needed. The possibility of using a variable time step for certain problems should also be considered. For example, a decomposition model could use daily time steps for the first month of simulation and longer time steps thereafter.

Grouping of Problems for Modeling

12. Elements of the matrix were combined to make it more manageable, and two groups of problems were developed. One group dealt with those control measures that immediately affect the macrophytes. This situation would occur with a number of chemical controls and the use of mechanical harvesters and would produce a large mass of dead plants. The problems addressed were oxygen depletion, increased nutrient load, turbidity, algal blooms, and fish kills. Only decomposition would need to be considered for many of these problems, especially for short-term effects. This is an area in which some information is now available and to which models could be put to immediate use.

13. The other group of problems dealt with delayed control techniques that would not kill large amounts of macrophytes in a short period of time. This could occur in the case of controlled release herbicides, biological control, or environmental management. Possible problems for this group are not as well defined, have more interacting variables, usually occur over longer time periods, are not as well understood, and therefore would be more difficult to model. Nevertheless, the participants agreed that models should be developed for both problem groups.

Control measures
with immediate effects

14. Models dealing with control measures with immediate effects were further subdivided into models for short-term (10-90 days) and long-term effects. Only a decomposition algorithm would be needed for the short-term effects unless the macrophytes were removed from the system. The long-term effects would require a model that allowed for regrowth of macrophytes. It would be similar to a model for control measures with delayed effects. A number of effects concerning community structure and function were discussed as ones that occur after one year, but concern was also voiced as to the reliability of models when a period longer than one year is being simulated. Part of this concern was due to the validity of present water quality or ecological models. Many of these models are untested or are tested only in a qualitative fashion. Quantitative tests are often incomplete, the tests are not standardized, or the tests have shown problems with the models.

15. Greater environmental problems are expected to occur in those situations where macrophytes are not removed from the aquatic system. In situations where macrophytes were removed from small (0.2-ha) plots, short-term effects on water chemistry and metabolism were negligible (Carpenter and Gasith 1978). Resuspension of sediments from treated shallow water areas of larger plots may cause increased turbidity, which is a problem that should be handled with hydrodynamic models. For long-term effects, harvesting can remove an active phosphorus pool from the system (Carpenter and Adams 1977; Prentki et al. 1979; Carpenter, in press), with important effects on phosphorus dynamics (Loucks and Weiler 1979).

16. In situations where macrophytes are not removed, a decomposition model could be used to predict increased nutrient load and oxygen depletion. Although not necessarily included in the same model, fish kills and algal blooms can be addressed by the use of information gained from a decomposition model. Care would have to be taken, since systems could react differently depending on the presence or absence of nutrient limitation.

17. The variables that should be included in a decomposition model were discussed in detail. To facilitate the initial development of a macrophyte decomposition model, the recommendation was made to assume that the treated area would contain only one plant species. The participants agreed that nutrient concentrations in macrophyte tissue are very important when decomposition is being considered and that these concentrations are not uniform. Titus (1977) has found significant differences in tissue phosphorus concentrations for Myriophyllum spicatum in Lake Wingra for different plant parts, for different times of the year, and for littoral sampling areas only 100 m apart. The knowledge does not exist at the present time that would allow the prediction of plant nutrient concentrations, and the recommendation was made to analyze plant tissue, at least initially, just prior to the application of a control measure to supply accurate information for initial values for the model. Seasonal nutrient curves would be made when sufficient information became available. The curves would subsequently be used in models that could predict the time of year control measures would produce the least amount of environmental damage. In addition to the variable for internal nutrient concentrations, environmental nitrogen would also have to be included as a state variable, since the decomposition process may be nitrogen limited. Other possible state variables included carbon and animals. The main driving variables agreed on were temperature and oxygen concentration, but the control method may also need to be included. The initial discussion proceeded with the assumption that the dead macrophyte mass would be partitioned into fine and coarse particulate matter and dissolved organic matter. The latter part of the discussion included the recommendation that the two particle sizes be combined to make the model more manageable.

18. The variable list for a decomposition model was not unanimously agreed on; undoubtedly, experimentation would be needed before decisions could be made concerning the effects of certain variables on decomposition. Part of the disagreement stemmed from whether the model was for short- or long-term simulation. An agreement was reached that most of the preceding discussion was for short-term models, defined as

the time most of the labile fraction requires to decompose. In most situations this would be less than 90 days. The comment was also made that a worse case prediction should be made, assuming that decomposition was instantaneous and all nutrients tied up in the macrophyte mass would be made immediately available.

19. One problem that may not be significant if all macrophytes were killed at the same time, but would occur if a decomposition algorithm would be included in a growth model, is the age of decomposing tissue. The sloughing of shoots and leaves and the senescense of whole plants may occur over a period of weeks to months, and nutrient release rates depend on elapsed time since death. These factors may make the partitioning of detritus into age classes necessary. Partitioning detritus by age was done by Carpenter (in press) when tissue phosphorus concentration during macrophyte decay was being modeled, and it is suggested as being important for nitrogen concentrations in empirical studies by Nichols and Keeney (1973). Partitioning detritus into age classes could increase not only the number of coefficients needed for the model but also the computational costs. One possible solution to this problem would be to divide detrital nutrients into compartments that behave in a similar manner. For example, detrital phosphorus may be divided into that which is leachable and that which is refractory. A similar technique was used by Boling et al. (1975). They created a detritus processing model in the form of a matrix whose entries were detrital biomass that was classified according to particle size and extent of microbial colonization. Detritus was transformed with time through the matrix from resistant, aggregated, whole organic material to fine particulate organic matter that is colonized by microorganisms.

Control measures with delayed effects

20. Because some of the control measures do not kill all of the plants in an area in a short period of time, it will also be necessary to have the capability to predict plant growth. This capability, in addition to predicting environmental problems, could eventually be used to predict the suitability of a particular area for macrophyte

colonization. There was general agreement that a model to predict macrophyte growth should have spatial resolution in the vertical direction. Justification for this recommendation was that most aquatic systems have strong abiotic gradients such as light, redox, temperature, and pressure along the vertical axis with a concomitant change in rates for biotic processes. Titus et al. (1975) have developed a model (WEED) with such resolution, and it was recommended that this model act as a starting point for an APCRP macrophyte growth model. WEED is a mechanistic model that incorporates the main physiological processes of photosynthesis, respiration, and excretion; biomass is divided into leaves, stems, roots, and carbohydrates. The main forcing functions are light and temperature.

21. Because the model WEED is site and species specific, additional development would be needed to allow for generality. Additional processes may be needed, with many in need of additional laboratory and field research. It was recommended that research in the near future be limited to the species *Myriophyllum spicatum*, *Hydrilla verticillata*, *Eichhornia crassipes*, and *Egeria densa*. If field research was planned for different parts of the country, the combination of different species and sites would allow researchers to decide whether models, algorithms and coefficients could be general, species specific, or region specific. Since the two important growth forms of macrophytes, submerged and floating, are represented, models that are specific for growth form could also be developed.

22. A number of possible simplifications to the WEED model were discussed that would attempt to retain as many essential features of WEED as possible. These modifications would reduce data requirements, thus making it a better management tool. The model would still simulate carbon gain as the net result of physiological processes. Simplifications that were discussed included combining leaves and stems, increasing the depth of individual strata, and replacing temperature acclimation with a response function for plants acclimated to different temperatures. The only way results of any of these or other changes to WEED are to be known would be to make the changes, run the simulations,

and compare predicted results with actual field-measured values. Other possible refinements to WEED deal with respiration, sloughing, sediment variability, nutrient limitations, phenologic cues, and interactions with epiphytes.

23. Any revised version of WEED, whether simpler or more complex, must consider the potentially significant weaknesses and assumptions of WEED. WEED multiplies some peak photosynthetic rate "PMAX" by two fractions reflecting light and temperature limitations on photosynthesis. PMAX is an indicator of the overall physiological state of macrophyte tissues, and thus it must incorporate the influences of pigment content, carboxylase activities, tissue age, and tissue nutrient status. It also implicitly incorporates the effect of inorganic carbon availability, which is possibly dependent on pH and total dissolved inorganic carbon concentration, although this effect could be modeled separately. PMAX is quite likely to vary seasonally with species and with site, and may be difficult to measure. WEED also had difficulty simulating growth to the surface for Myriophyllum spicatum near its greatest rooting depth (2.4 m) in Lake Wingra (Titus et al. 1975). This could be due to the extreme reduction in simulated photosynthesis when both light and temperature are distinctly suboptimal in spring, or to the failure of WEED to incorporate stem elongation behavior.

24. Other areas of concern dealing with mechanistic macrophyte growth models were noted. One dealt with the extrapolation from short-term laboratory measurements of photosynthesis and respiration to long-term estimates of growth in the field. Another concerned density-independent controlling factors such as winter kills or droughts, which are also unpredictable factors. If a model is based on long-term climatic observations, it may predict the "average" macrophyte problem expected, which can be very different from what is observed. One possible solution to this problem would be to use Monte Carlo or stochastic simulations. One other area of concern dealt with the coupling of littoral and pelagial zones.

25. A growth model that is more empirically based was also discussed. Macrophyte biomass would be separated into horizontal layers.

Daily net production would be estimated by regression that would incorporate light, temperature, species, and existing biomass. Net production would be partitioned among strata, possibly based on optimum leaf area. Other possible macrophyte growth models are available, although all are not necessarily horizontally layered. These are reported in Ewel and Fontaine (1979), Park et al. (1974), Scavia et al. (1975) and Wlosinski et al. (1974).

PART III: CONCLUSIONS AND RECOMMENDATIONS

26. Conclusions and recommendations based on the workshop are as follows:

a. All of the environmental problems that are listed in Table 4 can theoretically be addressed by models.

b. Future field and laboratory studies will be required as input to the modeling effort.

c. A number of models would be needed for the APCRP, ranging from simple regression to mechanistic models, including two-dimensional, coupled hydrodynamic-biological/chemical models. All should be developed with the use of a particular model being based on the questions asked and the information available.

d. A one-day time step would be suitable for most biological algorithms.

e. APCRP modeling efforts in the near future would best be served if research was directed toward *Myriophyllum spicatum*, *Hydrilla verticillata*, *Eichhornia crassipes*, and *Egeria densa*.

f. Models dealing with short-term problems for control measures that produce large amounts of dead plants in a short period of time without harvesting need only a macrophyte decomposition algorithm. The assumption should be made that the treated area would contain only one plant species. Development time for these models could be relatively short.

g. Because of the importance and variability of macrophyte nutrient concentrations for predicting decomposition and its effects on the ecosystem, macrophytes should be analyzed prior to application of control measures.

h. A macrophyte growth model should be spatially variable in the vertical direction. The WEED model (Titus et al. 1975) should be used as a starting point for a growth model for use within the APCRP.

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Table 1

Problem Species of Aquatic Macrophytes

Myriophyllum spicatum	Eurasion watermilfoil
Hydrilla verticillata	hydrilla
Eichhornia crassipes	floating waterhyacinth
Egeria densa	Brazilian elodea
Alternanthera philoxeroides	alligatorweed
Potamogeton illinoiensis	Illinois pondweed
Elodea canadensis	common elodea
Najas quadalupensis	southern naiad
Pistia stratiotes	water-lettuce
Cabomba caroliniana	fanwort

Table 2

Types of Control for Aquatic Macrophytes

Chemical

2,4-D

DMA (Weedar 64)

BEE (Aqua-Kleen)

Endothalls

Aquathol K

Aquathol

Hydrothol 191

Hydout

Diquat

Glyphosate (not yet cleared for aquatics)

Amitrol T

Dichlobenil

Fenac

Simazine

Biological

Insects

Neochetina eichhorniae

Neochetina bruchi

Arzama densa

Sameodes albiguttalis

Agasicles hydrophila

Vogtia malloi

Litodactylus leucogaster

Acentropus niveus

Fish

Ctenopharyngodon idella

(Continued)

Table 2 (Concluded)

Pathogens (Fungi)

Cercospora rodmanii

Fusarium roseum

Mechanical

Harvesters

Aqua-Trio (Aquamarine)

Allied Aquatics

Limnos Ltd.

Altosar

Environmental Management

Water level flunctuation (drawdowns)

Plant competition

Table 3

Environmental Conditions of Aquatic Macrophytes

Area

Rivers

Reservoirs

Streams

Canals

Lakes

Ponds

Backwater areas

Characteristics

Waterflow - 0 mph to slow moving

Depths where most problems exist - >0 to 12 m

Water temp - Tropical (South Florida) to Cold (Washington State)

Water body size - <0.1 hectare to thousands of hectares

Nutrient load - various

Sediment load - various

Turbidity - 0 to cloudy

Potable waters

Irrigation waters

Table 4

Possible Environmental Problems Caused by Control Measures

Increased nutrient load
Increased turbidity
Elimination of desirable species and/or habitat (fishes and plants)
Algal blooms
Fish kills
Contamination of water near potable supply intakes
Oxygen depletion
Buildup of toxic substances
Shoreline erosion due to elimination of shoreline vegetation
Degradation of aesthetic qualities

APPENDIX A: WORKSHOP PARTICIPANTS

Dr. John W. Barko
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P .O . Box 631
Vicksburg, Miss. 39180

Dr. Eldon Blancher
Marine Environmental Science Consortium
3940 Government Street
Mobile, Ala. 36609

Dr. Stephen R. Carpenter
University of Notre Dame
Notre Dame, Ind. 46556

Joseph L. Decell
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

Dr. Thomas D. Fontaine, III
Savannah River Ecology Laboratory
P. O. Drawer E
Aiken, S. C. 29801

Dr. Dennis E. Ford
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

Dr. Gordon L. Godshalk
University of Florida
Gainesville, Fla. 32611

Joseph L. Norton
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

Dr. Richard A. Park
Rensselaer Polytechnic Institute
Troy, N. Y. 12181

Donald L. Robey
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

William N. Rushing
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

Dr. John E. Titus
State University of New York at Binghampton
Binghampton, N. Y. 13901

Dr. Joseph H. Wlosinski
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631
Vicksburg, Miss. 39180

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