PROCEEDINGS

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CONTENTS

INTRODUCTION

Awareness of the complexity and delicacy of our estuarine environments continues to expand. The sensitivity of estuaries to man's abuses signals the need for better understanding of estuarine processes to prevent unintentional ruin. But the complexity of the estuary makes simplistic solutions unrealistic and detailed solutions difficult.

The difficulties of the problem, of course, do not lessen the need for better answers and fresh approaches. The speakers at the Second Technical Conference on Estuaries of the Pacific Northwest, and their papers which follow, help fill that need.

Several papers point out that estuaries are a social responsibility, requiring the cooperation of many individuals and the resolution of a multitude of conflicting interests. At the base of such cooperation and resolution is better understanding--more hard facts--about how physical, chemical and biological attributes of estuaries interact. Several papers provide better knowledge of estuarine ecosystems; several others, better knowledge of the physical properties of estuaries. Such knowledge is prerequisite to intelligent management of our estuarine and coastal areas.

It is to increased understanding and intelligent planning and management that the conference, and these proceedings, are dedicated.

Grateful acknowledgement is directed to those who participated in the program and discussions during the conference. Additional annual conferences are planned in order to continue to promote greater understanding of our Pacific Northwest estuaries.

Larry S. Slotta,
Director, Ocean Engineering Programs

John H. Nath,
Ocean Engineer, Department of Oceanography

Welcoming Address: Robert MacVicar, President, Oregon State University, Corvallis

It's a real pleasure to be back again to perform the ceremonial act which is a part of conferences. I've had the important task on a number of occasions to simply extend a word of greeting and then depart. That's all right. It's usually easier, but it leaves one kind of frustrated; you don't really know what happens, and you're very sure that no one really cares that you're there at all. So when Larry and the other people asked me to go beyond that and engage in a part of the program myself, talking about the University and its potential contribution to the solution of problems of coastal zone management, I said okay, maybe that wouldn't be a bad idea. Not that I know that much about it, but perhaps sometimes ignorance is not just blissful but also helpful. In looking at a very complicated problem through the eyes of a naive neophyte, one can discern, perhaps, patterns that a more specialized individual is not able to see.

COMPETITION IN THE COASTAL ZONE

I'm sure we don't have to remind ourselves of the importance of the ocean-land inter-face, but let's just put it on the record anyway. It is the competition of man and his needs--commerce, recreation, water, cooling things that are too hot or diluting things that are too toxic--and we could go on and list a whole other series of needs--with the needs of the biota of the coastal zone that really brings us here today. These demands impinge on this ocean-land interface and the needs of the rest of the biota that occupy this interface--the plants and animals other than the human animal--and these are often competitive. What man wants to do in order to achieve his objectives results in a very serious dislocation, and perhaps even total removal of a particular species or a whole group of species, and thus upsets the equilibrium that has perhaps taken many, many centuries to achieve.

If that weren't bad enough, his works create a biological competition frequently extraordinarily complicated and very poorly understood. What is even worse and more complicated is man's competition with himself. One particular agency wants to use the resource for a particular group, and some other group wants to use the resource for a different purpose for their economic advantage; these frequently have almost no overlap whatsoever. They are simply mutually exclusive; you can't use the same resource for both purposes at the same time. Hence, man is competing with himself for a scarce resource, a thin and fragile interface which, in terms of the total land surface is only a very small fraction of the land, and in terms of the ocean surface an even smaller fraction, but it is nonetheless the most critical of all the interfaces because it is at this point that man encounters the ocean and uses it.

Now I think it is fair to say that basically we have not been very well organized to deal with the competition of man and his works with the biological aspects of the coastal zone. Nor have we been very well organized to cope with the problems induced by different human needs competing for this scarce resource of space, of water quality and a variety of other sets of conditions. As a matter of fact, if you were to try to put this all together in some sort of diagrammatic form, you would come up with an extraordinarily complicated piece. Maybe I can reach far enough and show you how complicated it can get. I just happened to have someone hand this to me this morning. Not that you can see this to read it, but you can look at it. I am sure that this is an over-simplification; for almost every one of these arrows you could have sub-arrows, and every sub-arrow could have sub-sub-arrows, and so on. This, then, represents the complexity of the interactions that occur, and therefore perhaps an explanation of why it has taken us so long as a society to deal with the problems that are inherent in managing these competing systems--man and his works, and the biota, and within the human system all the competing operations.

CENTRALIZATION

As a result of this, it would be fair to say that we have looked primarily at short-range outcomes. We've tended to try to deal with the problem of the moment, the moment being maybe five years or ten years off in the future. That's what we've tried to do in our planning, in zoning and other resource allocation processing. It's just not been possible, at least it hasn't been done except in very isolated areas, to look in terms of generations, centuries, millenia; man has just not thought about this. He has assumed that this really wasn't something that had to be done. We are now recognizing that this isn't any longer a possible position and that we must begin to think not only in terms of decades and centuries; we must really begin to think in terms of attaining a "steady state" universe, a world in which there is a continuing renewal of everything that is utilized. We know that if we're looking for the "steady state" world, again the ocean-land interface is extremely critical. It is here that so much goes on that makes the utilization of the larger aquatic resource of the open ocean possible. We simply have to focus far greater attention on this relatively limited amount of area. Whether we talk about local governments, state governments or the federal government, I think we have to honestly say that we've just not been very well organized. We've had different competing organizations within county government, regional organizations, state government and the federal government, with all of the human results of competition, some of which are good, but in this case a considerable amount of which are not.

You may ask do we want to put it all in one agency? And make that agency the czar of the coast? Of course you get all sorts of reactions to this, and no one may want to say that this is a good solution. Somehow there does need to be created out of that maze I showed you these complex relationships, some of which are human, some of which are natural, some of which are organizational, some kind of comprehensive organization. Without it we cannot plan for longer than a few months or years. We can't plan in terms of decades or centuries unless we think comprehensively, and to think this way we need comprehensive organizational relations.

THE ROLE OF THE UNIVERSITY

How does the University get into this? In the first place, it generates a lot of information. Historically, its scientists and students have been the principle source of most of the data--the theories, the constructs about the coastal zone and its inhabitants, plant and animal. It has also been the source of practically all the trained manpower for the agencies that study the ocean and the land and the ocean-land interface. Regardless of for whom they work, the University has been the source of training these people in their various professions.

It isn't really the research, and it isn't the education I really want to talk about so much. I don't want anyone to think that I don't believe these are the number one and two on the University's agenda, number one being instruction and training, and number two being research. I do want to talk about public service. How does a university like Oregon State get involved in dealing with the practical problems of coastal zone management and so on?

Well, one of the obvious ways is simply by existing. It's there, and because it's there with its ongoing program it has certain influences that are simply a fallout that cannot in a sense be either planned or controlled; it just occurs. A professor studies a subject; he finds out something interesting and as a result of this, he is invited to make a speech or is interviewed by a newspaper reporter or he appears on television, and he tries to explain what his research and technical data means in terms of human life. Sometimes he does this poorly; sometimes he does this well. Sometimes he overshoots his audience and people don't understand what he is talking about. Sometimes members of his audience interpret his new ideas in terms of what they want to hear, what happens to conform to their particular ideas or what they consider to be in their best interests. This is the first thing in the area of public service that I would point to. Some of what a university does is almost uncontrollable and largely uncoordinated "fallout," if I may use that word, of the ongoing programs. We certainly wouldn't want to prevent this from happening, but occasionally the scientist and scholar do need guidance in terms of getting the most effective use out of the experience and exposure.

THE UNIVERSITY AS CONSULTANT

The second kind of service is consulting where there is an organized relationship; this isn't fallout. It is planned by the scholar but often is not coordinated by the university. A person who has a particular kind of knowledge, in this case relating to the air-ocean-land interface, is asked by some agency or corporation to provide consulting services. This may be just one shot or may be over a long period of time, either with or without compensation to the individual. It is an individualistic kind of thing. There is a second order of consulting in which the university organizes internally groups of individuals who collectively have expertise or competence, and these groups render consulting service that none of their members have individually. The document I showed you shows the possibility of arranging some kind of internal arrangement of university personnel to assist an agency outside the university solving its problem. This second order of consulting service is rapidly growing at Oregon State and I suspect will continue to increase both here and in other institutions. Generally these groups are funded by the university or by a grant and render their service without *individual* compensation beyond their regular appointments.

THE UNIVERSITY AS INVOLVED AGENCY

There is a third level in which we rarely get involved. When we do, we sort of "tippy-toe" along because we're not all that sure that this is what we ought to do. But nonetheless, we do get involved. And that is when sometimes a university group takes a position or arrives at a conclusion which is converted into a statement that has the word "ought" in it. A typical consultant usually says, "It's not my business what you do with my advice; take it or leave it; you've paid your money; it's your decision." We sometimes go beyond that to say, "You ought to do this." Here you get involved with the individual or group who fall off their position of being the detached, uninvolved scientists and start telling people what they ought to do. When single individuals are involved, the university president may say, "Well, that's his right of free speech; he's speaking as a citizen; he's not really a professor of mine when he says these things that people don't like to hear." It's more difficult--indeed impossible--to do that when you get into a university organized group because very obviously the university created the group and continues to make its existence possible. What do we do, then, when this group becomes sufficiently involved, sufficiently knowledgeable and sufficiently emotionally charged up to start saying, "You ought to do so and so." What do I do when they start putting value judgments into their conclusions? I wish I knew! I am, however, convinced that one of the functions of a public university is service. When you become involved in public service, you cannot avoid becoming entangled in public policy issues.

Although we normally don't talk too much about this, we are very much involved in the "ought to" business. We have been involved in the "ought to" business in higher education ever since Mr. Lincoln asked the scientific community to form the National Academy of Sciences to tell the government what it ought to do in the Civil War. That is, as far as I know, the beginning of the scientific community getting into the "ought to" business in an organized fashion in the United States. Prior to that there were all sorts of involved individuals, but the official organization of scientific talent is a little over 100 years old. The land-grant institution has been involved in the "ought to" business for at least 75 years. It has been telling the farmers what they ought to do for 75 years. When you go back and read the dogmas of this institution from 75 years ago, it says just as plain as day that you "ought to" put lime on your fields if you are in the Willamette Valley and you're going to raise crops, and here's how much you "ought to" put on. Now they didn't say, "Here's some nice data and here's some information and do what you please." That wasn't the attitude at all. There was a missionary zeal involved in the involvement of the School of Agriculture and the farmer, and it was said in pretty loud tones. We've always done that. In fact, we've done it so long that nobody even remembers that we do it any longer. If you read the recommendations, they state, "We recommend that you do so and so, that you spray with this chemical on this day ..." "If you want to make money, you ought to do..."

We're in the "ought to" business also, though less dramatically maybe, in the area of public policy in agriculture, but we're there. We get all involved in milk marketing orders, wheat allotments, soil banks and all the other means by which the federal government has managed agriculture for 50 years. The land-grant college and its scientific personnel have been right smack dab in the middle of it, running back and forth to Washington, members of interlocking directorates, partners of the whole machinery by which you arrive at some sort of consensus and public policy for agriculture in the United States and then issue directives and orders. We've been part of it. Let's just be honest and ask, "What's wrong with our being involved in other areas as well, as long as we do not overplay our role and assume that we are all-wise, all-knowledgeable and so on?" As long as there's a division of power and the maintenance of a healthy competition among scientific personnel within the institution and scientists outside the institution and other people who are involved in public policy, I believe we belong in the arena of action.

I think we are going to find ourselves more and more involved in the "ought to" questions. "Ought there to be nuclear power plants located on the Oregon Coast?" Some people say yes and some say no. But we are going to be involved, it seems to me, not only in rendering a public service as an institution, but as individuals and groups giving advice, doing consulting, and becoming involved in the organizations that make decisions. I believe the University is going to become more involved in public policy issues--as individuals, as groups and to some extent even as an institution, although the latter gets a little more complicated. We will be going beyond giving facts and then saying, "It's your decision, do as you please." We will be saying, "It's our collective decision; we want to have a hand in arriving at what is done."

There may be some questions that grow out of these comments. Some of you come from government and may resent the views I've expressed. Some of you may think it's an act of superarrogation to even talk like this. This is the way I see it as we struggle to think in terms of decades and centuries rather than in terms of months and years. I believe we have much to contribute as a university, and I am sure most of our scientists and scholars are willing to become involved in ways not customary in the past in many disciplines of our responsibility.

New Concepts in Environmental Planning

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Author's note--One of the suggestions given by participants of last year's (1971) Estuaries Conference was that the first presentation be very comprehensive, very different and even possibly controversial. It was felt that such a presentation might encourage a freer, more meaningful dialog between the diverse conference participants.

Somehow, I was chosen for this talk (I prefer not to speculate on why). I enjoyed presenting the talk and the lively discussion that followed. I have found it extremely difficult, however, to develop a written record of this happening. Nevertheless, after numerous threats from the conference chairman, I have finally provided him with the following written record of the ideas and feelings that arose from this happening.

INTRODUCTION

In this note I intend to present what I chose to call a macro-idea. Now, a macro-idea is a large (rather comprehensive) idea which arises out of the interaction of a number of sub-ideas. It is more than the sum of its sub-ideas. The removal of a single sub-idea may entirely change or destroy a macro-idea.

There are two general types of macro-ideas based on the structural arrangement of the sub-ideas. The first is the linear or chain type in which the sub-ideas are arranged in a logical chain. A given sub-idea leads to the next sub-idea which leads to the next, and so forth.

The second type is the web or net macro-idea. In this type, the sub-ideas are inter-connected with each sub-idea supporting and being supported by several other sub-ideas. Unlike the linear macro-idea, there are numerous pathways that one might follow in order to connect the sub-ideas.

In this note, I will attempt to present a net macro-idea. Unfortunately, the written and spoken forms of communication are linear (one-dimensional). Sub-ideas must be presented one at a time. I have attempted to follow the path of least resistance in tracing through the net of sub-ideas that make up my macro-idea, but the reader should be aware that this path is only one of many. I would suggest to the interested reader that several other pathways be examined in order to gain a better understanding of the macro-idea that I intend to present.

DECISIONS AND MATHEMATICAL MODELS

At last year's Estuaries Conference, I gave a presentation on mathematical models. A general discussion concerning the importance of basic assumptions applied to mathematical models and decision methods might thus be appropriate.

It has been long recognized that the assumptions made in the development of a mathematical model determine, to a large extent, the results obtained from the mathematical model. If the assumptions of the model are not acceptable, then the results of the model should not be considered acceptable. The proper use of mathematical models, thus, requires a continued examination of the model assumptions.

A decision method or procedure bears some resemblance to a mathematical model. Decision inputs are utilized to produce output results (decisions). Decision methods are also similar to mathematical models in that they are also based on sets of assumptions. These assumptions determine to a large extent what type of results (decisions) will be obtained. If the assumptions of the decision method are not acceptable, the decision results should not be considered acceptable. Thus, proper use of decision methods and procedures requires a continued examination of the assumptions. The assumptions concerning the adequacy of available knowledge as applied to the general area of environmental decision methods are of particular importance.

KNOWLEDGE AND IGNORANCE

One frequently hears the sincere plea for knowledgeable decisions concerning the management of the environment, yet the meaning of "knowledgeable decisions" has received little attention. In the past, decisions based upon the "best available information" have been considered adequate despite the often overwhelming evidence that the "best available information" is inadequate. As man's capacity to change his environment increases, decisions might be better based principally on an awareness of the ignorance (lack of knowledge) pertaining to the decision rather than solely on the knowledge (See Holling and Goldberg, 1971).

Basing decisions principally on ones ignorance pertaining to decisions rather than solely relying on the available knowledge at first appears to be irrational and unscientific. This feeling stems, in part, from our insistence of maintaining a narrowly defined view of scientific objectivity. It is considered essential for scientific observers to detach themselves from the system under observation. Knowledge is often considered as a description of the real observed system while ignorance is often considered an unfortunate property of the observer. It is reasoned that the decision-maker must be objective and thus the decision must be based on the knowledge of the observed system. I would like to suggest, however, that this view is misleading. Rather, both the ignorance and knowledge pertaining to a given decision would be better viewed as a relationship between the observer and the observed.

The observer (man) has certain capabilities. The observed systems (ecological and social) have certain properties. The relationship between the applied capacities (at a given time) of the observer (man) and those aspects of the observed system which correspond to such capacities (to some acceptable degree) define the knowledge relationship. There are, however, system properties which do not correspond well to the capacities of the observer (man). This later condition I will define as ignorance. Both ignorance and knowledge should be considered as relationships between the observer and the observed because both depend upon the capabilities of the observer and the properties of the observed system. Only by examining the nature of both the observer and the observed systems can a proper perspective for decisions concerning the observed system be obtained. Thus, the analysis of the ignorance and knowledge pertaining to decisions are both equally justified. The nature, capabilities and bias of the observer (decision-maker) must be analyzed with the same degree of scrutiny that one usually devotes to the objects. under study. In seeking to be objective, we must not naively restrict ourselves to an overly narrow definition of objectivity.

We may wish to separately identify those views and concepts which are primarily the personal views of individual observers from those which are supported by the methods, assumptions and concepts shared by the scientific community. However, we must recognize that the limitations and bias of these shared methods, assumptions and concepts influence what we do know and what we can know about any observed system.

THE ENVIRONMENTAL PREDICAMENT

The basic analytical approach which has recently provided man with his technological power is based on methods of qualitatively analyzing simply organized systems (methods developed during the 17th, 18th, and 19th centuries). Complex systems were studied (and designed) by decomposing these systems into simple sub-systems suitable for analysis. The assumption of the decomposability of complex systems (expressed in various ways) has been so widely accepted that it is seldom listed, examined, or even recognized along with other stated assumptions. The decomposition approach has permitted the development of many complex man-made systems. These man-made systems are having increasing influences on ecological systems. It is meaningful to investigate, therefore, how well the assumption of decomposition pertains to ecological systems.

Ecosystems have continuously adjusted over geological time to environmental changes by a process of survival tests of numerous species and systems of species. To survive, a species or system of species must be able to successfully compete within the system for necessary resources. In addition, systems of species which cannot effectively withstand the extremes and perturbations of their environment are eliminated and succeeded by systems of greater durability, resilience or stability. Thus, ecological systems have been tested and modified at all levels of organization so as to continuously select systems of greater survivability. The result of this evolutionary process at any given time is a complex net of interlocking systems selected on the basis of past survival from a large number of less durable possibilities.

For his own interests, man desires to predict the ecological changes that would develop as a result of his actions. Such ability would enable man to control his actions in a manner that would preserve and even enhance ecological systems for his benefit. One must examine the relative applicability of the assumption of decomposition when applied to ecological systems. As described above, the evolutionary process has led to complex nets of interlocking systems. The survivability of ecological systems, which is continuously subjected to the tests of survival, depends to a large extent on the system properties that result from the complex interaction of the parts. One must say, therefore, that ecological systems are relatively less decomposable than are man-made systems. Recall, however, that the assumption of decomposability is an important part of the analytical methods that man uses for analyzing systems.

A predicament that man faces should now be apparent if one considers *both* the capabilities of man (the observer) and the nature of the systems (man-made and ecological) which are the objects of his study. Decomposition is more applicable to man-made systems than ecological (and social) systems yet, decomposition is an important and useful means of obtaining knowledge. Man's knowledge is thus bias toward the more decomposable man-made systems. As man develops larger and still larger man-made systems, their influence on ecological systems will increase. The bias of his knowledge, however, means that man's capacity to expand man-made systems (and thus change ecological systems) will exceed by increasing amounts his ability to understand ecological systems. We can expect significant advances in the environmental sciences. The relevant point, however, is not that the environmental sciences will significantly advance but rather that it is unreasonable for us to expect that this advance can keep pace with the more rapid expansion of man-made systems. Man is faced with an *environmental predicament* which can be stated as: man's ability to modify the environment will increase faster than his ability to foresee the effects of his activities (See Bella and Overton, 1972).

The environmental predicament can be expressed in another way. Man's knowledge of ecological systems will increase but, because his capacity to change these systems will increasingly exceed his capacity to foresee what such changes will be, man's ignorance relative to environmental decisions will also increase. This concept is conceptually illustrated in Figure 1. Both the ability to change (line A) and the ability to foresee what that change will be (line B) are shown to increase with the former increasing at a higher rate than the latter. The difference between the two lines is defined as the relative ignorance because it defines the difference between the ability to produce environmental changes and the ability to foresee what such changes will be at a given time. As shown in the figure, the magnitude of this relative ignorance increases with time.

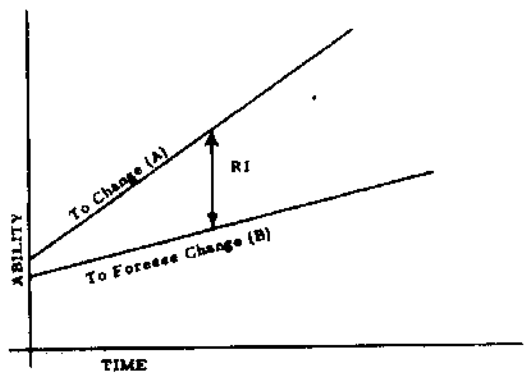

FIGURE 1. Conceptual Diagram of Relative Ignorance (RI)

Similar arguments related to the influence of man-made systems on social systems can be raised. Our inability to foresee our own reactions to the actions that we are capable of taking may be the most significant aspect of the *environmental predicament*.

The *environmental predicament* strongly suggests that environmental decisions must increasingly be based on the ignorance pertaining to these decisions. That is, man must increasingly recognize his inability to determine the total consequences of his combined actions. In the past, however, environmental decisions have been based principally on the presumption of adequate knowledge particularly at higher levels (often because of the political difficulty of admitting uncertainty or the possibility of undesirable outcomes). It is true that modern decision theory does not treat all outcomes of considered actions as certain but rather assigns a probability to each member of a set of possible outcomes. The set of possible outcomes chosen and the probabilities assigned, however, both result from the beliefs of the decision maker and thus reflect the bias and limitations of the knowledge available to the decision maker.

SIGNIFICANCE OF DECISION ASSUMPTIONS

It is pertinent at this point to investigate the general consequences of inappropriate decision assumptions concerning the adequacy of man's knowledge.

Consider the influences of a generally accepted (and used) decision method which assumes the adequacy of available knowledge. The nature of the knowledge of the decision-makers will have an influence on the transformation of the actual systems under management. That is, the response of the actual systems under management will depend on the perceived systems of the decision-makers. The bias and limitations of the decision-makers will have a continued influence on the transformation of the managed system. In general, decisions based on a given knowledge will, over time, tend to resist, reduce or eliminate those system properties that do not fall within the scope of that knowledge. The systems may, of course, resist such transformations and, thus, the degree of system transformation will depend on the capacities of the decision-makers to overcome such resistance.

Recall that the decomposition of complex systems is an important aspect of man's means to knowledge. If man's knowledge is assumed to be adequate, decisions based on this knowledge will tend to transform, over a period of time, ecological and social systems into more readily decomposable systems. That is, the complete acceptance and use by modern decision-makers of knowledge obtainable primarily through the decomposition of systems will eventually tend to resist, reduce or eliminate those properties of the managed systems which are not subject to analysis by decomposition.

It is generally believed that the complex interrelationships within ecological systems provide these systems with a stability and resilience. Ecologists often express this concept by indicating a positive relationship between ecosystem stability and the biological diversity within the system.

Social systems also have significant properties which are not subject to the decomposition process. Fellowship, love, and a sense of community are significant properties which would be impossible to examine by decomposing (isolating) individuals from society.

Other properties of ecological and social systems *can* be examined by different decomposition methods. The nutrient requirements of a given plant, the lethal temperature limits of a given animal, the caloric requirements of a given person, and a host of many other properties can be readily determined within acceptable limits. Few would doubt that technology has enabled man to significantly improve his quality of life by providing and controlling such factors for his benefit. As man satisfies these basic (decomposable) needs and as man's technological capability continues to increase, it is pertinent to ask to what degree his progress (which is based on relatively decomposable models) is being purchased at the significant sacrifice of those systems properties which are not subject to a decomposable analysis.

The increased productivity of a relatively few ecosystem components desired by man at the sacrifice of the overall ecological diversity and complexity has been a major concern of ecologists. Social critics likewise have expressed the concern that the progress and successes of modern affluent societies may pass a point where the human values lost (those values not subject to decomposable analysis) exceed (by increasing amounts) the additional benefits gained. Moreover, it is feared that population levels, particularly in underdeveloped nations, are becoming so high that mere subsistence (decomposable) needs can be provided only by significant ecological and social losses and risks.

Few ecologists or social critics urge modern societies to return to primitive conditions (though their opponents often unjustly insist that this is so). Many of the benefits gained by modern technology are real and are necessary at the population levels now present. We must, however, temper our knowledge with a humility so that the pursuit of those things which we do understand is not purchased by an unbearable loss of those things that we do not understand.

If environmental problems are to be effectively met in the next decade, a revolution in the way we approach problems and make management decisions must occur. The traditional approaches alone are not sufficient to deal with man's expanding capacity to change his environment and the unjustified presumptions of knowledge concerning this capacity.

Many aspects of necessary environmental planning approaches will, no doubt, conflict with accepted cultural values. However, these same environmental approaches may, ironically, receive their strongest support from other accepted values of our society. Increasing conflict between different values of our culture will likely characterize the the decades ahead. As an example, the desirability of unrestricted growth, which has been a cultural value of importance to our economic system, will increasingly conflict with the concept of humility which is a dominant (though often ignored) theme of the Christian religion.

Without becoming involved in the details of necessary environmental approaches or the associated value conflicts, it is possible to speculate on several related aspects of such approaches. First, control of excess growth, in number of humans, in the utilization of resources and in environmental demands must be provided. Second, interactions (community) and diversity (variability, complexity) within ecological and social systems will have a high value in their own right. Third, large scale irreversable changes will be avoided regardless of their perceived importance. Finally, actions which lead to the domination of a relatively few system (ecological and social) properties or components will be considered undesirable.

SUMMARY AND CONCLUSION

Man's capacity to produce changes in ecological and social systems will exceed by increasing amounts his capacity to understand the consequences of these changes. Traditional environmental decision methods which assume the adequacy of man's knowledge will tend to resist, reduce or eliminate those properties of ecological and social systems which do not fall within the scope of man's knowledge. These system properties, however, are essential to a desirable quality of life. Environmental appraoches which recognize the limitations and bias of man's knowledge are thus essential for the preservation and enhancement of the quality of life as perceived by this and future generations. Such approaches, however, will challenge the compatibility of many of our cultural values.

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Some Estuarine Factors Influencing Ascent of Anadromous Cutthroat Trout in Oregon

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ABSTRACT

The influence of estuary geometry, salinity and temperature on the summer distribution and movements of upstream-migrating adult cutthroat trout is discussed for three Oregon estuaries. It is concluded that high temperatures in upper estuary areas of some coastal rivers prevent passage of many fish that might otherwise migrate further upstream into freshwater. Ascending fish, as a result, congregate in estuary areas of suitable temperature and depth immediately downstream until water temperatures moderate later in the fall. The extended period of summer residence is advantageous to the estuary sport fisheries. Alteration of temperature regimes, depths or perhaps other features could change distributional patterns of fish and ultimately affect the success of fisheries.

INTRODUCTION

Oregon's comparatively small, shallow estuaries can be viewed as funnels through which essentially all natural and artificial production of anadromous trout and salmon passes to and from the ocean at various life stages. Conditions therein must be assumed to be of importance to the welfare of each migrant fish. To my knowledge, no ecological studies have been reported for these waters that examine the relationships between ascending adult salmonids and environmental characteristics of the estuaries. Two papers (Morgan and Cleaver, 1954; Korn, 1961) supplied limited data on timing of movements of adult coho salmon, *Oncorhynchus kisutch*, and steelhead trout, *Salmo gairdneri*, but no reference was made to physical, chemical, or other estuary features influencing the movements. Ecology of juvenile salmonids migrating downstream through estuaries has received more attention, but this information is also limited.

There may be a tendency to avoid detailed study of salmonid populations in estuaries. This situation could be partially brought about by a hesitance to confront the complexity of the estuary, as well as by an inability to sample adequately highly mobile populations of fish in the rigorous estuarine environment. Fishery management agencies have seldom possessed the resources required to pursue biological investigations within the saltwater environment. Other investigators have looked at lower biotic levels in estuary ecosystems, and although these studies are logical initial approaches, one can surmise that sampling difficulties may again have been a factor restricting work to other forms.

An opportunity to examine some relationships between ascending adult salmonids and Oregon estuaries occurred during a study of coastal cutthroat trout, *Salmo clarki clarki*, conducted by the Game Commission between 1965 and 1970 on the Alsea, Siuslaw and Nestucca Rivers. This study on the north-central coast was directed primarily toward improvement of angler catches of hatchery-reared cutthroat through the manipulation of liberation times. In order to evaluate the success of the stocking experiments, two major fisheries, a spring main stem fishery centering on juvenile fish and fall estuary fishery for sea-run adults, were monitored to estimate catch. To gain a better understanding of the observed timing and location of the estuary catch, information on fish distribution and movement was gathered and related to gross measurements of estuary geometry, salinity, and temperature.

The estuary studies depended to a large extent on the development of netting gear that would readily live-capture sufficient numbers of fish for tagging. A purse seine, a roundhaul seine, beach seines, gill nets, and trap nets were unsuccessful methods of capture employed during the first years of study. In addition to relatively small populations of cutthroat, the major obstacles to capture in the upper part of the estuary included strong tidal currents, submerged debris, and lack of suitable shoreline. These problems were eventually overcome and substantial fish catches were made in the Alsea by the use of SCUBA to remove submerged objects, by development of a rapid net-setting procedure (Giger and Williams, 1972), and by design of a mechanized beach seine suitable for the estuaries (Giger, 1972).

This paper reports some results of the estuary studies that centered primarily on the Alsea River. Data on chinook, *O. tshawytscha*, and coho salmon were obtained incidentally and some inferences are made about their estuarine movements. It should be emphasized that some of the conclusions are preliminary and warrant further study.

CHARACTERISTICS OF CUTTHROAT TROUT

Native populations of cutthroat trout exist in a wide variety of environments and exhibit varied life history patterns. Habitats and movements are known to include lifetime residence in limited sections of streams, and residence in and movements between smaller and larger streams, streams and lakes, streams and the ocean, and even lakes, streams, and the ocean.

The coastal subspecies of cutthroat trout in Oregon is essentially anadromous, i.e., migrates to sea and returns to streams to spawn, although most populations appear to contain a very small proportion of fish which become permanent stream residents. Nearly all fish live in freshwater from two to five years, then enter the ocean as juveniles in spring. After spending approximately three months at sea, during which time the fish probably do not range far from the coastline, all individuals return and may remain in the estuaries of larger streams for substantial periods of time before a late fall spawning migration into freshwater. Unlike salmon which die following their initial spawning, the spring seaward migration and late summer return of cutthroat becomes an annual event until death. Individual fish have been known to make at least five such successive migrations. Because of the annual spawning cycle and marked weight loss associated with a long cessation of feeding, sea-run cutthroat in Oregon rarely achieve a size exceeding about 20 inches or 4 pounds.

METHODS OF ESTUARY STUDY

Estuary Geometry, Salinity and Temperature

Published information in the desired form regarding salinity and temperature characteristics of the full lengths of the study estuaries was not available. For the Alsea estuary, Goodwin, et al (1970) reported on tidal and physical characteristics, and Matson (1971) later presented data for the lower portion of the estuary. For the purposes of this study, data on channel depth and longitudinal salinity and temperature profiles at high and low tide were obtained.

Summer and winter profiles were determined on each estuary for comparison, and spring data were collected on the Alsea River to diagram the patterns that might be expected to exist during the period of downstream migration.

To construct diagrams of longitudinal sections of each estuary, bottom contours were determined for the stream channel from the mouth to the head of tidewater using a Furuno RF-2, 50 kc recording echosounder. Depth readings were averaged to provide generalized diagrams of each estuary. Salinity and temperature measurements were made at 1-mile length and 5-foot depth intervals with a Beckman RS5-3 Portable Induction Salinometer. Measurement intervals were reduced where rapid salinity changes occurred. Data were gathered for moderately high and low tides and for normal streamflow conditions during the seasonal periods studied. No attempt was made to document all variations or extremes produced by winter floods, exceptionally high or low tides, etc. Additional measurements of salinity and temperature were taken throughout the summer at netting sites on the Alsea.

FISH DISTRIBUTION AND MOVEMENT

Approximately 2,000 sea-run cutthroat were captured and marked in netting activities on the Alsea estuary in the summers of 1969 and 1970. More than 300 tags from these fish were subsequently returned, and provided information on timing of migrations, estuary movements, length of estuary residence, and distribution and intensity of sport catch.

Estuary boat counts, conducted to measure angling pressure as part of the basic catch estimation procedure, were made for small geographical units to determine areas of angler concentration. This information was used, with verification from angler interviews and later from netting and tag return data, as an index to the longitudinal distribution of cutthroat in the estuary.

Sampling of the angler catch gave additional information on food habits and the movements of fish. Estuary maps supplied to anglers were used to pinpoint the locations of tag recoveries for comparison with environmental measurements. Tag returns from summer into late fall and from throughout the

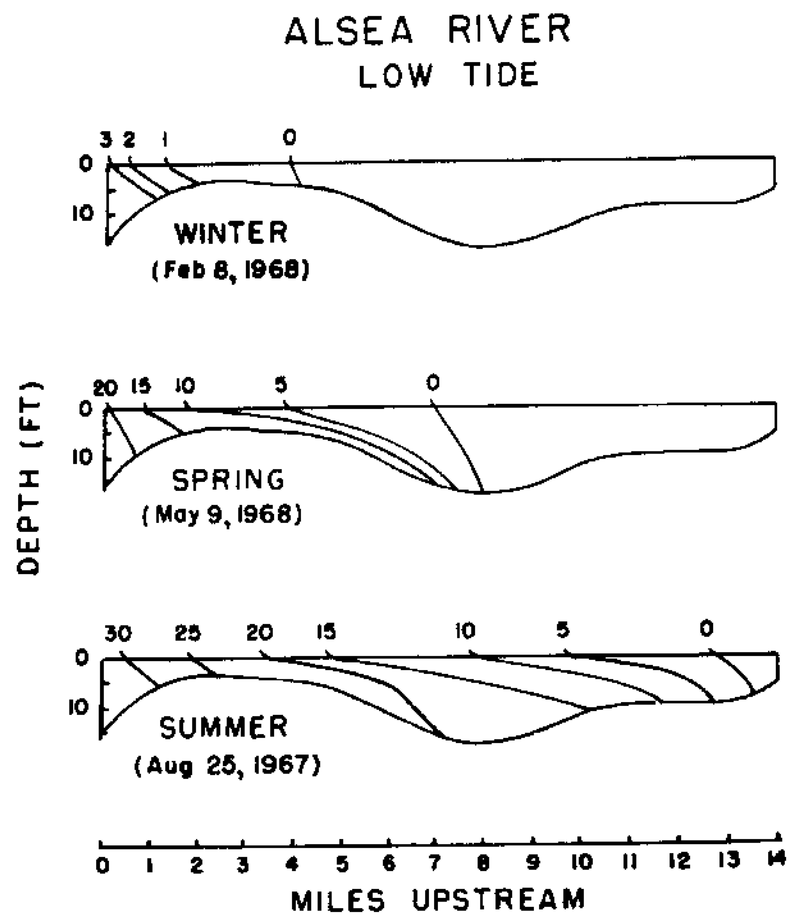

FIGURE 1. Salinity gradients (in parts per thousand) from stream mouth to head of tidewater on the Alsea River at moderately low tides during three seasonal periods.

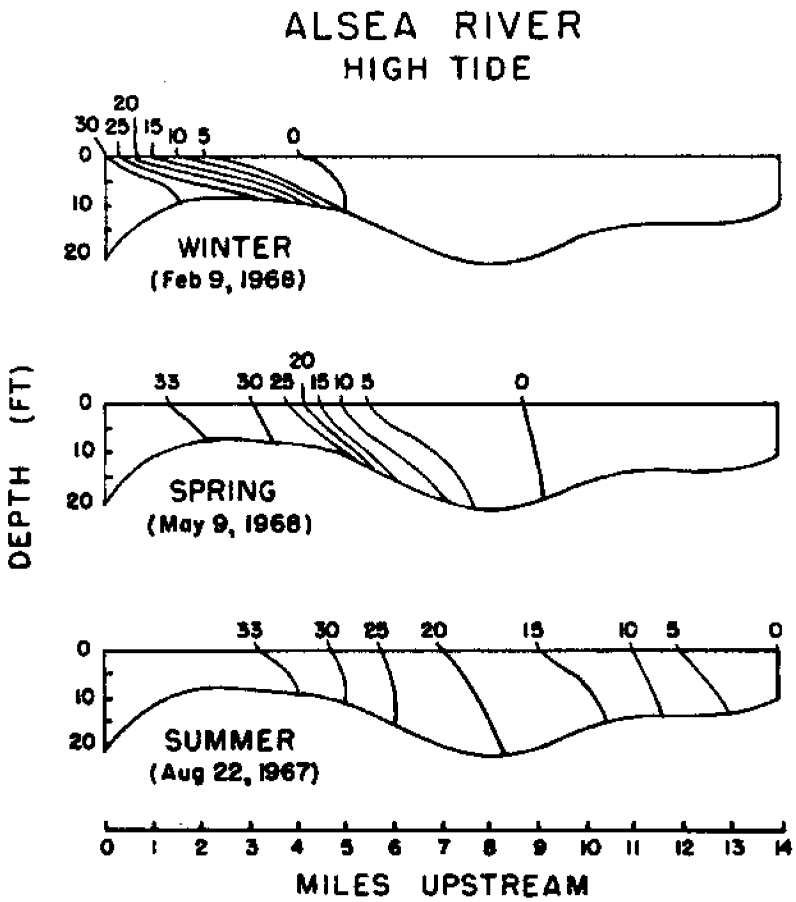

FIGURE 2. Salinity gradients (in parts per thousand) from stream mouth to head of tidewater on the Alsea River at moderately high tides during three seasonal periods.

stream system indicated to some degree the timing of movements into freshwater.

FINDINGS

ENVIRONMENTAL MEASUREMENTS

The Alsea, Siuslaw, and Nestucca estuaries were considered to be 14, 22, and 8 miles in length, respectively, and ranked 7th, 8th, and 10th in amount of acreage among Oregon estuaries south of the Columbia River. The estuaries were found to be similar in general character. Each had a wide, shallow, lower bay and long, narrow, deeper upper segment. Longitudinal diagrams indicated a deeper central section of tidewater that had its downstream origin near the zone of marked width constriction. This central section was shortest and most pronounced in the Alsea and Nestucca estuaries. Deep areas in tidewater were typically found at bends in the stream course.

Seasonal differences in salinity profiles on each estuary were generally large (Figures 1-4). During winter the wedge of seawater extended at most a few miles upstream on both tidal cycles, and the transition from fresh to salt water (>30 o/oo) took place within a short distance. In summer on the Alsea and Siuslaw, saltwater influence reached throughout the estuary at high tide, and nearly so at low tide. Salt water normally extended only about 5 miles upstream on summer tides in the Nestucca estuary. Summer salinity transitions in each stream were considerably more gradual than winter, and transitions in longer estuaries were more gradual than in shorter ones. Spring gradients in the Alsea estuary were intermediate between those for winter and summer.

Density stratification was evident in at least some parts of all salinity profiles, and was more pronounced at low than at high tide. Stratification was most evident on the Alsea estuary, where at one summer low tide, surface and bottom readings of 15 o/oo were 5-1/2 miles apart. Stratification was least evident on the Siuslaw at a summer high tide, suggesting little influence of freshwater flow on the longer estuary.

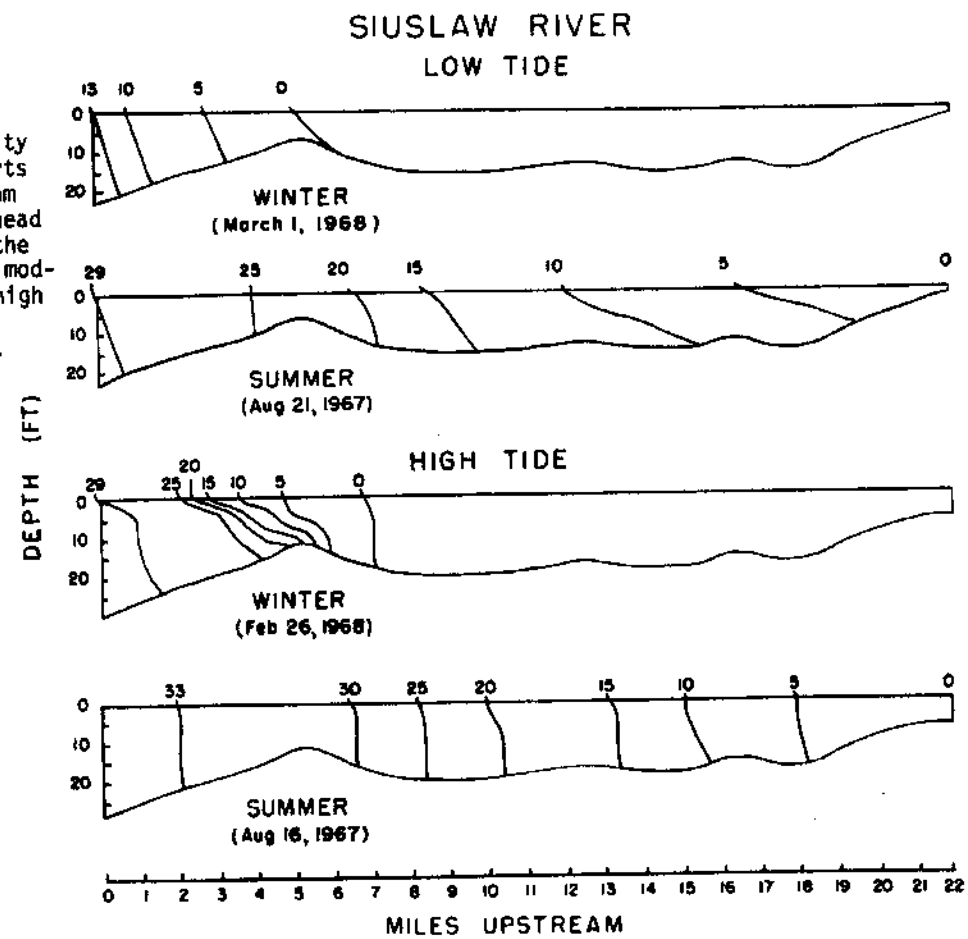

FIGURE 3. Salinity gradients (in parts per thousand) from stream mouth to head of tidewater on the Siuslaw River at moderately low and high tides during two seasonal periods.

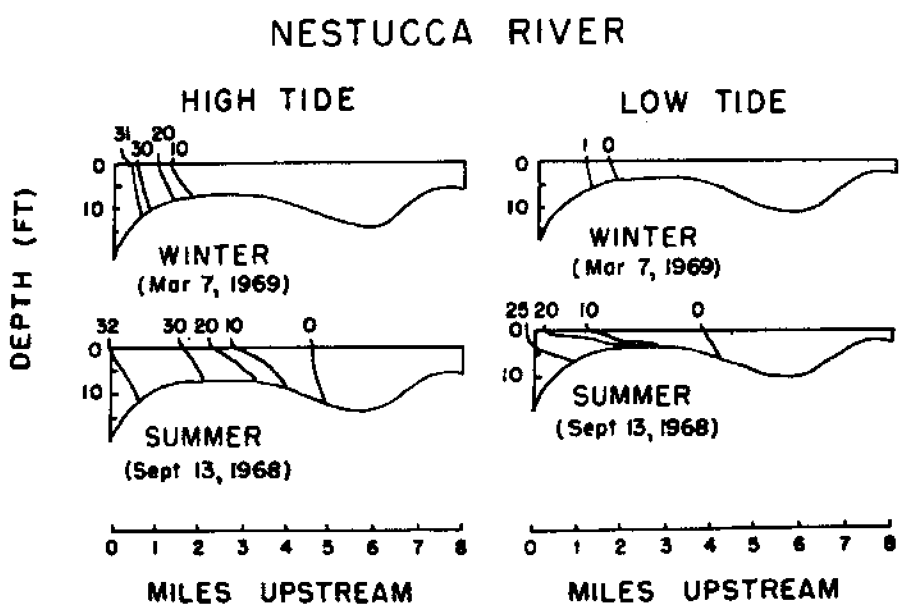

FIGURE 4. Salinity gradients (in parts per thousand) from stream mouth to head of tidewater on the Nestucca River at moderately low and high tides during two seasonal periods.

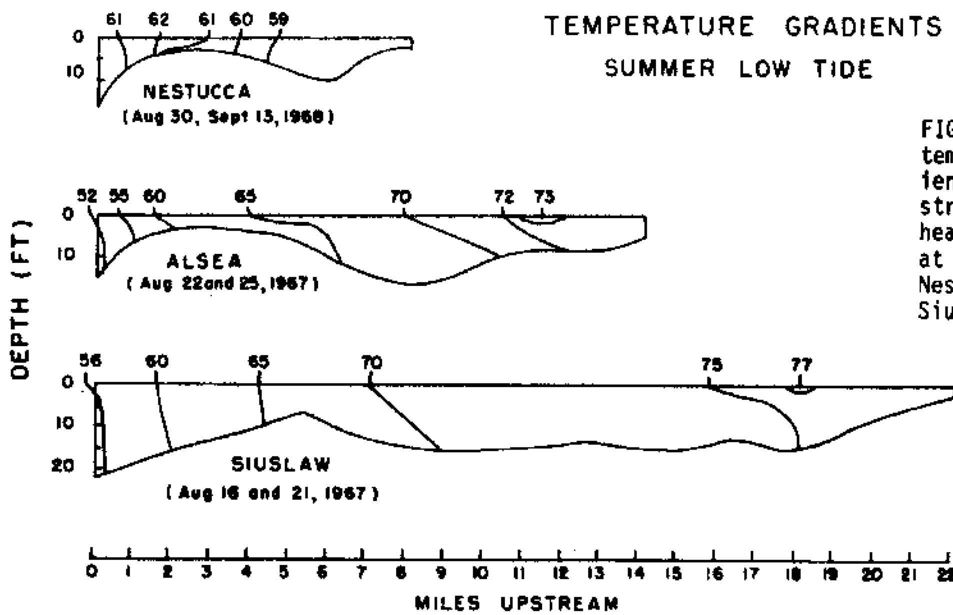

FIGURE 5. Summer temperature gradients (°F) from stream mouth to head of tidewater at low tide on the Nestucca, Alsea and Siuslaw rivers.

Temperature gradients on the Alsea and Siuslaw estuaries were similar, the Siuslaw tending toward a slightly higher mean temperature than the Alsea throughout the year. Highest summer temperatures on these two rivers were recorded from the upper estuary, 1 to 4 miles below the head of tide (Figures 5 and 6). The temperature maximums, in the range of 75-80°F (24-26.6°C), probably resulted from a relatively stable water mass in that area that was little influenced by the low streamflows or colder sea water. In contrast, temperatures in the largely freshwater Nestucca estuary were much lower, and highest readings were from the extremely shallow, lower estuary, 1 to 2 miles above the stream mouth. Summer temperatures varied greatly from stream mouth to head of tide, and winter temperatures were fairly uniform. In the Alsea and Siuslaw, winter estuary temperatures averaged 44 - 50°F (6.7-10°C), about 18-20°F below summer means.

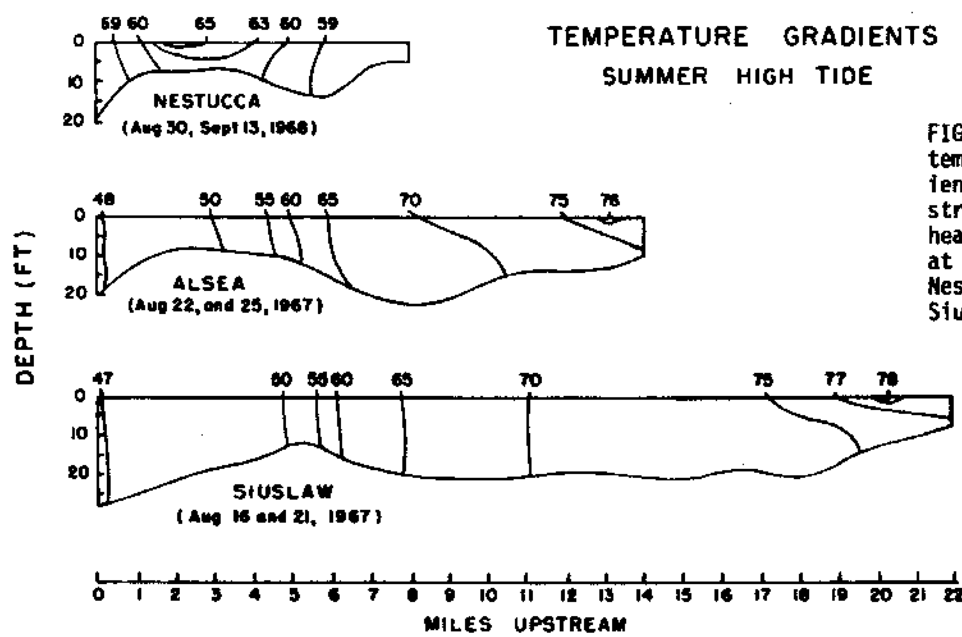

FIGURE 6. Summer temperature gradients (°F) from stream mouth to head of tidewater at high tide on the Nestucca, Alsea and Siuslaw rivers.

The most pronounced changes in temperature in all estuaries occurred on summer high tides near the lower entrance to the narrow, upper estuary. Steepest gradients were encountered on the Alsea and Siuslaw, where changes of 15°F (8.4°C) occurred in a distance of three miles. High and low tide temperature shifts on a particular day were slight in the upper estuary, but substantial in the lower bay of each river.

CUTTHROAT DISTRIBUTION AND MOVEMENT

Schools of cutthroat were found to enter estuaries from the ocean at different times in the summer and fall and at different times from year to year. No relationship between time of entrance and climatic, tidal or other factors was discovered, even though there were seasonal periods of more frequent run occurrence as well as substantial conformity of migration timing among streams (Figure 7). Earliest migrants entered between June 23 and July 21 and latest migrants until early October. Fish that had made spawning migrations from the ocean in previous years typically were the earliest entrants in summer. The annual periods of peak abundance of migrant and resident groups of cutthroat in the Alsea estuary in 1970 are summarized in Figure 8.

Net and fishery data indicated that sea-run cutthroat migrated quickly through the shallow, lower estuary of all rivers, then remained for varying periods in the narrow, deeper, central section of tidewater. Runs of fish migrated relatively intact to this area in the Alsea River, and though small numbers apparently passed through the upper estuary into freshwater soon after entrance from the ocean, dispersal of the majority of spawners to upstream or downstream tributaries took place later in the fall. Many cutthroat remained in the estuary for periods of 3 or 4 months or more. Tagging also showed that localized upstream and downstream movement of fish was common during residence in the central estuary.

Angling activity was concentrated in the areas where cutthroat were holding, the anglers taking advantage of the temporary residence of fish. Zones of heaviest angler concentration extended from 4-1/2 to 9-1/2 miles upstream from the ocean on the Alsea, from 7-1/2 to 15 miles upstream on the Siuslaw, and from 4 to 6-1/2 miles upstream on the Nestucca River.

The bulk of the migration of sea-run fish out of the estuary and into freshwater occurred in late fall concurrent with the first substantial fall rains and increases in streamflow. Smaller initial freshets were found to trigger upstream shifts in the distribution of fish within the estuary, without causing full-scale migration out of the estuary (Figure 9).

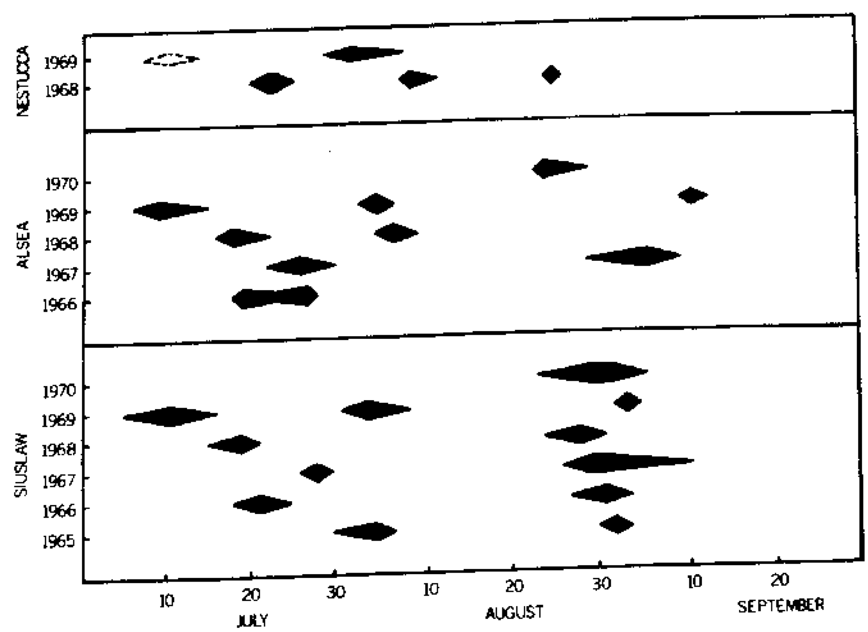

FIGURE 7. Timing of major summer and fall runs of wild cutthroat into estuaries of three coastal rivers, as indicated in the angler catch, 1965-1970. (Open diamond represents a probable but unconfirmed run).

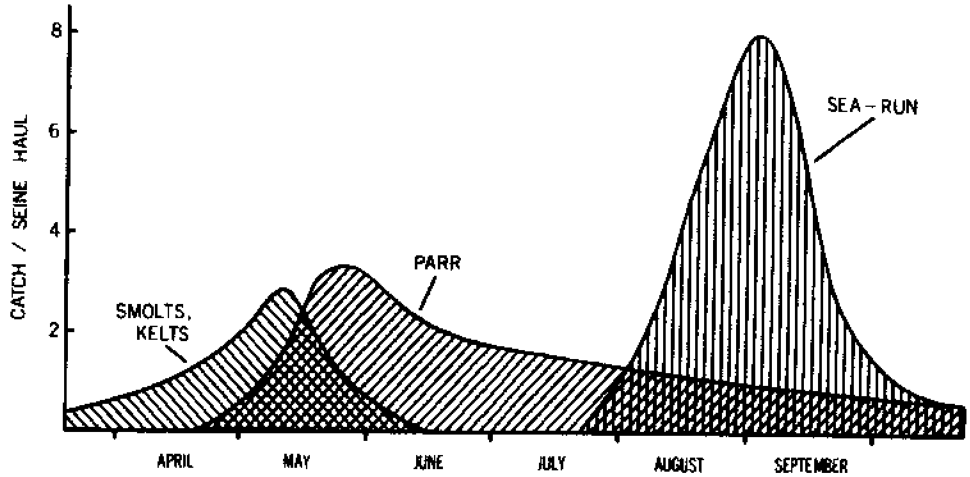

FIGURE 8. Generalized patterns of timing of downstream (smolts, kelts, parr) and upstream (sea-run) migrant wild cutthroat in the Alsea estuary, 1970, as indicated by the seine catch. Smolts are juveniles migrating to the ocean, kelts are spawned-out adults returning to the ocean, and parr are juveniles migrating only as far as the estuary.

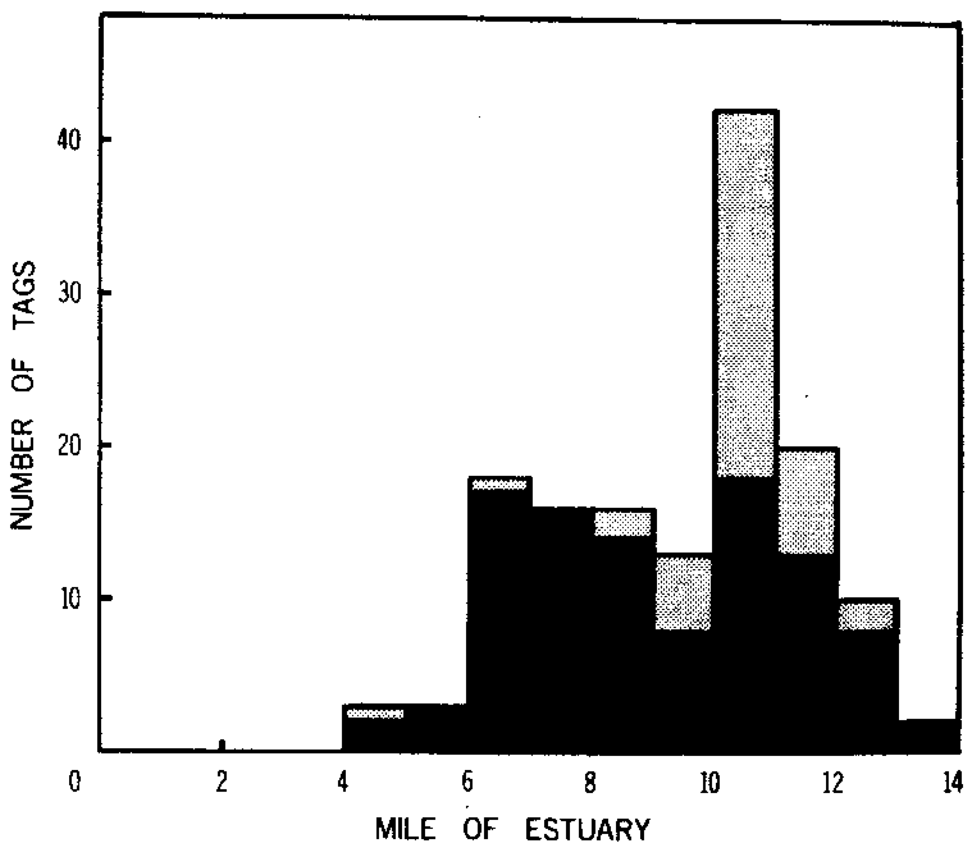

FIGURE 9. Distribution of tag returns by location for 143 angler-caught cutthroat trout, Alsea estuary, summer and fall of 1970. Light shading represents returns after September 17, following a sharp temperature decline.

RELATION OF ENVIRONMENT TO CUTTHROAT DISTRIBUTION AND MOVEMENT

In general, summer cutthroat distribution coincided with the central estuary areas that had greater mean depth, particularly on the Alsea and Nestucca Rivers where the length of these areas was more limited. Obviously migrants could not be expected to remain in the lower bays, where much of the channel was less than five feet deep on average low tides. Only a partial relationship was suspected, however, between cutthroat distribution and the deeper, central sections of each estuary. On the Alsea, the entire length of the narrow, upper estuary apparently had depths suitable for regular use by fish, as evidenced by substantial catches from upper areas in late fall (Figure 9). Restricted use of the upper reaches of the Alsea and Siuslaw estuaries by cutthroat in mid-summer was evidently caused by a separate factor.

The central estuary area preferred by cutthroat in summer months was characterized by relatively long shoals interrupted by deep pools that normally occurred at bends in the stream course. On the Alsea, highest angler and net catches were taken from specific shoals in the central estuary. Tag returns from the upper estuary in late fall, however, were not as noticeably correlated with shallow stretches. Whether or not shoal areas of the central estuary harbored more fish during July and August was not known. It may have been that shallow localities brought fish in closer contact with trolling gear or prevented some fish from escaping from the 10-foot deep seine.

In migrating to the central estuary, sea-run cutthroat passed through the majority of the salinity and temperature changes that occured on the Alsea and Siuslaw estuaries, and essentially the entire gradients on the Nestucca. Summer salinities in central tidewater holding areas of the Alsea and Siuslaw rivers generally fluctuated from 10 o/oo to 25 o/oo, depending on the tide stage. Water temperatures ranged from about 65 - 72°F (18.4-22°C). A freshwater environment and considerably more constant temperatures of about 56 - 60°F (13.4-15.6°C) characterized the summer holding area of the Nestucca in 1968.

Salinity changes appeared to have little effect on adult fish, as quick passage through the entire salinity gradient was demonstrated on the Nestucca estuary. The best indication that changes from salt water to freshwater have negligible influence, however, is to be found in many smaller coastal streams inhabited by sea-run cutthroat, where no estuary exists and where the transition to freshwater is abrupt.

Water temperature was suspected of being most influential of the estuary characteristics examined in influencing cutthroat distribution in and migration through the central and upper portions of the Alsea and Siuslaw estuaries. Fish migrating completely through these estuaries would have been subjected to temperature variations of approximately 30°F (16.7°C) in mid-summer and presumably would either not enter, nor remain for long, in the upper sections where temperatures of 75-80°F (24-26.6°C) were frequently reached. High upper estuary temperatures probably provided an effective block to large scale migration, and relatively few fish passed through to cooler sites in freshwater until later in the fall.

The Siuslaw River possessed the highest upper estuary temperatures, which may partly explain why the estuary fishery there was more successful and lasted well into the fall. Temperatures in the Nestucca estuary, with a total gradient of only 15°F (8.4°C) and maximums 10 - 15°F below those on the other two streams, were suspected of being less influential in restricting migration. This view for the Nestucca was supported by evidence that (1) high angler catch rates coincident with entrance of schools from the ocean were of shorter duration in the fishery, suggesting more rapid passage out of the estuary, and (2) larger relative numbers of sea-run fish were present in pools above tidewater in the summer and early fall.

Some support for the belief that upper estuary temperatures influenced cutthroat migration and estuary distribution was gained from fishery and tagging data on the Alsea River. In 1969, angling success and seine catches of cutthroat (and salmon) in the central estuary declined sharply between September 17 and 19, concurrent with the first fall rain and an increase in main stem streamflow from 72 to 565 cfs. Temperatures in the upper estuary also dropped sharply. A large proportion of the adult salmonids had either moved into upper tidewater above the fishery or entered freshwater. As the stream-flow increase was substantial and interrelated with the temperature decline, identification of the factor most likely stimulating migration was difficult.

In 1970, two less-appreciable fall increases in main stem flow occurred in the Alsea, from 73 to 138 cfs between September 4 and 8, and from 73 to 153 cfs between September 17 and 21. The increases probably had little effect on currents in the central estuary, but influenced temperatures greatly. Maximum surface temperatures during this period at the seining site in the central estuary declined gradually from 67 - 60°F (19.5 - 15.6°C), then dropped sharply from 60 - 54°F (15.6 - 12.2°C) between September 15 and 16. Some of the temperature decline was associated with an extended period of cloud cover. Net catches were apparently not affected by the first small freshet, but declined to almost zero from September 15 to 17 coincident with the second freshet and sharp temperature decline. Unlike the more extensive migration out of the fishery area in 1969, the small freshets did not stimulate many fish to leave the estuary, but shifted their distribution further upstream. Significant numbers of fish were still taken in the estuary by anglers after September 17, but the average catch location moved from 9.0 to 10.5 miles upstream (Figure 9).

Despite abundant food sources, sea-run cutthroat did not feed in the estuary during summer and fall residence. In fact, little feeding took place in the stream until after the completion of spawning in January and February of the following year. It seems safe to conclude that the estuary food supply had very little influence on ascending cutthroat.

The reaction of cutthroat trout to the ever-present reversals in flow direction and changes in velocity is a response that would be difficult to evaluate. Schools of fish entering the estuaries were evidently partially adhesive even after several weeks in tidewater. This plus the fact that tag returns were received in about equal numbers from above and below tagging sites suggested that fish were not strongly associated with specific underwater areas or objects. The reaction of schools of fish to reversing currents was possibly a positive rheotactic one in which fish oriented against the direction of flow, and either swam against the current or drifted with it.

SIGNIFICANCE OF ESTUARIES TO CUTTHROAT TROUT

The estuary is apparently a non-essential element of the life cycle of anadromous cutthroat trout in Oregon, a conclusion reached primarily by virtue of the fact that many smaller streams supporting populations of searuns have no estuary. Though cutthroat commonly return to streams months before engaging in an active spawning migration into the tributaries, this period of relative inactivity (both migratory and feeding) can as readily be spent in freshwater areas such as deep pools along the lower main stems of streams. It follows that if the estuary is not a requisite for migrants then a gradual adjustment from salt water to freshwater is also unnecessary, and there was no indication from the study that cutthroat were influenced by salinity changes.

The upper areas of some of Oregon's major estuaries are apparently prone to temperatures consistently high enough (70-80°F) in midsummer to block passage of many cutthroat that might otherwise migrate further upstream into freshwater. There is fair evidence that temperatures at these high levels can be detrimental to the survival of maturing adult salmon if experienced for certain periods of time (Brett, 1960). Many fish, as a result, congregate in estuary areas of suitable temperature and depth immediately downstream until water temperatures moderate later in the fall.

Many authors have emphasized the importance of increased stream-flow in stimulating upstream migration of adult salmonids, and some (Hayes, 1953; Pritchard, 1936) have stated that temperatures had little effect. Others (Foerster, 1929; Cramer and Hammack, 1952; Major and Mighell, 1966) believed that temperature changes influenced movements to a substantial degree. Obviously temperatures in some situations are at levels that do not restrict movement, but these seemingly opposing conclusions regarding the importance of flow and temperature might also be the result of a difference in point of view. While flow increases probably do frequently stimulate pronounced upstream movement, there is also the possibility that earlier, perhaps less strongly marked movements are at times restricted by high temperatures. In other words, temperature changes may not stimulate migration, but permit it. Flow and temperature are often intimately associated, and separation of effects can be difficult.

Chinook and coho salmon, in that order, entered the Alsea, Siuslaw and Nestucca estuaries later in summer than the cutthroat, but their subsequent movements were similar to those of cutthroat. Sufficient numbers of salmon were taken by the sport fishery and in netting operations to indicate that these fish were probably responding in similar manner to the conditions that affected cutthroat trout.

Unlike fisheries for salmon and steelhead trout, angling for sea-run cutthroat occurs almost wholly within the limited, central section of the estuary in the coastal streams studied. There is no ocean fishery, and relatively few are taken above tidewater in the late fall or winter. Add to this such facts as (1) many juveniles are residents of the estuary in spring and summer, (2) sea-run fish are present for extended periods in summer and fall, and (3) repeated migrations on an annual basis magnifies estuary use compared with other species, and one can conclude that estuaries of these rivers are probably of greater importance to sea-run cutthroat and cutthroat angling than to other salmonids.

The Siuslaw River estuary supports what, to my knowledge, is the world's largest sea-run cutthroat fishery. This fishery is worthy of careful perpetuation, as are the substantial tidewater salmon fisheries. The welfare of what remains of the natural environment of the Siuslaw estuary was recently threatened by plans to dredge a 16-foot channel almost completely through the upper estuary, where virtually all trout and salmon angling occurs. There are at least two potential consequences of such dredging to fisheries for trout and salmon that come to mind, based on the cutthroat studies. One is that by increasing the average channel depth, the influence of saltwater intrusion might be extended further landward, thereby moderating upper estuary temperatures to a greater degree. This could in turn effectively alter the summer distribution of cutthroat and salmon by permitting greater penetration of fish into the upper estuary or freshwater. Secondly, if shoals are important areas of sport catch as suggested by the Alsea data, there is no assurance that angling would not be adversely affected by removal of shoals and dispersal of fish in greater depth. Each of the above consequences could significantly reduce the sport catch. Certainly the argument that former dredging in the lower bay has not proven detrimental, and that future upstream dredging would therefore not be harmful, is far from appropriate. If there has been little influence in the past, it no doubt stems from the fact that salmonids characteristically spend little time in the lower bays of these estuaries.

ACKNOWLEDGMENT

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A Strategy for Modeling Primary Production in Stratified Fjords

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The Northeastern Pacific coastline is indented with numerous recesses variously identified as bays, sounds, or inlets on maps and nautical charts. However, those with relatively deep, laterally constricted basins qualify more specifically as fjords, or Type 3 estuaries, in the estuarine classification scheme of Hansen and Rattray (1966).

During the past two decades, many of these inlets have been surveyed and their oceanographic features have been described by a number of workers, including Tully (1949), University of Washington (1953), Trites (1955), Waldichuk (1957 , 1958), McAlister *et al.* (1959), Herlinveaux and Tully (1961), Pickard (1961, 1967), Herlinveaux (1962), and others. At the same time, however, biological production in these waters has been given comparatively scant attention. This may be due in part to the lack of reliable models of the biological systems of inlets. However, recent applications of analytic techniques to research in marine productivity have greatly facilitated the study of quantitative relationships between plankton and its environment. Most numerical phytoplankton models are based on a conservation equation that attributes algal biomass variations to photosynthetic and respiratory activity, sinking of cells, grazing by herbivores, and to mixing and advection in the medium. In some inlets, or segments thereof, certain of the numerical tasks can be obviated by using approximate expressions for the hydrodynamic variables derived by using similarity techniques. This procedure is described in greater detail in the next two sections of this paper. In the final section, the general approach is illustrated with a model of springtime phytoplankton blooms in the main basin of Puget Sound near Seattle.

INLET CIRCULATION AND HYDROGRAPHY

Before presenting the analytic details of an algal production model, we shall briefly review those features of inlet flow which are relevant to the problem at hand. It is characteristic of Type 3 inlets that the most vigorous circulation takes place in an upper brackish layer which moves persistently seaward above a landward-moving deeper layer of

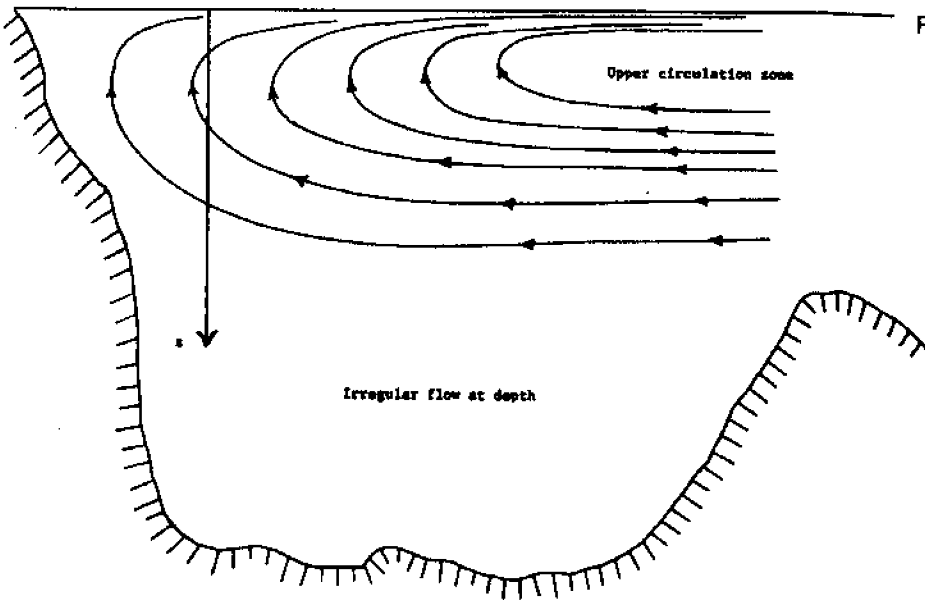


FIGURE 1. Schematic diagram of the flow pattern in the upper circulation zone of a deep inlet

saltier water, as shown schematically in Figure 1. The seaward-moving layer entrains from below denser, more saline water which is ultimately supplied to the basin by the sea, the predominant longitudinal transport mechanism at depth being advection rather than turbulent diffusion. It is generally believed that the principal entrainment mechanism is turbulence induced in the shear layer between the seaward-flowing surface layer and the deeper, landward-moving salt water. In some inlets, mixing is promoted by surface wind stress and by bathymetry. The influence of tides in an "ideal" fjord is indirect, in some cases providing an undetermined fraction of the energy involved in turbulent mixing, while fresh water runoff and gravitational convection dominate the overall dynamic balance. In any case, the entrainment process involves preferential upward transport from the lower zone to the surface layer through an intermediate halocline zone; the depth to which fresh water is mixed downward is indicated by the lower boundary of this zone.

The longitudinal variation of the depth of the lower boundary of the halocline zone is not large and, in the majority of inlets, the greatest density changes occur in the first decameter. These features are exemplified by the summertime salinity structure of Alberni Inlet, B.C., as shown in Figure 2. In summer, the depth of the lower boundary of the halocline zone in Alberni Inlet is somewhat less than a decameter, and according to our remarks above, it follows that surficial water penetrates no deeper than about a decameter over much of the inlet.

The turbidity of inlet waters depends critically upon the concentration of suspended particulates carried into the surface layer with the fresh water runoff, and also upon the density of algal blooms, when they occur. Over extensive portions of Northeastern Pacific inlets, the transparency of the water is such that the photic zone is roughly of the same order of magnitude as the halocline depth. This can be seen from Table I which compares Secchi disk and halocline depths in inlets

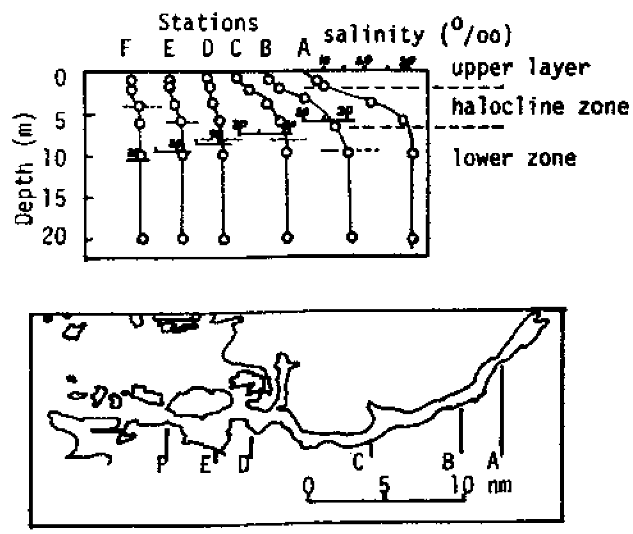


FIGURE 2. Summertime salinity structure in Alberni Inlet, B.C. (from Tully, 1958)

with large and small runoff, as reported by Pickard (1961). Since the Secchi disk depth gives a measure of the vertical dimension of the zone in which phytoplankton can photosynthesize effectively, we anticipate from these data a close relationship between the circulation and water mass characteristics, and the intensity of primary production in stratified inlets.

DEVELOPMENT OF QUANTITATIVE EXPRESSIONS

In order to avoid incapacitating complexity, we shall confine our attention to primary production in a steep-sided, relatively straight fjord segment. It will be assumed that the basin is sufficiently narrow to preclude the occurence of large cross-channel variations in the flow. We shall employ a coordinate system with the origin at the surface, near the landward end of the segment of interest (see Figure 1). The positive x-axis extends horizontally in the seaward direction and the z-axis is taken positive downward.

Under idealized fjord conditions, changes in momentum and salt concentration produced by longitudinal mixing are small compared with variations associated with vertical mixing and advection. We shall make the usual assumption that the time-average of the turbulent stress can be represented by the product of the horizontal velocity shear and a suitably defined eddy coefficient of viscosity, N_z. We shall further assume that the turbulent flux both of dissolved substances (e.g., salt) and suspensoids (e.g., algal cells) can be adequately represented by the product of a vertical eddy coefficient of diffusion, K_z, and the vertical gradient of the mean concentration of the substance in question.

A useful index of primary production is the concentration, C, or organic carbon of organic carbon of living algal cells. The field C (measured in units of mg carbon m^{-3}) is the solution of an equation which expresses the rate of change of C as the resultant of changes due to fluid transport, photosynthesis and respiration, sinking, and grazing by herbivorous zooplankton. Since large cross-channel variations are excluded from consideration, the equation for C may be averaged over the channel width, b. Furthermore, we will not be concerned with temporal changes in C associated with tidal motion, so that the equation for the phytoplankton concentration, as well as the equations for the circulation and the salt balance, may be averaged over a tidal cycle.

Since a detailed discussion of the derivation of the equation for a nonconservative substance is available elsewhere (e.g., Pritchard, 1971), only final results will be recorded here. The laterally-averaged equation for the time-mean concentration of plant carbon C(x,z,t) can be written as

$$\frac{\partial C}{\partial t} = \frac{1}{b}\frac{\partial}{\partial z}\left(bK_z\frac{\partial C}{\partial z}\right) - \frac{1}{b}\left(\frac{\partial buC}{\partial x} + \frac{\partial bwC}{\partial z}\right) - \frac{\partial w_s C}{\partial z} + P_r C - Z \qquad (1)$$

where w_s is the vertical sinking speed of an algal cell, P_r is the net specific production rate, and Z is the rate of concentration decrease by grazing. In principle,

Inlet	Runoff (m^3 sec^{-1}) (annual mean)	90% salinity depth (m)	Secchi disk depth (m) May-Sept.; central station
Gardner	580	10	1.5
Knight	410	12	1.5-4
Bute	410	9.5	1.5-3
Toba	270	15	1-3
Smith	120	5	4.5
Loughborough	100	3	4-8

Table 1: Vertical dimension of upper zone of salinity structure and Secchi disk depth in British Columbia inlets [abstracted from Pickard (1961)].

the equations which describe the circulation dynamics are to be solved, along with equation (1), in a suitable space-time frame, subject to appropriate boundary conditions. At the free surface, the flux of plankton is zero:

$$C = \frac{K_z}{w_s} \frac{\partial C}{\partial z} \text{ at } z = 0. \qquad (2)$$

Low concentrations of phytoplankton may be extant at depth in an inlet, due to cells borne into the basin with the salt water intrusion from the outside and also to sinking from above. In such case, at the sill depth and below the concentrations of plant carbon approach values which vary slowly in time and are to be determined from observation. When local longitudinal variations of C at the ends of the inlet segment are known to be of secondary importance (from field observations), then zero net flux conditions on C at the ends of the segment would be appropriate.

One could apply a vertical averaging procedure to each stratum of an inlet, constructing thereby a two or three layer box model in much the same manner as Pickard and Trites (1955) and others have done in different contexts. However, the scale and arrangement of compartments appropriate to a description of the biological processes may be different from that which is suitable for the circulation. An alternative to the box model approach consists of a numerical integration of the equations for the circulation and salt exchange in the inlet, followed by a numerical integration of equation (1) over the space-time domain of interest. Even under the most favorable circumstances, however, such an undertaking may involve rather large expenditures of time and money in computation. Furthermore, in view of the fact that the equations are highly nonlinear, there are many potential problem areas in the numerical analysis.

We suggest here an approach to modeling of primary production which attempts to avoid at least the most obvious disadvantages of the two procedures just described. Under the assumptions introduced earlier, the overall circulation dynamics in the upper zone is dominated by gravitational convection, with land and river drainage providing a continuous source of fresh water and with the sea acting as a continuous source of salt water. Since we exclude from consideration transients associated directly with tidal motion, the circulation will be quasi-steady state in the mean, as long as external factors, such as runoff and average surface wind stress, do not change drastically from one tidal cycle to the next.

In treatments of fjord circulation by Rattray (1967) and by Winter (in preparation) the mixing coefficients K_z and N_z, the velocity components u and w, and the density are expressed as products of powers of functions ξ of the distance x along the basin and functions of a similarity variable $\eta = z\xi^{\alpha}$, α real. In addition, longitudinal variations of cumulative fresh water runoff, R, and channel width, b, are expressed as powers of ξ. It can be shown that when certain relationships are satisfied amongst the several powers of ξ, then the equations of motion reduce to a set of ordinary differential equations. From these equations, it is possible to obtain approximate analytic expressions for the velocity components and the density distribution. Thus, for an inlet segment where the conditions of similarity analysis are reasonably well satisfied, there is available an approximate, self-consistent description of the steady-state circulation where the mixing coefficient, the salinity, and the velocity field are continuous functions of x and z. Expressions for the functions b, K_z, bu, and bw are then substituted into equation (1), and appropriate boundary conditions, such as equation (2). Nonlinearities in the resulting boundary value problem can be handled by quasilinearization techniques. When appropriate initial conditions are prescribed, the equation for C can be integrated numerically by using any one of a number of techniques.

Of course, it is unlikely that the conditions for similarity will be met rigorously in any specific instance. Nevertheless, even in those inlets where the requirements are only approximately satisfied, the solution may reproduce the main features of the flow and will constitute an adequate approximation for use in equation (1). If so, a considerable saving of time in analysis and computation will have been realized, and it becomes feasible to perform numerical experiments with the description of biological production.

MODEL OF AN ALGAL BLOOM IN PUGET SOUND

The usefulness of the described approach will be demonstrated by comparing predicted and measured algal concentrations in the main basin of Puget Sound off Seattle during a two-month period in the spring of 1966.

The central basin of Puget Sound is essentially an inlet-type of estuary, characterized by depths in excess of 200 meters, with 50 meter-deep sills at both ends (see Figure 3). The sill at the southern end separates the main basin from an involved system of shallower, low-runoff basins. The northerly sill separates the central basin from the Strait of Juan de Fuca, which is connected with both the Strait of Georgia and the Northeast Pacific Ocean. The flow pattern near mid-channel in the central basin is basically a two-layer system in which the vertical scale is, in part, dynamically controlled by the circulation itself. The general circulation in the main basin is such that the region bounded to the south by Blake Island and to the north by the confluence with Possession Sound constitutes a segment whose hydrography is suggestive of fjord structure of a classical type during episodes of spring and early summer runoff. The longitudinal variations of cumulative drainage area and channel width (see Figure 5) suggested a similarity analysis whose details are presented elsewhere (Winter, in preparation).

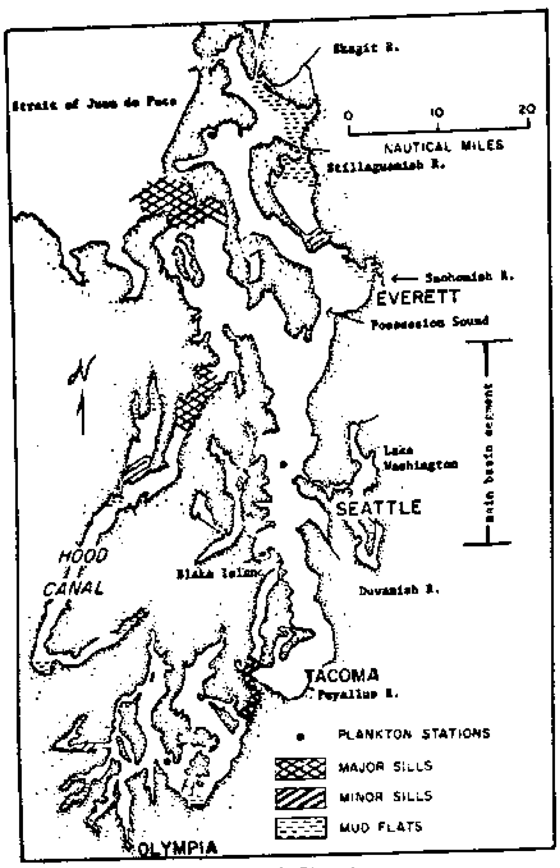


Figure 3. Puget Sound Chart

The field observations were made as part of a program initiated in 1963 to study primary production in Puget Sound, carried out under the direction of G. C. Anderson and K. Banse at the University of Washington with funds provided by the U.S. Public Health Service. During the spring of 1966, water samples were collected shortly before local apparent noon on a 250 meter deep station (Station 1 in Figure 3) on an almost daily basis. The environmental measurements included temperature, salinity, oxygen, phosphate, silicate, and nitrate (see Figure 4). Concentrations of chlorophyll α were ascertained and half-day measurements of carbon uptake (^{14}C) were made under neutral density screens which simulated the light intensity at the depths from which the samples were taken. The choice of the five "light depths" was made on the basis of the observed Secchi disk depth at the time of collection. Available light during the productivity measurements was determined with a solarimeter. Zooplankton was collected by a vertically towed closing net from the seabed to the 1% light depth (usually considered to be near the bottom of the photic zone) and from there to the surface. One immediate conclusion from the field observations of nutrients was that algal production at the site is not limited by, nor even proportional to, the availability of nutrient salts so that nutrients can be excluded from further consideration in the model.

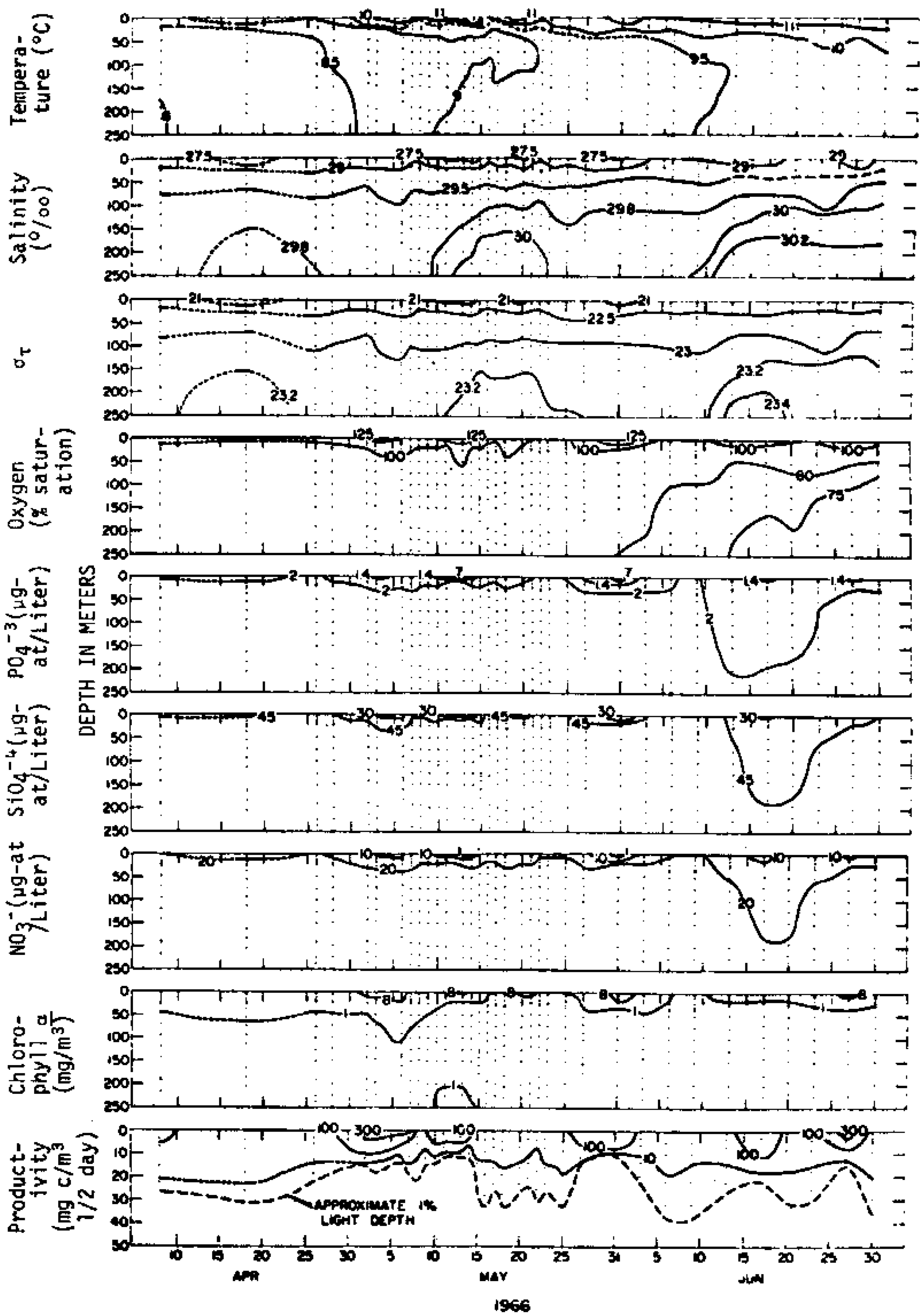
As discussed in detail by Winter, Banse, and Anderson (in preparation) the principal hydrographic inputs for the circulation submodel are river runoff from gauging stations and surface salinity; the salinity at depth was taken to be constant. Calculated salinity distributions with depth adequately reproduce the measurements from the mid-channel station (see Figure 6). In addition, the calculated horizontal velocity profiles are similar to those inferred from the very limited amount of historical data in hand.

The coefficient of the net specific algal production P_r was determined from Steele's relation

$$P_r = p_{max} \frac{I}{I_{max}} \exp\left(1 - \frac{I}{I_{max}}\right) - r_c, \qquad (3)$$

where p_{max} = maximum specific photosynthetic rate (mg C added/mg C) hr^{-1}, I_{max} = light intensity (cal cm^{-2} hr^{-1}) at which maximum photosynthesis occurs, and r_c = specific respiration rate (mg C lost/mg C) hr^{-1}. The papers of Steel (1962), Vollenweider (1966), and DiToro *et al.* (1970) may be consulted for details.

Figure 4: Hydrographic, nutrient, phytoplankton measurements from Station 1, main basin, Puget Sound.



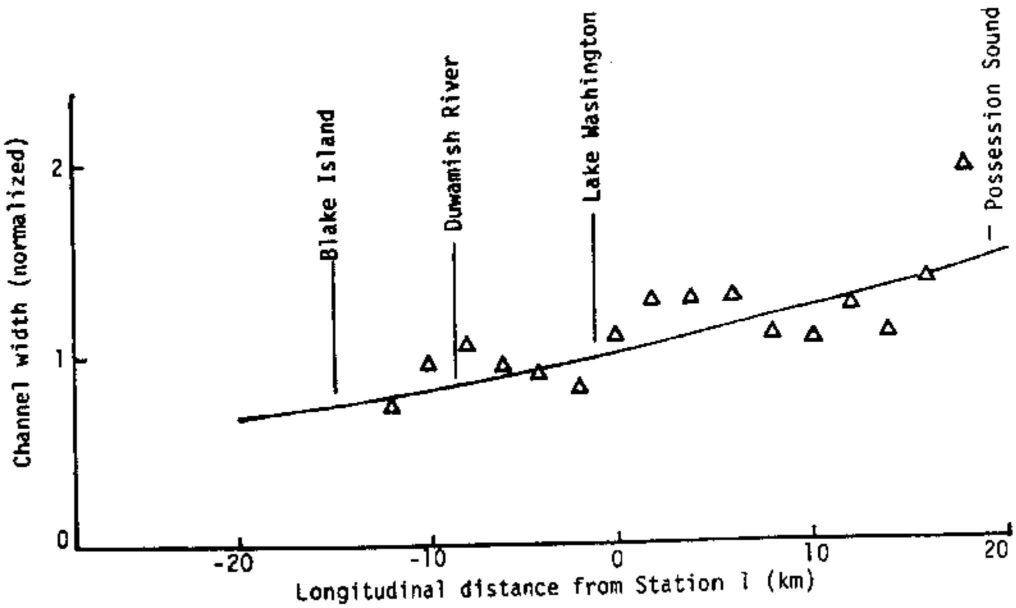


Fig. 5a. Longitudinal variation of effective channel width of main basin segment of Puget Sound

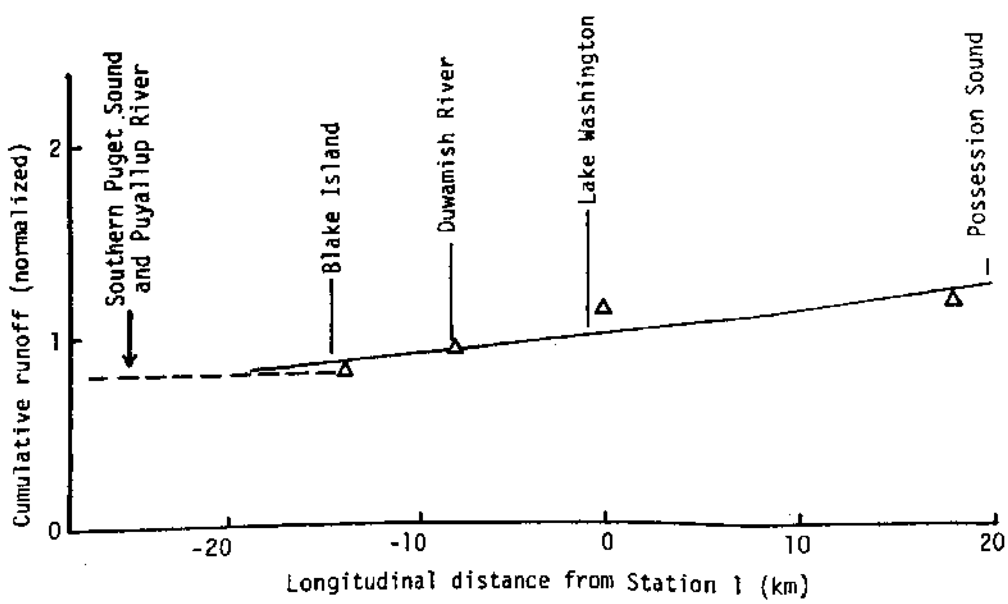


Fig. 5b. Longitudinal variation of cumulative runoff in main basin segment of Puget Sound

Internal consistency would require the replacement of net productivity p_r at the point (x,z) by some sort of time-mean value, since equation (1) has presumably been averaged with respect to a tidal cycle. In fact, Steele (1962) originally proposed the first term of equation (3) to study production of light-adapted algae on a much longer time scale than a single day. However, other workers have found Steele's representation and subsequent modifications of it (cf. Vollenweider, 1966; DiToro *et al.*, 1970) to be useful in describing production on a day-to-day basis. The conclusion is that if one is particularly interested in the short-time scale response of algae to environmental factors which vary diurnally (such as light intensity), but is willing to forego a description of the direct effects of tidal forces (e.g., advection by tidal currents), then diurnal variations may be retained in the expression for p_r in equation (1). Otherwise, the net photosynthesis term should be replaced by a time average.

As a rough approximation, the subsurface light intensity was evaluated as a constant fraction of the average (all day) light flux just above the surface, the latter being read from the shipboard solarimeter records or obtained from Seattle-Tacoma airport records. Following Strickland (1965), we used a reduction of one-half to account for varying atmospheric conditions, reflection losses at the water surface, and absorption of long wave length radiation in the upper few centimeters of the water column. As mentioned earlier in this presentation, the extinction coefficient in inlet waters depends critically upon the concentrations of suspended terrigenous sediment and of algal cells, particularly during seasonal episodes of extinction coefficient by a semiempirical relation in which the effects of both of the aforementioned factors were included.

The maximum specific photosynthetic rate was estimated from the observed trends of production per unit of chlorophyll as a function of depth. The rate fluctuated considerably in a manner which could not be correlated consistently with temperature, light, or any other environmental variables. Therefore, p_{max} was set equal to an average of 4.5 (mg C/mg chlorophyll a) hr^{-1} over the period, and I_{max} was set, on the basis of the same observations, at 550 cal cm^{-2} day^{-1}. The carbon-to-chlorophyll a ratio was assigned a slight seasonal increase, from 15 in January to 40 in July throughout the photic zone on the basis of unpublished

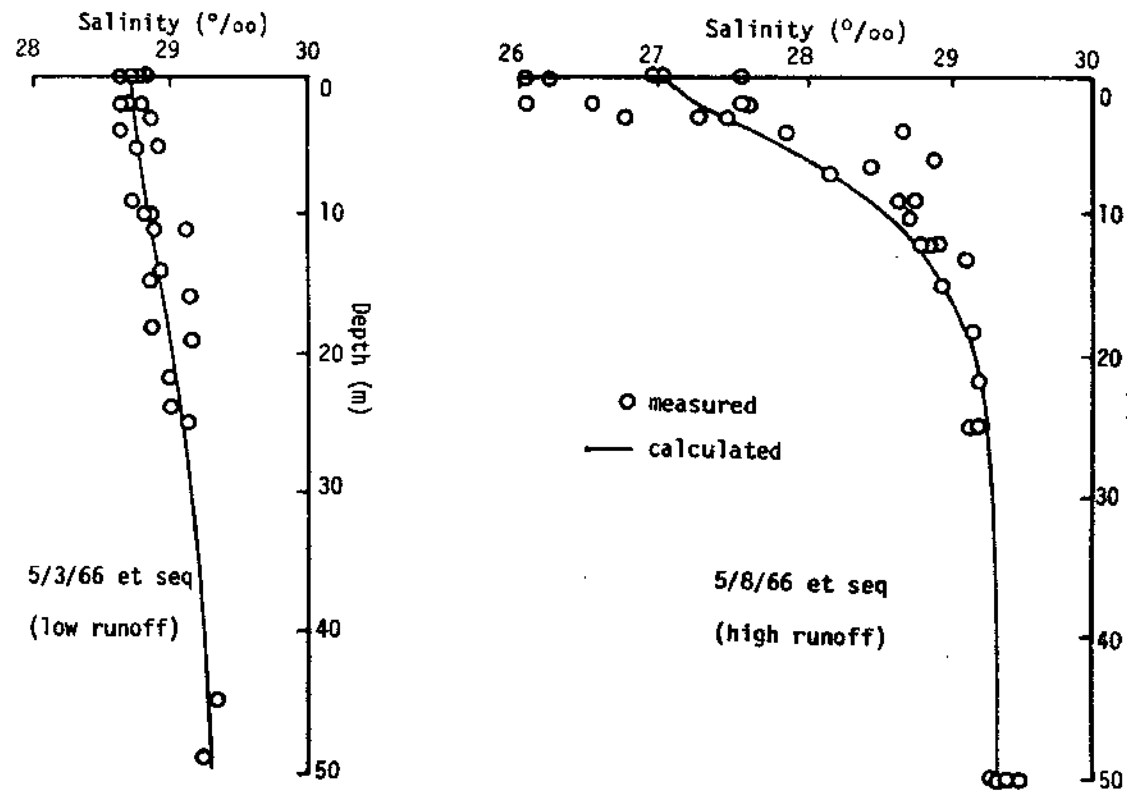


Fig. 6. Depth variation of salinity at Station 1 during 5-day periods in the spring of 1966

observations off Washington and Oregon. The respiratory rate was related to basis of the literature: the surface value was 0.0167 (mg C/mg C) hr^{-1} in daylight, 0.011 at night. The decrease with depth was assumed to follow a Gaussian whose slope was such that at the o.5% light depth, the respiration rate just balanced the daily photosynthetic rate. The possible effects of temperature changes during the observations were neglected. Predation was modeled by considering all herbivores (as determined by counts ans subsequent conversion to mass) to graze like females of the small copepod *Pseudocalanus elongatus*; thus, an hourly ration r was prescribed according to the Ivlev relation

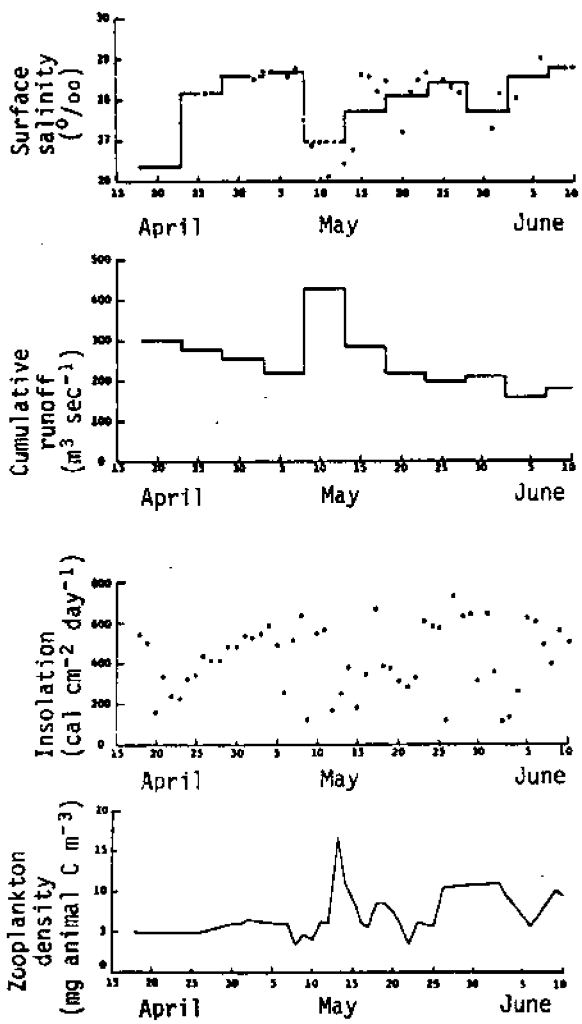


FIGURE 7. Input data for numerical integration of phytoplankton equation.

$$r = r_{max} \, (1 - e^{-kC}) \qquad (4)$$

where r_{max} is 0.02(mg plant C/mg animal C) hr^{-1}, k is 0.015, and C is the plant concentration expressed as carbon.

The vertical sinking speed of algal cells was assigned a representative magnitude of 3 meters day^{-1} on the basis of a survey by Smayda (1970). It is interesting to note that the entrainment of salt water into the halocline zone of a stratified inlet not uncommonly implies a net upward vertical velocity of the same order as the algal sinking speed, which implies that the halocline may act as a unidirectional "gate" for algal cells brought up from below.

Despite the fact that the foregoing assumptions and approximations tend to oversimplify the true situation, the model adequately reproduces the gross features of phytoplankton growth in the upper layers of Puget Sound during the spring of 1966. Calculations of phytoplankton density variations with depth and time at the mid-channel station were made for a sixty-day period beginning on 18 April when the observed algal concentrations were relatively low. Input data included five-day averages of surface salinity and river runoff, measurements of light intensity and zooplankton concentrations on a day-to-day basis (see Figure 7).

Evidence of a freshet can be seen in the five-day period beginning on 8 May. The average surface salinity corresponding to this period was increased slightly (from 26.75 °/oo to 27.00 °/oo) to improve the representation of the circulation at depth. Parameter assignments were made as described above and all other variables, such as flow velocity and extinction coefficient, were calculated by the model. The model was allowed to run without constraint to the middle of May, at which time, transient phenomena associated with strong winds and sudden changes in runoff began to dominate. One of the most obvious effects of transients on the biota during this period was a sudden decline in p_{max} to values which would be associated with a shade-adapted phytoplankton population. Since these effects were not included in the analysis, the model was constrained to give a uniform depth distribution of algae (mg chlorophyll a m^{-3}) until the transient effects became less influential several days later. On 23 May, two days after the last day with strong winds (30 knots), the constraint was removed and the model was allowed to run freely again. The final results are compared with the observed data in Figure 8.

As a result of "numerical experiments" with the model, we have been able to assess tentatively the roles played by various factors which can influence primary production in Puget Sound. For example, it is obvious that, despite their tendency to sink, algal cells will be advected persistently seaward with the surface layer. Moreover, the circulation calculations suggest that the estuarine mechanism keeps the photic zone resupplied with cells which are transported upward from the denser saline water intruding at depth. The circulation also exercises indirect control on primary production levels by governing the distribution of terrigenous segments which can modulate the light energy available for photosynthesis. The environmental event which is most likely to initiate an algal bloom in Puget Sound is a succession of days of high light intensity. On the other hand, the same event can initiate an episode of high runoff due to snow melt, and the growth of a bloom can be subsequently curtailed when the water in the Sound is rendered excessively turbid by a heavy sediment load. Contrary to previous speculations, high stability of the water column apparently is not an essential requirement for the onset of algal blooms in these waters.

Calculations based on our first-generation model suggest that the predicted rate of development of blooms is most sensitive to the value of the maximum specific rate of production p_{max}. The calculations also show that the maximum levels of plankton outbursts are critically dependent on the extinction coefficient and that self-shading limits the concentrations of the more intense blooms.

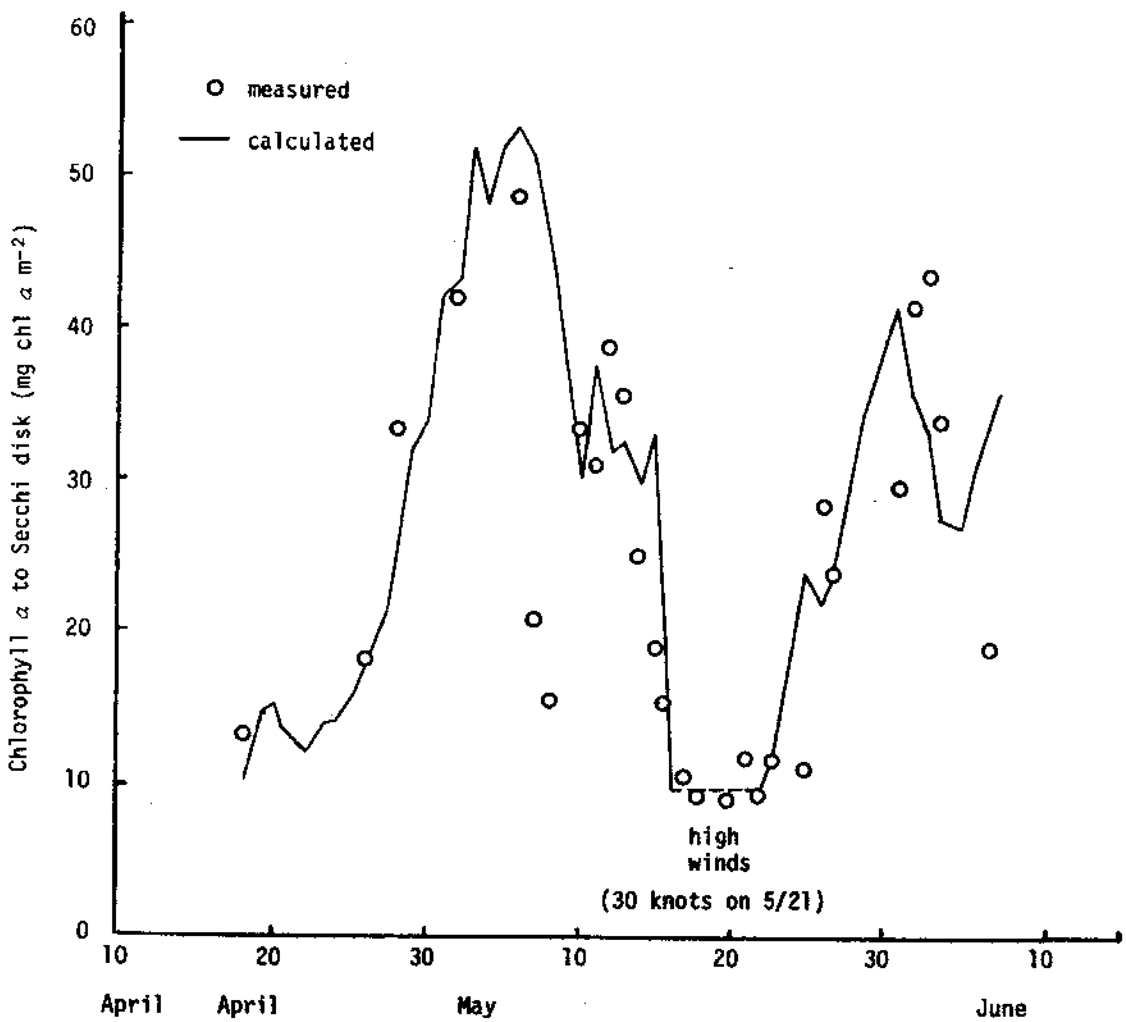


FIGURE 8. Measured (calculated) chlorophyll a from surface to measured (calculated) Secchi disk depth.

Finally, modeling experiments with data from the zooplankton hauls have led to the conclusion that grazing pressure by herbivores probably does not reduce the chlorophyll density in Puget Sound by more than 10 to 20% during blooms.

Although these conclusions are still tentative (pending more thorough analysis), a reasonable, self-consistent picture of phytoplankton ecology in deep inlets is emerging from these studies. We are thus encouraged in the belief that the modeling strategy described here will enable us to specify with some confidence those environmental factors which control algal blooms in the Puget Sound system and elsewhere.

ACKNOWLEDGEMENTS

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An Ecosystem Study in the Inside Passage of Southeastern Alaska

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Department of Oceanography
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In his autobiography, H.G. Wells stated that we know the past not by personal observation, but by induction. Indeed, the more distant the past, the less the observation and the more the induction. He suggested that we could know the future the same way. "By adequate knowledge of contemporary processes", wrote Wells, future conditions "could be brought within range of our knowledge and its form controlled. I did not say that the future could be foretold but I say its conditions could be foretold."

It is often asserted as fact, that scientists and engineers always think logically and that research, development, and applications have developed in straight lines. This misconception is based on the orderliness and logic of our textbooks which exclude the blind alleys, wrong turns, and often total confusion which more typically characterize our efforts. Moreover, nature, not our minds, presents the patterns and problems from which we adduce principles. In only the most relatively advanced areas do we know enough to make predictions, and *then* seek for verification in nature. Ecology is not one of these areas.

This morning I should like to describe some of our work, in a facinating geographic location, that has provided many interesting challenges and some rewards in trying to learn something about the (immediate) future from the (immediate) past. The location was chosen partly for the same reason that some mountains are climbed, because it was there. More to the point, it provided an estuarine area which behaved like an ocean but which behaved on a temporal and spatial scale that permitted me, at least, to believe that we could understand how an aquatic ecosystem functioned.

THE PROBLEM

Over the past three years we have been watching nature perform a variety of experiments in a small bay in southeastern Alaska. Our experiments have involved the annual seasonal cycles of thermo-haline circulation, nutrient ions, and the resulting qualitative fluctuations in the plankton.

We've chosen Auke Bay (Figure 1 and maps) near Juneau in particular, and the Alaskan Inside Passage in general, rather than the Pacific Ocean, because advection through the bay is relatively slow and the directions, if not the rates, are known. There is a strong, two-layered circulation in summer; upwelling is frequently present; seasonal cycles are similar from year to year; zooplankton usually occur as a single, mid-summer pulse; most chemical and biological properties, except zooplankton, are homogeneously distributed in the horizontal plane; small boats are usable even during poor weather, the laboratory of the National Marine Fisheries Service is nearby and provides logistic support of all sorts, and there is protection from the type of weather normally found in the open Pacific.

PLANKTON DEPENDENCE ON NITROGEN

The study began with the dissertation research of E. Bruce in 1967. Bruce first studied the seasonal cycle of plankton in Auke Bay as related to hydrography and nutrient distribution (Bruce 1969). He concluded that amino acids could be an important source of nitrogen for phytoplankton in the bay since blooms occurred even in the absence of detectable nitrate. (Figure 2 & 3) After the onset of the spring bloom, initiated by stabilizing of the water column, there is a decrease in nitrate in the upper, mixed layer to undetectable levels. In 1967 there was a second bloom in August caused by nitrogen excretion (ammonia and amino acids) due to zooplankton grazing. There was also probably an increase in area, which we were not measuring at that time. The second bloom consisted of *Skeletonema costatum*, whereas the initial bloom had been *Thalassiosira nordenskioldii*. (Figure 4).

The following year, Richard Iverson and Harold O'Connors spent the summer obtaining additional data to test Bruce's hypothesis. Nineteen sixty-nine was a "typical unusual year", however, in that the wind blew from the northwest periodically, causing appreciable mixing of the surface layer and eroding the pycnocline. A phytoplankton bloom of *Skeletonema* followed each mixing period. (Curl, Iverson & O'Connors 1971)

A pattern began to emerge. The spring bloom consisted typically of *Thalassiosira*

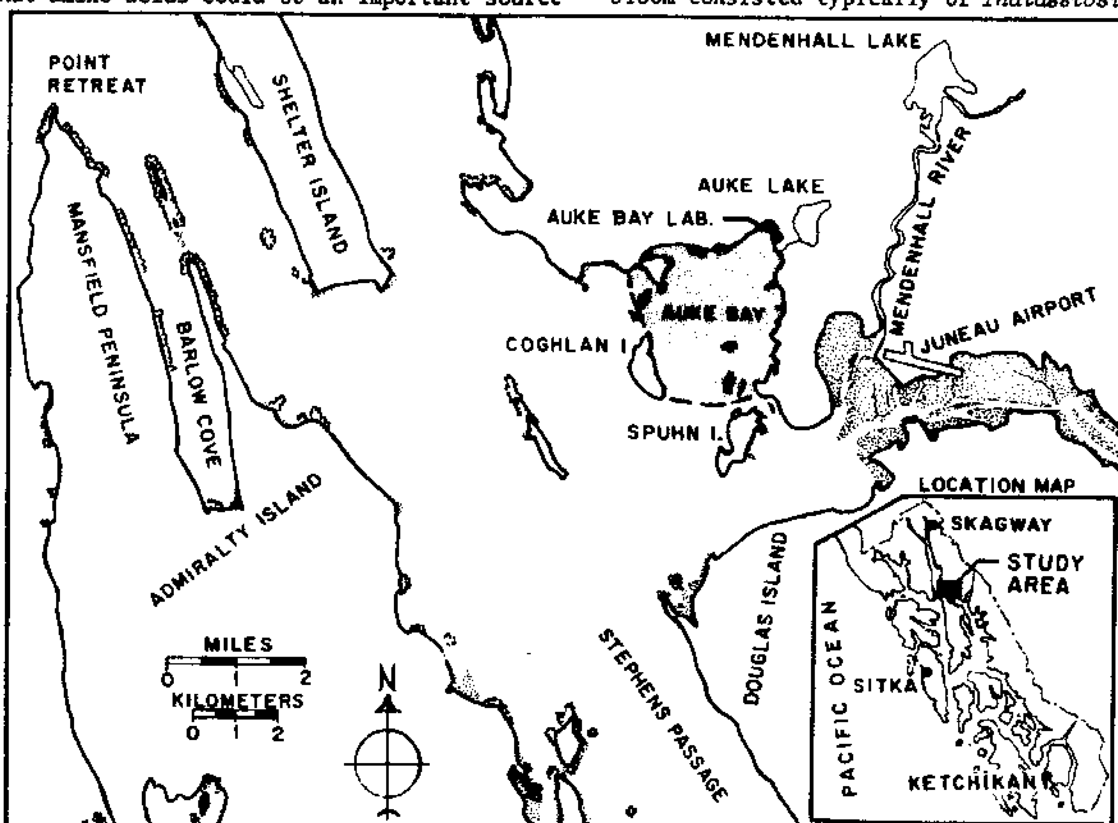

FIGURE 1. Location of Auke Bay in relation to major straits and passages in southeastern Alaska.

nordenskioldii when waters were cold and enriched with initially high nutrients. Subsequently the waters warmed and were low in nutrients except during periods of mixing, when *Skeletonema* bloomed.

We decided to investigate the causal relationships from several angles. Nancy Roelofs began a study of the differences in the activity of the enzyme nitrate reductose between *Thalassiosira* and *Skeletonema*. This enzyme mediates the conversion of assimilated nitrate ions to nitrite and its activity is a measure of the ability of an organism to use available nutrient. *Skeletonemo* had the higher enzyme activity at all nitrate levels in the medium at 15 C, whereas *Thalassiosira* had a higher activity at 10 C. Thus the competitive advantage of each genue appeared to rest on enzymatic differences. (Roelofs 1970)

At the same time, Karen Zakar undertook a study of the effect of light intensity on nitrate assimilation and nitrate supported growth of the two organisms. In addition, she obtained values for nutrient uptake kinetics which can be used in simulation models. Zakar's work was done with batch cultures. An alternative approach was tried simultaneously by D.P. Larsen, using chemostats.

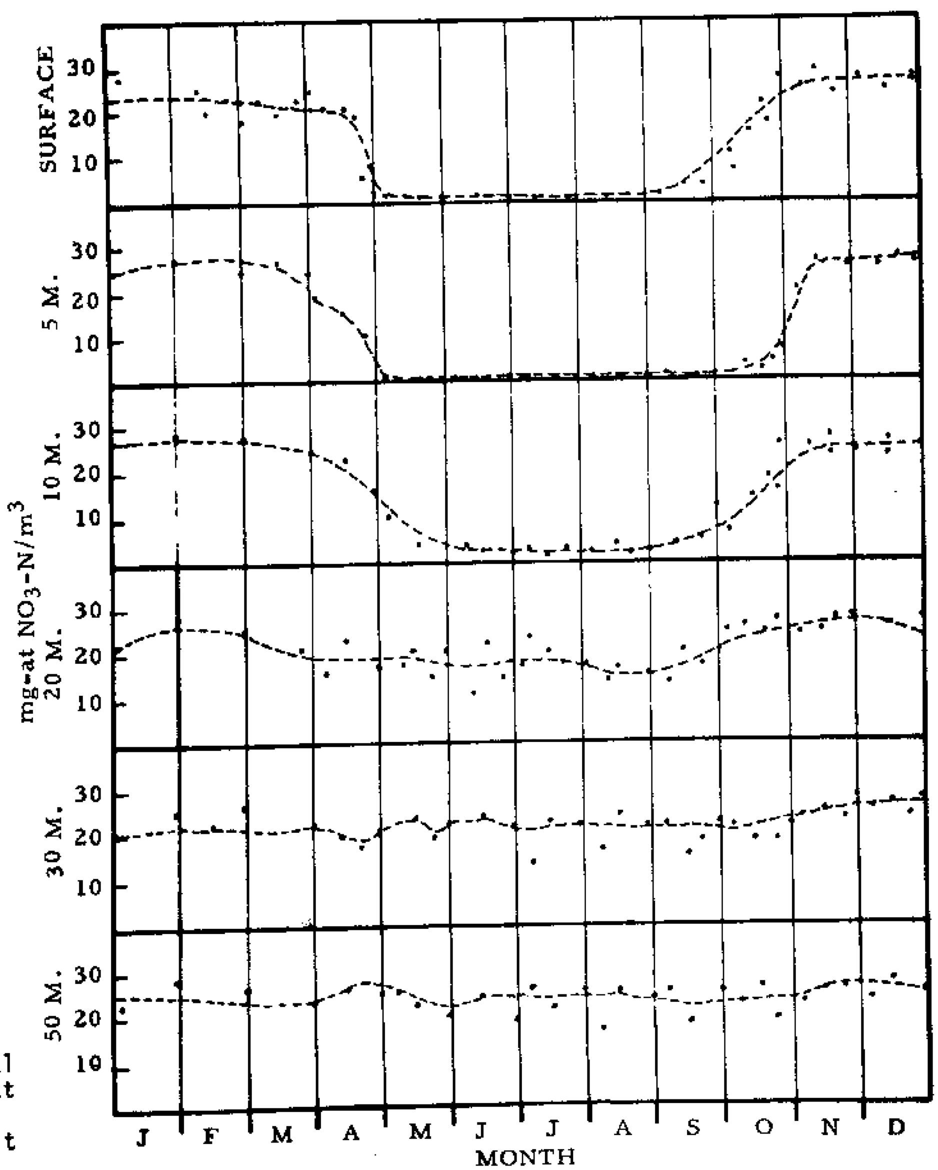

FIGURE 2. Seasonal cycle of nitrate at selected depths. (Curves are eye-fit to data.)

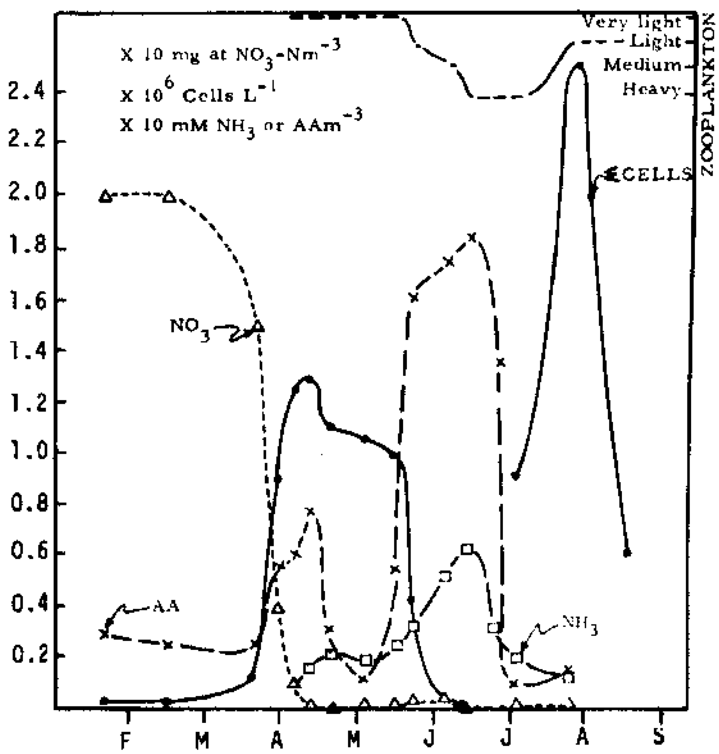

FIGURE 3. Interrelation between amino acids, NH_3, and NO_3^- and phytoplankton-zooplankton abundance.

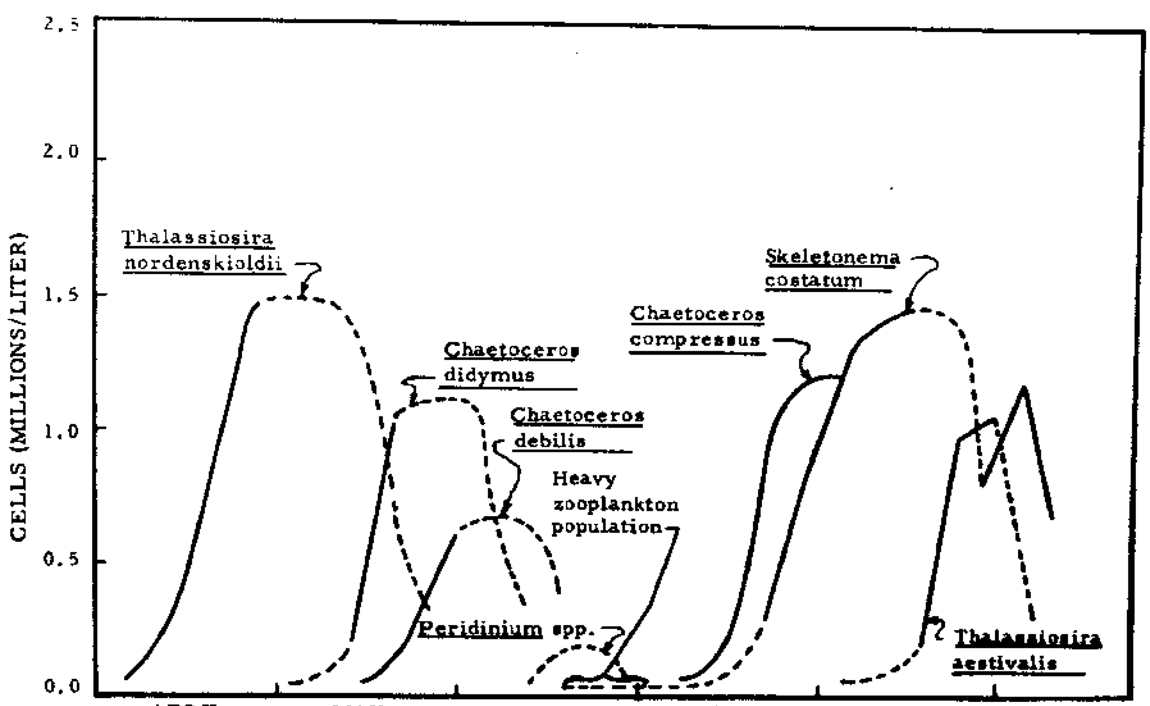

FIGURE 4. Order of succession of phytoplankton bloom which occurred in Auke Bay between mid-April and mid-September 1967

SIMULATION MODEL OF PLANKTON DYNAMICS

In early 1970 we felt we had sufficient data to attempt a simulation model of the plankton dynamics of Auke Bay. With the help of John Saugen of the Electrical Engineering Department at OSU, Iverson developed a model based on Steele's model for a phosphate-limited population in the North Sea. Iverson used the data he had obtained in 1969. As we suspected, the model showed that primary production was primarily related to wind-induced mixing as the main forcing function. The effect of herbivore grazing was shown to be negligible (in 1969) but the inclusion of terms for light-related photosynthesis, and respiration, improved the reality and precision of the Model.

The sequence of events is now thought to be: The initial (spring) bloom is initiated by the onset of stability, increasing solar radiation, and high levels of initial nutrients. Species composition at this time is controlled by temperature acting on enzymatic processes and by nutrient availability. Subsequent blooms and their composition are controlled by 1) periodic wind mixing, replenishing nutrients from beneath the pycnocline, 2) in-situ nutrient regenerations by grazing zooplankton or, possibly, directly from phytoplankton, 3) advection and stream flow, 4) rainfall, 5) grazing by zooplankton. The biological response varies according to the interactions of the forcing functions.

Concurrent with Iverson and Saugen's work, William Grenney and David Bella of the OSU Department of Civil Engineering developed two models, one to study the uptake and partition of nitrogen species into three compartments in a cell and the other to relate measurements of standing stocks of nitrate to uptake by cells on one hand and to supply by mixing in a two-layered estuarine system on the other.

Grenney's original effort was based on an analysis of Caperon's (1968) published results, using a three-compartment model. Attempts to apply the derived model to actual data were not very successful. In an effort to further refine the model, Phillip Larsen conducted batch and chemostat experiments. These experiments confirmed the uncoupling between cell growth and ambient (extracellular) nitrogen concentrations. This work is continuing.

In an effort to elucidate the kinetics of competitive uptake of ammonia and nitrate by unialgal and bialgal populations in chemostats, Dan Lundy has performed one experiment thus far, which suggest that although nitrate reductose may not be functioning in the presence of ammonia, there is uptake of nitrate.

AUKE BAY SAMPLING PROGRAMS

In April 1971, cruise C 7104-A set to sea to test the STD-shipboard computer system developed under the OSU Sea Grant Program (Becker and Curl 1971, 1972) and to investigate pre-bloom conditions in Auke Bay. The scientific party consisted of Peter Becker and Charles Samuelson, the designers, builders and operators of the STD system; Douglas Coughenower, analytical chemist, who was testing a newly-developed total dissolved nitrogen analyzer and who was to undertake a study of the distribution of nutrient nitrogen species in the Alaskan Inside Passage; Deborah Kirk, who was to later spend the summer of 1971 with Karen Zakar at Auke Bay; Cheryl Alber, laboratory, research assistant; Mark Halsey, marine technician; and Herbert Curl, Principal investigator.

The STD system permitted a complete hydrographic station to be made to 200 m in seven minutes, including pumped samples for nutrient analysis by auto analyzer, CHN samples, and chlorophyll/plankton samples. A total of seventy-five stations, mostly in the Inside Passage, and particularly in Auke Bay, were occupied. The Auke Bay and Glacier Bay stations were occupied in company with R.V. *Ursa Minor* who monitored pCO_2 and conducted nitrogen uptake experiments. This cruise was well-timed inasmuch as it coincided with the onset of the spring bloom (Coughenower and Curl 1973). Chlorophyll *a* was noted in any abundance only where some density structure had developed. There was some evidence that silicate could become limiting due to high concentrations of nitrogen and phosphorus. Upwelling occurred while we conducted a current meter study in Auke Bay.

In June 1971, Zakar and Kirk began another summer sampling program in the bay. Samples were taken for salinity, temperature, total available nitrogen, nitrate, ammonia, chlorophyll, cell numbers, and particulate CHN. Experiments were conducted to measure $^{14}CO_2$ fixation rates, urea uptake, amino acid uptake and NO_3 uptake. In addition, current velocity, meteorological and stream run-off data were obtained. Samples for inorganic nitrogen species were also obtained in the fresh water tributaries to Auke Bay. From these data we prepared a nitrogen budget for the bay (Kirk 1972). These data will also be used to improve the simulation model and to obtain some idea of nutrient kinetics in natural communities. The advection into the bay beneath the pycnocline is slower than the resolution limit of the current meters (2 cm/sec.). Dispersion of nutrient nitrogen was therefore calculated from either heat

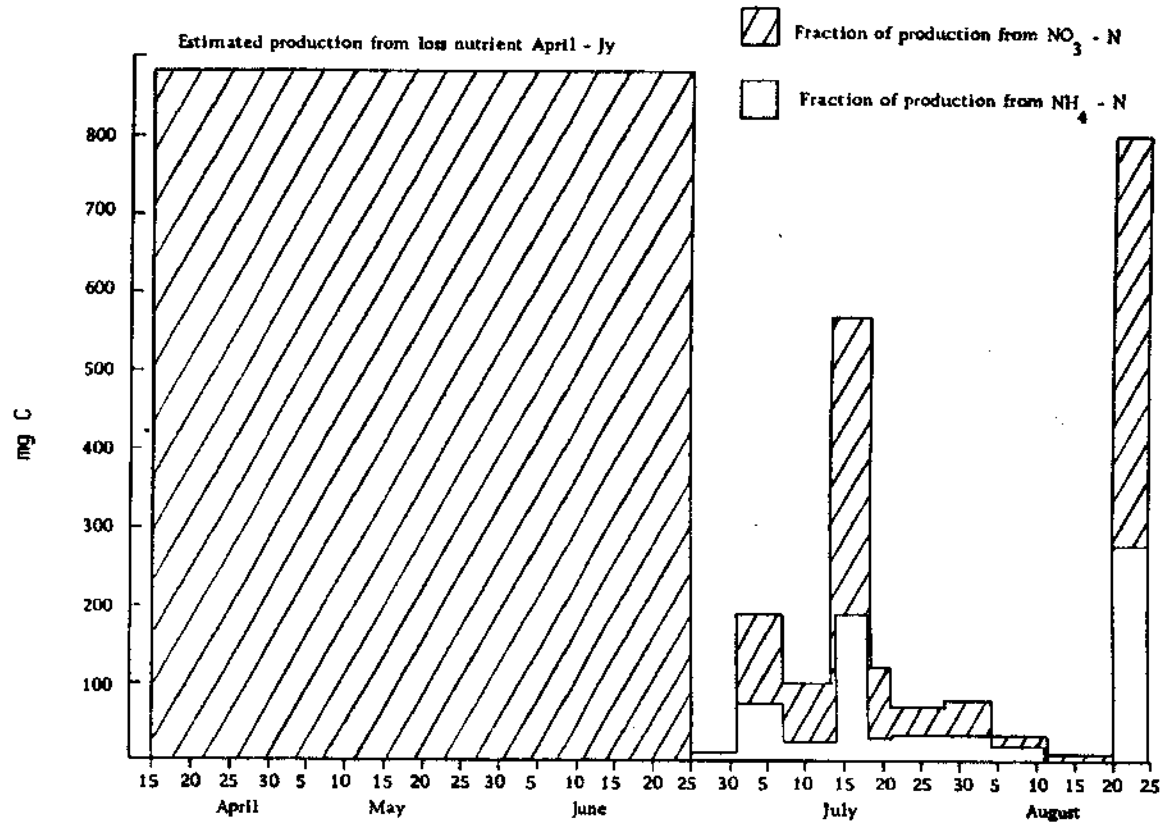

FIGURE 5. Estimated total production from nitrate and ammonia additions, April-August, 1971.

exchange across the pycnocline during periods of cooler weather or from deepening of the mixed layer during episodes of high wind velocities. Rates of nitrogen input into the surface layer from all sources is shown in Table 1. Vertical transport is one or two orders of magnitude greater than other sources. Production calculated from nitrogen input of all sources can be calculated assuming a realistic value for C:N ratio of 7 (Figure 5). Most of the year's production took place between the cruise in April and the first summer observation in June.

Subsequent calculated production was wind-induced and superimposed on a low background level due to diffusion across the thermocline.

PHYTOPLANKTON - ZOOPLANKTON RELATIONSHIP

Production calculated from physical parameters also assumes instantaneous utilization of the nitrogen. Zakar (1973) measured ^{14}C uptake during the summer of 1972 and found an exponential increase in ^{14}C uptake rate starting on 5 July and peaking on 5 August. One could conclude, since phytoplankton are integrators of light and nutrients, that there is a lag of about two weeks in the system. Thus phytoplankton increased despite grazing pressure. Zakar (1973) estimated a total production of 3.83 gC m^{-2} for the one month period. Kirk (1972) estimated a total production of 5.20 gC m^{-2} from nitrogen disappearance. The difference can be ascribed to grazing and sinking. Unfortunately, we have no good way of separating the two forms of loss. A single loss term could be used in numerical models (Iverson 1971) but this does not enable us to estimate how much production is available to the second trophic level.

FUTURE WORK

Our plans for future work include research at all levels of organization, from nature and control of nitrogen uptake by cells, on how internal nitrogen "pools" affect growth rate, on rates of nitrogen flow through the estuary, on the behavior of individual species, and on grazing rates.

TABLE 1. Rates of nutrient addition (nitrate and ammonia) to the surface 6 meters of Auke Bay, and the primary production calculated from these rates.

Period	Addition of Nutrient-N to upper 6 meters per @ time period: 1 Rainfall mg-at x10^{-2}		2 Auke Cr. mg-at x10^{-2}		3 North Shore mg-at x10^{-2}		4 Mendenhall River mg-at		5 Vertical Transport mg-at		6 Sum of Sources mg-at		7[a] ΔN mg-at		8[b] Available N	9[c] Calc. prod. mg C	10[d] Calc. prod. mg C/day
	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3			
25 Ju-30 Ju	7.90	3.96	2.40	2.89	3.85	1.08	0.56	0.43	2.52	1.40	3.22	1.94	-4.60	-1.3	0.60	55	88
1 Jy- 6 Jy	6.55	3.26	1.29	1.55	1.88	0.52	0.63	0.49	3.10	3.53	3.83	4.07	+4.60	+1.3	13.79	1155	192
7 Jy-13 Jy	0	0	4.93	7.17	7.15	2.43	0.57	0.44	4.70	3.38	5.39	3.91	-0.30	-1.7	5.29	613	97
14 Jy-17 Jy	23.2	11.6	0.82	1.87	26.40	0.63	1.31	2.46	11.0	6.20	12.81	8.74	+1.60	+0.4	22.54	1891	573
18 Jy-20 Jy	3.64	1.82	0.77	1.75	24.80	0.59	0.15	0.28	2.64	1.08	3.08	1.40	+0.03	-0.3	4.21	353	118
21 Jy-27 Jy	2.75	1.38	0.67	2.66	36.90	0.90	0.39	0.74	3.50	2.10	4.29	2.88	+4.29	+0.4	7.57	636	91
28 Jy- 3 Aug	20.88	10.44	0.11	1.64	1.04	0.56	0.04	0.67	3.00	1.50	3.26	2.29	-0.1	+1.0	6.45	544	78
4 Au -10 Au	15.05	7.52	1.07	5.62	6.30	1.91	0.04	0.58	0.90	0.60	1.17	1.33	-0.2	+0.6	2.92	246	35
11 Au -19 Au	17.28	8.64	3.24	4.54	7.35	1.53	0.07	0.84	1.13	0.76	1.48	1.74	-0.4	-1.7	1.08	92	10
20 Au -24 Au	7.18	3.59	2.41	3.26	7.43	1.10	3.24	1.92	30.00	15.00	33.40	17.00	-3.6	0	47.40	3988	797

[a] Δ N: difference in standing stock of nutrient between beginning and end of @ time period in upper 6 meters.

[b] Available N: net mass (mg-at) nutrient (NO_3 + NH_3) available for phytoplankton per @ time period.

[c] Calc. prod., mg C: Primary production calculated from net nutrient available: (mg-at nutrient N)(C/N)(mg C/g mol wt. C) where: C/N ratio=7, mg C/g mol wt. C = 12.

[d] Calculated primary production as mg C/day.

Despite the lacunae in our knowledge I think we are beginning to understand how relatively complex systems work. We feel fortunate in having picked a system that behaves consistently and is in such a beautiful part of the world. Perhaps we will soon be in a position to foretell the conditions of the future, if not the future itself.

ACKNOWLEDGEMENT

I am reporting work which could not have been accomplished without the dedicated efforts of all people mentioned earlier, as well as many others, including the crew of the R/V *Cayuse* and the personnel of the Auke Bay Fisheries Laboratory.

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Difficulties Ahead for Oregon Regarding Estuary Regulations, Control and Protection

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State of Oregon

The title of today's comments is a little bit misleading. I'm not going to talk about difficulties without at the same time talking about what we can do to solve the problems.

The estuarine and coastal zone is one of our most valuable geographic resources, but man and his activities have exerted tremendous pressure on it. Though he is part of nature, man has shown an extraordinary capacity to effect changes in the natural condition of this zone.

Man fishes the waters, fills the tidelands, hunts game, dredges the harbors, builds jetties, constructs roads, harvests the forests, stores the cut timber, plows the uplands, grazes the fields and marshes, grows shellfish and, in the process of many of these activities, pollutes the water and changes the structure of the estuary. Yet he is relatively unaware of the impact of his activities.

Industry seeks a cheap source of industrial water and a simple solution to waste disposal problems. Present trends in shipping have increased the demand for deep water frontage. Deep water access will be essential to the future competitiveness of Northwest industries which process large volumes of heavy raw materials.

Private and commercial developments are putting heavy pressure on shoreline property, both in estuaries and along the open coast.

Navigation channels are dredged and redredged in our bays and estuaries. Millions of cubic yards of spoil material are removed during the initial construction and during annual and periodic maintenance. For economic reasons, the best place to dump spoil has been in another part of the estuary or on its bordering tidelands and marshes. This simple act saves the project sponsors money, but the bill must be paid sooner or later, often with biological coin in terms of depletion of wildlife, degraded water quality and spoiled scenic beauty.

Modern man is playing a game of ecological truth or environmental consequences. If he continues to ignore or misread the ecological facts of life, he must endure the consequences of existence in an environment that can no longer respond adequately to his needs.

The resources and their self-renewing support systems in the estuarine and coastal zone are trying to tell us that something is wrong. Can we expect future generations to believe that we could find no alternatives to causing such widespread degradation of coastal and marine environments?

IGNORANCE AND ECONOMICS

The basic cause of our problem, of course, is people and too many of them. Why do people and communities that depend so heavily on the estuarine and coastal zone resources abuse them so recklessly? It comes partly from ignorance and partly from economics. It's cheaper to dump the spoil in the bay or the industrial discharge in the ocean. However, by the time awareness has replaced ignorance, there is usually someone who has established an economic interest in perpetuating the abuse. He has an economic advantage above those who do not have a bay or an ocean nearby in which to dump the waste. The product he produces is then artificially inexpensive. He has greater private profit margin at the expense of public resources.

As a result, when he disposes of wastes at a cost of other resources or users, he makes less effort to treat waste products, to install control devices for minimizing discharges, or to modify production practices to reduce or eliminate the formation of waste.

To put it another way, the environment has been put on credit--payment being through environmental degradation, loss of open space, polluted water and air, misuse of land and reduced renewability of aquatic resources--all part of the public domain. The time comes when we have to pay the bill.

Estuaries "die" at a progressively rapid rate because of the ever-lessening volume of water that surges in and out with the tide, flushing smaller and smaller amounts of silt, mud and other material out of the estuary into deep offshore waters.

In-bay spoiling reduces the tidal prism which results in changes in flushing action, circulation and current patterns. With basic engineering knowledge, in-bay spoiling should never be necessary, yet throughout our coastal areas construction interests and project sponsors ignore this basic knowledge. We can't afford to let them ignore it.

NEED FOR COMPREHENSIVE PLANNING

Local single-purpose interests push for these navigation projects and for Federal dollars to help subsidize their economy and improve the competitive relationship of the area's industry to state and world markets. As a result, ports are in competition with each other to get Federal tax dollars. Each port goes its own way, with very little thought given to regional port planning or overall resource management.

In the absence of such coordinated planning, adverse ecological impact often results. Bays are modified without thought of the effect on aquatic life or the overall question of environmental protection. The result is that the money spent--private funds as well as tax dollars--is not used to the best advantage of the area or region, but instead is used to offer a competitive advantage to a particular port.

The past and present tendency has been to deal with individual coastal zone problems in a piecemeal manner through specialists and special interest groups whose judgments require little compromise or arbitration. As a result, issues affecting our land, air, water, wildlife and open space more often than not crash headlong into what is usually a test of sheer political and special interest strength. Once in the context of environmental matters, the words "one must be practical" have an all too familiar ring. No massive research is required to document the inadequacy of our "practical" environmental decision-making--evidence surrounds us. A substantial percentage of our public problems, most conspicuous at the local level, are the consequences of unfortunate environmental decisions based on the practicality of an immediate solution.

Piecemeal thinking and decision-making or the "practical approach to practical situations" has resulted in today's and tomorrow's problems. These past "practical" solutions have again and again produced some very impractical results. One has only to look at the continued dredging of a bay and filling of its marshes, structural encroachment into the flood plain after the construction of a dam, the loss of beach sand because of a flood control reservoir, and the conflict of open space and industrial development in the urban community. Problems are made far more difficult than necessary by the failure of communities, governmental bodies, and their decision-makers to think in environmental terms. In addition, many professionals and agencies have either ignored their own expertise or failed to recognize the totality of the problems. All too often the immediate dollar gain for a few people was the decision rendered. Future generations were left with impractical results in poor planning and resources lost as a liability and social cost of private enterprise.

Regional planning in itself doesn't assure that area development will be based on sound environmental principles. Regional planning can end up as planned *abuse* of the land. A regional use plan is just what it says. It is a plan to use the land and as such it can become a tool of the developer.

Seen in this light, a land use plan can become a dangerous weapon capable of inflicting great environmental destruction.

THE YAQUINA BAY TASK FORCE

What is needed is a *conservation* plan to protect the productivity and fragility of our land and water. Such a plan should be based on ecological, biological and physical capabilities and limitations of the natural system. We must protect the renewability of our living resources. We must understand and work with nature--not against it.

Let me give you an example: Some six years ago, Yaquina Bay was just like any other estuary with all the same problems and all the same potentials for destruction. The difference was that there people became concerned and decided to do something to protect it. On the recommendation of the Governor's Office, the County Commissioners appointed the Yaquina Bay Planning Commission--later known as the Yaquina Bay Task Force. This planning group developed a total plan for the area involving water, sewers and land use. They brought in all the state and Federal agencies, including the planning capabilities of experts from the University of Oregon who developed not only a land use plan but a water use plan as well.

It took time to develop this kind of plan and this group gave it the time that was necessary. By April of 1971 the plan presented by the Yaquina Bay Planning Commission had been put into the form of a zoning ordinance approved by the County Commission so that there could be no changes around the bay that weren't in accord with the overall plans for the area.

As far as we know this is the first time anywhere that a plan has been developed that was not only a land use zoning plan but a water use zoning plan. Certain areas, for example, were set aside for oysters, and in those areas there could be no use of the tidelands except for growing food for feeding the animal life in the bay. Many of these areas would have been dredged and filled if there hadn't been a plan setting them aside for a specific purpose.

The present task force involved not only the concerned state and Federal agencies but the fishermen, the charter boat operators, the League of Women Voters and other concerned groups of citizens who care about preserving the resources the area has to offer. All zone change requests submitted to the Planning Commission now go to this task force and the people on the task force know they have an interest in preserving the plan intact; they are very firm about rejecting any proposal that doesn't fit in with the total plan for the area.

This doesn't mean there can be no changes made in what nature has created. Some dredging will be done as part of a plan for a marine recreation area, for example. What it does mean is that nothing will be done solely to accommodate one person who wants to make a profit. Anything that is done will be part of a total picture that has taken into consideration what is the best use of each part of the land and the water.

Once this kind of plan was developed, local people recognized that their own interests were being protected--not encroached upon. Today they support the decisions and recommendations of the task force as does the Planning Commission itself. What has been done at Yaquina Bay could be done on all the estuaries of Oregon if people once recognized how much they have at stake and how much there is to be gained by sound planning.

Let's look at some of the guidelines we might adopt to preserve our ecological values:

1. Preserve all marshlands, bay waters, stream courses and flood plains for open space.

2. Limit the uses occurring along shorelines to those that derive special benefit from this location without creating adverse effects.

3. Limit structural encroachment to those uses that require a waterfront location.

4. Prohibit landfill activities in bays, wetlands, or ocean front.

5. Protect the quality of all estuarine and coastal waters for all beneficial purposes.

6. Control through lease agreement or purchase beach areas and marsh islands whenever possible.

7. Conserve streambeds and marsh areas for surface water impoundment and ground water recharge purposes.

8. Either eliminate or strictly control bridges, highways or roadway fills over or through the bays and wetland areas.

9. Protect the unique ecological, biological, and physical aspects of the community and enhance these values for total public benefit.

Our demands for goods and services from our estuaries and coastal wetlands are increasing at a time when these areas are decreasing. The renewable and depletable resources of these areas must be used wisely or we will no longer have them to use.

We have many rights, but we do not have the right to use land and water in any way that we see fit. We are short-termers on this earth; however, we must be concerned with long-term, ecologically sound management of our resources. Our land and water resources were here long before we came on the scene, and they should be passed on to the next generation enhanced, not diminished in value.

MANY PURPOSES OF COASTAL ZONE

Estuaries and coastal wetlands serve many purposes: navigation, fisheries, wildlife conservation, recreation, industry and scientific research. However, any planning of these areas must be based on the multiple-use/shared-use philosophy. First--and of overriding importance--is how to accommodate all the valuable public purposes, and second, as many of the private purposes as can be reasonably accommodated. Not everything can be done at the same time on any single piece of land or body of water. Some uses are complementary and harmonious, while others may conflict so seriously that there is no possibility of working things out. Uses imcompatible with other uses must be *wholly* ruled out.

The waters of Oregon's estuarine areas support significant sport and commercial fisheries and a growing maricultural industry. The estuarine areas are an important migration and wintering place for waterfowl and other migratory birds of the Pacific flyway. This area is also for people who want the opportunity to walk, to sail a boat, to fish, to hunt, to swim, or to merely observe the natural world--the simple values that add quality to a complex life.

If man's progress is to be compatible with estuarine and coastal environment, he must understand his place in that environment. In the long run abusing nature for human advantage is a contradiction in terms.

When we lack sufficient knowledge of what a given action will do to the environment, we ought to proceed with the greatest caution. Instead we are using our land, water and air today as an experimental laboratory and our entire living space may be in hazard.

ROLE OF THE DEQ

Managing a coastal zone should be a process of determining balanced and best uses of land and water. The Department of Environmental Quality isn't going to be timid in protecting our estuaries. We will be as aggressive as we need to be because estuaries are a valuable and irreplaceable resource. The Department believes that developmental intrusion should be prevented unless there is a clear showing of public benefit or absolute necessity. The same is true for industrial waste discharges. We are responsible for safeguarding the uses and resources of this vastly important zone and we expect to do this.

Courts have held that responsible agencies can deny permits for structures, works or uses of navigable waters on the basis of econogical concerns. The Department of Environmental Quality is taking aggressive action regarding the discharge of effluent into our rivers, estuaries and offshore waters.

People used to believe that the ocean could provide infinite dilution of any substance introduced by man, and that rivers would carry polluting materials safely out to sea. But recently, when Thor Heyerdahl made his famous Ra Expeditions, he found evidences of pollution all the way across the ocean. We have learned--dangerously late--that the ocean does not have unlimited capacity to take care of everything and anything produced by man. There are places on our coastlines where water is polluted, fish and shellfish are unfit to eat, water sports are virtually eliminated, biotic communities are under stress, degraded or destroyed, and the beaches are no longer a place to seek solitude. We like to think these problems are limited to over-populated California, but unless we take very aggressive action to protect our coast line, we may well find the same things happening in Oregon.

However great our concern about the coast, we need to be that much more concerned about the estuary itself, which is the most fragile segment of the coast line. I want to assure you that the Department of Environmental Quality will take a very, very close look at anything that threatens to damage our estuaries, and we'll be as tough as we have to be to make sure that the rich resources they provide are not lost.

The Department believes that pollution from domestic, industrial and agricultural wastes must be controlled on site. Adequate facilities and measures should be an integral part of an industry, and the costs should be part of the competitive price structure just as rent on a building or the electric bill or any other cost of doing business is part of the final price for the product arrived at in the competitive market place.

In ports where petroleum products, chemicals, etc. are to be handled, the Department believes contingency plans should be formulated to handle discharges of liquid cargo. Onshore treatment facilities with shipboard hookups should be installed to provide secondary treatment of shipboard and sanitary wastes from all vessels visiting the port.

SUMMARY AND CONCLUSION

What I am saying, in summary, is that our estuaries are among our richest but most fragile resources. We must protect the renewability of those resources in order to be sure that what we define as progress doesn't mean destruction of the environment. A lot of man's activities in the coastal zone that have been labeled as progress have meant very little other than trouble for fish and wildlife as well as for man.

Public purpose comes first. After all aspects of the public's interest in our coastal resources are considered, then we can try to accommodate as many private purposes as are consistent with that public interest as part of an overall plan--this means integrated management planning of land and water adapted to the capabilities and limitations of the natural resources of the estuary.

The entire coastal zone is a public resource. The responsibility for preserving and enhancing this resource is a firstline responsibility of public agencies.

The development and implementation of ecologically sound management and use plans for the coastal zone can yield handsome dividends to individuals, the community and the nation, both tangible and intangible, year after year. Our job is to arouse and inform public concern and to assure that important coastal resources are not destroyed while the public is in the process of learning. It's a job that has tremendous impact on the future of Oregon, and we look to you for support and help.

The National Shoreline Study

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THE NATIONAL SHORELINE STUDY

The subject of this paper is the National Shoreline Study, recently completed by the Corps of Engineers. The River and Harbor Act of 1968 (Public Law 90-483) gave the Chief of Engineers responsibility for appraising and studying the condition of the shorelines and for developing means for protecting, restoring, and managing them to minimize damage from erosion. The report resulting from that study represents the first overall appraisal of shoreline problems on a national level.

HISTORY

The Corps of Engineers has been actively engaged in developing methods of shore protection since 1930 when Congress established the Beach Erosion Board (now the Coastal Engineering Research Board), to make studies in cooperation with cities, counties, or states on beach erosion problems. By various legislative acts the Federal interest has gradually increased over the ensuing 40-year period. The present Federal participation in erosion control cost is 70 percent for publicly owned, non-Federal parks and conservation areas; 50 percent for other publicly owned shores; up to 50 percent for privately owned shores where protection will result in public benefits; and no contribution for privately owned areas where no public benefits will result. Federal participation is limited to the first costs of a project, and the regulations do not provide for expenditure of Federal funds for future maintenance.

Under the present program, work has generally been confined to short reaches of public beach, and progress in shore protection has been slow. A study published in Senate Document 10, 90th - '66-'67 Congress, revealed that of $185 million in authorized projects, only $28 million or 15 percent had been invested, of which $11 million was Federal. Reasons cited for that minimal progress were (1) that Federal and State participation was insufficient, and (2) the lack of Federal interest in the protection of private shores. Illustrating the slow pace of shore protection work is the fact that neither the Seattle District nor the Portland District has a completed project nor even an authorized project. At the time of the shoreline study, Seattle District had four beach-erosion studies, two of which were in a deferred status. Portland District does not have a study in any status.

Former Senator Joseph Tydings of Maryland, along with 21 other Senators, introduced the legislation for the shoreline study to determine the magnitude of erosion problems on a national basis. Senator Tydings noted that the normal cost of damage from shore erosion along the coastal region from the New England states to the state of Texas is nearly $31 million annually. Also the Senator pointed out, there is no coordinated effort nor is there a comprehensive plan for the shorelines. Those deficiencies in the existing program, coupled with the high economic loss due to erosion each year, pointed up the need for the study and, perhaps, new policies.

EIGHT STUDY AREAS

The authorizing act delineated eight items of work to be accomplished during the study (Figure 1). Those items may be included in three categories: Shore Erosion Inventories; Shore Protection Plans; and Shore Management Guidelines. The study was a broad appraisal of the problem and did not recommend specific projects. It indicates where erosion occurs and what costs are involved in protective measures, and locates the urgent problem areas.

Work on the study was divided into separate efforts, with Division and District Engineers doing the major portion of the field work; the Coastal Engineering Research Center prepared protection guidelines which present typical protective structures, general design criteria, and order of magnitude cost estimates. The Office of the Chief of Engineers prepared guidelines on shore management, including principles of comprehensive planning, zoning, and other nonstructural alternatives. The Chief of Engineers' report to Congress summarizes the information contained in the other volumes and recommends priorities. The report was submitted to Congress in August 1971 and it has generated a considerable amount of interest nationwide.

PACIFIC NORTHWEST UNDEVELOPED

Turning to the Pacific Northwest area, the study found the coast to be still relatively undeveloped. That fact may be considered a fortunate or unfortunate circumstance according to one's own values. However, due to that undeveloped state, erosion problems have not yet had a great impact--excluding, of course, those who are directly concerned with the loss of their property. The regional inventory report for Oregon and Washington shows that of Oregon's approximate 500 miles of ocean and estuarine shoreline, 165.5 miles are experiencing erosion, of which 14.5 miles are estuarine shoreline. Erosion problems are considered serious enough to warrant remedial action along 58.5 miles of ocean shoreline and 5.5 miles of estuarine shores.

FIGURE 1. National Shoreline Study Authorization

1. SHORE EROSION:
   a. Determine areas along such coasts and shorelines where significant erosion occurs.
   b. Identify those areas where erosion presents a serious problem because the rate of erosion, considered in conjunction with economic, industrial, recreational, agricultural, navigational, demographic, ecological, and other relevant factors, indicates that action to halt such erosion may be justified.

2. SHORE PROTECTION:
   a. Describe generally the most suitable type of remedial action for those areas that have a serious erosion problem.
   b. Provide preliminary cost estimates for such remedial action.
   c. Recommend priorities among the serious problem areas for action to stop erosion.

3. SHORE MANAGEMENT:
   a. Provide State and local authorities with information and recommendations to assist the creation and implementation of State and local coast and shoreline programs.
   b. Develop recommended guidelines for land-use regulation in coastal areas taking into consideration all relevant factors.
   c. Identify coastal areas where title uncertainty exists.

The figures reported for the State of Washington are somewhat less than Oregon; 77.5 miles of ocean shoreline are suffering erosion, of which about 2.5 miles are deemed serious enough to require remedial action. Estuarine shorelines in Washington with erosion problems total approximately 29 miles, with about 5 miles of that total requiring some remedial action.

Recalling the language of the authorizing act (Item 1b, Figure 1), there were many factors to be considered in determining whether remedial measures are justified. While no single factor was intended to exert a greater influence on the decision than the others, economics played a major role in designating certain erosion areas as locations where action was justified. There was no area where shore erosion posed an obvious threat to human life and, in the absence of that consideration, economics provided a useful basis of comparison.

THREE OREGON AREAS NEED ACTION

There are three areas in Oregon where remedial action will be needed, at some future date, to prevent the loss of large capital investments in navigation improvements, as well as the loss, for at least a period of time, of usable navigation channels. Those locations are Clatsop Spit at the mouth of Columbia River, Bayocean Peninsula at Tillamook Bay, and the mouth of Siuslaw River. At each of those locations continued erosion threatens an eventual breakthrough which would outflank the jetty systems and result in a second entrance to the estuary. The problems at Clatsop Spit and Bayocean Peninsula have been with us for several years, and Portland District has maintained a surveillance program at each of those sites to monitor the extent of the problem.

At Clatsop Spit the beach is eroding from the south jetty to a nodal point located about 3 miles south. The maximum erosion has occurred adjacent to the south jetty where the high-water line has receded nearly 800 feet. From the nodal point to Tillamook Head, about 12 miles farther down coast, the shoreline has been accreting. Maximum accretion, about 208 feet, occurred near the mouth of Necanicum River. Averaged over the total length, the annual rates of erosion and accretion are about 6 and 7 feet, respectively. The city of Seaside, located just south of Necanicum River, has a somewhat unusual and rather ironic problem of too much sand. The accretion along the beach results in the sand building up and overtopping the seawall and spilling onto the adjacent promenade. The city has a nearly annual task of cleaning up the sand and hauling it away.

Bayocean Peninsula is without doubt the area's best known and most cited example of beach erosion. The spit, a natural barrier about 4 miles in length, separates Tillamook Bay from the Pacific Ocean. In the early 1900s a semi-resort area developed on the spit, and by 1909 a hotel, a large natatorium, and several summer cottages had been constructed. The operating company was beset by various legal and financial troubles and was eventually forced into bankruptcy. The resort was closed in 1915 and was reopened in 1928, but there was little further development. Winter storms battered the area, destroying the natatorium in 1932; and erosion was a continuing problem. The area was eventually abandoned and, in November 1952, severe storm waves combined with higher than normal tides breached the spit at the narrow southern end. The breach was rapidly widened by successive storms, reaching a width of nearly one mile. Many thousands of yards of sand and gravel were washed into the bay, destroying about one-third of the existing oyster beds. A combined rock and sand fill structure, designed and built by the Portland District, closed the breach in 1956. The surveillance program, which was initiated in 1939, shows the erosion rate has lessened at the southerly end of the spit subsequent to the closure but has increased along an area extending north.

Under existing regulations the Corps of Engineers has been unable to justify the cost of remedial action at either the Clatsop Spit or Bayocean Peninsula locations. Without a change in our regulations or a significant increase in the development of the area, the District can do nothing but continue to monitor the problem. Changes in the regulations are dependent upon action by the Congress, and given today's climate of ecological concern, any rise in development of the areas will meet strong resistance. The problem at Siuslaw River is of more recent origin and we have only begun to gather field data to assess the extent of the problem and to determine what can be done to alleviate it. The beach is eroding at the landward end of the south jetty and could, if it continues, result in a breakthrough. The erosion is occurring primarily on the river side and it is expected that a proposed plan to construct a system of permeable groins will help to stop the erosion.

OTHER OREGON COASTAL AREAS

Other areas along the coast are experiencing erosion problems in varying degrees. Along the northern Oregon coast, landslides are probably the main cause of land loss.

One notable example is the Ecola State Park slide which occurred in 1961. The slide involved 125 acres of land in popular recreational area. Other slides have occurred in that same general area over the years, and traces of many others can be observed as one travels down the coast. An excellent article on the incidence of slides appeared in the Ore Bin, November 1965; the article was co-authored by Mr. William B. North and Dr. John V. Byrne.

EROSION PREVENTION

Several preventive measures to combat erosion are available and all are effective to a point, but nearly all have somewhat less desirable features. All are extremely expensive. The preliminary estimates contained in the shoreline study ranged *from 0.75 to 1.75 million dollars per mile for the Oregon and Washington coasts. The structural methods considered included seawalls, revetment, and groin fields.* Revetment and seawalls are not particularly compatible with recreational use of the area. Sea-walls protect the uplands, but there is little or no beach seaward of the wall and a sandy beach is the prime asset of shore-front property.

Groin fields some times have the unhappy result of merely transferring the problem from one locale to another. *A greater degree of effectiveness can be obtained by using methods as nearly similar as possible to the natural ones. Dunes and beaches can be rebuilt artificially by placing sand on the shore.* Such *beach nourishment* seems to offer a good solution for some problem areas. Since the primary use of the coastal region is recreational, restoring the beaches is important. Separate protection of short reaches, for example, by individual property owners is difficult and costly and often fails, as the adjoining unprotected land continues to recede. In some instances, as previously mentioned, *ill-conceived and inadequately designed groin fields can actually accelerate erosion of adjacent areas.* Coordinated action under a comprehensive plan which considers the entire segment of a receding shore is not only more effective, it will, in the final analysis, be less costly. *It would seem appropriate that some agency of the State or local government assume the function of providing a comprehensive plan.*

Sand in the beaches and dunes is nature's method of protecting our shores. Sand is a diminishing resource and, at some locations, in extremely short supply. More and more coastal states are establishing controls to prevent indiscriminate use of the resource. *Mining of beach sand for construction purposes is being regulated and curtailed.* Mechanical bypassing of sand at coastal inlets is coming into increasing practice. Hopper dredges are being equipped with pump-out capability so that the sands removed from navigation channels can be placed ashore rather than dumped at sea. *Dune planting with beach grasses and other vegetation reduces losses from wind erosion.*

WHAT SHOULD BE DONE

It has been suggested in some quarters that erosion of the land masses by the forces of the wind and seas is a natural thing and has been taking place for centuries, and man should merely accommodate himself to that fact. The relatively undeveloped state of the coastline in the Pacific Northwest does seem to lend itself to some type of a management program which would hopefully prevent our creating a more severe problem than the one we have. All too often in the past, man's activities have been less than beneficial in terms of preventing erosion. *Many large dune areas have been leveled for real estate developments; dunes have been lowered for easier access to the beach. Homeowners, building on their ocean-front lots, build to the edge of the lot and lower the dune for a better view.*

As our population increases and our economy rises, the coast will be facing increasing demands for development. It is important that long-range plans be made for coastal development which take into full account the hazards involved in the occupancy of the coastal lands and provide properly for safeguarding against them. *Procedures can be adopted which will preserve the natural protective features; regulations can minimize the cost of providing man-made features.*

Protection of the shoreline is not an easy task but we do possess the technical skills to accomplish the job. The costs are high and will continue to go higher, but the task must be undertaken as a cooperative effort with all levels of government participating.

Physical Modeling of Residence Times in Tidal Basins

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THE PROBLEM

In pollution studies, the most important physical parameter of a receiving basin is its memory. If the memory is known, the effect of past events can be evaluated, for instance, on a present record. Probably more important, it allows predictions for the future of present or coming events.

The memory of a water body depends on its topography and on the input of energy. With a complicated topography and a low input of energy for renewal and mixing of the water go long memories.

The memory is most conveniently described by a single parameter, the residence time. Synonymous notions are detention time and flushing time.

The average residence time defined as the ratio of total basin volume V to the average throughflow $\bar{Q}$

$$\bar{t} = \frac{V}{\bar{Q}}$$

has only a limited value if the actual flux of renewal water does not flush the entire basin. For instance, the estuarine circulation flushes only the upper layers of a deep fjord and has a negligible effect in the lower layers.

If the fjord has high sill, the tidal flow is deflected away from the bottom, and does not flush the water column much below sill elevation.

In the same way, a separation pocket behind a headland is not flushed by a flow deflected offshore by the headland. The pocketed water is renewed by the much slower processes of entrainment and diffusion.

These examples are given to demonstrate the need for a more detailed answer to the question of residence time than its gross average $\bar{t}$. Ideally, one might give the pertinent information as a map showing isolines through points with the same residence time. At any rate, it appears useful and necessary to break down the basin in subbasins according to realistic estimates of the local residence time.

METHODS OF INVESTIGATION

There are three basically different methods one can use to gain insight in the memory of a basin: *in situ* observations, numerical modeling, and reduced scale physical modeling.

In situ *Observations*

Observations of movements and constituent concentrations of coastal waters contain a record of past and present events which is often very difficult to analyze.

The long ago past is represented by processes with large time scales, such as the state of the adjacent ocean. This boundary condition characteristically varies from year to year and necessitates repeated observations over several years. The same holds true for other geophysical processes such as the freshwater runoff and the coastal monsoon winds.

The annual cycles of the processes mentioned above require seasonal observations, say every two or three months.

The more recent past is represented by "tides" due to persistent wind fields with duration from one to perhaps thirty days without reversals.

The astronomical tides are predictable periodic waves that can readily be taken into account. The principal tidal periods of 12.4 and 24.8 hours can be covered with a number of observations throughout the tidal period. However, synoptic coverage requires many observation platforms and is very costly.

Further down the time scale, there are the so called long period waves, which can be broken down by their causes:

•Barometric waves accompanying storm tracks have durations of one to twenty hours and suck up a hump which adds to wind setup by tangential shear.

•Seiching is a resonance phenomenon whereby unspecified, small inputs of wave energe feed into a standing wave mode of basin resonance. The most common periods appear to lie within the range of two to forty minutes.

•Internal waves, standing as well as progressive ones, are particularly troublesome in stratified water because they often have both long periods and large amplitudes.

•Long-period waves tend to introduce noise in field observations. Time-averaging may require longer sampling time than is practically feasible, and so long-period noise is not easily avoided.

•Swell and storm waves, on the other hand, are less of a problem, since a relatively short sampling time of less than a minute is sufficient to average out this source of noise. The waves do cause operational difficulties, however.

It is readily appreciated that the mapping of a coastal basin by *in situ* observations is a tedious and slow process. The analysis cannot be carried very far before a period of observations of several years has covered a set of characteristic events for the basin. Therefore, it is expedient to turn to a model at an early stage.

Models

Prediction requires a model of some kind of the phenomena being studied. In order to be of practical use, the model nearly always turns out to be a simplified one. The less important forces at work are neglected, and a smaller set of perhaps only the two or three largest forces is considered.

The two greatest assets of models are: 1) Initial and boundary conditions can be controlled and 2) Extreme events can be covered by extrapolations.

The importance of the first point is made clear when one considers the many and largely unknown past events that are present on an *in situ* record. On a model, all these past events can be programmed so that a cause-effect relation can be established.

Certain extreme events form normally the design criteria for any coastal structure or outfall. These important events stand only a very remote chance of being recorded within any reasonable pre-construction period of *in situ* observations. In contrast, the model is tested for the design conditions.

Numerical Models

Numerical modeling of tidal flows is feasible today for basins with bottom friction and kinematic lateral boundaries only. In a case like the present one with lateral friction predominating, no satisfactory scheme for numerical models has been developed yet. The greatest problems are to predict the free stream-lines and the energy dissipation associated with the shear flows along jet and wake boundaries.

Another obstacle to modeling, numerically as well as physically, is the layering of the basin due to vertical density gradients. The double role of pycnoclines, being at the same time both sources and sinks of turbulence, is very hard to model.

Physical Models

Reduced-scale physical models have proved very useful in studying circulation and dispersion in estuaries of many kinds. Well-known examples are the models of San Francisco Bay, Chesapeak Bay, and Puget Sound.

The scales of such models, and consequently their cost, vary within wide limits. The scaling is based on a comparison of the magnitude of the forces acting on the water bodies under consideration. These forces are gravity (F_g), pressure (F_p), Coriolis (F_c), and friction forces (F_f), respectively. Their sum is balanced by the inertia force or acceleration force ma:

$$ma = \Sigma F$$

The relative magnitude of the forces depends on the strength and duration of the driving forces and the nature of the resisting forces.

Difficulties arise primarily with friction forces. If an important part of the friction is due to energy dissipation in boundary layers at solid boundaries, similarity between model and prototype is only feasible in fairly large-scale models, with horizontal length scales L_r of the order $1:10^3$.

On the other hand, if the energy dissipation is primarily in the free boundary layers of jets and wakes due to irregular topography, a workable similarity is obtained with length scales of the order $1:10^4$.

A variation of one order of magnitude on the linear scale means a variation in cost of more than 10. Moreover, the possibilities of actually accommodating estuary models to scale 1:1000 are limited to a few laboratories with adequate facilities.

A model to scale $1:10^4$ requires little space and can be built almost anywhere.

SCALE EFFECTS IN PHYSICAL MODELS

Friction

Scale effects on friction arise because the viscosity cannot be scaled down. Experience has shown that if the Reynolds number

$$Re = \frac{VL}{\nu} \qquad (1)$$

V = characteristic velocity

L = characteristic length

$\nu = \frac{\mu}{\rho}$ kinematic viscosity

exceeds a critical value depending on the type of flow under consideration, turbulent friction is adequately reproduced. For pipe flow this critical Re is 2000 when L = D, the pipe diameter, and $V = \overline{V}$, the average velocity. For free surface flows L = R, the hydraulic radius, and the critical Re is about 10^3. For free flows such as jets, the critical Re is an order of magnitude less, so a sufficient condition for a workable friction similarity is then

$$Re_m > 10^2 \qquad (2)$$

Distortion:

The model Reynolds number Re_m can be written

$$Re_m = Re_p V_r L_r \qquad (3)$$

where index m stands for model, p for prototype and r for ratio of model to prototype value of any quantity a:

$$a_r = \frac{a_m}{a_p} \qquad (4)$$

The flows under consideration, tidal motion and freshwater runoff, are gravitational, and so Froude's model law should be used:

$$Fr_r = \left(\frac{V}{\sqrt{gH}}\right)_r = 1 \qquad (5)$$

where H_r is the vertical scale ratio given by

$$H_r = L_r\ \delta \qquad (6)$$

L_r = horizontal length scale ratio

δ = vertical distortion

Inserting from (5) and (6) in (3) one gets

$$Re_m = Re_p L_r^{3/2} \delta^{1/2} \qquad (7)$$

From (7) it is seen that the limiting prototype flow that can be modeled depends on the horizontal scale L_r and the vertical distortion δ. For tidal flows, a minimum wave height that will yield detectable flows in a model is h_m = 1 cm. A minimum horizontal scale ratio to secure reproduction of relevant topographic details is $L_r = 10^{-4}$. These restraints determine the combination of size and flow that can safely be modeled:

$$\text{Restraint 1 (reproduction)} : L_r \geq 10^{-4} \qquad (8)$$

$$\text{-"- 2 (detection)} : L_m \delta \geq 10^{-2} m$$

Assume the prototype wave height to be 1 metre, giving $L_r \delta = 10^{-2}$. The limiting prototype Reynolds number is, from (7),

$$Re_p = \frac{Re_m}{L_r(L_r\delta)^{1/2}} = \frac{10^2}{10^{-4} \cdot 10^{-1}} = 10^7$$

or, since ν is of order 10^{-6} m²/s:

$$V_p L_p \geq 10 \text{ m}^2/\text{s} \qquad (8b)$$

This requirement is not very restrictive. If the mean flow velocity is 0.1 m/s, (8b) is satisfied if the width of the channel is 100 m or more.

The distortion implicit in the above example is $\delta = 10^{+2}$, which is rather extreme. Farmer and Rattray (1963) report an interesting model study of Puget Sound with L_r = 1:40000 and δ = 34.6.

It should be borne in mind that in the basins under discussion, the problem with bottom friction, which invariably arises in distorted models of open channels, does not occur since boundary-layer turbulence is unimportant. Therefore, higher distortions are permissible, especially if the side slopes are uniform throughout. For a combination of steep side slopes and tidal flats, some distortion of the flow pattern is conceivable as a result of vertical geometric distortion. For this reason, it is better to satisfy (8) by increasing L_r rather than δ.

Diffusion

Scale effects on the diffusion process arise because molecular diffusion, like molecular viscosity, cannot be scaled down. Diffusion is correctly reproduced if Peclet's number

$$Pe = \frac{VL}{D} \qquad (9)$$

is the same in model and prototype. Here D is the apparent diffusion coefficient, which is the sum of molecular and a turbulent component

$$D = D_m + D_t \qquad (10)$$

Inserting (9) in (10) the scale ratio for Pe becomes

$$Pe_r = \frac{V_r L_r}{(D_m + D_t)_r} \qquad (11)$$

The turbulent diffusion coefficient D_t is the product of a characteristic eddy velocity and eddy size, with a scale ratio

$$D_{t_r} = V_r L_r \qquad (12)$$

The molecular diffusion coefficients are the same in model and prototype.

The scale ration (12) for D_t is the same as (3) for Re. Using the limiting value $V_r L_r = 10^{-5}$ arrived at previously, the scale ratio Pe_r can be computed if D_p is known. As the vertical diffusion coefficient cannot exceed the horizontal one, the former is used for estimates of scale effects.

The order of magnitude of D_p must be known and can be obtained from tracer experiments *in situ*. The table below covers the range of minimum values to be expected in stratified estuaries.

D_p	Vertical diffusion coefficient cm²/s		
	0.1	1	10
D_{T_m}	10^{-6}	10^{-5}	10^{-4}
$D_m = D_{t_m} + D_{m_m}$	$1.1\cdot10^{-5}$	$2\cdot10^{-5}$	$1.1\cdot10^{-4}$
$\frac{D_m}{D_p}$	$1.1\cdot10^{-4}$	$2\cdot10^{-5}$	$1.1\cdot10^{-5}$
Pe_r	0.09	0.5	0.91

A model with $L_r (L_r \delta)^{1/2} = 10^{-5}$ will reproduce mixing with order of magnitude accuracy if the turbulent diffusion coefficient D_{t_p} is about 1 cm²/s. The scale effects increase with decreasing turbulence in the prototype and vice-versa. If $D_{t_p} = 0.1$ cm²/s the model exaggerates diffusion rates nine times under a given concentration gradient. On the other hand, if $D_{t_p} = 10$ cm²/s, the molecular diffusion causes about 10 o/o too high diffusion rates in the model.

Lateral Forces

The Coriolis force is

$$F_c = \rho f v \qquad (13)$$

ρ = density of water

$f = 1.5\cdot10^{-4} \sin \phi \; s^{-1}$

ϕ = latitude

F_c acts at right angle to the right of the velocity vector $\vec{v}$ (on the northern hemisphere).

Centrifugal forces:

The other independent force acting at right angle to $\vec{v}$ is the centrifugal force

$$F_n = \rho \frac{v^2}{r} \qquad (14)$$

r = radius of curvature of streamlines

The ratio of the centrifugal force to the Coriolis force is

$$\frac{F_n}{F_c} = \frac{v}{fr} \qquad (15)$$

Inserting sin 60 = 0.866 as an example gives

$$\frac{F_n}{F_c} = 7.7\cdot10^3 \frac{v}{r} \qquad (16)$$

(16) shows that for $v/r > 10^{-3}$ the Coriolis force is an order of magnitude less than the centrifugal force and consequently unimportant.

For $v/r < 10^{-3}$ the Coriolis force may or may not be important.

If a model reveals a cyclonic circulation, the model results can be considered conservative, because the Coriolis force will enhance a cyclonic motion.

On the other hand, if the model indicates an anticyclonic circulation, its strength is overrated, because the resisting Coriolis force is not reproduced on the model.

In either case, however, the flow pattern revealed by the model is determined by the fixed boundaries and should be correctly reproduced.

Straight streamlines:

An oscillating flow with period T and maximum velocity V_m has an average inertia force

$$\bar{F}_i = \rho \frac{4\bar{V}}{T} = \frac{8}{\pi} \frac{\rho V_m}{T} \qquad (17)$$

and an average Coriolis force

$$\bar{F}_c = \rho f \bar{V} = \frac{2}{\pi} \rho f V_m \qquad (18)$$

if the flow is a sinusoidal function of time.

Forming the ratio

$$\frac{\bar{F}_c}{\bar{F}_i} = \frac{1}{4} fT \qquad (19)$$

we see that the lateral force is proportional to the period T and exceeds 10% of the inertia force if

$$T > 0.4f^{-1} \qquad (20)$$

Any oscillating flow with period less than about 50 minutes can be neglected on the 10% level (20).

Tidal flows, however, will deviate appreciably from straight flow unless the Coriolis force is checked. Normally, the Coriolis force in straight channels is balanced by a lateral surface slope. This gives the gravity force a component to the left, matching the Coriolis force to the right of the velocity vector.

The tilting water surface does not affect the flow pattern in a homogeneous water column, because the tilt is so small that the crossflow becomes negligible. Therefore, a model which is without appreciable Coriolis effects because model periods are small, will not have scale effects from this cause.

If the water column is layered and the flow takes place in the upper layer only, the lateral slope of the pycnocline is likely to be large.

The surface slope

$$\tan \alpha = \frac{fV}{\rho} \qquad (21)$$

is of order 10^{-3} to 10^{-4}. In contrast, the interface between a flowing layer of density ρ and a still layer of density $\rho + \Delta\rho$ acquires a lateral slope given by

$$\tan \beta = - \frac{\rho}{\Delta\rho} \tan \alpha \qquad (22)$$

The reasonable value $\rho/\Delta\rho = 10^2$ gives $\tan \beta$ of order 10^{-1} to 10^{-2}. In an oscillating flow the periodic reversal of the pycnocline slope would generate a circulation which should not be neglected. Such a Coriolis-induced circulation would not show up in a model.

If no significant lateral sloped have been observed in isohalines or isotherms in the prototype, no significant Coriolis-induced circulation is present.

VERTICAL CIRCULATION

The preceding discussion relates to water bodies of homogeneous density. This does not limit our results to waters without vertical density gradients, however. In jet theory, the presence of such gradients is shown not to affect the process of horizontal entrainment significantly. We infer, therefore, that if horizontal circulations are well-reproduced in homogenious water, they are equally well-reproduced in stratified water.

Except for the separation in the lee of bottom sills, circulations set up by the tidal flows are essentially horizontal.

Vertical circulation is primarily induced by fresh water runoff, causing entrainment across the surface of zero horizontal velocity separating the seaward outflow from a landward inflow. The pycnocline acts as a pervious bottom for the outbound overcurrent. A correct modeling of the vertical rate of entrainment through the pycnocline should be reproduced to scale.

Hydrodynamically, entrainment is a complex process of breaking gravity waves in the pycnocline. These internal waves are oscillatory, and the geometric distortion which is necessary for other reasons, precludes similarity of entrainment except by chance.

Model experience (Ippen 1966) shows that the exaggerated horizontal slopes resulting from vertical distortion requires additional turbulence-generating resistance elements to prevent excessive horizontal velocities. In the present case, the same procedure is suggested. Many ingenious methods have been devised for raising the level of turbulence. One very flexible method that may prove useful is the release of small air bubbles through perforated pipes. The rising bubbles will directly stimulate entrainment. A satisfactory reproduction of the vertical circulation can be assumed when the distribution of fresh water in the basin is reproduced.

CONCLUSIONS

The feasibility of small-scale physical models of a class of tidal basins which are otherwise hard to model is discussed in the preceding examples. This class consists of basins with a complex bathymetry such as deep, winding fjords with or without sills, or an archipelago.

Of particular interest are the possibilities of:

a) obtaining residual tidal currents quickly and inexpensively, compared with *in situ* observations.

b) simulating residence times in stratified basins.

The restrictions on the methods are for a) that the tidal range should be appreciable and for b) that some information is available on the vertical eddy diffusion coefficient from *in situ* tracer experiments.

The small-scale physical model is not a high-precision tool, but that is true of the two alternative methods of investigating complex coastal basins, too. Its chief advantage is probably that it displays local closed circulations, which are ignored in the present generation of mathematical models.

The Influence of Wind on the Surface Waters of Alberni Inlet

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Anyone familiar with the inlets of the Pacific Northwest is aware of the strong winds that can occur along these steep-sided arms of the sea. It has been known for a long time that wind has a profound effect on the density structure of the highly stratified surface waters of inlets. Sandstrom (1904) for example, found that movements of the surface layer in the Gullmar Fjord depended upon the wind direction. Following a long series of daily measurements at Borno, Pettersson (1920) used a regression analysis to examine the same phenomena. In his extensive study of Alberni Inlet, Tully (1949) found up-inlet winds tended to increase the depth of the upper zone. Practical engineering problems such as the design of cooling water intake structures, have inspired more recent attempts to understand the problem (Wada, 1966).

THE PROBLEM

These studies have generally concentrated on steady state aspects of wind effects; yet it seems likely that in inlets the surface waters are in a state of almost continuous imbalance under the influence of rapidly changing wind-stress. These effects are important: the surface layer thickness can change by a factor of two or three in a few hours. Apart from the engineering aspects, an understanding of the way wind affects an inlet will aid oceanographers in interpreting data collected as input to models of biological and physical processes. I shall describe an experiment designed to examine the time dependent structure of the wind effect and also a model which attempts to explain the observations and provides a basis for prediction.

METHOD

Alberni Inlet was chosen for the experiment because of the excellent background data for the area as well as ship and barge facilities kindly made available for the observation period by the Fisheries Research Board of Canada. The experiment was timed to coincide with a Canadian Hydrographic Service current and tide survey of the inlet during the late winter and spring of 1971.

To monitor the salinity structure special instruments were built to measure conductivity with fourteen probes to a depth of 9 meters. The salinity gradient is strong enough to dominate the conductivity profile; in addition salinity effectively determines the density structure.

The instrument was housed in a buoy (Figure 1) which was moored to a floating dock or log-boom. Wind was measured using four recording anemometers mounted 2 meters above the ground on exposed points. Figure 2 shows the disposition of instruments: Hohm Island near the inlet head, Stamp Narrows and Sproat Narrows were the principal stations for measuring conductivity.

OBSERVATIONS

The wind was mainly confined to the region up-inlet of Spencer Creek. Though strongly diurnal it included some low frequency components of 3 to 4 day periods. Figure 3 shows the wind together with Sproat Narrows current measurements provided by the Canadian Hydrographic Service. The 2 meter current is closely tied to the wind; at 15 and 40 meters the current is mainly tidal, but with an unexplained down-inlet bias in the 40 meter data. That the 2 meter diurnal current fluctuations are wind-driven and not tidal can be demonstrated by spectral analysis of long time series; indeed there appears to be nearly twenty times more diurnal energy at this depth than can be attributed to the tide alone.

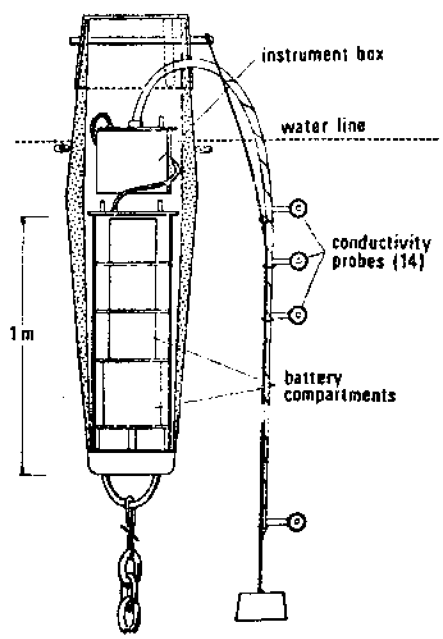


FIGURE 1. Instrument Buoy

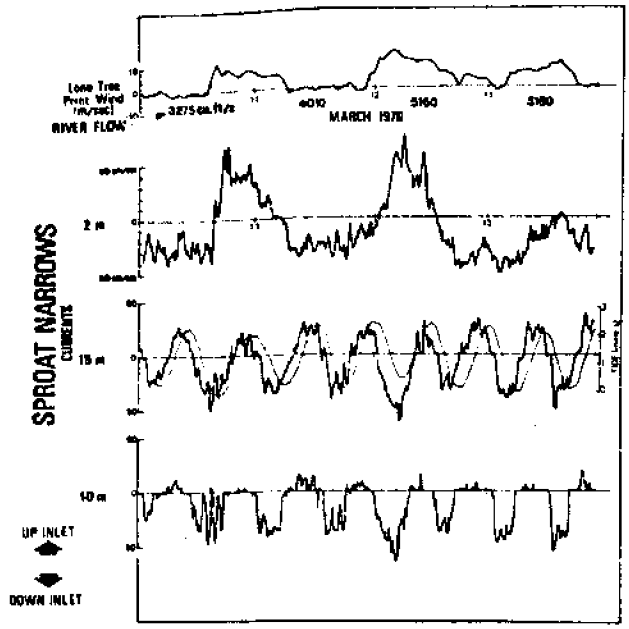


FIGURE 3. Wind and Current at Sproat Narrows

Figure 4 shows contours of constant conductivity derived from the conductivity data taken near Hohm Island during a period of strong up-inlet winds. The wind appears to induce a sudden increase in the surface layer thickness, followed by a slow return to equilibrium. The contours also indicate the presence of a strong internal tide which had been observed previously by Tully (1949). It seems likely that this is generated over the shallow sloping bottom topography at the north end of the harbor. The oscillation is reduced to about one-half its amplitude at Stamp Narrows and is only sporadically apparent at Sproat Narrows.

Using estimates of the temperature distribution based on measurements taken every few days, it is possible to estimate the salinity profile. The temperature need not be known very precisely since, as mentioned earlier, the salinity dominates the conductivity in these highly stratified waters. We may conveniently parameterise the profiles by considering the thickness of fresh water that would occur if we replaced the water column by a two-layer fresh and salt-water system, the lower layer containing all the salt from the original water column and having a salinity equal to that found at the greatest depth of measurement.

Figure 5 shows a short section of data from the three main stations parameterised in this way. The sequence is revealing. A strong up-inlet wind precedes a temporary reversal of the 2 meter current. The fresh water thickness increases first at Hohm Island, quickly followed at Stamp and Sproat Narrows. The system only slowly returns to equilibrium.

Since strong winds frequently occur with increased precipitation, river flow changes often occur with the other effects. However, sudden increases in the fresh water thickness of the type just described occur even in the absence of fluctuations in the river discharge. It seems likely that the effects are dominated by the wind.

It is also possible to define a mixing parameter which represents the difference between the potential energy of the observed water column and the potential energy of the two-layer system described earlier. The mixing energy derived in this way shows marked variations with considerable increases occurring during periods of strong wind. The wind effect on mixing is more pronounced as we move away from the inlet head.

ANALYSIS

It is a remarkable feature of the observations that most of the wind energy is at the diurnal frequency, yet the surface layer response is mainly confined to lower frequen-

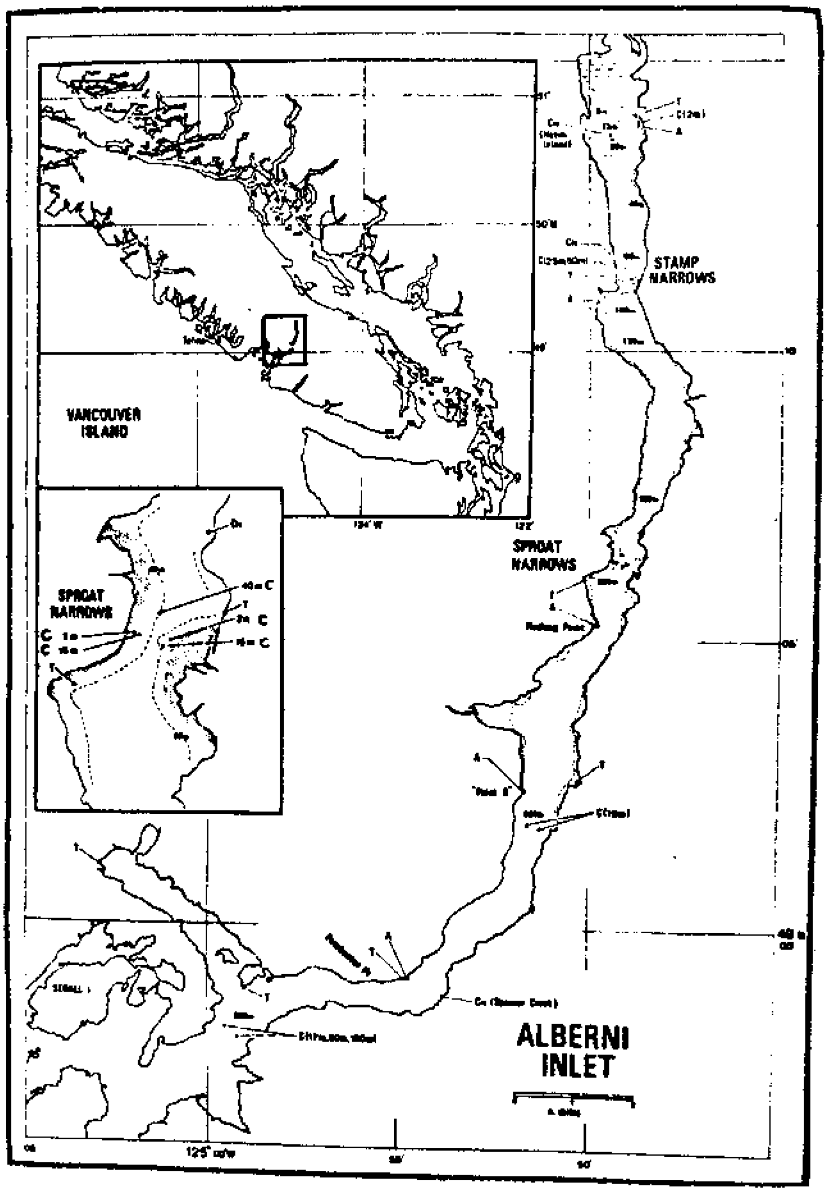


FIGURE 2. Map showing location of instruments. Inset shows detailed layout at Sproat Narrows. Legend:
- Cn Conductivity Profiler
- A Anemometer
- T Tide Gauge
- C Current Meter

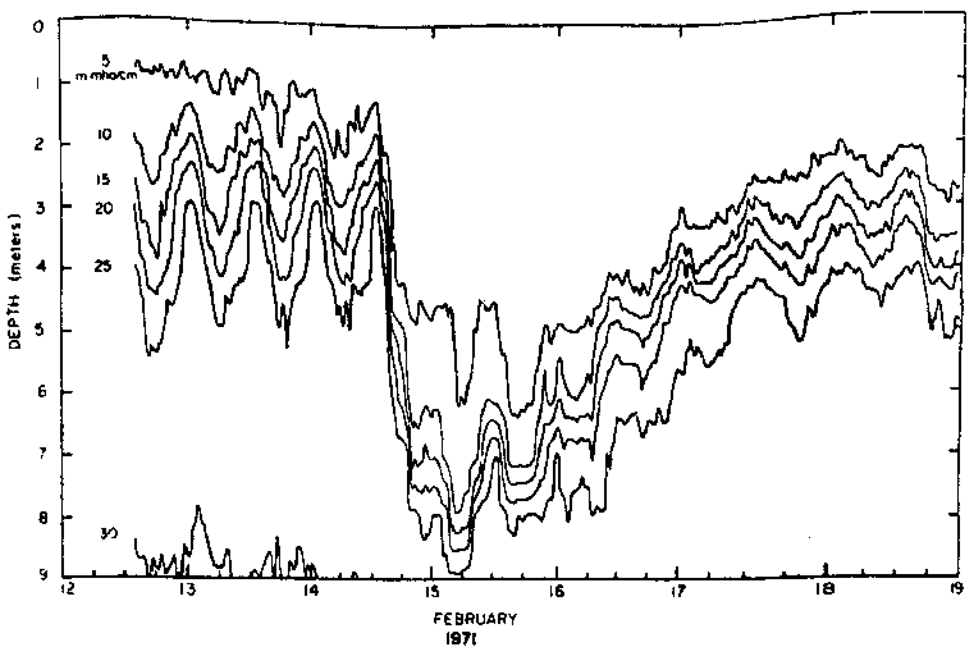


FIGURE 4. Contours of constant conductivity from Hohm Island Station.

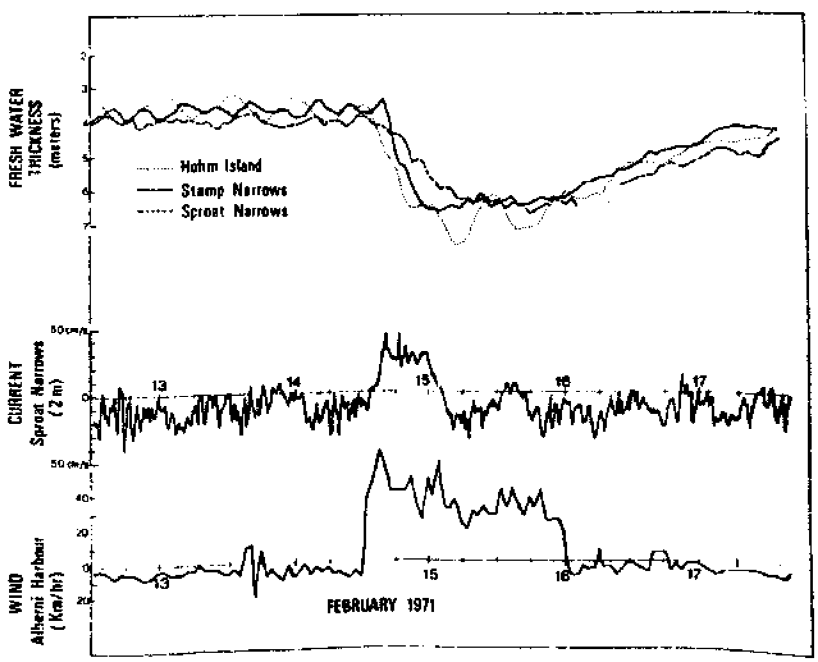


FIGURE 5. Fresh Water Thickness at the 3 Main Stations, together with wind and 2m. current measurements.

cies. This is best described by power spectra which show the contribution to variance represented by fluctuations of different frequency. Figure 6 shows the fresh-water thickness spectrum derived from 33 days of data taken near Hohm Island, together with the wind-stress spectrum for the same period.

Apart from a sharp peak at 12 hours due to the internal tide, most of the surface layer thickness energy has a period of 3 or more days. If changes in the surface layer thickness are wind induced, there must either be some non-linear transfer of energy from high to low frequencies or alternatively a coupling between wind and thickness that greatly improves as we move down the frequency scale.

To explain some of these features I propose a simple model of an inlet consisting of two layers of fluid in a semi-infinite canal of constant width and depth (Figure 7). The layer depths are h' and h'', (h'+h''=h), the relative density difference is $\frac{\Delta\rho}{\rho}$ and the displacement of surface and interface η' and η'' respectively. I shall make the rather drastic assumption that the wind effects can be treated separately from the general estuarine circulation; rotation effects will also be neglected. Friction between the two layers is assumed proportional to the difference in the depth-mean velocity of each layer and friction along the sides and bottom of the inlet is assumed proportional to the transport in each layer.

Rattray (1964) has shown how the integrated linearised equations of motion and continuity for each layer can be transformed into a single Normal Mode equation applicable for both surface and internal modes, to lowest order in $\frac{\Delta\rho}{\rho}$. Let u' and u'' be the transport in each layer, and

$$U = \frac{h''}{h} \cdot u' - \frac{h'}{h} \cdot u''$$

$$c = \sqrt{(g \frac{\Delta\rho}{\rho} \frac{h'h''}{h})}$$

W = Wind-stress (kinematic)

K = Combined frictional coefficient

Then with the friction defined above, the internal mode equation becomes

$$\frac{\partial^2 U}{\partial t^2} = c^2 \frac{\partial^2 U}{\partial x^2} + \frac{\partial}{\partial t} (\frac{h''}{h} W - KU) \qquad (1)$$

Having solved for U, changes in the surface layer thickness, represented by the term $(\eta' - \eta'')$, can be recovered using the following relationship obtained from the vertically integrated equations of motion:

$$(\eta' - \eta'') = \frac{1}{c^2} \int_0^x (\frac{h''}{h} W - KU)\, dx - \frac{1}{c^2} \int_0^x \frac{\partial U}{\partial t}\, dx$$

I have solved the model for a uniform wind-stress acting over the region $o \le x \le d$ in two cases: first for a periodic wind and second for a wind constant during a certain time but zero outside this interval. The first solution is useful for examining the coupling between wind and surface layer thickness at different frequencies. The second can be used with hourly wind-stress measurements; linearity of the model allows us to superpose solutions to obtain a corresponding prediction of changes in the surface layer thickness. The Boundary Conditions in each case are as follows: U = 0 at x = o, x = ∞, and the layer thickness and transport are matched

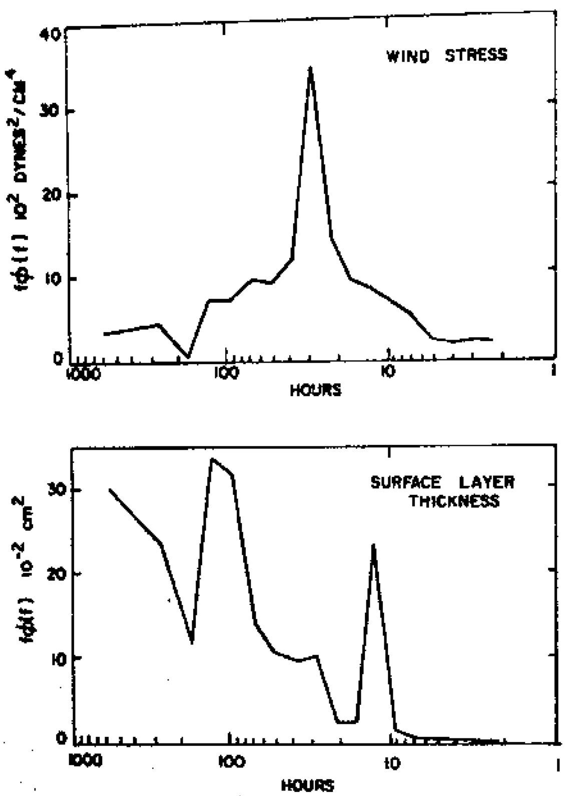


FIGURE 6: Power Spectra of Wind-Stress and Surface Layer Thickness

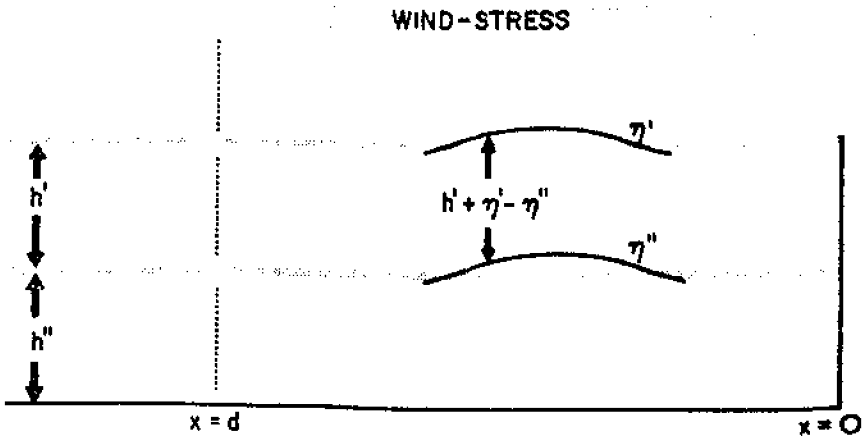


FIGURE 7: Theoretical Model of Inlet

at x = d. Zero initial conditions are assumed for the second solution.

The second solution involves a convolution integral that must be evaluated numerically for appropriate values of x and d. But if d is sufficiently large, effects due to the finite extent of the wind can be neglected and a solution in closed form for x = o is possible:

$$(\eta'-\eta") = \frac{T}{c}\left\{t'e^{-1/2Kt'}(I_o(1/2Kt')+ I_1(1/2Kt'))H(t')-te^{-1/2Kt}(I_o(1/2Kt)+I_1(1/2Kt))\right\} \quad (2)$$

where the wind-stress is of magnitude T acting over the interval $0 \geq t \geq t_1$, I_o and I_1 are the zero and first order modified Bessel functions and H is the unit step function:

$$H(t') = 0 \qquad t' \leq 0$$

$$= 0 \qquad t' > 0 \qquad \text{where } t' = t - t_1$$

Average values for most of the parameters in (1) are fairly easily estimated from measured density distributions in the inlet. I have taken c =85 cm/sec and calculated wind-stress from wind velocity in the usual way using a drag coefficient of 1.4×10^{-3}. $\frac{h"}{h}$ can be taken as unity with little loss in accuracy. K is harder to estimate. If we use the fact that the internal semi-diurnal tide has decayed to one half its amplitude between Hohm Island and Stamp Narrows and solve (1) for a free wave of this frequency, we find the decay corresponds to a frictional coefficient of K=.8 hrs^{-1}. Using these parameters and a wind-stress acting over the region from Spencer Creek to the Inlet head, it turns out that effects due to the finite stress distribution are not important at x = o for the conditions encountered in this study. For the sake of completeness, however, they have been included in the following calculations.

From the spectra shown in Figure 6 together with cross-spectral estimates obtained from the wind-stress and surface-layer data, we can calculate the gain and phase relationship that would exist between the two signals if they were connected by a linear process. Figure 8 compares the gain and phase derived from the data with that predicted by the model. Though unable to predict the detail of the observed result, the theory can account for the general shape of the curve, both in gain and phase.

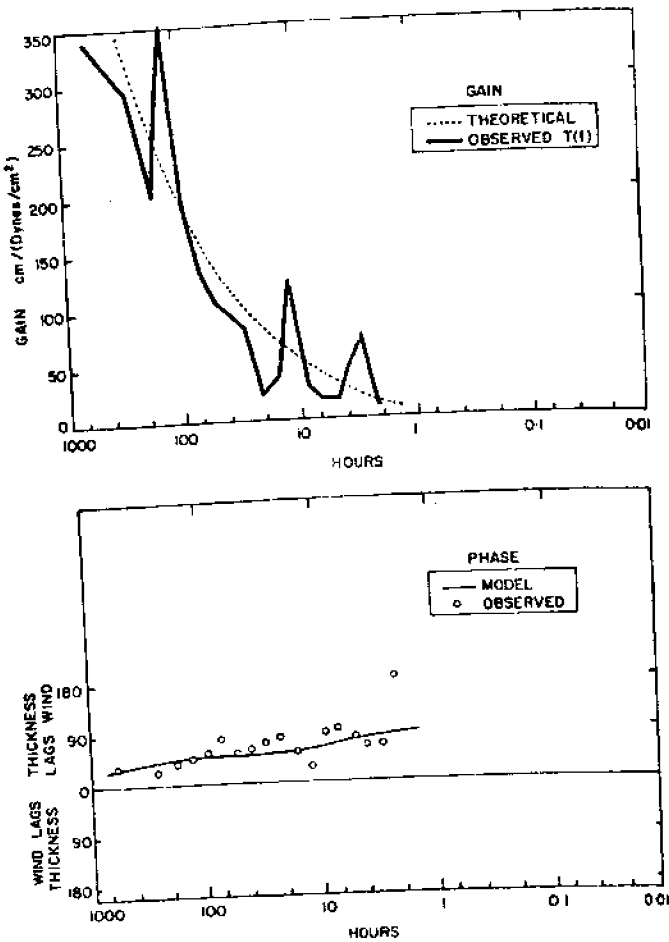
I have applied the measured wind-stress to the second solution in order to obtain a time series comparison with the observed fresh water thickness. Figure 9 shows model solution and observations together with the measured wind-speed. Since the model starts off with zero initial conditions it takes a few days to catch up with the observed thickness, but thereafter reproduces the main features with some fidelity.

SUMMARY

Observations of wind, current and surface layer thickness in Alberni Inlet have helped elucidate some of the ways in which the system responds to a surface stress. Much of the wind energy is diurnal and a close coupling exists at this frequency between wind and current at a depth of 2 meters. On the other hand, most of the energy associated with changes in the surface layer thickness is of significantly lower frequency.

A simple two-layer frictional model is able to explain much of what is observed and can be used to predict the surface layer thickness on the basis of measured wind speeds.

FIGURE 8. Gain and Phase for the model compared with Amplitude and Phase Transfer Functions derived from the spectra.



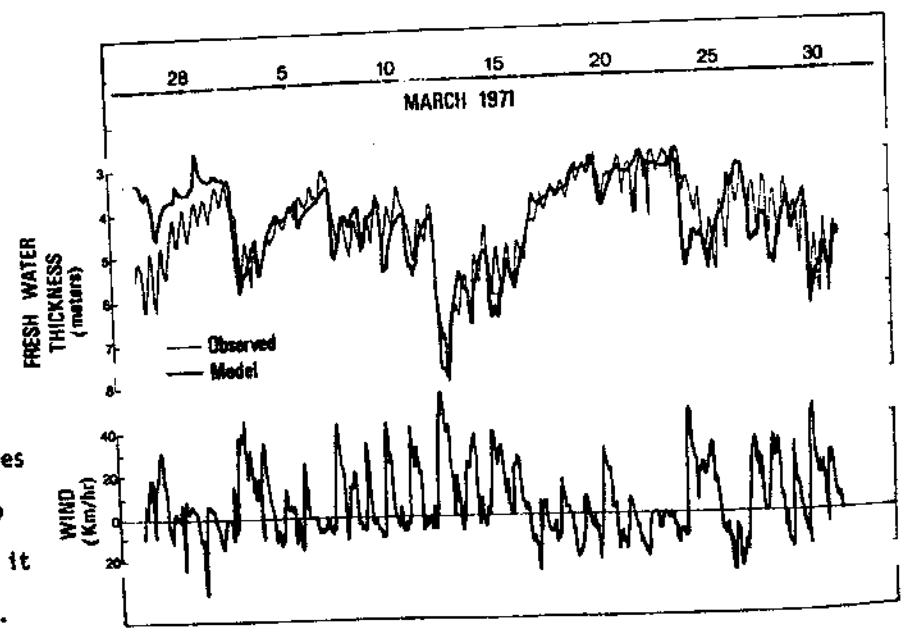


FIGURE 9. Comparison of Model solution with time series data. The model takes a few days to catch up with the observations since it starts with zero initial conditions.

ACKNOWLEDGEMENTS

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State of the Art of Floating Breakwaters

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Floating structures have long been used as barriers to waves, and the present nomenclature seems to have been dated from 1905 with Joly's article "On Floating Breakwaters". The subject lay dormant, however, until World War II when the Bombardon was deployed as one of the methods of building instant harbors for the invasion forces on the Normandy beaches. The potential military uses for mobile harbors led to a great deal of work during the postwar years on concepts, theories, and experimentation with configurations which could be towed to a site, either anchored in position, or sunk in place with the prospect of later removal and reuse. The concern of this paper is only with the floating units, rather than the broader category of "transportable" breakwaters.

Representative writings of the postwar period are those by Minikin (1948) who discussed floating breakwaters in somewhat general terms, Carr (1951) who set forth some of the principles governing the characteristics of "mobile" breakwaters, and the review of the performance of the Bombardon by Lochner, Faber, and Penny (1948). In 1957, the Naval Civil Engineering Laboratory began a concerted exploration of the existing knowledge of transportable units that could serve as breakwaters or piers. The military objectives are apparent from the site criteria set for this study, which were: wave height, 15 feet, period, 13 seconds, tidal range 12 feet, minimum water depth 40 feet, and in-shore transmitted wave height of 4 feet. The results of the exploration are summarized as Technical Report 127 (1961), and is an invaluable state of the art assessment up to that time, with particular emphasis on military use under rather severe wave criteria. An excellent sequel updating this report was issued as Technical Report 727 (1971) which is a survey of concepts for transportable breakwaters, including more than 60 in the "floating" category. In this report summary is the statement:

> "Recurring efforts, spanning 125 years or more, have not produced a breakwater for temporary installations which is easily transported, effective over a broad range of wave conditions, and able to endure in very high seas".

In view of this statement, the question naturally arises, "Why bring the subject up again?"

Further assessment is warranted in view of potential civil uses on relatively protected inland waters. The shutdown time of weather dependent, water-borne activities like construction, logging and cargo handling could be reduced by floating, transportable breakwaters. The infant mariculture industry might find more sites suitable for its special facilities if suitable wave protection could be provided. These uses are "miscellaneous", however, in comparison to the boat-oriented uses of the floating breakwater. For instance, a Pleasure Boating Study (1968) of Puget Sound waters of the State of Washington forecast an increase of 41,500 moorages for summer use and 25,200 for the winter season during the period 1966-1980. Whether that many moorages can be developed economically is another matter. Most of the harbor sites in the maximum use areas that are blessed by natural protection from wind waves have been developed already, so artificial protection will be required. Fixed breakwaters of rubble, timber, piling, or fill, are quite expensive if the water depth is very great, and if foundation conditions are not suitable. These fixed structures also may interfere adversely with the balance of littoral drift, shellfish habitat, the paths of migratory fish, and may conflict with coastal zone regulations. It is natural to look toward floating structures as possible alternatives.

There are several sites in the Puget Sound area where floating breakwaters are being seriously considered. Funds have been allocated (March 1972) for one that will be 900 feet long for the Robinson Crusoe Marina in Friday Harbor in the San Juan Islands: design plans for one at Oak Harbor on Whidby Island are nearing completion. Boating is on the increase in large lakes and in reservoirs formed by dams, and marinas on these water bodies, often will require shelter from the wind waves. In view, then, of the potential uses from a new perspective, it is timely to reexamine the floating breakwater with regard to types, transmission characteristics, anchoring forces, economics, and multiple-use prospects.

TRANSMISSION CHARACTERISTICS, GENERAL

The purpose of the floating breakwater (Fig. 1) is to reduce the transmitted wave energy, which may be accomplished by a mix of the following mechanisms:

1. Reflection

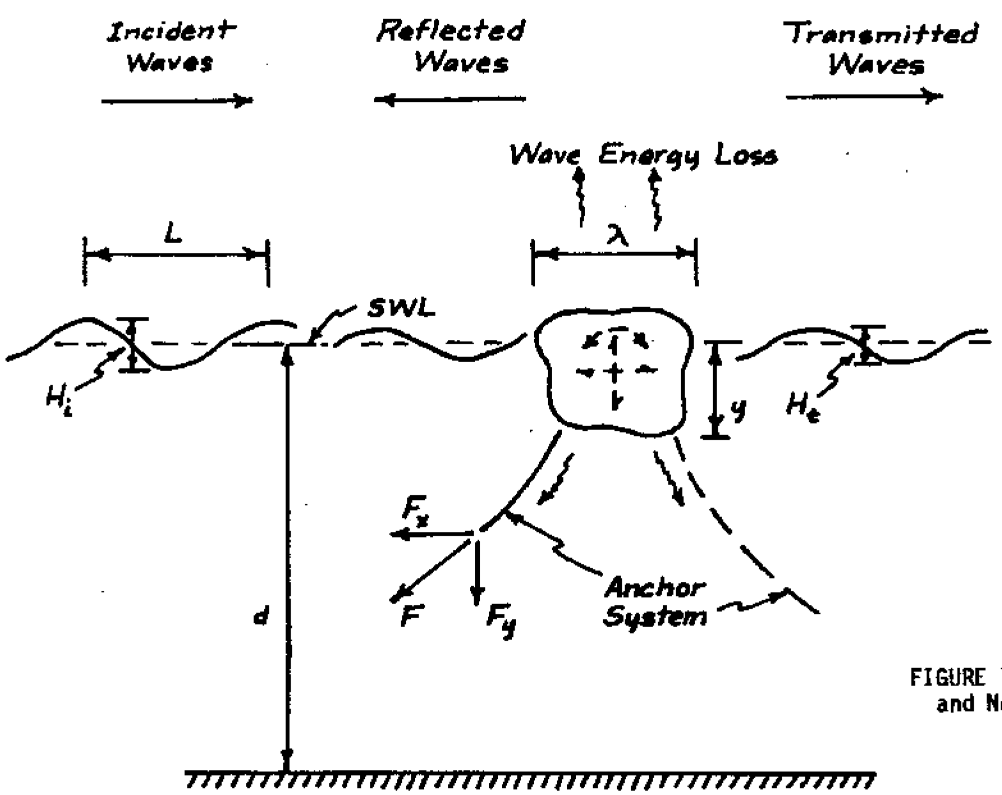


FIGURE 1. Definition and Notation Sketch

2. Energy loss through turbulence produced by wave breaking conditions and hydraulic damping of the structure.

3. Interference with internal orbital motion and dynamic pressure field.

4. Inelastic deformations of the structure and its moorings and superposition of transmitted waves with those generated by motion of the structure.

Although the real concern is with *energy* transmitted, the effectiveness of the floating breakwater is expressed ordinarily as a "transmission coefficient", the ratio of the transmitted wave height to incident wave height, i.e.,

$$C_T = H_i/H_T \tag{1}$$

Nearly all analyses and experiments on transmission characteristics have been based upon monotonic (single-frequency) waves, where the determination of height ratios is quite simple, and does convey a ready, visual picture of transmission capabilities of the particular unit. However, a return to the basic energy concept, or some index of energy content, will be needed when studies are made on the real world of random wind-generated waves.

A floating breakwater is a displacement vessel at anchor and can, in general, undergo the motions in translation of sideway (chordwise motion) heave (vertical) and surge (spanwise), and the rotational components of roll (about longitudinal axis), pitch (chordwise axis), and yaw (vertical axis). Most of the laboratory work has been done in the limiting two-dimensional case of regular, monotonic waves with crests parallel to the breakwater, and only three components of motion, sideway, roll and heave, are involved. These are the dominant motions so far as transmission of energy is concerned, but the surge, pitch and yaw are likely to be at least as important so far as the structural features are concerned in the field installation, where connections between units and to anchors must perform under random waves, and under wave crests of finite length which generally are not parallel to the longitudinal (spanwise) axis of the breakwater. The failure of the World War II Bombardon was attributed to the collapse of the links between the units, rather than a breaking of anchor lines or failure of the structural body. Although the generalized motion of the floating breakwater under random loadings is yet to be solved exactly, there are some simple cases which show the role of key parameters.

Carr (1951) assumed that the transmission coefficient for a rectangular cross section anchored in shallow water could be predicted from linear wave theory, hydrostatic pressure distribution, linear damping and just the sidesway component of motion and obtained

$$C_T = \frac{1}{\sqrt{1 + \left(\frac{\pi W}{\gamma L d}\right)^2 \left(\frac{T^2}{S^2} - 1\right)^2}} \tag{2}$$

This equation predicts the trend of transmission coefficient CT with the breakwater properties of weight W, sidesway period S, and the wave proverties of length L, and period T. The water depth is d and the specific weight of water is γ. The transmission coefficient is unity when the wave period is equal to the sidesway period S, but decreases thereafter as S becomes progressively greater than T, as the wave length gets shorter, and as the weight gets larger. Although the analysis was based on some simplifying assumptions for a rectangular cross section anchored in shallow water, experiments on other geometries and relative depths show similar trends.

BREAKWATER GROUPS

The rectangular cross section analyzed by Carr is not the most effective attenuator, but the unknown hydrodynamic factors of drag, added mass, pressure distribution and energy losses, along with the structural motion have, so far, blocked the development of predictive analyses for the responses of the more complex shapes. As a consequence, it has been necessary to resort to experimental procedures to evaluate their characteristics. Although there have been many different forms proposed and tested, there are some geometric similarities that have been used to propose the six representative groups shown in Fig. 2; the transmission coefficients, anchor forces and other features will be discussed in a later section.

The single-prism group contains the simplest forms and those which offer the best prospects for multiple use, i.e., as walkways, storages, boat slips, etc. Kato (1969) reported an interesting comparison of the rectangular and trapezoidal sections. The inverted shape gave lower transmission coefficients, but developed higher anchor forces.

The log boom or raft is a configuration that is used in the field by the lumber industry, and has secondary use as a floating breakwater. It will provide protection from waves of very short period, but becomes quite ineffective for longer waves. Kennedy and

Marsalek (1968) conclude that a "flexible porous floating breakwater extending over two or more wave lengths can greatly attenuate waves of moderate length."

The twin hull, catamaran-style pontoon illustrates one way of distributing a given weight away from the rectangular form to achieve a longer roll period and potentially a more stable platform. The extra corners provide additional zones of energy loss, and the water mass between the hulls may add damping action, although this latter effect does not appear to be a very large; possibly the mass would be more effective if it were restrained within the structure.

The sections in the A-frame group utilize combinations of vertical walls acting as reflecting surfaces and outriggers for stability and to develop a large roll period for a given weight. A particular member of this group will be discussed in more detail subsequently.

The perforated pontoon represents a subgroup of the single-prism class, having openings which create extra sources for energy loss, and also some prospect for a disruption in the wave profile passing beneath the structure.

The last group, "flexible assemblies" differs from the log raft group in that the structural elements absorb and dissipate wave energy. The performance of bags as wave attenuators have been tested when filled with air, water, or with viscous fluid floating on the surface, restrained at intermediate depths, and lying on the bottom. A novel configuration in this group is the Wave

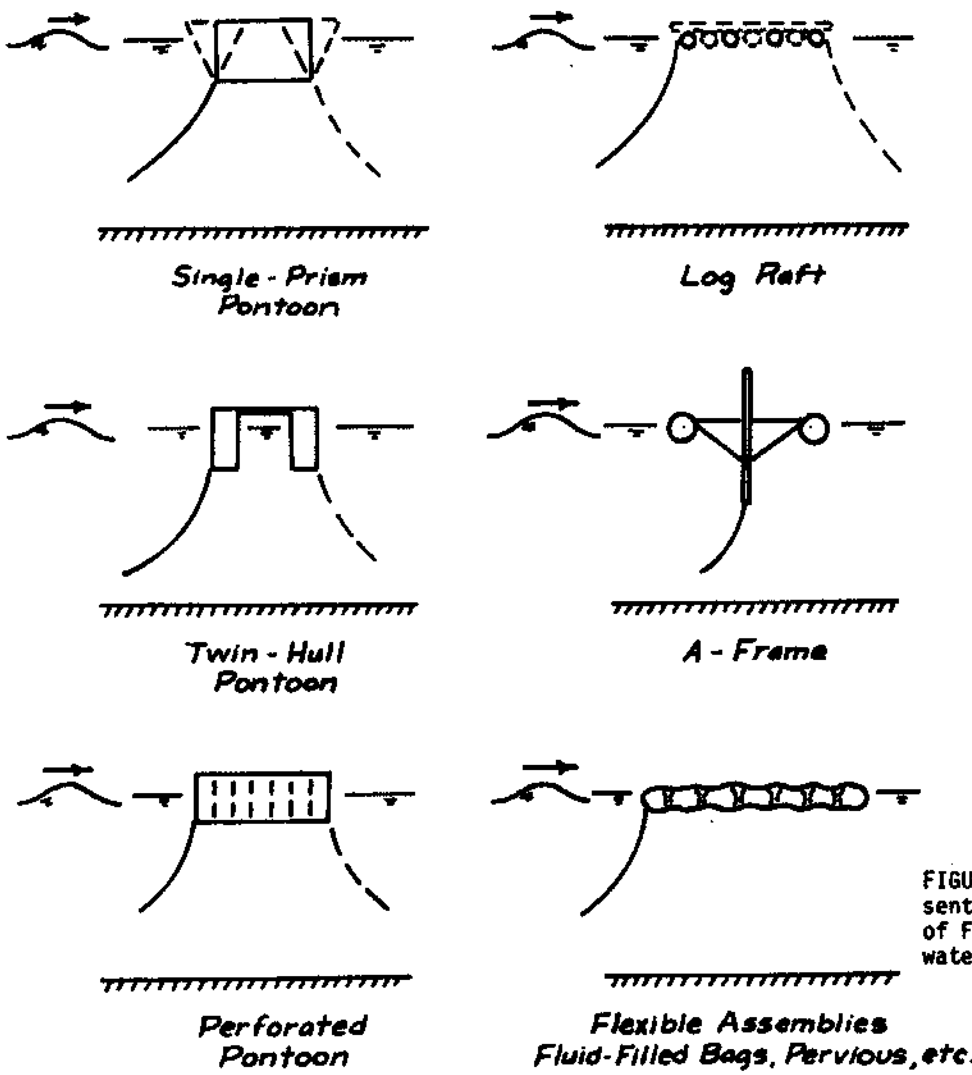
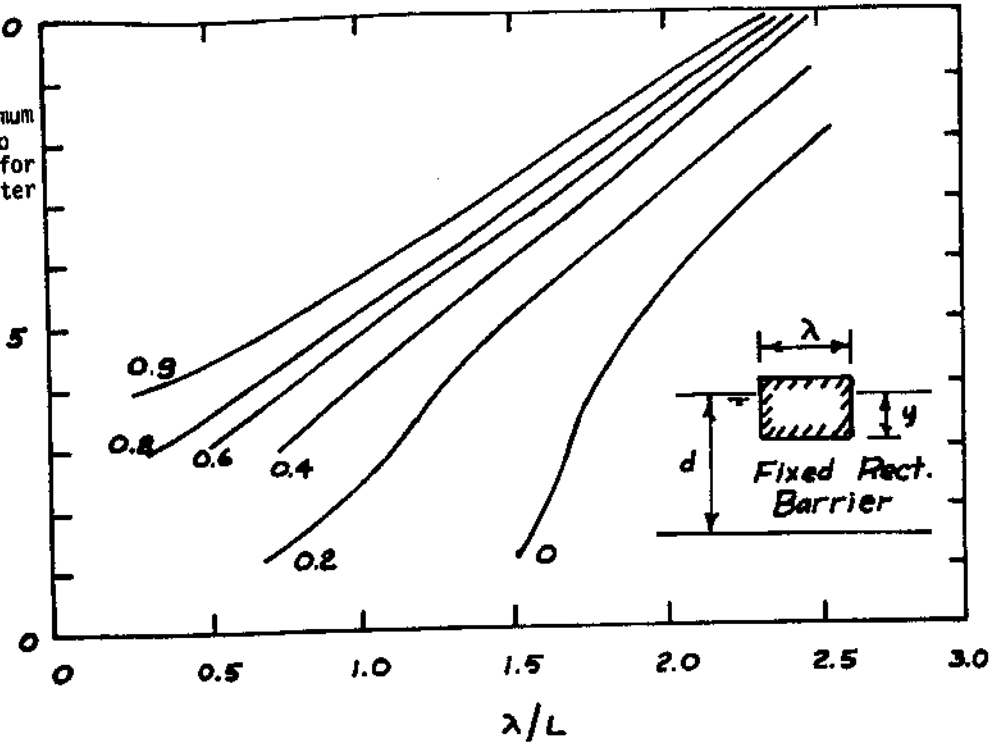


FIGURE 2. Representative Types of Floating Breakwaters.

FIGURE 3. Minimum Values of y/d to yield C_t = 0.2 for λ/L and L/d (after Macagno)



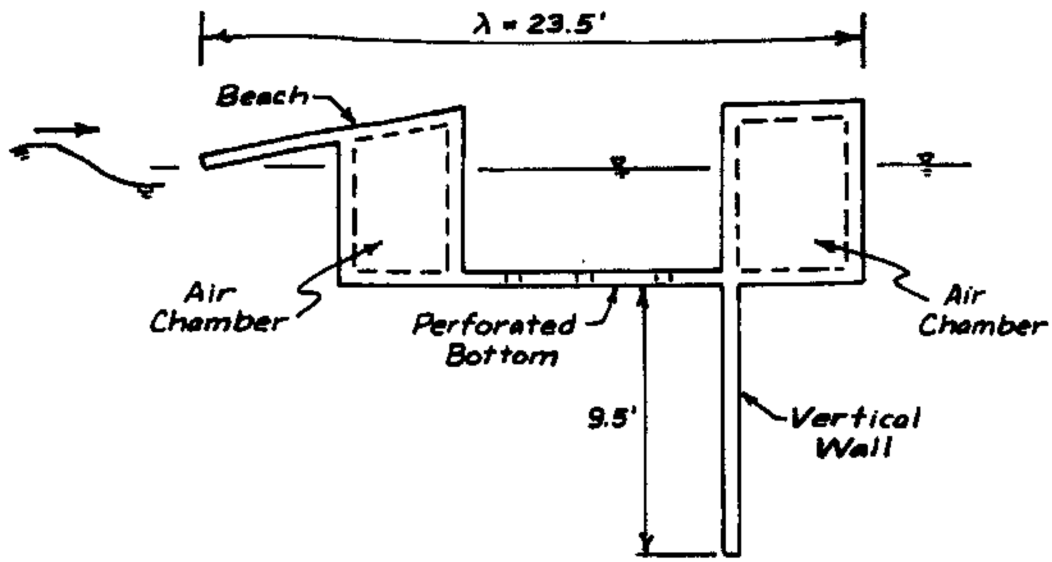
Maze, an assemblage of interconnected tires, which presents a porous reflecting surface, causes disruption of the normal wave kinematics and absorbs energy through the flexing of the tires under the applied wave loading. Transmission coefficients comparable with other configurations have been obtained (Technical Report H-68-2, 1968).

TRANSMISSION COEFFICIENTS FOR TYPICAL SECTIONS

A dimensional analysis of the floating breakwater will disclose a number of characteristic length ratios upon which the coefficients of transmission and reflection, as well as other performance characteristics will depend. One set is the ratio of the structural width to wave length, λ/L. This term is conparable to the "W/L" term in Carr's prediction for the transmission coefficient, Eq. 2. A time ratio of some period of the structure to wave period is used sometimes in lieu of the length ratio, but unless the particular period, (heave, roll, or sway) that bears most importantly upon the transmission coefficient can be identified, the time ratio offers little advantage, and even can be misleading, for the performance of a free structure cannot be compared on a time ratio basis with the same structure in the fixed mode.

To show the results of an analytical relation between wave length, structural width and transmission coefficient, the work of Macagno (1954) on a fixed rectangular barrier is replotted on Figure 3 for a transmission coefficient of 0.2. This work was done for a transmission coefficient of 0.2. This work was done during the post World War II period, and shows the interest of that era in the large-scale applications in exposed waters. The analysis does not extend into the lower left hand corner, where the depth-wave dimensions likely for a marina on inland waters would fall. The graph does show, however, the important trends that for waves relatively long with respect to depth, the penetration required for a low transmission coefficient becomes large, but that some tradeoff can be made by increasing the structural dimension λ.

Several special forms of breakwaters were studied by Chen and Wiegel (1969, 1970) and one in the A-frame group is shown with its transmission characteristics on Fig. 4. This unit was designed to incorporate all of the major mechanisms to reduce the transmission of wave energy. The vertical wall serves as a reflecting surface, the sloping beach causes run-up, possibly wave breaking, and a spilling into the inner chamber from which the water can flow through the bottom to interfere with wave motion. Energy is lost as water flows through the porous bottom, the two air chambers provide a large moment of inertia and thence a large roll period. The wall dimension is such that the center of roll is above the point of anchor attachment, with the beneficial combination that the horizontal wave force that would cause a force in the anchor line induces a roll which tends to reduce the extension of the anchor line, and the force in it. For the structural width of 23.5 feet, the transmission coefficient for a wave length up to about 55 feet is about as low (0.2) as can be expected. It is not likely that a configuration can be devised to produce a lower transmission coefficient, within the same range of basic dimensions of penetration and structural width, for this one incorporates the major barriers to transmission; the economics of fabrication is a separate consideration.



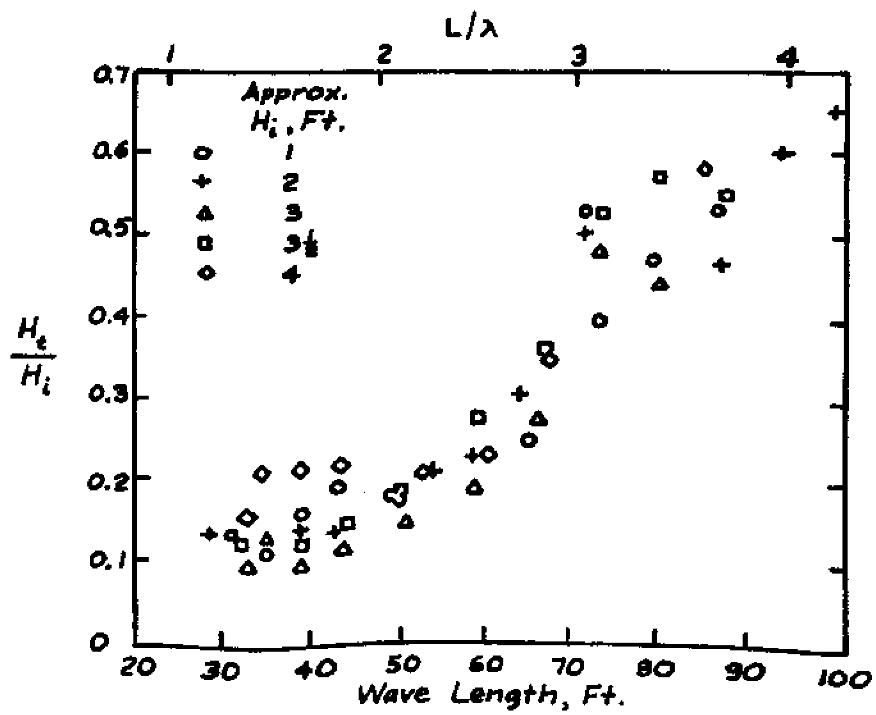


FIGURE 4. Composite Breakwater Performance - 1:12 Scale Model Data (after Wiegel)

Although there is a multitude of different breakwater forms, there is a relatively narrow band covering their performance as indexed by the transmission coefficient verses the relative length ratio λ/L, as shown on Fig. 5, where results for five of the basic forms are given together for comparison. All data are from two-dimensional, monotonic wave tanks. The data for the log raft (Nece, Richey, 1971) corresponds to a prototype log assembly of 2.7-foot diameter logs connected together loosely, and shows that to be effective should have a width of 1.5 to 2 wave lengths. The A-frame curves (Hay, 1966) marks a more realistic upper bound on the performance envelope. Beneath this curve lie those for the rectangular box (Nece, Richey, 1972), the twin-hull design (Davidson, 1971) and a porous rectangular unit having a ratio of open area to planform area of about 0.3. The curves have been drawn through the centers of the experimental range at each wave setting. The trough in the curve for the box shape at λ/L = 0.2 occurred when the heave period was equal to, but out of phase with, the wave period. This response would not be at all likely to occur in a random wave system. The box and porous shapes develop transmission coeficients as low as about 0.2, comparable to the results shown on Figure 4, but do require a larger value of λ/L to achieve this level of performance.

The data on Fig. 5 referred to deep water conditions; the performance of the same box and twin hull shapes, along with the theoretical values of transmissission coefficient for a fixed structure are shown as Fig. 6 in the shallow water case for the penetration ratio y/d = 0.5. Somewhat higher transmission coefficients develop, due to the different distribution of energy with depth in the deep and shallow water cases.

Field measurements of floating breakwater performance are very scarce. One set of data for waves having a length of 50 feet and height of 4 feet was reported by Hay (1966) for an A-frame type having a span length of 50 feet. The results are reproduced as Fig. 7, together with coefficients that were computed from diffraction diagrams given in TR-4 (1966). The close agreement between the measured and computed coefficients indicates the dominance of the diffraction phenomena. The protected area is confined to a zone within about a wave length of the structure.

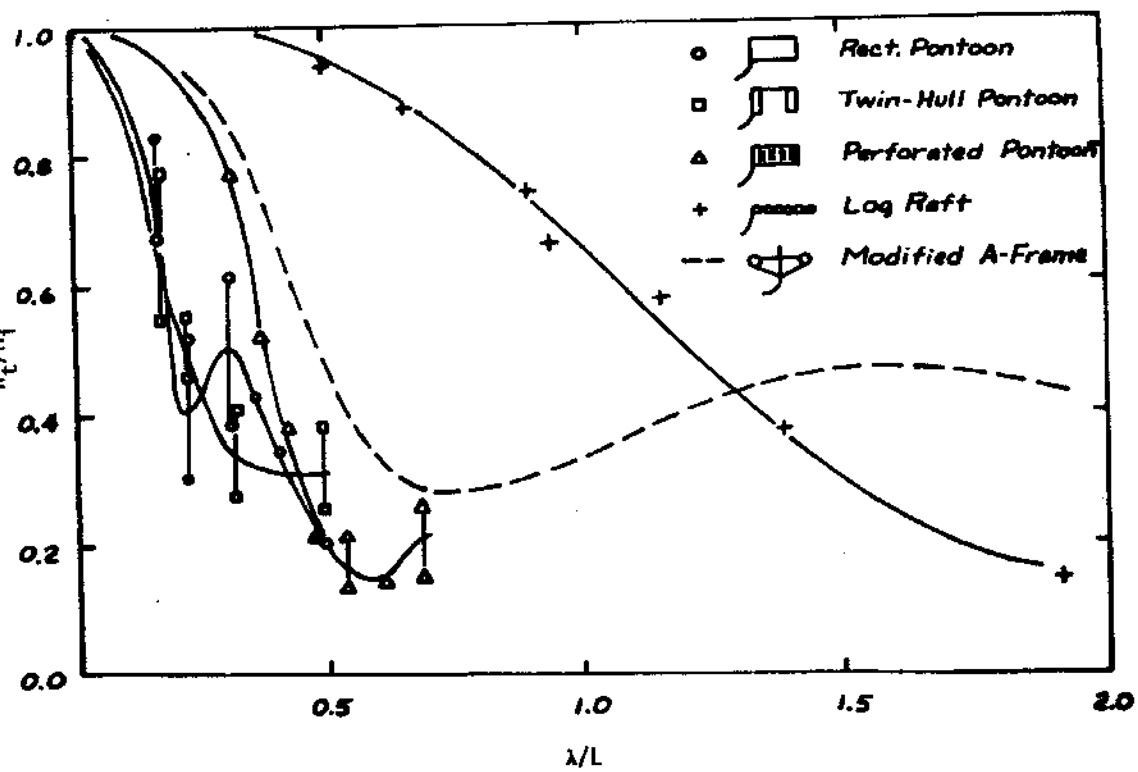


FIGURE 5. Transmission Coefficients for some Representative Breakwaters in Deep Water.

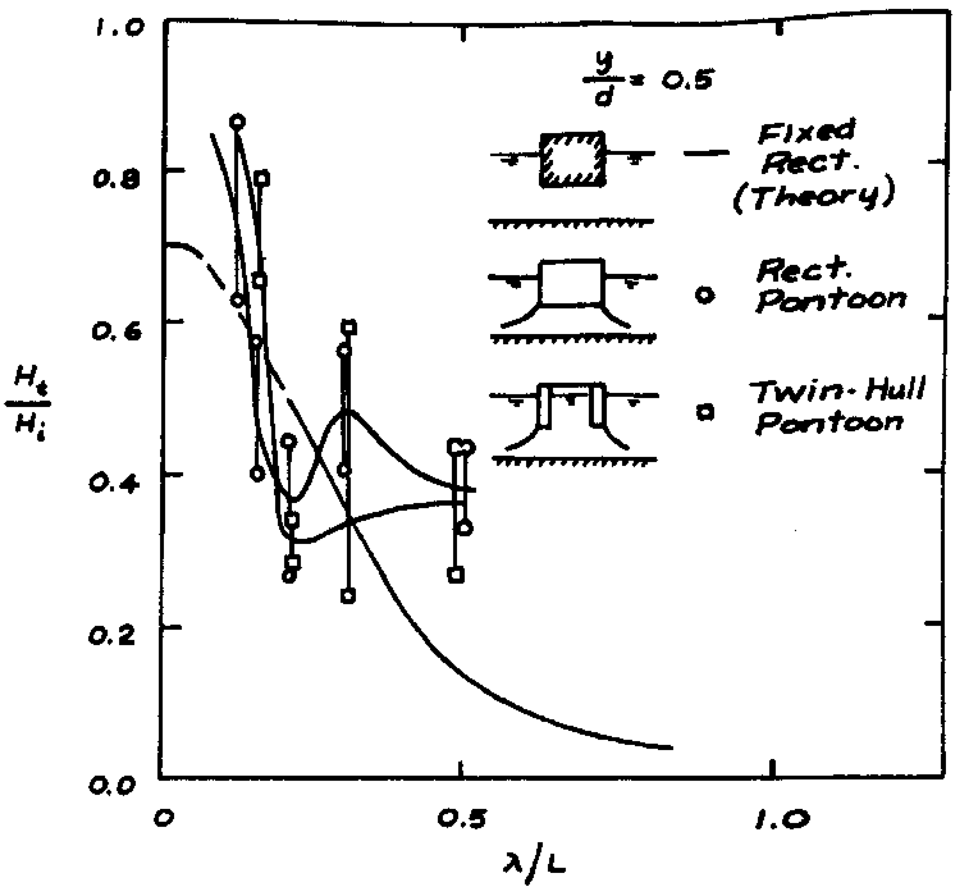


FIGURE 6. Transmission Coefficients for Three Breakwaters in Shallow Water.

Another example showing the superposition of diffraction and transmission coefficients is shown in Figure 8, the photograph of the "Hasler Seabreaker", which was described in *Hydrospace*, April 1971. This unit takes the form of a shallow pontoon, with a tubular superstructure and an outrigger float. Some cost estimates appear in a later section.

FORCE COEFFICIENTS

The mooring system for a floating breakwater should be based upon conservative predictions of design forces. There are far fewer data available on forces than there are on hydraulic characteristics, and their extrapolation from laboratory data to prototype installation entails some tenuous assumptions about similarity conditions. Only the peak force values are considered; predictions of the force as a function of time are not attempted in view of the role of elastic restraints, the inertial and damping characteristics of the breakwater, and the differences between the single-component wave used in most lab data available and the random wave which the unit will experience in the prototype situation. Fatigue life may be more important than peak force values, but this facet as applied to floating breakwaters apparently has not been reported in the literature.

Design values for anchor forces may be estimated from published force data normalized in some form such as the one given by Ippen (1966):

$$F_x = F_{x\,max}/\gamma(H_i/2)y$$

in which F_x = dimensionless horizontal force coefficient per unit length

$F_{x\,max}$ = maximum horizontal force

γ = specific weight of water

H_i = incident wave height

y = characteristic linear dimension

Force coefficients for four configurations are shown on Fig. 9; it does appear that break-waters of similar geometries will occupy similar regions of Fig. 9, although

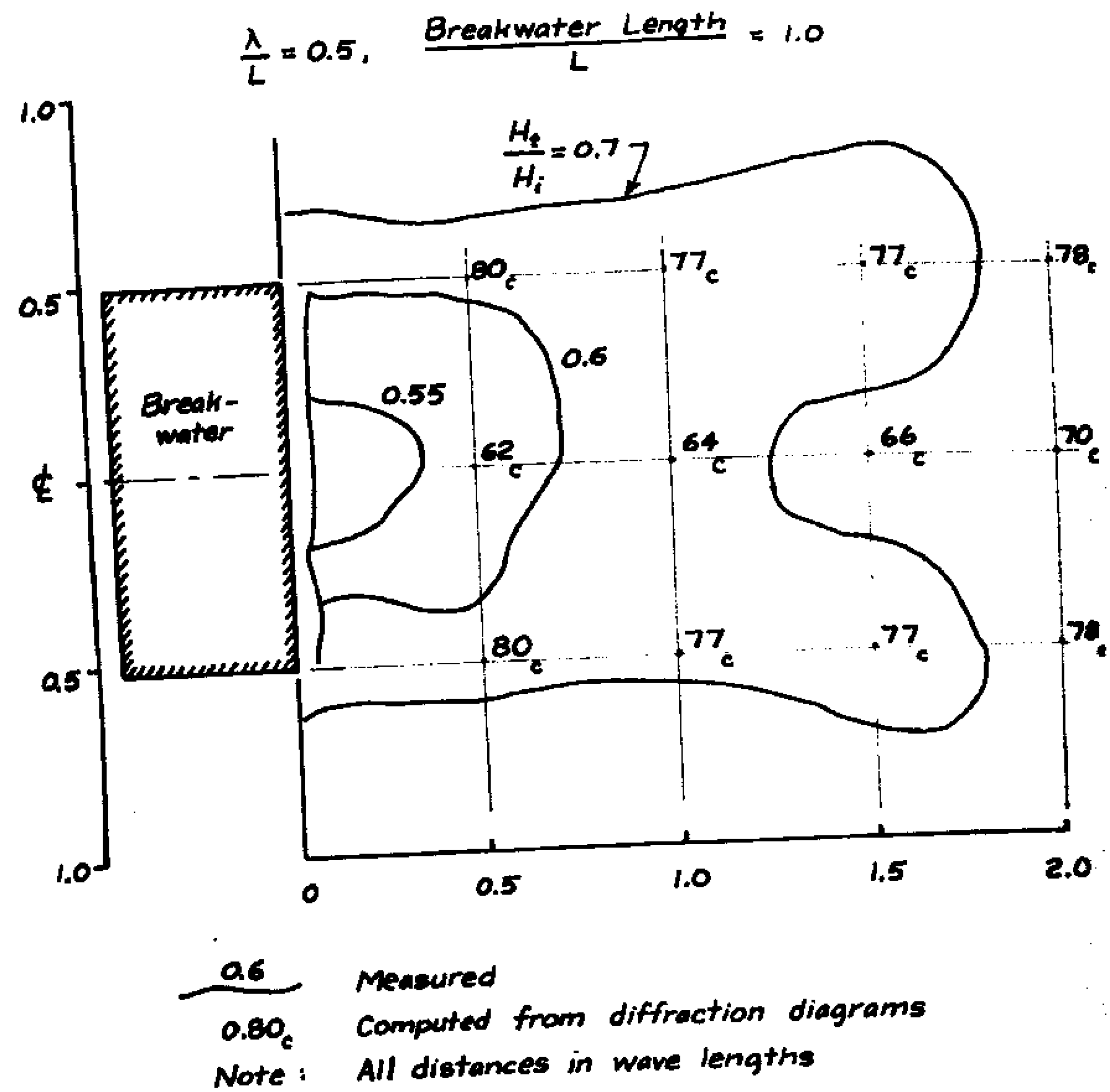
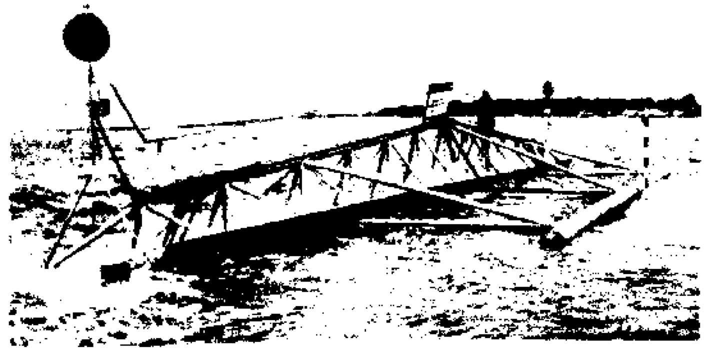
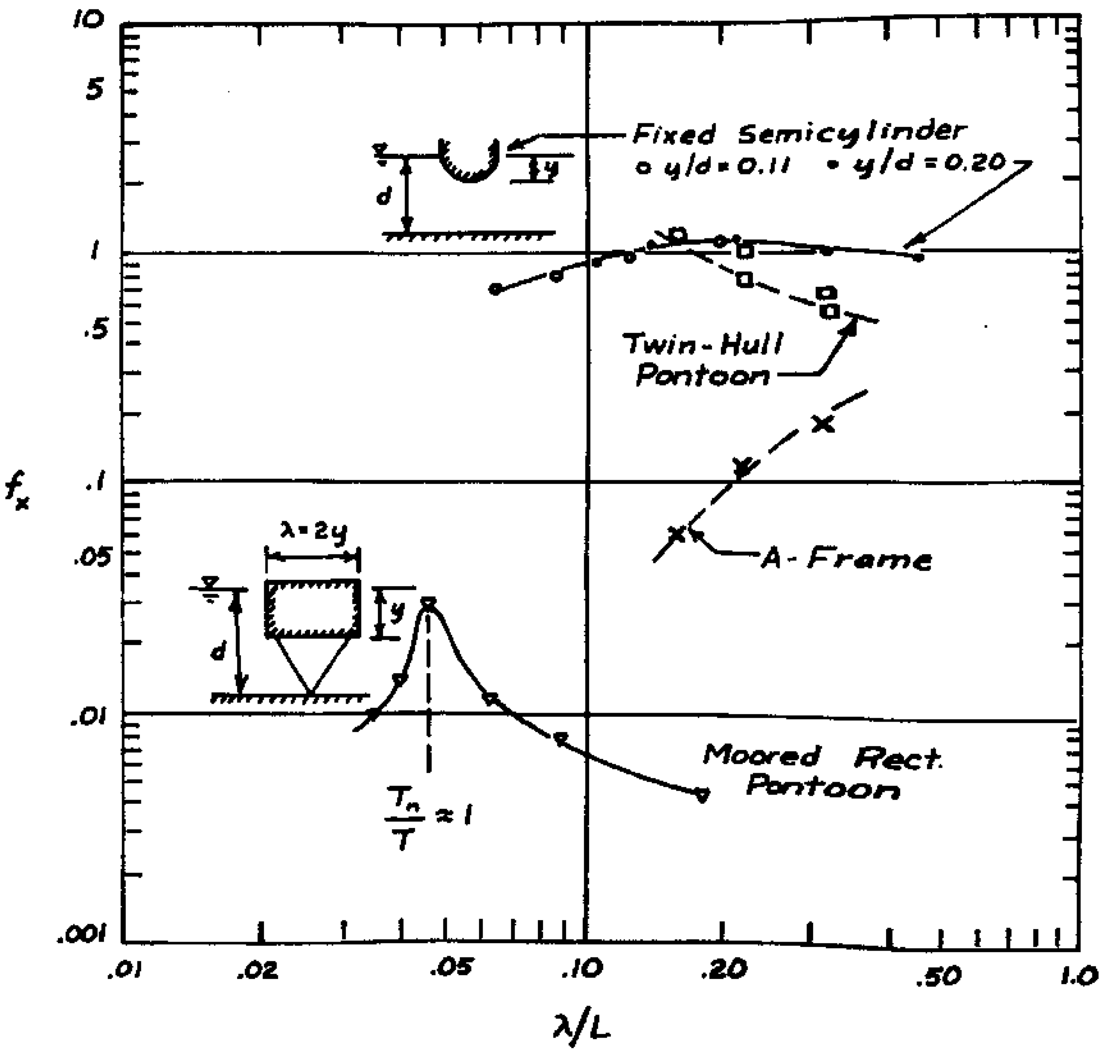


FIGURE 7. Diffraction Diagram for Modified A-Frame Breakwater in Deep Water

more cases need to be included before firm conclusions can be drawn. Force coefficients for different forms can differ by an order of magnitude, as shown by the comparison of the twin-hull section and A-frame. Model tests for anchor forces are recommended whenever possible.

The models contributing to the data of Fig. 8 were tested under the condition that the crest length of the incident wave impinged on the full span length of the breakwaterwater, since the models were two-dimensional. In the random wave in nature, the probability of this situation developing decreases as the span length of the structure increases relative to the crest length. Tratteberg (1968) presents data showing a five-fold reduction in maximum force per unit span length as the ratio of span length to wave length increased from 1 to 5. A single data point verifying this trend can be taken from a report by Hartz (1972) on field measurements of the forces in the anchor lines of the Hood Canal Floating Bridge (State of Washington) which have shown the forces to be essentially unaffected by any individual wave characteristics. Of course, this structure is quite rigid and is very long with respect to any wave crest-length possible at the site. Eie, Tratteberg and Torum (1970) brought some aspects of three dimensional waves into evaluating the forces on a fixed pontoon by using a principle employed in naval architecture that forces on floating structures may be calculated on the basis of a transfer function and the two dimensional wave power spectrum to obtain the one dimensional force power spectrum. Laboratory data were used to determine the transfer function. More work of this basic nature is needed to reduce the current reliance of anchor force prediction on experimental data.





$$f_x = \frac{(F_x)_{max}/\text{Unit Length}}{\gamma\left(\frac{H_i}{2}\right)y}$$

FIGURE 9. Force Coefficients

FIELD INSTALLATIONS

Two marinas in the Puget Sound area may receive floating breakwaters during 1972 as components of the overall facilities. The plans for the one at Oak Harbor call for about 2,100 feet of the rectangular pontoon shown on Figure 6; the schematic layout (Davidson, 1971) is shown on Figure 10. Very poor foundation conditions at the site precluded a conventional, fixed structure. The floating breakwater for the second site, the Robinson Crusoe Marina at Friday Harbor, San Juan Islands, will have a 900-foot floating breakwater initially. Water depths of 40-50 feet at this site made a fixed structure a much more expensive alternative.

BREAKWATER COSTS

Most of the attention to date on floating breakwaters has been confined to the transmission and anchor force characteristics, as dependent upon the geometric variables of form, chord length, and penetration; the only data that could be found in the literature on the cost of competetive designs were those for military uses in Technical Report 127 (1961). The brochure on the Hasler Seabreaker specifies its Type 6S (span length of 214 feet) weighing 74 tons, to provide a transmission coefficient of about one-third for an incident design wave with a significant height of 3.1 feet. This unit would cost about $500 per pound. Bids on the floating breakwater components on the Robinson Crusoe Marina average somewhat less than $400 per foot for a design wave of about 3 feet.

The cost figures quoted are very approximate, and may not include comparable auxiliary components, such as anchor systems, yet they do serve as one point in a cost-effective study which is needed so that a selection of breakwater type can be based upon economic considerations.

CONCLUSIONS

The performance characteristics of major concern for floating breakwaters are the transmission coefficients, anchor forces and motion. Theoretical approaches to evaluate these have to date been limited to simple forms and so there is still a strong reliance on experimental data. A large number of floating breakwater concepts have been proposed and tested in the laboratory with relatively little on anchor forces. Although there have been many different geometries investigated, all can be placed into a few general groups, and performances of each member within these groups is quite similar. Transmission coefficients between 0.2 and 0.3 can be obtained for cases where the ratio of chord length to wave length is large enough; minimum values of this ratio vary from about 0.5 for the more efficient section to about 2 for the flexible log-raft types.

Prospects for a floating breakwater to be competitive with fixed structures appear to be favorable at sites where conventional forms are not suitable and where the exposure to the extreme wave event is excluded through restricted seasonal use. The points in favor of their use are:

1. Cost is only slightly dependent upon water depth and foundation conditions.

2. Minimal interference with shore processes, shoreline conservation principles, fish migration, and with circulation and flushing currents essential from the water quality standpoint.

3. Flexible in platform arrangement to accommodate changes either seasonal or in long term growth patterns of the area they are designed to protect.

4. Have multiple-use potential, in contrast to rubble mound or pile structure.

The points detracting from their use are:

1. Motion may limit multiple use.

2. Uncertainties, due to lack of field performance data, in the magnitudes of applied loadings and maintenance costs dictate conservative design practices.

3. Designs must be matched to site conditions, with due regard for the long wave lengths that may occur with the infrequent storm; the floating breakwater, unlike the fixed structure, can fail quite abruptly to meet its design objective without necessarily suffering any structural damage.

Contributions from the following areas of research will aid in refining the current procedures for designing floating breakwaters:

1. Development of theory, possibly as extensions of techniques from naval architecture, to describe more adequately the forces, motions and hydraulic characteristics of different designs to reduce the dependence upon experimental data.

2. Systematic measurements, with Item 1 above in mind, at full-scale dimension in the natural environment to correlate with the theoretical and laboratory works.

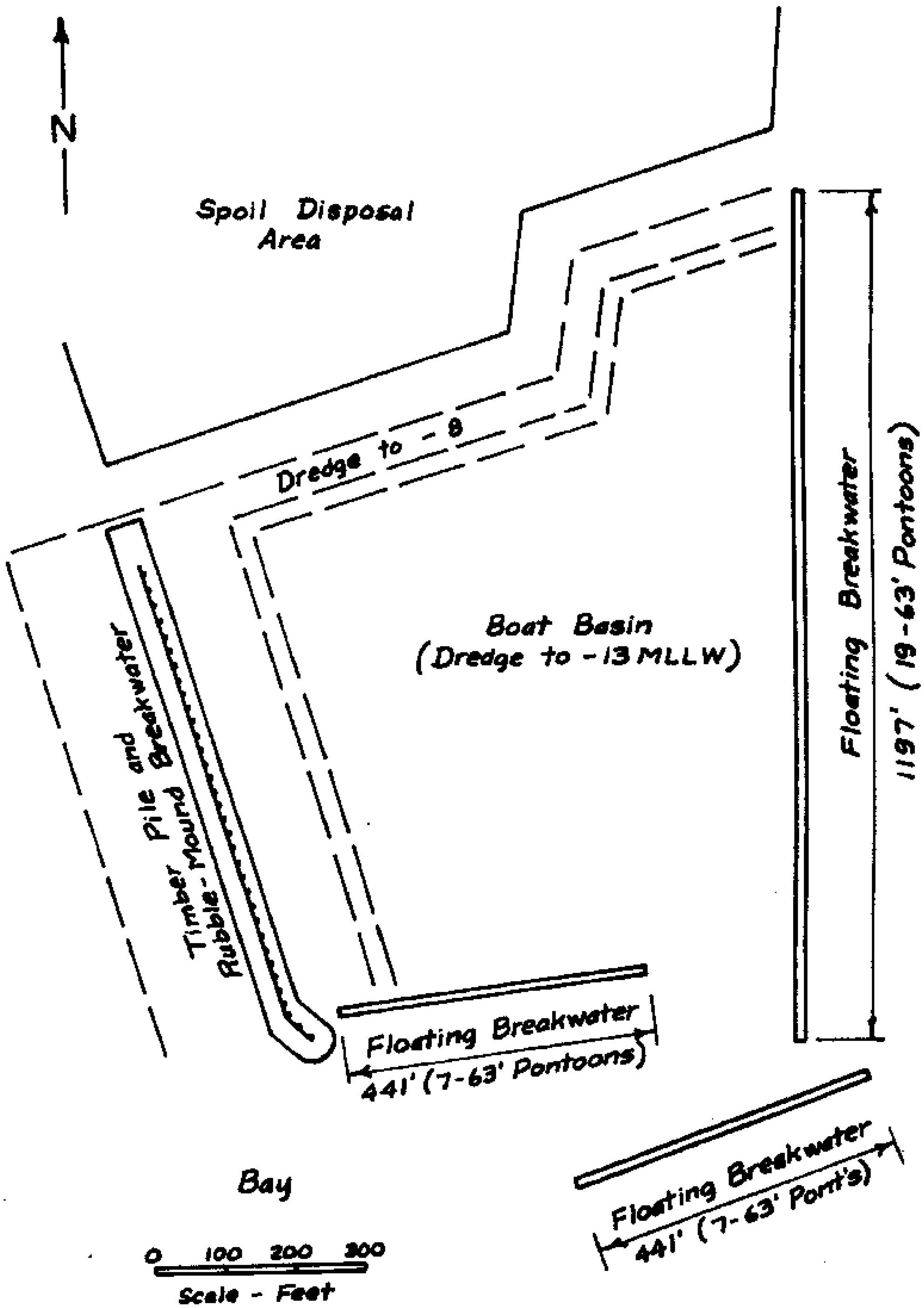


FIGURE 10. Schematic Plan of Proposed Marina in Puget Sound, Washington

3. Field experience with actual installations to acquire operation guides on the practical aspects of maintenance and repair.

4. Cost-effective analyses to optimize configuration and attenuation characteristics.

5. Considerations of the three-dimensional, random aspects of wind-generated waves in the selection of plan form configurations.

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Laws and Regulations of Pollution and Navigation in Pacific Northwest Estuaries

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U.S. Coast Guard
Portland, Oregon

It all started one day in 1790 when Alexander Hamilton announced to the Congress that smugglers were driving America bankrupt. He asked for 10 "cutters" to stem this drain on our treasury. He got the cutters; they got the smugglers; and our nation was allowed to live past the tender age of 14. And since that day, nearly 182 years ago, the Coast Guard and its antecessors have been the principal Federal maritime law enforcement agents.

The Coast Guard's broad basic authority exists in Title 14 of the United States Code, namely: "The Coast Guard shall enforce or assist in the enforcement of all applicable Federal laws on and under the high seas and waters subject to the jurisdiction of the United States; shall administer laws and promulgate and enforce regulations for the promotion of safety of life and property on and under the high seas and waters subject to the jurisdiction of the United States covering all matters not specifically delegated by law to some other executive department. . ."

Further on in Title 14 we find the general and specific authorities relating to cooperation with other agencies. An historical note in the United States Code, annotated succinctly sets forth the expected results of such cooperative efforts. "This high degree of cooperation, a natural attribute of a producing and servicing agency, is important not only because it greatly promotes the quantity and quality of the services performed, but because the concentration of these functions in one agency results in savings to the government of manpower, funds, and equipment."

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* The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

In addition to the definition of the Coast Guard's duties, organization, powers, etc. contained in Title 14 of the United States Code there are two other titles of the Code under which the Coast Guard operates in the Coastal Zone. They are: 33 USC (Navigation and Navigable Waters) and 46 USC (Shipping).

The prime implementing regulations for the Coast Guard's functions are found in the Code of Federal Regulations in Titles: 33 CFR (Navigation and Navigable Waters) and 46 CFR (Shipping). Another 40 CFR (Protection of Environment) also contains pertinent regulations.

It should be noted that enforcement of the provisions of these titles of the United States Code and the Code of Federal Regulations is *not* the exclusive province of the Coast Guard. We share responsibilities with several other agencies, including the Corps of Engineers and the Environmental Protection Agency.

There are five operational program areas within the Coast Guard directly related to our law enforcement responsibilities. These are under the general supervision of the Commandant of the Coast Guard at the Headquarters level. The field level execution of these programs is carried out by our shore and floating units located and deployed to best meet the public's needs. The operational programs are:

AIDS TO NAVIGATION

The Coast Guard establishes, maintains, and operates aids to maritime navigation (including electronic systems) required to serve the needs of the Armed Forces and the commerce of the United States. The specific purposes of these aids are to facilitate navigation and prevent disasters, collisions, and wrecks.

In the Coastal Zone these aids to navigation take the form of buoys, lighthouses, lightships, fixed structures on shore and in the water, sound signals, radio beacons, radar and radio advisory systems.

When devising the appropriate combination of maritime aids to navigation for a particular area or waterway several pertinent factors are considered, namely:

type of maritime trafic, i.e. commercial and/or recreational; type of goods carried; density, distribution, and frequency of traffic; natural hazards, e.g. shoals, currents, winds; environmental impact, especially if a stranding or collision should occur; and economic impact.

Also within the general scope of this program the Coast Guard administers laws and regulations related to bridges over the navigable waters of the United States. This activity includes approval of plans and locations of bridges, alteration of bridges which are unreasonable obstructions to navigation, operation of draw bridges, and lights and signals on bridges for safety of maritime navigation.

MERCHANT MARINE SAFETY

This program calls for the enforcement of laws and regulatory standards the primary purpose of which is to promote safety of life and property in vessels of the United States. These regulations provide for the inspection of merchant vessels, approval of vessel plans and equipment, licensing and certificating of merchant marine officers and seamen, documentation of United States vessels, and containment and handling of dangerous and hazardous goods in maritime transportation.

The scope of the Merchant Marine Safety Program is broad but has many specific and detailed statutory limitations and conditions surrounding it. These limitations and conditions derive not only from domestic legislation but also from international treaties and conventions. The full force of the laws and regulations upon which this program is based applies only to certain types, sizes and classes of United States vessels and merchant marine personnel. There is only limited application (and in some cases no application) to foreign flag vessels.

The major portion of maritime traffic moves in and through the Coastal Zone. Hence the affect, in the Coastal Zone, of the Merchant Marine Safety Program is to insure that certain vessels are suitable for the service in which engaged and that the operating personnel are competent to operate them, thus minimizing the danger to the vessels, personnel, and the environment.

An important and vital aspect of this program is the investigation of marine casualties to obtain information for the prevention of future casualties. Information derived from such investigations will be utilized, if necessary, to develop and institute appropriate corrective measures, regulations and standards, or recommend marine safety legislation.

A recent addition to the Coast Guard's responsibilities in Merchant Marine Safety came in the form of the Vessel Bridge-to-Bridge Radiotelephone Act of 1971. The Coast Guard shares responsibility with the Federal Communications Commission in implementing this Act. The purpose is to provide a positive means whereby operators of approaching vessels can communicate their intentions to one another, through a conveniently located radiotelephone. The ultimate intent is to reduce marine accidents and thus enhance safety of people, property and the environment.

RECREATIONAL BOATING SAFETY

Laws and regulations aimed at reducing accidents, injuries, and fatalities and improving the environmental quality related to the operation of pleasure craft are enforced by the Coast Guard in this program area.

The Coast Guard is the principal Federal agency engaged in Recreational Boating Safety law enforcement. However, the declared policy of the Congress (Federal Boat Safety Act of 1971) is to encourage enforcement by the various states of compatible and consistent state boating laws and regulations.

National construction and performance standards and regulations for boats and associated equipment are being established to improve boating safety and to foster greater development, use, and enjoyment of all waters of the United States. These federal standards and regulations will preempt state and other political subdivision laws and regulations which do not conform to the Federal standards and regulations. These standards and regulations must be consistent with laws and regulations pertaining to the installation and maintenance of sanitation equipment.

PORT SAFETY

The Coast Guard enforces laws and regulations designed to safeguard vessels, harbors, ports, and waterfront facilities in the United States and its territories, including waters subject to the jurisdiction of the United States, from destruction, loss, or injury from sabotage or other subversive acts, accidents, or other causes of similar nature.

This program first came into being as Port Security in World War I. At that time the principal emphasis was the enforcement of anchorage regulations. In World War II the enforcement authority was expanded to include loading and discharge of explosives on vessels and the control over movement of vessels. The Korean conflict brought a re-intensification of the Port Security Program via the Magnuson Act. Today we continue our operations under this authority but with a shift in emphasis to general safety of our ports.

There is before the Congress proposed legislation, The Ports and Waterways Safety Act, to promote safe and efficient maritime transportation and the safety and environmental quality of United States ports, harbors, and navigable waters. This Act, when passed, should provide a broad program including:
Marine traffic systems; regulation of the anchorage, mooring or movement of vessels; handling of dangerous goods; protection equipment requirements for structures and facilities; regulation of the use of and/or access to vessels, structures, facilities, waters, waterfront, and shoreline areas as necessary for their protection; inspection and approval procedures to insure compliance with the provisions of the Act.

MARINE ENVIRONMENTAL PROTECTION

The detection, prevention, abatement, and elimination of pollution in the marine environment is the purpose of the laws and regulations enforced within the scope of this program.

Because of its general maritime law enforcement responsibilities, the Coast Guard has for considerable time been involved in various aspects of Marine Environmental Protection through the Refuse Act of 1899, and the Oil Pollution Acts of 1924 and 1961. We are continuing to function under the provisions of the 1899 Refuse Act and the 1961 Oil Pollution Act (the 1924 Oil Pollution

Act has been repealed). However, the principal law under which we now operate is the Federal Water Pollution Control Act, as amended (FWPCA). Under this Act the Coast Guard is the Federal agency designated to receive notices of discharges into the water of oil and other hazardous materials.

Much of the responsibility for the field activity related to the enforcement of laws and regulations on pollution of the marine environment has devolved on the Coast Guard. The prime reason for this is that the Coast Guard already has in existance a trained force, throughout the Coastal Zone, normally on a 24 hour alert status for search and rescue and other tasks. This force can respond and be deployed quickly whenever and wherever a water pollution takes place.

There is currently before the Congress legislation which will, if passed, further amend the FWPCA. This legislation, the Muskie Bill, will place greater responsibilities for water pollution control on all activities, public and private, government and non-government, and the individual and society as a whole.

On Christmas Eve 1971 the Coast Guard published, in the Federal Register, proposed pollution related regulations to govern the operation of facilities and vessels and the transfer of oil to or from certain vessels to prevent the discharge of oil. The salient points of these rather comprehensive regulations are:

Facility regulations apply to large facilities capable of transferring oil to or from vessels which have tank capacities for oil of 10,000 gallons or more. After April 3, 1973, a formal Coast Guard permit will be required for shoreside facilities engaged in oil transfer operations. Each facility must provide an operations manual and operate in accordance with it. Facility equipment requirements are defined (containment systems for small discharges on shore and discharges on the water will be required). General requirements for the operation of an oil transfer facility are listed and include personnel qualifications for designation as the person-in-charge of transfer operations. Vessel operation regulations are analagous to facility regulations to minimize loss of oil from accident or normal operations. Inland barges built or modified after December 31, 1972 will be required to be of double wall construction. A deck spill containment system will be required on all vessels capable of handling more than 10,000 gallons of oil. Prior to January 1, 1975 all vessels will be required to have a means to retain all oil bilge wastes on board when operating in navigable waters or the contiguous zone of the United States. Vessels of 100 gross tons or more will be required to seal their bilge and ballast overboard discharge valves in the closed position while operating within these waters. Tank vessels will be required to have, post, and use specific oil transfer procedures. Tank vessels containing oil must be attended at all times. A declaration of inspection form for pollution prevention must be completed prior to commencement of transfer operations. Merchant Marine officers and seamen will be required to possess greater knowledge of pollution laws, regulations and abatement procedures. Certain pollution prevention equipment will be required prior to the issuance of a vessel certificate of inspection. The existing vessel drydocking interval will be shortened to not more than three years for single skin vessels.

Regional direction for Coast Guard law enforcement in the Pacific Northwest is provided by the Commander, Thirteenth Coast Guard District. From his office in Seattle the District Commander provides general supervision for field units located in Washington, Oregon, Idaho, and Montana.

The two categories of Coast Guard field activities primarily concerned with maritime law enforcement in the Pacific Northwest Coastal Zone are:

MERCHANT MARINE SAFETY - MARINE INSPECTION OFFICES (MIO): the Seattle MIO covers the Washington coast, the Straits of Juan de Fuca and Puget Sound; the Portland MIO looks after the Oregon coast plus the Columbia and Snake Rivers systems.

PORT SAFETY AND MARINE ENVIRONMENTAL PROTECTION - CAPTAINS OF THE PORT (COTP): the Seattle COTP has jurisdiction on the Washington coast from Point Grenville north, the Straits of Juan de Fuca, and Puget Sound; the Portland COTP covers the entire Oregon coast, the southern Washington coast to Point Grenville plus the Columbia and Snake Rivers systems.

The Portland Captain of the Port office is quite typical of most Coast Guard units in that it is a multi-mission operation, i.e. the personnel assigned to the office function to some degree and at some time or another in most of the Coast Guard program areas. The primary responsibilities and activities, however, lie in the Port Safety and Marine Environmental Protection Program areas. Although the ensuing discussion will separately address these two programs it must be kept in mind that at the practical, operating level the demarcation between them is, more often than not, indistiguishable.

PORT SAFETY PROGRAM

In the Port Safety Program area compliance with the following requirements is checked by Coast Guard inspectors through regular visitations to waterfront facilities and boardings of vessels:

Conformance with good housekeeping and safety practices on waterfront facilities, e.g. adequate guards, designated smoking areas, welding and hot work under safe conditions, arrangement and accessibility of safety equipment and cargoes, safe practices in electrical wiring, heating equipment and lighting, and adequate control of liquid cargo transfer systems.

On board vessels, foreign and domestic, we look for conformance with the safety regulations related to the safe handling, stowage, and transportation of explosives and other dangerous goods. Boardings are conducted on both dry cargo and tank vessels.

Our activities also include:
Control of the movement and anchorage of vessels (every vessel, with some few exceptions, entering the waters of the United States is required to give at least twenty four hours advance notice of arrival to the Captain of the Port). Issuance of identification credentials for persons requiring access to waterfront facilities or vessels. Enforcement of regulations related to anchorage grounds and special anchorages. Investigation of suspected violations of vessel load line regulations.

Visitations by Port Safety inspectors to the various ports within the Portland Captain of the Port Zone are based on the amount of maritime traffic which utilizes the port. For example -- daily visits are in order in Portland, while at Vancouver and Longview inspections are carried out two or three times per week. In Astoria, weekly visits have been appropriate. Once monthly at Coos Bay, Grays Harbor/Willapa Bay and the Tri-Cities has been adequate for Port Safety enforcement.

SPILL PROTECTION

Within the framework of the Marine Environmental Protection Program the Captain of the Port, Portland is, under the provisions of the FWPCA, the On Scene Coordinator (OSC) in the coastal portion of the Portland COTP Zone, namely, the Oregon coast, the southern Washington coast to Point Grenville, the Columbia River to Bonneville Dam, and the Willamette River to Oregon City. In the event of a large spill, the OSC initiates and directs action in accordance with the provisions of the Oil and Hazardous Materials Pollution Contingency Plan (National and Regional plans are called for in the FWPCA). The OSC is the single, Federal executive agent predesignated by the Contingency Plan to coordinate and direct pollution control efforts at the scene of a spill or a potential spill.

Although we must be ready to act when a large spill occurs, most of our activity is directed toward the multitude of small spills which happen every day, e.g. in the Portland/Vancouver area 235 water pollution cases were investigated by COTP, Portland during calendar year 1971.

The Captain of the Port carries out the following activities with respect to the enforcement of water pollution laws and regulations:

Received reports of spills. Conducts pollution surveillence patrols. Investigates pollutions reported or discovered. Monitors clean-up action. Directs clean-up action where the spiller isn't doing the job properly or at all. Reports the results of the investigations and clean-up action to the District Commander (assessments, of civil penalties or referral for criminal action are the responsibilities of the District Commander. Conducts training programs for Coast Guard personnel throughout the COTP Zone. Provides assistance to individuals and companies who have existing or potential pollution problems through the detection of potential sources, assessment of pollution potential, and consultation and guidance in setting up spill contingency plans and prevention programs.

Protection of the environment is not simply a matter of enforcing laws and regulations.

You, as individuals and members of your respective enterprises, must: Be aware of what constitutes pollution. Be on the look-out for pollution and report it to the Coast Guard. Be conscious of the possible pollution results of your own actions. Evaluate your own private and/or corporate pollution potential. Then eliminate your polluting practices.

The vigorous and reasonable enforcement of laws is a part of the solution to many of society's problems. But, as in most problems affecting large numbers of people, and this includes those of the Coastal Zone, the principal ingredient in the solutions is people -- people cooperating to find the answers. It must be remembered, however, that the solutions are not simple, cheap, or going to be achieved overnight.

REMEMBER: THE WATER YOU SAVE WILL BE YOUR OWN!

Technical and Economic Issues in the Water Quality Management in Yaquina Bay

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Joseph B. Stevens, Associate Professor of Agricultural Economics
Howard F. Horton, Professor of Fisheries
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The need for methodology to enable decision makers to define more clearly the alternatives among conflicting water use programs is well known. To help develop such methodology as relates to water pollution control, a cooperative program of research was undertaken at this institution by personnel of the Departments of Agricultural Economics, Fisheries and Wildlife, and Civil Engineering. Dr. Emery N. Castle, Head of the Department of Agricultural Economics, was Project Leader, and the investigation was supported jointly by the U.S. Public Health Service, the Oregon Agricultural Experiment Station, and the Oregon State University Sea Grant Program.

Yaquina Bay in Lincoln County, Oregon, provided the empirical setting for the study. This area has an estimated population of 10,000 and is centered on the estuary of the Yaquina River. Newport and Toledo are the largest cities, and tourism, commercial and recreational fishing, and timber products industries provide the economic base for the area. Several other much smaller communities were included in the study area (Figure 1).

The dual orientation of the area's economy toward industrial production and tourism provided a focus for our approach to the problem. Much public controversy had arisen when the construction of a Kraft paper mill in the upper estuary near Toledo was proposed in the late 1950's. Conservationists and businessmen were concerned that the discharge of Kraft mill effluent (KME) into the bay would have a deleterious effect on the recreational and esthetic resources of the estuary. The problem was resolved when it was agreed that the mill would dispose of its wastes directly into the ocean via a pipeline. This public policy debate was

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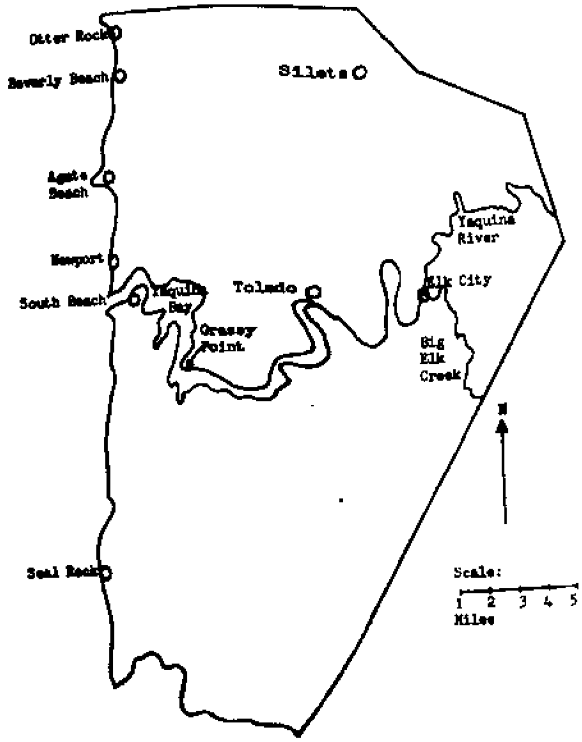

Figure 1. Yaquina Bay area, Lincoln County, Oregon.

thought to provide a realistic setting within which the objectives of the study could be pursued.

Our approach to the problem was to assume that Yaquina Bay was an unpolluted estuary. Economists then evaluated the recreational resource in the absence of water pollution. Alternative methods of waste disposal from the Kraft paper mill were then evaluated by the engineers. Assuming that the effluent would be disposed by dilution in the estuary, biologists predicted the loss of economic organisms. Economists converted the biological losses to economic losses based on human responses to the fishing success-effort relationship. And finally, economic impacts on the community were evaluated, and conclusions drawn with respect to institutional arrangements for water quality management.

Throughout the study emphasis was placed on measurement methods by which the physical and economic consequences of similar water pollution problems could be evaluated. Instead of being primarily concerned with the quantitative magnitudes which were applicable to the study area, our efforts were directed mainly toward making explicit the kinds of data necessary for an analysis of the problem, and how these data could best be treated to develop information which is meaningful for public policy purposes. Details of the entire investigation were presented in a recent final report (Stoevener *et. al.*, 1972).

ALTERNATIVE WASTE DISPOSAL METHODS[1]

Waste disposal into Yaquina estuary may be accomplished by various alternative methods. The degree of pollution resulting will vary with the method used. Disposal methods are:

1. Dilution by outfall at various points in the estuary.
2. Treatment by various methods followed by dilution in the estuary.
3. Storage during low river flows with disposal at high river flows.
4. Low flow augmentation.
5. Disposal of wastes on land.
6. Disposal by pipeline of all wastes to the ocean.
7. Disposal by barge of strong wastes to the ocean and disposal of weak wastes in the estuary.

In this report, only alternatives 1, 2, 6, and 7 were considered.

Alternative 1 (disposal by dilution) was selected as the example for our study because it was the least costly and incorporated many problems common to estuarine waste disposal. Harris (1964), using the method for determination of the average concentration of a pollutant introduced into a well mixed estuary developed by Stommel (1953) and applied to Yaquina estuary by Burt and Marriage (1957), computed the concentration of KME that would occur in the estuary from discharges at Toledo and Grassy Point (Figure 2). These computations were based on salinity and river flow (33 cfs) data taken in August, 1955, when conditions were considered most critical for the fishery resource (Stoevener *et. al.*, 1972).

BIOLOGICAL EFFECTS OF WASTE DISPOSAL

Biologists and economists used angler survey techniques to determine the most frequently caught fin-fish species in Yaquina Bay (Parrish, 1966). The five most important species were the white

[1]Condensed from Harris (1964).

seaperch (*Phanerodon furcatus*), striped seaperch (*Embiotoca lateralis*), pile perch (*Rhacochilus vacca*), starry flounder (*Platichthys stellatus*), and kelp greenling (*Hexagrammos decagrammus*). These fishes and the dungeness crab (*Cancer magister*) were used in bioassay tests. In addition, the young of walleye surfperch (*Hyperprosopon argenteum*) and English sole (*Parophrys vetulus*) were used as test animals.

Purpose of the bioassays was to determine the effects that various concentrations of KME would have on the distribution of the important recreational fisheries in the bay. With few exceptions, laboratory bioassay procedures were patterned after those recommended by Doudoroff *et. al.* (1951). Bioassays were conducted in 18 liters of standing sea water mixed with KME to some predetermined percentage. Aquaria were wide-mouth, five-gallon, glass jars. Experiments were conducted in a dark, constant temperature room at 19 ± 2 C. Samples of KME were supplied by the paper mill and represented a composite of seven days discharge. All bioassays were conducted for 96 hours or until more than 50% of the test organisms died. In this way, 48-hour and 96-hour TL_m's were determined for each test species.

Maximum allowable concentrations of KME for each species were then computed by use of an application factor of 1/10 of the 48-hour and 96-hour TL_m (currently the National Technical Advisory Committee [1968] recommends an application factor of 1/20 of a 96-hour TL_m for unstable or biogradable materials [such as KME]). The results of these determinations and calculations are shown in Table 1.

The original distribution of each species in Yaquina Bay was determined from creel census data on angler catch. Assuming that species would not inhabit those areas of the estuary where KME concentrations predicted by Harris (1964) were higher than the maximum allowable concentration predicted above, it became a matter of subtraction to determine the reduction in distribution for each species. These data were converted to percentage reductions. Table 2 presents a portion of the results.

These data became an imput to the economic analysis. But before leaving the discussion of the biological work, let us focus on some areas of needed research:

1. The avoidance reactions of estuarine fishes to various dilutions of KME is not known. If estuarine fishes tend to avoid sub-lethal concentrations of

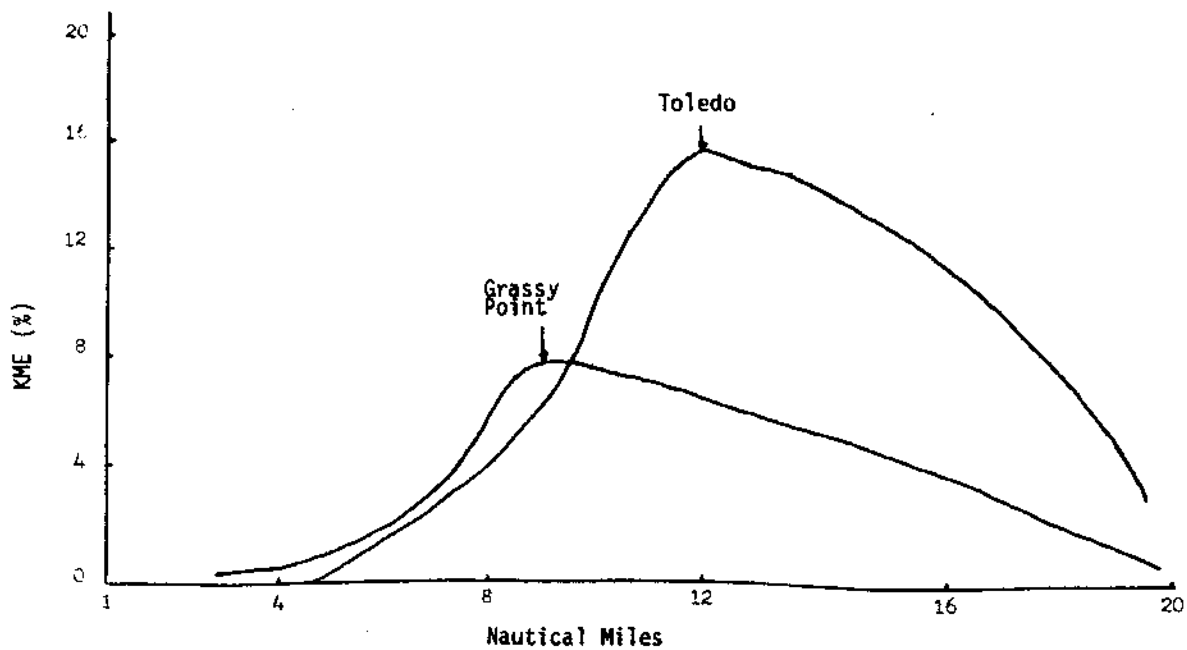

FIGURE 2. Curves of concentrations of Kraft mill effluent resulting in Yaquina estuary from discharge points at either Grassy Point or Toledo (from Harris, 1964).

Species	1/10 x 48-hr TL_m	1/10 x 96-hr TL_m
White seaperch	1.70	1.06
Striped seaperch	1.73	0.96
Starry flounder	2.50	1.22
Kelp greenling	3.10	1.52
Walleye surfperch	1.10	0.52
Dungeness crabs	--	--

Table 1: Maximum Allowable Waste Concentrations, by Species.

KME, avoidance tests could be more important to the prediction of changes in fish distribution than toxicity tests.

2. Additional research on application factors is needed. Toxic substances affect fishes and their environments in so many different ways that the use of uniform application factors is obviously ridiculous.

3. Information is lacking on the life histories of estuarine fishes. Knowledge of the temperature and oxygen requirements and salinity tolerances of the individual species is needed, so that the effects of variations of these factors on fish under the stress of KME pollution can be measured.

4. Tests should be made to determine the effects on the bottom fauna of the fiber beds resulting from the discharge of KME in an estuary.

5. The seriousness of tainting fish flesh by KME should be determined. Taste may take precedence over toxicity in determining the effects of KME on the economic value of a fishery.

6. And finally, flowing water bioassays should give more reliable results than standing water tests where accumulation of metabolic wastes are an added pollution factor.

Species	Original Distribution (Nautical mi.)	1/10 x 96-hr TL_m Predicted Distribution (Nautical mi.)	1/10 x 96-hr TL_m Percent Reduction in Distribution
Kelp greenling	11	5.8	47
Starry flounder	11	5.0	55
White seaperch	11	5.0	55
Striped seaperch	7	5.0	29
Walleye surfperch	11	3.8	66

Table 2: Effects of Grassy Point Disposal on Distribution of Certain Fishes in Yaquina Bay.

THE ECONOMIC VALUE TO SPORT-ANGLERS OF THE YAQUINA BAY FISHERIES

As discussed to this point, the attribute of water quality which appears to be of most biological significance for the Yaquina Bay sport fishery is the toxicity level. Changes in this parameter may bring about changes in the extent, vigor, and composition of the fishery resources. This characteristic, however, clearly refers to *water* quality rather than to the quality of the *recreation* as experienced by the angler. As such, then, changes in physical parameters of water tell us nothing about the monetary value of the fishery resource supported by this water.

When economists refer to "monetary value" of a non-priced recreation resource such as a sport fishery, it should be noted that there are two distinct types of monetary values. The one which will be discussed later refers to the stimulation of local or regional economies through expenditures made by recreationists. Another aspect of monetary value, however, has to do with the willingness of recreationists to sacrifice other goods and services in order to recreate (Stevens, 1969). The first question in the minds of many noneconomists is whether or not sport fishing can be subjected to conventional economic analysis. That is, can the value of salmon fishing be viewed in the same manner as the values of bread, meat, or automobiles? One might observe that the latter are priced by market forces, whereas sport angling is not. This is an accurate observation, but it simply reflects the fact that a policy of free access has been established for sport fishing on publicly owned waters. The presence or absence of a "price" reflects only whether or not a market has been allowed to operate; it does not indicate whether or not the commodity has "value" in the sense of providing satisfaction to users.

In that public policy has established free access to sport fisheries, direct measures of value (such as market price) which would reveal the willingness to pay by anglers are not available. For this reason, the developing economic methodology in this area of research has had to make inferences about willingness to pay from other data. In general, researchers have relied on "transfer costs" incurred by the angler as a means by which to make these inferences. Marion Clawson (1959) has suggested that a "recreational experience" consists of five separable, but related, phases. These include anticipation, travel to the site, experience on the site, return from the site, and recollection. In this context, the price variable for a sport fishing experience includes those costs incurred while transporting the angler to and from the site, as well as those incurred at the fishery. "Transfer" costs thus include such costs as travel, food, lodging, and any entrance fees or access charges which may actually be levied.

As a simplified example of the use of transfer costs to make inferences about nonmarket values, consider Figure 3. Three geographic zones surround the recreation site; each contains one thousand persons. Transfer costs are greatest for the most distant zone ($3 per day); thus, one might expect fewer visits from this zone than from this zone than from zones 1 and 2.

In addition to transfer costs, other variables have also been helpful to researchers in explaining the demand for, and thus the monetary value of, particular recreational resources. As with other goods and services, family income is usually considered as an important determinant of demand. Recently Brown, Nawas, and Stevens (1972) have found travel time or distance to be helpful in explaining the demand for big game hunting in Oregon.

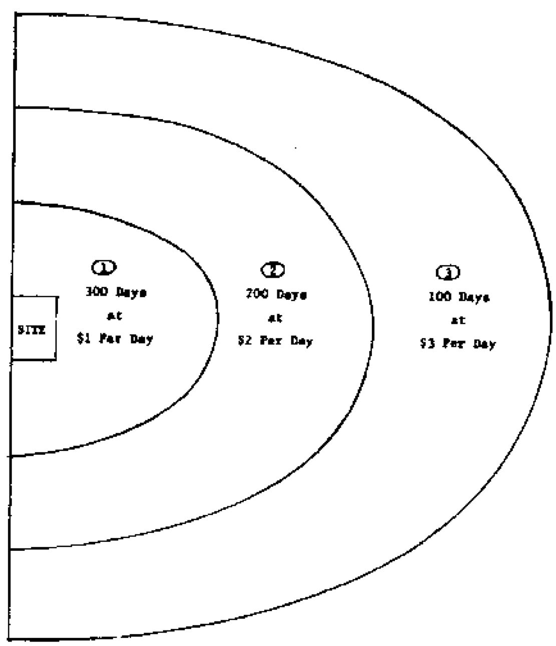

Figure 3. Recreation Days Taken at Three Different Distances from Site (One Thousand Persons in Each Distance Zone)

The methodology which we followed in estimating the adverse economic effects of each of the waste disposal alternatives had as its first step the estimation of demand functions for the Yaquina Bay sport fisheries in a (relatively) non-polluted situation. In other words, we asked, "what would be the effects of transfer costs and incomes on the demand for bay fishing and clamming, given a water quality regime established by ocean disposal of the Kraft mill effluent?" Data with which to estimate the demand functions came from interviews with 369 bottomfish angling parties, 120 salmon angling parties, and 69 clam digging groups. Estimates of the demand functions, with standard errors in parentheses, were:[2]

for the bottom fish fishery:

$$\ln Q = 8.32341 - \underset{(0.07366)}{0.68069}\, P^{**} + \underset{(0.12744)}{0.13274}\, I - \underset{(0.00743)}{0.01285}\, I^2$$

$(R^2 = 0.92)$

for the salmon fishery:

$$\ln Q = 5.59954 - \underset{(0.05770)}{0.69690}\, P^{**} + \underset{(0.10448)}{0.53153}\, I^{**} - \underset{(0.00490)}{0.02214}\, I^{2**}$$

$(R^2 = 0.95)$

for clamming:

$$\ln Q = 8.28347 - \underset{(0.45902)}{1.17091}\, P - \underset{(0.17442)}{0.15330}\, I$$

$(R^2 = 0.73)$

where:

Q = number of angler days per 10,000 population in various income and distance zones during a 12-month period in 1963-1964,

P = average variable transfer costs per participant day in that zone, including actual costs of meals, lodging, and expenditures at marinas, and an imputed round-trip travel cost of 6 cents per mile,

I = average yearly family income of anglers in that zone,

I^2 = average squared value of family income.

[2] A double asterisk (**) after a variable indicates that its coefficient was significantly different from zero at the 0.01 level.

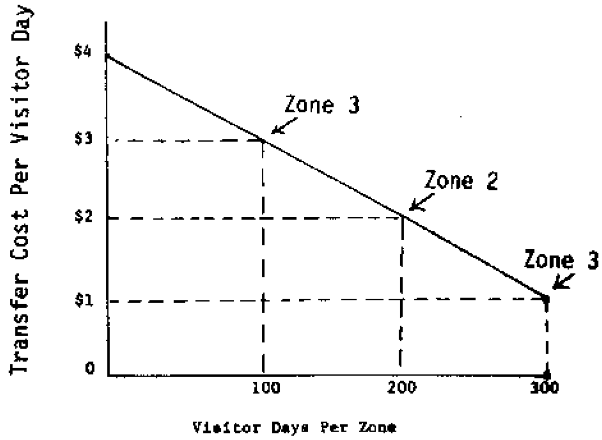

Figure 4. Demand for the Recreational Experience as a Whole

These equations represent what Clawson would term demand functions for the recreational experience *as a whole*. A diagrammatic representation of the earlier three-zone example is shown in Figure 4. The estimates of these functions then make possible the derivation of a demand curve for the site *itself*. By holding the income variable, the equations will yield estimates of the quantities of angling effort which would be taken at a series of assumed increases in the price paid by anglers for access to the fishery. In the three-zone example, a $1 surcharge (or added cost) specifically for the right to fish would

(a) cause zone 1 users to reduce their number of visits from 300 to 200,

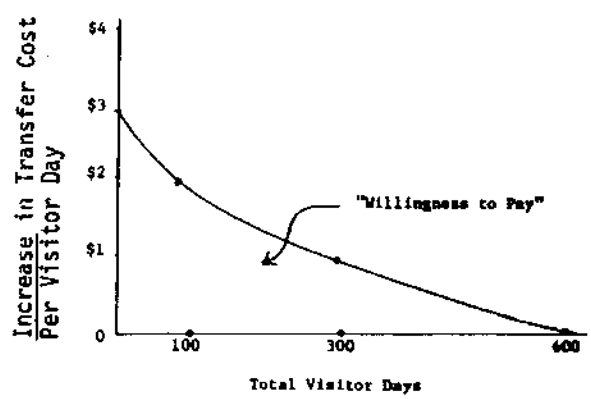

Figure 5. Demand for the Recreation Site Experience

(b) cause zone 2 users to reduce their number of visits from 200 to 100,

(c) cause zone 3 users to reduce their number of visits from 100 to 0.

In other words, we are using data from one set of users to predict what another set of users would do if they were faced with similar circumstances (Figure 5).

Having estimated demand schedules for the Yaquina Bay fisheries (Table 3), their *value* to recreationists may be inferred from the extent of "consumers' surplus", or the willingness to pay by users. Summed over the three fisheries, this value amounted to $62,819 per year in 1964. Briefly stated, the consumers' surplus technique is based on the premise that all anglers, with one exception, receive a "surplus" from not *having* to pay that price which they would be *willing* to pay for use of the fishery. The exception is the marginal user, who actually pays all that he would be willing to pay, and thus derives no surplus. If the price of the commodity were to increase, some portion of total consumers' surplus would be removed because (a) those users close to the margin would no longer purchase the commodity, and (b) the gap between actual price and the demand price by non-marginal users would narrow. Carrying this example one step further, if price were increased from an existing level (zero, in the fishery case) to that price where all users are priced out of the market, the total consumers' surplus would have been eliminated.

Having established these initial estimates of demand and value for each of the three fisheries, the relevance of the bioassay analyses which was discussed earlier can now be brought into sharper focus. In the biological analyses, the distribution and concentrations of Kraft mill wastes were translated into long-term toxic effects on recreationally important fishes and invertebrates in Yaquina Bay. These effects, in turn, were used to predict the reductions in fishing success which would be associated with each of the disposal alternatives. This procedure was intended to provide a missing link between *water* quality and the quality of the *recreational experience*, i.e., we made a prior hypothesis that angling success has a high degree of relevance to the decision framework of an angler, and that this variable can be viewed as joining transfer costs and family income as important determinants of demand. There is no doubt that characteristics other than angling success may also be part of the bundle of quality attributes of a sport fishing experience. On the other hand, the angling success variable seemed both relevant and easy to measure.

Price increase per angler day, (dollars)	Bottomfish	Salmon	Clams
0	28,372	10,236	6,446
0.50	20,207	7,204	3,592
1.00	14,332	5,075	1,998
1.50	10,244	3,589	1,113
2.00	7,238	2,558	620
3.00	3,682	1,275	54
4.00	1,854	564	0
(Total Consumers' Surplus or Willingness to Pay)	($42,273/yr.)	($14,872/yr.)	($5,674/yr.)

Table 3: Estimated Number of Angler Days Taken at Alternative Increases in the Price Paid to Fish at Three Yaquina Bay Sports Fisheries.

The demand model for sport fishing at Yaquina Bay could then be fully specified at:

$$Q = f\ (P,\ I,\ I^2,\ S),$$

where S represents angling success. Measurement of the relationship(s) between angling success and quantity demanded (angling effort) was accomplished in several different ways. Time and space do not permit a detailed explanation of the estimates of "success elasticities" (Table 4) except to say that they were derived independently of the demand models discussed earlier. An example of the estimation procedure can be shown for the offshore Winchester Bay[3] salmon fishery over the 1952-1964 period with standard errors of the coefficients in parentheses:[4]

$$Y = -418.755 + 209.537\ X_1^{**} + 0.19870\ X_2^{*}$$

$$(R^2 = 0.67) \qquad (65.766) \qquad (0.08186)$$

where

Y = total angler trips per year into the offshore fishery, per 10,000 population in Oregon,

X_1 = average number of salmon taken per angler trip,

X_2 = real per capita income in Oregon.

This equation revealed a positive, significant relationship between angling effort (Y and angling success (X_1). It also made possible the estimation of a "success elasticity" which indicates the expected change in angler effort associated with

[3] The Winchester Bay data were thought to be appropriate for use in the Yaquina Bay since much of the in-bay salmon fishing effort is due to rough bar conditions which prevent fishermen from fishing in the ocean fishery.

[4] A single asterisk (*) after a variable indicates that its coefficient was significantly different from zero at the 0.05 level. A double asterisk (**) indicates that the coefficient was significantly different from zero at the 0.01 level.

Fishery	Time Series Data: short-run	Time Series Data: long run	Cross-Section Data from Hypothetical Situations, Angler Stratum a/
Salmon	0.375 b/	0.999 c/	0.00 (0-25 miles, < $8,000)
	0.584 d/		0.00 (0-25 miles, ≥ $8,000)
			0.52 (26-200 miles, < $8,000)
			0.76 (26-200 miles, ≥ $8,000)
Bottomfish	0.09 b/	d/	0.66 (0-25 miles, < $8,000)
			0.95 (0-25 miles, ≥ $8,000)
			0.66 (26-90 miles, < $8,000)
			0.93 (26-90 miles, ≥ $8,000)
			0.88 (91-200 miles, < $8,000)
			1.18 (91-200 miles, ≥ $8,000)
Clam	e/	e/	0.80 (0-25 miles, < $6,000)
			1.07 (0-25 miles, ≥ $6,000)
			0.97 (26-200 miles, < $6,000)
			0.54 (26-200 miles, ≥ $6,000)

Table 4: Estimates of "Success Elasticities", or the Expected Percent Increase in Angling Effort Associated With a 1.0 Percent Increase in Fishing Success.

a/ Data in parentheses indicate distance from angler's residence to Yaquina Bay, and yearly family income.

b/ Estimated for time periods of one day.

c/ Estimated for time periods of one year.

d/ Estimated for time periods of one week

e/ Estimates were not made

a unit change in angling success, holding all other variables constant. An elasticity of +0.999 was computed from this equation, indicating that a 10% increase in angling success would induce an increase in angler effort of 9.99%.

At this point, an appeal to intuition may be helpful as a partial substitute for detailed discussion of our subsequent methodology. Earlier, we had (in effect) asked "What would anglers be willing to pay for sport fishing in a relatively unpolluted Yaquina Bay?" Our estimate of this value was $62,819 per year, or the sum of the areas under the three demand curves. At this point, we (in effect) asked "What would anglers be willing to pay for fishing if water quality and fishing success were to decline?". The intuitive (and appropriate) response is "...less than before". The demand function (or the schedule for willingness to pay) could be expected to shift to the left with lower levels of angling success.[5] This says that a lesser quantity of angling would be taken at any given increase in price above the prevailing (zero) price for fishing. Conversely, it says that anglers would be willing to pay less for any given quantity of angling effort. As the demand for an-

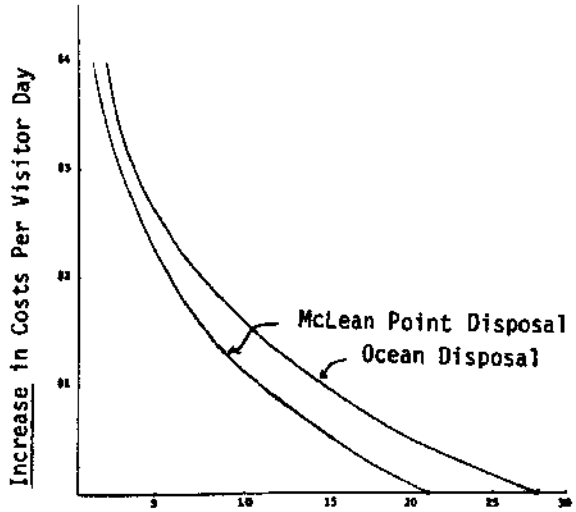

Figure 6. Demand for Bottomfish Angling at Yaquina Bay

gling shifts to the left with lower levels of angling success, the area under each of the demand curves (or the willingness to pay) becomes smaller (Table 5).

Having derived measures of willingness to pay for each of the three fisheries in the *absence* of water pollution and in the *presence* of varying degrees of water pollution, the potential direct benefit associated with a particular waste disposal alternative is synonymous with the difference in areas under the two demand curves (Figure 6). It can be seen from Table 6 that the largest benefit, $20,239 per year, would be associated with disposal of the pulp mill effluent at McLean Point, midway between the pulp mill and the ocean. Two factors account for this. If the mill wastes were released at McLean

[5]The estimates of "success elasticities" were used to reduce the values of the quantity variables (in the original demand equation) according to the disposal alternative and the consequent reduction in angling success. Leaving transfer cost and income variables unchanged, new demand equations were estimated which revealed "willingness to pay" corresponding to each disposal alternative. For further detail, see Chapter VI in Stoevener, *et. al.* (1972).

	Consumer Surplus or Willingness to Pay		
	Bottomfish	Salmon	Crab
Existing:			
Ocean disposal..	$42,273	$14,872	$5,674
Alternatives:			
Toledo..........	36,266	3,955	5,674
McLean Point....	31,590	10,990	0
Toledo-Ocean....	38,751	10,488	5,674

Table 5: "Willingness to Pay" for the Three Fisheries.

Disposal Alternatives	Reduction in Consumer Surplus or Willingness to Pay		
	Bottomfish	Salmon	Clam
Toledo................	6,007	$10,917	$ 0
McLean Point...........	10,683	3,882	5,674
Toledo-Ocean...........	3,522	4,384	0

Table 6: Direct Benefits Per Year Associated With the Three Disposal Alternatives.

Point, the damage to the down-bay bottomfish fishery would be greater than for the other two alternatives. Also, the McLean Point outfall is in the immediate vicinity of the clam beds. As a consequence, waste

INDIRECT ECONOMIC EFFECTS UPON THE COMMUNITY OF THE YAQUINA BAY SPORT FISHERIES

We alluded earlier to another measure of economic value which might result from the existence of the sport fisheries at Yaquina Bay and which might change with varying levels of activity in these fisheries. These are indirect effects associated with expenditures made by fishermen in the local area. Fishermen may purchase food, gasoline, fishing tackle, etc. in Newport in conjunction with their fishing trips to Yaquina Bay. Businessmen directly supplying recreationists with these products benefit from the latter's expenditures. Moreover, a portion of the increase in the incomes of these businesses is spent again locally, for example, to hire laborers or to purchase supplies. This permits another series of beneficial effects to be recorded.

If an economy were completely self-sufficient, and if individuals and businesses would not retain any of the income increases for savings, the chain of beneficial effects would continue forever; the "multiplier" would be infinitely large. Under actual conditions the size of this multiplier can have a considerable range. High values are often cited by those with great expectations for the community impact of a certain resource development plan. As we think about this phenomenon it becomes clear that the size of the multiplier of a certain type of expenditure depends largely upon the geographic size of the area and its economic complexity. In general, a smaller area and one which has a relatively simple or highly specialized economy depends much more upon imports than does a larger more complex economy. This means that the second and subsequent rounds of expenditures are at least partially made outside the local area. From the local area's point of view they represent "leakages"; the flow of funds within its borders becomes interrupted and no further beneficial effects will result.

Beyond these considerations then, the size of the multiplier is an empirical question, i.e., we need to measure it. In our study we used a measurement technique commonly known as "input-output analysis". Without going into many details of the method, let us indicate that this technique is capable of describing an economy's structure in considerable detail. It depends upon a classification of the activities in the economy, generally by industrial sectors, and obtaining the value of the flow of goods and services among these sectors and between them and the rest of the world as well. In our case we set up a classification of 16 local sectors. Personal interviews were conducted with a sample of about two hundred businesses and a similar number of households to ascertain the flow of goods and services within the economy. Table 7 shows the result when the sample data were expanded to the relevant population. The numbers in Columns 1-16 represent inter-industry purchases. They are the sales made by the sector listed on the left to the sector whose number appears at the top of the column. For example, the entry in the 6th row and 12th column indicates that an estimated $300,000 worth of goods were sold by the Fisheries sector to the local Wholesale and Retail (product-oriented) sector. The column labeled "Final Demand" depicts the remaining sales by a sector; in this case they reflect mostly exports.

Now making the simplifying assumption that a sector's requirements in terms of goods and services from another sector are a linear function of the first sector's

TABLE 7. Transactions Matrix, Yaquina Bay Area, Oregon, 1963 (Thousands of Dollars).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Final Demand	Total Sales
1. Lumber, Pulp & Paper...........	1,042										400					281	46,887	48,609
2. All Other Manufacturing.......	3		1	15	2	2		2	1	1	54	32			5	15	160	294
3. Hotels, Motels, Trailer Parks...						1					75				3	244	643	966
4. Cafes & Taverns.	11			2		1	*									1,112	859	1,985
5. Marinas & Marine Supplies........	6					64		4			4				*	57	573	708
6. Fisheries.......						358						300					3,991	4,649
7. Service Stations Automotive Sales & Repair........	2,002		*	2	48	78	1,043	708	68	1	214	52	40	90	76	5,353	1,776	11,552
8. Communications, Transportation..	1,721		19	38	68		24	21	19	38	40	38	5		35	725	192	2,981
9. Professional Services........	22	1	1	1	20	8	1		31	7	3	20	4	4	24	787	216	1,196
10. Banks & Loan Agencies........	60	6	24	24		60	12				6	30	18		3	1,250	116	1,658
11. Construction....	1,001		41	3	9	6	4	1	4	2	1,354	51	45	5	39	1,487	2,356	6,406
12. Other Product-Oriented Wholesale & Retail...	256	1	170	358	17	356	18	4	27	9	94	135	35	21	62	7,066	1,363	9,990
13. Other Service-Oriented Wholesale & Retail...	43		273	70	14	24	107	22	34	33	120	118	70	7	136	1,941	692	3,706
14. Agriculture.....	70	39										220		3		34	141	507
15. Government......	675	2	21	3	2	10	25	13	5	29	22	47	31	16		596	2,556	4,052
16. Households......	6,983	117	319	571	169	949	1,066	793	595	430	1,349	1,234	2,041	33	2,167	126	5,868	24,808
Import & Value Added...........	34,717	128	97	899	359	2,732	9,252	1,413	412	1,108	2,672	7,714	1,417	329	1,500	3,734		
Total Purchases.	48,609	294	966	1,985	708	4,649	11,552	2,981	1,196	1,658	6,406	9,990	3,706	507	4,052	24,808		124,069

* Less than five hundred.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Lumber, Pulp & Paper...........	.02144										.06244					.01132
2. All Other Manufacturing.......	.00005		.00123	.00749	.00337	.00051		.00080	.00100	.00072	.00837	.00322			.00123	.00062
3. Hotels, Motels, Trailer Parks...						.00029					.01171				.00084	.00983
4. Cafes & Taverns.	.00023			.00102		.00028	.00004									.04481
5. Marinas & Marine Supplies........	.00011					.01382		.00124			.00058				.00008	.00231
6. Fisheries.......						.07701						.03003				
7. Service Stations Automotive Sales & Repairs.......	.04120		.00029	.00086	.06812	.01683	.09026	.23758	.05665	.00041	.03343	.00517	.01092	.17786	.01874	.21578
8. Communications, Transportation..	.03540		.01934	.01692	.09570		.00207	.00719	.01567	.02289	.00627	.00380	.00126		.00864	.02922
9. Professional Services........	.00044	.00357	.00140	.00068	.02887	.00176	.00012		.02577	.00407	.00042	.00202	.00097	.00830	.00588	.03174
10. Banks & Loan Agencies........	.00123	.02028	.02469	.01202		.01283	.00103				.00093	.00299	.00483		.00074	.05037
11. Construction....	.02059		.04266	.00139	.01219	.00118	.00033	.00027	.00350	.00135	.21134	.00506	.01212	.00911	.00963	.05993
12. Other Product-Oriented Wholesale & Retail...	.00526	.00230	.17571	.18033	.02341	.07657	.00158	.00123	.02223	.00557	.01464	.01349	.00949	.04042	.01533	.28483
13. Other Service-Oriented Wholesale & Retail...	.00088		.02823	.03544	.01989	.00512	.00927	.00742	.02865	.01963	.01874	.01179	.01901	.01450	.03394	.07825
14. Agriculture.....	.00144	.13258										.02202		.00493		.00139
15. Government......	.01388	.00778	.02184	.00139	.00320	.00205	.00217	.00432	.00398	.01757	.00349	.00468	.00824	.03117		.02401
16. Households......	.14366	.39809	.32974	.28760	.23810	.20414	.09226	.26586	.49704	.25938	.21060	.12350	.55081	.06503	.53478	.00508

TABLE 8. Direct Coefficients, Input-Output Data, Yaquina Bay Area, Oregon, 1963

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Lumber, Pulp & Paper...........	1.02747	.00925	.01580	.00771	.00771	.00530	.00240	.00650	.00120	.00637	.00880	.00370	.01330	.00348	.01296	.02136
2. All Other Manufacturing.......	.00099	1.00160	.00439	.00940	.00481	.00162	.00041	.00190	.00310	.00184	.01190	.00391	.00223	.00074	.00343	.00355
3. Hotels, Motels, Trailer Parks...	.00280	.00592	1.00844	.00487	.00450	.00381	.00153	.00417	.00758	.00406	.01932	.00219	.00812	.00190	.00883	.01378
4. Cafes & Taverns.	.01049	.02443	.03198	1.02102	.01787	.01466	.00634	.01727	.03121	.01666	.01838	.00870	.03289	.00715	.03253	.05718
5. Marinas & Marine Supplies........	.00076	.00139	.00196	.00124	1.00115	.01583	.00036	.00223	.00180	.00098	.00181	.00096	.00188	.00044	.00195	.00324
6. Fisheries.......	.00247	.00566	.01302	.01041	.00477	1.08937	.00145	.00387	.00766	.00388	.00479	.03503	.00759	.00297	.00771	.01261
7. Service Stations Automotive Sales & Repairs.......	.11677	.16749	.19856	.12418	.20627	.10562	1.13628	.36289	.24863	.10344	.16013	.06271	.20280	.24024	.21155	.32872
8. Communication, Transportation..	.04518	.02020	.04745	.03615	.11162	.01368	.00738	1.02173	.04140	.03663	.02625	.01113	.02788	.00683	.03501	.04548
9. Professional Services........	.00840	.02350	.02670	.01644	.04332	.01357	.00494	.01320	1.05023	.01696	.01473	.00904	.02605	.01432	.03079	.04333
10. Banks & Loan Agencies........	.01355	.04928	.06475	.03672	.02156	.03128	.00865	.02079	.03728	1.01989	.02388	.01391	.04395	.00894	.03957	.06769
11. Construction....	.04569	.04618	.11837	.03999	.04870	.02869	.01209	.03202	.06190	.03256	1.30495	.02294	.07588	.02569	.07199	.10370
12. Other Product-Oriented Wholesale & Retail...	.07604	.17399	.40013	.31995	.14651	.18250	.04464	.11897	.23540	.11932	.14713	1.07657	.23336	.09118	.23707	.38768
13. Other Service-Oriented Wholesale & Retail...	.02491	.05549	.36149	.08190	.06183	.03851	.02400	.04720	.09792	.05670	.06904	.03196	1.09062	.03420	.10526	.12198
14. Agriculture.....	.00362	.13808	.01046	.00897	.00445	.00474	.00124	.00343	.00661	.00341	.00554	.02462	.00650	1.00730	.00674	.01086
15. Government......	.02140	.02833	.04694	.01616	.01603	.01247	.00661	.01626	.02501	.02876	.01853	.01148	.03003	.03689	1.02174	.03714
16. Households......	.22868	.54448	.71272	.44583	.39811	.31977	.14032	.38474	.69544	.37137	.40908	.19366	.73308	.15915	.72488	1.27428
TOTALS.....	1.62922	2.29527	3.06316	2.18157	2.09921	1.88162	1.39864	2.05717	2.55237	1.82283	2.32346	1.51251	2.53586	1.64142	2.55203	2.53258

TABLE 9. Inverse Matrix, Input-Output Data, Yaquina Bay Area, Oregon, 1963

level of output, a direct coefficient matrix (Table 8) can be calculated. The entries in this table are referred to as "direct coefficients", because they indicate the direct output response required in the sector of the row when the output of the sector of the column changes by one unit. For example, the entry in Row 12 and Column 4 indicates that, as sales in the Cafes & Taverns sector increase by one dollar, an additional 18 cents will be purchased from the Other Product-Oriented Wholesale & Retail sector.

The final operation which is required is an inversion of the matrix just discussed in order to obtain the indirect coefficient matrix (Table 9). Unlike the direct coefficients, the entries in this table portray not only the direct impact upon a sector's output when production in another sector increases by one unit, but they include the effects of all of the economy's interrelationships as described by the model. For example, the coefficient in Row 12 and Column 4 indicates that sales in the Other Product-Oriented Wholesale & Retail sector will increase by an estimated 32 cents for each dollar increase in output of the Cafes & Taverns sector. This effect is due not only to the direct relationship between these two sectors, as described by Table 8, but it also reflects the fact that, as a result of its output change, Sector 4 made purchases from sectors other than 12. The resulting increases in output by these sectors, as well as by Sector 12, led to additional purchases from Sector 4. The coefficient 0.31995 is an estimate of the effect of all of these direct and indirect inter-dependencies in the economy.

The sums of the columns of interdependence coefficients presented in Table 9 are of special interest. These are our estimates of the "multipliers". They indicate the total effect, in terms of the economy's output, resulting from a one dollar change in the final demand faced by the industry of the column. For example, an increase (decrease) of one dollar in the final demand of the Cafes & Taverns sector (Column 4) will generate an estimated additional increase (decrease) of $1.18 of output in the economy. We note that the multiplier of Sector 3 is the largest (3.06).

The coefficients in the Households row (16) have special significance of their own. Ultimately, we wish to ascertain the effects of some external incident (a change in final demand related to the water quality change) upon the incomes of the private individuals in the area who provide labor, capital and management inputs for the operation of the local economy. These effects, even though they are closely correlated to the size of the multiplier, provide a better measure of the change in the economic well-being of the residents of the area, than do the multipliers. After all, the latter measure gives an indication only of the change in the total volume of sales in the area.

Our survey of recreationists indicated that sportsmen spent approximately $154,000 annually in the area. When these expenditures were allocated to the various sectors in the input-output model and the multipliers applied to them, they explained a total of $317,000 of sales in the economy. Similarly, using the coefficients of the household row, they accounted for approximately $59,000 of household incomes.

But how do these measures change when water quality, fishing success, and fishing effort change? To estimate these numbers the same procedures are used with the input-output model, but the initial expenditures are adjusted to the level expected to result from the estimate of lowered fishing effort. Table 10 presents the results. These results are further summarized in Table 11. If we changed from the present method of waste disposal to those indicated in the Table, household incomes would change by as much as $18,000 annually.

These estimates are subject to a number of limitations. First, they are based on all of the estimates discussed earlier. Hence, any errors in those estimates are also contained in these. There are, however, additional limitations to be mentioned here. Students of input-output techniques have generally agreed that models of the type employed here are most appropriately used to describe the existing structure of a regional economy. They are less well suited for the analysis of the effects of significant changes imposed upon the economy from the outside. Such models can only portray the impact of these exogenous variables within the existing economic structure, which is determined by the trade relationships existing before the economic change occurred. In other words, such influences as changes in factor or product prices which are likely to affect the existing trade relationships cannot be reflected in the model. The application in this study required, of course, that prediction of the consequences of exogenous changes, namely, variations in the levels of recreational expenditures. Perhaps there is one ameliorating circumstance: as indicated earlier, the effects analyzed here involve proportionately small variations in the levels of final demand. Hence, required changes in trade relationships are also likely to be small.

Another source of error which is also difficult to assess is contained in the data used for the construction of the input-output model. As was indicated, part of the data was collected through sample surveys. The effects of sampling errors in data collection for input-output models are difficult to quantify. No attempt at formal quantification was made in this study. Furthermore, on the basis of a subjective evaluation, the various primary and secondary data sources did not seem to be of uniform reliability. Data from various sources had to be combined and reconciled with one another. It is likely that these processes involved errors of judgment. The only possible checks on the extent of these kinds of errors is the comparison of the results from this study with those obtained from other

Sector	Disposal Alternative		
	Ocean	Toledo or McLean Point	Toledo & Ocean
Lumber, Pulp & Paper	$ 1,163	$ 818	$ 972
All Other Manufacturing	724	509	605
Hotels, Motels, Trailer Parks	24,669	17,371	20,623
Cafes & Taverns	28,037	19,722	23,437
Marinas & Marine Supplies	47,782	33,611	39,943
Fisheries	2,066	1,453	1,727
Service Stations, Automotive Sales & Repairs	42,742	30,059	35,718
Communications, Transportation	8,616	6,062	7,203
Professional Services	3,619	2,546	3,025
Banks & Loan Agencies	4,313	3,035	3,605
Construction	7,461	5,251	6,237
Other Product-Oriented Wholesale & Retail	63,482	44,663	53,070
Other Service-Oriented Wholesale & Retail	18,827	13,250	15,740
Agriculture	1,586	1,116	1,326
Government	2,930	2,062	2,449
Households	59,380	41,765	49,619
TOTAL	$317,397	$223,293	$265,299

Table 10: Effect of Sport Fishing Expenditures upon Total Sales, by Disposal Alternative and Sector, Using Input-Output Analysis.

Disposal Alternative	Effect Upon	
	Total Sales	Household Incomes
Toledo and Ocean................	$52,098	$ 9,761
Toledo and McLean Point.........	94,104	17,615

Table 11: Estimated Effects upon Total Area Sales and Household Incomes, of Changing from Ocean Disposal to Alternative Waste Handling Systems.

studies. One such comparison was made. Generally, the multipliers estimated by this model were consistent with those obtained in the other application (Bromley and Stoevener, 1968).

But even beyond these considerations there is the question of relevance of the indirect benefits. We have seen that the size of the multipliers is largely a function of the complexity and geographic size of the economy to which they pertain. If this is so, one may justifiably ask: "Why not increase the size of the study area and thus enlarge the quantity of the indirect benefits?" Without carrying this argument to the extreme one could easily justify considering this question in the context of the national economy. But doing so would require our facing up to another issue. From the national viewpoint thus adopted, are these benefits real? Is it not possible that the expenditures made by sportsmen in the Yaquina Bay area might have been made elsewhere leading to the same beneficial effects on the national economy? We can only give an affirmative answer to the second question. However, we have estimated these effects because knowledge of them not only sheds light upon some aspects of the local debate about water quality management, but it is also useful for the analysis of local institutions for water quality management. In the comprehensive publication on our project which was mentioned earlier, we report on this subject. It is another element lending generality to our work in the specific problem setting of Yaquina Bay.

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Pacific Northwest Coastal Zone Management as it Relates to Estuary Protection

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First, let me say that I firmly believe that the only complete protection for Oregon's estuaries is through coastal zone management. The opinions expressed in this talk are to be considered my own and not construed as policy for any group of which I am a member.

At a meeting in Newport, Governor McCall asked the coastal people to form a coordinating council or committee, the purpose being to coordinate the local planning efforts into one coastal zone plan. After this initial request, which received varied reactions, we, on the coast, did form the Oregon Coastal Conservation and Development Committee. This initial effort was comprised of 24 members, including one county commissioner, one port commissioner and one elected city official from each of the seven coastal counties.

It was determined that there were some 208 governmental bodies (including federal and state agencies and local units of government) that have traditional and/or legal interests in the management of the coastal zone. A substantial part of Oregon's coastal zone management problem arises out of the interagency conflicts over jurisdiction. Added to this is a maze of duplicating mandates in planning on both the federal and state level. It became apparent that one of the first tasks requisite to a rational management of coastal resources was the determination of just who was to call the shots in the role of coordination. It is, however, neither necessary nor desirable for all power relating to coastal zone management to be vested in one state agency. The need was for the designation of one state agency as the "lead agency", with authority to coordinate a coastal zone management program. Such an agency came into being with the passage of our own bill, SB 687, by the Oregon Legislature.

Witness the recent "Keystone comedy" act that went on in the Siuslaw estuary. A poor uninformed citizen thought he had the right to fill his own land just because he paid taxes on it. Local Port complained because material being used (stumps) was objectionable. Local State biologist did nothing, saying he was a friend. Then State agency No. 1 plus Federal agency inspected the fill and threatened court action if corrective measures were not taken, whereupon indignant property owner outlined, in letter form, his intent to comply with detailed plan of action. Back came a letter of glowing praise for his spirit of cooperation. Next, while waiting for a favorable tide, another threat of court action -- all because he did not have a permit to fill. So with two pieces of equipment he set out to remove the illegal portion of the fill. Two days later, before he could finish, up pulled state agency No. 2 and demanded he quit removing the fill until he had legal permit for removal. How easy all of this would have been if there had been a state inspector stationed on the coast.

In writing our bill, we tackled the problem of what actually is the coastal zone in Oregon. Keeping in our minds that estuary protection was our first priority, we sought the answer. Two of us had toured several East Coast states where initial coastal zone management started. In some states, it was apparent that the coastal zone had been drawn with political subdivision boundaries. This resulted in jigsaw puzzle maps that, in my opinion, had very little to do with sound comprehensive planning.

To further complicate things, Senate Bill 296 was introduced as an estuary protection proposal. This bill defined the coastal zone as a very narrow zone bordering the actual estuaries. This closely resembled the San Francisco Bay Plan. I had been in touch with the Bay Area Group for several months. I asked them why they didn't design their program to include more of the estuary. The answer given was that they had included all that was politically possible at the time. An expression of envy was apparent for Oregon's chance to do better.

After looking at the past track records in other states, we took the step we felt was necessary to get the job done. Our definition of the coastal zone in Oregon was from the top of the Coast Range to the three-mile limit offshore. Without controlling the entire watershed of any given estuary, little can be done to protect that estuary.

A simple example, in layman's language, might be one's own bathtub. Consider it a miniature estuary and set up hard and fast rules about keeping the edges clean. Then ignore the incoming water -- water that could be half silt, such as some of the wintertime estuary streams and rivers. The results are the same -- a bathtub full of mud and a dying estuary. Sedimentation is currently the largest single threat to Oregon's estuaries.

Then came U.S. Senate Bill 582, providing federal funds to a coastal zone state for planning purposes. The arbitrary inland extent for study purposes in this bill was seven (7) miles inland from the high tide line at the ocean. Almost all of Oregon's estuaries extend beyond this seven mile boundary. Realizing that if this federal bill became law we would be stymied with unrealistic boundaries, we sought help. I contacted our attorney, who suggested proper language for an amendment. This was then forwarded on to Senator Hatfield who modified our proposal. The Senator was responsible in passing the following amendment:

"...provide that where section or inland boundaries divide an existing local, region, or state political subdivision, or planning unit, the state may, for the purpose of this act, include the entire political subdivision."

This, in effect, makes the matching funds available for our entire coastal zone planning effort as we designed it. We feel this was a major amendment to the bill. Another Hatfield amendment to the bill was that the local unit of government must be consulted as the planning process in going on.

With the passage of our bill, we became a state commission and, officially, a state agency. The make-up of the Commission was changed to 24 elected coastal officials plus six Governor's appointees representing statewide interests. Fears of outside interference were soon laid to rest by the caliber of people the Governor appointed. Their outside look at our daily problems has proved invaluable. However, the Willamette Valley people seem to share our distrust of outsiders in their planning efforts. After considerable chiding, they did appoint one coastal person to their planning efforts. Unfortunately, the statewide interest people did not get backed up with statewide funds. At present, our Commission is operating entirely on county and port donations.

Our legislative mandate as I interpret it is to prepare a coordinated comprehensive natural resource use plan for our coastal zone by 1975. This plan is to contain policy statements and standards for all resources within the coastal zone of Oregon. This plan is to be in the form of a legislative proposal so that implementation can be insured.

To accomplish this task the full cooperation of state and federal agencies, as well as local units of government, will be needed. In addition, a massive citizen involvement at the outset is essential. The OCC&DC also will have the opportunity to identify and possibly ask for interim solutions at the 1973 Legislature.

The estuary is an ever-changing, complex living thing requiring a very delicate management program. This program should be based on hard technical facts, as opposed to emotions. An in-depth search on past case history is essential to avoid interim mistakes that could cause severe damage.

Just as the estuary is an ever-changing unit of life, so is the human population that lives around it. Times are changing very rapidly with the somewhat new awareness of our environment. People are becoming active and are running for positions on local units of government on the coast. They want to become involved at the decision-making level. They want a hand in forming policies, goals and standards that affect their way of life today, as well as their future generations. I believe the majority of the user population is truly concerned with the wise use of Oregon's natural resources in the coastal zone.

Most of Oregon's estuaries are now utilized on the multi-use concept. This is due to the proximity of vast supplies of standing timber and tremendous recreational potential, both of which are now essential in order to maintain a year-round economic balance. However, the Willamette Valley's population explosion is putting a heavy boating demand on all Oregon estuaries and their fishery resources. The tourist industry, highly-touted as one of our finest and cleanest industries, grows only with more and more people. This, in turn, creates more severe problems for local service districts.

At this point in time, Oregon can be proud of its coastal zone. This should be credited to former local officials who ran the counties, ports and cities, as well as the state legislators. In recent times, such actions as ports having state natural resource agencies pick all dredge spoil sites is realistic. Passage of SB 224 adding fills to state permit systems is a step in the right direction. However, wetlands and marshlands are, as yet, unidentified and unprotected.

The permit system as a tool for protecting areas of critical environmental concern is very weak. The man or firm applying for a permit for, say a development on a sand spit, agrees in advance to work according to rigid guidelines set down by the permit authority and so is granted a permit. Now then, during the course of construction, after having opened up 40 acres of active sand, he goes broke, so he says good-bye and returns to California. The resource has been damaged and there is an open wound which, in turn, can spread and damage the estuary. Without some kind of performance bond requirement to go with the permit system, wholesale damage may result. This requirement should be mandatory and the amount adequate.

With the help and cooperation of people like Kess Cannon, Hal Brauner, Governor McCall and many others, the OCC&DC will complete its legislative mandate on time. The development of policies and standards based on the carrying capacities of the natural resources should insure the protection of the same. Our job will also be made easier because of one of the finest Marine Science Centers in the United States, the OSU Marine Science Center at Newport, Oregon.

On behalf of our entire Commission, I can assure you we will continue to pursue our legislative mandate. This pursuance shall continue through and including the overall implementation of this worthwhile program.