EUTROPHICATION MANAGEMENT MODELING

A Position Paper

by

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EUTROPHICATION MANAGEMENT MODELING

INTRODUCTION

The workshop on modeling the eutrophication process will discuss attempts to model specific components of the eutrophication problem. The discussion of my panel will focus on management modeling.

Management models are used primarily as decision-making tools and their effectiveness can be measured according to their ability to provide an improved basis for making decisions. Little work has been done in eutrophication management modeling. However a significant amount of research has been done on water quality management modeling in river systems.

During the past three years I have developed management models for regional water allocation (Heaney, 1968), regional water pollution control (Heaney, *et. al.*), and air pollution control (Bunyard, *et. al.*, 1970) using network-type mathematical programming formulations. The environmental system is described using a link-node configuration wherein the commodities of interest enter or leave the system at the nodes and move from node to node along feasible links. Economic optimization is achieved by establishing a criterion which measures the efficacy of moving along a given link. An upper and/or lower bound may be placed on flow along a link, i.e., a capacitated link. Also, amplified or attenuated flow along a link is permitted, i.e., generalized network.

This work indicates that environmental management models contain several common elements which are listed below.

1. statement of objectives
2. description of study area

3. selection of commodities to be analyzed
4. inventory of sources for each commodity
5. inventory of controls for each commodity
6. description of spatial and temporal transport processes
7. analysis of control costs and benefits
8. formulation of performance standards
9. formulation of institutional constraints
10. algorithms for system optimization

Each component will be described briefly in the balance of the paper. The integration of these components into a mathematical programming model will also be sketched. This presentation should provide a point of departure for our discussion on eutrophication management modeling.

1. Statement of Objectives

The logical first step in the analysis is to clearly and explicitly state the objectives of the study. It is incomplete to say that pollution should be minimized without placing a well specified list of constraints on the minimization. We might select as an objective the minimization of cost subject to satisfying a prespecified water quality goal. An alternative (but related) objective would be to maximize the water quality of the lake subject to a budgetary constraint.

2. Description of the Study Area

It is necessary to partition the entire area of interest into subsets which provide a mutually exclusive and collectively exhaustive representation of the system. The area of interest includes not only the lake itself but also its entire contributory drainage area. A sample partition of a lake into a number of cells is shown in Figure 1. Complete homogeneity is

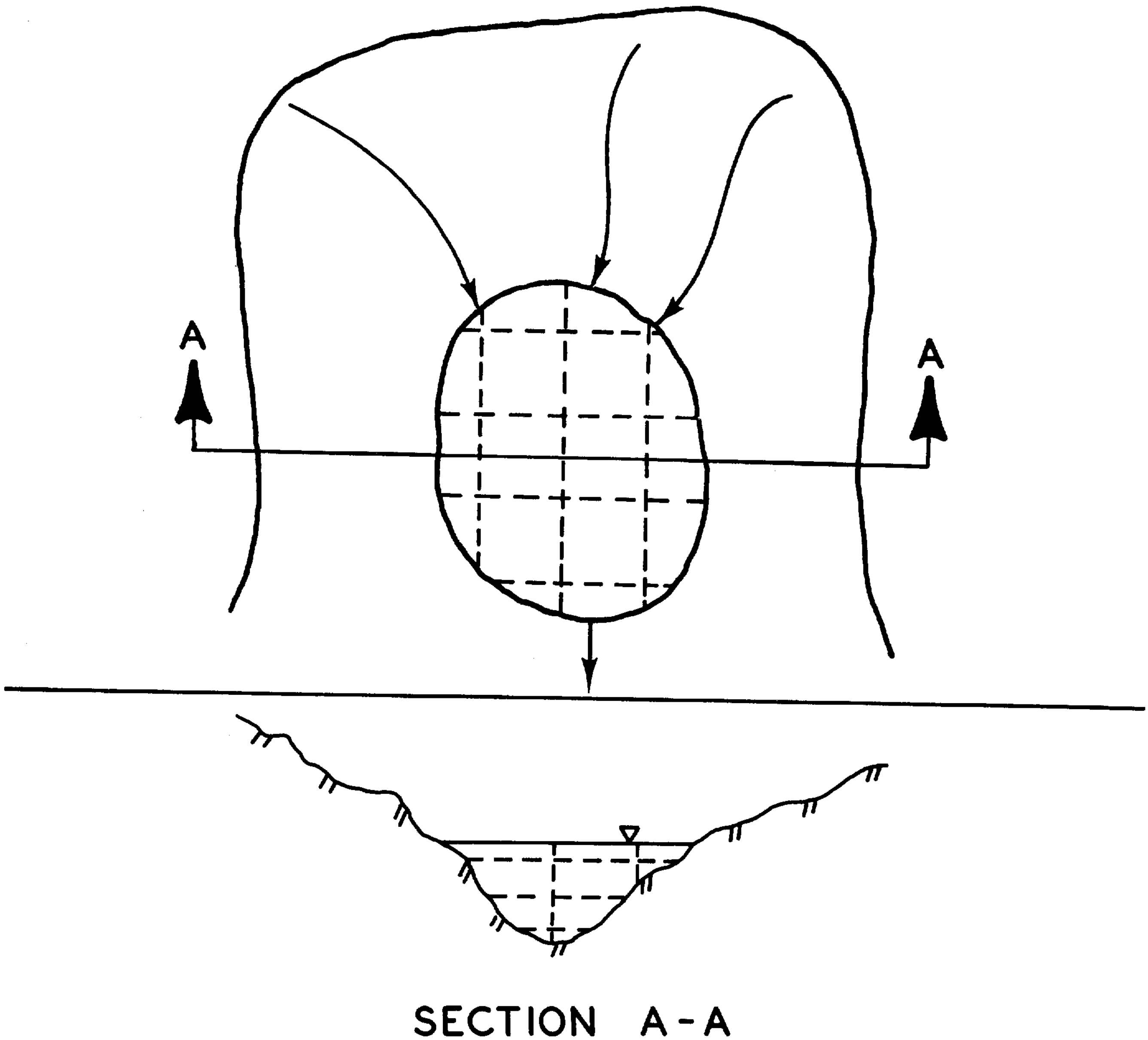


FIGURE I. SAMPLE DELINEATION OF STUDY AREA AND PARTITIONING LAKE INTO CELLS assumed within a single cell. Also it is necessary to specify the time interval to be analyzed and how many such periods will be considered simultaneously. The average residence time of a parcel of water in the lake provides a guideline in selecting the total time horizon to be examined. It is not necessary that the total time horizon be divided into periods of equal duration although it is typical to select a uniform time interval such as an hour, day, or year.

3. Selection of Commodities to be Analyzed

It is often perplexing to attempt to select from the large subset of biological, chemical, anc physical characteristics of pollution, some small subset of "indicator" commodities. It is not always apparent which commodities to select and much time can be wasted if clear selection guidelines are not established. Previous efforts have demonstrated that the commodities can be partitioned into three classes: carrier, conservative, and nonconservative (Heaney, 1968). This taxonomical scheme permits the investigator to view the model building process in a more generalized context.

4. Inventory of Sources for Each Commodity

During each time period it is necessary to describe how much of a given commodity is entering the system from the known sources, e.g., domestic and industrial wastes, farmland drainage. The pollutional load is estimated as the product of an activity coefficient, e.g. # BOD per capita per day, multiplied by the number of activity units, e.g., population. The activity coefficients are estimated by specialists in the environmental field whereas the estimates of activity units usually are obtained from demographic studies, Leontief-type models, and so on (Isard, 1960).

5. Description of Controls for Each Commodity

We need an inventory of the preventative controls for modifying the input quantity, and therapeutic controls for modifying the transport properties of the selected commodities. A tabular summary of such an inventory is shown in Figure 2. A single control may affect more than one commodity and more than one control may exist for regulating a given commodity.

6. Description of Temporal & Spatial Transport Processes

Given the selected commodities we may write continuity equations which describe the transport of a given commodity through the system, its interdependencies with other commodities, and its interperiod interdependencies with itself. These equations are a mathematical representation of the biological, chemical, and physical processes that are taking place in the system. A simple network representation of the spatial and temporal transport of a commodity i during two time periods is shown in Figure 3.

7. Economic Analysis

This phase of the discussion could include a cost analysis of the various controls and discussion of a methodology for quantifying benefits. One interesting question in developing eutrophication management models is the time lag that occurs from when an investment is made in a control and the water quality goal is achieved. In pollution of flowing bodies such as rivers and the atmosphere the goal is attained shortly after the control is implemented. This is not the case for "standing" bodies of water due to the residual effect. Thus, the time dimension must be added. The cost of attaining a given goal tends to increase as the time horizon

FIGURE 2. INVENTORY OF CONTROLS FOR EACH COMMODITY

	CONTROL						
COMMODITY	1	2	3	4	5	- - - - - - - - - - - - - - - - - - - -	p
x_1	x		x				
x_2		x					
.							
.							
.							
x_m					x		
- - -	- - -	- - -	- - -	- - -	- - -	- - - - - - - - - - - - - - - - - - - -	- - -
x_{m+1}				x			x
x_{m+2}	x	x					
.							
.							
.							
x_n	x	x	x	x	x		x

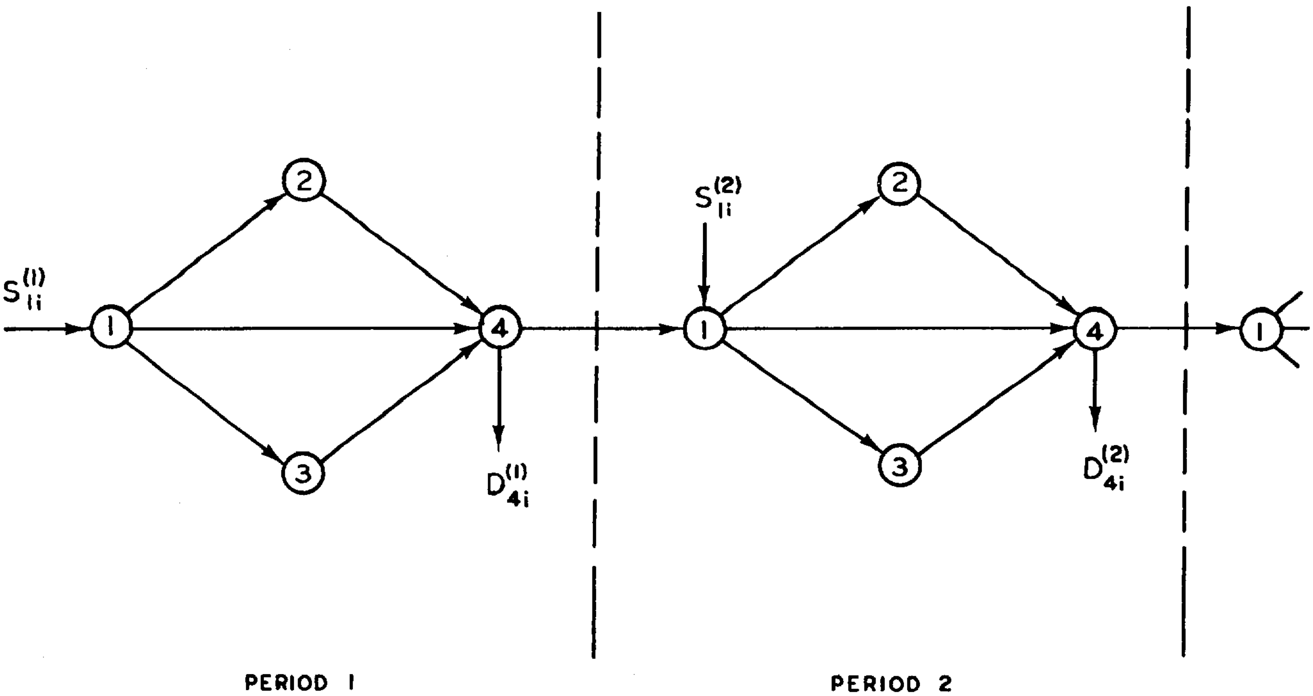


FIGURE 3. DESCRIPTION OF SPATIAL AND TEMPORAL TRANSPORT PROCESSES

is shortened.

The eutrophication investment problem might be characterized as a series of discrete investments over time which result in a continuous stream of benefits over an extended period of time. These benefits are both tangible and intangible. Our knowledge of the quantification of benefits is incomplete but it would include evaluation of recreation, land valued, esthetics, etc.

8. Formulation of Performance Standards

Environmental quality standards formulations fall into two broad categories: effluent or receiving system. The latter formulation requires a model which can simulate the movement of the pollutant through the carrying medium (air or water). A comprehensive evaluation of the allowable quantity of a given commodity at selected points in the lake is needed for each time period. Because of the extended residence time in lakes the standards need to take cognizance of the cumulative effects which occur.

9. Formulation of Institutional Constraints

Public institutions and policies provide the framework within which the activities of the water resource system function and hence exert a significant influence on the management of the system. The analysis and determination of optimal combinations of public institutions and policies that will promote fulfillment of environmental management objectives, together with periodic re-evaluation of the validity of the assumptions upon which they were originally based, are essential components of a sound management plan.

10. System Optimization

A significant advantage of using a network type formulation of environmental problems is that it permits us to utilize the wide variety of algorithms that are available for optimizing multi-commodity network flow problems. In addition there are the efficient mathematical programming formulations of transportation-type problems. A detailed discussion of optimization techniques is outside the scope of the discussion. The interested reader is referred to a recent book by Hillier and Lieberman (1967).

A schematic diagram of a mathematical programming management model for water and two carried commodities is shown in Figure 4. There is an objective function and a set of constraints. In this illustration the selected objective is to minimize the cost of satisfying specified water quality standards (Step 1). The size of the model is determined by the extent to which the study area is partitioned and how many time periods are being analyzed (Step 2). This is a three-commodity problem (Step 3). The sources of each commodity are inputs to the right-hand side supply vectors, $S^{(k)}$ (Step 4). The controls being considered are represented as alternative paths or control links. In this illustration, control alternatives exist for commodity 2 (Step 5). The description of transport processes are embodied in the individual commodity continuity matrices $A^{(k)}$ and the intercommodity interdependency matrices, $D^{(k',k)}$ (Step 6). The control costs are summarized in the coefficients $C^{(2T)}$ of the objective function and the technological limits on controls are expressed by the control bounds (Step 7). The performance standards are specified in terms of commodity 3 (Step 8). No specific institutional constraints are included in this illustration (Step 9). Lastly, the problem is solved using a selected computational algorithm (Step 10). The post-optimal analysis of the solution is included in this last component.

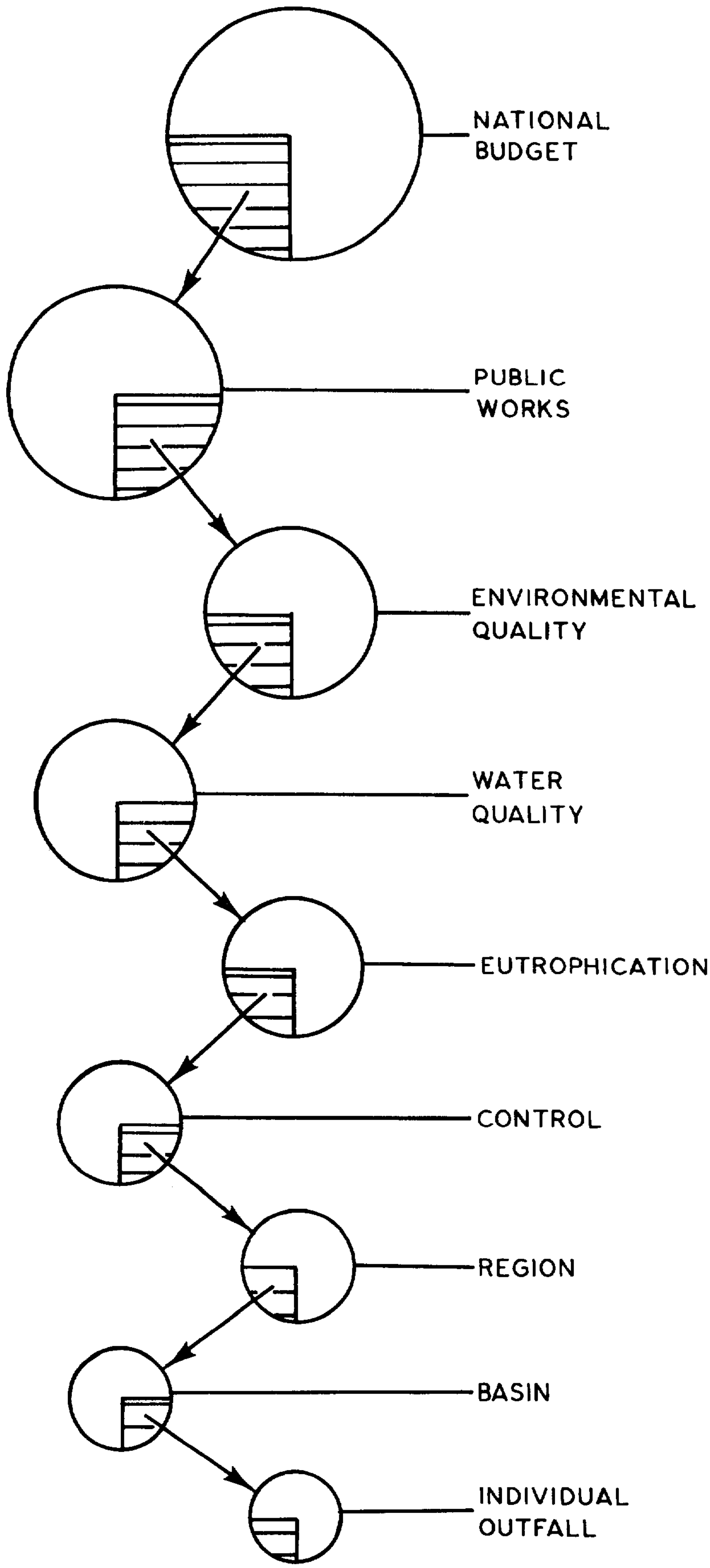
MINIMIZE $Z = [C^{(2T)}]' [Q^{(2T)}]$: CONTROL COSTS } OBJECTIVE FUNCTION

SUBJECT TO: LINKS

	WATER	COMMODITY ②	COMMODITY ③	CONTROL				
WATER NODES	$A^{(1)}$ CONTINUITY	0	0	0	$Q^{(1)}$ WATER VECTOR		$S^{(1)}$ WATER SUPPLY	
COMMODITY ② NODES	$D^{(1,2)}$ INTERDEP.	$A^{(2)}$	0	$T^{(2)}$	$Q^{(2)}$ COMMODITY ② VECTOR		$S^{(2)}$ COMMODITY ② SUPPLY	
COMMODITY ③ NODES	$D^{(1,3)}$ INTERDEP.	$D^{(2,3)}$ INTERDEP.	$A^{(3)}$ CONTINUITY	0	$Q^{(3)}$ COMMODITY ③ VECTOR	=	$S^{(3)}$ COMMODITY ③ SUPPLY	CONSTRAINTS
COMMODITY ③ STANDARDS	$p^{(1,3)}$ COUPLING	$p^{(2,3)}$ COUPLING	$p^{(3,3)}$ COUPLING	0	$Q^{(2T)}$ CONTROL VECTOR		$\underline{Y}^{(3)}$ COMMODITY ③ STANDARD	
CONTROL BOUNDS	0	0	0	I			$\bar{Q}^{(2T)}$ COMMODITY ② CONTROL UPPER BOUNDS	

$$[Q^{(1)}], [Q^{(2)}], [Q^{(3)}], [Q^{(2T)}] \geq 0$$

FIGURE 4. ILLUSTRATIVE MATHEMATICAL PROGRAMMING FORMULATION OF PROBLEM


NATIONAL BUDGET
PUBLIC WORKS
ENVIRONMENTAL QUALITY
WATER QUALITY
EUTROPHICATION
CONTROL
REGION
BASIN
INDIVIDUAL OUTFALL

SUMMARY

It is important to emphasize that the management model, like other models, seeks to assist us in analyzing complex systems. Its purpose is to provide information regarding the problem at hand. It does not, and cannot provide all of the information which is needed in the decision making process.

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DISCUSSION

MANAGEMENT MODELS

FRUH: One technical point, which came up yesterday morning in the second session and also goes back to Don O'Conner's model. We can take measurements and get productivity and nitrogen and phosphorus and find out how many algae in terms of chlorophyll for mass. However, the biggest difficulty, technically, now, is to take that algal mass and say, this is the problem in the algal mass - the odor. Then this is the dollar sign for removing the odor in the water treatment plant. Or, this is the algal bloom, and this is the mat that floats into the shoreline and this is the dollar value that has gone down on the land.

BREZONIK: Some of that has to be done on a stochastic basis. There are things you cannot predict.

FRUH: But that's what we checked in our research.

BREZONIK: You just don't know, for example, when the wind is going to blow from the south, and blow your algal blooms into the shore, where your setting may be. Based on past records you can say that 80% of the time the wind does blow from the south, and perhaps make some sort of prediction based on that, or how much of a problem you are going to have with the scum layer on shore based on productivity in the lake.

PATTEN: Can I ask if you have any information whether the technology is available to solve a multiple objective problem simultaneously?

HEANEY: You can solve them to the extent that you have multiple goals.

PATTEN: Do you have to weight these and lump them into some sort of an index, and then maximize and minimize that index?

DYSART: We are using some words here and I think we ought to clarify them. I would say that we must distinguish between objectives and goals. I look upon goals as being extremes. Goals - such as water quality standards. I think that an objective could be either the minimization, as stated here, of cost, subject to certain environmental quality, or maximizing quality, subject to your budgetary constraints. Your comments regarding whether it has to be an extreme situation - I think that an optimal level of development of use in a river basin, whatever the optimum is, is going to be a blend of different purposes and uses of the water resources.

PATTEN: It is a rather involved type of thing, and it is never extreme in any one sense.

DYSART: I think we have to talk about a blend of purposes, in that case there will be this trade-off. There are a number of purposes of development. Qualitative oriented purposes, such as recreation or aesthetics. We have quantitative oriented purposes such as flood control and power, and some of these are complementary, some of them are very competitive. We would probably be in trouble if we had to say, formulate what blend these were going to be.

HEANEY: I would just like to make one short point: I think we have become accustomed, after a day and half, to thinking about modeling, in general, as a dynamic process, we are not looking for a one shot deal as far as typical modeling processes. We get an optimal solution. We have a simulated model, we have all of the inputs. Based on that we go back, re-do some of our homework, and go ahead with the same learning process. I just don't want to get static.

SCHAAKE: I would like to ask the panel to comment on how they see interaction between this kind of a framework for doing this problem process and the world of the rest of society, the world of political process, and whether or not we are dealing with a problem that might be called a sociological problem, in a technological sense, or a technological problem in a sociological sense. I think there is a difference between objectives and constraints.

HEANEY: Dr. Shapiro suggested an eutrophication index, and we had a real lively discussion. Everybody is sitting here and they've got their own definitions, and he was boldly suggesting a single index. Now, the dollar, in my opinion, is this index. Not the best. Perhaps there is a better one. I would like to have an alternative that allows us at least to measure the relative value.

REYNOLDS: Basically, John had a good point, that the dollar may not be a sacred measure of all this. There are deficiencies. It probably is the best one we've got to work with, but we do need to recognize some of the deficiencies. Address yourself to prices, for instance, we have the prices of commodities that are reflected by the market index. We can find out the price of a particular agricultural commodity, or particular stocks and bonds, and things like this. The market may not always work perfectly. If the market worked perfectly, prices should be the reflection of people's tastes and preferences. We have other indications, and that is political process. Maybe part of this comes through in our system in the United States. We temper the prices. It could happen with the benefit-cost ratio. Benefit-cost ratios in the past have been, well, there are devaluating procedures now, but they would measure the tangible benefits and they would recognize the intangible benefits, so that if they went past that point where there was maximum benefit, you see they were bringing in part of the intangible benefit within a non-market commodity, so there are sometimes other things in our system besides prices that have a significance.

GIBBS: I would like to say, John, that pertaining to modeling, if you or anybody else would give us some insight into how we can measure the eutrophic model.

SCHAAKE: The way to make progress is to look at those assumptions (we're back on the road block) and use the model to gain insight into what's happening.

HEANEY: That's exactly what Eckstine's models, the economist's models, modeled, and they have been very successful. They were awarded the Nobel prize in modeling. Their models were extremely simple.

SHELDON: We have the uncertainty of risk, and for many of us, particularly in eutrophication problems, pesticide contamination, and so on, and that is the uncertainty and the possibility of some way to reverse that. I think perhaps the thing you are trying to analyze in this case would be to minimize risk. I know there are ways to do this. This is certainly a criterion that doesn't always come to the fore.

GIBBS: I would like to comment on the assumption of the independence of utility companies to lower production costs. The business of the economic work that has been done in water pollution control has recognized the fact. They term this the relationship between production function, and consumption function, or vice versa, as analogous of the pulp mill producing waste in the stream and its effect on the fisherman downstream. So there is a relationship between the production function of the pulp mill and the consumption function of the fisherman downstream. Conceptually they have recognized this and tried to get measurements.

SCHAAKE: I also see the possibility of this whole program running in more than one way. I don't see the uniqueness of the solution. I live where Thoreau lived and I love it there. I think the environment is great. I wouldn't want to live anywhere else. I just believe that we could have more of that. This is part of the value of the lake.

MOREAU: We are talking about possible objectives, to translate all of this to equivalent market situations. What I suggest is that when we come back to the basic decision, about the eutrophication process, we come to the question of environmental quality, the same questions relating to redistribution of income. The environmental quality is becoming an object unto itself the same as redistribution of income, and is not something to be counted in the benefit-cost calculations. The system is something separate.

SCHWARTZ: I think the political decision has already been made, and we don't have to calculate the values. It's just like, people decide if we're going to have ballet, or we're going to have museums, we're going to have education, we're going to have trips to the moon, or we're going to have national security. We don't have to calculate the benefits of this. The decisions have been made. I think what happened recently, or what is happening now in Congress relates to this. In the President's budget there was 200 million dollars for water quality program, facilities, and so on. The House of Representatives upped this at one time to a billion dollars. It got back down to 600 million. The Senate now has gone to a billion and there is going to be a compromise and it may be six hundred million. I think this sort of exercise you are doing here is a problem in how to achieve these objectives at minimum cost, it is not how to go through benefit-costs and justify it.

GIBBS: Are these adequate funds to clean every lake in the United States?

SCHWARTZ: We are developing our technology. There may be cheaper ways of doing this. The way we are doing it now may not be the best way.

GIBBS: Some allocation has to be made. Why would we clean this lake and not this lake?

SCHWARTZ: I think that in terms of supply and demand, which we are dealing with, there is a multiple dimensional demand function that exists.

MOREAU: We don't reach those decisions in the market place. The point is, we reach it through a political process.

PATTEN: I would like to know how many private dollars are invested in this meeting, for example. I regard ourselves as externalities of the major public interest. This is public costs. The whole operation of all public service is represented. Most of us are on the public payroll in one way or another.

MOREAU: That is just the overhead.

PATTEN: This is a pretty critical operation. I don't think that industry has done a comparable operation. What is being done about it? My understanding is that these problems are solvable right now, technically. In relation to the power structure.

BARTSCH: I am not sure I understand your question. Is your question really asking this: Is industry doing something with relation to eutrophication?

PATTEN: I know they are doing something, but I don't know what they are doing.

BARTSCH: We are aware that there are a considerable number of industries that are involved very deeply in the problem of improving the environment. One industrial complex, which is the soap and detergent industry, is vitally concerned with the problem of eutrophication, for obvious reasons, the inclusions of phosphorus in detergent formulations. This industry is involved in a national Government-industry joint effort to explore many of the aspects of eutrophication. I am not sure I can state the number of dollars that are being contributed to various activities.

EUTROPHICATION MANAGEMENT MODELING

Summary Statement

by

The Panel Members

EUTROPHICATION MANAGEMENT MODELING

Following an opening statement by the Chairman, the discussion was opened for comments from the participants. A summary of these comments is contained below.

Opening discussion indicated the lack of adequate models for predicting the response of the lake to control of nitrogen and phosphorus. Thus, at least in the near future, it will be necessary to make control decisions without a good understanding of the expected changes in water quality and the benefits to be derived.

The problem of multiple objectives was discussed briefly. It was pointed out that the optimal level of development will be a blend of different purposes and uses of the water resources. Computationally, the multiple objective problem can be transformed into an equivalent single objective function with other goals included as constraints. (Charnes *et*. *al*., 1967).

Animated discussions followed regarding the appropriateness (or even relevance) of attempting to measure the benefits of effectiveness of environmental control. It was suggested that environmental quality is an object unto itself, the same as redistribution of income, and is not something to be counted in the benefit-cost calculus. The use of a monetary measure of the "value" of environmental control also was challenged because of its inadequacies.

The panel agreed that the dollar is certainly an incomplete measure of value. However, it is, at present, the best available index and allows us to measure the relative desirability of alternatives. If the market worked perfectly, prices should reflect people's tastes and preferences. We have other indicators through the political process which may alter the prices. Benefit-cost ratios in the past have measured tangible benefits, and recognized the intangible benefits. Thus, if they were bringing in the intangible benefits of a non-market commodity, they could deviate from the point where net measured benefits were maximized.

One of the participants felt that the political decisions with regard to the environment have been made and we don't need to calculate values. He felt it was analogous to a public decision for museums, education, and national security. Given the proposed national commitment to environmental control, he felt it was unnecessary to go through benefit-cost analysis to justify it.

A panelist responded by asking whether these funds would be adequate to clean every lake in the United States. He did not think so and emphasized that even with large sums of money, it will be necessary to establish priorities and make allocations. Environmental control must compete with other uses since the supply of money is far less than the demand. One of the panelists has prepared a chart showing how this allocation process works from the national level on downward. This chart is shown on the next page.

Final discussions dealt with the extent to which the private sector has made commitments to environmental control. It was pointed out that industry has been involved in solving this problem for a number of years. However, their commitment has been unimpressive in comparison with the size of their profits.

In summary, eutrophication management modeling is in an embryonic stage of development. There is little information available on the alternative control measures and the response of a lake to these controls. Consequently, eutrophication control decisions are, and will continue to be, made in a highly speculative framework.

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