AQUATIC ECOSYSTEM ANALYSIS & MODELING

1975

A Sea Grant Perspective

by
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Waimanalo, Hawaii

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on behalf of those members of the ecosystem analysis and modeling community who participated in the Sea Grant workshop held on this topic and who provided much of the substance of this publication

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This publication is an outcome of the Sea Grant Workshop on Aquatic Ecosystem Analysis and Modeling held at the University of Wisconsin, Madison, on July 21, 22 & 23, 1975.

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I. INTRODUCTION

The Office of Sea Grant (OSG) presently supports aquatic ecosystem analysis and modeling projects at a number of institutions. OSG's interest at this time lies in assuring that current projects enjoy good communications with each other and that the focus of Sea Grant's future support to such projects is sharpened in order to achieve maximum return for the limited funds available to Sea Grant for work of this type.

To this end, an intentionally small and informal workshop was convened in July 1975. In fact, the retrospective consensus is that it was entirely too small and informal. In order to make up in part for perceived deficiencies in the workshop itself, the chairman produced a draft report that was based upon issues explicated or implicated in the workshop and supplemented by his own views. As a means of sidestepping total blame for the product, the chairman issued it as a review draft for the participants and was rewarded in due course with well turned responses in no uncertain terms. With these responses smoldering in one hand, the review draft was dismembered and recreated in its final form as expressed here. Had the responses to the review draft been in agreement, the rewrite task would have been comparatively simple. Of course, they were not in all cases. Therefore, the chairman has been unsuccessful in sidestepping the blame for what appears here while acknowledging with sincere gratitude the wealth of scientific talent that provided the bases for this document in the workshop and in the criticisms of the review draft.

Frankness is frequently dangerous and yet circumspection frequently obscures what is so. The review draft was called dangerously frank by one workshop participant and this version may also contain that danger. To lay any such ghosts, let it be said here that ecosystem analysis and modeling is a very young and potentially very valuable tool for intelligent management of aquatic resources. Because of its youth, it necessarily is today a long way from achieving its full potential. To obfuscate the problems this discipline faces today would be counterproductive just as it would be counterproductive to employ the discussions of problems in these pages as weapons to inhibit the advancement of the young discipline.

The workshop was held at the University of Wisconsin's Madison campus and hosted by Dr. Robert Ragotzkie, Director of that university's Sea Grant College Program. It was organized and conducted by The Oceanic Institute, Hawaii, under Sea Grant No. 04-5-158-13 with Joe A. Hanson acting as chairman and raporteur. Dr. Hugh J. McLellan and Thomas E. Murray of OSG guided and monitored the effort. A list of participants appears in Appendix D.

Section II is a summary of recommendations which follows the examination of issues contained in Section III closely enough to serve also as a rough executive summary. Section III examines issues pertinent to the recommendations.

II. RECOMMENDATIONS

The purpose of this section is to boil down the issues discussed in Section III into recommendations which the Sea Grant system can implement. Consequently, this section is a rough summary of those issues and yet is vulnerable to criticism on the basis that it is too narrow just as its predecessor in the review draft of this report was criticized for being too lofty. Be that as it may, herein are some general thoughts on Sea Grant's role in aquatic ecosystem analysis and modeling followed by some guidelines for evaluating proposals and monitoring continuing projects. These are followed by a few comments on a second workshop.

A. The Sea Grant Role

Sea Grant cannot be all things to all men. It must concentrate its efforts so that its charter is best served with the resources at its command. Certainly, supporting effective analysis and modeling projects that will lead to better management of aquatic resources is appropriate. Development of analysis and modeling talent is just as important right now as is production of good aquatic resource management tools: the one is a prerequisite to the other.

Given that the development of both talent and applications are important within the framework of Sea Grant's charter, the next issue is how to focus things in terms of institutions, geography, and subject matter. The established Sea Grant policy of concentrating funds on colleges and universities while involving industry and local government to the maximum remains appropriate for Sea Grant's aquatic ecosystem analysis and modeling support. Sea Grant's logical geographic or, perhaps better "geoecological", choices appear to be: 1) The Great Lakes, 2) bays and harbors of the three coasts as well as Alaska and Hawaii, 3) major rivers and other inland waterways, 4) tidal estuaries, and 5) swamps. How many projects to support and, in fact, how many of the above geoecological opportunities can be pursued under Sea Grant funding will depend upon the level of funding available each year and the quality of projects proposed and in being. Whatever funds are available and whatever geoecological choices are made, it seems that Sea Grant-supported projects should focus sharply on management of water quality in support of the highest and best use of the resource involved.

Moreover, it is absolutely essential that Sea Grant-supported aquatic ecosystem analysis and modeling projects serve purposes that are generally acknowledged and supported within whatever region is involved. Sea Grant should consider employing its advisory service resources to gather information and community resources during the initial phases of any such project. In any case, no such project should be launched past its initial investigative phase until there is a high level of confidence in local support. This means that Sea Grant may wish to fund exploratory and organizational work at a modest level before committing significant funds to analysis and modeling. This early work should result in a proposal that is clearly do-able, valuable, and well supported locally; if not, the work should go no further.

The in-house capability to evaluate proposals and ongoing projects is always a problem for any funding agency. In a realm as immature as aquatic ecosystem analysis and modeling, the problem is particularly acute. Peer reviews, regardless of their well publicized problems, can help here. Recognized authorities can be employed to evaluate proposals and review the progress of projects so long as such authorities are carefully selected and appropriately compensated. Moreover, supporting exploratory and planning activities at modest levels can assist in giving such consultants something that they can get their teeth into. This can work so long as everyone involved has common criteria to work toward and to evaluate against. Such criteria are the subjects of the next subsection of this section.

B. Criteria for Evaluating Proposals and Projects

If these criteria are agreed to be complete, it will be surprising. No doubt each reader can think of others that are equally or more important. They are phrased here as questions to be asked of each proposal for the initiation or continuation of an aquatic ecosystem analysis and modeling project. If the project is proposed for continuation, these questions can be asked in retrospect as well as in prospect. To the extent that these questions are valid, they should be asked by the writers as well as the reviewers.

1. What is it precisely that the project may be expected to accomplish and how will it contribute to improved management of the aquatic resources in question, as well as to development of aquatic resource management talent?

2. Is what is proposed within the state of the art and, if some aspects are not, are the proposed approaches for advancing the state of the art realistic and nonduplicative of other efforts within or outside of Sea Grant?

3. Can progress made by the project be measured realistically?

4. Is an initiating solution strategy or means for arriving at it adequately spelled out?

    a. Are determinism and stochasticism employed appropriately and effectively?

   b. Are the levels of detail and generality appropriate to the problem?

   c. Has the problem been adequately bounded?

   d. Does the work proposed truly promise to result in a model that is capable of validation with the empirical resources available?

   e. Are lead times for model development realistic and is the model likely to become usable in time to be a valuable resource management tool?

   f. Have timing factors internal to the model been adequately treated?

   g. Has the ecosystem restructuring issue, if it applies, been adequately dealt with?

5. Are the respective roles of laboratory and field data as well as their sources adequately identified?

6. Does the computer hardware and software fit the job proposed for it?

7. Is there adequate knowledge and appropriate utilization of previous and concurrent work by other teams?

8. Are project management, structure and mechanisms for intra- and inter-project communication adequate and realistic and is the iteration phenomenon handled well?

9. Is Sea Grant likely to be able to support the proposed project at an adequate level over an adequate period of time?

10. Viewed in the context of other proposed and ongoing projects, does this one rank high enough to fall within the scope of Sea Grant's funding capabilities?

C. Another Workshop?

The participants were unanimous in their agreement that another workshop would be valuable. While certainly not unanimous, the consensus of those in the workshop and those who responded to the review draft would place a second workshop somewhere in the first half of 1977. Several of the participants have suggested that a second workshop should be larger in attendance and much more tightly structured. Probably it should concern itself with such questions as:

1) where Sea Grant should concentrate its support, 2) interproject communications, 3) project and proposal evaluation criteria, and 4) initiating a system of qualification and ethical standards.

Most of the questions asked and issues mentioned here are expanded upon in the next section.

III. SUMMARY OF ISSUES

This section's intent is to treat as concisely as possible those issues which surfaced explicitly and implicitly during the workshop phases 1 and 2. To the extent that this section communicates these issues clearly, it will be clear that the issues are the basis for the recommendations given in the previous section. This section is formatted in three parts: part one examines the purpose and promise of aquatic ecosystem modeling, part two explores the functional issues, and part three describes the management issues.

A. The Purpose and Promise of Aquatic Ecosystem Modeling

First, let it be agreed that aquatic ecosystems (bodies of water characterized by combined and interdependent physical, chemical and biological states and subject to changes in state) throughout and surrounding the United States and their possessions are, in fact, capital assets. As capital assets, then, it is appropriate to employ them in their "highest and best" uses as well as to maintain them in the best condition for those uses. Note that this agreement admits as appropriate high levels of pollution in water bodies used solely as, say, harbors--just so long as such levels of pollution do not adversely affect the highest and best use of adjacent aquatic ecosystems. If this is a selfishly anthropomorphic point of view, it nevertheless reflects the true nature of the relationship between human societies and aquatic ecosystems.

So, our society, faced with the task of maintaining its aquatic ecosystem capital assets while utilizing them to their fullest, must determine how much of what kind of use each such ecosystem can tolerate without unacceptable changes in its state. The uses we make of aquatic ecosystems are far too numerous to list in any specificity here; they include such diverse purposes as waste disposal, swimming, water storage, fishing, transportation, aquaculture, sinks for terrestrial runoff, scenic attractions, industrial water supplies, recreation centers, and so on. It is obvious that many of these uses are very likely mutually incompatible at the first order as well as incompatible in terms of the state that is appropriate to the aquatic ecosystem of which use is being made. What is meant by appropriate state? Near pristine may be an appropriate state for a recreational aquatic ecosystem while polluted to the extent that it is nearly devoid of aquatic life may be appropriate to an aquatic ecosystem devoted to some forms of industrial use. Argue though we might with the idea of intentional pollution as a highest and best use, it is a possibility that comes to mind if one is freezing in the dark.

One means of determining how much of what kinds of use can be made of aquatic ecosystems without altering their states in the direction of undesirability is to do it empirically; to try and see what happens. We've done this in the past and found with some dismay that the answers frequently come too late; come only after irreversible changes in state have seriously devaluated an aquatic capital asset; only after restoration to an acceptable state is found to cost more than we are willing or able to pay.

Another way is to employ highly conservative rules of thumb to restrict uses of aquatic ecosystems to levels very likely far below those which would result in undesirable state changes. But this approach is inherently incompatible with the highest and best use idea and contains seriously adverse economic ramifications.

What it all boils down to is that we need to develop means of determining in advance how much of what kind of use is appropriate to each aquatic ecosystem. This, then, is the purpose and the promise of aquatic ecosystem analysis and modeling--and the necessity for learning to do them well. Aquatic ecosystem analysis and modeling are not necessarily expensive; but even if they were very expensive, so long as they produce valid results, they still are vastly cheaper than their alternatives. Valid results before the fact at minimum cost is the goal of aquatic ecosystem analysis and modeling.

B. Functional Issues

Eleven issues bearing upon the scientific, technical, and procedural aspects of aquatic ecosystem analysis and modeling are examined in this subsection. Although the section is indeed broken down so, the issues stated are not discrete entities in themselves but rather convenient titles for interlocking segments of a sphere which contains the whole. Other authors would employ different titles in examining the same sphere with equal or superior effectiveness. It is the whole that is important here, not the titles of the segments.

1. The Relative State of the Art Today

Here we arbitrarily define a model of the entire ecosystem as "model" and models of segments of the system as "submodels". The submodels into which the workshop format divided aquatic ecosystem models are: 1) hydrological dynamics submodels (wind and wave action, currents, tidal action, dispersal, and diffusion), 2) water quality submodels (including physical states, chemistry, and elements of microbiology), 3) microbiological submodels (including all microscopic life forms in the ecosystem from viruses through phytoplankton and zooplankton as well as all microscopic benthic life), and 4) macrobiological submodels (including benthic fauna, fish population dynamics, etc.--essentially the upper trophic levels). These categorizations are arbitrary and convenient and few real submodels fit neatly into a single category. Rather, they tend to emphasize a category and extend tentacles into adjacent categories.

Figure 1 contains six purely subjective relative value graphs which reflect in combination about where it seems that the state of the art in each of the submodeling categories stands with respect to the others. These graphs illustrate a fair consensus of the workshop attendees but should not be taken for anything more than graphic representations of very definitely non-unanimous opinion.

In summary, the state of the art as reflected in the four submodel categories appears with notable exceptions to be that hydrological and fisheries submodels which, while individual examples may or may not be very sophisticated, are in good supply and are being used in policy development while very broad W. Q. and microbiological submodels by and large are not developed to a point of wide practical application as yet. Moreover, in the majority of cases, working interfaces between the submodels have yet to be developed.

Dr. Canale disagrees with the above statements and with Figure 1. He points out that dissolved oxygen models were first written more than 25 years ago and have for years been in regular use by government agencies for establishing BOD and COD loading limits. Dr. Canale also mentions operational models for coliforms, phosphorus, and algal standing stocks. He suggests, then, that limited chemical water quality submodels enjoy the widest use of any of the four categories and that microbiological submodels are probably at least as well developed as macrobiological submodels. And Dr. Canale's objections should not be dismissed as merely one dissenting vote; they illuminate important points.

The first point is that the workshop clearly did not expose the full breadth of aquatic ecosystem modeling throughout the world or the nation; presumably, it exposed that of the Sea Grant projects. The second point is that the accuracy or inaccuracy of this report's view of the state of the art is quite sensitive to one's point of view and should be taken as a point of view itself rather than an authoritative revelation. There are indeed submodels which predict dissolved oxygen variability, algal levels, phosphorus levels, nitrogen levels, and coliform bacteria counts (see University of Michigan projects in Appendix B). However, it seems that these submodels rely upon submodels of hydrological dynamics and for the most part do not exhibit a level of representation of the whole chemical or microbiological subsystem comparable to the level of hydrodynamics represented by hydrological models. In fact, since the distribution of chemicals and microscopic organisms is determined by the hydrological dynamics, submodels of the latter would seem to be a logical prerequisite to valid submodels of the former. Only when the distribution dynamics as well as the physical variables by location are known is it possible to represent the chemical reactions and microbiological responses that will ensue at given locations over time.

There are an impressive number of hydrological models in existence now. Most, if not all, basically are expanded mass balance equations approached with finite difference or finite element techniques and finally expressed as sets of

Key: Hydro = Hydrological submodels
W.Q. = Water quality submodels
Microbio = Microbiological submodels
Macrobio = Macrobiological submodels

See text for further explanation

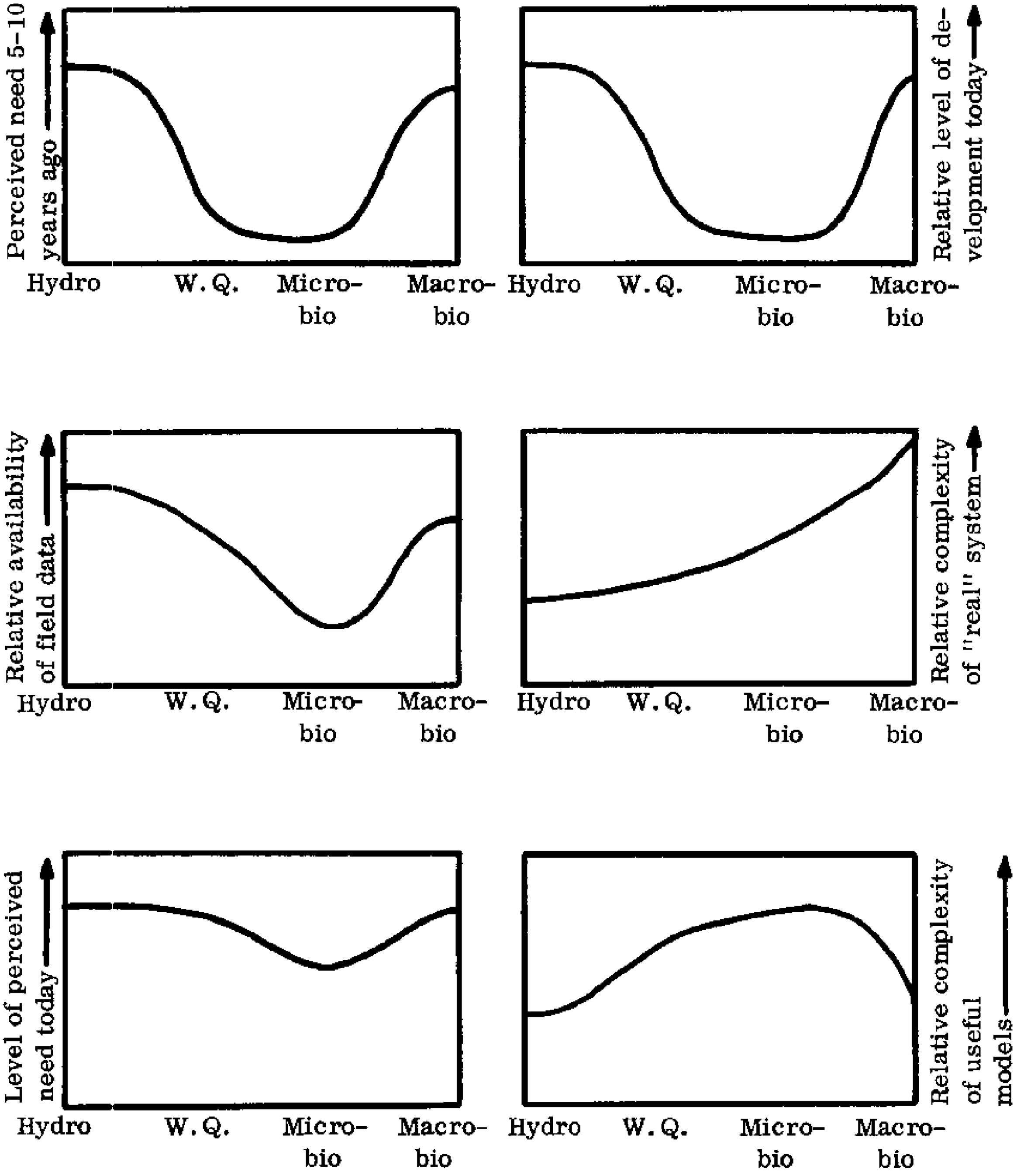

Figure 1. Some relative value curves based on opinion and reflecting roughly the state of the art in aquatic ecosystem submodels today.

simultaneous partial differential equations for automated handling. Finite difference approaches usually are followed when one- or two-dimensional models are built, although Leendertse at least has used such an approach in a 3-D model. Finite element approaches are found in two- and three-dimensional models.

Use of prior work by others in hydrological modeling appears rather high. There is evidence that the work of Leendertse influences to some extent the work of later investigators. And members of the Wisconsin workshop appeared to be on a firm communication footing with respect to hydrological modeling techniques. As Leendertse points out, however, direct transferability of models from one geographic application to another is difficult; one reason appears to be that models always contain assumptions which may or may not be explicit and one man's assumptions may be another's data base. This problem is examined farther on under another heading.

Fishery models employed in past years usually have been expressions or expansions of the Beverton-Holt equation and most often handle only single species dynamics as functions of predation and food supply while assuming that water quality, competition, and hydrodynamics are constants. As such, they have not been interfaced directly with microbiological, water quality, and hydrodynamic submodels. This is not to say that the dynamics of aquatic ecosystems that affect the population dynamics of a species of interest are ignored in all cases. These factors can, and frequently are, entered indirectly into fisheries simulations with the mechanism of making several simulation runs beginning with different starting values.

Water quality dynamics in terms of physical (not mechanical) and chemical phenomena are beginning to appear in models that began life as hydrodynamical submodels and which have the purpose of assessing water quality distributions throughout an aquatic ecosystem. Certain microbiological transfer coefficients are appearing, too. So far, these inclusions appear to be attempts to expand submodels that basically are hydrodynamical in nature so that they will include dynamic expressions that handle differences between purely hydrodynamical predictions and observed data. That is, the intention is to predict water quality and its time-dependent variations throughout a water body and the vehicle for doing so is evolving toward a fundamental hydrodynamic model augmented with only those physical, chemical, and microbiological equations that are determined to be necessary to cause the model to fit the data. This sort of evolution, well executed, should result in highly useful water quality simulation submodels that survive the test of Occam's razor and, thereby, are as economical as possible. Such submodels are not concerned, then, with physical/chemical and microbiological dynamics per se but, rather, only with those aspects of those dynamics that are necessary to explain water quality dynamics in the terms the submodel employs in its outputs. Whether or not this evolution is progressing toward an effective interface with macrobiological submodels remains to be seen.

All in all, the state of the art today seems to be one in which acceptable progress toward valid and useful water quality models is being made simultaneously with progress toward increasing sophistication, validity, and usefulness in fisheries submodels. With reference to Figure 2, it seems that, driven by a perceived social need to predict more accurately the dynamics of water quality, hydrological submodels are expanding to include physical/chemical and microbiological submodels while fishery (macrobiological) submodels are increasing their sophistication and sensitivity to water quality and must inevitably seep into microbiology and physical/chemical submodels while developing sensitivities to hydrological factors that, for them, become significant. Viewed from afar, this all appears to be rational progress in useful directions. Viewed from within, we face the problem of managing this bilateral seepage in such a way that whole aquatic ecosystem models that will do what we want them to do are achieved as quickly and economically as possible.

Be this as it may in the broad perspective, Sea Grant would seem to be well advised to concentrate its support in establishing hydrological models and expanding them to become refined and valid tools for predicting water quality before they are augmented with more sophisticated micro- and macrobiological submodels.

2. Determinism versus Stochasticism

The general trend among ecosystems analysts and modelers today is in the direction of determinism. We tend to think of ecosystems as complex webs of cause-effect relationships that can be treated with the calculus of differences--given enough time and computing capacity. Within this trend we tend to resort to stochastic equations only when we recognize that we don't know enough about the mechanisms involved or when a deterministic approach would be too cumbersome. If the relatively short-term (1-100 years) dynamics of aquatic ecosystems exhibit spontaneous behavior that can only be treated stochastically (given our present mathematical tools) we tend not to acknowledge such behavior.

Are there decision nodes in the eutrophication history of a typical aquatic ecosystem; nodes from which the path of eutrophic evolution may choose spontaneously one of multiple possible paths which themselves manifest varying degrees and qualities of reversibility or irreversibility? Probably such paths and nodes do exist but we cannot yet be sure. Laboratory experiments involving repeated multiple algal species responses to nutrification under seemingly identical conditions do not always yield identical species compositions. But the experimental controls are suspect.

Looking at it another way, might we save time and effort by employing stochastic techniques to replace difficult and cumbersome chains of dispersion and diffusion coefficients as well as some chains of transfer coefficients? Can

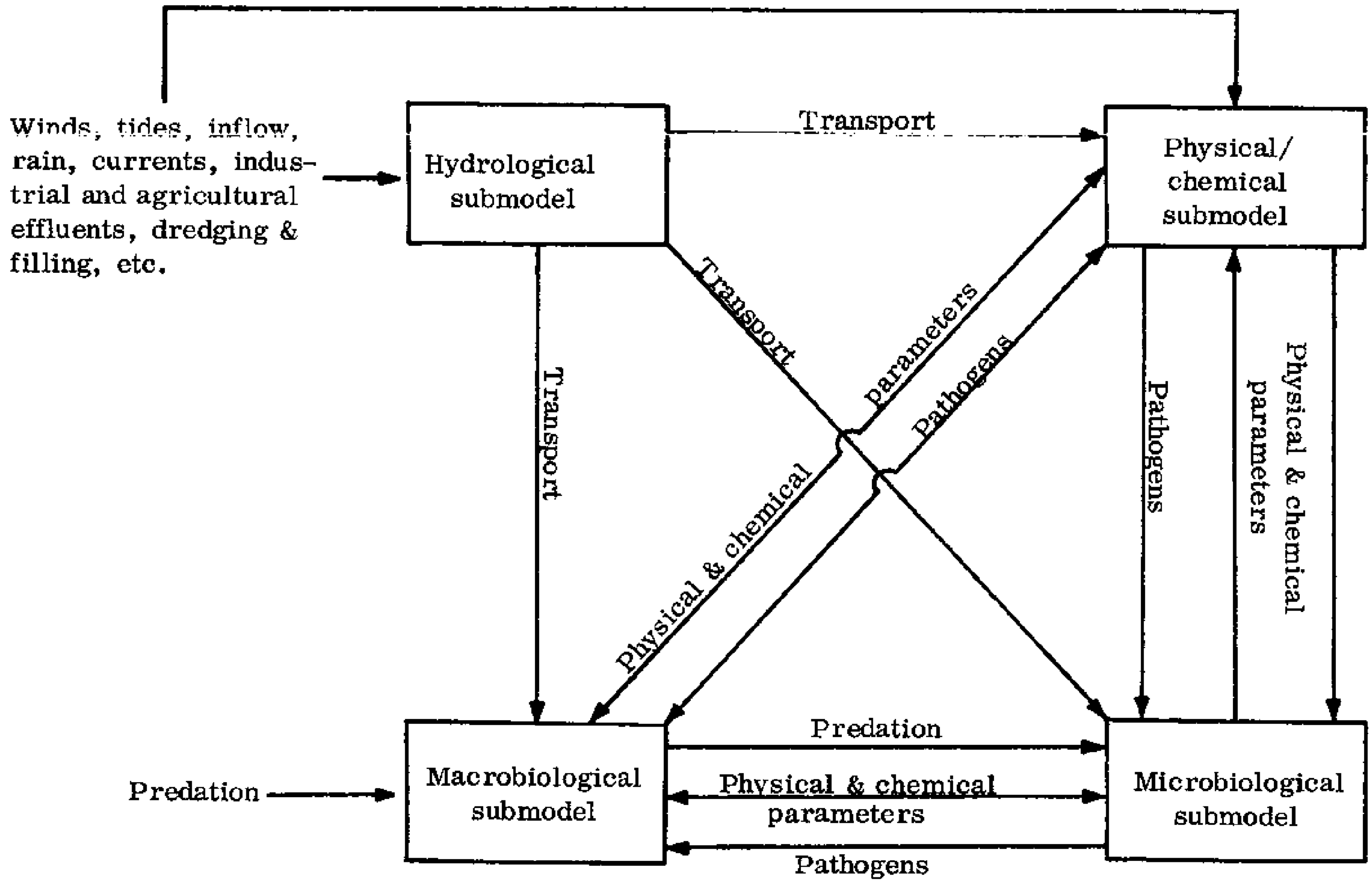

Figure 2. A generalized, idealized, and outrageously simplified expression of an aquatic ecosystem model.

we be happy with models which, like the weatherman, offer us a 20% chance of 80% turbidity today?

And then, of course, there is the whole question of just how representative of the ecosystem dynamics as they really are our deterministic mathematics are. The philosophical trap is something like this: if a model is based upon a human hypothesis that can only be tested for validity against the real world; and if the data we collect from that real world do not agree with the model's outputs; and if we therefore modify certain constants and coefficients in the model to mold it to the data; then how can we prove we didn't develop an invalid model with "fudged" constants and coefficients which, while it may fit the data, will not predict ecosystem behavior beyond the data because it is an invalid abstraction of the ecosystem? Since full knowledge over an extended time period of all of the inputs to, and state conditions of, an aquatic ecosystem is a practical impossibility, it is clear that a wide variety of numerical expressions could translate the input data we can collect to the ecosystem state data we can collect--and only one or a few of these expressions would be a valid abstraction of the dynamics of the ecosystem.

Moreover, the data themselves are suspect: we cannot know that our model-based expectations, as they impact the times, frequencies, and locations at which we take data as well as the instruments we use, do not contaminate the data.

It seems that this train of logic drives us either to abandon ecosystem analysis and modeling altogether or to rely heavily on the professional judgment of persons with a record of proven performance in the discipline. Clearly, abandonment is not a practical alternative. Speaking practically, we must achieve a resource bank of people who make ecosystem analysis and modeling valid and workable. As this resource bank grows, models and analytical techniques will become more sophisticated and more comprehensive. Extrapolation from today's viewpoint leads to a conclusion that these future models and analytical techniques will evolve as ever more elegant hybrids of today's determinism and stochasticism. On this basis, we can expect them to employ deterministic methods where cause-effect chains appear appropriate and stochastic or semi-stochastic formulae at decision nodes--loci at which one branch may take one of two or more succeeding paths (see Figure 3).

This is not, by the way, a new revelation. Figure 3 represents an approach that has been in use in simulation and gaming for years. What seems likely in the future is an evolution along this established path toward more formalized methods, more rigorous techniques, better data and methods for handling it, and an ever higher degree of verisimilitude between models and the ecosystem which they seek to simulate. Very possibly, this evolutionary path will parallel the evolution of good water quality models and their subsequent evolution into whole ecosystem models.

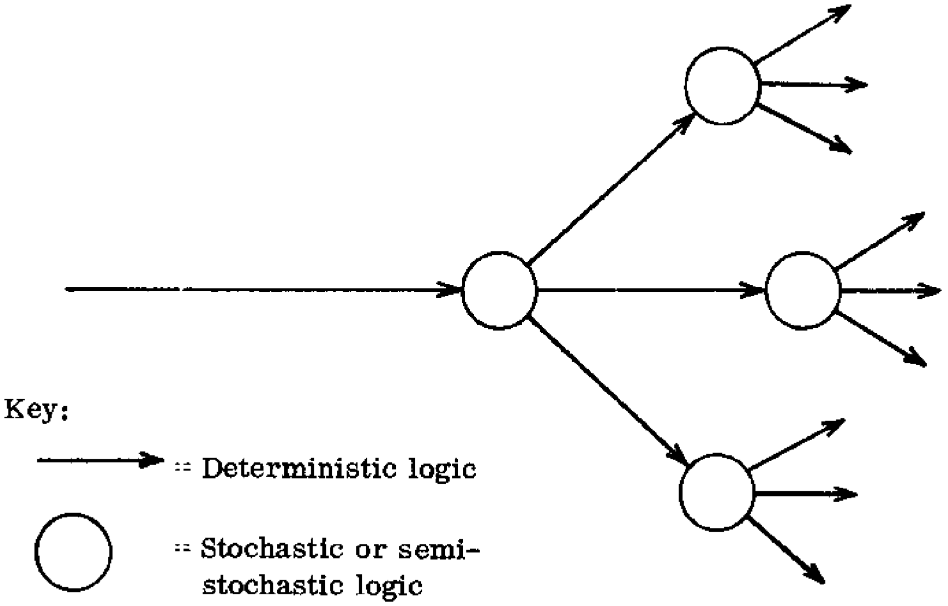

Figure 3. Logic sequence of a hybrid model.

3. Detail versus Generality and Sensitivity versus Confidence

The more detailed our models, the more sensitive, difficult to manage, costly, difficult to verify, accurate, and lengthy in their development times they most likely will be. The more general, the less sensitive, the easier to manage, the cheaper, the easier to verify, the less accurate, and the shorter in their development times they are likely to be. The more sensitivity (which usually accompanies detail) we build into our models, the shorter the time steps they represent and the more difficult they are to validate; and so the lower the level of confidence we can gain in their validity. The less sensitive a model, the easier it is (usually) to gain confidence in its validity--so far as its validity goes.

The ultimate in a useful, general, and insensitive model would be a rather simple transfer coefficient that stated simply something like "at present (or proposed) rates of discharge of urban wastes into this aquatic ecosystem, total eutrophication will occur at time (t)." But there is no way to validate such a model without waiting for time (t) and then validation is very easy: the level of confidence would be either 1 or 0. The ultimately detailed and sensitive model might describe the entire ecosystem in terms of simultaneous chemical reactions. Its time steps would be microseconds; one could gather some validation data at any time and any place; and it would be a practical impossibility to validate it to any level of confidence.

As aquatic ecosystem analysis and modeling evolves, the goals we should set in this realm involve identifying types of reactions that can be simulated with a given level of detail. For example, if the chemical balancing equation for $A \rightleftarrows B = xA + yB$ at time (t), it is of no use to simulate ion exchanges over times vastly less than (t) when x and y can be derived easily by using fractions of (t) (when the starting values are known). Similarly (and somewhat less facetiously), simultaneous differential processes that require a very large number of iterations to achieve convergence should be carefully examined before a great deal of time is spent in coding and debugging. Might there not be a more general expression that would require a much smaller investment and still result in an acceptable level of confidence? All this is to do nothing more than to encourage analysts and modelers to continue expanding their efforts to achieve expressions of aquatic ecosystem processes which survive Occam's razor--and then to document them so that others may benefit from their efforts.

4. Boundaries and Bounding

Any part of nature to which we may assign the term system is, by our own definitions, a subsystem. If that is true, then the boundaries we draw between the subsystem that interests us at the moment and all the rest of nature are to some degree arbitrary. Moreover, it cannot be shown *a priori* that systems concepts of order, hierarchy, entropy, feedback and so forth are significantly more immanent in nature than, say, arithmetic systems whether they be to the base 2, 8 or 10; both types of concepts are useful in dealing with nature so long as internal consistency is maintained and neither concept can be demonstrated to be anything beyond a human intellectual creation.

Some of the boundaries we set when we define an ecosystem to focus our attention upon are dimensional; usually capable of representation as x, y and z from some reference point and sometimes involving the time dimension. And the choice of these boundaries clearly is *ad hoc*. From experience, we learn that monitoring the transfers that occur in both directions across our ad hoc boundaries is an immense practical problem and almost always is done less than adequately in terms of our own minimum standards.

In every case, empirical determination of the transport of energy and matter across arbitrary ecosystem boundaries is an imposing challenge. Consequently, analysts find themselves with a very practical motivation to place boundaries so as to minimize the challenge. The problem of setting boundaries and knowing boundary dynamics can go so far as to reduce the geographic or substantive dimensions of the ecosystem studied. Carried to its logical extreme, this approach would result in our taking five-gallon water samples from an ecosystem and carrying them to the laboratory where we could experiment with them under controlled conditions--and this, in some cases, is not a bad idea.

A wise and earthy philosopher once offered the insight: "When the only tool you have is a hammer, everything looks like a nail." There is another kind of bounding we do sometimes consciously and sometimes not. Probably all analysts and modelers would agree that it is an a priori truth that we limit our simulations and analytical efforts to those things for which we have conceptual and manipulative tools. How many of us are willing to admit that we may also bound our cognition of "real" aquatic ecosystems on the same basis? The urge to detour into Korzybskian general semantics will be resisted here with the remark that the tools we have to work with almost certainly impose some sort of bounds on our cognition of the ecosystems we seek to analyze and model.

But to return to physical boundaries, setting boundaries and achieving a workable strategy for handling boundary dynamics, both in the model and in the field, are critical to the design of an aquatic ecosystem modeling and analysis project. If the strategy has not already been worked out at the time a proposal for funding is submitted, then the proposal should, as a minimum, contain the plan for developing such a strategy.

The whole boundary issue is so closely related to the validation issue that one can consider the two as parts of the same issue; for, if we had data acquisition and management resources equal to the task, both issues could be resolved easily.

5. Validity and Validation

Following the "hammers and nails" metaphor, and obeying our own Aristotelian rules of logic, we discover that we cannot prove that any so-called "real life" system with which we choose to concern ourselves exists beyond the boundaries of our capabilities to conceptualize it and to validate our concepts through our five senses and the instruments (abstractions in themselves) that these five senses (and the cognition which organizes their operation) have constructed. Whether or not we might like to dismiss this concern as being entirely too metaphysical, the fact remains that one's cognition of a physical thing is separate and distinct from the thing itself; and, not only is this cognition an abstraction, it is also an extraction in that it contains less detail than does the thing. Metaphysics or no, analysts and modelers who ignore this paradox place themselves in danger of creating internally consistent entities which are, simply put, invalid.

At the risk of belaboring the point, Figure 4 is an overly simplified but very real and practical example of the validity problem which ecosystem analysts and modelers face.

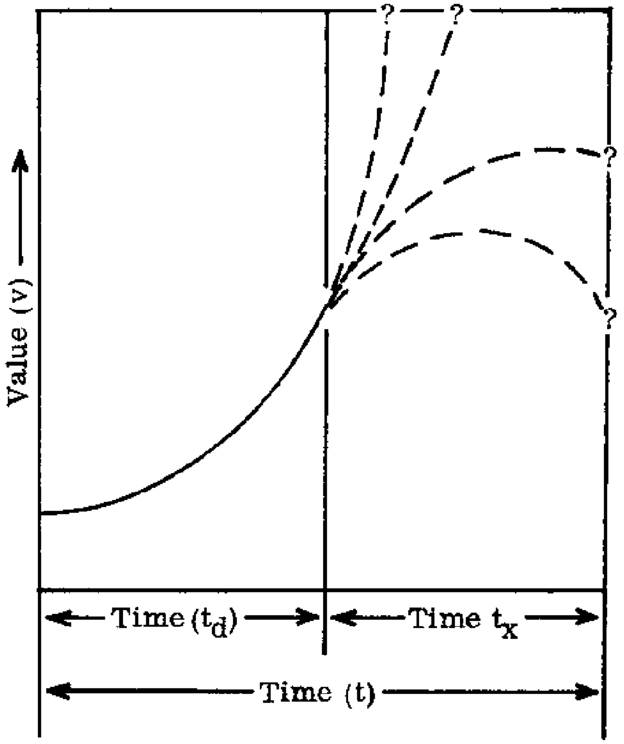

Figure 4. Which extrapolation is valid?

Time (t_d) is the time over which data with which to validate some hypothetical model exist or can be obtained. But time (t) is the period with which the analysis and simulation is concerned. Note that the analysis and simulation must be concerned with times and values beyond those represented in field data or the requirement for the work (at least the simulation) is obviated. How, then, do we determine which of the dashed lines represent the change of value (v) over time (t_x)? We do it, of course, with an equation that represents an accepted concept of the dynamics of (v). And here we are back where we began: there is no empirical proof unless it lies in small-scale laboratory data or data from similar ecosystems; so it is necessary to rely on peer group agreement that one's concept is valid.

This paradox does not invalidate ecosystem analysis and modeling any more than it invalidates chemistry and physics. It is a paradox that underlies all science and a very wide spectrum of human experience. The paradox is ameliorated (although not entirely dismissed) as each scientific discipline matures on a diet of ever broader and deeper empiricism. For the immature discipline of ecosystem analysis and modeling, the paradox raises a caution flag to test carefully the empirical and conceptual ground as we proceed lest we find ourselves, like some cartoon character, far beyond the edge of the cliff before we become aware enough to crash.

With the validity issue as thoroughly muddied as space permits, we can now proceed to the simpler question of validation with the casual observation that the practical problems involved in collecting enough data to validate a model or submodel of a geographically extensive aquatic ecosystem are enormous as shown in this storybook example. Ideally, analysts facing such a challenge would set up remote, continuous monitoring stations at all important locations in the living ecosystem. For exemplary purposes, let's say there would be only a hundred such stations. Now, each station would monitor a variety of hydrological, physical/chemical, microbiological, and macrobiological parameters. Let's say that the total number of parameters sensed by each station would not exceed 100. If each station were to transmit each parameter over a separate microwave telemetry channel, the number of channels (10,000) is likely to exceed the local surplus; so a channel-sharing query-response system must be employed--which means data cannot be sampled simultaneously but must be sampled serially. Now, ignoring the fact that remote sensors for many important biological phenomena (carbon fixation rates in phytoplankton, for instance) are not yet within our technological abilities, let's say that we obtain 100 each of our monitoring units for a bulk-order price of only $50,000 each--most optimistic; the sensor units then will only run us 5 million dollars. Probably for another 2-3 million we could obtain and program the needed communications control and data buffering, logging, and preprocessing gear. With this gear on hand, a programming, computer technician, and field technician staff of 50 or so people along with associated terrestrial and aquatic transportation equipment, test instruments, replacement inventory (remote equipment has a habit of disappearing in storms and as a result of vandalism) and so forth probably would run us just under two million dollars a year. Allowing the above postulates, which are hugely optimistic at present, a five-year field data program of adequacy would approach $20 million--if we had the technology to do it. If defending the national aquatic environment were considered by our society to be as important as arms races with other nations, we could probably afford a couple of hundred such projects. At the moment, most aquatic ecosystem analysis and modeling projects are funded at a level of a few hundred thousand dollars per year--in toto and at best.

Today, field data collection is more likely to be done by students in skiffs and trucks at places that are relatively easy to reach and only during fine weather. Today, we usually are attempting to validate our models against field data that are entirely inadequate. Today the only alternatives, then, to people with the professional excellence to achieve in spite of these restrictions are to stop ecosystem analysis and modeling altogether or to divert a significant fraction of the national budget toward emplacing monitoring gear that is within the state of the art while we develop adequate monitoring gear that is not yet within the state of the art.

Today's technological and fiscal restrictions intensify the previously mentioned danger of simulation validations being themselves invalid. As this danger increases, so must our reliance upon the professional excellence, responsibility, and ethics of the analysis and modeling project team.

6. Lead Times and Time Steps

Lead times for developing worthwhile aquatic ecosystem models and time step problems within models are two subjects related logically only by their mutual dependence on the time dimension. However, on a more subjective plane, the timing problems analysts and modelers face with respect to their sources of funds and users may have implied solutions buried somewhere in the mechanisms modelers employ to handle time step disparities within the models themselves.

The lead time problem in ecosystem modeling is an amplification of an elderly cartoon still sometimes in evidence in backrooms of a variety of service groups such as typing pools. The picture may be almost anything; the caption reads: "Of course I want it done today. If I wanted it tomorrow, I'd give it to you tomorrow!" You see it is most usually true that our socio-economic machinery does not respond to non-critical problems. Future issues, not yet critical, do not usually receive high priority. And so it is that aquatic ecosystems usually are obviously stressed before enough money to support an ecosystem analysis and modeling project is devoted to the task. This leads to the paradoxical situation in which valid results are demanded immediately and valid results can only be derived from a lengthy development program. More painfully, the situation can lead to premature and irrevocable decisions that the analysis and modeling repudiate subsequently. How it might be done effectively is obscure, but somehow we must make progress toward assuring that ecosystem analysis and modeling projects begin early enough to have some promise of producing usable results in time to be effective. In any case, proposals to study aquatic ecosystems which involve extended lead times should be scrutinized rather carefully if expert opinion concludes that the ecosystem of concern is already in a highly stressed condition. And note the paradox here, the analysts and modelers are hard put to attract monetary support until they convince others that the ecosystem in question already is in danger. And, by the time they can prove it, it may be too late. Just how does one convince the patient to begin treatment before the disease becomes terminal?

Turning from the temporal issues in the world for which models are developed to those in the world about which they are developed, we see that the essence of ecosystems as subjects for analysis and modeling is the time dependency of the spectrum of states in which they can be. The state of such a system is taken to be different at time $t = n$ than at time $t = n-1$; and the state at $t = n-1$ is a subset of the parameters that determine the state at $t = n$.

If we build constant time steps into our models and the models' responses are nonlinear, as they very often are, then the steps may be too long to be practical during some transitions and too short to be significant during others. The alternative to the constant time step is to build feedback control (servo) loops into the models that sense the rate of change of significant variables and then adjust the length of time of $t = n \rightarrow t = n+1$ as a function (possibly an integral function) of one or more rates of change of significant parameters during the step $t = n-1 \cdot 2 \cdot 3 \ldots x \rightarrow t = n$. Good models of non-linear ecosystem dynamics contain such provisions. Models of nonlinear dynamics that do not adjust their time steps as a function of change rate exponents may either be missing some important system dynamics or be using more computer time than is justified--or both.

When we move toward the interfacing of one submodel with another, the problem worsens. For example, a hydrological submodel may be valid with time steps of several hours while one phytoplankton response submodel might require time steps on the order of a few minutes while another treats phytoplankton responses as seasonal phenomena. In either case, the time steps of the hydromodel will not match those of the phyto. This is not an overwhelming problem since averaging interpolation buffers or summation buffers can be built into the code that interfaces the two submodels so long as the flow of data between submodels is in only one direction. But, if, say, phytoplankton population dynamics have fluctuated through x cycles during, say, $t = n \rightarrow t = n+1$ of a hydrodynamic submodel, and only an average value for the x cycles is passed to the hydrodynamic model, then the phytoplankton distributions manifested in its outputs may be invalid. Such problems are by no means insoluble, but they do persist as barriers to effective interfaces between submodels; barriers to be overcome on a case-by-case basis.

Can aquatic ecosystems analysts now employ their technical timing interface techniques to deal with the timing problems they face with their users and funders? Can users and funders be educated to support ecosystem analysis and modeling early enough to give the discipline and the ecosystem a fair chance?

7. Ecosystem Restructuring

Carrying on from the fundamental issues of time steps, we note that, as aquatic ecosystems continue to be stressed over time, the gradual adjustments which result reach thresholds beyond which the ecosystems undergo restructuring--sometimes significantly and sometimes drastically. Massive fish kills are examples of this phenomenon and it appears most often to result in the new system achieving a state that exhibits a good deal less structural complexity than did the previous one: species disappear; ecological niches disappear and the community framework is not at all the same as it was. Moreover, in any aquatic ecosystem this phenomenon can occur as a chain of restructuring events leading ultimately, if contamination stress is great enough, to a virtually lifeless body of water.

If we are curious about the whole range of potential futures of an aquatic ecosystem, our analysis and modeling must accommodate such restructurings. Yet, in order to do so, either there must be several submodels or a single model must contain a system of stress threshold branches--which makes it several submodels hooked together. Dr. Canale reports that one of the University of Michigan's models handles this question by using phosphorus loading levels as triggers for changing from one structural basis to another. Where the value of a single parameter is valid, the process of sensing and changing from one submodel to another is simplified. When the transition is known to occur as a function of the product of several values, the process is somewhat more complicated. When it is not known with any certainty how or why such threshold transitions occur, models of them must represent nothing more than educated guesses and should not be taken as anything more than that.

8. Solution Strategies

If we nutrify a small pond continuously, eutrophication will ensue and proceed to the point that the pond becomes a bog and then eventually dry land. We understand this process from our experience and from the literature. The scientific community agrees in general that the eutrophication process does occur and even understands roughly the sequence of events that comprise it. Thus, a general model of eutrophication of this mythical example pond would behave in ways that did not surprise its creators nor their peers. A model (and system) such as this has been called "intuitive" in that there are no big surprises in its responses to inputs. But if we did not now understand the process of eutrophication; if we were pretty sure of the sequence of events but did not know their outcome; then, were we to build a model made up of the smaller pieces which we did understand, its overall eutrophic behavior probably would surprise us and we might call it "counter-intuitive". For the purposes of this section, then, intuitive models or submodels are those having surprise-free response patterns even though the absolute value of the outputs may be interesting enough to be a little surprising; while counter-intuitive models or submodels exhibit surprising behavior patterns as well as surprising results. Anyone who objects to the terms "intuitive" and "counter-intuitive" as they are employed here may complain to Jay Forrester.

Now, for those models, submodels, or pieces thereof which we do (or think we do) understand, we can develop general mathematical statements or chains thereof which represent what Dr. Connor has termed a "solution strategy". The term is apt in that the statement(s) make explicit how the problem of simulating understood behavior patterns will be handled. For example, it may be decided that, in some mythical submodel, phytoplankton levels at time t_1 will be a function of phosphorus, nitrogen, temperature, light, and CO_2 concentrations at time t_0 limited by a maximum mytotic rate value which is species specific. This would be the solution strategy for determining phytoplankton levels at given times and this strategy could then be expressed in a series of simultaneous differential equations or some surrogate thereof and finally reduced to computer code which, when given t_0 and species mytotic values would determine phytoplankton concentrations of species (s) at times $t_1 \cdot t_2 \cdot t_3 \ldots t_n$.

In this mythical and somewhat trivial example, it is easy to see that resources (P, N, CO_2, etc.) will be used up, light below the surface will be attenuated by turbidity, and temperature may change, too. So t_0 values of these variables must be changed at t_1 in order to compute values at t_2--and so on. Clearly, with no added inputs beyond those given at t_0, this response curve will be assumtotic. Now, if other submodels in the system affect levels of P, N, CO_2, light, and temperature, these, too, must be represented first as general solution strategy statements and then as formal equations and finally as debugged code. And they must be interfaced with the phytoplankton submodel within compatible time sequences. Now there will be two levels of equations: those which play out submodel changes between t_n and t_{n+1} and those which adjust t_{n+1} starting values for the submodels before calculations of t_{n+2} are made. Where the modeled system may contain ten input sources for variables of concern, an order of magnitude more variables than the above example, ten phytoplankter species, a variety of bacterial reactions, climatic drivers of light and temperature and so forth, it is easy to see that the complexity of this whole physical-chemical-microbiological submodel could become considerable. Moreover, if hydrological and macrobiological submodels are included, too, the complex becomes complex indeed. And how to handle this complexity is the overall solution strategy.

The selection of solution strategy usually may be based upon literature, experience, and whatever data base exists. Data should be gathered and analyzed and literature searched until all principal investigators involved become comfortable with the solution strategy chosen. If a grant or contract proposal is written after the solution strategy has been developed, that strategy should be explicated in the proposal and supported. If the solution strategy has not been settled at the time a proposal is prepared, the proposal should describe how and with what resources the solution strategy will be derived. In any event, development of the mathematical model should be withheld until total agreement on the beginning solution strategy is achieved by all principals in the project. Then all should acknowledge that the final solution strategy will be a product of iteration and be willing to have it change and refine and to communicate changes to one another.

Finally, the aquatic ecosystem modeling discipline will mature only to the extent that it develops a firm foundation in refined solution strategies. Therefore, all solution strategies should be documented along with their strong and weak points and made available to other investigators. This is an imperative for the health and growth of aquatic ecosystem analysis and modeling.

9. Laboratory Data and Field Data

Assuming that a beginning solution strategy is in hand, the issue of data with which to support it and verify its predictive ability becomes visible. Subsections B.4 and B.5 above discussed the problems of obtaining adequate field data. This subsection is confined to a brief examination of the respective roles of laboratory and field data.

First, it is possible to glean from the foregoing discussion of solution strategies that they may be strongly driven by the results of laboratory experiments. In addition, it is well recognized that far from all necessary aquatic ecosystem data can be obtained from laboratory experiments; for example, tidal currents in an estuary are seldom an appropriate subject for the laboratory. Moreover, support for the predictive ability of a model ultimately must be based upon data collected from the field.

Both types of empiricism have their roles in aquatic ecosystem analysis and modeling and the roles are inherently complementary. Proposals for such projects should make the respective roles of laboratory and field data clear and reports covering such projects should contain evaluations of the effectiveness of both types of data in the project. The construction of this sort of a literature base is important to the growth of the discipline.

10. Hardware and Software

The mathematical model may be limited only by knowledge, imagination, and the state of our mathematical tools but the simulation model faces more practical limitations; namely, computer hardware and software. As a rule, the smaller and less expensive computers are easier to use, more restricted in what they and their software can do, slower, and capable of accessing less data quickly. Generally speaking, one does not expect to run a simulation consisting of over 100 simultaneous partial differential equations on an IBM 360-20. The larger and more expensive machines are not always available, require greater sophistication to take advantage of their hardware and software abilities, much faster, more prone to bugs, a great deal more flexible, capable of accessing huge data files fairly rapidly, and potentially more expensive.

A project team that, for any combination of the foregoing considerations, decides to restrict itself to a smaller hardware/software system does thereby decide to restrict itself in a number of attendant ways. First, if the model is to be large and complex, it will either have to be very clever with its housekeeping, or employ a small data base, or be satisfied with some rather elongated simulation runs. Second, the variety of output forms and formats will very likely be quite restricted since sophisticated plotters and displays are not characteristic of the smaller systems. Third, the number of equations that can be run simultaneously will be small so that the simulation model may have to be "modularized" and this means adding more code which further extends running times. Fourth, computer programmers have a habit of doing "cute" things with assembly languages in order to get slow systems to run faster; this leads to code in the simulation model that is difficult or impossible to maintain or modify once the programmer who committed the act has left the project. All in all, the smaller hardware/software systems beget simpler simulation models; if a sophisticated model is attempted with such a system, the project team almost invariably finds itself either simplifying the model or moving to a larger system.

The larger systems are faster and more flexible and usually demand a higher level of technical sophistication in the persons who use them effectively. They most usually are more expensive but, if the system has adequate time-sharing capabilities, the extra expense may not be great in the long run. The reason for this is that, although the larger systems cost much more per unit time, they can do a great deal more in that time. If, for example, one must use eleven hours of machine time at $10/hour to do what he could do in one hour at $100/hour, then the slower and cheaper system is a dubious bargain--particularly when personnel time and other factors are equated. If the machine has remote access time sharing, and the project is so fortunate as to have a remote terminal in its space, convenient access to the system is greatly enhanced and the simulation model usually is developed and debugged much more rapidly.

All in all, developing and debugging simulation models is a task with sufficient inherent challenge that it needs no additional strangulations through the device of inadequate computing systems. It is the responsibility of the project team to assess its computing system requirements adequately and assure that the simulation model will not be stunted in its growth by lack of adequate computing capabilities. It is the responsibility of funding agencies to verify that this task has been completed well before a proposed project receives support.

The foregoing generalities, however, should not be taken to mean that more simplified simulations on smaller machines are of little or no value. Quite the contrary. Where simpler models are appropriate, so are smaller and less complicated computers. In fact, some of the more significant simulation developments such as H. T. Odum's work are accomplished with inexpensive computer hardware. Moreover, until a solution strategy which clearly demands sophisticated hardware and software is developed, it is inappropriate to pay the price for them. The message here is that the hardware and software should fit the task and be neither too large nor too small for the job they must do.

11. Disciplining the Discipline

Ideally, each and every aquatic ecosystem analysis and modeling project would use the work that had gone before as a foundation upon which to build a further contribution to the discipline--as well as a solution to pragmatic problems of policy. But an ideal world ours is not. Hugh McLellan summed up the current state of affairs in his introductory remarks at the workshop. His statement makes up in succinctness for anything it may lack in kindness; to wit, "It seems that all proposed projects promise products of nearly unlimited utility and find that all previous work essentially is without value for the problem at hand." Dr. McLellan's statement may be slightly overdrawn, but its point hits the mark quite well. The transference of techniques and products among aquatic ecosystem analysis and modeling projects today is indeed quite low.

Of reasons for this there are plenty. Frequently, computer programs are undocumented or poorly documented. Computing hardware and software often are incompatible and, "it is easier to write your own new code than to modify and translate someone else's"--entirely true. Objectives, critical parameters, and assumptions implicit in the models usually differ significantly. Scientific backgrounds and approaches of principal investigators may differ. Time constants may vary markedly. Even with good documentation, help from people thoroughly familiar with a simulation frequently is necessary, and these people may have moved on and be no longer available. If the previous work is more than a few years old, its techniques may be obsolete in terms of today's hardware, software, and mathematical mechanics.

Proposed solutions to the technology transfer problem covered a wide spectrum from the concept of a "super software system" (such as NASA's NASTRAN is to finite element structural analysis) through a "how to" cookbook on developing solution strategies and the attendant automated routines. The attendees achieved high unanimity that we are nowhere near the place at which the aquatic ecologists' NASTRAN could be developed--even if the considerable funding required was available. At the other end of the spectrum, a text on the development of solution strategies attended by suggestions for and examples of translating solution strategies into effective simulation models received a unanimous vote in favor. This text would still be far less than a cookbook. By and large, the workshop consensus indicated that we have not yet achieved the generalization of principles necessary to the writing of a truly useful cookbook; there still are too many differences among ecosystems for which general principles have not yet been derived.

C. Management Issues

Clearly, the foregoing technical development issues contain forceful management implications. We believe that the foregoing management implications are clear and that they need no further expansion here. This subsection, then, focuses its attention on management issues beyond those that are purely technical.

1. Standards of Excellence

Established disciplines and the professions that relate to them have well recognized standards. These standards derive from a well structured and widely agreed upon foundation of knowledge. New contributions to the knowledge base are readily evaluated and assessment of the degree to which they contribute to the base is made possible if not exactly easy. Most well established disciplines and the professions that apply them may be said to have standards of excellence.

In the case of aquatic ecosystem analysis and modeling, such standards are as yet available for neither the techniques nor their products. And, for at least three very good reasons, it is not going to be easy to get there from where we are.

First, the field is not yet entirely sure of its substance. Is its substance creative insight into the workings of aquatic ecosystems that stems from some fortunate combination of innate talent and extensive education? Is it the advancement of mathematical tools and their application? Is it computer hardware and software technology? Is it the technology and techniques of field data collection and analysis? Is it broader and better laboratory work? Almost certainly it is all five. But in what orders and in what combinations? The framework for this foundation has yet to be built. First, we must become clear on the substance and then form it into an agreeable framework.

Second, and this is probably endemic to all emerging fields, funding generally is not reliable enough for any one project to establish unilaterally a discipline-wide substantive framework that can be expanded upon by others. Each analysis and modeling project tends strongly to be restricted in terms of geography and policy issues; in other words, it is highly applications oriented. Moreover, one of the workshop members pointed out that, if we will acknowledge the truth, the Federal and state agencies that fund much of such work today tend to be creations of political expediency. Consequently, their policies, personnel, structures, and fiscal foundations tend to be somewhat less stable than many of us would like. As a result, many ecosystem analysis and modeling projects are vulnerable to externally imposed perturbations in direction and funding. That the foregoing is a real problem is almost certainly true. But the extent to which it is serious probably is open to some argument.

Third, any field that is new enough to exhibit the first two conditions is an attractive nuisance in terms of opportunistic incompetence. When one considers all the problems aquatic ecosystem analysis and modeling face along with the fact that the value and excellence of its products are subject to interpretations, vulnerable to fuzzy initial objectives and sometimes hidden in the mysticism (for many) of computers, it is not difficult to imagine technical incompetence augmented by quick wit surviving entirely undetected for some time.

There is no quick solution to this problem. The discipline demands standards of excellence and we do not yet have them. The shortest and most economical route from here to there seems to lie in the chartering of an ad hoc commission to lay out a proposed initial charter of standards and ethics. These might then be refined and ratified by the entire senior community and reviewed and revised annually thereafter.

2. Topics and Goals

If one wishes to build a bridge, he needs to know certain fundamentals such as how wide the river is and what sort of traffic his bridge is to carry. If one wishes to do an aquatic ecosystem analysis and modeling job, he needs to know certain fundamentals such as how broad the problem is and what sort of decision traffic his work should support. As yet, bridges are not constructed of fiberglass because its structural and economic superiority over conventional bridge materials remains unproven. Here the bridge builders have it all over the model builders, for the bridge builders already have proven materials and methods and the model builders usually do not.

If the decision to embark upon an aquatic ecosystem analysis and modeling project arises from a need initially perceived from the political perspective, can the project be given topics and goals that are valuable and probably within reach technically speaking? And, to turn it around, if the initial impetus for the project arises from professional interests of the analysts themselves, can they find things that they really can do that are also valuable in the political arena?

It is by no means a trivial challenge, but it is one that must be met; policy makers must be involved from the beginning; topics and goals toward which progress can be measured must be explicit; and analysts and modelers must be open and honest about the goals they know they can attain, think they can attain, and know they might not attain. Anything less stands entirely too great a chance of culminating in arguments over whether the work was worthwhile or not.

3. Communication Within and Without

Progress in intricate technical realms is a function of cooperation and cooperation is a function of communication. Total communication within a complex and developing discipline is an unachievable ideal; as such, it is something worth striving for. And so it is that we find communication between aquatic ecosystem modeling projects and even communication within projects usually acknowledged to be inadequate.

Taking the easier issue first, we find correlations between the level of communication within projects and the number and similarity of backgrounds of the key project members. Managing intraproject communication when the number of principals is small and they are all civil engineers working on a hydrodynamical problem is likely to be a fairly easy task; managing intraproject communication for a whole aquatic ecosystem modeling and analysis project involving dozens of principals of widely divergent disciplinary backgrounds is likely to be a whole different kettle of fish.

There is, however, good precedent in the annals of the aerospace industry. One of the precepts of "systems management" as practiced in that industry is to divide the project into subsystems, having well defined interfaces with other subsystems and then to assign subsystem responsibility to subsystem managers who will communicate with each other as the project manager affords them the motivation and freedom to do so. Subsystem managers then take responsibility for communication within their own subprojects and may divide them into sub-subsystems and sub-subprojects. If done well, this approach results in a pyramidal management and information exchange structure that has a major deficiency: that deficiency is that people toward the lower end of the pyramid who could be synergistic but are in different subgroups might not find themselves communicating. And this deficiency largely can be overcome with frequent project review meetings wherein the progress and problems of each subproject are presented and discussed openly. In practice, this utopian ideal is sometimes approached; the key seems to lie in the technical competence and personalities of the project and subproject managers.

Interproject communication is an even more imposing problem. If we were to attempt to communicate adequately through the medium of written correspondence and journal articles, we would approach a state in which most of the effort went into writing up one's own work and reading of the work of others. Computerized information storage and retrieval systems are expensive and have worked well with well bounded and high structured information categories. Unfortunately, aquatic ecosystem modeling does not yet meet the qualitative criteria, nor does it yet enjoy a level of funding that would permit a nationwide automated data bank net with a time-sharing conversational mode query capability. The interim answer to the interproject communication problem, then, appears to be annual workshops supplemented by a monthly abstracting service. This is not quite an adequate solution but it is one we should be able to afford and it is certainly better than the level of interproject communication that exists today.

4. Managing Iteration

When a group is doing something it doesn't yet know how to do, it will make mistakes by doing things that are entirely reasonable in light of what it understands when the mistakes are made. Later, when understanding is greater, the mistakes become apparent. They are then corrected in light of the new knowledge. And even the corrections may prove to be mistakes and demand correction in light of some later and broader understanding. This is iteration.

Iteration, like New York City, is nobody's fault because it is everybody's fault. To demand that people do things they don't already know how to do without making mistakes is paradoxical. To demand that people, in order to avoid mistakes, do only what they already know how to do, is to halt the evolution of human knowledge.

So, in things such as aquatic ecosystem analysis and modeling, iteration is something that happens and it happens whether or not the project team wants it to happen. If the team resists iteration, effort goes into the resistance, communication tends to break down, doing the work is more difficult, and the product may suffer. It is, then, a good idea not only to accept iteration but to encourage it. When the team accepts iteration as natural and, therefore good, iteration can be managed cooperatively; no effort goes into resisting it; communication very likely is strengthened; the work is easier; and the product is enhanced. Managing iteration, then, begins with encouraging it. When iteration becomes something that is acceptable to do, the team members themselves will work out ways to do it effectively.

Among the tricks that can be employed to encourage effective iteration is the one of being sensitive to and open about things in a model that are indeterminate in terms of how they work and in terms of how sensitive the model is to them. If a given black box in the model is indeterminate in both these realms, then there is little justification in devoting very much time and effort to determining the box's transfer coefficient until the model's sensitivity to it is uncovered. So there is some justification for assigning a more or less arbitrary transfer coefficient to that black box early on, flagging it as arbitrary and fully intending to give it a harder second look <u>if</u> it turns out to be something to which the model is at all sensitive. If this is done in all cases wherein it seems appropriate, iteration is encouraged in two ways. First, no one has any involvement with the arbitrary coefficient and so no one is bothered if it is replaced. Second, very little time is spent developing previously unknown transfer coefficients before the first trial runs of the simulation model; therefore, the first runs and resulting sensitivity analyses can occur much earlier in the project--leaving more room for iteration.

5. The "We and They" Issue

a. The We and They Issue Between Modelers

The workshop repeatedly assumed a form that placed hydrodynamicists and "biologists" or "ecologists" on different sides of an imaginary fence. Several times someone would call the assemblage on this distinction and there would be overt agreement that the distinction was invalid and useless; that the ecosystems of concern were continual and that all who dealt with the modeling of any part of their dynamics were ecosystem modelers (or analysts). Then the discussions would return almost immediately to references to ecologists and hydrodynamicists. There did not seem to be anything we could do to dispel this distinction in the behavior and presumably the minds of most of the participants.

So there it is. Is it bad? It is true that there is a tendency to develop hydrodynamical models first (or apart) and that they frequently don't entirely fit the interface needs of the more biologically oriented models when the latter go into development. And it is not clear that even this is very bad. Usually the outputs of the hydro-models can be adjusted to more or less fit the interface needs of the other models, albeit at some effort and expense, so not too much is lost in this regard. But isn't it valuable for the form and substance of the hydrodynamic solution strategy to be created with sensitivity to the chemical and biological dynamics? And isn't it valuable for the form and substance of the chemical and biological dynamics solution strategy to be entirely sensitive to the hydrodynamics? Isn't this the only route to creating truly integrated models that do not depend on marginally effective "adaptors" to achieve workable (or seemingly workable) interfaces between submodels? The consensus of this workshop is that it is the only route.

How to achieve this degree of integration is abundantly unclear. Perhaps, in first-generation models we will have to tolerate adapter mechanisms in the submodel interfaces and look toward achieving true integration (gradually) in second-, third-, or fourth-generation models. On another hand, perhaps we can learn to select principals and manage modeling efforts so that true integration occurs naturally as an effect of the principal people in the project and of an aura of cooperation and synergism created by these people and the management.

Universities typically are quite rigid in their disciplinary devisiveness and the boundaries are not crossed easily and without personal risk. Perhaps universities usually are not ideal environments for doing applied multidisciplinary developments--which ecosystem modeling and analysis projects surely are. Perhaps long-lived workshops of the sort employed with apparent success by Buzz Holling in British Columbia are an appropriate mechanism. There workshops occurred by UBC-centered efforts, but were not of UBC itself. They contained principals from government and the business community, as well as academicians. Perhaps this approach bears examination as a solution to the other part of the "we and they" problem, too.

b. The "We and They" Issue Between Modelers or Analysts and Users

It was said and acknowledged in the workshop that users usually expect models to be tangible products (computer programs) that, in effect, are crystal balls capable of foretelling the future. It was said and acknowledged in the workshop that users usually do not know what they want specifically and (not surprisingly) don't know what to do with whatever products they do get. One can use this to justify continuing involvement of ecosystem analysts in a project--promise of continued employment. Or it can be used to prove that users are incompetent in this realm--if that is what one wishes to do. Or it can be used to question how well the users and the ecosystem analysts are communicating. Or one can challenge the truth of the assertion itself. But it is not clear how any of the above approaches will lead to better models used better.

If one assumes that the users, be they politicians, bureaucrats, scientists, or businessmen are the users of the results of ecosystem analysis and modeling products, then one <u>must</u> assume two more things. First, the users--if only they may be capable and adequately informed, must know the <u>kinds</u> of decisions to be made and therefore the <u>kinds</u> of answers that they need and can use. Second, it is unethical for ecosystem analysts and modelers to provide users answers that they cannot understand, or do not need,or cannot use.

This leads to the conclusion that agreement upon the objectives of any ecosystem analysis project--agreement reached unanimously and really--should be achieved early in the project (or before it is started) and maintained throughout the life of the project. The agreement should be explicit, detailed, and clear. Disagreements that remain unresolved for any length of time (a few weeks or a few months in unusual cases) should be treated as stimuli for re-examining the wisdom of continuing the work. For, to continue work when those responsible for creating the products and those responsible for using them are not or may not be in full agreement on the form and substance of the products can be nothing more nor less than unethical.

The Holling type of workshop is the only obvious route to initiating and sustaining agreement between the analysts, modelers, and users. In the Holling approach, all work together with an explicit time commitment; each assumes equal responsibility for the form, substance, and products of the project and all stay with the work until understanding <u>and</u> agreement are clear. And the entire "we and they" issue thereby disappears. It should be tried beyond British Columbia. It might work.

6. <u>Levels of Support and Times of Grace</u>

The philosophy subsection of this section alluded to the phase-lag issue wherein ecosystem analysis and modeling results frequently are demanded earlier than they can be produced. It came out clearly in the workshop that one of the we-and-they things that must be resolved early in the life of such a project is when it will be reasonable to expect results, what the results will be, and what level of support and participation will be needed to achieve the results. The project team must be afforded an adequate opportunity to achieve success by both the user faction and the funding faction. A team that is concentrating its efforts on assuring enough funding to stay in business while defending its unproductiveness to the user faction is a team that is not concentrating wholeheartedly on the task for which it was formed. And there is a positive feedback effect in this in that the more the team must fight for funds and defend its lack of results, the poorer the results; thus the harder it must compete for funds and defend its results. To escape this sort of destructive cycle, there must be early and clear agreement on what results are reasonable with a given amount of time and level of funding. It is the responsibility of the project team, the users, and the funding agency to assure that such an agreement is reached clearly and explicitly before a project proceeds very far.

Implicit in the foregoing is the idea of times of grace; some significant period of time during which the project team can be free to concentrate on what it has contracted to do; a time during which the team is supported and not distracted by the funding agency and the users. Implicit in the time of grace idea is the recognition that it is finite. When it is over, results, not excuses, are to be expected.

7. Project Managers

To the degree that a project team member views his commitment to a multidisciplinary project as a detriment to his disciplinary ambitions, he will be a less effective team member. Conversely, to the degree he can view his participation in the project as being in alignment with his professional ambitions, he tends to be a more effective team member. Moreover, he needs to remain convinced that his participation in the project is good for him and so must somehow be both drawn in and protected by his project manager. This situation, which occurs frequently in universities, demands a forceful, understanding, and charismatic project manager who is himself free of concerns that the project may not be in his own best professional interests. And this, it seems, is the key to all the rest of it.

APPENDIX A

SELECTED READINGS

The references listed here were employed by the author as a basis for interpreting the issues that came up in the workshop. This list does not contain all Sea Grant aquatic ecosystem analysis and modeling publications; these are given in the project summaries to the extent they have been supplied by the contributors of the project summaries.

Alexander, C. "Notes on the Synthesis of Form". Harvard University Press. 1968.

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Lindeman, R. "The Trophic-dynamic Aspect of Ecology" in W. Hagen "Readings in Population and Community Ecology". W. B. Saunders Co. 1964.

Mar, B. "Where Resources and Environmental Simulation Models are Going Wrong". Conference on Ecological Modeling, International Institute for Applied Systems Analysis, Vienna, Austria, Sept. 4-6, 1973.

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Patten, B. "Systems Analysis and Simulation in Ecology". Academic Press, 1971 and 1972. (2 vol.)

Raser, J. "Simulation and Society". Allyn and Bacon, Inc., Boston. 1969.

Kelly, R. "IIPS Vancouver Regional Simulation Project - 3rd Year Report". Resource Science Center, U. British Columbia, Vancouver 8, Canada.

Regier, H. "Fishery Regimes: The Roles of Slogans and of Science". University of Toronto (undated).

Robinson, H. and D. Knight (ed.) "Cybernetics, Artificial Intelligence and Ecology". The MacMillan Press, Ltd. (London) 1972.

Von Bertalanffy, L. "General System Theory". George Braziller, New York. 1968.

APPENDIX B

SUMMARIES OF RELEVANT SEA GRANT PROJECTS IN AQUATIC ECOSYSTEM ANALYSIS AND MODELING

The brief summaries given here are intended to provide a reference base upon which to evaluate the contents of this report since, to a degree, they reflect the collective frames of reference the participants brought with them to the workshop. They are reproduced here as submitted by their originators with no changes other than any superficial editing that may have been appropriate. Where participants did not provide the requested summaries, the author had no choice but to substitute information from NOAA form 90-2's. Also, although a standard format for these contributions was requested, what appears here is what was submitted.

1. University of Michigan

a. Project Title: Mathematical Modeling of Total Coliform Bacteria in Grand Traverse Bay

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: Sea Grant 1971-1973

Objectives: To determine optimum bacterial pollution control strategies for Grand Traverse Bay using modeling techniques

Description: The natural die-away rate of coliform bacteria as a function of temperature was determined. This information, along with bay circulation patterns (provided by A. W. Green, Jr., University of Michigan), and loading was used to develop both dynamic and steady state contaminant profiles in two dimensions.

Publications:

"Modeling the Spatial Distribution of Coliform in Grant Traverse Bay", (with A. W. Green, Jr.), proceedings of the Fifteenth Conference on Great Lakes Research, pages 719-729, 1972.

"Steady State Modeling Program - Application Manual", (with S. Nachiappan), Sea Grant Tech. Report No. 27, MICHU-SG-72-207, 1972.

"Modeling and Simulation of Lakes and Impoundments" (with D. A. Scherger, W. S. Lung), Proceedings of the Fifth Annual Association of Environmental Engineering Professors Workshop, Mathematical Modeling in Environmental Engineering, ed. T. M. Keinath and M. P. Wanielista, page 439, 1972.

"A Water Quality Model of Coliform Bacteria in Grand Traverse Bay", (with R. L. Patterson, J. J. Gannon and W. F. Powers) Journal of the Water Pollution Control Federation, 45, No. 2, Feb. 1973.

"Field Verification and Application of a Model of Total Coliform Bacteria in Grand Traverse Bay", Journal of Water Pollution Control Federation, (1972), 46 (11), pp. 2261-2424.

"Some Applications of Optimization Techniques to Water Quality Modeling and Control", (with W. F. Powers) IEEE Transactions on Systems, Man, and Cybernetics, Vol SMC-5, No. 3, May 1975.

Uses: The model can be (has been) used to evaluate the impact of storm water overflow, boat holding tank spills, and waste treat plant discharges on the coliform levels in Grand Traverse Bay.

Future Plans: Respond to requests by users.

b. Project Title: A Complex Food Web Model for Lake Michigan

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: Sea Grant 1973-1975

Objective: To understand and control the effect of nutrient inputs on eutrophication and the fishery of Lake Michigan.

Description: The model is a coupled system of 24 nonlinear differential equations which simulate the seasonal behavior of 7 zooplankton, 4 phytoplankton and 13 nutrients. The model is two-layered and has no horizontal definition. The top predator in the model is the alewife. The model forcing functions are external nutrient loadings, sunlight, temperature, and water transparency. The model has been calibrated using field data from Grand Traverse Bay.

Publications:

"The Effects of Temperature on Phytoplankton Growth" (with A. H. Vogel), ASCE, Environmental Engineering Division, 100, No. EE1, Feb. 1974, page 231.

"A Food Web Model for Lake Michigan: Part 1 - Justification and Development of the Model", (with A. Vogel) University of Michigan Sea Grant Technical Report No. 40 March (1974).

"A Food Web Model for Lake Michigan: Part 2--Model Formulation and Preliminary Verification" (with L. M. DePalma and A. H. Vogel) University of Michigan Sea Grant Technical Report No. 43, May (1975).

"A Plankton-Passed Food Web Model for Lake Michigan" (with L. M. DePalma and A. H. Vogel) chapter in Modeling of Biochemical Processes in Aquatic Ecosystems, Ann Arbor Science Publishers, Ann Arbor, in press.

Uses: The model has been used to determine the effect of eutrophication on zooplankton species composition. Zooplankton species distribution in turn affects the competition between various fish. The model has also been used to determine the affect of heavy alewife predation of zooplankton composition.

Future Use: It is planned to use the model to help understand how the chub fishery in Lake Michigan can be restored.

c. Project Title: Experimental and Modeling Studies of Protozoan Predation on Bacteria

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: University of Michigan and Sea Grant 1971-1973

Objectives: To develop a sub-model for protozoan predation on bacteria.

Description: Various freshwater protozoan feeding (on bacteria) studies are conducted in both flask and chemostat cultures. The growth rate and yield of the protozoan are determined and related to prey (bacteria) concentration. These results are used to develop bacterial and protozoan feeding submodels. The submodels are coupled systems of nonlinear differential equations. The results of long-term predation studies are compared with model calculations.

Publications:

"Experimental and Mathematical Modeling Studies of Protozoan Predation on Bacteria" (with T.D. Lustig, P.M. Ruback and J.E. Salo) Biotechnology and Bioengineering, XV, pages 707-728, 1973.

"A Multi-Group Model for Predator-Prey Interactions", (with E. Villarreal and Z. Akcasu) Biotechnology and Bioengineering XVII, pages 1269-12990, 1975.

"A Theory of Interacting Microbial Populations: Multi-Group Approach" (with E. Villarreal and Z. Akcasu) Journal of Theoretical Biology, in press.

Uses: The protozoan feeding and yield submodel is a necessary component of any large nutrient recycling ecosystem model.

Future Plans: Laboratory and modeling studies will be expanded to include two protozoan predators.

d. Project Title: Mathematical Modeling of Biological Production in Grand Traverse Bay

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: Sea Grant 1972-1974

Objectives: To determine optimum nutrient control strategies to limit algal productivity in Grand Traverse Bay.

Description: The model is a system of nonlinear differential equations which simulates the spatial and seasonal distribution of nutrients, chlorophyll, and zooplankton in Grand Traverse Bay. The model has been calibrated using accounts for fluid circulation, nutrient inputs, the annual variation of temperature and sunlight, and light extinction in the water.

Publications:

"A Methodology for Mathematical Modeling Biological Production", Technical Report to University of Michigan Sea Grant Project, 1971.

"A Dynamic Model for Phytoplankton Production in Grand Traverse Bay", (with S. Nachiappan and D. Hineman) Proceedings of the 16th Conference on Great Lakes Research, page 21-33, 1973.

"A Model for Biological Production in Grand Traverse Bay" (with D. Hineman and S. Nachiappan), University of Michigan Sea Grant Report No. 37 (1974), 115 pages.

Uses: The model can be (has been) used to evaluate the impact of economic development and population growth on algal levels in Grant Traverse Bay. Algal levels are in turn related to the recreational value of the bay waters.

Future Plans: Respond to requests by users.

e. Project Title: A Chloride and Total Phosphorus Model for Saginaw Bay

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: Sea Grant 1973-1975

Objective: To determine the impact of the control of point and nonpoint sources of phosphorus on water quality in the bay.

Description: A two-dimensional steady state model is being developed for chloride and total phosphorus using bay circulation data (provided by A. W. Green, Jr., University of Michigan) and loading rates from streams and the atmosphere (provided by K. Mancy, University of Michigan). The model was calibrated and verified using measured chloride distribution patterns during two periods in 1974.

Publications:

"A Model for Total Phosphorus in Saginaw Bay" (with J. Squire) in preparation for Journal of Great Lakes Research.

Uses: The model has been used to show the relative impact of point vs. non-point sources of phosphorous. The model can also address problems concerning chloride pollution.

Future Plans: Respond to request from users.

f. Project Title: A Long Term Model for Eutrophic Lake Recovery Following Alternative Restorative Techniques

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: USEPA 1972-1975; Sea Grant 1973-1975

Objectives: To predict the long-term effects of various management techniques on water quality.

Description: A differential equation model was developed for a small eutrophic lake which included nutrient cycling, plankton growth, macrophyte growth, and interactions with the sediments. The model was verified using data collected from White Lake, Michigan.

Publications:

Lung, Wu-Seng (1975) Long-Term Prediction of the Role of Sediments in Lake Recovery, Ph.D. Thesis, Department of Civil Engineering, University of Michigan.

Uses: The model has been used to predict the impact on water quality of a land disposal (spray irrigation) wastewater treatment scheme recently constructed in Muskegon County, Michigan.

Future Plans: Compare model predictions with field data to be generated over next three years.

g. Project Title: A Sub-Model for Oxygen Utilization by a Protozoan-Bacterial Ecosystem During Stabilization of Organic Matter

Principal Investigator: Raymond P. Canale
Department of Civil Engineering
University of Michigan

Funding History: University of Michigan and Sea Grant 1971-1973.

Objectives: To develop a submodel for protozoan and bacterial oxygen consumption during stabilization of organic matter.

Description: Oxygen use by a freshwater protozoan-bacterial community is monitored in a flask culture. The energetics of oxygen utilization is divided into various mechanisms and modeled using mathematical techniques

Publications:

"Utilization of Oxygen by a Bacterial-Protozoan Community" (with F. Cheng), ASCE, Environmental Engineering Division, 100, No. EE1, Feb. 1974, page 171.

Uses: The oxygen uptake submodel is a necessary component of any large ecosystem model for oxygen in aquatic systems.

h. Project Title: Water Circulation Modeling and Measurement

Principal Investigator: A. W. Green, Jr.
Atmospheric and Oceanic Science
University of Michigan

Funding History: 1972-1976

Objectives: To provide dynamic models of water circulation and diffusion of contaminants in lakes and bays to water resource managers. To provide models of circulation and diffusion to ecosystem models. To aid field observers in planning measurement programs in order to obtain optimum information from observations. To validate the models by correlating results with field data.

Description: A fine grid (2 km resolution) numerical dynamic model for diffusion and transport in Saginaw Bay has been developed and initially checked out.

Uses: These models provide information about water circulation and diffusion which is valuable to water resource managers and planners, since they show regions of stagnation, active exchanges, and distributions of the transports. Stagnation zones should not be used for water supplies or swimming. Distribution of transports and diffusion show where material is carried.

i. Project Title: A Dynamic Model of Alewife Population in Lake Michigan

Principal Investigator: Richard L. Patterson
School of Natural Resources
University of Michigan

Funding History: 1973-1974

Objectives: To estimate carrying capacity of Lake Michigan for alewives and the impact of predation by sport fishes on the long run stability and biomass levels of alewives in Lake Michigan.

Description: Numerical models of reproduction, growth, recruitment, and mortality of alewives are developed and synthesized into a numerical model of population biomass. Time is the single independent variable in all cases. Temperature and available food supply are two environmental variables used to force the models. Other input variables are a) effect of spawning on food consumption, predation rates of salmon, and harvest rate by commercial fishermen.

j. Project Title: Dynamics of Great Lakes Fisheries

Principal Investigator: A. L. Jensen
School of Natural Resources
University of Michigan

Funding History: 1974-1975

Objectives: To transfer catch and effort data for major fish species of United States waters of the upper Great Lakes from data sheets to punched cards, and to apply yield equations to these data for the purpose of fishery management.

Description: Catch and effort data for whitefish have been compiled and analyzed separately for 27 statistical districts in the U.S. waters of the three upper Great Lakes. This analysis provides a sound basis for management of the Great Lakes whitefish fishery. A paper, Assessment of the United States Whitefish Fisheries of Lake Superior, Lake Michigan, and Lake Huron, was prepared and submitted for publication to the Journal of the Fisheries Research Board of Canada. The results of this work have also been communicated to fishery scientists in the State of Michigan Department of Natural Resources and the National Marine Fisheries Service.

Uses: The information will be made available to the National Marine Fisheries Service, the Bureau of Sport Fisheries and Wildlife, and the State Departments of Natural Resources. The information will be useful for fishery management.

2. University of Wisconsin

a. R/FA-2 Application of Fish Growth Model (Continuing)

Principal Investigator: James F. Kitchell, Institute for Environmental Studies, UWMSN

A model of fish biomass dynamics (Kitchell et al 1974) provides the basis for an integrative and synthesizing approach to analysis of both the fish growth process and the interaction between predator-prey and environment. The model has been recently modified to account for numbers-biomass interactions within the framework of cohorts identified as functional groups and/or age classes of a given consumer species (Koonce et al, in preparation). It has proven to have potential for diverse applications as indicated by recent uses in (a) simulating the dynamics of energy-budgeting processes of fishes in heterothermal habitats (e.g. power plant effluents), (b) studies of benthic insect populations and (c) evaluations of management strategies for northern pike (*Esox lucius*) populations.

Four steps may be defined in utilizing a model for evaluation of resource-related problems: (1) Model formulation, (2) Implementation, (3) Validation, (4) Application.

The development process is perhaps most demanding of the four, and as noted above, has already been accomplished. In the past few months, several improvements have been implemented to provide maximum flexibility for application to a wider variety of situations. Program changes have been made which greatly facilitate user interaction with the model via teletype and a user's manual has been prepared. After implementing changes in the program, it was revalidated using previous test data with satisfactory results.

Parameter estimation required for implementation is largely specific to the applications desired. A major advantage of this particular model is that it was designed to utilize parameters that generally have been or can be measured. Thus, the primary effort in implementation is a literature search directed to that species of interest; this has been initiated for walleye and perch.

Demand for physiological parameters required for energetics simulations is substantial yet generally available for walleye, perch, and coho salmon or closely related forms. Research of C. Norden (see BR-7) is yielding comparable information for alewife and smelt. Population structure and trophic exchange parameters are often site specific yet also generally available as the result of ongoing U.W. Sea Grant sponsored research efforts on Lake Michigan and through collaboration with University of Michigan (Great Lakes Research Division) and Bureau of Sport Fisheries and Wildlife personnel at Ann Arbor, Michigan.

Application of the energy budgeting subroutine of the model will be employed to determine those interactions between ration, temperature and biomass (mean size and population density) that will optimize the growth process for walleye and perch maintained under intensive culture conditions. Both the process and product of these simulation studies will be conducted in consultation and collaboration with Calbert's aquaculture subprogram.

The ultimate goal of work on coho-alewife predator-prey interactions is a modeling effort directed largely to simulations of environmental manipulation and fisheries exploitation strategies as a tool for determining the relative significance of long-term change in the pelagic zone of the Lake Michigan ecosystem. Manipulations will be performed to evaluate the importance of:

1. Physical-chemical conditions (e.g. temperature)
2. Predator-prey distribution discontinuities which will be based on information gleaned from ongoing Sea Grant supported research on Lake Michigan (BR-7, LR-1, LR-2, FA-1)
3. Fishery exploitation levels

All will be designed to examine stability of the coho-alewife interaction and its potential as a Great Lakes resource.

Selected References:

Kitchell, J.F., J.F. Koonce, R.V. O'Neill, H.H. Shugart, J.J. Magnuson and R.S. Booth. "Model of Fish Biomass Dynamics." Trans Amer. Fish Soc. 103:786-798, 1974.

Koonce, J.F., J.R. Peterson, J.F. Kitchell and P.R. Weiler. "A Numbers-Biomass Model for Aquatic Consumers." MS paper.

b. R/GB-3 Regional Water Quality Management

Principal Investigator: Harold J. Day, Environmental Control, UWGB

Co-Investigators: Erhard Joeres, Civil and Environmental Engr., UWMSN; Robert Lanz, Environmental Control, UWGB

Background:

The continuing investigation of water quality management alternatives in the lower Fox River watershed will terminate during the next grant year. Leadership in the development of an areawide management organization, focused on water quality in the river and the bay, continues to be a primary motivation for the study. Progress toward understanding and/or implementing regional water quality management continued primarily as a result of Sea Grant support, even though many other activities, including massive investments by the private and public sectors and hearings on water quality conducted by both state and federal agencies, have occurred within the period of the study. Recent federal legislation focused on water quality improvements confirms the high priority of this concept and the value of this project.

Objectives:

The continuing objective of the study is to provide an improved basis for decision making related to water quality management in the lower Fox River and Green Bay. Secondary objectives for the final year are:

1. Calibrate the watershed response model using new data obtained by the Sea Grant faculty and staff of the Wisconsin Department of Natural Resources (DNR).
2. Improve existing response models by including some recent advances in water quality modeling relating to feedback mechanisms in nitrification, and the stochastic nature of the system.
3. Use the response model to determine the limits of quality management achievable through low flow augmentation, and through reaeration at some of the hydroturbines and critical reaches of the stream.
4. Develop a management model using the watershed response model and economic data obtained from public sources and simulate the

river and bay system under several regional management policy alternatives to predict the resulting physical and economic changes.

5. Adapt these system response and management policy models for the watershed to a man-computer conversational mode to make them effective demonstration tools for use with decision makers throughout the Fox River Valley.

6. Organize and conduct local meetings, both industrial and municipal, using a remote access interactive computer terminal to demonstrate the results of different policy decisions, such as the downstream water quality effect of constructing a new waste water treatment plant, to local leaders.

Approach:

During the first half of the 1973-74 study period, the water quality response model will be completed, and a cost-effectiveness management model framework which uses the river-bay response model will be developed and used to simulate the economic and technologic consequences of policy decision in the river basin. During the second half of the year, the computer program will be adapted for use in a portable terminal, providing more direct access to the computer by citizen and civic groups. A meeting for river basin community leaders will be held to discuss the study's results and to observe the remote terminal in action. The representation at this and similar meetings of both municipal and industrial leaders having waste treatment responsibilities will be encouraged.

Progress:

1. Hydrologic and hydrographic data on the river and bay system; municipal, industrial and agricultural waste loads to the river and algae contributions from Lake Winnebago and the downstream river reaches, have all been collected and are ready for use in the system response model.

2. The mathematical model to simulate the river system prepared by Quirk, Lawler and Matusky for the DNR in 1969 has been improved to reflect the wider range of data available and also to account for that part of the lower bay east of the ship channel extending approximately five miles beyond the mouth of the river.

3. Data collected during the inventory effort have been organized on a map of the region for use by public schools of the area and other interested organizations. The map and accompanying narrative will be published by the summer of 1973 in time to assist in the public demonstrations of the river system simulation planned

during late 1973 and early 1974. Data collected as a result of related Sea Grant projects were used by the federal EPA during their 180-day hearings on water quality at both Green Bay and Appleton-Neenah-Menasha.

Applications:

The Great Lakes Basin Commission has selected the lower Fox Valley as one of the ten problem areas to get special EPA funds for study of water pollution. Recent federal legislation in water pollution control has provided the basis for direct application of the results from this study into the public arena. In light of the Federal Water Pollution Control Act Amendments of 1972, the strong possibility exists for the creation of a community-based regional organization titled the "Fox River Valley Improvement Association" (FRVIA) to serve this function.

All past and ongoing Sea Grant projects in the Green Bay area would have application to the FRVIA effort; this study would be particularly useful both in assisting during the creation and in contributing data and experience during the ongoing agency investigations.

c. R/GB-1 Phytoplankton and Nutrient Modeling in Lower Green Bay (1974 project)

Principal Investigator: Michael Adams, Botany, UWMSN

Co-Investigators: Edward H. Dettmen, Environmental Studies, UWMSN
Paul Sager, Ecosystems Analysis, UWGB
Joseph Koonce, Limnology, UWMSN

Background:

An important component of water quality degradation, particularly in inland lakes and in bays and estuaries, is the stimulation of blooms of algae by nutrients released into waterways as a result of man's activities. The lower end of Green Bay is a particularly striking example of this phenomenon, exhibiting algal blooms having densities near the mouth of the Fox River which are up to two orders of magnitude larger than farther out in the bay (Sager, 1973).

Modeling and experimental work on Green Bay in the past few years has produced a large data base characterizing the hydrologic and biological behavior of Green Bay. Simultaneous research on other aquatic systems by the International Biological Program (IBP) has produced substantial progress in the development of mathematical models of biological systems. Among these are models of phytoplankton and zooplankton production. The availability of the Green Bay data base provides an opportunity for adaptation of these models to a flow-through system such as Green Bay. This permits both a test of the models on Green Bay, and an opportunity to draw together previously obtained biological and hydrologic data.

Objectives:

The objectives of the proposed research are to adapt models developed by IBP for use in a system such as Green Bay, to simulate spatial distributions of algal biomass and nutrient concentrations along transects in lower Green Bay, and to investigate the consequences of reduced nutrient loading of the lower bay by the Fox River.

The aquatic primary and secondary production models developed by IBP generally assume spatial uniformity of nutrients and food resources. Transport and dispersion processes must be introduced into these models to make them applicable to lower Green Bay, since hydrologic flow and mixing affect the spatial distribution of both nutrients and biota.

The models will be run with data characterizing the hydrologic inflow and nutrient loading from the Fox River to Green Bay for periods during which data exist for nutrients and algal biomass along transects in the lower bay. This will permit comparison of model performance with observed Green Bay response. This portion of the work would involve an analysis of the sensitivity of model behavior to variations in environmental conditions. Transect data of the type needed already exist for the summer of 1969, and it is proposed that more be obtained during the summer of 1973.

Approach:

Previous studies on Green Bay have determined the general flow and mixing characteristics of water in the lower bay. Ahrnsbrak and Rabotzkie (1970; Ahrnsbrak, 1971) used conductivity and transmissivity data collected during the summer of 1969 to calculate diffusivities along the bay using a one-dimensional model. This study, and another by Modlin and Beeton (1970), showed that water entering the bay from the Fox River moves toward the east shore of the bay, with a well-defined plume of river water extending along this shore north of Point Sable. Modlin and Beeton have also determined the flushing rate and lakeward transport rate of Fox River water in Green Bay. The percent river water in this plume changes slowly in the lower bay, with the water off Point Sable containing approximately 60% river water (Ahrnsbrak and Ragotzkie, 1970).

Surveys of algal populations and nutrients show much steeper gradients. Sager (1973) finds a change of approximately two orders of magnitude in phosphorus concentrations and algal populations along a transect originating at the mouth of the Fox River and extending approximately 21 km up the center of the bay. This attenuation rate, which is high when compared with that for conductivity, is presumably due to uptake of phosphorus by algae and losses of algae to sinking and grazing. It is proposed to simulate these changes in algal population and phosphorus concentration.

The IBP model for phytoplankton production describes algal growth as a function of light intensity, temperature and nutrient concentrations (Hasler and Koonce, 1971; Koonce, 1972). The model is based on the assumption that accurate description of subcellular processes is an important key to understanding phytoplankton dynamics. The basic model consists of four differential equations representing algal biomass and internal concentrations of nitrogen, phosphorus and reduced carbon. This explicit treatment of internal cellular nutrient concentrations permits the model to simulate the processes of luxury nutrient consumption and subsequent use of these reserves during periods of external nutrient depletion. This feature makes the model particularly suitable for simulation of the temporal change in nutrient concentration experienced by a phytoplankton population being transported along Green Bay. Other processes included in the model are excretion by phytoplankton and sinking and grazing losses.

Calculations of grazing losses are based on a generalized formalism developed by IBP for predator-prey interactions. The formalism takes into account temperature dependence of grazing and the relative preferences of zooplankton for various algal species.

The approach taken to modeling the distribution of phytoplankton populations along a transect will be to divide the transect into a number of segments, each of which represents a volume of bay water centered on that segment. Calculations for any given time interval will determine phytoplankton production, loss to sinking, grazing, diffusion, and lateral transport by water movement. Simultaneous calculations for each volume element will determine changes in nitrogen and phosphorus concentrations due to algal uptake, excretion,diffusion and transport, and changes in the zooplankton population. Thus, nutrient concentrations and phytoplankton and zooplankton populations in any given volume element will be a function of primary and secondary production rates in "upstream" volume elements at previous times and of transport and diffusion rates into and out of that volume element.

Data needed to perform the simulation include Green Bay mixing characteristics, Fox River discharge rate and nitrogen and phosphorus concentrations of Fox River water, water temperature and turbidity along the transect, solar radiation and wind speed, all over the period of simulation. Data needed for validation of model results are periodic nutrient concentration and phytoplankton population data along the transect during the time period to be simulated.

Wherever possible, the model will be parameterized to make use of generally available data rather than on-the-spot measurements, thereby minimizing data collection needs and making the model more useful as a management tool. Wind speed and solar radiation data of the form needed may be obtained from standard U.S. Weather Bureau data. Fox River discharge data are available from the gauging station maintained by the U.S. Army Corps of Engineers at the Rapide Croche Dam at Wrightstown, Wisconsin.

All other data needed for simulation and validation are available for the summer of 1969. It is proposed to use the results given in the papers by Modlin and Beeton (1970) and Ahrnsbrak and Ragotzkie (1970) to describe transport and mixing. The remaining Fox River and Green Bay data have been obtained by one of the authors of this proposal (Paul Sager). The Green Bay data are for a transect originating at the mouth of the Fox River and extending approximately 21 km up the center of the bay.

The proposed modeling effort would be considerably strengthened by the availability of data along a transect which follows as closely as possible the mean position of the Fox River plume centerline along the east shore of lower Green Bay. This is expected to be the main path along which phytoplankton will be transported, and availability of data along this path would permit more straightforward calculations. It is proposed to collect the necessary Fox River nutrient data and nutrient, phytoplankton, temperature and turbidity data along a 25 km transect following the plume during the summer of 1973. Mixing and transport parameters obtained previously and described above would be used in conjunction with these data.

Applications:

The proposed research will provide an opportunity to adapt advanced primary and secondary production models to Green Bay and test their effectiveness as tools for predicting water quality. Such tools would be of great use both to other researchers and to regulatory agencies attempting to evaluate in advance the consequences of proposed policies for controlling nutrient releases into waterways. The large expense of such control programs would make prediction of expected water quality improvement highly desirable for agencies such as the Wisconsin Department of Natural Resources and the U.S. Environmental Protection Agency.

References:

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3. Hasler, A.D. and J.F. Koonce, "A Process Study of Nutrient Uptake Rates and Phytoplankton Growth Kinetics," Eastern Deciduous Forest Biome Memo Report # 71-65, 12 pp., 1971.

4. Koonce, J.F., "Seasonal Succession of Phytoplankton and a Model of the Dynamics of Phytoplankton Growth and Nutrient Uptake," Ph.D. Thesis, Zoology Department, University of Wisconsin-Madison.

5. Modlin, R.F. and A.M. Beeton, "Dispersal of Fox River Water in Green Bay, Lake Michigan," Proc. Thirteenth Conf. on Great Lakes Res., I.A.G.L.R., I: 468-476, 1970.

6. Sager, P.E., Personal Communication, College of Environmental Science, University of Wisconsin-Green Bay, 1973.

3. University of Rhode Island

a. Project Title:

(1) Development of an Integrated Three Dimensional Hydrodynamic, Salinity and Temperature Model

(2) Analytical Modeling of Coastal Zone Areas

Principal Investigators:

Dr. Frank White, Mechanical Engineering and Applied Mechanics and Ocean Engineering Department

Dr. Malcolm L. Spaulding, Ocean Engineering Department

Age and Annual Funding History:

	Age	Funding
(1)	Second Year	$24,000/Yr.
(2)	First Year	$25,000/Yr.

Research in the modeling area has been underway at the University of Rhode Island for approximately 5 years.

Users, Uses, Objectives:

To develop a three-dimensional model for salinity, temperature and circulation that would include the effects of wind, gravitational circulation and vertical temperature structure. The development of the proposed model would provide a sound, reliable basis on which could be developed water quality, ecological and coastal planning models for Narragansett Bay, as well as the Block Island Sound area.

(1) Development of a hybrid model constructed as a marriage between finite-element and finite difference modeling techniques for prediction of effluent transport from waste discharges in the coastal zone.

(2) Application of the existing two-dimensional vertically-averaged hydrodynamic and mass-transport models to the Block Island-Rhode Island Sound area.

(3) Using computer-generated movies and plots, refine existing techniques for presentation of model predictions.

Model Development and Application:

Development:

Two and three dimensional numerical models using finite differences and finite element techniques to solve for coastal zone hydrodynamics, salinity, temperature, and water quality parameters. Predominant driving forces are the wind and tide.

Application:

Models are being applied to local coastal areas to include Narragansett Bay, Block Island Sound, Rhode Island Sound, and Buzzards Bay to give estimates of the circulation and transport of constituents of use by local communities and private industries.

Validation:

Verification of model predictions are performed by use of existing data sets and supplementing these with any information collected by other organizations in the study area. Preliminary effort is underway to devise techniques to determine which boundary conditions and field stations provide the most information for the least cost.

Interface:

The results of model predictions are used in studies performed for local government, and private industry and coordinated through the Coastal Resources Center. Coordination within the University, particularly with the eco-simulation group, is maintained by contracts between the individual investigators of the various projects.

Future Plans:

1. Extend application of the three dimensional models to the southern Rhode Island coastline and continue to explore the relative importance of wind, tide, and outer continental shelf water mass movement as driving mechanisms for the flow.

2. Develop a three dimensional model that filters gravity waves and thus allows larger time steps to study wind driven coastal zone circulation.

3. Continue efforts to use interlacing of various models and grid systems, both finite difference and finite element, to develop computational and procedural techniques to aid in the siting of shore and vessel originated waste discharges.

4. Develop techniques to determine the sensitivity of model predictions to boundary condition representation; the ultimate goal being to develop optimum sampling networks to minimize data requirement for understanding of coastal zone circulation.

5. Continue work on developing tidal current and height charts to aid the local boating community.

6. Extend modeling techniques to investigate the consequences of hurricane in the coastal zone and their influence on coastal communities.

b. Project Title: Systems Ecology Studies of Narragansett Bay

Principal Investigator: Scott Nixon, Graduate School of Oceanography

Funding History:

	Fed.-Sea Grant	Matching
To date	269,616	60,864
Proposed	61,147	3,853

Objectives:

The major objective of this project is the analysis and modeling of the Narragansett Bay ecosystem with a view toward its management and evaluation of its response to inputs resulting from increasing population and development. Specific objectives for 1975 include (1) the simulation of various perturbations and management strategies on the Bay using the working model, (2) the application of the model to additional water systems to explore its general applicability, (3) sensitivity analysis of the model, (4) field and laboratory experiments and measurements to attempt to discover the mechanism regulating the fall production dynamics in the Bay where observed data departs significantly in some years from simulated values, (5) complete the analysis of the role of bottom communities in bay nutrient cycles begun this year, (6) continue exploration of the role of high and low marsh areas in bay nutrient cycles.

Applications:

(1) The model will be used to respond to specific requests of state agencies including Statewide Planning, Department of Natural Resources and Public Health. For example, we are now examining the effect of relocating sewage outfalls on bay nitrogen dynamics for the R.I. Public Health Department.

(2) The basic model is being applied to different waters to test its applicability; for example, use of the model has been made in an RFF study of Mexican lagoons, and agreement has been reached with AID to use the model off Peru.

(3) EPA is interested in the role of emergent marshes in estuarine nutrient dynamics. We are providing information on this.

Accomplishments during Past Twelve Months:

The ecological simulation model now provides realistic simulations of phytoplankton, zooplankton, and five nutrients in eight spatial elements around the Bay.

Progress:

(1) Laboratory measurements of respiration, excretion, feeding, and particle-size selection have been obtained for adult menhaden.

(2) Laboratory measurements of respiration, excretion, feeding and fecundity as functions of temperature have been obtained for the common estuarine carnivore, *Mnemiopsis ledyi.*

(3) The annual cycle of nutrient regeneration (5 forms) by bottom communities has been measured *in situ*.

(4) Measurements on the role of marshlands in bay nutrient cycles have begun.

c. Project Title: Effect of Dredge Spoil Disposal on Benthic Animals

Principal Investigator: Saul B. Saila, Graduate School of Oceanography

Funding History:

	Fed.-Sea Grant	Matching
To date	16,842	4,016
Proposed	10,808	2,058

Objectives:

(1) To determine the status of recolonization of dredge spoil in Rhode Island Sound by benthic invertebrates.

(2) To identify the natural habitats of colonizing species.

(3) To predict the future benthic community type on the disturbed area and its value in terms of food for commercial species.

(4) To provide data on contamination of sediments and animals at the study site.

(5) To examine aspects of the natural history of dominant Rhode Island Sound benthic species which relate to the effect of spoil on these animals.

During 1975-76, detailed statistical analysis of the data will be carried out to identify species groups and response patterns. Broader aspects of resource management in Rhode Island Sound will also be considered.

Applications:

(1) This research will be used in regional decisions on ocean disposal of dredge spoil. Within a year such a decision will be made concerning a large volume of spoil from Fall River, Mass. The proposed dump is at depths equivalent to those at the study site, outside of state controlled waters.

(2) Results on rates of recolonization and identity of recolonizing species will be published in a scientific journal. These results will be of particular interest because of the long temporal data base at this site.

Progress during Past Twelve Months:

(1) Facilities have been set up for sorting preserved animals and for observing live animals. Over 100 quantitative $0.1m^2$ grab samples have been obtained from both spoil-affected and natural bottoms. Identification and counting has been completed for half the grab samples. Direct observation of eight sample locations has been made by divers.

(2) It has been determined that: (a) spoil in both erosional and depositional areas still have low densities of benthic animals four years after deposition; (b) colonization of silty spoil has been by members of natural silty bottom communities; and (c) deposit feeders are important on natural sand bottoms in Rhode Island Sound. Sediments from grabs have been submitted to the National Water Quality Lab, Narragansett, for contaminant analysis.

d. Project Title: Ecosystem Analysis - Application in a Coastal Town

Principal Investigator: Candace A. Oviatt, Graduate School of Oceanography

Funding History:

	Fed.-Sea Grant	Matching
To date	10,947	2,474
Proposed	13,479	1,284

Objectives:

(1) To apply ecological systems analysis to document the historical and existing patterns and interactions between man and nature in the coastal zone and to quantify them at least on a gross level.

(2) To generate a "macro-model" that may be used to simulate the general consequences of long-range management strategies in terms of the stresses that human and economic development will put on natural ecosystems and to explore general constraints that the natural ecosystems of the coastal zone may impose on development.

Applications:

Work will be combined with parallel work by economist and sociologist. The resulting concepts and plans will be presented to the South Kingstown planner and the Town Councils of South Kingstown and Narragansett, and to citizen groups to be used as a basis for discussions of effects of various kinds of coastal zone development. Derived plans and general principles will be published where suitable.

Progress during Past Twelve Months:

A large amount of basic data on human ecology has been collected, including past and present quantitative data for: land use (including distribution of ownership and lot sizes), land sales, building activity, agricultural use and yields, surface and ground water, quality and quantity, soil types, air quality, commercial fishing activity and yields, industrial production and effluent, recreation and tourism, energy use (gasoline, diesel, heating oil, electricity, natural gas, wood, coal, marine gas), garbage and rubbish generation and disposal, roads, automobiles and traffic, human population levels (composition, and demographic parameters), food consumption, mental and physical health, public services, education, employment and income, etc. Work has begun on collection of natural ecology data and on development of a conceptual model for the towns.

4. Louisiana State University

Project Title: Marine-Fresh Water Exchange and Coupling with Biological and Chemical Systems

Principal Investigator: B. L. Smith, Center for Wetland Resources

Funding History:

	Fed.-Sea Grant	Matching
To date	39,272	38,852

Objectives:

The objectives of this project are to couple coastal oceanography and meteorology to the marine-fresh water boundaries, and correlate water exchange and circulation to biological and chemical systems. The three-year program had first year objectives of reviewing existing models, developing applicable mathematical methodologies, and collecting and reducing available field data. Second and third year activities include interfacing the driving functions, water exchange, circulation, mixing and water height with nutrient transport, marine-fresh water boundaries, biological activity and chemical processes. Statistical techniques will be incorporated and verification through empirical testing will be undertaken.

Applications:

The coupling of coastal oceanographic processes with biological-chemical system is a critical requirement in the LSU continuing systematic studies and particularly in ecosystems investigations. Products of this research will contribute significantly to the planning efforts of a variety of agencies including the Corps of Engineers, Louisiana Wildlife and Fisheries Commission, Louisiana Superport Authority, State Department of Public Works, and Louisiana Highway Department. It will also provide considerable support to LSU's concurrent Coastal Zone Management program.

Accomplishments during Past Twelve Months:

A computerized implicit finite difference solution to the hydrodynamic equation of motion in two dimensions has been developed. Also, the feasibility of synthesizing water exchange driving function has been determined through a preliminary examination of Gulf derived coastal oceanographic and meteorological data. Finally, a critical area

(Barataria Bay) has been selected for methodology validation and much field data has been collected and reduced for application with the mathematics.

5. University of New Hampshire

Project Title: The Hydrodynamic and Environmental Modeling of the Great Bay Estuary System

Principal Investigator: Barbaros Celikkol, Mechanical Engineering

Proposed Funding: Fed.-Sea Grant, 33,900 Matching, 18,600

Objectives:

The first year objectives are:

1. Adapt Leendertse's and Wang and Connors mathematical models to UNH computer and the Great Bay Estuary.
2. Design an experiment with the National Ocean Survey to calibrate and validate the models.
3. Carry on the field experiment with National Ocean Survey and carry on additional field work.
4. Calibrate, validate the models and make comparative studies.
5. Initiate model improvements.
6. Initiate the study of environmental parameters such as transient pollution, salinity intrusion, temperature distribution.

Applications:

Information will be used to advise the New Hampshire Coastal Zone Commission, Water Supply and Pollution Control Commission. It will also be made available to the Normandeau Associates and the Public Service Company of New Hampshire.

6. University of Washington

Project Title: NORFISH - A Concept Directed Toward a Total System Quantitative Approach to Management of North Pacific Coastal Zone Resources

Principal Investigator: L. J. Bledsoe, Fisheries/Quantitative Science

Funding History:

	Fed.-Sea Grant	Matching
To date	513,000	222,600
Proposed	69,900	36,100

Objectives:

Long Range:

1. In-house quantitative capability for solution of fishery problems.
2. Quantitative management tools for fishery resources.
3. Interdisciplinary facility for quantitative expression of biological, social, legal, and economic factors related to fishery problems.
4. Provide information on the effects of alternate management strategies.
5. Supply college graduates with capability for whole system based resources management.

Specific Objectives for 1975-76:

1. Data implementation, calibration and exercise of the northeastern Pacific fishery system simulator.
2. Implementation of salmon system simulator at Washington State Department of Fisheries.
3. Liaison with and support for quantitative studies of public and private fishery agencies.
4. Publication and dissemination of NORFISH fishery systems research.

The above capabilities will be directed toward improved utilization, in the broad sense, of oceanic and coastal zone living resources, especially fisheries, of the northeastern Pacific.

Applications:

NORFISH products will be available through Sea Grant Advisory Services to commercial fishermen and the fishing industry for the enhancement of their operations. NORFISH also supplies logistic support or advisory publications directly to the Pacific Marine Fisheries Commission, the Food and Agriculture Organization of the United Nations (FAO), NMFS, the Washington State Department of Fisheries (WDF), and the International Pacific Halibut Commission. Support to the Washington State Department of Ecology in their coastal zone management activities has been provided.

Accomplishments during Past Twelve Months:

1. Salmon troll fishery system analyzed for optimal management.
2. Prototype fishery system planner demonstrated for northeastern Pacific.
3. Economic history and enhancement methods analyzed for Skagit River salmon production.
4. Atlas of productivity of Bering Sea trawl fishery produced using 3-dimensional graphics.
5. Information system accesses 130 million bit data base for Washington Department of Fisheries.
6. Halibut model analysis projects economic return under various alternatives.
7. Planning map and statistical area atlas produced for FAO.

7. Massachusetts Institute of Technology

a. Project Title: A Biochemical Model for Coastal Waters with an Application to Red Tide Outbreaks

Principal Investigator: Prof. F. M. M. Morel, Civil Engineering Dept.

Funding History:

	Fed.-Sea Grant	Matching
To date	-0-	23,339
Proposed	32,300	47,594

Objectives:

The objectives of this project are twofold: 1) develop a biochemical model of coastal waters which accounts for the effects of oligoelements on the microbiota; 2) test experimentally the hypothesis that trace metal chelation--copper in particular--plays a key role in the triggering of certain dinoflagellate blooms (red tides).

Applications:

The successful development of a predictive biological model as proposed herein will augment considerably the set of tools available to deal with the great complexity of coastal water management. One of the most obvious and immediate impacts should be to permit rational decisions regarding the nature and the degree of treatment necessary for domestic waste waters.

Successful completion of the experimental part of the project will provide us with all the information and experience we would need to artificially trigger and control a red tide in the laboratory. This, of course, would augment considerably our understanding of the mechanisms of red tide outbreaks in New England waters.

An actual modeling of the conditions that result in a red tide would represent the synthesis of both parts of the project. This should prove extremely valuable for prediction and control purposes.

Accomplishments during Past Twelve Months:

So far we have 1) chosen the parameters that need to be included in the first version of the model: nutrients and essential trace metals; 2) defined the principles on which to build the model; 3) gathered a part of the necessary fundamental information on some of the parameters; 4) obtained basic experimental data on the growth of Gonyaulax tamarensis; 5) started to interpret literature data by computing heavy metal speciation in Gonyaulax culture media; and 6) initiated a systematic experimental study of the effect of copper activity on the growth of Gonyaulax tamarensis.

b. Project Title: The Sea Environment of Massachusetts Bay and Adjacent Waters

Principal Investigator: J. J. Connor, Department of Civil Engineering

Funding History:

	Fed. -Sea Grant	Matching
To date	500,500	318,375
Proposed	125,100	61,048

Objectives:

The general objectives of the project are the definition of the physical dynamics and water quality environment in Massachusetts Bay. Initially, the primary emphasis was placed on field measurement programs in order to establish base line information. This phase has been completed and emphasis has now shifted to the verification and application of numerical models which predict circulation and dispersion processes in coastal waters such as Mass Bay. The predictive numerical models will be extended by incorporating techniques developed in Estimation and Optimization Theories, and this will provide capabilities for design of cost-effective monitoring systems. The water quality aspects of the project are now focused on validating a hypothesis for the triggering mechanism causing red tide in Mass Bay.

Applications:

Information derived from the data will be applied to environmental impact studies in the Mass Bay area. Procedures and optimal data acquisitions systems will be developed on the basis of field experience for general application to environmental impact assessment. The information will be transmitted to the National Oceanographic Data Center (NODC) routinely after appropriate data reduction and analysis. The numerical models will be released to government agencies, environmental consulting firms, and other potential users. Extensive application for coastal zone management in Massachusetts is anticipated.

Accomplishments during Past Twelve Months:

An intensive field experiment designed to show the interrelationships of the nitrogen nutrient cycle in the Bay was undertaken as a culmination of the routine nutrient sampling program. The vertically averaged circulation and dispersion mathematical models along with user's manuals are being distributed. An extensive model verification program is well under way for the "Mass Bay". This involves cataloging and analyzing all current meter data in the Bay, running the computer programs with the observed tidal and wind conditions for various time intervals, and evaluating the predicted vs. observed response. Similar analyses will be carried out for dispersion. A workshop which presented the developments of the Mass Bay Sea Grant Project was held in October. Two new and significant areas of study have been initiated: design of cost-effective environmental sampling networks, and study of the

c. Project Title: The Sea Environment in Massachusetts Bay and Adjacent Waters

Principal Investigators: J. Connor and B. Pearce

Project Age and Annual Funding History: Project initiated July 1971. Annual funding level approximately $150,000 from Sea Grant and approximately $75,000 from industrial sources

Objectives:

The general objectives of the project are the defintion of the physical dynamics and water quality environment in Massachusetts Bay. In the initial phase, the emphasis was on field measurements and the establishment of baseline information for Mass Bay. In the fall of 1972, work on developing numerical models for predicting hydrodynamic circulation and dispersion was initiated. These models utilize the finite element method and the software has been designed so that the capabilities can be applied by engineers in consulting firms and government agencies to evaluate the transient response of coastal waters having irregular land boundaries. Starting in September 1974, the deterministic modeling effort was extended to incorporate stochastic methods. Our first objective was the implementation of the Kalman filter estimation technique in the dispersion model. This will provide a capability for assessing the effectiveness of a sampling network and opens up new opportunities for the design of cost-effective observation networks. A second objective was the development of solution strategies for circulation and dispersion studies in coastal waters taking into account the randomness of the wind and tidal perturbations. We are concerned here with the numerical simulation of dispersion processes over long time periods where fluctuations in tidal and wind excitation should be considered.

Description of Models:

1. CAFE-1

Finite element formulation for vertically averaged hydrodynamic circulation. Computes transient response (surface elevation and the depth averaged velocities) over a two-dimensional region due to tidal and wind excitation. Can treat arbitrary boundary geometry and variable depth. Extensive verification studies have been carried out for Mass Bay. This involved comparison of observed velocity distributions with the "predicted" velocities.

2. CAFE-2

Finite element formulation for 2 layer circulation. Same computational features as the one-layer model. Verification studies are now underway. We were planning to use field data for summertime conditions in Mass Bay that was to be obtained by EG&G during the summer of 1974. Unfortunately, they did not go out into the Bay until October 1974. Also, their data on the motion of the surface elevation is inaccurate. We made some measurements last summer with our own equipment (current meters), and are now working on the data.

3. DISPER-1

Finite element formulation for vertically averaged dispersion. Computes transient distribution of vertically averaged concentration over a two dimensional region having an irregular boundary. Can handle distributed or point loads applied in the interior domain and either concentration or flux boundary conditions. Results of the NOMES experiment (summer 1973) have been utilized for verification of the numerical model.

4. DISPER-2

Finite element formulation for dispersion in 2-layered flow. Has been designed to utilize the output of the 2-layer circulation model. Computes the transient average concentration in each layer. The program allows for entrainment, decay, settling, and variable layer thickness. A field experiment designed for verification of the 2-layer dispersion model was conducted last summer and the data is now under analysis.

5. DISPER-ESTIMATION

A version of DISPER-1 with the Kalman filter capability added. Program development is nearly completed. We are now attempting to identify some simple examples which we can use to check out and illustrate the method. We will also look for some "real" applications. The program computes the transient vertically averaged concentration distribution over a two-dimensional region with a numerical integration scheme. At certain discrete times, observed values of the concentration at certain points in the interior region (i.e., the sampling network) are combined with the "predicted" values and a new estimate is generated. The Kalman filter method uses a linear combination of observed and predicted values with the constants of combination determined by minimizing the trace of the error covariance matrix. One can also exercise the program without field data. This is the mode for assessing the effectiveness of a sampling network which is measured by the final value of the trace of the error covariance matrix.

Future Plans:

The project is scheduled to be completed by June 1977. The last year's effort (July 76 - June 77) will be essentially a wrap-up of the software and publications aspects. We also plan to have a national Sea Grant Conference on "Environmental Modeling" at M.I.T. in June 1977.

APPENDIX C

AGENDA

SEA GRANT AQUATIC ECOSYSTEM MODELING WORKSHOP

Conducted By - The Oceanic Institute
Hosted By - The University of Wisconsin
Sponsored By - Office of Sea Grant - NOAA

Dates: July 21-23, 1975

Place: Room 313, Wisconsin Center
702 Langdon Street
Madison, Wisconsin

Program Chairman - Joe A. Hanson, Oceanic Institute

Monday, July 21, 1975

7:30-9:00 a.m. Registration: 3rd Floor Wisconsin Center, 702 Langdon Street

9:00-9:20 a.m. Welcome and introduction to the purpose and objectives of the workshop - Bob Ragotzkie, University of Wisconsin Sea Grant Director, and Hugh McLellan, OSG

9:20 a.m. - 12:30 p.m. Session I. Overview of Current Sea Grant Ecosystem Modeling Projects. Chairman - Joe Hanson (Roughly 10 minutes for each presentation with 10 minutes for discussion)

University of Michigan	Ray Canale
Mass. Inst. of Technology	J.J. Connor
University of Rhode Island	Malcolm Spaulding
University of New Hampshire	Barbaros Celikkol
University of Washington	Lewis Bledsoe
Louisiana State University	Lincoln Smith
University of Wisconsin	Kwang Lee

12:30-1:30 p.m. Lunch - Wisconsin Center Cafeteria

1:30-4:30 p.m. Session II. Hydrological Mechanics of Aquatic Ecosystems
Chairman: J. J. Connor - MIT
Discussants: Barbaros Celikkol - UNH
Bert Green - U. Mich.
Malcolm Spaulding - URI
Bernie LeMehaute - Tetratech (OSG Advisor)
Don O'Connor - Hydroscience, Inc.
(Review Team)

4:30-6:30 p.m. Session III. (Part 1) Physical and Chemical Dynamics of Aquatic Ecosystems
Chairman: Ray Canale
Discussants: J. J. Connor - MIT
Kwang Lee - U. Wisc.
Gerald McHugh - LSU
Bob Ellis - Rensselaer Poly. Inst. (OSG advisor)
Don O'Connor - Hydroscience, Inc. (Review Team)

6:30-7:30 p.m. Attitude Adjustment: Lake Lounge Room on the 3rd Floor of the Wisconsin Center. There will be sumptuous hors de'oeuvres arranged by Delphine Skinner of U. Wisc. and a cash bar.

Tuesday, July 22, 1975

8:30-10:00 a.m. Session III. (Part 2) A continuation and completion of the deliberations of the previous afternoon.

10:00-12:00 Noon Session IV. (Part 1) Microbiological Dynamics of Aquatic Ecosystems
Chairman: Scott Nixon - URI
Discussants: Lincoln Smith - LSU
Ray Canale - U. Mich.
Bryan Pearce - MIT
Bernie Le Mehaute - TetraTech (OSG Advisor)
John Caperon - U. Hawaii (Review Team)

12:00-1:00 p.m. Lunch - Wisconsin Center Cafeteria

1:00-2:00 p.m. Session IV. (Part 2) A continuation and completion of the morning's deliberations.

2:00-5:30 p.m. Session V. Macrobiological Dynamics of Aquatic Ecosystems
Chairman: Louis Bledsoe - U. Wash.
Discussants: Malcolm Spaulding - URI
Scott Nixon - URI
Ray Canale - U. Mich.
Bob Ellis - Rensselaer Poly. Inst. (OSG Advisor)
Ted Foin - UC, Davis (Review Team)

Wednesday, July 23, 1975

8:30 a.m. - 12:30 p.m. Session VI. A round-table wrapup aimed at stating where Sea Grant-supported aquatic ecosystem modeling stands today and determining where it should be headed in the future.
Chairman: Joe Hanson

1. Opening Remarks: Tom Murray - OSG Asst. Prog. Director

2. Observations of the Review Team:
    - Don O'Connor
    - John Caperon
    - Ted Foin

3. Observations of the Sea Grant Advisors
    - Bernie Le Mehaute
    - Bob Ellis

4. Round-table Discussion

APPENDIX D

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