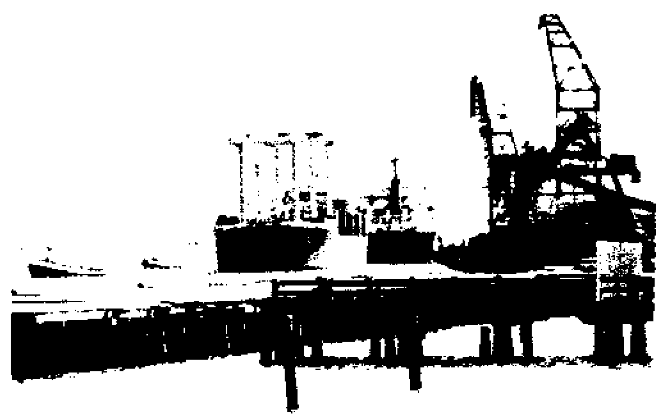
PROCEEDINGS
3rd annual
technical conference

estuaries

of the
PACIFIC NORTHWEST
MARCH 15-16
1973



Oregon State University
Engineering Experiment Station
Circular No. 46

OREGON STATE UNIVERSITY
Sea Grant College Program

Publication No. ORESU-W-74-002

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The Oregon State University Sea Grant College Program is supported cooperatively by the National Oceanic and Atmospheric Administration, within the U.S. Department of Commerce, by the State of Oregon, and by participating local governments and private industry.

CONTENTS

Welcoming Address: Roy A. Young, Vice President for Research and Graduate Studies, Oregon State University

It is a pleasure to welcome you on behalf of Oregon State University to the Third Technical Conference on Estuaries of the Pacific Northwest.

Dr. Slotta and others planning the conference have arranged a varied program that includes a list of timely topics dealing with estuarine problems and opportunities.

We are pleased at Oregon State University to be a part of the rather broad, but probably not yet sufficiently intensive, program of research and management of estuaries that will be discussed here today and tomorrow.

We are in a period when questions seem to arise more rapidly than answers can be developed, yet a period when the availability of new information exceeds the availability of funds and legislation for implementation of research or management programs.

This is a period when the use of the terms "coastal zone management" and "land use planning" give comfort to conservationists and bring fear to developers, a time when those attempting to manage and plan for the protection and improvement of our coastal resources find public understanding and fiscal resources lacking or inadequate.

This is also a time when the Federal government may decide to withdraw support of programs in states with the justification that such programs are now handled more appropriately under state jurisdiction with funds provided through revenue sharing. It is also a time when one finds a deficit in revenue when one compares the sum of the reductions with the total available through revenue sharing.

Along the line of this last subject, I should like to comment briefly about trends in availability of Federal research support.

As I am sure most of you know, training support of most types is on the way out for at least two reasons: (1) a belief that there is now an oversupply of trained manpower in most fields, and (2) a philosophy that questions the propriety of providing graduate students with a stipend and research support to assist them to qualify themselves to earn a better salary.

Those who support the latter philosophy apparently do not wish to consider two important points: (1) that most graduate students forego many thousands of dollars of income during their period of graduate study, and (2) that graduate training enables students to make a much greater contribution to society than would be possible with undergraduate education alone.

Whatever the reasons, NSF and NASA traineeships have been terminated. NIH training grants will, for the most part, be phased out over the next three years and EPA training grants are being reduced in number and weakened significantly by the elimination of stipends. Tuition, fees, a modest expense allowance, and a limited amount of dollars, possibly 20 percent of what is needed for stipends, will be provided in Fiscal Year 1974 by EPA.

On the encouraging side, it is expected that increased funds will be available for basic project research through NSF and that funds available through the RANN Program will be up about $7 million.

These increases are little more than cost-of-living increases but they are far better than reductions such as have occurred in most agencies. There are also indications of substantial increases in support through legislation such as the Kennedy Bill.

There are many questions about the policies and philosophy of the present administration and the desire of Congress and their impact on budgets that probably will not be answered clearly for several months.

It is obvious, however, that there will be increased emphasis on supporting research related to solution of national problems. So hopefully there will at least be a continuation of support at current levels to enable those of you concerned with estuarine problems to pursue your interests.

May I extend wishes to you for a stimulating and enjoyable conference.

Overview of Commercial Aquaculture in Oregon

John R. Donaldson, Associate Professor
Department of Fisheries and Wildlife
Oregon State University, Corvallis

What is all the fuss and excitement about? There is absolutely nothing new about the idea of farming water. It is at least several thousand years old. The Chinese raised carp and the Romans fattened oysters before Christ was born. Many people of the world today depend on water cultured stocks for their protein as they have for centuries. The art of fish farming or aquaculture, to use the more erudite title, is well established for things such as carp, oysters, trout, shrimp and numerous other species less well known to us here in the Northwest such as the 25 million metric tons of yellowtail produced each year in Japan.

Science has bolstered the artisans of aquatic husbandry in this century with the resultant that more and better pounds can now come from a given unit of water. Often the water, both qualitatively and quantitatively, comes from and is used in areas that only a half-score years ago would not have been considered. By far the greatest portion of these advancements in the areas of nutrition, disease, genetics, and facilities have come from federal, state and academic institutions. Other advancements in the basics of aquaculture have come from the commercial sector. Their contributions have come in efficiency of operations aimed at cost cutting.

In the Pacific Northwest, and especially Oregon, commercial aquaculture means only two groups of animals, trout and oysters. Trout farms in Oregon number only twenty-six. Most of these are small family affairs that operate "you-catch-um" ponds or sell fish for stocking farm ponds. The economic impact of this industry is minuscule. Oyster rearing in Oregon presently represents our only real effort in aquaculture. However, according to a recent report on oysters by Breese and Wick (1972) Oregon production falls behind that of Washington and California

A new opportunity for harvesting products from sea water is the semi-culturing of chum salmon now possible under a permit system in Oregon. The biological and legal details of the new venture will no doubt be discussed by later speakers today, so I will only mention it briefly. Four permits have been given thus far by the Fish Commission of Oregon. One of these operators has a substantial start while the others are getting underway with a token stock of some 10,000 eggs this year. If the chum respond to this form of husbandry, and the scientific leaders on the OSU staff working at Netarts Bay say there is real hope, it could mean a new natural resource based industry for Oregon with a species that was on its way to extinction.

When you add it all up, however, there is not much in the way of aquaculture in Oregon to overview. Although there are no figures available to represent the value of this industry in total, it is safe to say that it is orders of magnitude less than the dollars generated by commercial fishing and processing. Must aquaculture remain at this low level? Are there no opportunities for expansion? What are the possibilities for future expansion? The collective answer to these questions is an affirmative, yes, there is a big future.

In order to explain my optimism let me describe for you a scheme that I personally have great faith in becoming a reality. What is to follow is a "what if" game with the "if" almost entirely removed. This will be a story of how to become a fish farmer in Oregon.

To become a fish farmer you obviously are going to need water, land, some kind of fish and possibly food. Your first decision is what fish.

If you choose oysters the scenario is well written. You do it either on the bottom of bays or floating from rafts. Breese and Wick (1972) cover the basics. Whether you sink or float you need a piece of in-bay real estate. If you can locate a suitable site, that is not already taken, it is quite possible that it can be leased from the State through the Fish Commission. Once established you join the "oyster seed game" which has plagued Northwest oyster culturists from the beginning. However, as a result of research, such as that being done at the OSU Marine Science Center, the complete domestication of the oyster is now possible. "Oyster factories" where spawning and setting are controlled are being built and availability of good seed will be assured. More people will no doubt begin to oyster farm. Clams are also farmable to a degree and await investment in energy and ideas. Mussels, because of their productivity, would be easy to rear, however, marketing is the hurdle with them.

What if you choose crustaceans? Here the art is less precise, especially in the Pacific Northwest. The problem common to all crustaceans is that they practice intra-specific aggression and when crowded under artificial situations, it becomes particularly devastating. The Oregon species most likely to succeed under man's thumb is the crayfish. Research at OSU, under Sea Grant support, has begun to unravel the technology leading to crayfish husbandry. A signficant finding is that they do well in warm brackish water. Lobsters would probably be next as there is a developed technology on the East coast and their market value is especially titillating. Crabs and shrimp have problems associated with their life styles, but effort and imagination will see to their domestication in time.

What about the fishes with fins? Here I'm afraid, because of being born a salmonid biologist, my prejudices will show. There are other fishes to culture such as flatfishes and possibly a variety of sea-type perch, but the state of the art plus the economics keep them back on the shelf. With salmon and trout the story is different. There is a vast technology and the economics are right.

If you choose chum salmon your problems with water, land and food are easy as the eggs and young fry prior to migrating to sea take little water and space and no food is required. The sea does all the work and covers all the costs. It is almost like something for nothing and it takes no fish husbandry experience. However, you are occupied only a small portion of the year and thus it is highly seasonal. Most operators must have another job at least until many thousand chums begin to return. To say the least, the private chum salmon hatchery permit has stimulated considerable interest among coastal residents who have access to a stream direct to the ocean. However, the results of hearings in the Oregon Legislature on SB 96, which proposes a $100,000 surety bond on chum salmon hatcheries, will influence this ardor. Again I leave the details for following presentations by Al Hampson and Bill McNeil.

What if you want to rear salmon and trout in captivity for the market? The problems as stated before, are land, water, brood stock and food. You need a freshwater hatchery where eggs are incubated and the young fed to market size. Better yet is to feed them in freshwater until they are physiologically ready to go into saltwater, then transfer them for the final rearing. Saltwater rearing has the advantage of slightly better growth and results in a quality of fish far better than those reared in freshwater. Their market shelf life is also significantly longer.

The types of rearing facilities used are quite variable. The freshwater plant needs year-around water of reasonable quality. Copious amounts of gravity-flow water are practically out of the question. These sites have long been taken up. However, with the development, in recent years, of the technology to recycle water within a hatchery there is no longer the dependence of a source of water with high quantity and quality. Needing only ten percent of your total volume as make-up water, a major facility can be built around one cubic foot per second of water

Saltwater rearing can be done two ways. Floating pens can be rafted in bays and estuaries and the tides used to circulate water through the enclosures. Major facilities are being built in Puget Sound to rear millions of pounds of pan-size fish for market yearly. This approach is not possible in Oregon as it is viewed by our regulatory agencies as a pollution risk in our bays. If you want to use saltwater in Oregon you must get up on land and pump the water into ponds. The land based operation is twice as costly to construct. However, feasibility studies have shown that due to differences in maintenance, replacement and operation costs, the ponds are actually cheaper over time. The higher risk factor in open-bay rearing versus ponds is also recognized.

All species of salmonids can be reared in saltwater to market size in a year's time, however, fall chinook, coho and rainbow trout are recognized as the most suitable. Once nutrition and disease problems are reduced, chum salmon will be on the list. Presently the only source of salmon eggs is by purchase from the State agencies, if they have surpluses. Since there may not always be surpluses available a commercial operator should have his own brood stock. SB 265 is presently before the Oregon Legislature and if passed will add chinook and coho to the chum salmon hatchery permit. A fish farmer would liberate migrants to go to sea and then manage the returns to allow him to take surplus eggs for his contained rearing. Another real possibility for a source of eggs is to rear your own salmon in captivity to maturity as you do with the trout. This technology is progressing rapidly under the direction of the National Marine Fisheries Service in Puget Sound.

With land, water and a stock of fish arranged for, there remains the considerable problem of food. Fish food manufacturers prepare several types of feed that up until recently were readily available. However, the recent halt in Peruvian fish meal exportation has put the fish food business into crisis conditions. As availability has dwindled prices have risen. Therefore, in order to proceed with a major rearing program the wise farmer must consider producing his own food. This is not a simple task. First a source of fish, either whole or scrap, must be obtained, then a facility designed and operated to reduce the price of food which is the major portion of production costs. This not only must, but can be done. Without question, food represents the difference between profit and loss in commercial salmon culture.

In order to insure quality of the product to the market an operation should have its own processing facility. Fish products, especially in the fresh state, have not always been treated well in order to insure quality. By following a product from harvest through to consumption, an operator can keep control of quality. The food production and the processing of the products can share a common facility.

All the foregoing discussion, as to how to get into fish farming with salmonids, has assumed that you just go out and do it; not so. There are a myriad of permits needed. The following list of permits with comments added will allow the prospective fish farmer to see what is needed to get into business.

1) Private Game Fish Hatchery License:

   This is by far the easiest and cheapest ($5) of the permits. A letter to the Oregon Game Commission is all that is needed. The permit allows you to commercially raise game fish, which includes all the trout and the five species of salmon until they are fifteen inches in length.

2) Chum Salmon Hatchery Permit:

   This permit allows you to incubate and release to a stream, migrant chum salmon which on their return to your facilities as adults you can harvest commercially. An application, along with $100, is submitted to the Fish Commission of Oregon. Following a close review, the applicant is given a hearing before the Commission. They are very careful about the awarding of these permits. An applicant can expect it to take three months or more even under the most ideal situations.

3) Water Right:

In order to take water from a natural stream a permit must be secured from the State Engineer. A fee of $33 along with details of where and how much must be supplied. Three to six months are required to obtain a permit providing water is available.

4) Waste Water Discharge Permit:

Although this permit is free, it is by far the most complex and difficult to obtain. The Department of Environmental Quality has set very strict standards with regard to the effluent from a fish hatchery. Very careful production schedules must be worked out showing pounds of fish, food to be fed, and water volumes. Treatment facilities must be designed to meet the standards. Six months at least are needed to accomplish this chore and with ever more involvement by the federal Environmental Protection Agency, one can expect this permit to take up to one year.

5) Construction Permit for Navigable Waters:

Another free one, but also time consuming. The Corps of Engineers requires a permit for any construction that will take place in navigable waters. A pump intake or outflow system would require such a permit. At least three months are needed.

6) Local Zoning and Building Considerations:

State-wide planning efforts have brought zoning restrictions to most areas. This is especially true of estuaries. Coordination with local zoning is essential in order to get approval to proceed. Codes for building and sanitation are becoming more stringent and attention must be paid to these details. They also take time.

If you have made it through the organizational morass, and of course, have secured the necessary financing, you are ready to operate a truly integrated fish farm. Rather involved feasibility studies have shown that a complete system operated at a level of several million pounds being marketed annually is the best way to proceed. If you include mollusk and crustacean culture you are then truly an aquaculturist. Obviously it is not for the casually interested person or the faint of heart.

A diversified production program that encompasses the entire process, for each species to be reared, is an exciting new concept for a natural resource based industry in Oregon. It also can be made compatbile with the present-day rash of environmental concerns. Yet there are objectors in the form of other user groups. The commercial fishermen fear competition in the market place while the sports fishermen view it as another dollar-oriented use on what they feel are their exclusive fish. If SB 265 passes, more fish will be put into public waters for all to catch, and at no cost to the state. The sportsmen still do not see the obvious advantages to resource enhancement that this will provide. The commercial fishermen are quick to see this fact.

Several of our estuaries are suited to this type of development. Those of us who have studied the bays and the life in them for so long, must now realize it is time to get involved with actual production. The need is not for more research to develop technology, we know enough now to start. The problems are legal and social. We, and I mean academicians, have not done our homework with the state and federal agencies that control the environment and the user groups such as commercial and sports fishermen. They, for the most part, are unaware and suspicious as to what aquaculture is all about. The private and public lending institutions, that are needed to provide the large amounts of capital to do the job right, must be educated as to what can and can't be done.

If aquaculture in Oregon is to live at all, it is in these areas that support is needed. We are not free of physical and biological problems and never will be, but these can be challenged as we go along.

The base work has been done. We must now believe that fish farming can be done and see that someone goes out and does it.

Legal Aspects of Aquaculture

Alfred A. Hampson, Attorney
Hampson & McLean, Attorneys at Law
Portland, Oregon

The law deals by and large with contracts, and vast sections of law deal with fish treaties. Foremost among those legal writings is the famous treatise on a treaty by Robert Bencheley, written when he graduated from Harvard. He wrote his final thesis on "Cod Fishing in the Grand Banks from the Point of View of the Cod." Perhaps I should make my presentation on aquiculture law from the point of view of the fish.

There is an historical background for aquiculture law. For many years English judges and lawyers, who hammered out what we call the Common Law, were confused by the fact that fish and wild animals would not readily come under the thumb of man. It bothered them that there were creatures that didn't pay attention to the rules and the laws. So they eventually worked out something they called a "ferae naturae," which means wild animal.

This solution applies also to fish. The "ferae naturae" lives and exists on its own without ownership, and can be owned only when it is reduced to effective possession. Certainly, one of the few pleasant things about going to law school is studying this concept, because all of the cases deal with whether you owned the fox when you caught him, and if he escaped and someone else caught him, was he yours or another hunter's?

Two kinds of laws deal with aquiculture. First, in arrogance, legislatures have declared certain fish to be the property of the State of California or of the State of Oregon. They haven't told the fish this, and the fish, I'm afraid, is a ferae naturae and anybody who gets him can have him regardless of the laws of the states of California or Oregon--regardless of the fact that they assert ownership. To be sure, there is a difference without a distinction here. The Crown, and therefore the states, has always had the right to control the taking of fish or game, but it still has not necessarily owned them.

The second type of law, of historical interest, was that there were all kinds (at least there were two or three kinds) of fish owned solely by the Crown. They were such exotic species (or perhaps just tasted so good) that the Crown would not let anyone else catch or eat them. The classical example is the sturgeon, which commoners were prohibited from eating. Similarly, all of the swans in the Thames River in England are owned by the Queen. They are her own personal property and no one else can own the swans. (I don't know that anyone else wants to.)

Three kinds of marine situations pertain to the law of aquiculture: (1) the sedentary marine creatures, such as oysters; (2) the "transitory" ones such as fish, and (3) the situation in-between where you put transitory creatures in a pen and raise them in captivity. Needless to say, different laws apply to each situation.

Along the Pacific Coast laws dealing with this subject have been or could be promulgated by four states and one nation --the Quinault Indian Nation. I would not have the temerity to deal with the treaty between the Quinault Indians and the United States, but I can speak generally about fishing treaties with the Indian nations. States cannot regulate the taking of fish by the Indians, except to keep the Indians from exterminating a species of fish. The Indians answer quite reasonably that "when we ran this show, there weren't any fish exterminated." But as far as the details and permits and those types of things are concerned, they are for the most part free and are not in any way related to the problems that face the rest of us on the Pacific Coast.

Alaska changed its constitution to permit aquiculture. There is now a bill before the Alaska legislature which, according to my last information, had not passed. It is a much broader bill than exists in either Oregon or California, but it will be filled in by regulations adopted by the controlling agencies. There are no such regulations yet.

Washington's law deals primarily with pen-rearing of fish. There is a casual reference to ocean rearing, but for the most part it is directed at raising fish in pens in Puget Sound.

California was the first state to pass a law dealing specifically with aquiculture, and did so in 1969. They amended it drastically in 1971, declaring it to be an experimental law that applied only to Waddle Creek in Santa Cruz County and declaring it to exist only for 61 days following the 1975 regular session of the legislature. This law, by and large, carries with it its own regulations. There is only one facility operating on Waddle Creek and it is being watched closely by the California Fish and Game Commission.

One difference between California's law and Oregon's is the fact that the fish have to be marked before they're permitted to go to sea. These fish are raised to the pre-smolt size, then they are clipped and released. There seems to be some difference of opinion as to whether they are operating their facility well and whether they understand either the economics or the biology of what they are doing. But I guess that they are still struggling along. The requirement that they thin, clip, and mark the fish, I suppose, must grow from the legal concept of who owns the fish. Since we call it fish farming, the California Legislature felt that the operators had to put a brand on the fish just as we put a brand on cattle before we let them out on the range. This presents very serious biological problems.

Oregon's law was patterned after the California law but was made a good deal broader. When it was initially introduced into the legislature, it covered all breeds of anadromous fish. It was subsequently limited to chum salmon by the legislature.

There is apparently a great deal of hostility based on fears that commercial interests would purchase streams and exclude sports fishermen. On the other hand, some enthusiasm has been exhibited by people who feel that releasing chinook and coho salmon into the waters would increase those available to be caught by sportsmen.

Oregon Senate Bill 265, introduced by the Committee on Agricultural and Natural Resources, is an attempt to put back into law those words which were excluded in the 1971 Legislature. The bill, passed by the 1973 Legislature, would permit the raising of chinook and silver salmon.

There was another bill in the Oregon Legislature--Senate Bill 96. It provided for the posting of a $100,000 bond for any person or corporation operating a private fish hatchery. This bill would have effectively destroyed the attempt to develop this type of industry. The capital requirements to get a $100,000 bond are three: $100,000 in cash pledged to the bonding company; or, $100,000 in negotiable securities; or, a net worth of $300,000 of which about $80,000 is in liquid securities. This requirement would limit the bidding considerably. At the hearing before the Senate committee, a number of people spoke against Senate Bill 96, pointing out to the committee what appeared to be the unfairness of it. There did not appear to be anyone who spoke in favor of it. The bill was subsequently killed in committee.

Generally the law of aquiculture, at least as we are concerned with it, falls into the two groups--the sedentary through the oysters, and transitory through the fish.

As to the oyster culture, in 1969 Oregon passed a law which permitted acquiring platted oyster lands for $2.00 an acre. These permits are very similar to the Taylor grazing rights for cattlemen. They almost imply ownership, but if the lands are not used for the production of oysters, they lapse back into the public domain.

On the other hand, wild lands can be sold and transferred just as other land. As a result of this law, there are, I am told, very few oyster lands which have not been spoken for. Washington has a somewhat similar law and so does California. Once you have acquired these lands or have leased them from an owner, you run into the same problems the law has created for all those people who want to go about their business and make a living.

Another topic I think we have to deal with concerns the raising of freshwater fish in trout ponds. The law, needless to say, goes both ways on this subject. In California, you are flatly prohibited from having a freshwater hatchery in a situation where the fish can possibly escape into the natural waters of the state. In Oregon, there is no such provision. But assuming you want to go into fish farming, either raising fish in captivity or commiting them to go out to sea, it is necessary to get permits from the Oregon Fish Commission and from the Oregon Game Commission. Then you have to get water rights from the State Engineer. There has to be a drawing of your facilities. There has to be a scientific calculation of the quantity of water you will use. If you have a settling pond upstream from your facility there is a disagreement whether you should or should not have a permit to store water. If you talk to one engineer, he's in favor of it; if you talk to another engineer, he says it isn't necessary.

Aquiculturists must deal with the Department of Environmental Quality (DEQ), responsible for the general well-being of the environment. It is something, I think, that somewhat surprised L.B. Day, the former director of the DEQ, when the problem first came up. I think that the department has endeavored to be realistic and fair, although I think from time to time it might be somewhat guilty of over-kill. They have so many problems with so many industries that I think they occasionally get a little feverish and their little spines stick out. I think perhaps there will be more cooperation between those who have licenses and the DEQ, and the tendency toward overprotection will remove itself. I do not think that dealing with the DEQ will present any problem which cannot be worked out.

The last problem you have is that if you go into the public waters, you have to get permits from the Coast Guard and from the Corps of Engineers because you may be a navigation hazard. This is essentially a yes/no situation. It's not hard to get one if you aren't a navigation hazard; impossible to get one if you are.

I had hoped when I accepted this assignment to be able to present a learned and detailed discussion of the law in all its pristine beauty. However, there almost isn't any law. In fact, when I discovered the lack of law, I went to the dictionary to look up the word, and I discovered that there is no such word as aquiculture. So here we are really working in a vacuum. how about aquaculture

Some people question how we can get the biologist to work with the engineer. It would appear, however, that many of the hazards we are facing are those of the law. The question might better be phrased--how can we get the lawyers and the legislators to work with the biologists? Trying to get lawyers to work with anyone is difficult enough. I think this could be achieved if we could work out a plan or position of what aquiculture is and where everyone would fit into it. Too often the biologist looks at it almost as Frankenstein looking at his monster. They have created something beautiful in itself--a life that didn't exist before. The engineer looks at the fantastic problem of recirculating and dealing with the problems of waste which he can solve by his intellect. The lawyer weighs all the risks. Each of them, expert in a limited area, tends to operate in a vacuum, never dealing with the others.

Obviously, we who are in favor of aquiculture must talk to one another; but it is important that we talk to the sportsman also, so that we can allay his fears if they are not well founded; or if they are well founded, so we can protect him. You'd be surprised how many more sportsmen vote than aquiculturists. In the same vein, it is important to talk to the commercial fishermen. They feel, I think, very much a threatened species. Every two years they have to go to the Legislature and argue that it is their livelihood that someone is trying to take away. I think very possibly that we could work out a statement of policy, expressing where we stand. If it could be agreed to by the disparate groups involved, a policy statement would go a very long way toward bringing the internecine war to an end.

Ocean Ranching of Pink and Chum Salmon

William J. McNeil, Chief
Anadromous Fishes Investigations
National Marine Fisheries Service
Auke Bay Fisheries Laboratory, Alaska

ABSTRACT

Although pink and chum salmon constitute the bulk of total landings of salmon on the Pacific coast of North America, wild stocks of these two species have been reduced to about 50 per cent of historic levels. There is considerable interest and speculation in opportunities to increase the numbers of salmon available for harvest by mass production of juveniles in hatcheries. This report reviews the outlook for hatcheries and raises questions about management of fisheries on mixed wild and hatchery stocks and about institutional arrangements for the operation of hatcheries.

INTRODUCTION

Pink and chum salmon together constitute about 60 per cent of the total U.S. harvest of Pacific salmon. Historic catch records suggest, however, that the ocean is capable of producing at least twice the number of pink and chum salmon now harvested. Reduced recruitment of juveniles to oceanic nursery areas is thought to be mainly responsible for the reduced population.

North American streams and lakes produce five species of salmon, which differ in age and size at maturity. Chinooks, the largest, typically weigh over 20 pounds and 3 to 6 years old at maturity. Pinks, the smallest, average only 4 to 5 pounds at maturity and live only 2 years from the time the egg is fertilized. Coho, sockeye, and chum salmon are intermediate in size and typically live 3 to 5 years. All five species spawn only once and die a few days later.

Chinook, coho, and sockeye salmon require freshwater nursery areas, but pink and chum do not. Instead, they make their early growth in estuaries and inshore waters before spreading westward across the North Pacific Ocean (Figure 1).

Catches of North American pink and chum salmon declined rapidly through the 1940's, and landings are still low. Southern stocks have been depressed more than northern stocks. In Oregon for example, chum salmon were decimated in the 1950's and the fishery for this species was closed south of the Columbia River in 1962. Even in Alaska, trends in annual landings (Figure 2 offer little comfort. The once prolific southeastern Alaska pink stocks have suffered about a two-thirds reduction in landings (Figure 3).

Overfishing is strongly implicated as the dominant force which initiated a rapid decline of pink and chum in the 1940's. However, reduced survival of eggs and young in streams and estuaries, from poor land and water-use activities, probably contributes to the present depressed state of stocks in many areas. If natural or man-caused imbalances have not reduced the capacity of oceanic feeding grounds, the numbers of harvestable fish can probably be increased through strict management of wild stocks and artificial propagation.

Many pink and chum stocks can be revived with known management tech-

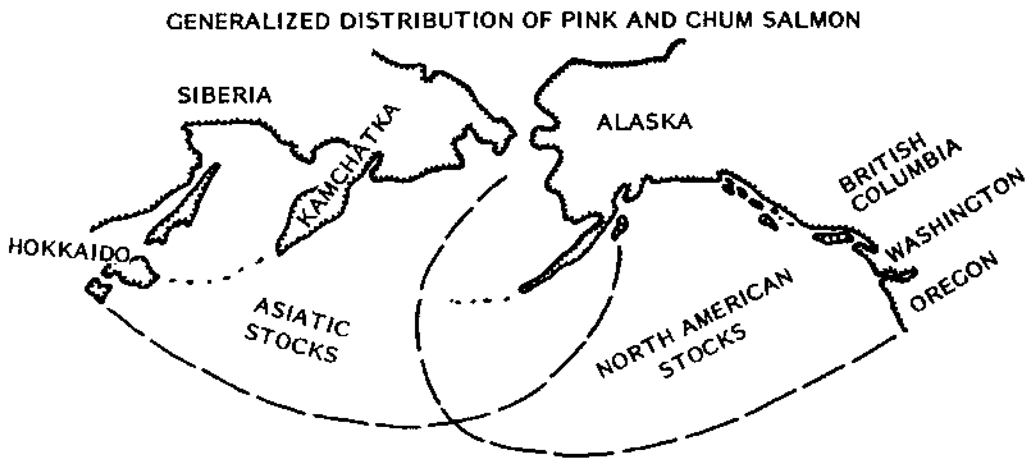

Figure 1. General ocean distribution of pink and chum salmon.

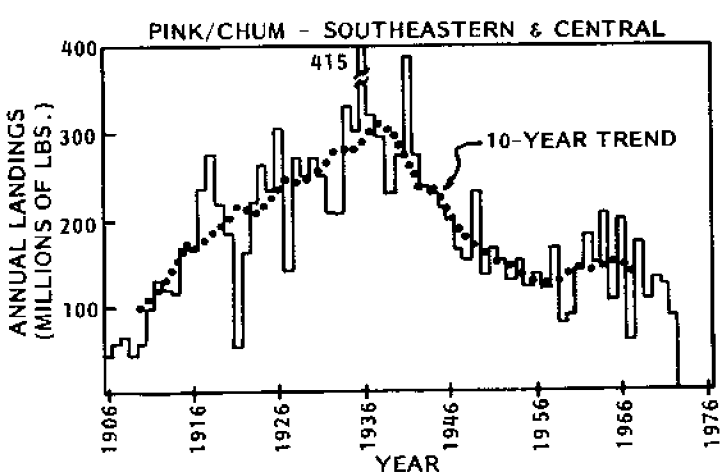

Figure 2. Annual landings of pink and chum salmon in southeastern and central Alaska.

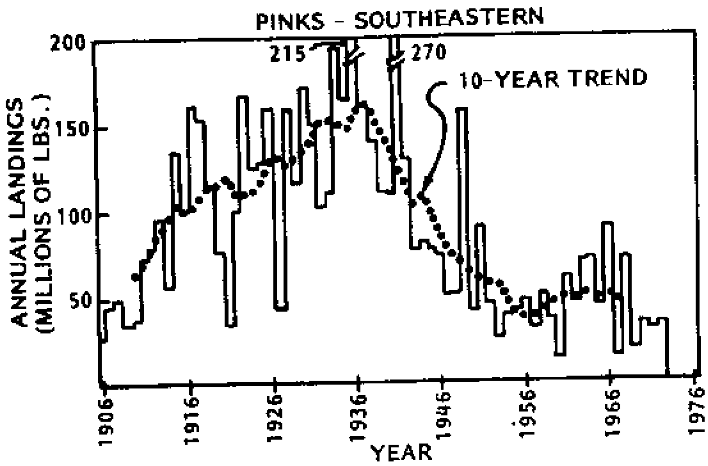

Figure 3. Annual landings of pink salmon in southeastern Alaska.

niques, particularly in areas of Alaska where man has not yet exerted a major impact on spawning streams and estuaries. However, severe restrictions on harvest will be required, perhaps for several cycles where runs are seriously depressed. There is no scientific basis to expect that closures alone will suffice to rebuild those stocks which have been reduced to remnants. It will probably be necessary to propagate pink and chum salmon artificially where chronic overexploitation occurs.

Several approaches to rehabilitation of salmon runs are being made. The Japanese have a highly successful hatchery program for chum salmon and raise substantial numbers of pinks. The Russians have recently constructed several large hatcheries which release more pinks and chums than Japanese hatcheries. Spawning channels have become popular in Canada as an alternative to hatcheries. Public hatcheries in the United States no longer produce many pink and chum salmon; instead, they propagate primarily chinook and coho salmon, which are popular recreational species as well as valuable commercial fish. Private hatcheries are raising chum salmon in the Pacific Northwest in an attempt to rehabilitate this formerly important commercial species without committing public tax funds.

In this report I review the status of technology on the propagation of pink and chum salmon fry in hatcheries for the purpose of ocean ranching. The concept of ocean ranching relies on a natural "homing instinct" that causes salmon to return to the stream of their birth at maturity. I discuss the biological feasibility of hatcheries in detail, and raise questions on the control of harvesting mixed stocks of wild and hatchery fish to avoid overfishing wild stocks and on institutional arrangements for operating hatcheries.

STATUS OF ARTIFICIAL PROPAGATION

The Japanese began to build hatcheries in 1876; and numerous state, local, and private hatcheries now release 400 million to 600 million juvenile pink and chum salmon annually to sustain coastal fisheries on Hokkaido and Honshu Islands. Chum is the most important species in Japan: about 4 million hatchery adults return annually to coastal waters and provide an annual harvest of about 30 million pounds (Anonymous, 1966). Furthermore, studies of marked fish indicate that Japanese vessels on the high seas harvest at least an equal quantity (Kanid'yev et al., 1970).

The Russians were forced into a large-scale pink and chum salmon hatchery program in the 1960's to compensate for overexploitation of their stocks by the Japanese high seas fishery. The Russians now release more pink and chum salmon from hatcheries than do the Japanese; their 21 Sakhalin Island hatcheries alone produce more than 600 million juveniles. Although they obtain only about 0.4 per cent return from hatchery-reared chum salmon fry in their coastal fisheries, the Russians believe that Japanese high seas fleets harvest most of the Russian hatchery fish.

The importance of Japanese and Russian hatchery programs can best be comprehended by comparing the annual release of chum salmon from hatcheries into the western North Pacific Ocean with the recruitment of wild chum fry into the eastern North Pacific Ocean from all North American spawning streams combined. Published reports suggest that about one billion juvenile chums are released annually from hatcheries in Asia, which is probably a larger number than originate from all wild stocks in North America. The estimated number of chum salmon fry produced by wild stocks in North America is based on the following statistics and assumptions:

1. Over the past ten years, about 8 million chum salmon have been harvested annually by United States and Canadian fishermen. There is no indication that Japanese fishermen harvest many North American chums.

2. Based on an assumed 50 per cent rate of exploitation, the average total return (catch plus escapement) of chum salmon to North American was 16 million fish annually. (This is a conservative estimate of rate of exploitation.)

3. Based further on an assumed 2 per cent marine survival of wild fish (Bakkala, 1970, pp. 53-54), 800 million fry were required to produce 16 million adults. Fry production probably has averaged somewhat less than 800 million.

In marked contrast to recent successful hatchery programs in Russia and Japan, attempts to raise pink and chum salmon in public hatcheries in the Pacific Northwest have mostly failed. Although the Washington Department of Fisheries continues to raise a few million chums at two hatcheries, large-scale production of pinks and chums came to an end in the late 1930's after consistent failure to establish runs of hatchery fish. Very low marine survival of hatchery pink and chum salmon at Pacific Northwest hatcheries has contributed to the belief that hatcheries are less efficient than natural reproduction (Noble, 1963 and 1964).

In seeking suitable alternatives to hatcheries, fish culturists began to experiment with spawning and egg incubation channels in the 1950's. Promising results from early tests prompted the International Pacific Salmon Fisheries Commission (Cooper, 1972) and the Canada Department of Environment (Fraser, 1972) to construct commercial-scale spawning channels in British Columbia. The early indications are that marine survival of pink and chum salmon fry produced in these channels is much higher than has been experienced in Pacific Northwest hatcheries.

A spawning channel is usually a water diversion canal with a bed of silt-free gravel for spawning. Waterflow is controlled at a head gate and the number of spawners at a fish weir. In most cases the adult salmon are allowed to spawn naturally, but to achieve optimum density, their numbers are held between one and two spawners per square meter (both sexes). In a few instances, fertilized eggs are planted artificially. The protected environment of the channel ensures higher survival of embryos and alevins (larvae) than a natural spawning bed.

Recent advances in our understanding of the requirements of pink and chum salmon alevins have led to development of hatchery incubators which use a gravel substrate. For example, the technique of spreading pink and chum alevins on gravel in tanks is widespread in Russian hatcheries and is used also in some Japanese hatcheries (Kanid'yev et al., 1970). It affords alevins a more natural environment than standard smooth-bottom incubators.

Two types of gravel incubation hatcheries are being field tested in North America. In one type, newly fertilized or eyed eggs are buried in gravel-filled tanks with an upwelling flow of water. In the other type, newly fertilized eggs are placed on screen trays and suspended in a water column with an upwelling flow; after the eggs hatch, the alevins drop through the screens and rest on the surface of a shallow layer of gravel.

CRITERIA FOR HATCHERY DESIGN

The incubation of salmon eggs and alevins to the fry stage requires relatively little water or space. In conventional hatchery practices, trays of newly fertilized eggs are arranged horizontally in troughs or are stacked vertically. Water is directed through a series of trays; the water is usually re-aerated as it passes from one tray to the next. Alevins may be retained in the incubation trays until the yolk is absorbed, or they may be transferred to open tanks to complete their development.

Hundreds of millions of pink and chum salmon fry have been raised by conventional techniques and released, but there have been no documented cases in North America where survival of hatchery fry has approached survival of wild fry. In almost every case, survival has been too low to justify the propagation of pink and chum salmon in hatcheries. We now recognize some reasons why these hatchery fry probably had a low fitness for survival.

The velocity of water flowing past alevins in conventional troughs and trays greatly exceeds the velocity under natural conditions in spawning beds. Furthermore, the smooth troughs or screen trays may fail to satisfy the tactile requirements of alevins (Bams, 1969), because the movements of the alevins are not restricted as they are in gravel beds of streams. Although conventional hatchery methods yield high egg-to-fry survival, the fry are undersized (Brannon, 1965; Poon, 1970), show a reduced capacity to perform work (Bams, 1967), and have a high incidence of malformed yolks (Disler, 1953; Emadi, 1972).

The ability of fry to feed and grow may also be related to their early incubation history. An unpublished experiment with pink salmon fry[1] compared growth and survival of fish from a tray incubator with fish from a gravel incubator. Average weight of surviving fish after 75 days of feeding on an unrestricted diet was 4.2 grams for fry from the tray incubator and 6.5 grams for those from the gravel incubator. From the tray incubator, only 37 per cent of the initial fry survived, whereas from the gravel incubator, 88 per cent survived. The incidence of non-feeding "pinheads" was high among fish from the tray incubator and low among fish from the gravel incubator.

Fry which will not feed are a common problem where pinks and chums are raised at public hatcheries. The high incidence of malformed yolks with associated structural deformities may explain in part why pink and chum fry from tray and trough incubators exhibit poor growth and low marine survival. Bams (1972) feels that poor survival of hatchery fry is due primarily to poor conversion of yolk to body tissue and the resulting small size and poor condition of fry.

The first evaluation of marine survival of pink salmon fry from a gravel incubation hatchery was recently reported by Bams (1972), who compared 77,000 marked hatchery fry with 75,000 marked wild fry. Bams estimated a 6.6 per cent marine survival of hatchery fry and a 6.5 per cent survival of wild fry--the difference was not statistically significant. His estimate of 6 to 7 per cent marine survival of pink salmon is similar to observations on wild fish.

Combined observations of 17 brood years[2] of pink salmon at Sashin Creek, southeastern Alaska (Ellis, 1969), and 11 brood years at Hook Nose Creek, British Columbia (Parker, 1964), revealed that 2.7 per cent of the outmigrating fry returned to spawn. Although rates of exploitation are unknown, they probably exceeded 50 per cent most years and may have neared 80 per cent for individual stocks some years. This means that marine survival of pink salmon has averaged in excess of 5.4 per cent for Sashin Creek and Hook Nose Creek. A marking experiment on 1960 brood year pink salmon from Hook Nose Creek yielded an estimated 22 per cent marine survival and 95 per cent exploitation (Parker, 1964). Three similar marking studies on pinks at Bella Coola River, British Columbia, yielded 5.2, 4.4, and 1.9 per cent marine survival of 1961, 1962, and 1963 brood years (Parker, 1968).

Marine survival of chum salmon is more difficult to evaluate because of the variable age of return. Chums live 1 to 3 years longer than pinks, and marine survival would be expected to be lower. Parker (1962) estimated marine survival of chum salmon from Hook Nose Creek to be 2.8 per cent. Parker's estimate is consistent with information available on spawner-recruit relationships for chums in Alaska (Anonymous, 1966).

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[1] W.J. McNeil, 1971. Culture of salmon acclimated to seawater. Fourth Progress Report, May 15, 1971. Oregon State Univ. Marine Science Center. 4 p. (processed).

[2] The term "brood year" refers to the year of spawning.

It is largely beyond our capability to exercise control over marine survival, but it is important that we have some idea of what to expect in terms of fish returning for harvest from a release of a known number of fry. In fresh water we have an opportunity to control and increase survival to much higher levels than in nature.

Statistics on freshwater survival of pink and chum salmon for streams in Canada (Pritchard, 1948; Hunter, 1959; Parker, 1962), Alaska (Wright, 1964; Olson and McNeil, 1967; Ellis, 1969), and Russia (Semko, 1954; Kanidyev et al., 1970) show that the survival to outmigrant fry is quite variable and usually less than 20 per cent of potential egg deposition. A recent compilation of data for Sashin Creek pink salmon (Ellis, 1969) reveals that there is a 27-fold difference in annual freshwater survival (0.8 to 21.7 per cent) in Sashin Creek.

Gravel incubation hatcheries are capable of increasing average egg-to-fry survival five to ten times over natural streams. Hatcheries also afford a means to avoid broad annual fluctuations in fry production and to make efficient use of a relatively small number of spawners.

Hypothetical examples of surplus production of pink salmon stocks from natural or wild spawning and from a gravel incubation hatchery are compared in Table 1. The survival figures used in Table 1 represent stocks of wild pink salmon in Canada and Alaska and of hatchery stocks in Japan, Russia, and Canada (Anonymous, 1966; Kanid'yev et al., 1970; Bams, 1972).

Just how effective gravel incubation hatcheries might become in North America remains to be determined, but the last two columns of Table 1 reveal the potential advantage of hatchery stocks over wild stocks.

HARVEST OF WILD AND HATCHERY STOCKS

The operation of large hatcheries would not relieve the need for continued restriction on the harvest of pink and chum salmon in the common property fishery because the conservation of wild stocks will continue to demand high priority. Even when survival is good, wild stocks would probably not support more than 75 per cent exploitation. Much lower exploitation will be required most years to be assured of enough spawners. Hatchery stocks, on the other hand, should sustain much higher exploitation, perhaps as high as 95 per cent because of the small numbers of brood fish required to restock hatcheries. In the face of differing requirements for preservation of each type of stock, how do we provide for complete utilization of hatchery fish and avoid overharvesting wild fish on the fishing grounds?

Because the common property fishery must be managed to achieve adequate escapements of wild fish to spawning streams, large surpluses of fish will return to successful hatcheries. These surplus hatchery fish would become available for harvest after they segregate from wild fish. Such segregation will usually occur at the mouth of the hatchery stream.

State-owned hatcheries in Oregon and Washington began to receive substantial numbers of surplus coho and chinook salmon about ten years ago. In 1970, these public hatcheries placed more than 5 million pounds of surplus salmon on the commercial market (Jeffries, 1971; Ellis, 1971). It is very likely that they also contributed another 20 to 30 million pounds to common property commercial and recreational fisheries from California to southeastern Alaska.

Although commercial salmon fishermen are dependent on hatchery fish in the Pacific Northwest, they have been very vocal in criticizing management agencies for allowing too many fish to return to hatcheries. It seems probable, however, that the present high rate of exploitation already threatens wild coho and chinook stocks in the Northwest, and any further increase in exploitation could be disastrous unless it is selective for hatchery fish.

It is unlikely that wild pink and chum stocks could sustain as high a rate of exploitation as coho and chinook stocks because of differences in factors which limit recruitment of young to the ocean. In pink and chum salmon relatively large numbers of spawners are required for maximum production of fry which migrate directly to sea. On the other hand, relatively few coho and chinook salmon can provide sufficient fry to stock the stream nursery areas. These areas are occupied by young cohos and chinooks for periods up to three years before they migrate to sea.

TABLE 1

SURPLUS PRODUCTION OF PINK SALMON FROM WILD AND GRAVEL INCUBATOR HATCHERY STOCKS
WITH VARIOUS ASSUMED SURVIVAL SCHEDULES

Initial No. of eggs	Survival to fry	No. of fry	Survival to adult	No. of adults	Replacement spawning stock[1]	Surplus production	Exploitation rate
WILD STOCKS							
1,000,000	.07	70,000	.04	2,800	1,000	1,800	.64
1,000,000	.10	100,000	.02	2,000	1,000	1,000	.50
1,000,000	.02	20,000	.05	1,000	1,000	0	0
GRAVEL INCUBATOR STOCKS							
1,000,000	.80	800,000	.04	32,000	1,000	31,000	.97
1,000,000	.85	850,000	.02	17,000	1,000	16,000	.94
1,000,000	.80	800,000	.005	4,000	1,000	3,000	.75

[1]Assumes an average fecundity of 2,000 eggs per female.

Surpluses of fish that escape the common property fishery and return to a hatchery potentially will be much larger for pinks and chums than for cohos and chinooks because of the need to hold exploitation below 75 per cent most years to conserve wild stocks. Only limited information is available on marine survival of pink and chum salmon from hatcheries, but Kanid'yev et al. (1970) report 1.5 per cent return (catch plus escapement) of chums from hatcheries in northeastern Hokkaido, Japan, over a twelve-year period.

It is instructive to use this information to predict surplus production of chum salmon returning to a hypothetical hatchery (see Table 2).

TABLE 2

Assumed number of eggs placed in hatchery	50,000,000
Fry production (85 per cent of eggs)	42,500,000
Adults returning to common property fishery (1.5 per cent of fry)	637,500
Harvest in common property fishery (60 per cent of returning adults)	382,500
Adults returning to hatchery	255,000
Brood stock (2,700 eggs per female)	37,000
Surplus for harvest at hatchery	218,000

Many surplus pink and chum salmon escaping the common property fishery and returning to a hatchery will be mature fish no longer prime for canning. Nevertheless, these fish retain considerable market value for caviar and bait eggs, smoking and drying, animal food, and bait; even the carcasses can be used for animal food and bait. All adults returning to a hatchery, including brood fish, have potential markets.

Public fishery agencies in the Pacific Northwest are faced with substantial marketing problems which have been created by the sizeable surpluses of coho and chinook salmon at the hatcheries. Roberts (1972) cites some common complaints voiced by fishermen: "Salmon sold from hatcheries is of poor quality, this hurts our markets. A public agency shouldn't be in the fish business. Those returned hatchery fish are lowering the price of salmon caught by commercial fishermen."

These problems are symptomatic of a successful public hatchery program because such hatcheries will have a surplus, even with heavy exploitation. To alleviate these problems, serious consideration must be given to institutional arrangements for raising, harvesting, and marketing fish that return to the hatchery. Ideally, the income from surplus hatchery fish should underwrite the cost of hatcheries without threatening the economic security of fishermen. It seems a paradox that a technology which offers the promise of increasing the supply of salmon could also complicate the management of wild stocks and marketing

One step toward insurance that surplus fish will underwrite the cost of operating hatcheries is to create a legal basis for private hatcheries. This is being tried on a restricted basis in California, Oregon, and Washington. Private hatcheries are licensed and regulated by state fishery agencies, but no public tax funds are used for construction and operation. In Oregon, any administrative costs incurred by the state are charged to the private hatchery. Hatcheries built and operated by Indians on tribal lands are exempt from state and federal regulations. Salmon from private hatcheries are public property from the time they are released until the time they are recaptured in trapping facilities operated by the hatchery.

Private hatcheries now licensed by state fishery agencies include one coho salmon hatchery in northern California and four chum salmon hatcheries in Oregon. The Washington Department of Fisheries has authority to license hatcheries, but to my knowledge they have not yet approved any applications. At least two Indian tribes (Quinault and Lummi) operate private salmon hatcheries on their reservations in Washington.

Should "proprietary" fisheries created by private hatcheries prove to be financially successful, a salmon farming industry will most likely emerge over the next several years. Such a proprietary fishery conceivably could attain economic importance in its own right, while at the same time contributing substantial numbers of fish to the common property fishery. Figure 4 shows a systems model for pink and chum salmon which integrates production from wild and hatchery stocks to provide fish for harvest in a common property and a proprietary fishery.

The economic risk of private salmon hatcheries is undoubtedly high because we have very little information to pass judgment on feasibility at this time. Even if fish returning to a private hatchery do not have sufficient value to cover costs, there is a possibility that fishermen would tax their catches to cover the deficit, provided they are convinced that the added value of hatchery fish in their catch makes the added subsidy worthwhile to them. There may even be circumstances where the operation of hatcheries by fishermen's associations might become practicable, especially where limited entry to the fishery would give the participating fishermen a proprietary interest in any hatchery fish returning to a particular fishing ground.

Even though private pink and chum salmon hatcheries are highly speculative, significant economies in costs of construction and operation are imminent in the development of gravel incubation hatcheries. If costs of producing 1,000 fry can be held at about $6 (including amortization), then a 1.5 per cent return of chums or a 3 per cent return of pinks to the common property fishery would be sufficient for a self-supporting hatchery under the hypothetical conditions shown in Table 3.

The examples in Table 3 provide slim margins for profit. If my estimate of the cost of fry production, market value of surplus fish, or exploitation in the common property fishery is too low, the hatchery would lose money. Money would also be lost if my estimate of the marine survival is too high. The example serves to identify the key elements which require evaluation: (1) Cost of producing fry, (2) marine survival, (3) exploitation in common property fishery, and (4) market value of surplus hatchery fish.

Emergence of a salmon hatchery industry will require intensified support from government in research, development, and advisory services. Private hatcheries will require (1) assistance on establishing criteria for design and operation of hatcheries; (2) greater knowledge of fish genetics and selective breeding of stocks, disease control, and nutrition where short-term rearing of fry is involved; (3) answers to harvesting, processing, marketing, and socio-legal problems. Because state fishery agencies will administer and regulate private hatcheries, it is imperative that they participate in research, development, and advisory projects along with National Marine Fisheries Service Laboratories and Sea Grant universities.

TABLE 3

	Chum Salmon	Pink Salmon
Cost of fry	$6/1000	$6/1,000
Total return per 1,000 fry	15 adults	30 adults
Common property harvest (60 per cent exploitation)	9 adults	18 adults
Return to hatchery	6 adults	12 adults
Required for brood stock	1 adult	1.5 adults
Surplus for proprietary harvest	5 adults	10.5 adults
Value of surplus ($1.30/chum, and $.60/pink)	$6.50	$6.30

We may have already entered a period of transition from strictly public artificial propagation of salmon to a partnership between public and private propagation. Many questions need to be resolved by state legislative and administrative bodies before we can convert a "problem" of surplus hatchery fish into an "opportunity" to allow these surplus fish to pay the cost of operating hatcheries and to avoid continued heavy subsidization of public hatcheries. It is prudent for state fishery agencies to proceed with caution as they broaden their salmon management programs to include the assignment of limited proprietary rights to salmon. If properly executed, a partnership between government and private sectors of the economy can greatly broaden the financial base for expansion of salmon resources for the benefit of fishermen, processors, and the public.

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Dynamics of Isolated Plankton Populations in Yaquina Bay, Oregon

J. Kenneth Johnson, Graduate Student
and
Charles B. Miller, Assistant Professor
School of Oceanography
Oregon State University, Corvallis

Zooplankton populations in estuaries can be restricted to short, particularly suitable zones. These populations can be of considerable importance as food sources for the commercial fisheries and wildlife of the estuary. However, they are potentially vulnerable to changes in estuary circulation, salinity, and temperature that might result from engineering activities in the estuary such as dredging, or thermal outfalls. With this significance in mind, a study has been initiated of the population dynamics of *Acartia tonsa*, a copepod, restricted to the upper estuary of the Yaquina River, Oregon.

The general planktology of Yaquina Bay is well known from the work of Frolander (1964), Zimmerman (1972), and Frolander, et al (in press). The lower estuary is dominated by two copepod species groups which are shared with the nearshore oceanic water (Miller, 1972). Alternations between southerly currents along the Oregon coast during the summer and the northerly Davidson Current during the winter result in a "summer-northern" group and a "winter-southern" group. The summer group is typified by the copepods *Acartia clausi* (Giesbrecht, 1889) and *Pseudocalanus gracilis* (Sars, 1903). Both species are present in the estuary year around but are dominant during the summer. The winter group, typified by *Paracalanus parvus* (Claus, 1863) and *Corycaeus anglicus* (Lubboch, 1857), is absent from the estuary during most summers.

The seasonal cycle of the zooplankton inhabiting the brackish water of the upper estuary, however, has been shown to be very different from that of the lower estuary (Zimmerman, 1972). The upper estuary is characterized by an annual population explosion of *Acartia tonsa* during the months of July, August and September, followed by a rapid decline to virtual extinction by the end of November. *A. tonsa* is a species of southern affinities and is a minor component of the nearshore zooplankton in the northerly Davidson Current during the winter. The summer repopulation of the upper estuary appears to derive from the oceanic population.

This annual population explosion affords an excellent opportunity to study the factors governing the population dynamics of *A. tonsa* in a restricted geographic location. Other studies such as Mullin and Brooks's (1970) work on the production of *Calanus* suffer from the disadvantage of unknown but potential mixing with other populations on different schedules of development. In contrast, the Yaquina Bay *A. tonsa* population is protected from mixing with other populations. There are no *A. tonsa* offshore in summer. However, the population is not completely contained there are some losses to the lower bay by flushing and to the upper bay by tidal diffusion. Losses to the lower bay appear to be very small during the summer (Zimmerman, 1972)

Explanation of the production of *A. tonsa* in the field can be attempted by measuring the rates of fecundity and growth under controlled conditions in the laboratory and extrapolating to the natural population (Heinle, 1966). In addition, the rates of production can be corrected for simultaneous rates of age specific mortality by sampling the entire range of the natural population and estimating the absolute abundance of each life stage (Mullin and Brooks, 1970). This paper is a preliminary report of ongoing research into the population dynamics of *Acartia tonsa* in Yaquina Bay.

FIELD METHODS

Zooplankton samples were collected twice weekly (Monday and Thursday) from May 15 to November 20, 1972. Samples were collected during daylight hours without regard to the stage of the tide. The five stations regularly sampled are referred to in Figure 1 as Buoy 21, Buoy 29, Buoy 39, Buoy 45 and Toledo Bridge. The first four stations correspond with navigation buoys in the immediate vicinity. An additional station 2 1/2 miles above Toledo was sampled weekly during the months of August, September and October.

Three zooplankton samples were simultaneously collected at each station by using three Clarke-Bumpus (1950) samplers (12.5 cm diameter) fitted with nets of differing mesh sizes. Mesh sizes of 0.239 mm, 0.112 mm, and 0.064 mm were used to quantitatively sample the water column for adult *A. tonsa*, copepodite stages and naupliar stages, respectively. The 0.239 mm and 0.112 mm Clarke-Bumpus samplers were fitted into a frame to tow side-by-side, while the 0.064 mm Clarke-Bumpus sampler was mounted just above them on the towing wire. The two coarser nets were fished for six minutes. The 0.064 mm net was closed with a messenger after one minute to prevent clogging of the fine mesh by silt and plankton.

All tows were oblique to a depth of about five meters in mid-channel. A calibrated propeller flow meter in the

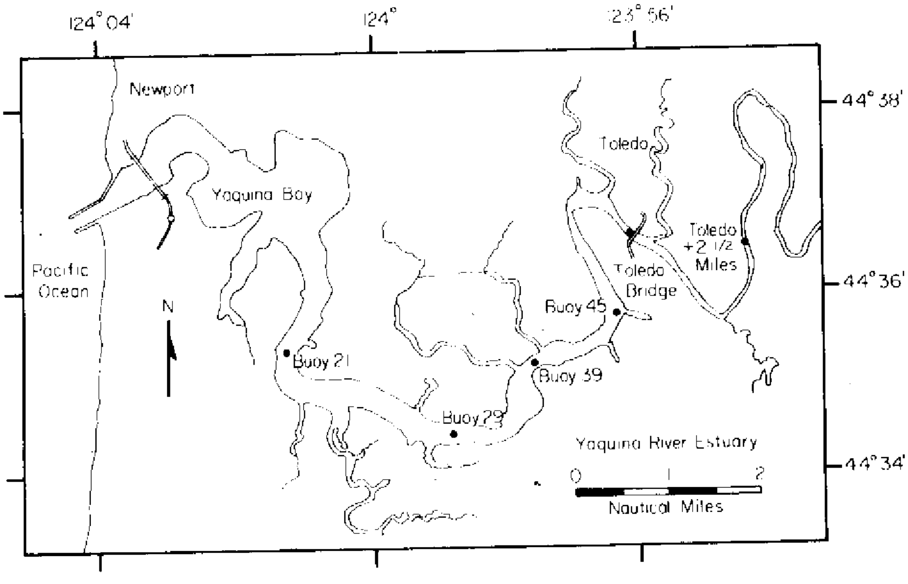


Figure 1.

mouth of the coarser nets generally indicated that approximately five cubic meters of water had been filtered. Immediately after recovery of the nets, the samples were preserved in 5 per cent formaldehyde.

Physical data were also collected at each station. An N.I.O. bottle equipped with a reversing thermometer was used to collect both water samples and temperature data just above the river bottom. Surface water samples were obtained with a bucket, and surface temperature was determined with a bucket thermometer. Salinity was determined by inductive salinometer in the laboratory.

Plankton samples were sub-sampled with a 1 ml Stempel pipette. Each zooplankton sample was diluted to ten times the settled volume of plankton. After stirring, successive 1 ml sub-samples were removed from the sample and counted until either a minimum of fifty specimens of a given stage had been counted or a total of 5 ml had been examined under 250X magnification.

LABORATORY METHODS

Fecundity Studies

To measure egg production, an adult male and female *A. tonsa* were placed in seawater of 25‰ salinity in each of twenty-five 250 ml beakers and maintained at 21°C in a circulating water bath. The experimental salinity and temperature approximated the average physical conditions at Buoy 39 at the beginning of August. Eggs and stage I nauplii were counted and removed from the beakers with an eye dropper on every second day. Fresh food consisting of approximately equal parts of *Isochrysis galbana*, *Rhodomonas* sp. and *Thalassiosira* sp. (an approximate total of 50,000 to 70,000 cells/ml) was added after each count. Every fourth day the adults were transferred to fresh water. Females that died during the first two weeks were replaced and a new experiment started. The replacement of dead males, however, did not necessitate the start of a new experiment. After the first two weeks, dead females were not replaced and the experiments gradually terminated at the end of thirty-nine days.

Growth Studies

Experiments to determine the rate of growth from egg to adult were also performed at 21°C in a circulating water bath. Eggs and stage I nauplii were obtained by placing male and female adults in beakers for 48 hours. After removal of the adults, the eggs and stage I nauplii from all beakers were mixed together. Equal portions of the mixture were then used to innoculate sixty 600 ml beakers. Growth rates were compared under conditions of natural food organisms and laboratory cultured food organisms. Half of the beakers contained estuary water (25‰) collected in the vicinity of Buoy 39 from which the largest phytoplankton and all zooplankton had been removed with a 0.064 mm filter. The remaining beakers contained sterilized sand filtered sea water (27‰) to which was added an approximate algal concentration of 50-70,000 cells/ml consisting of equal parts of *Isochrysis galbana*, *Rhodomonas* sp. and *Thalassiosira* sp. This algal concentration was maintained by adding fresh food every second day to replace grazing losses. The water was changed every fourth day. Food was not added nor the water changed in the beakers containing the estuary water. Once a day the contents of two beakers of each experiment were concentrated with a 0.064 mm filter and preserved in 5 per cent formaldehyde.

RESULTS

Physical Properties of the Yaquina Estuary

The Yaquina Estuary alternates between a partly-mixed (Type B) and well-mixed (Type D) estuary (Burt and McAlister, 1959). High river runoff during the months of November to May causes the estuary to become partly-mixed with a vertical salinity gradient between 4‰ and 19‰. From June to October, the estuary becomes well-mixed with a maximum salinity gradient of 3‰ due to low river runoff.

Salinity data collected during the present study (Figures 2, 3, and 4) indicated the upper estuary was well mixed from late June through October, 1972, with isolated exception at all stations. The weak partial mixing seen

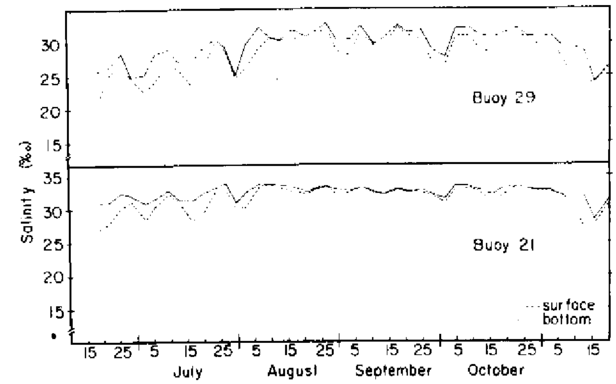


Figure 2.

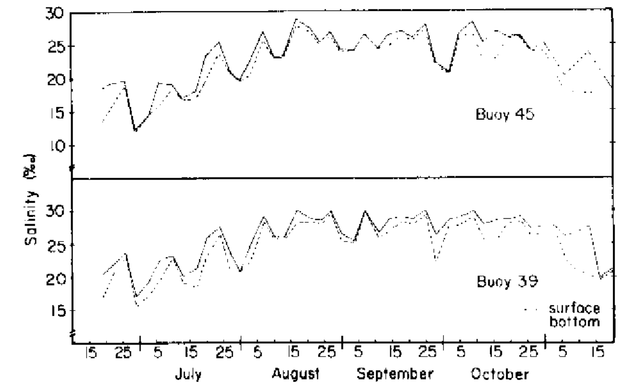


Figure 3.

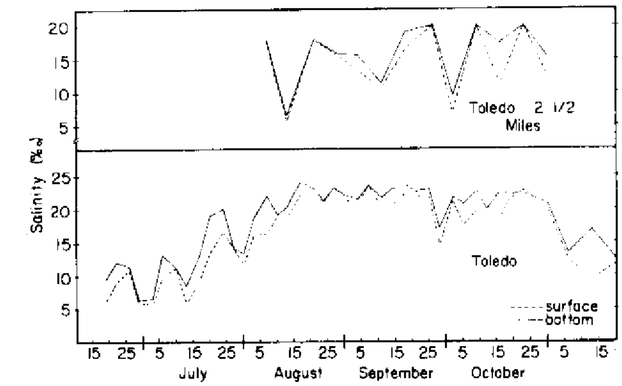


Figure 4.

at Toledo on several occasions was likely caused by waters of high salinity collecting in a localized depression in the river bottom at the Toledo bridge sampling station.

Mean salinities at the lowermost station, Buoy 21 (Figure 5) fluctuated the least during the study period, ranging from 27.1‰ to 33.8‰. The high salinities indicate that water at Buoy 21 is under strong oceanic influence during the summer. Buoy 39 had a salinity range of 15.6‰ to 30.1‰. The range at Toledo, a station under moderate to strong fluvial influence, was 5.6‰ to 24.3‰. Mean salinities were highest at all stations during the months of August and September. The influence of the mixed diurnal tides on the changes of salinity between samplings was important at all stations but most pronounced at Toledo + 2 1/2 miles during August and September.

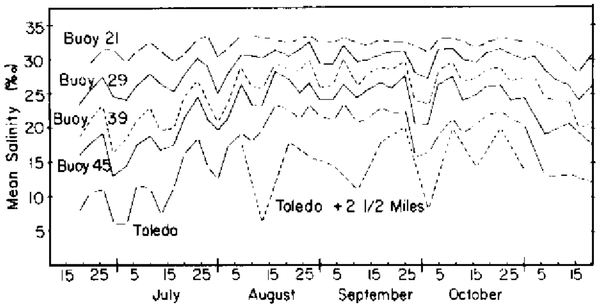


Figure 5.

Temperature at all stations (Figures 6 and 7) increased during early June and July, peaked in late July, gradually declined in August, and then fell rapidly throughout September and October. While the two Toledo stations (Figure 8) experienced the greatest seasonal extremes of temperature during the study period (23.6°C to 10.3°C), Buoy 21 experienced the most extreme variations in temperatures on a two week cycle. Fortnightly spring tides alternately introduce cold oceanic water far up into the estuary or allow the warmer upper bay water to flow much farther down into the lower bay than normal. In addition, cold, high salinity, upwelled, coastal waters may be carried into the estuary by tidal influx, depending on local coastal wind conditions during the summer.

Culture Studies

The egg production of *A. tonsa* was measured under culture conditions of 21°C and 22‰ salinity sea water. Rates were determined as the average number of eggs/day/female for 34 females. The daily rate was 30.5 (± 3.0) eggs/day with a range of 10.4 to 47.2 eggs/day.

Females were maintained for a maximum of 31 days. Estimates of maximum egg production were not attempted as the

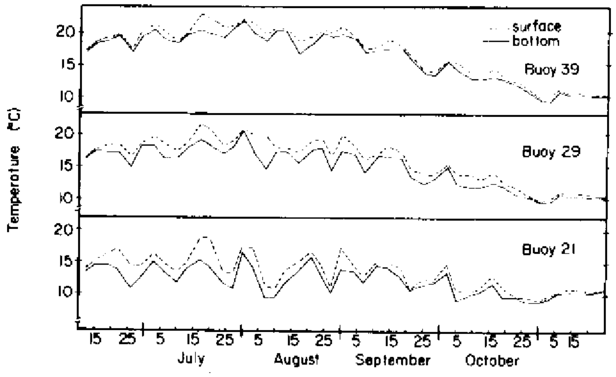


Figure 6.

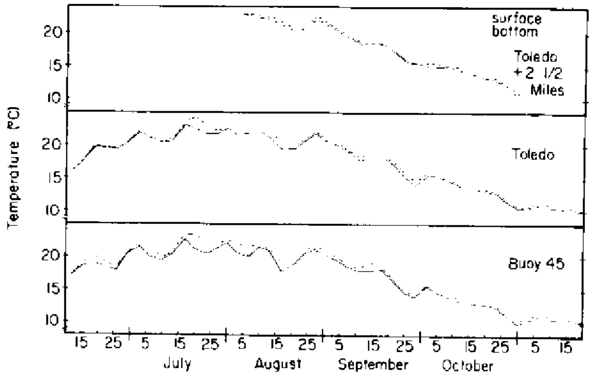


Figure 7.

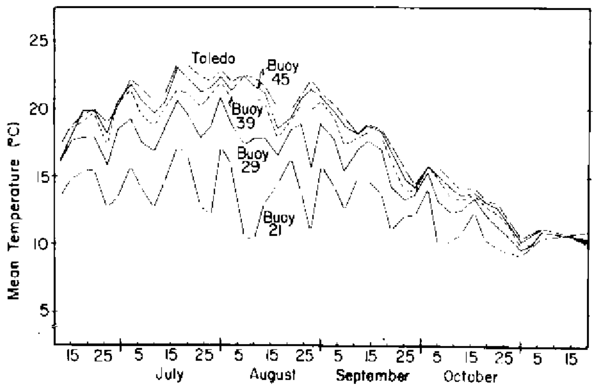


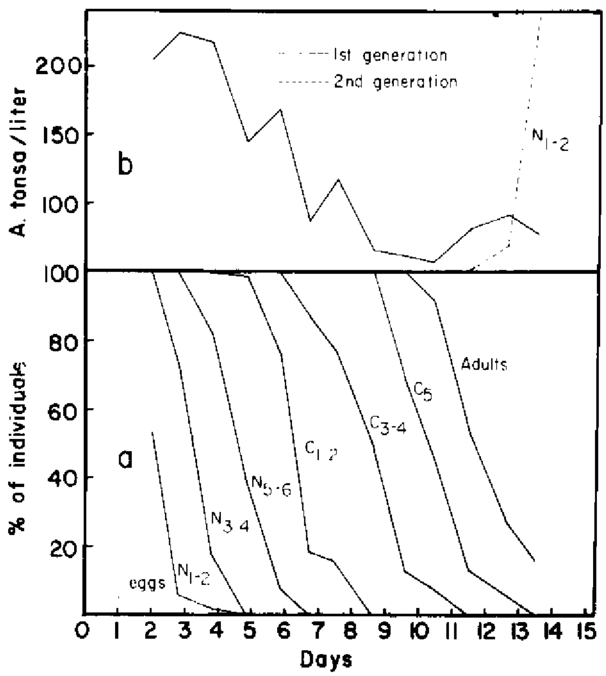
Figure 8.

reproductive time span prior to capture was not known. However, Wilson and Parrish (1971) worked with Atlantic *A. tonsa* females which had molted from Stage 5 copepodites to adults in the laboratory. They found that *A. tonsa* have an average life span of 37.7 (± 2.5) days with a total egg production of 1256.2 (± 184.9) eggs. This averaged out to 33.3 eggs/day/female (n = 6). Thus comparable data agrees that *A. tonsa* is capable of sustaining high egg production over a long time span. It must be noted, however, that continued presence of males was essential. A single mating was inadequate to permit realization of a female's total reproductive potential (Wilson and Parrish, 1971).

Adult *A. tonsa* were successfully reared in the laboratory from eggs through the eleven instar stages. In counting, the *A. tonsa* stages were grouped: Nauplii I-II, Nauplii III-IV, Nauplii V-VI, Copepodite I-II, Copepodite III-IV, Copepodite V, and Adults. The numerical abundance of each stage was expressed as a percentage of the total count of the two combined replicate samples for a given experiment. Thus the average stage of development on a given day was calculated as the midpoint of each group of stages.

Growth from egg to adult required an average of 11 1/2 days at 21°C on a mixed algal diet (Figure 9a). Nauplii varied little in the time required per instar. The copepodites, however, varied increasingly in individual growth rate with increasing age. Nevertheless, the mean time in each stage of development plotted against time yields a straight line, indicating a constant rate of growth. This is in agreement with Heinle's (1969) work on the Atlantic *A. tonsa*.

Mortality rates (Figure 9b) were higher during the naupliar stages than the copepodites stages. Approximately 50 per cent of the nauplii had died by the time the



Figures 9a and 9b.

median individual reached copepodite I-II. Another 25-30 per cent died as copepodites, thus only 20 per cent of the original population survived to adulthood. Second generation nauplii appeared 12 1/2 days after the first eggs were produced, indicating egg production probably commenced on the 11 th day when the median individual reached adulthood. A replicate experiment verified the above observations.

Growth rates in estuary water (Figure 10) at 21°C were nearly identical to those rates observed in the cultured algal diet experiment. Approximately 11 3/4 days were required for half the population to reach adulthood. The rate of reproduction was the only significant difference between the results of the two experiments. The low number of second generation nauplii produced in estuary water was probably due to the depletion of the natural food supply. Few phytoplankters remained at the end of thirteen days.

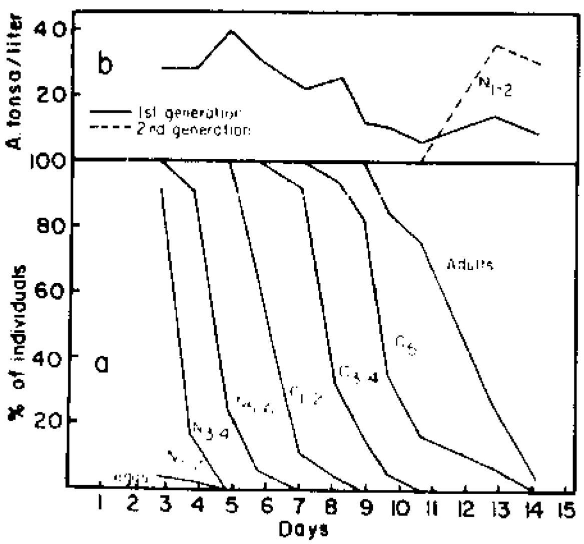


Figure 10.

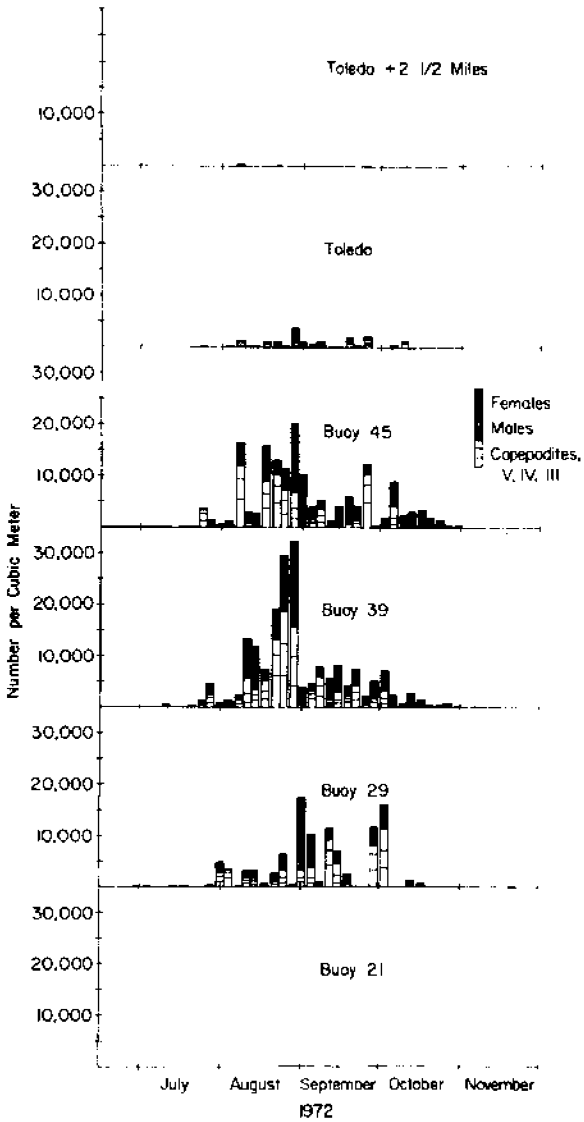
Experimental growth rates of the Yaquina Bay *A. tonsa* at 21°C agree well with similar work done on the Atlantic coast. Heinle (1966, 1969) found the growth of *A. tonsa* from egg to egg in raw estuary water required 5, 7, 9, and 13 days at 30.7°C, 25.5°C, 22.4°C and 15.5°C respectively. A mean generation time of 25 days at 17.5°C was reported for *A. tonsa* by Zillioux and Wilson (1966). However their experimental animals were maintained on a suboptimal algal diet. Temperature is thus an important determinant of the rate of growth of *Acartia tonsa*. The effect of temperature will be seen to be especially significant in the upper reaches of the Yaquina estuary as the shallow waters there reach much higher temperatures than farther downstream.

Distribution and Abundance of A. tonsa

Counting was recently completed for the adult and copepdoite stages III, IV and V, using the 0.112 mm net samples. Estimates of adult abundance were also made using the 0.239 mm net samples. However, the latter estimates were rejected as too low when a comparison of simultaneous catches with the 0.112 mm net revealed a significant loss (40-60 per cent) of adult males through the mesh during the Months of July, August and September. Moderate quantities of the slightly larger females were also lost from the 0.239 mm net. The seasonal variation of the escapement from the 0.239 mm net was caused by a reduction of body size resulting from the high rate of metabolism and maturation induced by high water temperatures.

The calculation of age specific mortality rates will not be attempted until estimates are available for the absolute density of the remaining copepodite and naupliar stages. At that time other population dynamic parameters, including the instantaneous rate of increase (r), instantaneous birth rates (b) and biomass, will be computed to estimate the production of *A. tonsa* in Yaquina estuary.

The range of the population of *A. tonsa* in the Yaquina estuary extended from B-21 to Toledo + 2 1/2 miles. These two stations represent the extreme limits of the population, since few adults and only rare copepodites were ever present. The bulk of the population was restricted to B-29, B-39, B-45 and Toledo with a center in the vicinity of B-39 (Figures 11, 12, and 13). The copepodites generally exhibited a more restricted distribution than the adults, indicating reproduction and survival of young were highest between B-29 and B-45. The center of the population was not static around B-39 because of tidal movement. Frolander (1964) demonstrated that horizontal transport of distribution centers can be on the order of several kilometers over a twenty-eight hour span in the Yaquina estuary. Sampling without regard to the stage of the tides in this study occasionally showed the population



Figures 11, 12, and 13.

center to be at B-45, 1.0 nautical mile upstream from B-39, or more rarely at B-29, 1.4 nautical miles downstream from B-39.

The complexity of analyzing a moving population was circumvented by considering the mass of water inhabited by *A. tonsa* as a closed system. This is reasonable because of the low diffusive losses of *A. tonsa* to the lower bay (Figure 11). Therefore the maximum density per cubic meter observed on a given sampling day was considered as the approximate population center, regardless of location in the river. Plotting the maximum density values observed for both copepodites and adults on successive sample days generate an unsophisticated but workable model of the population dynamics (Figure 14). The density of adult *A. tonsa* was less than 50 animals/m^3 from June 19 to July 6. Four days later, adults reached a minor peak at 127.8 animals/m^3 before declining again. A heavy phytoplankton bloom occurred concurrently from July 10 to July 13. Seventeen days later, the adults peaked at a new maximum of 2,262.7 animals/m^3 and the annual population explosion was underway. The heavy phytoplankton bloom was apparently the triggering mechanism for the population explosion as maximum egg production occurs under favorable food conditions. This principle was verified during the laboratory experiments on egg production rates.

A maximum density of 16,759 adults/m^3 was observed in the upper Yaquina estuary on August 28. Ten days later the adult population had crashed to a density of 2,142 adults/m^3.

The total egg production of the population is greatest when the adults attain their maximum density. Therefore, the frequency of the six adult peaks was used to infer growth rates from egg to adult under fluctuating field conditions. The average time interval between adult peaks in July and August, for example, was 16 days at an approximate temperature of 20°C. This interval is longer than the laboratory-derived estimate of 11 1/2-11 3/4 days at 21°C. Development rates decreased during

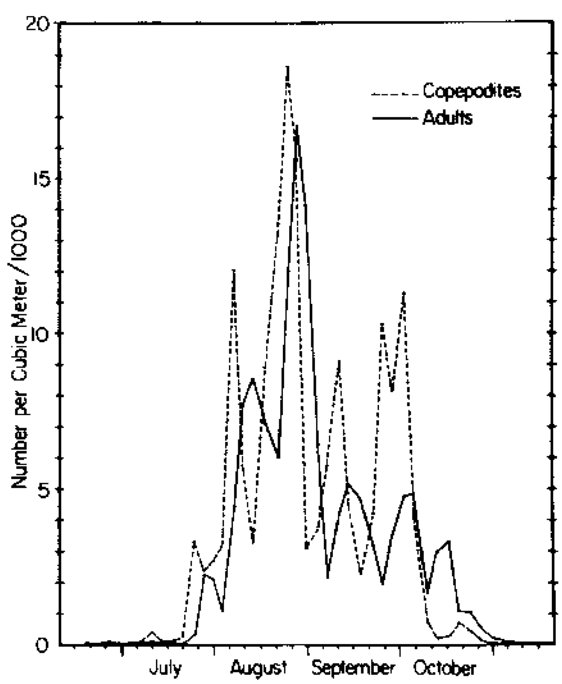


Figure 14.

September, October and November, however, due to the falling water temperature (Figure 8). Starting with the August 28th adult peak, it required 17 and 19 days for eggs to reach maturity at estimated temperatures of 18° and 16°C respectively. The apparent bimodality of the copepodite peak at about September 28 is probably attributable to sampling variability.

The origins of the final adult peak in mid-October are obscure because there is no associated copepodite peak shortly preceding it.

DISCUSSION

The crash in early September and subsequent overall decline of the population cannot be attributed to flushing by short term influxes of fresh water from rainstorms. Very little rain fell during the summer and early fall, with the exception of one prolonged rainy period during September 18 to 24 when 2.83 inches of rainfall were recorded at the Marine Science Center at Newport (Figure 15). A graph of the mean salinities associated with the population center (Figure 16) revealed that no significant dilution occurred as a result of the rainfall. This is reasonable since most of the early precipitation in the fall is soaked up by the undersaturated soil of the Yaquina River drainage basin (Kulm and Byrne, 1966). The marked increase in rainfall during October is not reflected in the salinity until about one month later.

We believe that the seasonal decline of water temperature in the upper bay plays a major role in the decline and eventual extinction of the *A. tonsa* populations. An examination of the temperatures associated with the population center (Figure 16) reveals a gradual and fairly consistent rate of decline throughout September and October with two periods of possible significance. Temperatures fell from 20.5°C to 17.5°C between August 24 and September 7, the period of population crash. Another major drop from 18.0°C to 13.5°C occurred between September 18 and 29 during the heavy rains. Neither of these two temperature decreases would normally be considered as constituting thermal shock as the changes were less than 5°C and occurred over a span of many days. This range is well within the tolerance range of the adults (Heinle, 1969). It is possible, of course, that the larval stages are much more sensitive to temperature and have narrower tolerance ranges than the adults.

It is most likely however, that the effect of temperature results from its effect on development rate. Experiments by Heinle (1966) have demonstrated that even a 1° or 2°C decrease in water temperature results in a pronounced increase in the time required for development from egg to adult. This will decrease the population's intrinsic rate of increase and thus increase the interval during which each generation is exposed to predation prior to reproduction.

The nature of predation on *A. tonsa* has not been completely documented in the Yaquina estuary, but the small pelagic fishes undoubtedly take a significant toll, Russell (1964). Dense schools of herring and anchovy fingerlings were commonly observed in the surface waters at B-39 during August and September. Hydrozoan medusae also may be major predators: *Phialidium* attained its maximum summer density coincident with the population crash of *A. tonsa*.

Alternate hypotheses about the causation of the population crash have not,

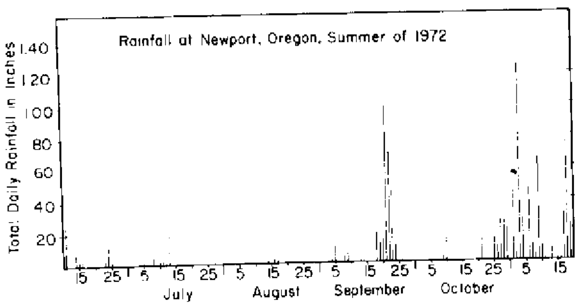


Figure 15.

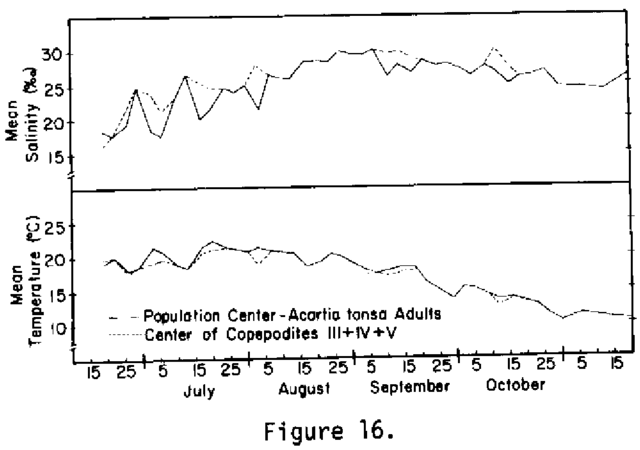


Figure 16.

of course, been eliminated. Depletion of the algal food supply is an outstanding possibility.

In conclusion, we would like to re-emphasize the engineering implication of this work. *Acartia tonsa* is the dominant herbivore in upper Yaquina Estuary during the summer and, consequently, accounts for the bulk of the secondary plankton production. We know that the young of the commercially important anchovy, *Engraulis mordax*, are important predators. Adult *Engraulis*, in turn, are an important prey of salmonid fishes in the nearshore oceanic waters. Only a restricted section of the estuary provides an appropriate habitat for the population explosion of *A. tonsa*. Changes in the flow patterns of the bay, such as might result from deeper dredging to Toledo, for example, could readily flush the population out. Pollution in the area of B-39 could conceivably eliminate the whole food chain by removal of the localized *A. tonsa* link. It is, therefore, clear that the consequences to planktonic life forms must be considered when contemplating any modification of an estuary.

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Concerns on the Horizon for Effective Coastal Zone Management

Ellen Lowe, Commissioner
Oregon Coastal Conservation and
Development Commission, Salem

There are some ominous clouds on the horizon of effective coastal zone management in Oregon as I look to the future. Clouds can be quite amorphous so I wish to emphasize that my perceptions are from my own frame of reference and in no way are meant to reflect the view that another coastal commissioner may hold of the same horizon.

THE OCC & DC

To assist you in understanding my concern, I wish to take a few minutes to describe the structure and legislative charge of the OCC & DC. The Commission, a state agency, embodies a concept of local-state partnership with twenty-four representatives of the thirty member commission appointed from elected officials representing counties, cities and port districts, the very units of government at the local level who will be largely responsible for the implementation of our coastal zone management effort. The remaining six members of the commission are appointed by the Governor to represent the state at large. That is my category.

Our legislative charge is to prepare and recommend to the 1975 session of the Oregon Legislature, coordinated policies and plans, and their methods of implementation, for the wise management of the natural resources in the coastal zone. Our plan is to be submitted in the form of a series of management policies and standards against which proposed uses of the natural resources of the coastal zone may be evaluated. A key legislative request is that we establish a basis for determining preferences between conflicting uses of natural resources. Our task is not to achieve a final product but to develop a dynamic and continuing process.

The opportunity to be part of this task came as a real surprise to me for I had not been active in the state-wide environmental movement. But I was beginning to make public noises as a member of the Salem Planning Commission about the need to create regional palnning and implementation mechanisms in order to protect local livability goals. My husband and I had also commented more than once about the condominium which rests on our beach between Nelscott and Taft where we so often walk. The term provincial may have fit us.

When I accepted the appointment, my first stop was the state library; I "tried" to read everything I could find on estuaries. Greek would have been as clear in many instances. Thus with a self-image quotient of zero I went to my first meeting, but a little listening told me that glossaries or perhaps an interpreter would have been useful for a majority of the commissioners. I might add that at our preliminary budget hearing this week, a state legislator said that he needed a glossary to read our report.

It isn't the definition of terms that is so necessary, however, but the clarification of relationships. Decision-makers can operate under the most environmentally sound goals and policies available to man and still blissfully authorize a series of small projects that combine to create barriers to those goals. IBM has used a two-page ad with a large picture of a rugged coast line. The one line of printing says "No one can take the ultimate weight of decision-making off your shoulders. But the more you know about how things really are, the lighter the burden will be." I believe you have the capacity to lighten the burden of the OCC & DC if you will.

Oregon State University took a first step in its current methodology study which Peter Klingeman will discuss later this afternoon. The limited funding and time frame, however, suggest that it is just a beginning. The National Science Foundation is currently seeking study areas that have some universal and practical application. In my judgment this pursuit qualifies. I am aware that such an endeavor is not only a scientific challenge but also a very human one. The correspondence of some coastal officials concerning OSU's study left little doubt of some of the deep-seated resentment against the academic community. Thus it will take patience, thick skin, an occasional deaf ear and directness to gain the confidence and understanding of those who need your expertise in order to make decisions in the public interest. You are part of the general public--it's in your interest as well as ours for this communication to develop.

SPECIFIC RESEARCH NEEDED

Now may be the appropriate time to reveal why you are being addressed by a coastal commissioner whose favorite book on the coast is not technical but a volume of Jeffers' poetry. Last fall at an OCC & DC meeting, Maradel Gale, another commissioner, and I were looking through some information which was used to support a Corps of Engineers dredging project. Part of the justification was a letter from a colleague of many of you. The letter was an excellent discussion of the factors that contribute to the silt and sedimentation deposits in estuaries. It discussed reasons for and benefits that might be derived from renovation of the ecosystem of the bay--but in our judgment it didn't address itself to the specific dredging project. Mrs. Gale shared our joint concern with Larry Slotta, but since she is taking law school finals I'm pleading our case today (or maybe it's a sermon).

In order to keep your responses from being innocently misused or deliberately distorted we urge you to structure your comments so they will concisely depict the available alternatives and the consequences of each. Also when a particular problem needs a series of actions rather than one, it's vital that the interdependencies of the approaches are also discussed. A half a loaf is not always superior to none. I realize that my request may be asking you to respond to a different question than the one posed--but remember many of us are still struggling in an attempt to ask the right questions.

You have an added burden in interpreting our cries for help. It should go without saying that those of you who are part of the public agency or university sector should respond in terms of the overall public interest. The public is the purchaser of your expertise and remember this becomes part of the record available to the citizen-type public as well as the decision-makers.

While I'm talking about the citizen-type public, may I remind you of your own citizenship. You should not confine your contribution to technical advisory committees but offer your time and talents to citizen groups as well. Dr. Paul Rudy, chairman of the Coos County Planning Commission, is one of the most positive forces on the Oregon Coast. Look to your own area for service opportunities and don't be hesitant to volunteer.

Even if you develop a methodology that will succinctly articulate the alternatives available to decision-makers and maybe even become policymakers yourselves, we still aren't home free. I wish to discuss briefly some additional barriers to our coastal goals.

COMPLEX PATTERN OF LOCAL GOVERNMENT

One of these barriers in my view is the very sturcture of local government. If we were to design an efficient and responsive planning process we would find it totally divorced from reality--an efficient planning process would be impossible to mesh with the pattern of governments which are part of Oregon. Rather than restructure our local government we, by default, often invite state and federal intervention. In a recent address, Lloyd Anderson, city commissioner from Portland, suggested that an area's ability to utilize its resources, to fairly distribute its tax base, to plan and program in a sound way is diminished by the square of the number of governmental jurisdictions that exist in that area. We need to ask "why" about many of our units of local government. We may find that the reasons for the original boundaries and functions no longer exist while other needs are being bypassed. The "why" needs to be asked in terms of overall goals in order to demonstrate that the *status quo* may be false security.

Discounting Astoria, which really is part of the Columbia system, there are fourteen port districts on the Oregon coast. Three of our coastal waterways are each under the jurisdiction of two port districts. It appears to me as if the potential for wasteful duplication and competition will remain unless we seek a unified coastal port district. We have one coastal zone in which we are trying to achieve a variety of waterway services--fourteen port districts present an obstacle. Some of the county and city boundaries also seem illogical. If we begin to examine what creates a concept of community, we will start the development of more responsive government.

PLANNING FUNDS UNCERTAIN

A need we share with many other groups tackling domestic challenges is the instability of our funding. The passage of the Coastal Zone Management Act in 1972 raised our expectations. The OCC & DC on a national level appeared to be the logical recipient of research grants. The Nixon administration did not create a "coastal zone planning" line item in the current budget. Thus $313,000 of our anticipated budget of $645,870 will have to be sought from other sources. And we shall not be alone in the line. It's another indication that the political process should be no more foreign to the oceanographer at Newport than the holder of a garbage contract in Chicago.

Our political awareness need not only be acute on the national scene but more importantly on the local level. I brought a few extra copies of our commission publication, Estuary Planning Guidelines. It should be a positive force in gaining public understanding and support. It supplies a methodology for working with our many publics to gain common commitment to implement plans. You will find it helpful in your citizen contracts. You amy also wish to use it as a yardstick to measure the degree of public involvement of our commission. Don't allow us to function in isolation. It breeds contempt, not support.

Some recent court cases, particularly the Fessano case in Washington County, reinforce the importance of adequate comprehensive plans. Any changes in the plan will have to be substantiated by evidence that the proposed use could not be accommodated in already designated areas. This not only makes it incumbent upon us to develop the best possible plan based on our current store of knowledge but also design systems whereby the plans can be monitored and updated in an orderly fashion.

And this brings me back to my original request. Only with your translation of the technical to the understandable will we be able to interpret the relationship between standards for development and proposed land uses and our stated goal to achieve wise management of our coastal natural resources.

I can't plan effectively *for* people--neither can you--but together we can plan *with* people.

Robinson Jeffers said it so well,

> ...the greatest beauty is organic wholeness, the wholeness of life and things, the divine beauty of the universe. Love that, not man apart from that...

Adaptation of Existing EPA Criteria to Ecological Characterization of Pollution in Sediments

M.P. Wennekens, Oceanographer
Marine and Coastal Zone Management Division,
State of Alaska, Juneau

The economic realities of modern society require that a viable level of unimpeded waterborne commerce be maintained. Continuously accreting sediments must be periodically removed (maintenance dredging) from interfering shoals while at times undisturbed sediments must be excavated (new work) to allow for expansion of navigational accesses and harbor facilities. Modern society, however, with the realization that a good portion of the sediments have become the repository of a wide array of ecologically hazardous anthropogenic discards and that haphazard redistribution of the sheer volume of removed sediments can physically obliterate bottom dwelling life, demands that an effective balance be maintained between the necessity of insuring effective protection of aquatic ecologies from degradation and eradication and the sustenance of an effective level of waterborne commerce.

In January 1971, the Environmental Protection Agency (EPA), with the intent of providing new safeguards against unregulated disposal of polluted sediments, issued somewhat informally, through its Commissioner for Operations, a document entitled "Criteria for Determining Acceptability of Dredge Spoil Disposal to the Nation's Waters."

The EPA Criteria, as stated in Appendix I, provide the regulatory procedures and guidelines upon which considerations for the granting or denial of Corps of Engineers Permits are based.

Applications of standard laboratory and analytical procedures, as detailed in the AMSTS, various FWQA/EPA and Corps of Engineers manuals, presented only minor difficulties for obtaining the basic sets of required EPA measurements. Interpretation and applicability of the resulting data as to their ecological significance and effectiveness toward environmental protection, however, presented a much more difficult problem. To those charged with the responsibility of assessing potential environmental impacts, the EPA documents provided neither explanations nor background for the ecological relationales of the quoted limits for Zn, Hg, Pb, C.O.D., Volatile Solids, Oil and Grease, Total Kjeldahls Nitrogen and other parameters.

The quoted limits for heavy metal were particularly bothersome as the zinc levels in the sediments collected in San Francisco Bay, San Diego and Long Beach Harbors as well as other localities in need of dredging along the California coast were most frequently in excess of the EPA limits. Thus many samples that could be passed as "clean" by the other parameters, still were deemed "polluted" because of high zinc. After awhile, on the argument that zinc levels could be expected to be high because of the rather high zinc concentrations in surrounding parent soils, somewhat arbitrary decisions were made to "overlook" zinc as a "pollutional" indicator.

The zinc argument serves to illustrate the nature of the very fundamental problem posed by the issuance of the EPA Criteria, mainly *what* should be measured and *why* to provide *ecologically* meaningful, effective and enforceable criteria. For example on the argument that, due to the many lead and silver deposits in the watersheds of the various streams, high concentration of such metals could be expected in the outwashed sediments, thus warranting their elimination from "pollutional" assessment.

This paper attempts to address itself to the Civil and Sanitary Engineer being continuously pressed on one side to get a project completed as expeditiously as possible while being confronted on the other side, with the necessity of providing effective safeguards against unwarranted environmental damage, all of this to be accomplished at minimum cost.

The information presented was developed in terms of the above constraints. The measurements were provided in accordance with accepted engineering sampling, analytical and data reporting practices. The information had to be obtained and made available within strict time constraints as various factions were anxious to forestall lengthy delays in their decision-making processes.

This paper will attempt to demonstrate that, by applying insight and basic knowledge of the most likely processes controlling the sediments-pollutants-biology interactions, "standard" practices can be modified to yield pertinent ecological information.

It is also hoped that the information presented will impress upon those faced with the difficult task of establishing criteria and procedures aimed at environmental quality protection that hasty decisions without proper definition of ecological protection objectives and in depth assessment of the extent to which available knowledge can be applied toward the solution sought, can only result in ascerbic and frustrating situations in which many dollars can be expended with little or no effectiveness toward the required environmental protection.

"POLLUTIONAL" CHARACTERIZATION OF SAN DIEGO HARBOR SEDIMENTS: HYDROCHEMICAL CONSIDERATIONS

San Diego Harbor acted for many years as a presumed "assimilative" sump for various forms of wastes, until the continuing degredation of the quality of its waters forced the implementation of extensive (and costly) remedial measures, as shown in Figure 1 (Dodson, 1972).

The bottom deposits of San Diego Harbor consist of various natural admixtures of gravels, sands, silts, clays, organic matter, gases, tests and skeletal remains of various forms of life, all variously interspaced within a complex, moderately strong polyelectrolyte. To the natural admixtures are superimposed a wide array of liquid and solid anthropogenic additives, which once introduced into the system undergo complex reactions with both the natural constituents and one another.

The hydrochemical processes are primarily responsible for the so-called "assimilative" capacity of the "receiving waters" and as such provide for additional stages of "treatment," generating their own specialized types of sludges which in turn become incorporated in the suspended and deposited sediments.

Usually overlooked from similative capacities considerations, is the controlling physical-chemical role exerted

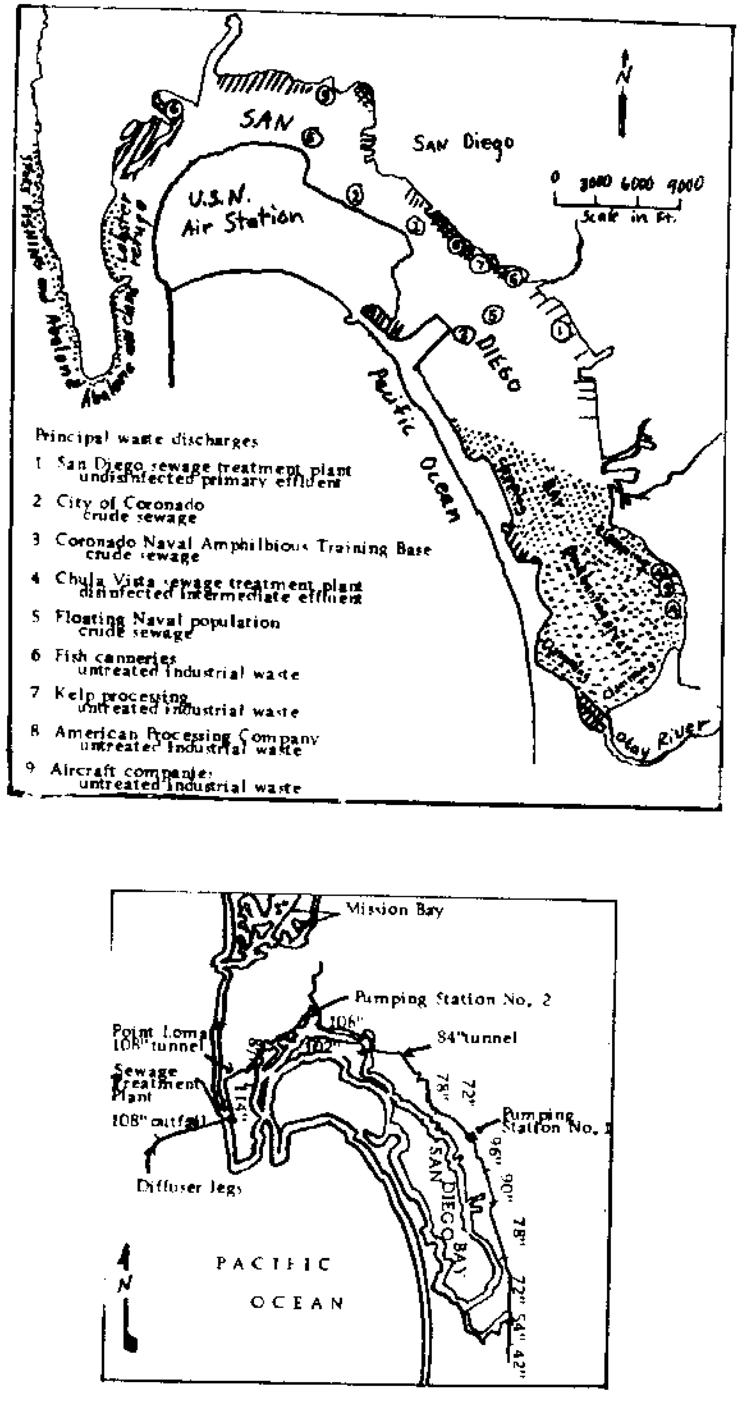


Figure 1. Clean up of San Diego Bay. (Dodson, 1972)

by particulates, especially the fine clay-colloidal sizes. The importance of solid-liquid interfaces in hydrochemical processes is slowly being recognized, as exemplified by the findings and recommendations by various National Science Foundation workshops (Waste Management Concepts for the Coastal Zone, 1970; Marine Environmental Quality and Marine Chemistry, 1971). New treatises in marine and aquatic chemistries (Horne, 1969; Stumm and Morgan, 1970) discuss in detail the basics of various interfacial processes. One of the more comprehensive summaries of the processes controlling the behavior, paths and fate of anthro-additives released into the marine environment, with pertinent references to the role of particulates can be found in the 1971 National Academy of Sciences document entitled: "Radioactivity and the Marine Environment." More specific information on the hydrochemical properties of inorganic and organic particulates can be found in Grim (1968), Salomon (1962), Krone (1969, 1972), Hood (1969), Richards (1969), Sharma (1971), Horne *et al* (1971), Saila *et al* (1971), among others.

A comprehensive survey of the literature indicates that the fine inorganic and organic particulates in the fine silt, clay and colloidal particle sizes (less than 50 microns) exert a dominant control upon the geo-biochemical fate, transport, dispersal, deposition, recycling and biological uptake of the bulk of the anthro-additives introduced into the harbor and coastal waters.

The objectives of the present paper are to demonstrate the importance of particle size separation for the pollutional characterization of aquatic sediments and to outline the manner by which the analytical results can be translated into more meaningful ecological information.

EXPERIMENTAL AND SAMPLE PROCESSING PROCEDURES

Two sets of sediment samples were collected and analyzed:

a) Thirteen surface (grab) samples collected at the locations shown in Figure 2.

b) Five bottom cores collected at locations also shown in Figure 2.

All sample processing and analytical procedures were performed in accordance with the procedures outlined in Appendix II.

I. SURFACE SEDIMENTS

A. Whole Sample Analyses. The results of whole sample analysis of the surface sediments are shown in Table 1 (U.S. Corps of Engineers, S. Pac. Div., Sausalito Lab., 1972). For interpretative purposes, the analytical results are plotted in the manner shown in Figure 3, the primary intent of the graphs being to underscore the relationships between the various parameters; because of the large differences in concentration ranges, the various parameters are grouped together on an arbitrary ordinate.

Several interesting relationships can be observed between the amount of fine particulates, inferred organic levels as measured by Total Kjeldahl Nitrogen, Volatile Solids, Oil and Grease, C.O.D. and the variations in heavy metals concentrations. The peakings in the organic and heavy metals concentrations for locations E 5 E and # 12 E could be related to the proximities of sewage outfalls prior to rerouting in the newly constructed collecting system (Figure 1).

Of special interest are the results from locations E 2 C at the lower reach of the harbor and E 17 C at its upper reach. At both locations the drastic drop in the levels of fine particulates and "organics" correlates with a sharp decrease in heavy metal levels. The only exception to the pattern is Hg and As at Station E 17 C where a peaking up rather than a drop occurs; no ready expanation can be provided for the Hg and As behavior, sample mislabelling being a good possibility. Replicate measurements would be needed to confirm their behavioral non-conformity with the other heavy metals. Fe also peaks up at location E 16 C while behaving as the other metals in the rest of the harbor sediments.

The patterns of behavior exhibited by all the physical and chemical sedimentary parameters conform well with predictions based

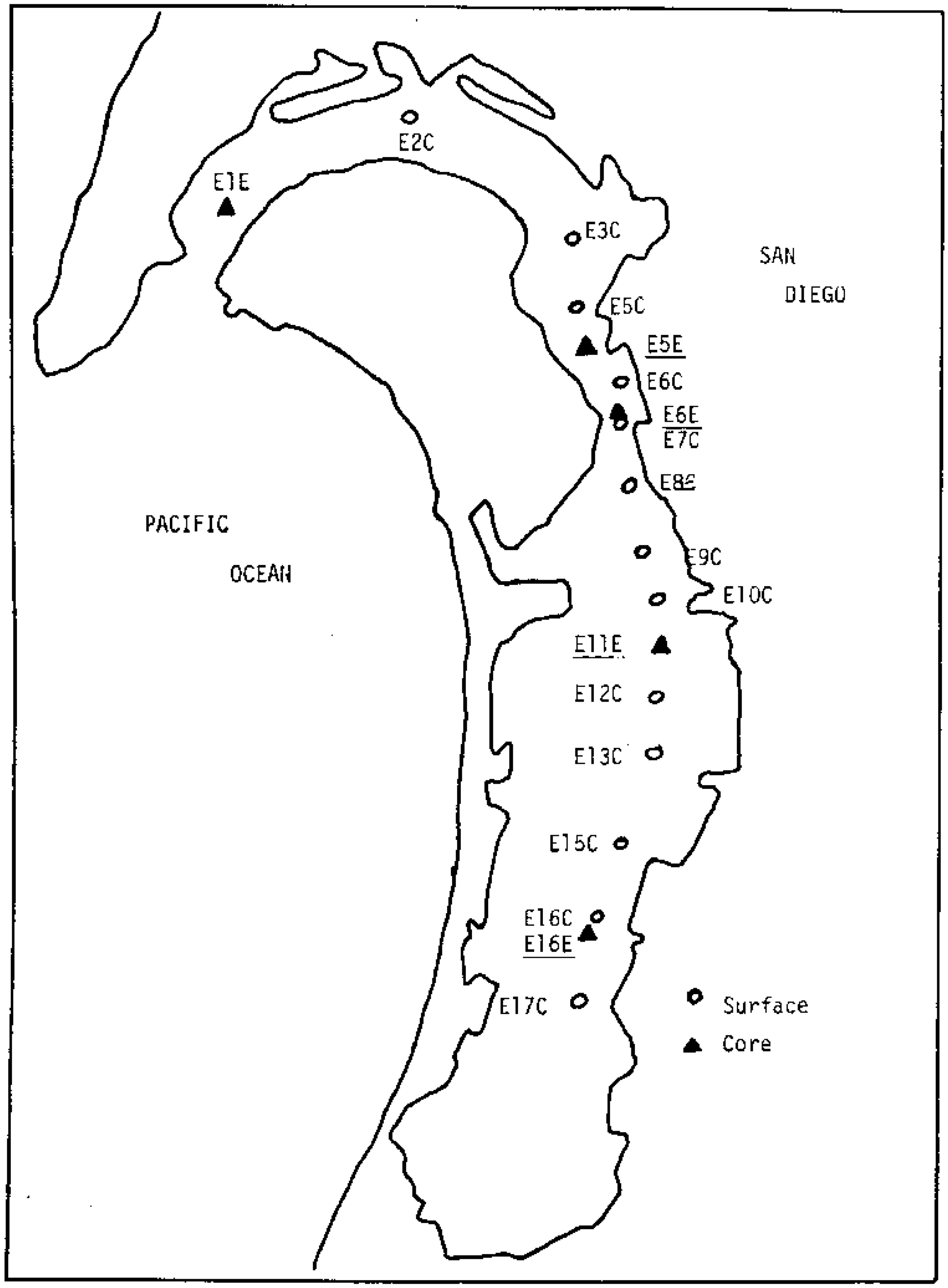


Figure 2. Sediment Sampling Locations, San Diego Harbor.

TABLE 1

February 1972

SAN DIEGO HARBOR - SAN DIEGO, CALIFORNIA

PROPOSED CHANNEL DEEPENING PROJECT
IDENTIFICATION AND CHEMICAL ANALYSIS OF SAND AND SILT
OR CLAY FRACTIONS OF BOTTOM SAMPLE NO. E5-C
Depth 48.0 ft. Below MLLW
Coordinates, Old Town(a) S15,300 E2,800

		Soil Sample Fractions				Water Samples	
		As Received Sample E5-C	Sand Sample E5-C(A) +0.074	Silt of Clay Sample E5-C(B) -0.074 mm	EPA Limits (Sept '71)	Sample Washwater from San Diego Bay	As Received San Diego Bay Water
Moisture Content							
% of Dry Wt.		64.3	30.5	452.0	---	---	---
Total Solids		---	---	---	---	44.05 g/L	40.73 g/L
Volatile Solids, % of Dry Wt.		5.9	2.1	12.6*	6.0	26.90% of Dry Wt.(b)	18.98% Dry Wt. (b)
C.O.D., % of Dry Wt.		5.7*	0.5	8.2*	5.0	2117 ppm	17 ppm
Total Kjeldahl Nitrogen, % of Dry Wt.		0.24*	0.04	0.42*	0.10	162 ppm	16 ppm
Oil and Grease, % of Dry Wt.		0.27*	0.05	0.46*	0.15	33 ppm	19 ppm
Iron, Fe, % of Dry Wt.		3.95	0.63	2.48	---	1 ppm	1 ppm
Reported as $1x10^{-4}$ % Dry Wt.						Reported as ppm	
Mercury	Hg	0.84	1.13*	1.84*	1.0	0.009	0.009
Lead	Pb	43.0	46.0	110.0 *	50.0	0.04	0.04
Zinc	Zn	176.0 *	98.0	210.0 *	50.0	0.03	0.02
Cadmium	Cd	1.5	3.2	8.3	---	< 0.005	< 0.005
Copper	Cu	84.0	1.8	7.2	---	0.01	0.01
Chromium	Cr	55.0	9.8	74.5	---	< 0.2	< 0.2
Arsenic	As	0.525	0.16	2.87	---	0.001	0.005
Nickel	Ni	10.0	4.6	28.0	---	0.03	0.03
Total Phosphorous	P	596.0	123.0	608.0	---	0.7	0.07
Sulfide	S	743.0	11.0	392.0	---	< 0.04	< 0.04

* Exceeds EPA limits (Sept. 1971)
(a) Old Town reference point. Navigational Chart 5107
(b) Including water of Hydration of Sodium Chloride

NOTE: The Soil Sample Fractions are shown as % of dry weight or as $1x10^{-4}$% (or parts per million) of dry weight
1 ppm = $1x10^{-4}$%
(1 ppm = 0.0001%)
1% = 10,000 ppm

The water analysis results are shown in parts per million (ppm) and in grams per liter (g/L)

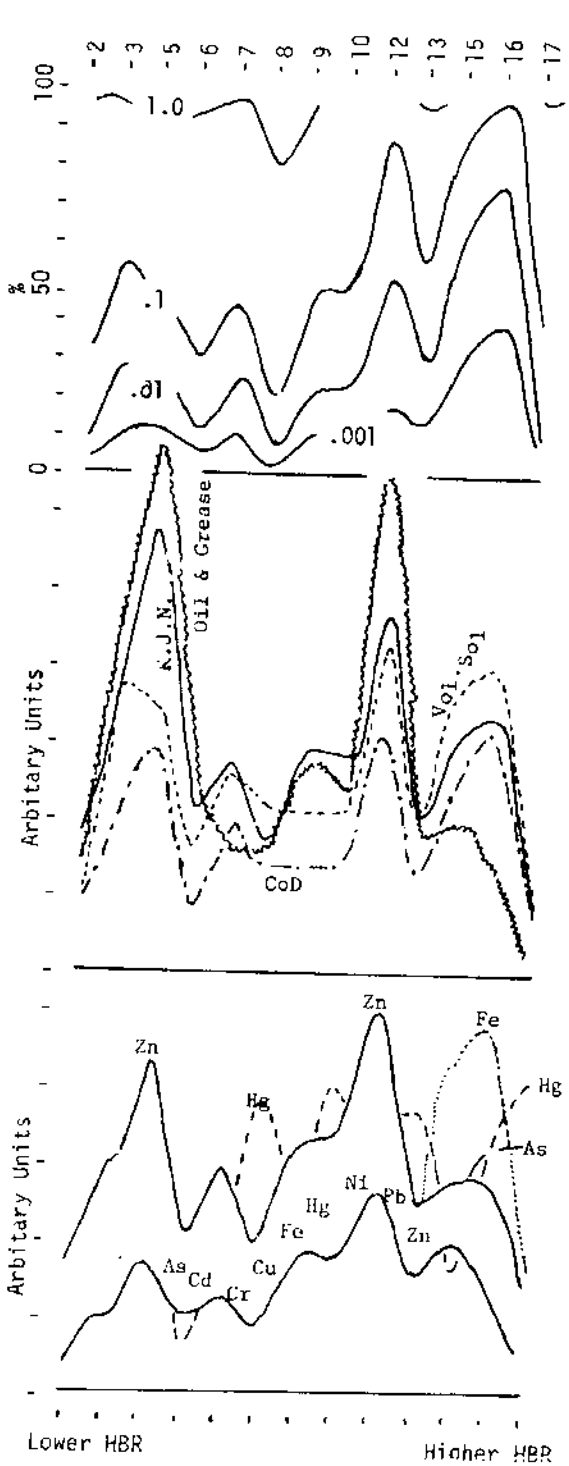


Figure 3. Granulometeric, "Organic," Heavy Metals relationships, Surface Sediments, San Diego Harbor.

upon the physical-inorganic-organic chemistries of fine particles. The peaking and dropping of "organics" and heavy metal concentrations strongly suggest that the heavy metals are in some form of organo-metallic complex. A similar correlation between organic and heavy metals levels was observed in San Francisco Bay as illustrated in Figure 4 (Peterson *et al*, 1972). The organic-heavy metal relationship is rather well-illustrated in San Diego Harbor for locations E 13 C through E 17 C for which high percentages of fine particulates, with relatively low levels of organics correlate with low levels of heavy metals.

B. Particle Size Separation. To investigate and define further the relationships between fine particulate-organic and heavy metal concentration, location E 5 C was resampled and analysis performed by separating the sediments into "coarse" and "fine" fractions, as described below:

> *Fractional Grain-Size Separation.* The sample was wet sieved in general accordance with Engineering Manual EM 1110-2-1906, Laboratory Soils Testing, 30 November 1970, using U.S. Standard No. 18, mesh, 1.0 mm opening and No. 200, mesh, 0.074 mm opening sieves. The sieves were constructed of stainless steel wire cloth, and the technician wore rubber gloves during the washing process as a precaution against contamination. Sea water from San Diego Harbor was used for washing and was applied to the material on each sieve by action of a battery filler type syringe. The material retained on the No. 18 sieve, consisting primarily of sea shells, was not tested. All wash water was collected in evaporating dishes and decanted after a period of settlement. All samples of the decanted wash water, the plus 0.74 mm, sand fraction and the minus 0.074 mm, silt or clay fraction were saved for pollution analysis. (U.S. Corps of Engineers, S. Pac. Div., Sausalito Lab., 1972).

The analytical results are shown in Table I. The fine fraction of the sample, wet sieved through a No. 200 mesh sieve with harbor water, accounted for about 40 to 45 per cent of the dry weight of the sample. The differences between the organic and heavy metal concentrations in the coarse and fine fractions are obvious and further confirm the results of the whole sample analysis. Of interest in

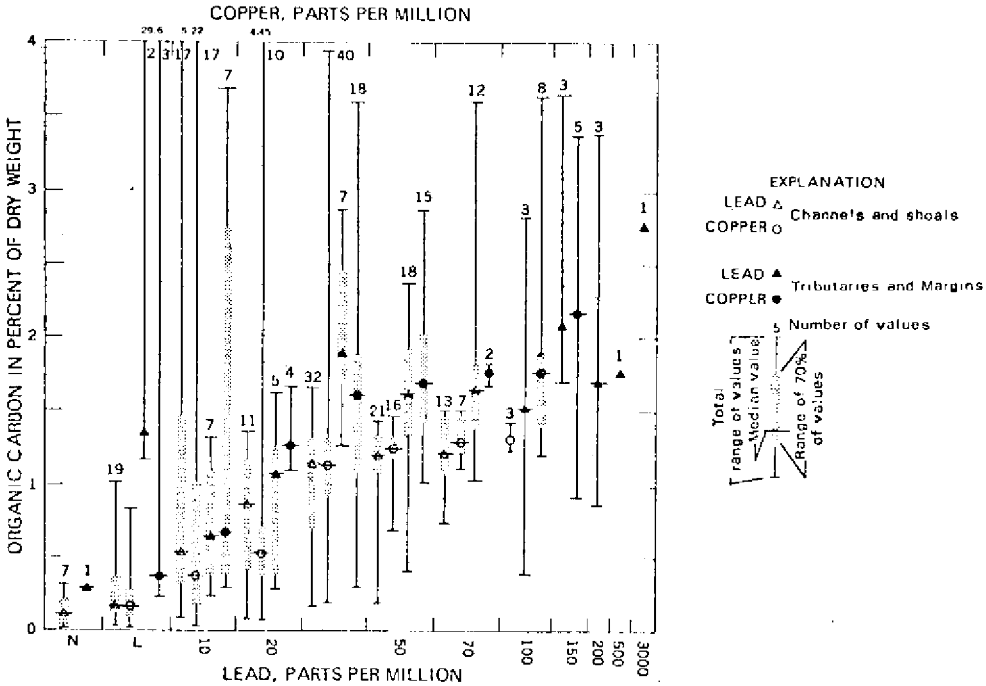


Figure 4. Organic Carbon, Lead, Copper relationships, San Francisco Bay Sediments. (Peterson et al, 1972)

Table 1 is the fact that apart from certain portions of the "organics," the concentrations of heavy metals in the original harbor water and in the "wash water" remained identical, showing no evidence for heavy metals resolution during the wet sieving procedures. The results suggest that little or no resolution of heavy metals is to be expected from mechanical stirring of sediments during dredging.

II. CORE SEDIMENTS

The preceding whole sample analyses provided only for a general longitudinal distribution of the "pollutional" characteristics of the surface sediments of the harbor.

If one refers to Table 2 and supplies the information as outlined in Appendix I to characterize the "acceptability" of the sediments for disposal in open waters, one finds that for certain locations, "organics suites also contribute to additional pollutional classification.

Inferred from such measurements is that all of the sediments to be dredged are "polluted," and unacceptable for open water disposal. From a practical disposal standpoint, the question immediately arises; how much is actually polluted and needs to be excluded from redispersal into open water, and how much can be considered as clean, and can be redistributed in the most beneficial manner. With a better appreciation of the three-dimensional distribution of pollution in the harbor sediments, engineering evaluations of the total volume of material that would require contained disposal can be derived and appropriate removal techniques formulated.

To study the vertical pattern of distribution of pollutants in the San Diego Harbor sediments, five cores were collected as shown in Figure 2. Two sets of analyses were performed, one on an "homogenized" portion of one-half whole core; the others, on a strata by strata basis.

A. Homogenized Core. Based upon engineering arguments that, in practice, dredging equipment tends to "homogenize" the sediments by intermixing "polluted" material with "clean" material, request was made the the certification of the quality of the dredged material for redispersal in open water be based upon "homogenized" samples.

January 1972

TABLE 2

SAN DIEGO HARBOR - SAN DIEGO, CALIFORNIA
PROPOSED CHANNEL DEEPENING PROJECT

IDENTIFICATION AND CHEMICAL ANALYSES
OF
BOTTOM SAMPLES

Lab No.	Hole No.	Coordinates, Old Town (a)		Depth, ft. Below MLLW	Moisture content % dry wt.		Volatile Solids % dry wt.	C.O.D. % dry wt.	Total Kjeldahl Nitrogen % dry wt.	Oil and Grease % dry wt.
					Total Sample	No. 10 Sieve(b)				
PC-275	E 2-C	S 13,600	W 9,300	50.0	39.2	40.9	2.0	1.08	0.070	0.036
PC-276	E 3-C	S 12,800	W 700	58.4	73.4	87.5	6.6*	4.27	0.148*	0.177*
PC-277	E 5-C	S 15,300	E 2,800	48.0	64.3	188.3	5.9	5.71*	0.237*	0.274*
PC-278	E 6-C	S 17,500	E 6,500	34.0	34.1	106.8	3.4	1.51	0.082	0.091
PC-279	E 7-C	S 18,900	E 6,700	45.2	71.9	90.2	5.1	3.52	0.108*	0.065
PC-280	E 8-C	S 20,200	E 8,800	32.5	33.0	68.3	4.3	2.90	0.062	0.068
PC-281	E 9-C	S 22,600	E10,500	37.5	57.9	63.2	4.1	2.70	0.115*	0.113
PC-282	E10-C	S 23,900	E12,200	34.4	64.5	65.2	4.1	2.93	0.105	0.096
PC-283	E12-C	S 27,400	E16,800	33.6	124.1	127.1	8.2*	6.04*	0.183*	0.259*
PC-284	E13-C	S 29,600	E18,500	37.0	60.6	62.6	4.2	2.62	0.085	0.067
PC-285	E15-C	S 34,700	E19,500	40.8	142.2	146.5	8.5*	5.43*	0.125*	0.074
PC-286	E16-C	S 37,000	E19,000	16.6	147.5	150.5	9.0*	6.36*	0.138*	0.046
PC-287	E17-C	S 39,000	E20,100	2.2	37.4	42.4	1.4	0.62	0.024	0.009
EPA Maximum Limits (Sept. 1971)							6.0	5.0	0.10	0.15

(a) Old Town reference point. Navigational Chart 5107
(b) Chemical analyses were run on material passing the No. 10 sieve.
* Exceeds EPA limits.

TABLE 2 (Continued)

January 1972

SAN DIEGO HARBOR - SAN DIEGO, CALIFORNIA
PROPOSED CHANNEL DEEPENING PROJECT

IDENTIFICATION AND CHEMICAL ANALYSES
OF
BOTTOM SAMPLES

Lab. No.	Hole No.	Iron Fe % dry wt.	Mercury Hg	Lead Pb	Zinc Zn	Cadmium Cd	Copper Cu	Chromium Cr	Arsenic As	Nickel Ni	Total Phosphorous P	Sulfide S
			Reported as 1×10^{-4} per cent of dry weight									
PC-275	E 2-C	1.31	0.33	10	62*	0.4	20	14	0.387	2	185	79
PC-276	E 3-C	3.13	0.50	21	112*	1.1	66	37	0.141	10	370	441
PC-277	E 5-C	3.95	0.84	43	176*	1.5	84	55	0.525	10	596	743
PC-278	E 6-C	1.65	0.08	23	87*	0.8	50	21	0.358	5	306	62
PC-279	E 7-C	2.45	0.33	23	114*	1.0	53	32	0.392	8	290	584
PC-280	E 8-C	1.53	0.76	30	74*	0.7	32	19	0.392	4	240	279
PC-281	E 9-C	3.31	0.48	21	129*	0.8	67	41	0.458	3	288	91
PC-282	E10-C	3.19	0.77	28	124*	0.9	74	40	0.469	5	383	71
PC-283	E12-C	5.36	0.68	28	204*	1.2	123	68	0.652	7	542	259
PC-284	E13-C	3.82	0.74	15	93*	0.7	57	34	0.349	5	242	70
PC-285	E15-C	8.60	0.30	21	113*	1.1	76	54	0.500	9	426	47
PC-286	E16-C	10.27	0.50	13	115*	0.6	60	57	0.561	8	486	10
PC-287	E17-C	1.59	0.82	6	47	0.3	13	17	0.558	1	212	26
EPA Maximum Limits (Sept '71)			1.0	50	50	---	--		---	--	---	---

*Exceeds EPA Limits.

Fish and Game and Water Quality Control Board representatives were also greatly concerned about the possibilities of particulate resolution of particulate-heavy metals bond as a result of the mechanical agitation of the sediments and of the potential effects of turbidity upon various forms of marine life.

The consensus was that land containment of the variously polluted sediments would provide for the maximum environmental safeguards. However, the large volume of material (about 9 million cubic yards, of which, based upon the surface samples analysis, about 600,000 cubic yards were classified as polluted), even with the availability of a few shore sites for fills, made land containment a major undertaking, and a very costly proposition if the material had to be transported to inland sites. Two alternative solutions were being considered, ocean disposal for the more hazardous material and utilization of the "clean" material for beach nourishment along the Coronado-Silver Strand shores.

To assess, in an ecologically meaningful manner, the pros and cons of the homogenizing concepts, two sets of analyses were performed on one-half of longitudinally split Core E 11 #; the core was selected because of its location in a seemingly high pollution area. One-half of Core E 11 E half was thoroughly mechanically mixed and subjected to suite of analyses previously outlined. The other half of Core E 11 E half was thoroughly mixed, an aliquot sample dispersed in salt water and allowed to settle differentially in accordance with the following procedure:

> Separation of samples by sedimentation; about 3/4 pint of soil was placed in a 1000 ml beaker which was then filled with Steinhart Aquarium sea water. After stirring, the sand was allowed to settle and the suspension poured into an evaporating dish. The beaker was again filled with water and the process repeated until the water was clear after stirring. After flocculation occurred, the clear water was removed from the evaporating dish. (U.S. Corps of Engineers, S. Pac. Div., Sausalito Lab., 1972).

The "coarse," rapidly settling particles and the fine slowly settling "floc," which accounted for about 55 per cent of the total amount of the sediment, were then subjected to the suite of analyses previously outlined. The results of the "homogenizing" experiment are shown in Figure 5.

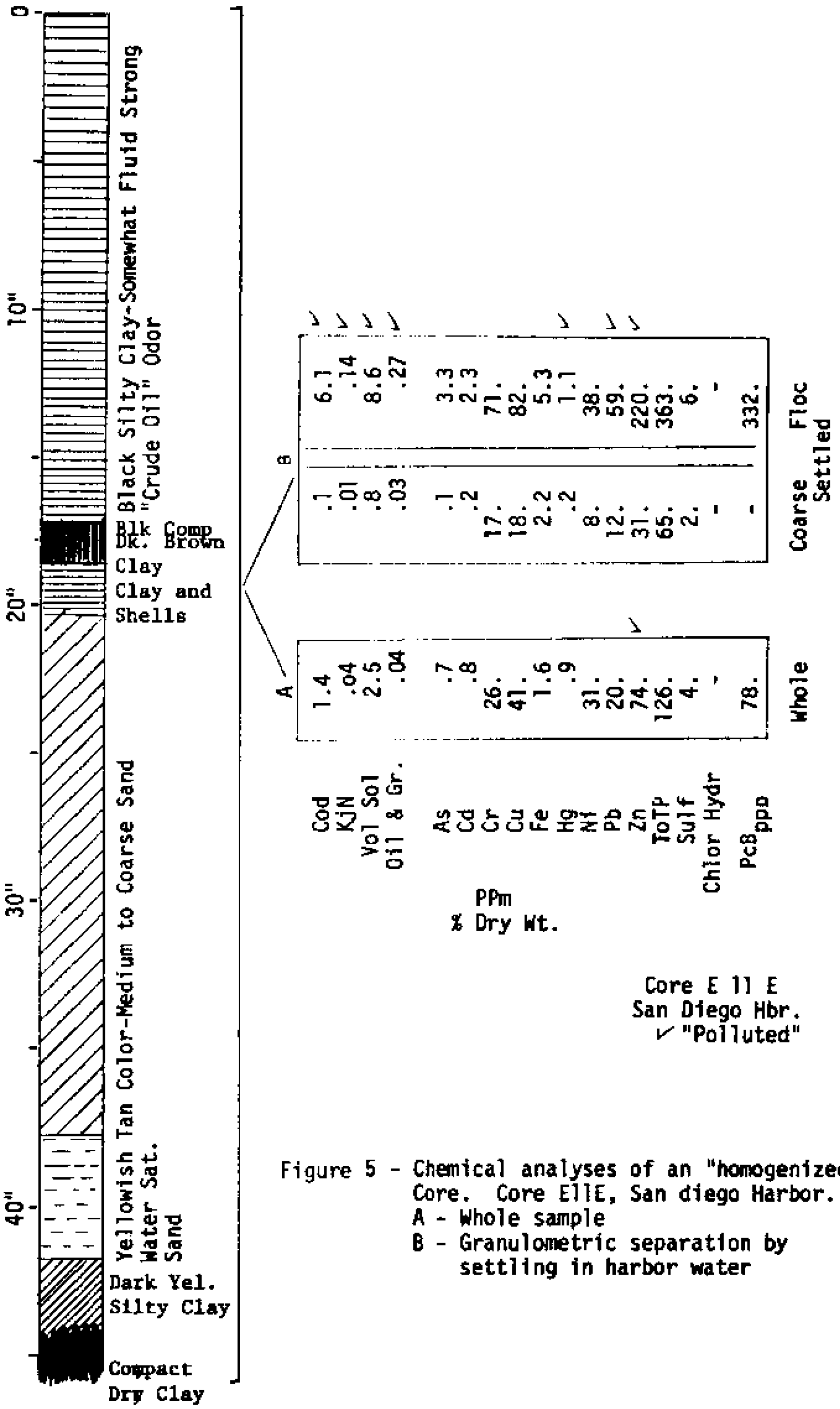
Settling rates were also performed with the following results:

> Two 1000 ml soil Steinhart Aquarium sea water suspensions were prepared using 20 and 40 per cent soil by weight. The 20 per cent suspension was 8.6 per cent soil by volume and the total density was 32.2 lbs/cu ft. The soil was dispersed and allowed to settle with periodic measurements taken from the surface of the water to the surface of the flocculated soil.
>
> It was determined from a settling test conducted on a homogenized sample from Core E 11 E that approximately 2 to 2 1/2 hours were required to complete sedimentation. The increase in water depth after that time is due to consolidation of the soil. Flocculation occurred within 30 seconds after dispersion. The sand settled in about 15 seconds. The 20 per cent soil suspension settled at the rate of 3 inches per hour and the 40 per cent at 1 inch per hour; however total settling times, 2 to 2 1/2 hours, were about the same for both suspensions. (U.S. Corps of Engineers, S. Pac. Div., Sausalito Lab., 1972).

The results of the homogenizing and settling experiments show that the main concentration of pollutants directly associated with the fine fraction of the sediment mix. Under dredging condition, which will induce a high degree of mechanical mixing with harbor water, the resulting turbidity would therefore consist of fine particulates carrying the bulk of the pollutants. The ecological significance of these experiments will be discussed further on.

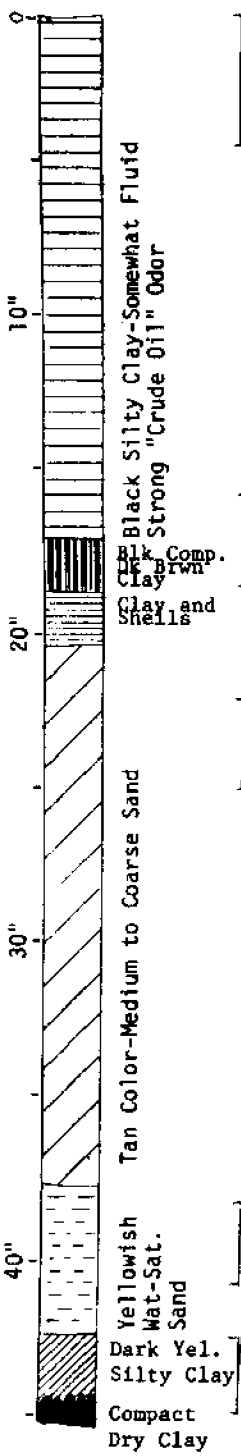
B. Particle Size Differentiation for Sedimentary Strata. The vertical distribution of "pollutants" in the various cores was investigated by selecting samples from various well-defined sediment strata, and subjecting them to the identical suite of analyses previously described. The results are illustrated in Figures 6 through 10.

1. Core E 11 E. The analytical results of the strata analyses for the remaining longitudinal one-half of Core



	A Whole	B Coarse	B Settled Floc
Cod	1.4	.1	6.1 ✓
KjN	.04	.01	.14 ✓
Vol Sol	2.5	.8	8.6 ✓
Oil & Gr.	.04	.03	.27 ✓
As	.7	.1	3.3
Cd	.8	.2	2.3
Cr	26.	17.	71.
Cu	41.	18.	82.
Fe	1.6	2.2	5.3
Hg	.9	.2	1.1 ✓
Ni	31.	8.	38.
Pb	20.	12.	59. ✓
Zn	74. ✓	31.	220. ✓
ToTP	126.	65.	363.
Sulf	4.	2.	6.
Chlor Hydr	-	-	-
PcB ppb	78.	-	332.

Figure 5 - Chemical analyses of an "homogenized" Core. Core E11E, San diego Harbor.
A - Whole sample
B - Granulometric separation by settling in harbor water



	Coarse	Fine	Coarse	Fine	Whole	Whole	Coarse	Fine
CoD	.8	8.2 ✓	.3	5.1 ✓	.1	.1	.1	.3
KjN	.02	.16 ✓	.05	.1	.02	.01	0	.18 ✓
Vol Sol	1.3	8.9 ✓	2.4	9.6 ✓	1.8	1.5	.8	6.1 ✓
Oil & Gr	--	.46 ✓	--	.1	.02	.02	--	.03
As	--	5.2	.2	2.5	.2	.1	.1	.6
Cd	--	3.0	.1	1.3	.1	.2	.2	.9
Cr	--	83.	18.	70.	12.	25.	22.	80.
Cu	--	118.	6.	32.	9.	6.	4.	51.
Fe	--	5.3	1.7	5.4	1.5	1.8	1.4	4.4
Hg	.6	1.4 ✓	.1	.5	.3	.2	.1	.6
Ni	--	44.	11.	35.	10.	9.	10.	9.
Pb	--	71. ✓	10.	25.	5.	7.	5.	44.
Zn	--	248. ✓	18.	70. ✓	16.	8.	6.	71. ✓
Tot P	--	363.	119.	411.	51.	34.	18.	97.
Sulf	--	27.	--	19.	2.	2.	5.	4.
Chl Hyd	--	--	--	--	--	--	--	--
PCB ppb	--	59.	--	146.	19.	83.	23.	197.

PPM
% Dry Wt.

Core E 11E
San Diego Hbr.
✓ "Polluted"

Figure 6. Stratigraphic and Granulometric chemical analyses of Core E 11 E, San Diego Harbor.

E 11 E shown in Figure 6 should be compared directly with those of the "homogenized" half of the same core. As indicated, not all of the strata samples were subjected to particle size analyses, due to the fact that visual inspection indicated mostly coarse material. (See physical description of the individual sediment layers.)

The analytical results revealed several interesting features:

a) As in previous analyses, the fine particulates exhibited the highest values for heavy metals concentrations, the higher concentrations correlating with the higher levels of organics.

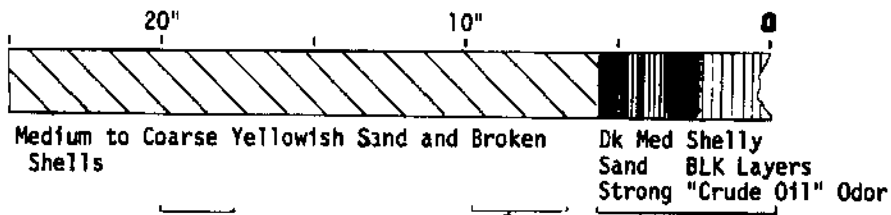
b) Well-defined concentration gradients could be observed between the surface and bottom layers of the core, the surface sediments being the highest in the organic-heavy metal concentrations.

c) The levels for Zinc, Total Kjeldahl Nitrogen and Volatile Solids could, by applying the EPA Criteria for acceptability, classify most of the fine fractions as "polluted." The concentration values for the "hard pan" layer, which effectively prevented any further penetration of the core barrel, readily suggests that such values are those of natural sedimentary deposits and that they should not be construed as being indicative of pollution.

On the basis of the present results, taking into account known inherent heterogeneities in the distribution of the only clearcut pollutional classification that could be given to core E 11 E, based upon particle size differentiation is for the top sediment layer of the core.

2. *Core E 1 E.* The stratification and sedimentary characteristics and results of particle size analyses for core E 1 E, collected near the seaward entrance of the harbor, as shown in Figure 2 are illustrated in Figure 7. The lower portion of the core was analyzed whole due to the very low content of fine particulates. The sedimentary transition between the upper and lower strata was extremely sharp, as indicated.

One of the most salient observations, at the time of the splitting of the core was the very strong "crude oil" smell and the presence of bituminous-like inclusions in



% PPM Dry Wt.	Whole	Whole	Coarse	Fine	
CoD	.1	.1	.1	9.3	✓
KjN	.01	.01	.01	.23	✓
Vol Sol	1.1	1.1	.9	11.1	✓
Oil & Gr	.02	.01	.02	.77	✓
As	.7	.6	.5	3.8	
Cd	.2	.2	.2	6.7	
Cr	5.	17.	22.	92.	
Cu	12.	12.	6.	264.	
Fe	1.	1.4	1.1	7.6	
Hg	.4	.4	.2	3.4	✓
Ni	9.	6.	12.	67.	
Pb	5.	15.	12.	176.	✓
Zn	15.	11.	39.	441.	✓
Ptot	206.	136.	317.	540.	
Sulf	2.	5.	7.	63.	

Core E1E
San Diego Hbr.
✓ "Polluted"

Figure 7. Stratigraphic and Granulometric Chemical Analyses of Core E 1E, San Diego Harbor.

the sandy upper layer. The analytical results, based upon particle size differentiation show very high values for "organics" and heavy metal levels which undoubtedly correlate with the heavier hydrocarbon fraction residues. The "pollutional" status of the upper six or so inches is rather obvious.

The lower portion of the core consisted mainly of odorless, clean, rather coarse sand intermixed with broken shells. The physical appearance of the sediments as well as the analysis show that the lower portion of the sediments can safely be classified as "clean."

3. Core E 5 E. The stratification and sedimentary characteristics as well as the analytical results for Core E 5 E are shown in Figure 8. Both the upper portion and the lower portion of the core consisted of rather coarse sand intermixed with whole and broken shells. The shell material, in the top portion of the core, was heavily coated with a black film. Zinc and lead were in excess of the EPA criteria; the organics were low.

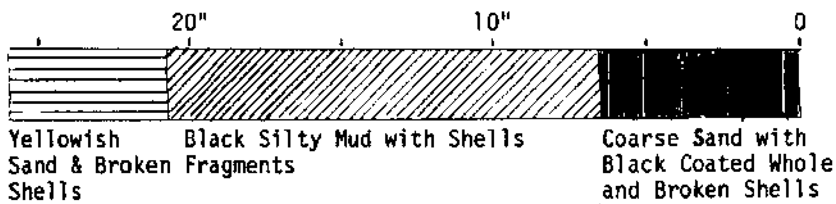
The center section of the core exhibited high levels of organics and very high levels of heavy metals in the fine fractions. A "polluted" classification can readily be assigned to this particular section of the core sediments.

Based upon the low organic-heavy metals levels, a non-pollutional status can be assigned to the lower strata.

4. Core E 6 E. The stratification, sedimentary and chemical characteristics of Core E 6 E are shown in Figure 9.

The core, the longest obtained of the series, exhibited not less than six different, well-defined sediment layers. The most salient feature of the core at the time of splotting was the very strong "fishy" odor emanating from the layer located between 18 and 30 inches below the top of the core. Several live small clams and marine worms were observed at the time of the splitting of the core. The results of analy sis of the fine fraction show high organics and Cr, Cu, Pb, and Zn content, which would clearly assign a "polluted" status to these particular sediments, a "polluted" status which cannot readily be reconciled with the healthy appearance of the marine life found associated with the sediments.

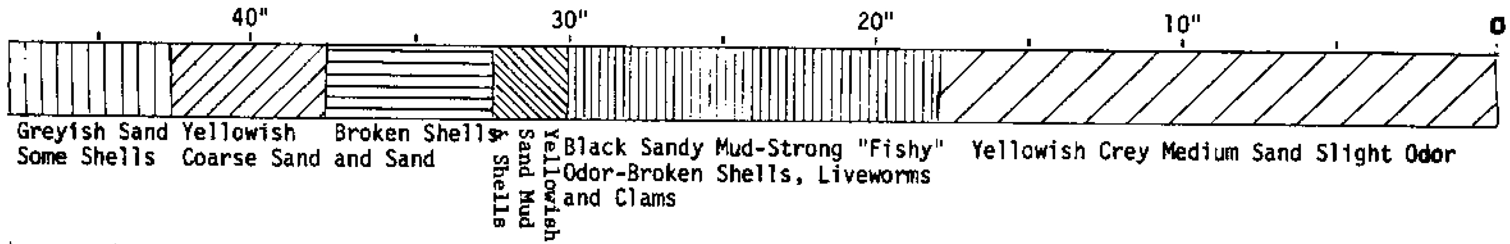
The remainder of the core consisted of coarse material with insufficient amounts of fine particulate for analysis. It is interesting to note that the organic and heavy metal concentrations between the unsorted top and bottom sediment fractions and the sorted coarse fraction of the cen-



% / PPM Dry Wt.	Whole	Coarse	Fine	Whole
CoD	.2	.9	5.8 ✓	1.5
KjN	.02	.01	.16 ✓	.04
Vol Sol	2.5	1.9	11.2 ✓	3.2
Oil & Gr	.07	.03	.31 ✓	.1
As	16.	1.4	11.9	3.5
Cd	.3	.5	2.1	.9
Cr	28.	17.	148.	15.
Cu	55.	128.	156.	74.
Fe	1.6	1.6	8.2	2.0
Hg	.7	.3	2.7 ✓	.6
Ni	16.	13.	62.	22.
Pb	31.	49.	279. ✓	99. ✓
Zn	19.	50.	275. ✓	100. ✓
Ptot	148.	147.	497.	223.
Sulf	11.	5.	360.	37.

Core E 5 E
San Diego Hbr.
✓ "Polluted"

Figure 8. Stratigraphic and Granulometric Chemical Analyses of Core E 5 E, San Diego Harbor.



PPM % Dry Wt.	Whole	Coarse	Fine	Whole
CoD	.1	.1	9.4 ✓	.2
KjN	.01	.01	.31 ✓	.02
Vol Sol	.8	.8	11.9 ✓	.7
Oil & Gr	.01	.03	.68 ✓	.02
As	.6	.6	8.4	.6
Cd	.1	.3	3.8	.1
Cr	17.	18.	150.	17.
Cu	6.	10.	235.	10.
Fe	1.3	1.3	7.	1.5
Hg	.4	.4	2.0 ✓	.5
Ni	7.	10.	52.	9.
Pb	2.	10.	131. ✓	2.
Zn	11.	28.	252. ✓	19.
Ptot	174.	142.	618.	129.
Sulf	2.	3.	47.	11.

Core E 6 E
San Diego Hbr.
✓ "Polluted"

Figure 9. Stratigraphic and Granulometric chemical analysis of Core E 6 E, San Diego Harbor.

ter layer do not differ markedly from one another.

5. *Core E 16 E.* The stratification, sedimentary and chemical characteristics of Core E 16 E, obtained in the upper reaches of the harbor are illustrated in Figure 10. As in the other samples, the relationships between fine particulate-organic-heavy metals concentrations hold. A clear "polluted" status can be given only to the upper portion of the core. The similarities between the organic and heavy metals levels for the unsorted samples and coarse sorted fractions should be noted.

DISCUSSION OF RESULTS--ECOLOGICAL AND ENGINEERING APPLICATIONS

The results of the various physical and chemical measurements performed upon the surface and core sediments from San Diego Harbor indicate:

1. A well-defined relationship exists between the amount of fine particulates, organic levels and concentration of heavy metals.

2. The concentrations of heavy metals increase as the organic content of the sedimentary mix increases, suggesting a prevalence of organo-metallic complexes.

3. The distribution of "pollution" within the sedimentary column is usually confined to definite strata, usually in the surface layers. However, polluted layers can be found below the surface, interleaved between other strata.

4. Resolution of the pollutants sorbed to the fine particulate as a result of mechanical stirring and resuspension is highly unlikely.

The results obtained show that, by slightly modifying sample processing practices and standard analytical techniques, informative and meaningful ecological and engineering data can be obtained.

ECOLOGICAL CONSIDERATIONS

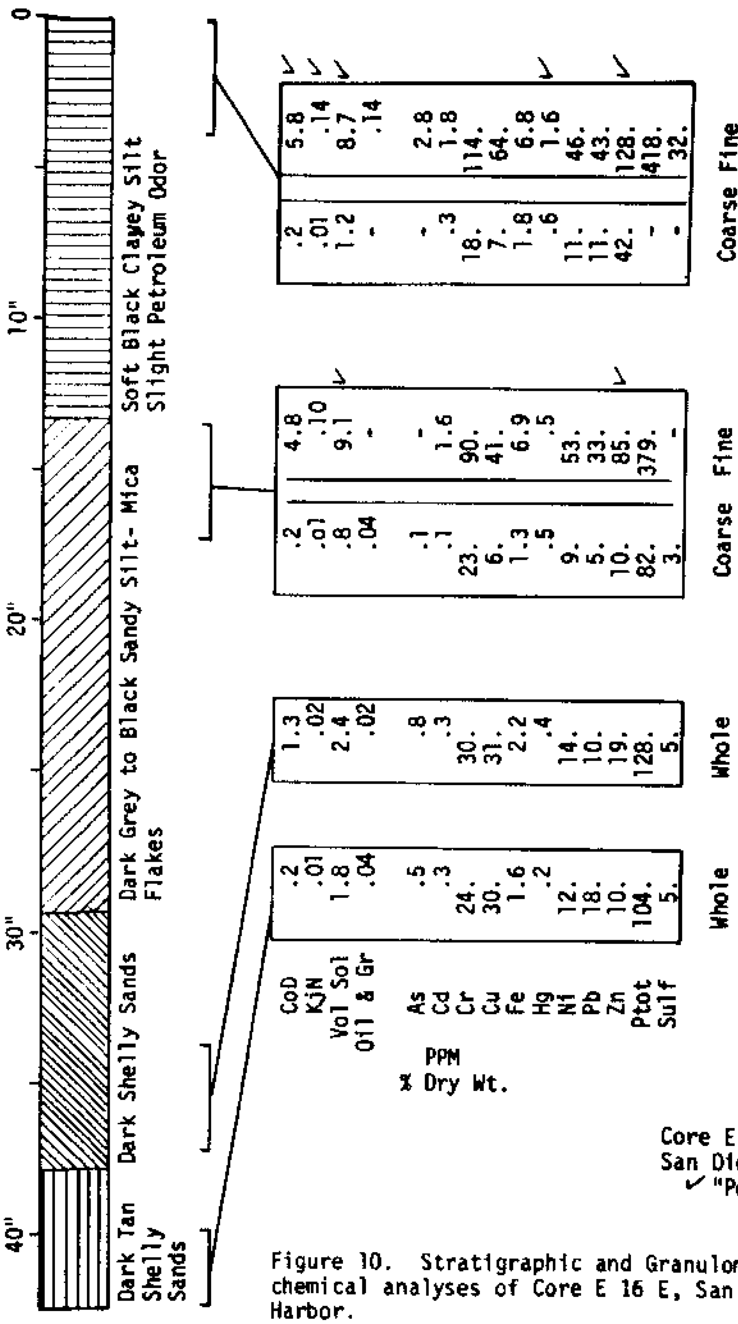
Traditionally, consideration of the impacts of dredging, sediment redispersal and disposal has focused mostly upon the physical impacts of turbidity and smothering of bottom life.

The present results, demonstrating the close relationships between fine particulates, organic content and heavy metals, provide new insights into the most likely pathways for the translocation of pollutants from sediments to pelagic and benthic biological systems. The size of the particles involved, less than about 30 microns, places them in a size range readily amenable to ingestion by filter and detrital feeders. The fact that the concentration of heavy metals and other constituents becomes higher as the organic content of the fine particulate increases also indicates that this material can be sought preferentially by the particulate feeders and sorted from the more inert material. Indications are that under "polluted" conditions, the heavy metals are most likely in an organometallic state, which immediately suggests that their toxicity and translocating mobility into biological systems will be high.

Larval and metamorphic stages of a great variety of marine life are filter feeders and to a lesser extent detrital feeders. They can thus scavenge for the mix of particulates carrying the organo-metallic as well as organic pollutants; the biological uptake of variously polluted fine particulates poses the most serious threat to aquatic life, as developing embryos, metamorphic, larval and juvenile stages are most sensitive to low level pollutants, a fact repeatedly demonstrated by laboratory studies.

The concern about the potential, adverse effects of turbidity thus takes on a much more ominous meaning. To gauge properly the ecological impact of turbidity-borne pollutants, the natural processes controlling the sorting, transport, settling and deposition of fine particulates must be examined. Knowledge of the length of time to which a particular "soupe" of filter and detrital feeders will be subjected to a cloud of fine, slowly settling, organic-pollutant rich particulates, and of the rate at which such particulates can be scavenged, is most crucial. Once deposited, the fine sediments can be resorted, resuspended and reconcentrated from an "homogenized" mix by a number of natural processes (Drake *et al*, 1972), processes which must be fully taken into account for long range impact assessments.

The fate of the fine particulates during dredging operations and after disposal can be predicted.



	Whole	Whole	Coarse	Fine	Coarse	Fine
CoD	.2	1.3	.2	4.8	.2	5.8 ✓
KjN	.01	.02	.ol	.10	.01	.14 ✓
Vol Sol	1.8	2.4	.8	9.1 ✓	1.2	8.7 ✓
Oil & Gr	.04	.02	.04	-	-	.14
As	.5	.8	.1	-	-	2.8
Cd	.3	.3	.1	1.6	.3	1.8
Cr	24.	30.	23.	90.	18.	114.
Cu	30.	31.	6.	41.	7.	64.
Fe	1.6	2.2	1.3	6.9	1.8	6.8
Hg	.2	.4	.5	.5	.6	1.6 ✓
Ni	12.	14.	9.	53.	11.	46.
Pb	18.	10.	5.	33.	11.	43.
Zn	10.	19.	10.	85. ✓	42.	128. ✓
Ptot	104.	128.	82.	379.	-	418.
Sulf	5.	5.	3.	-	-	32.

Core E 16 E
San Diego Hbr.
✓ "Polluted"

Figure 10. Stratigraphic and Granulometric chemical analyses of Core E 16 E, San Diego Harbor.

I. *OPEN WATER DISPOSAL, SHALLOW WATER "SLUG" RELEASES*

"Slug" release of several thousand cubic yards of sediments into a few tends of feet of water usually induces bulk entrapment and settling of the sediment mix, primarily as a result of the downward momentum of the settling mass. Under such conditions, there is only limited opportunity for differential settling of coarse and fine particles; much of the turbidity generated near the bottom under such conditions will most likely be the result of the sudden disturbance of bottom sediments by the sinking mass. Release from hopper dredges which tend to disperse the sediments over a significant area will favor differential sorting and settling of coarse and fine particles.

II. *OPEN WATER DISPOSAL, DEEP WATER "SLUG" RELEASES*

"Slug" release of a sediment mix into several hundred feet of water (i.e., beyond the 100 fathom line), favors, once the initial momentum is dampened, differential sorting of particles, such sorting becoming progressively more effective as the depth of water increases. Under such conditions the density structure of the water column can induce the finer portion of the particulates to "layer out" at density interfaces, a phenomenon recently observed along the Santa Barbara-Oxnard shelf area of southern California (Drake, 1971; Drake *et al*, 1972).

Density interfaces are also known to be layers where planktonic and small nektonic forms concentrate. Thus, under deep water disposal conditions, the resorting and layering out of fine-pollutant bearing particulates can form a pollutant "soup" within layers of high filter feeding activity.

III. *RESORTING AFTER DEPOSITION*

Once deposited on the bottom, the various particles can be resorted from the sediment mix by tidal currents and turbulence induced by shoaling waves. Progressive resorting and "winnowing" of the fine particulates can continue for rather long periods of time, providing a steady supply of fine-pollutant rich particulates, which again can layer out at density interfaces and be transported long distances away from the depositional source, if not quickly scavenged by the local populations of filter feeders (Drake, 1971). Thus, even if initially deposited as an "homogenized" mix, the polluted fines can readily be sorted out, reconcentrated and redispersed in a most ecologically harmful manner.

IV. *BEACH NOURISHMENT*

It is often advantageous to redistribute dredged sediments along the beach to control erosion. Once an "homogenized" mix is deposited along the beach, wave and wind action can quickly resort the fines from the coarse. Thus the fine particulate, with its complex suite of pollutants, can readily become reconcentrated in the surf zone or in blowing dust. These facts alone provide the strongest arguments against any "pollutional" certification practices based upon gross analysis of "homogenized" samples.

Toxicity bioassays, to be ecologically significant, must relate to the most likely manner by which the pollutants ingress into various forms of aquatic life. As presently practiced, bioassays focus primarily upon the effects of pollutants *in solution*, not to particulate-bound pollutants. Such bioassays provide little or no information as to the effects of polluted, suspended or deposited particles and are of extremely doubtful ecological value.

ENGINEERING CONSIDERATIONS

The information gained from the experiments performed on the sediments of San Diego Harbor, suggests new approaches to engineering techniques and practices to control and mitigate the adverse environmental impacts of the dredging of variously polluted sediments.

To the water quality engineer, the most pressing problem is to control turbidity, especially in the silt-colloidal size fractions. By using and updating present drilling mud recovery and ore separation techniques, differential sorting of sediment during dredging operations is feasible. Sorting mechanisms can be incorporated with suction dredge equipment, as the homogenizing of the sediments into a watery slurry makes the material amenable to a variety of separation processes, such as air flotation.

Selective dredging of polluted sedimentary layers is presently technically feasible. Selective dredging requires first, rather exact field surveys to quantify precisely the volumes of sediments to be removed, then it necessitates precise techniques to control the operations of the dredge cutting head to insure that the polluted layers are removed with only minimal amounts of clean material.

The economics of disposal dictate that the bulk of polluted fines be reduced to the strictest practical minimum whenever special containment is required. Dewatering of the material is essential and is a problem requiring special attention. In some cases, the organic levels can be high enough to warrant wet pyrolysis.

Controlling the escapement of fine particles from various waste treatment facilities must also be seriously considered; a treatment facility operating at 85 per cent efficiency in particulate removal might allow 90 per cent of the pollutants to escape chelated or sorbed to the unfiltered 15 per cent of the suspended fine particulates.

CONCLUSIONS AND RECOMMENDATIONS

The results of the present experiment indicate that, through proper application of standard field and laboratory procedures and analytical techniques, interpretive information can be derived to describe pollutant-sediments associations, evaluate ecological hazards stemming from particulate borne pollution, adapt control and abatement measures to existing technological and engineering capabilities and recommend new technological approaches to long range abatement and control of sediment pollution.

The present results also clearly indicate that surface (grab) sediment samples are not effective in defining and quantifying the pollutional character of aquatic sediments and that cores are essential in discriminating, on a stratigraphic and granulometric basis, between "clean" and "polluted" status of sediments.

For ecological and engineering applications, the gathering and processing of two basic sets of cores is recommended. To establish an initial sediment quality baseline, reconnaissance cores, few in number but collected at locations carefully preselected on the basis of known or suspected sources of pollution and local peculiarities of the subsurface topography as it relates to sediment transport, erosion and accretion, should be processed in accordance with the procedures previously outlined. Such cores should be analyzed in the greatest detail possible.

Based upon the detailed information gathered from the physical and chemical analyses of reconnaissance cores, additional cores, collected from a sufficiently dense grid of stations to properly quantify the stratigraphic and granulometric extent of sediment pollution, should be obtained to provide engineering estimates of the actual volumes of sediments requiring special removal techniques (i.e., selective removal of polluted layers), special processing techniques (i.e., separation of fine fractions through air flotation, dewatering of fine fractions) and special disposal requirements (i.e., containment in a sealed area, wet pyrolysis).

The results of the present investigation also indicate that any establishment of a sediment pollutional index requires some form of granulometric-organic-heavy metal relationship. Establishment of an organic sediment index, in a manner similar to the one developed by Ballinger and McKee (1971) would be most useful in strengthening the observed relationships between high organic levels and heavy metal concentrations. Similarly an organic sediment carbon-lipid index would be most purposeful in establishing a relationship with chlorinated hydrocarbon concentrations.

Finally, it is strongly recommended that sediment pollutional classification also include measurements of the chemical state of various pollutants, such as the percentage of organo-metallic fractions of various heavy metals, classes of petrochemicals and various other known and potentially harmful organics.

ACKNOWLEDGMENTS

This study could not have been brought to fruition without the active interest and support of Mr. K Speeg and F.E. Dunn, Chief and Assistant Chief, Planning Division and of Mr. Olin P. Weymouth, Head, Coastal Engineering Branch, U.S. Army Corps of Engineers, South Pacific Division, San Francisco. The effective and untiring help extended by the staff of the Coastal Engineering Branch and the financial support provided by the Los Angeles District during the conduct of the study are most heartily acknowledged and appreciated.

The keen interest, high professional standards and quality of laboratory performance of the staff of the South Pacific Division, Sausalito Laboratory, were most effective in providing the analytical results presented in this study.

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APPENDIX I

1971 ENVIRONMENTAL PROTECTION AGENCY

Criteria for Determining Acceptability of Dredged Spoil Disposal to the Nation's Waters

Use of Criteria. These criteria were developed as guidelines for FWQA evaluation of proposals and applications to dredge sediments from fresh and saline waters.

Criteria. The decision whether to oppose plans for disposal of dredged spoil in U.S. waters must be made on a case-by-case basis after considering all appropriate factors; including the following:

(a) Volume of dredged material.
(b) Existing and potential quality and use of the water in the disposal area.
(c) Other conditions at the disposal site such as depth and currents.
(d) Time of year of disposal (in relation to fish migration and spawning, etc.).
(e) Method of disposal and alternatives.
(f) Physical, chemical and biological characteristics of the dredged material.
(g) Likely recurrence and total number of disposal requests in a receiving water area.
(h) Predicted long and short-term effects on receiving water quality.

When concentrations, in sediments, of *one or more* of the following pollution parameters exceed the limits expressed below, the sediment will be considered polluted in all cases and, therefore, unacceptable for open water disposal.

Sediments in Fresh & Marine Waters	Conc. % (dry wt. basis)
Volatile Solids	6.0
Chemical Oxygen Demand (COD)	5.0
Total Kjeldahl Nitrogen	0.10
Oil-Grease	0.15
Mercury	0.0001
Lead	0.005
Zinc	0.005

When analyzing sediments dredged from marine waters, the following correlation between volatile solids and COD should be made:

TVS % (dry) = 1.32 + 0.98 (COD %)

If the results show a significant deviation from this equation, additional samples should be analyzed to insure reliable measurements.

The volatile solids and COD analyses should be made first. If the maximum limits are exceeded the sample can be characterized as polluted and the additional parameters should not have to be investigated.

Dredged sediment having concentrations of constituents less than the limits stated above *will not be* automatically considered acceptable for disposal. A judgment must be made on a case-by-case basis after considering the factors listed in (a) through (h) above.

In addition to the analyses required to determine compliance with the stated numerical criteria, the following additional tests are recommended where appropriate and pertinent:

Total Phosphorus
Total Organic Carbon (TOC)
Immediate Oxygen Demand (IOD)
Settleability
Sulfides
Trace Metals (iron, cadmium, copper, chromium, arsenic and nickel)
Pesticides
Bioassay

The first four analyses would be considered desirable in almost all instances. They may be added to the mandatory list when sufficient experience with their interpretation is gained. For example, as experience is gained, the TOC test may prove to be a valid substitute for the volatile solids and COD analyses. Tests for trace metals and pesticides should be made where significant concentrations of these materials are expected from known waste discharges.

All analyses and techniques for sample collection, preservation and preparation shall be in accord with a current FWQA analytical manual on sediments

APPENDIX II

ANALYTICAL PROCEDURES

Volatile solids, chemical oxygen demand (COD), total Kjeldahl nitrogen, oil and grease, zinc, iron, copper and chromium were run according to "Chemistry Laboratory Manual, Bottom Sediments" compiled by Great Lakes Region Committee on Analytical Methods and published by the Environmental Protection Agency, Federal Water Quality Administration, December 1969.

Mercury, Hatch and Ott Method using Coleman 50 Mercury Analyzer.

Lead, cadmium and nickel, Federal Water Pollution Control Administration (FWPCA)

Atomic Absorption Methods, Nitric Acid Soluble. (November 1969)

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After the Studies--Then What?

William S. Cox, Director
Division of State Lands, Salem

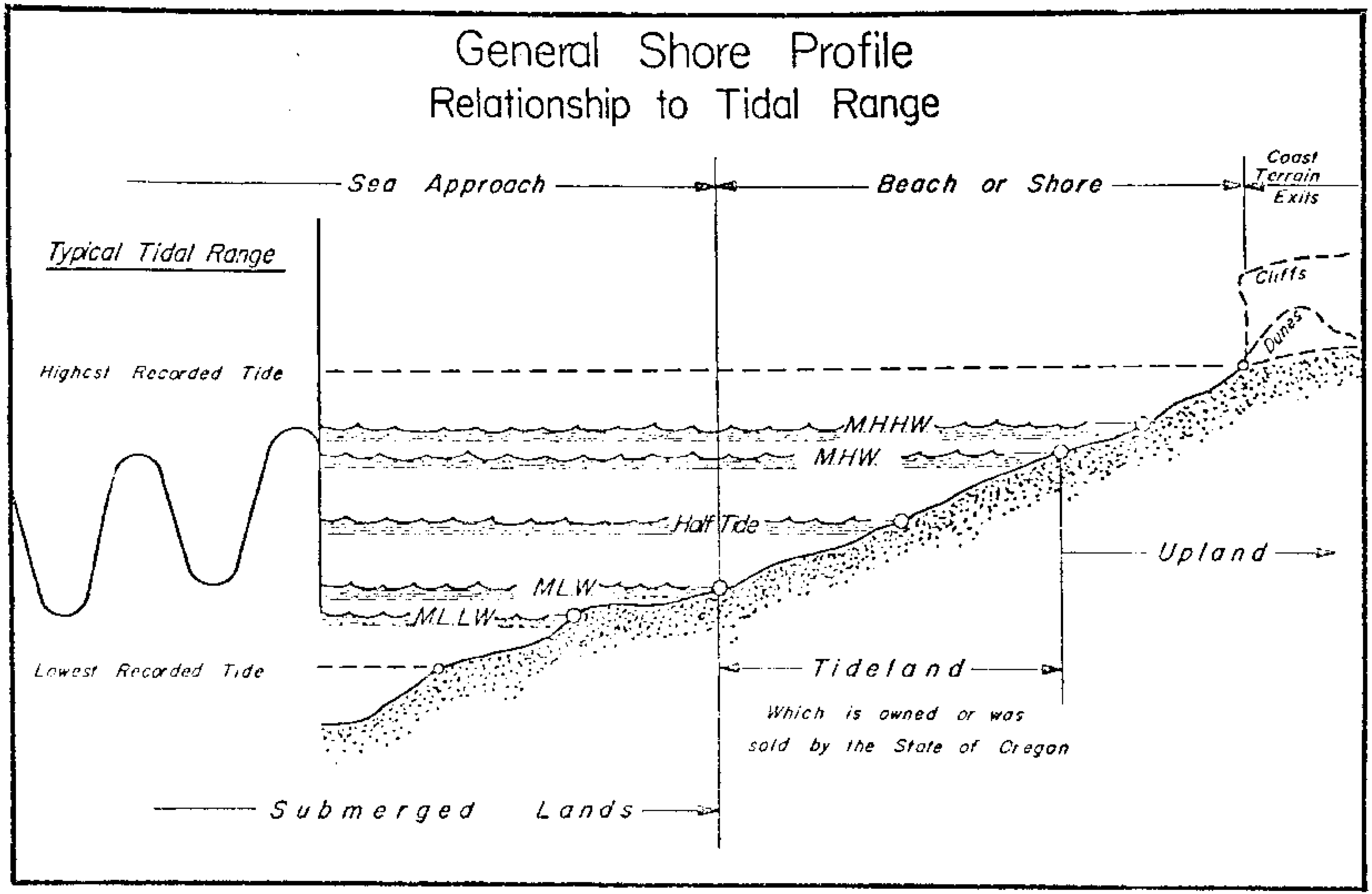
We've become aware of our environment! We know we need to protect it! Scientific work and studies have provided us with the knowledge we can use to protect it.

In Oregon a major portion of our environmental efforts have been focused on the estuaries. Estuary protection is accomplished in three different ways.

The first is *prevention* through the mechanism of proper zoning and legally enforced permit systems. Any proposed project for an estuary would have to meet stated standards and conditions or not be allowed. The use of adequate standards and conditions are dependent upon a thorough knowledge of our estuaries and their ecological systems. The standards which are set must truly represent the criteria needed to protect the estuary.

The second method is the *ability to stop a project which is taking place* in an estuary and which has not been authorized through zoning and/or permit systems. The protection agency must be able to go to court and justify the issuance of a temporary restraining order or injunction stopping the project. Since we're working with resource protection statutes, the Court, hearing the request for an injunction or restraining order, has required that the State show that the objectionable project is creating resource damage before they will immediately issue an order to stop it. The Courts have been reluctant, without a hearing, to issue a stop work order if the project is located on the landowner's private property. They feel that due process requires a hearing to allow the individual to justify his project before the Court. The difficulty with the hearing requirement is that in the case of a landfill the project can be completed within a few days and it is difficult to schedule and allow adequate notice of a hearing before the landfill project is completed.

A third method of protection and less desirable than the first two is *to*


General Shore Profile
Relationship to Tidal Range
Sea Approach
Beach or Shore
Coast Terrain Exits
Typical Tidal Range
Cliffs
Dunes
Highest Recorded Tide
M.H.H.W.
M.H.W.
Half Tide
Upland
M.L.W.
M.L.L.W.
Lowest Recorded Tide
Tideland
Which is owned or was sold by the State of Oregon
Submerged Lands

attempt to remove a damaging project after it has been completed. Usually the cost of removal is significantly greater than the cost of the project itself. Courts have been reluctant to require removal especially if the individual is using his own property unless it can be shown that sustained significant resource damage will result, and that the removal will not cause more resource damage than allowing the project to remain in place. Very often the resource protection agency is required to show that a project would not have been allowed had a permit been applied for. This involves extensive administrative action and an administrative hearing before seeking court assistance.

The State Land Board and the Division of State Lands, who are among the major resource protection coordinators for estuaries, feel that the key to adequate resource protection is not only a thorough knowledge of the legal remedies and their application to the multitude of fact situations that exist in our estuaries, but also a thorough knowledge of all available scientific information which can be used in a court of law to demonstrate the need for immediate legal action to stop resource damage in our estuaries.

My purpose in appearing before this estuary conference is to bring to you information on the legal relationships which exist in our estuaries and the problems of enforcement. Adequate protection very often is based upon presenting the right scientific information at the right time, and in the proper forum. The enforcement agencies need your help.

At this moment, from our reference point, landfills and estuary alteration projects seem to be the greatest dangers to our estuary environment.

Who owns the lands encompassed by the project? This is a key question to the resource protection agencies. If the project involves state-owned lands, the state has the legal remedy of trespass available which does not involve showing resource damage. All that is needed is to show that the project is occupying state land without permission.

Oregon's estuaries are a mixture of private and public ownership. At the time of statehood (1859), Oregon, by virtue of its state sovereignty, became the owner of all estuary water lands from the high tideline[1] on one bank to the high tidelines on the opposite shore (see diagram 1). Private upland ownership extended down to this high tideline.

The state-owned waterway lands were historically divided into two classifications: submersible lands and submerged lands. The submersible lands,[2] also known as tidelands, extended from the ordinary high tideline to the ordinary low tideline. The submerged lands[3] extended from the ordinary low tideline on one shore to the ordinary low tidelines on the opposite bank.

The State handled these two classifications differently and to understand some of the enforcement problems we need to touch on these differences. The submerged waterway lands were to be administered by the State as a trust to protect fishery and navigation[4]. The submersible waterway lands were held by the State in its proprietary capacity even though some elements of the trust still applied to these lands.[5]

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[1]"Line of ordinary high water" means the line on the bank or shore to which the high water ordinarily rises annually in season.

[2]"Submersible lands," except as provided in ORS 274.705 means lands lying between the line of ordinary high water and the line of ordinary low water of all navigable waters and all islands, shore lands or other such lands held by or granted to this state by virtue of her sovereignty, wherever applicable, within the boundaries of this state as heretofore or hereafter established, whether such waters or lands are tidal or nontidal.

[3]"Submerged lands," except as provided in ORS 274.705, means lands lying below the line of ordinary low water of all navigable waters within the boundaries of this state as heretofore or hereafter established, whether such waters are tidal or nontidal.

[4]35 Ops. Att'y Gen. 844 (1971)

[5]"From all this it appears that when the state of Oregon was admitted into the union, the tide lands became its property and subject to its jurisdiction and disposal; that *in the absence of legislation or usage, the common law rule would govern the rights of the upland proprietor, and by that law the title to them is in the*

In the late 1800's, the state, acting to stimulate economic development, sold or granted much of its estuary tidelands to private individuals. It also granted licenses to use state-owned waterways for certain purposes.[6]

The state can quickly stop a landfill or have it removed if it has been placed on state-owned lands. However, the process of stopping a landfill on privately owned estuary lands is slow and difficult. Government is in the position of telling a private individual what he can or cannot do on his own property. The "rights" of a private landowner are protected against arbitrary governmental action by the United States Constitution.[7] Also the government cannot so restrict the *reasonable* use of an individual's property to the point that the landowner is in the position of having his property taken without just compensation.[8]

The establishment of public-private boundary lines is a prerequisite to immediate estuary protection. The Division of State Lands during this last biennium has undertaken to map the estuary tidelands. An example of a Division tideland report can be found as an appendix to this paper.

A further concern of the Division in its protection efforts is the extent of the so-called riparian use "rights" according to which the estuary waterfront owner may use the state-owned submerged and submersible lands fronting his property. Early English Common Law which forms the foundation for Oregon law has been said to give the riparian owner many use rights to the waterlands in front of his property. A 1972 Attorney General's Opinion[9] clarified these "rights" in terms of Oregon law. This opinion defines the Common Law right as one of access to the water only. Other so-called rights, such as the wharf right can be controlled by the legislature.

The state's waterway trust responsibilities, mentioned earlier, cannot be minimized. The original sovereign grant of ownership to the waterway lands contained the public trust dedication. Even though some of these lands are now in the hands of private individuals, they are still impressed with the trust restrictions. If the proposed use of private land, such as a landfill would constitute a loss of this public right, then a specific administrative procedure must be followed. This procedure includes specific administrative fact findings and an opportunity for public comment.[10]

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state; that the state has the right to dispose of them in such manner as she might deem proper, as is frequently done in various ways, and whereby sometimes large areas are reclaimed and occupied by cities, and are put to public and private uses, *state control and ownership therein being supreme, subject only to the paramount right of navigation and commerce.*" *Bowlby v. Shively*, 22 Or. 247 (1892), affirmed 152 U.S. 1 (1893).

[6]"The owner of any land lying upon any navigable stream or other like water, and within the corporate limits of any incorporated town or within the boundaries of any port, may construct a wharf or wharves upon the same, and extend the wharf or wharves into the stream or other like water beyond low-water mark so far as may be necessary and convenient for the use and accommodation of any ships, boats or vessels that may or can navigate the stream or other like water." ORS 780.040

[7]"All persons born or naturalized in the United States, and subject to the jurisdiction thereof, are citizens of the United States and of the State wherein they reside. No State shall make or enforce any law which shall abridge the privileges or immunities of citizens of the United States, nor shall any State deprive any person of life, liberty, or property, without due process of law; nor deny to any person within its jurisdiction the equal protection of the laws." U.S. Const. Amend. XIV

[8]"Private property shall not be taken for public use, nor the particular services of any man be demanded, without just compensation; nor except in the case of the state, without such compensation first assessed and tendered; provided, that the use of all roads, ways and waterways necessary to promote the transportation of the raw products of mine or farm or forest or water for beneficial use or drainge is necessary to the development and welfare of the state and is declared a public use." Oregon Const. Art. I, § 18.

[9]Op. Att'y Gen. No. 6951 (October 30, 1972).

[10]"(1) The Director of the Division of State Lands shall issue a permit to remove material from the beds or banks of any waters of this state applied for under

A public-trust proceeding was used to stop further filling of a slough in Coos Bay. The administrative findings of fact were affirmed in a state review of the denial decision and were just recently reaffirmed by the Coos County Circuit Court. Whether the decision will be appealed further is not known. If the decision stands it will be the first time in Oregon a landfill project has been stopped on privately owned tidelands by applying the public trust doctrine.

Since many of the critical areas of our estuaries are in private ownership and control, the resource protection agencies must also look to the environmental protection laws to prevent and stop damaging projects. One of the essential permit laws most used for estuary protection is the removal/fill permit law, ORS 541.605 *et seq.* This law requires that any removal or fill of 50 cubic yards or more of material within the bed or banks of a natural waterway in this state cannot be allowed without a permit. The law has been an excellent tool for obtaining resource agency control over waterway projects on private owned land.

ORS 541.620 if he determines that the removal described in the application will not be inconsistent with the protection, conservation and best use of the water resources of this state as specified in ORS 541.610.

(2) The Director of the Division of State Lands may issue a permit applied for under ORS 541.620 for filling waters of this state. In determining whether or not a permit shall be issued, the director shall consider the following:

(a) Whether the proposed fill unreasonably interferes with the paramount policy of this state to preserve the use of its waters for navigation, fishing and public recreation;

(b) Whether the proposed fill conforms to sound policies of conservation and would not interfere with public health and safety;

(c) Whether the proposed fill is in conformance with existing public uses of the waters; and

(d) Whether the proposed fill is consistent with a duly enacted zoning or land use plan for the area where the proposed fill is to take place." ORS 541.625

The individual resource agencies administer special laws which also can be used in estuary protection. Examples are the Fish Commission's licensing of oyster beds (ORS 274.060) and the Department of Environmental Quality's air and water pollution abatement laws (ORS 449).

One of the essential prerequisites for using the environmental protection laws to stop projects on private property is to be able to show that significant resource damage will occur if the project is allowed to take place. The difficulty centers on the fact that one small project will occupy a relatively insignificant amount of tideland and cause a very minor amount of damage when compared to the total existing tidelands of an estuary. We also need something more than one man's expert opinion. It is always possible for the opposing party to find an expert of equal stature to disagree with the state's expert.

The state resource protection agencies then have basically three tools for resource protection: (1) the state ownership of much of the waterway lands, which provides a non-environmental means of controlling the use of estuary lands; (2) the application of the public trust doctrine and, (3) the application of the state's environmental protection laws.

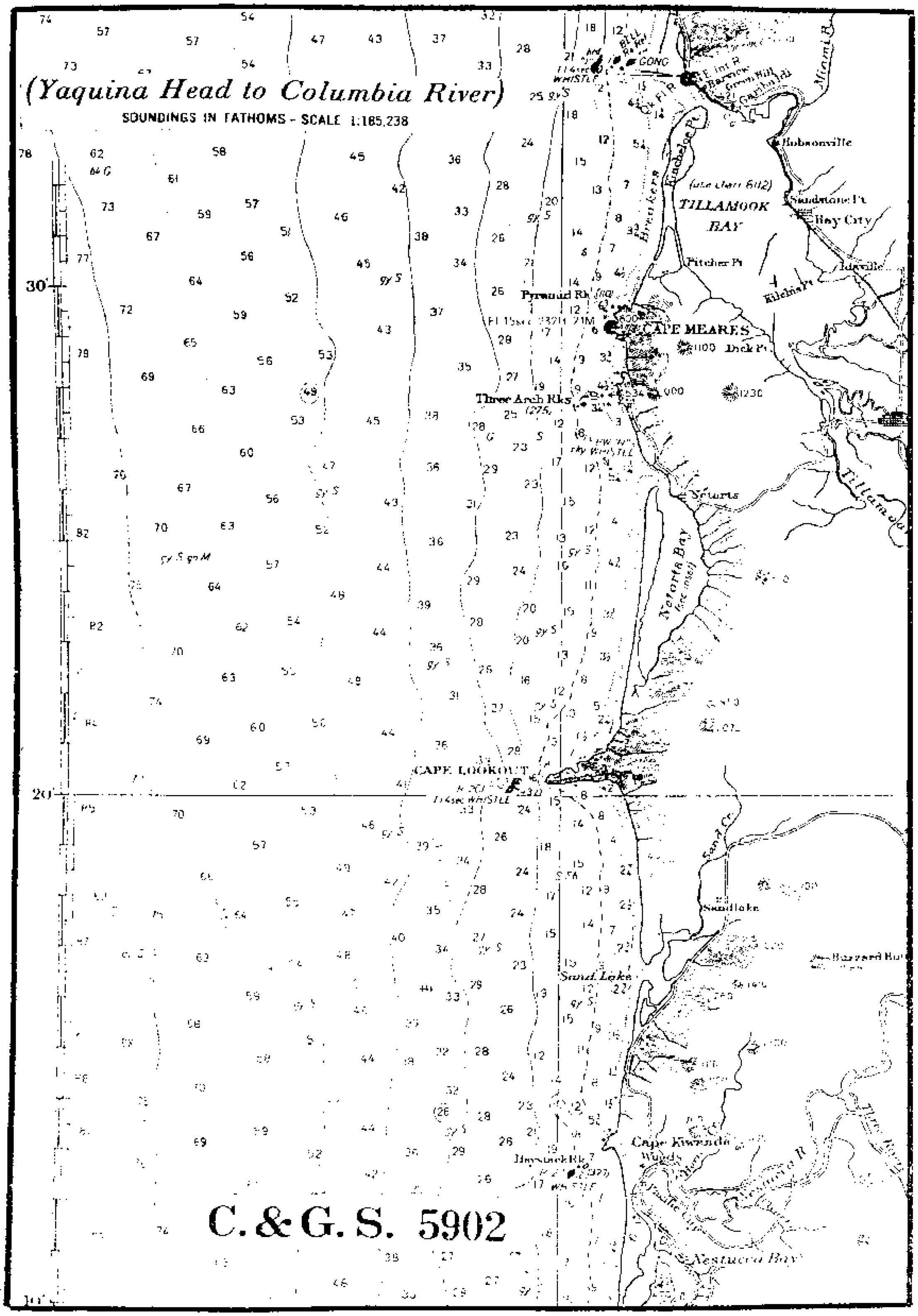
Adequate land use planning and zoning can be also good protection tools. However, this means of enforcement has not as yet been developed to its fullest extent.

It should also be noted that the federal government, too, has control authority in our estuaries. They will have an increasing impact on estuary protection as time goes by.

In discussing the enforcement problem with you, I have been guilty of harping on one subject, the need for scientific information about our estuaries. With the presentation of better scientific information I am sure that the resource protection agencies can say -- after the studies comes protective action.

TIDELANDS OF NETARTS BAY

The 1857 General Land Office survey map of Netarts Bay called the bay "Oyster Bay." Evi-


(Yaquina Head to Columbia River)
SOUNDINGS IN FATHOMS - SCALE 1:185,238
TILLAMOOK BAY
Hobsonville
Bay City
Pitcher Pt
Pyramid Rk
CAPE MEARES
Three Arch Rks
Netarts
Netarts Bay
CAPE LOOKOUT
Sandlake
Sand Lake
Cape Kiwanda
Haystack Rk
Nestucca Bay
Nestucca R
C.&G.S. 5902

dently, the large oyster population must have impressed the early settlers of the area enough to influence the selection of the bay name. Although the name did not prevail, oysters remained abundant until the 1930's when a destructive parasite was unintentionally introduced through seeding with a foreign osyter. Today, both native and cultivated oysters remain at insignificant levels because the parasite continues to infect the bay.

Netarts Bay covers an area of 2,325 acres (1,513 acres of tideland, 812 acres of submerged land). The bay drains an area of 13 square miles through 14 small creeks. The fresh water discharge amounts to only 60,000 acre feet per year. It is interesting to note that the annual discharge through Netarts Bay is the same as that passing through Sand Lake, yet Netarts is 4 1/2 times larger, much deeper, and possesses a vastly different shape.

The tideland survey of Netarts Bay was conducted during the month of March as weather permitted. The mean high water and mean low water lines were photo identified on 1970 aerial photographs at the respective predicted tide stages. Important areas (ownership other than State) were viewed on at least two different days to confirm that the predicted tides were reasonably close to the actual tides. During the days of the field investigation, the wind did not exceed the 15 knot threshold considered necessary to influence the tide by 0.2 to 0.4 feet.

Because tidal ranges are published for Netarts Bay by the National Ocean Survey, the actual tides were not observed during the time of our field work. There are no published Tidal Bench Marks for the area and the nearest mean Sea Level Datum Bench Mark is seven miles away on U.S. Highway 101.

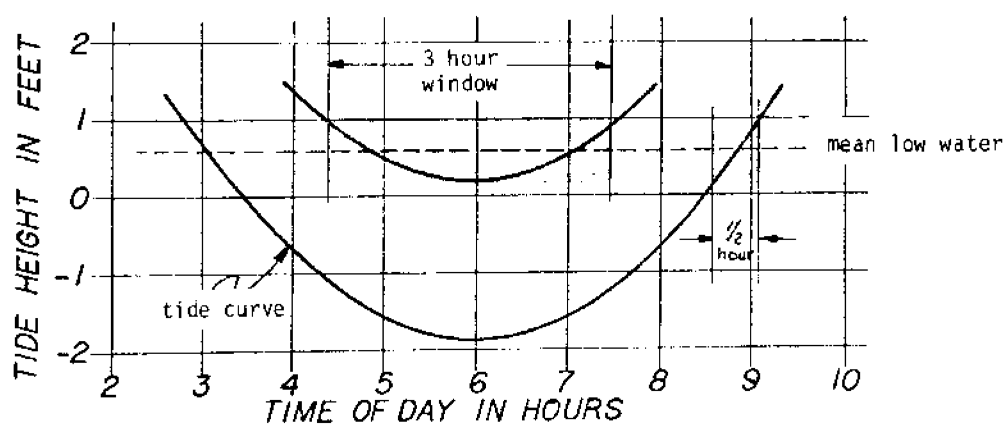
Photo identification of mean low water requires observing the water level during a predicted height of plus to minus 0.4 feet on each side of mean low water. Certain tide curve shapes are more desirable than others. When the tide ebbs far below mean low water (-2.0 feet for example), the water level falls rapidly past the mean low water height and a time window of only 30 minutes results. On the other hand, a tide 0.4 feet below mean low water expands the observation period to three hours as the following example illustrates.

Netarts was the first estuary in which we used a boat and it proved to be indispensable. Identification of low water works best with the observer standing as high as possible in the boat. The boat operator then maneuvers the craft up each of the submerged channels as far as depth will allow. Many stops to get a view at a different perspective are necessary.

Both color and black and white photos were used on this project. The relatively inexpensive black and white photos were used for field identification of high water, low water, section corners, control points, and to record field notes. The pertinent material was than transferred to color photos borrowed from the Highway Department. Many minor changes were made based on the greater detail present in the color photography. The value of using color photographs in this type of investigation cannot be emphasized strongly enough.

National Ocean Survey Chart 5902 was used as a base for this survey. The streets of Netarts, county road along the east bank, and the high water line along the southwest shore were used for primary control of the aerial photographs. We were able to use portions of the shoreline in this area for control because of its stability. The greater length of it consits of an abrupt ledge three to four feet above the bay's silt and sand bed. The grass covered ledge lies one to two feet above mean high water and then slopes up gently westward.

Four tideland parcels were sold between 1876 and 1900. The earliest of these deeds appears

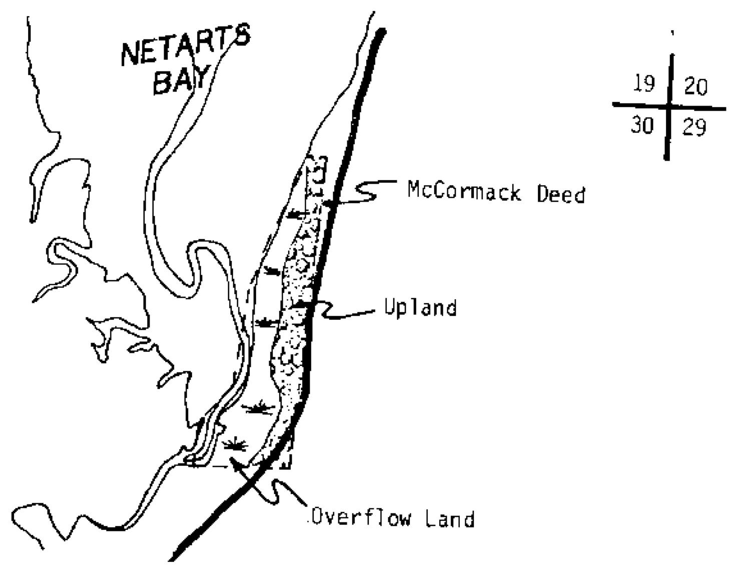


to have been an attempt to convey 15 acres of overflow land in the extreme southeastern portion of the bay. The parcel was sold to Tilmon W. McCormack for $18.75 on May 10, 1876. The area is described by a metes and bounds survey beginning at the meander stake between sections 19 and 30. As the following sketch indicates, more than just overflow land is bounded by the survey.

The metes and bounds survey surrounds seven acres of upland and six and one half acres of grass and marshland. Also included is one acre of tideland and 0.5 acres of submerged land. Higher levels of the upland are estimated at 20 feet above mean sea level.

By 1896, all of the land encompassed by the McCormack deed was patented to other individuals by the General Land Office. Title questions involving this area have apparently been resolved.

The three *tideland* parcels that were sold contain 86 acres. Eighty-four acres are in private ownership and two acres are with Tillamook County. A large portion of the private holdings (41 acres) are owned by the Oregon State University Foundation. The Foundation is a private corporation that manages property conveyed to the University.



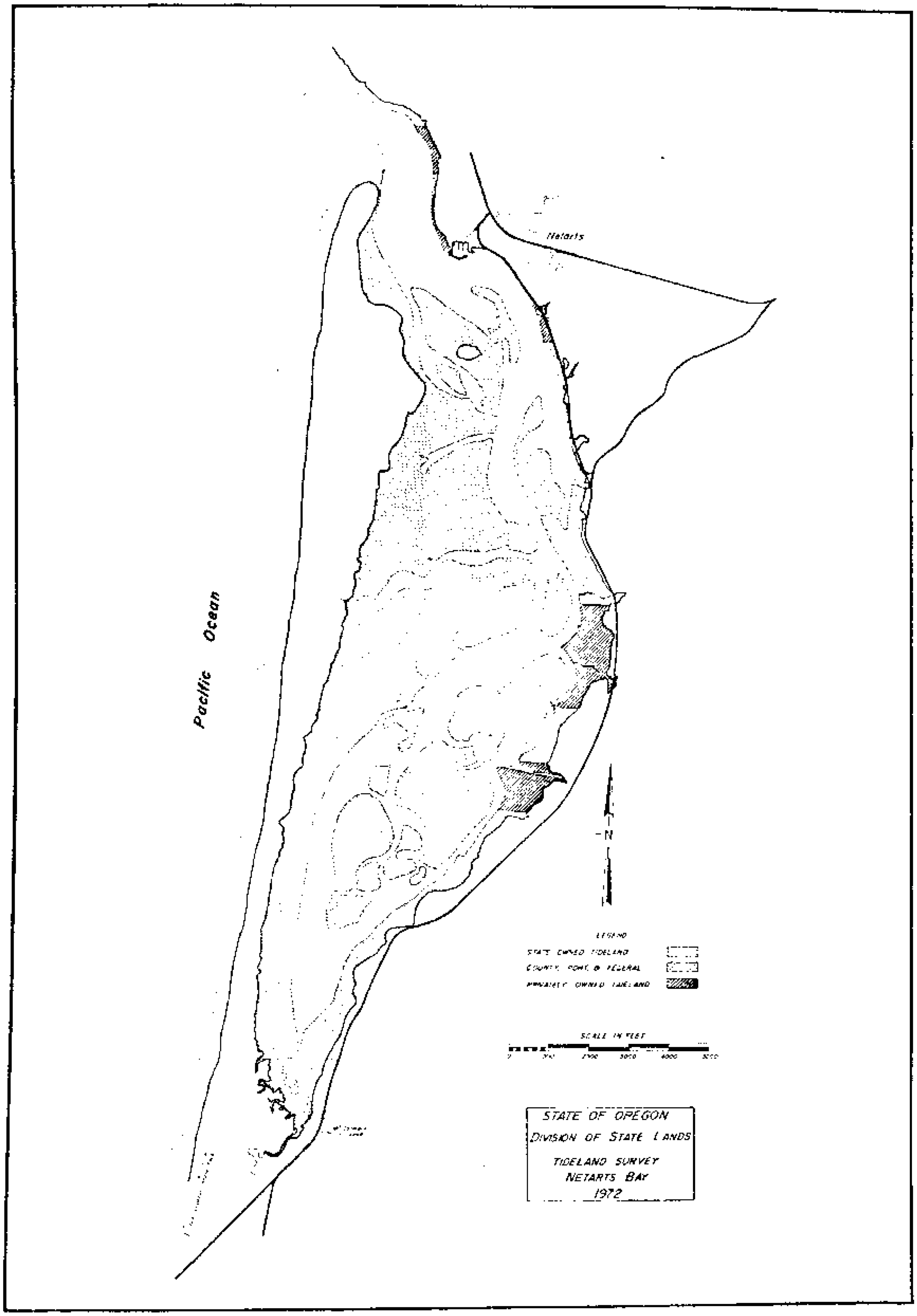
State of Oregon

Division of State Lands

DEED ABSTRACT FOR NETARTS BAY

NAME	BOOK & PAGE	DATE	TOWNSHIP & RANGE	SECTION	GOV'T LOT	TYPE OF SURVEY	ACRES AS SOLD	CLAUSES	PRESENT OWNERSHIP
George W. Phelps	Y-86	Nov. 1,1900	1S, 10W 2S, 10W	6	6	M&B LW	14.35	None	County&Private
William O'Hara	U-438	Feb.15,1883	2S, 10W	5	1,2,3	F&A	23.11	None	County&Private
E. R. Thompston	L-545	July 28,1883	2S, 10W	17	1,2,4	F&A	37	None	Private
Tilmon W. McCormack	C-255	May 10,1876	2S, 10W	30	1,2	M&B	15	Yes	County&Private

M & B - Metes and Bounds F & A - Fronting and Abutting LW - Low Water


Netarts
Pacific Ocean
N
SCALE IN FEET
STATE OF OREGON
DIVISION OF STATE LANDS
TIDELAND SURVEY
NETARTS BAY
1972

Comprehensive Planning for the Coastal Zone

Jack G. Johnson, Chief
Planning Branch
Oregon Water Resources Board, Salem

Although other definitions may abound, "comprehensive" can be defined as "including much; inclusive" and "planning" as "the dynamic and continuous determination and implementation of courses of action in order to achieve a defined goal."

Planning is one of those areas of endeavor which often are described in terms which are not accurately descriptive. The basis for such inaccuracy may be either intentional or unintentional, and there are numerous examples of both cases.

Without too much effort, it can be determined that "comprehensive planning" generally has not lived up to its billing. This is true not only in the coastal zone but in other areas as well. For that reason, initial portions of this discussion will deal with comprehensive planning, generally, before addressing the specific situation in the coastal zone.

For the record, perhaps it should be noted that the deficiencies inherent in that situation are accentuated due to the coastal zone's unique natural resources and related values and the stresses caused by human population striving to experience the benefits to be gained in or from the coastal zone. And it is this reason that has focused so much attention on this portion of our nation in the last several years and has brought about conferences such as this one, which is directed solely toward the technical problems of a particular areas within the State of Oregon.

"Comprehensive planning" generally is a much-employed term that has a tendency to mislead the listener or reader into believing the planning process to be more functionally inclusive than it is in reality. Similarly, common or accepted use of the term has lulled planners into feeling that they have accomplished more than they really have. Often the term "comprehensive" is attached in anticipation of broadening the spectrum of the planning process only to find a situation develop later much akin to that of the child whose eyes were bigger than his stomach as he passed through a buffet line and later struggled unsuccessfully to eat all that he had heaped upon his plate.

In reality then, can we hope to achieve the theoretically comprehensive plan, or comprehensive planning process? Our experience with the present state of the art forces us to answer in the negative, but we can aspire to some dramatic improvements in the present situation. In fact, we are beginning to hear increasingly of planning processes and resultant plans that are markedly more comprehensive than anything undertaken but a few years previously.

This is in the face of the tremendous amount of data and information acquired during the last decade which impresses on us the realization of how little we really know about this world and ourselves. Yet, while faced with an awareness of the growing improbability of ever being truly comprehensive in the theoretical sense, the human mind and spirit accept the challenge to try to do the best job possible. In setting such a source, it is incumbent that we seek out and rectify the flaws within the comprehensive planning process.

And it is to that issue that the major portion of this discussion is directed in the hope that past experiences and present observations can improve the planning process for the coastal zone and elsewhere. Although this is a technical conference, much of the discussion will be couched in a practical, empirical sense; because to be effective ultimately in terms of successful implementation, technical data and procedures must be translated into practical terms and courses of action.

COMPREHENSIVE PLANNING DEFICIENCIES

It is heartening to note that comprehensive planning has improved and it is continuing to do so; nevertheless, there are significant deficiencies which beset the process. While most of these deficiencies are not technical in nature, they are too important to ignore, for such negligence will only continue to plague our efforts to successfully utilize technical information and expertise. Some of the basic deficiencies which are discussed in more detail in subsequent sections are as follows:

1) The process often is oriented toward achieving goals which themselves are deficient.

2) The process, although "comprehensive," may not be very inclusive.

3) The process may overemphasize the "determination or formulation" phase often at the expense of "implementation."

4) The process often is discontinuous and too rigidly oriented toward producing a singular product.

5) The process often fails to integrate adequately the various types and levels of decision-makers.

DEFICIENT GOALS

The planning process must be guided by goals and objectives. While this may seem almost too obvious to merit stating, it is surprising how many planning programs either omit or inadequately address this phase. Needless to say, the process will be greatly improved when goal setting is an initial and integral step in which a broad spectrum of interests has had an opportunity to participate. The goal-setting process, in turn, must be structured to accept that type of input and to reflect the unique characteristics of the various types and levels of decision-making and the nature of the concerns.

In a simplified sense, those levels of decision-making are the local, state, and federal governments and the private sector as well as the systems and hierarchies within each. Again simplified, the concerns can be broadly categorized as technological, environmental, economic, social, or political and the goal-setting process must be able to deal with each.

Goal setting is not an easy task. Experience has shown that it is particularly difficult for groups to identify or express goals and objectives at the inception of a study. Recent experiences, however, suggest that a strong program of citizen participation, able leadership, and appropriate techniques can secure the needed input for defining an initial set of planning goals and objectives. Then, as alternative plans are formulated and evaluated, the initial set of planning goals and objectives can be re-evaluated and, to the extent necessary, reformulated.

It is an interesting observation that many planning processes strive to establish goals and objectives through a negative approach by identifying problems. This approach fails to address those values which have not yet experienced problems. Apparently, it is easier to identify that which individuals or society do not like than it is to identify that which they do like. It is suggested, however, that the best approach would be to formulate goals and objectives on the basis of both problems which are perceived and values which are held in esteem.

It must be recognized that goals and objectives can be expressed in many forms: positive or negative, tangible or intangible, general or specific, and in the form of needs, demands, desires, projections, or even problems to be rectified. Whatever the form, goals should be developed with care in accordance with accepted principles, such as those employed in "management by objectives" processes; because goals and objectives obviously set the stage for the remaining steps in the planning process.

COMPREHENSIVE BUT NOT INCLUSIVE

The term "comprehensive" is used too loosely too often. Generally, comprehensive planning occurs on the basis of a singular function; hence, the terms comprehensive land-use planning, comprehensive water resource planning, comprehensive transportation planning, and comprehensive health planning. The foregoing are comprehensive only within the context of that particular function and not within the context of the relationship of one to another.

Needless to say, planners and other participants in the planning process should strive for greater inclusiveness in their comprehensive planning. While such inclusiveness seems to be appearing in a number of planning activities across the country, it is not yet prominent within Oregon and certainly not within the coastal zone--and probably for good reason. While necessary resources such as funds and personnel generally have not been available, it also is true that the state of the art is not yet adequate to meet truly comprehensive planning needs. The latter case also explains the rash of planning methodologies being sought and developed to assist the planning participants to cope. It was precisely this situation last fall that led a state-federal planning team here in Oregon under the auspices of the Pacific Northwest River Basins Commission to contract Oregon State University for development of a "general planning methodology for analysis of estuarine natural resources." The results of this multidisciplinary effort should be available soon and, hopefully, will provide useful alternative planning approaches for dealing with the complexities of the estuarine system.

Using project planning as an example of the evolutional progress being made, past efforts were addressed initially to single-purpose projects, later to multiple-purpose projects, and more recently to project formulation stressing multiple-objectives and multiple means of accomplishing the specified objectives. Although the benefits of comprehensive planning are too great to ignore, the compounding complexities provide ample reason why professional planners have moved cautiously.

For the coastal zone and elsewhere, comprehensive planning ultimately must be broadened to encompass--in an integrated fashion--such elements as land use, natural resources, housing, transportation, parks and open space, health services, education, communications, and public utilities. For our coastal zone, that point in time is still far off. Progress can be affected, however, by linking more closely together the natural resource planning usually undertaken by state and federal agencies and the urban or regional type planning, which usually is carried out by local and regional units of government. While many contend that state government is the logical level for such integration, perhaps the critical thrust is that of simply establishing a viable, cooperative planning process where all levels are mutually supportive toward a common set of goals and objectives which reflect all levels.

MEANS MORE IMPORTANT THAN END

There is a tendency by professional planners, especially those more insulated from the direct demands of the public, to overemphasize the formulation or evaluation phase to the detriment of the implementation phase. Defined another way, the situation is one where the means is more important than the end. Driven by various demands including those of a legislative body, or the innate desire for technical production, the process becomes a maze in which the planner often cannot see the real world which he ought to be addressing.

Too often the approach is to develop a very complex, involved, and extended process directed toward achieving some optimal course of action relative to the adopted goals and objectives. Soon the technical aspects of the process become so demanding of the participants that they can't adequately address the human elements with which they must communicate and work. When this happens, experience indicates vividly that the planning suffers because the potential for successful implementation is markedly reduced. And often nontechnical aspects of the planning process, such as those which are of a social and political nature, are either ignored or are largely left to others to be addressed after a study is completed. More often than not, these missing ingredients are the ultimate cause of planning failures.

An example of a complex procedure might be the somewhat controversial system to be employed in the evaluation of federal water and related land resource programs. Although the principal agencies are using slightly different methods, the basic approach is much the same. Programs are to be formulated and evaluated in a comprehensive manner under multiple objectives where the costs and benefits of each alternative for each objective are displayed for the benefit of decision-makers. In a detailed and complex system of principles, standards, guidelines, and procedures, planners are entangled in a web of complexities oriented toward projections, optimization, cost-sharing, benefit-cost ratios, and other facets, none of which may identify or assess adequatley those legal, institutional, political, or other roadblocks, which may, in the end, negate the efforts of the most dedicated planners. What is laudible, however, is the intent to provide an improved display of alternative courses of action, cause/effects, impacts, benefits, and costs, so that decision-makers have more usable information available to them. If the procedure can be kept simple enough, a decision-maker, such as the Congress, may no longer be forced to participate in a "take it or leave it" situation in reviewing a project proposal, but more logically might be able to choose those components having concomitant benefits, costs, and impacts which appear to be in the public interest.

A DISCONTINUOUS PROCESS

Planning is a continuous process, and we fortunately seem to be entering a period of time when more people are awakening to that fact. In the past, we have seen multitudes of studies commissioned with their successes measured upon the production of a report within the allotted time and funds. Many of these reports resulted in a plan which might have been appropriate for a relatively limited period but which were also relatively inflexible. Such inflexibility did not allow for the recommended plan to accommodate the various changes which could be expected to occur in the future, thereby insuring that the plan would be outdated. Comprehensive planning, in the sense being discussed here, should not be thought of or carried out in such a manner, but should be every bit as continuous and dynamic as it is comprehensive.

Much of the discontinuity can be attributed to the project-oriented approach of numerous public agencies. Such agencies operate programs which are only a collection of unrelated, uncoordinated individual elements or projects. Those elements begin with authorization and/or funding and end no later than expiration of the same. Little thought is given to the benefits of supporting a basic, continuing planning service.

FORGETTING THE DECISION-MAKERS

Earlier discussion on other deficiencies touched on the need to address the various types and levels of decision-making. The necessity to recognize and deal with the various levels of decision-making is important enough to merit special attention, however. This is especially true as planning becomes more goal oriented, with those goals being expressed by all political levels. Furthermore, the unique characteristics of each level exert their peculiar influence on the formulation process and the potential for implementation.

Perhaps the most important improvement which could be made in the planning process would be institution of and commitment to a truly "comprehensive," cooperative, and continuing planning program based on a positive approach to achieving mutually identified goals. Although the term is somewhat overworked, a planning team in the fullest sense of the word "team" is precisely what the planning process needs.

That process could be greatly enhanced by state and federal governments defining as explicitly as possible their goals, objectives, policies, standards, and criteria and providing the necessary personnel to assist local and regional governments in the planning effort. Considerable improvement would result from continuity of assigned personnel for the purpose of servicing planning programs in selected geographical areas. Only in this way can a lasting spirit of mutual trust and cooperation develop and exist over an extended period of time among those having a stake in the planning process.

It should not be expected, however, to experience planning without also experiencing pressure and conflicts. These are the signals whereby the planning team defines the boundaries and proceeds to seek the balanced and final course. If such conflicts are skillfully managed and publicly aired, it is the public which will benefit--if it has the opportunity to be party to and understand the planning process. Public participation or involvement is widely espoused these days, and rightfully so, but it is not an easy task if the public is to participate in identification of goals, formulation of alternatives, assessment of impacts and tradeoffs, and selection of final course of action. Considerable attention must be devoted to methods of providing meaningful participatory opportunities to interested segments of the public.

In summarizing the deficiencies of comprehensive planning as noted herein, very likely it might be stated that nothing profound or new has been stated. That probably is true because planning itself is hardly a newcomer. The approaches, thrusts and emphases change with the times but the basic structure of the process remains essentially intact--as do many of the deficiencies of that basic process. But because those deficiencies remain, they continue to deserve identification in the hope that they will be rectified.

COMPREHENSIVE PLANNING IN THE COASTAL ZONE

Slowly beginning to emerge is the shape of the future planning structure. The increasing rejection of piecemeal planning, particularly at the state level, is the dominant factor in the definition of that structure and the roles of its various elements.

Hopefully, we will see improved expressions of broad national goals and policies and more specific state goals and policies. With the improved definition of the federal and state positions, regional and local planning programs can proceed with more assurance than in the past.

Local and regional entities alone cannot be expected to shoulder the burden of comprehensive planning, however. There are indications that state government will move to add its presence to the planning teams in the field if adequate personnel levels can be achieved and maintained. State agencies must continue to increase coordination and integration of programs, either through official or unofficial actions, in order that the positions of the agencies are more consistent with each other.

One of the constant deficiencies in state planning is the absence of a coordinated state planning function. Individual agencies are left to go their own ways even though they may be desirous of some form of coordinative leadership. For various reasons, a number of unsuccessful attempts have been made over the years to establish some form of state planning office. This void is once again being addressed, this time in the current legislative session as part of the state land-use planning proposals.

It appears, therefore, that there will be significant change in the role of state government as it moves to marshall its resources, effect necessary corrdination and bulwark local planning programs. Unless there is an equally significant change in the federal camp, however, the federal government will continue to generate problems for planning at the other levels as well as within its own planning structure.

National problems often reach a "crisis" stage which precipitates various far-reaching actions. These actions are taken in response to a specific problem and often without regard to coordination with or impact on other functions, aspects, or areas. Application of federal policies and programs nationally also provide little opportunity to accommodate unique situations within a state, thereby stifling potentials for excellence.

A case in point is the federal requirement through EPA for river basin water quality management plans as a prerequisite to federal financial assistance for wastetreament facilities. The law expresses little concern for coordination with other planning programs, even those which may be closely related and federally funded. Now in effect are the 1972 amendments to the Federal Water Pollution Control Act which impose another system of planning requirements, again with little regard to other planning programs.

The subject of the National Coastal Zone Management Act presents both problems and opportunities to the nation and individual states. In many states, as well as nationally, it precedes general land-use legislation and, in any case, raises questions of compatibility with general land-use planning. The states also are counting on the funds authorized by the Act, however, these essentially have been impounded by the Executive Branch. The absence of guidelines, which will come from NOAA, do nothing to ease the uncertainty relative to the impact of the Act.

Up to this point, there has been little mention of the role of the institutions of higher education. That role might be essentially as defined by President McVicar in his opening address at last year's conference when he said that it is absolutely essential that knowledge acquired through reserach efforts be put to work rather than being buried in the library. It seems that for a number of years, the academic community preferred not to become too deeply involved with planning processes generally, and perhaps with good reason. It ought to be apparent now, however, that comprehensive planning can use all the help it can get. Planners, particularly at the state and federal levels, have intensified efforts to effect liaison with and secure assistance from the universities, but the burden has been on the planners to take the initiative. With respect to research, it appears that the real world is the premier laboratory and the universities would do well to take the initiative to perform some analyses in that laboratory to become acquainted well enough with the planning processes to be able to formulate their own proposals as to how they may participate.

One important suggestion bears repeating, having been previously discussed relative to planning methodologies. It is very crucial that means be developed to effectively utilize our data and information in the planning process. Proper use is not being made of much data and information presently, and the situation will continue to worsen without the benefit of adequate methodologies and modern data processing techniques. Without these tools, the comprehensive planning process will never mature much beyond the present stage due to the inherent complexities and demands upon the primary participants. The development and application of practicable methodologies, therefore, present exceptional opportunities for the universities to improve the planning process.

This is an opportunity to raise another point for the universities to consider if they are really interested in being part of the comprehensive planning team. Public agencies are responsible for management of much of the coastal zone and actually for the whole state. As an example, about 53 per cent of the state is in federal ownership and another 3 per cent in state ownership. In the course of their research and teaching responsibilities, university staff members investigate and analyze various agency activities. Criticism is voiced periodically about the performance of various agencies in discharging their responsibilities and often with good cause. There appears to be considerable opportunity to assist and improve agency planning and decision-making processes--provided that a greater knowledge of and appreciation for agency activities could be achieved. The only adequate and reasonable means of doing this would be a period of service or internship with appropriate agencies. In this respect, it is an interesting observation that public agencies are benefiting from a considerable number of high school and university students under various sponsorship program;s but those same offices are rarely, if ever, frequented by the teaching and research staffs of the schools. One has to wonder about the logic and priorities in such a situation.

In conclusion, some personal and admittedly subjective observations about the ongoing planning programs in Oregon's coastal zone may be of value. These observations stem from responsibilities in a major state agency planning program incorporating intensive cooperation with local interests and federal agencies; and a six-month assignment to coordinate activities preceding establishment of Oregon's Coastal Commission.

1) The Oregon Coastal Conservation and

Development Commission is pioneering in efforts to define important policies and standards for areas of critical concern. If successful, the product will serve as a model for and be of benefit to planning efforts in other areas of Oregon.

2) The Oregon Coastal Conservation and Development Commission's concern and responsibility for regional matters and public participation also would be of benefit if employed in other areas of Oregon.

3) Councils of government serve a useful role in intergovernmental coordination if the issue of the manner of designating representatives to the councils (elective or non-elective) can be resolved in such a way as to generate public confidence.

4) Local planning can do the necessary planning job, if coordinated within designated areas; augmented by state and federal technical assistance; and provided with state and federal policies, standards, goals and objectives.

5) State and federal governments must accept the planning process as a continuous function which deserves support in relation to the extent of state and federal interests and obligations in a particular area or activity.

6) The planning process must seek a measure of conformity in the coastal zone with respect to manner of public participation in order to facilitate such participation. Consideration should be given to reimbursing the expenses of designated or authorized public representatives such as advisory committee members.

7) Efforts should be undertaken to remove or alleviate legal, institutional, and financial impediments to objective planning and to implementation of "optimal" plans or other agreed upon courses of action.

8) Planning participants should recognize that it is unlikely that all interests can be satisfied, and decision-makers should take positive action upon satisfaction that reasonable effort has been devoted to formulating and displaying alternative courses of action.

The subject of comprehensive planning, in the coastal zone or elsewhere, is complex, sometimes nebulous, the subject of very few texts, often in need of abundant commonsense, and a subject which is of extreme importance to all who care about our future. It is hoped that this discussion has addressed some aspects which, in turn, will generate appropriate actions to improve and maintain the comprehensive planning process.

General Planning Methodology for Estuarine Natural Resources

Peter C. Klingeman, Associate Professor
Department of Civil Engineering
Oregon State University, Corvallis

This paper summarizes the main features of a new approach to planning and decision-making for Oregon's estuarine natural resources. The general methodology presented here was developed by the author and David A. Bella[1] with the assistance of eight specialists from several disciplines[2]. The methodology was developed for the Oregon Study Team (state and federal agencies) of the Pacific Northwest River Basins Commission, with specific financial support from the Portland District, U.S. Army Corps of Engineers, and the National Marine Fisheries Service, National Oceanic and Atmospheric Administration. During the study, frequent discussions were held with members of the Oregon Study Team and the Oregon Coastal Conservation and Development Commission (OCC & DC)

The objectives of the study were:

1. to examine the physical, chemical and biological characteristics and their interrelationships for Oregon estuaries, to see how they affect planning and decision-making;

2. to develop a general methodology for making planning and management decisions for Oregon's estuarine natural resources;

3. to determine the information needed to implement the methodology; and

4. to examine the constraints on planning caused by insufficient and inadequate information.

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[1]Associate Professor of Civil Engineering, Oregon State University.

[2]D.R. Hancock, biological oceanography; H.F. Horton, estuarine fisheries; M.S. Inoue, systems engineering; C.D. McIntire, aquatic ecology; W.S. Overton, decision theory and ecology; L.S. Slotta, ocean engineering; C.L. Smith, cultural anthropology; J.M. Standar, decision theory.

Two reports were prepared under this study: (1) General Planning Methodology for Oregon's Estuarine Natural Resources and (2) Descriptions and Information Sources for Oregon's Estuaries.

SOME STARTING DEFINITIONS

Planning, or the systematic process for determining ways to accomplish goals, has been dealt with most effectively by use of different planning levels with varying scopes of responsibility. In this methodology, two distinct levels are recommended: the strategic level and the tactical level. The latter is further subdivided, as will be discussed later. Here, strategies are defined as concepts and procedures to follow in the comprehensive (regional and long-term) employment of resources to accomplish set goals; tactics are concepts and methods to follow for the immediate or local employment of resources to accomplish set goals. Strategic planning, in the sense of this study, is comprehensive regional planning with a broad scope of responsibility whereas tactical planning is local, smaller-scale, detailed planning involving individual estuaries.

THE NEED FOR NATURAL RESOURCES PLANNING AND MANAGEMENT

There are both "positive" and "negative" needs for natural resources planning and management. Both types of needs are compelling. The urgency of the needs and the strength of the measures called for are variable among the kinds and locations of the natural resources, being generally greatest for scarce resources and in those areas where population pressures are greatest.

The positive need for natural resource planning and management is to improve the quality of life for man. While a somewhat elusive goal to define, this is not purely an "economic ethic" nor an "ecologic ethic." The goal of improving the quality of life goes beyond seeking material and spiritual comforts. It also requires a responsibility on the part of man to present and future generations. In relation to natural resources, this responsibility requires a different perspective than purely an exploitational, economically grounded view. It requires a strong sense of "husbandry," conservation, and protective use. It may call for boldness in some instances to effect change or to markedly alter the character of an estuary. It may also call for caution against taking some actions in recognition of the limits of man's knowledge and the inability to foresee consequences.

The negative need for natural resource planning and management is to protect those rsources against undesired depletion, exhaustion, extinction, misuse, and abuse. Today there exist many examples and monuments to these undesirable conditions. They provide a strong motivation to plan ahead and manage carefully so that the bad things which have occurred elsewhere won't be repeated. Because there is a great deal to learn from the mistakes of others, such insights may be used advantageously in natural resource planning and management.

THE NEED FOR PLANNING LEVELS

Various planning levels are important in natural resources planning to adequately consider these resources from different perspectives and scopes of responsibility. To illustrate this, consider the following example. Suppose that eight estuaries exist along a state's coastline and are numbered consecutively. Suppose also that three general plans have been proposed for development and preservation of these estuaries. Plans A and B represent "all or nothing" development schemes and differ in that under plan A the even numbered estuaries would all be extensively developed and the odd numbered estuaries would be preserved untouched, whereas under plan B the odd numbered estuaries would be extensively developed and the even numbered estuaries preserved. Plan C represents a moderate degree of development in all eight estuaries. Table 1 illustrates this situation.

From the regional viewpoint, plans A and B are essentially the same in preserving a diversity of estuarine conditions, whereas plan C is quite different and would greatly narrow the range of diversity of estuary types.

From the local viewpoint, plan A is the exact opposite of plan B, whereas plan C is a compromise.

The determination of which plan is best will depend upon regional and local goals and policies. However, the decision cannot be made at one level only and still adequately meet the positive and negative

TABLE 1

ILLUSTRATION OF THE NEED FOR PLANNING LEVELS

Estuary number	Plan A Develop only the even-numbered estuaries	Plan B Develop only the odd-numbered estuaries	Plan C Moderate development of all estuaries
1	Preserve	Develop	Moderate
2	Develop	Preserve	Moderate
3	Preserve	Develop	Moderate
4	Develop	Preserve	Moderate
5	Preserve	Develop	Moderate
6	Develop	Preserve	Moderate
7	Preserve	Develop	Moderate
8	Develop	Preserve	Moderate

needs for natural resource management described earlier. The most effective environmental planning structure would consist of a number of planning levels of varying scopes of responsibility. Such planning levels would not only be related to each other but would also relate to other components of the entire socio-economic structure.

EXISTING PLANNING LEVELS FOR OREGON'S ESTUARIES

Several levels presently exist in the planning and decision-making process for Oregon's estuaries. These include organizational levels, planning process levels and levels for different types of planning and decision-making activities.

The planning and management for Oregon coastal zones is carried out by five distinct groupings or levels of agencies and organizations. These are the federal agencies, the regional interstate organizations, the state agencies, the regional intrastate organizations, and the local organizations. Each group has a different role and range of responsibilities regarding estuary planning and management. Furthermore, the scope of total activities and proportion of effort devoted to estuaries varies among and within groups.

The planning process for natural resources can also be viewed in terms of the decisions which must be made. When placed in such a context, three distinct levels of planning and related decision-making can be identified. These are: overall policy planning and decisions, functional planning and decisions, and project planning and decisions. These are sequential, the second following the first and the third not possible until the second has been carried out.

Finally, the types of planning and decision-making activities can be divied into strategic and tactical. These have already been described.

Figure 1 shows the planning and decision-making levels for Oregon's estuaries.

PLANNING LEVELS RECOMMENDED IN THIS STUDY

For better coordination and more effective planning of estuarine resources, it is recommended that the types of activities be arranged around three planning levels. As shown in Table 2, these are a regional strategic planning level, an intermediate tactical level for advance planning and the provision of professional services for individual estuaries, and a local tactical level for specific planning and projects in individual estuaries. Comparison of

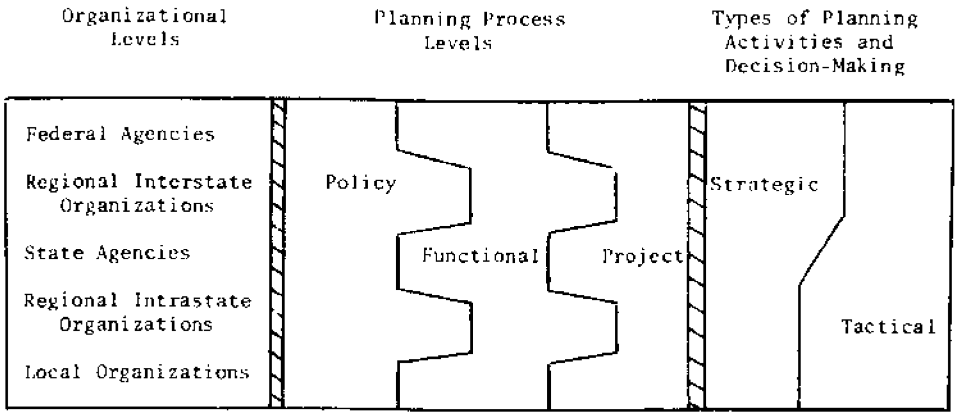

FIGURE 1. Planning and Decision-Making Levels for Oregon's Estuaries

Tables 1 and 2 with Figure 1 will show how the existing planning organizations, processes and activities are incorporated in this recommended approach.

SOME FEATURES OF THE RECOMMENDED METHODOLOGY

The following are some of the important features provided by the proposed methodology for estuarine natural resources planning and decision-making:

1. "Local" interests retain a key role as originators of specific detailed plans.

2. State and federal agencies retain their role of planning for their limited authorized functions.

3. State and federal agencies and regional organization (interstate and intrastate) jointly establish strategies and tactics, strategic plans and tactical plans for natural resources use and protection with a primary goal of improving the quality of human life now and in the future.

4. State and federal agencies and regional organizations cooperate to maintain the overall diversity of Oregon estuaries and estuarine resources.

5. A state-federal interagency group of "resource professionals" provides essential advance planning and professional services for individual estuaries. This includes: natural resource data and environmental data; guidelines for natural resource use; identification of potential alternative actions and general environmental impact assessments for potential alternatives; priorities for needed planning and actions; and reviews of specific plans.

6. Strategic planning will identify at an early date certain estuaries or portions of estuaries suited for "protection" status, giving an early opportunity to initiiate activities for maximum protection of natural resources there.

7. Specific plans originating at the "local" level, including those of state and federal agencies, are reviewed for compliance with policies and guidelines established at the strategic level and intermediate tactical level.

8. Data gathering, analysis, and interpretation are coordinated at the strategic and intermediate tactical levels, deficiencies are identified, and supplemental data collection is initiated to improve overall planning and detailed planning.

STRATEGIC PLANNING

The basic concerns in this environmental planning methodology include the following: the improvement of the quality of human life, the avoidance of large-scale irreversible change, the avoidance of dominating environmental change, the preservation of environmental options, preservation of the self-organizing capabilities of ecosystems,

TABLE 2

RECOMMENDED PLANNING LEVELS FOR ESTUARINE NATURAL RESOURCES

Planning Level	Planning Purpose	Planning Group
Strategic-level planning for Oregon estuaries as a group.	Regional strategies to improve quality of life, protect natural resources, maintain diversity of estuarine resources and types. Interagency cooperation to implement strategies.	Federal-state interagency group with regional level coordination.
Intermediate-level advance planning for individual estuaries.	Policies and guidelines for natural resource use in the estuary. Professional services. Coordination and clarification of responsibilities.	Federal-state coastal zone interagency group, separate from the above, with state-level coordination
Local-level specific planning for individual estuaries.	Specific plans, both comprehensive and limited in scope. Implementation of plans. Management.	Public and private entities "local" to the estuary and vicinity. State and federal agencies with specific projects or programs in the estuary.

the maintenance of a balance among preservation, conservation, and development, and the continuance of a diversity of estuarine types and conditions. These concerns form the basis for strategic-level environmental planning.

The local environmental strategy to improve the quality of human life has been termed the "diversity approach" in this methodology. This approach or strategy places a high value on environmental variety. It seeks to maintain as broad a diversity of Oregon estuarine systems as possible. This calls for the uneven distribution of man's environmental influences, to provide a variety of development, conservation, and preservation actions. Such variety is deemed essential not only among different estuaries but also for the separable systems within individual estuaries.

This planning methodology recommends that the basic environmental concerns expressed at the strategic level be implemented by use of a functional classification system and a strategic decision group capable of making decisions which result in developmental diversity among the estuarine systems. These systems include both the aquatic regions and the adjacent lands.

Functional classification of each estuarine system by the strategic decision group involves, first, agreement upon the primary reliable function of that system (production or protection) and, second, designation of the systems as a "production," "protection," or "mixed" system along a spectrum of potential development-conservation efforts. This is illustrated in Figure 2. Production refers to encouragement of man's use of the estuarine system for the highest yield of those goods most useful to man. Protection refers to holding man's development at its present level or reducing the level of development to protect the natural self-organizing capabilities of the system. Mixed systems are intermediate between production and protection systems.

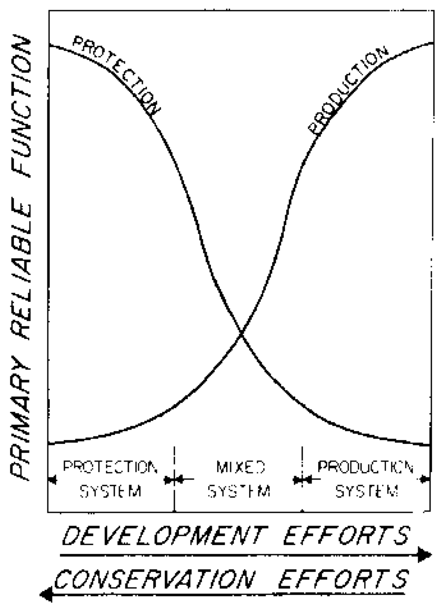

FIGURE 2. Functional Classification for Estuarine Systems

Collectively, the three system categories permit implementation of the environmental strategy of diversity. The diversity approach requires that Oregon's estuarine systems be well distributed along the full range of development-conservation efforts (the horizontal axis of Figure 2), so that the broadest possible variety of conditions will be available. The balance among estuarine systems along this spectrum of efforts must be maintained at the strategic planning level. For example, if local interests press for development of certain systems a shift toward greater conservation efforts will be needed at other systems to maintain diversity.

INTERMEDIATE-LEVEL TACTICAL PLANNING

The central feature of the tactical planning methodology is the recommended intermediate planning level between the broad strategic planning level already described and the specific local planning level currently in existence.

The basic environmental concerns are the saem at the intermediate tactical level as at the strategic level. However, these are rephrased into more-specific guiding concepts. Six concepts for tactical planning are particularly emphasized. First, the estuary should be recognized and described as a system so that proposed activities or alterations will be viewed in terms of their effects upon that system, rather than as isolated, localized alterations. This involves treatment of the system as an entity having properties, undergoing various kinds of processes and interactions, and possessing a range of inputs and outputs. Second, and closely related to the first, a "systems" approach should be used for analytical treatment of estuarine natural resources to show roles, functions, characteristics and interrelationships. The system state, boundaries, adaptivity and uniqueness are among the many considerations here. The limits of human knowledge of the system must be recognized, as well as the differences in human perception of the system. Third, the habitats of biological resources in estuarine systems must be identified. Furthermore, because developmental activities generally lead to progressive loss of many habitats, steps must be taken to preserve habitats if biological diversity and ecosystem self-organization are to be maintained. Table 3 shows different ways by which habitats may be identified and described. Fourth, environmental impact assessment should be an integral part of planning, from start to finish. At the intermediate tactical level such assessment is a basic feature of advance planning as well as of specific-project review. Several elements of environmental impact assessment are shown in Table 4. Fifth, "preventive" planning should be used as part of total planning to learn from past mistakes and to avoid past errors and poor judgment. The counterpart to preventive planning has generally worked well-successful past projects are often modified for application to new situations. With unsuccessful projects it is often possible to find a relativley few causes for failure, to identify some of the cause-effect relationships, and to trace repercussions throughout the system. Documentation of such case studies at the intermediate tactical level would help local planners to avoid many common pitfalls. Sixth, flexibility should be an important feature of current plans in order to preserve future options. These may be required due to present ignorance of estuarine systems as well as to changing knowledge, needs, and capabilities.

The following may be taken as "tactics" to apply at the intermediate tactical planning level:

1. Set policies and guidelines for natural resource use.

2. Characterize the estuary as a system;

TABLE 3

CONSIDERATIONS IN HABITAT IDENTIFICATION AND DESCRIPTION

I. Features of Space

Water depth:

- floodplain/surgeplain zone
- surf splash zone
- marshes
- intertidal zone
  - upper
  - middle
  - lower
- subtidal zone
  - shallow
  - deep

Location in estuary:

- entrance
- near-mouth
- middle reaches
- upper end
- riverine
- channels
- constrictions, points
- embayments
  - deep
  - mud flat
  - marshy

Typical salinity range:

- near-marine
- intermediate, high salinity
- intermediate, low salinity
- near-riverine, mildly brackish

Bottom sediments and substrate condition:

- bedrock
- rocky, boulders
- gravelly
- sandy
- muds
  - silty
  - clayey
- vegetation, plants
- organic debris
  - wood chips
  - logs

Vegetation type found:

- shoreline
- aquatic, intertidal
- aquatic, subtidal
- sedges
- grasses
- algae

Association with structures:

- pilings, piers
- jetty rocks
- log booms

II. Value of Species to Man

Direct:

- commercial
- recreational
- aesthetic

Indirect:

- commercial
- recreational
- aesthetic

Basic life support
Non-essential

III. Functional Role of Species

Producers
Consumers
Decomposers

IV. Biological Group or Behavioral Characteristics

Plankton
Neuston
Nekton
Benthic
Epiphytes

TABLE 4

ELEMENTS OF ENVIRONMENTAL IMPACT ASSESSMENT

I. Statement of Proposed Action

II. Existing Conditions in Context of Proposed Action

- Area involved:
  - Condition of area
  - Problems
- Resources involved:
  - Condition of resources
  - Problems

III. Alterations of Existing Conditions by Proposed Action

- Physical changes proposed
- Area to be affected by physical changes:
  - Immediate
  - More distant
- Systems to be affected by physical changes:
  - Biological
  - Physio-chemical
  - Human
  - Other
- Time frame for alterations to occur

IV. Probable Environmental Impacts

- Resources impacted
  - Aquatic
    - Biologic
    - Mineral
    - Other
  - Terrestrial
    - Biologic
    - Mineral
    - Other
  - Interrelationships of resources
- Time frame
  - Short-term (during construction)
  - Long-term (during post-construction operations)
- Areas involved
  - Immediate (local) area
  - Distant areas within estuary
  - Distant areas beyond estuary
  - Interrelationships of areas
- Character of imapcts
  - Direct vs. indirect
  - Primary vs. secondary
  - Avoidable vs. unavoidable
  - Isolated vs. cumulative
  - Beneficial vs. detrimental
  - Enhancement vs. deterioration
  - Reversible vs. nonreversible
- Possibilities for future modification
  - Renewability of resources affected
  - Reversibility and retrievability of resource commitment
  - Loss of future options
  - Restriction on range of beneficial uses

identify and describe all resource subsystems in order to better assess the effects of proposed plans.

3. Do advance planning in order to be ready for evaluation of specific planning proposals.

4. Take an advance look at the possible alternative actions for each estuary.

5. Take an advance look at the probable environmental impacts of potential alternatives.

6. Do preventive planning to understand avoid past mistakes.

7. Determine the present limits of scientific knowledge and the levels of ignorance about natural resources.

8. Determine the acceptable environmental risk levels and acceptable margins for planning error for individual estuaries.

9. Prefer those alternative actions which preserve future options, in order to accommodate new scientific information and new needs.

Implementation of intermediate-level tactical planning as recommended here involves the formation of an intermediate-level group of resource experts from state and federal agencies and other appropriate groups.

The recommended planning procedures for individual estuarine systems are shown in Figure 3. The concepts and tactics previously described are integral parts of the process depicted in Figure 3.

LOCAL-LEVEL TACTICAL PLANNING

The local planning process takes many forms and varies tremendously in detail and thoroughness. The Oregon Coastal Conservation and Development Commission has recently developed guidelines for local estuarine planning (OCC&DC, 1973) so that better, more comprehensive planning may be accomplished. These guidelines are represented diagrammatically in Figure 4.

At several steps in the local planning process of Figure 4 the availability of a technical advisory group and of technical services is essential (see TAG designation). Furthermore, comparison of Figures 3 and 4 shows that technical services might be applied beneficially to other steps in Figure 4.

Intermediate-level tactical planning can be made highly compatible with local-level tactical planning. Furthermore, the efforts of OCC&DC and others in improving local planning can be greatly supported by the natural resource planning methodology discussed here. This methodology can be used to coordinate and increase the participation of state and federal agencies in estuarine planning.

CLOSING REMARKS

The general planning methodology described here will not resolve all problems regarding estuarine natural resources. Planners and decision-makers will always be faced with the "environmental predicament;" (a) that man's ability to change the environment exceeds his ability to foresee what that change and its effects will be at a given time (Bella, 1972) and (b) that some degree of relative ignorance will always exist as long as man increases his ability to change the environment. This is shown in Figure 5. Planning must adequately recognize the limits of man's knowledge. There will always be some uncertainty regarding the outcome of estuary modifications, no matter how carefully the modifications are planned. But thorough planning along the lines recommended in the general planning methodology proposed here will help to minimize man's relative ignorance and to improve the decision-making process concerning estuarine natural resources.

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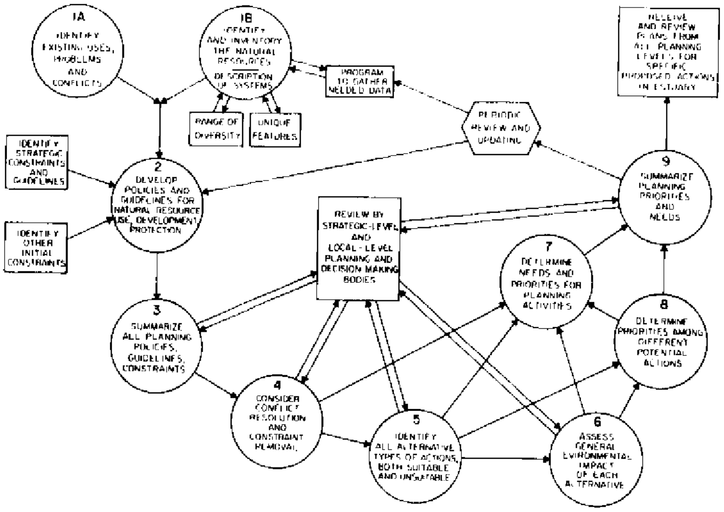

FIGURE 3. Intermediate-Level Tactical Planning Process for Individual Estuarine Systems

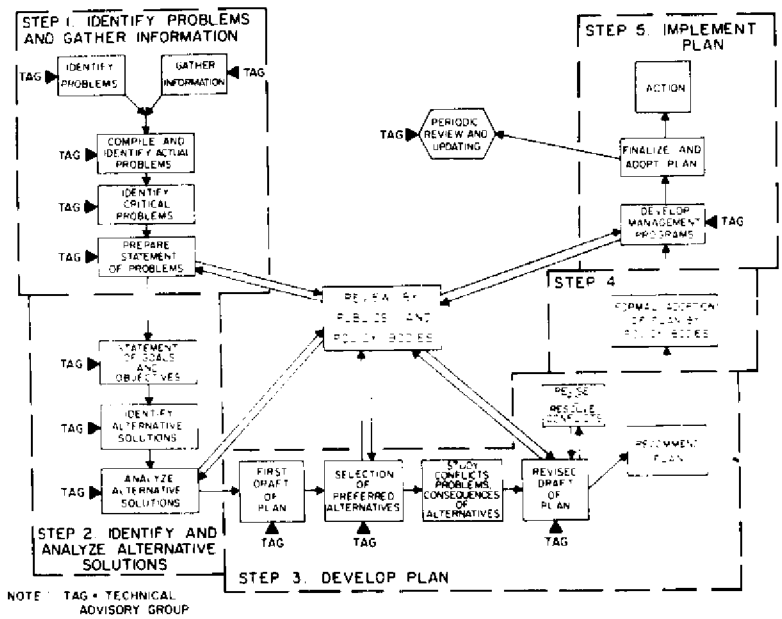

FIGURE 4. Proposed Guidelines for Local-Level Planning at Individual Estuaries (Adapted from OCC&DC, 1973)

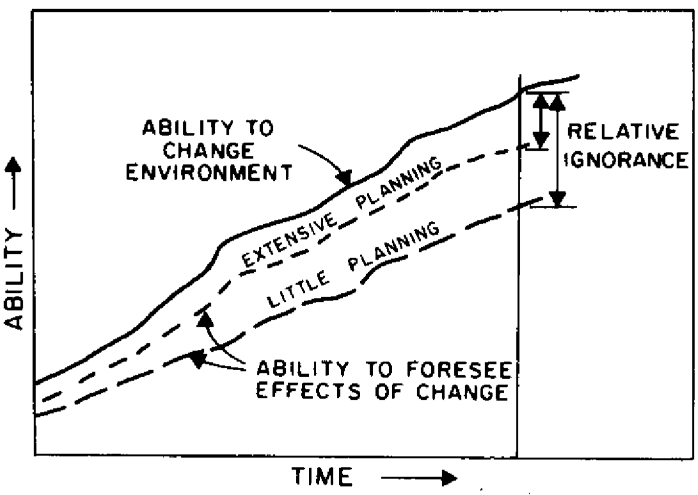

FIGURE 5. Conceptual Diagram of the Environmental Predicament and the Ability of Planning to Close the Gap of Relative Ignorance

My Life on the Water Front

Joel W. Hedgpeth, Professor
School of Oceanography
Oregon State University
Marine Science Center, Newport

As one of a long line of Methodist circuit riders I am entitled to use a text or a moral for my discourse. But I must remind you that such a family tradition means that you may be in for a long sermon; as one of my great uncles wrote to my grandfather in 1886, "I am in very poor health bearly able to walk--could not cut wood enough to cook a meal for my life but thanks to God I can preach just as loud and long as I ever could without any inconvenience."

In any event, my moral is that water should have its own right to be, its own right to go its immemorial way to the sea, to exist for its own sake. I started thinking this way many years ago after a discussion with an agricultural engineer (I cannot now remmember who he was) in Giannini Hall in Berkeley. I was mentioning that there might be a requirement for a certain flow of water in a certain stream to enable the salmon to continue living in that stream. He asked "What are they going to do with that water--waste it?" His reaction startled me and had not a little to do with setting me on my way as a preacher for the environment. However there is nothing duller than the saved preaching to the converted, and if at times I say unkind things about engineers you will realize that I am hoping to save some souls.

I decided to approach this problem by the way of my family history, which in a way has always been involved with water problems. When my father's people came West in 1858 they were the first wagon train to take the Beale Trail west from Albuquerque and they stopped for a few days at that famous water hole, El Morro. This place is only about an hour and a half from Albuquerque these days, but every fifteen minutes by automobile at 70 miles per hour represents an entire day's travel in my grandfather's day. From this place they travelled to the Colorado River where they encountered another sort of water problem--the barrier of the river. They were backed up against the river, waiting for the opportunity to cross by ferry when they were attacked by Indians and lost their stock and wagons. Some of our people have never cared for Indians since but I suppose it is appropriate that my mother became a missionary to save the Indians from their heathen ways. In any event, many of my people finally came to rest at Academy, a few miles east of Fresno--where there is very little water, just as the hills begin to rise toward the Sierra.

As for myself, I came to the light of day on the shore of an estuary--or not far from the Oakland estuary. I was born in a Victorian mansion in West Oakland. We all tend to view or understand things in the light of our own experience--the only normal or usual weather is that in which we were born--all others are not quite right. And so it is with other things. But te Oakland estuary is only a tidal channel between Oakland and Alameda--hardly a real estuary at all. This has had perhaps a far-reaching and undesirable effect on people in the San Francisco Bay region--it has taken them a very long time to understand that the real estuary is the bay and river itself. They did not realize the bay itself was an estuary until almost too late.

My own studies of water, especially as it flows to the sea, were begun at a very early age, significantly enough on the shores of Whiskey Creek, near North Fork in Madera County. This stream flows into the south San Joaquin and thence passes Stockton, where I began my formal education in the old Lincoln School, but before then I was taken for walks along the ocean beach at San Francisco by an old maid aunt. So, very early I was introduced to the full range of aquatic environments from a mountain stream to the sea itself, and began school in the middle of it all, the Delta country of California. My real beginning on the seashore, however, was not on the ocean beach of San Francisco, but at Pebble Beach just below Pescadero. In a way I have known this place before I was born since my grandmother used to sit in the little cove for hours picking pebbles and my mother introduced me to the place and I have visited it many times since. I always stop and gather a few pebbles despite the signs asking us not to pick the pebbles. The sign used to read "Rock Hounds and Pebble Puppies, You can't take them with you" but that sign disappeared. It is probably in a Stanford frat house. Anyhow I feel that I have a hereditary right to a few pebbles from this beach. It is also where I first saw a living pycnogonid, but that is another story.

I was introduced to California water problems sooner than I realized, for among our family friends was a former governor, George C. Pardee. He was the chairman of the first commission to consider a general plan for California water, which led inevitably to the grandiose schemes now so prevalent there. For some reason or another that I do not now remember, he gave me some advice: "I like the cut of your jib, don't change it." I wonder if he ever suspected what such advice might do, and he certainly would have been astounded had he lived to see me as one of the principal witnesses in hearings against an important phase of the California Water Plan. Of course, he might not have approved of diverting the water past the Delta either, but as far as the reports of the committee go, he had no feelings whatever for water as part of a living system, of the aquatic environment itself. Water was simply something to be moved around to meet man's needs. At the time the governor gave me his unsolicited advice I was not completely confirmed in the error of my ways.

This, I must again remind you, took place on the shore of the Oakland Estuary, which is not a true estuary at all. It has been only in the last five or six years that we have heard the San Francisco Bay and delta system referred to generally as an estuary. All the plans and public discussions that were part of the development of the California Water Plan and indeed of the recent movement to save San Francisco Bay, never mentioned that this region was actually an estuary. Yet casual inspection of maps should have revealed to anyone that the original system included a delta region of channels and marshes of almost the same area as the open water surface of the bay itself. The concept that salt gets into river water by being pushed up from the ocean against the stream gradient was incomprehensible to the man who directs the California waterworks, Mr. William Gianelli. When confronted with data that bottom drogues actually moved into the bay from the ocean and far upstream, he thought it must be some kind of mistake. The whole working system of an estuary was incomprehensible to him, as it seems to be to many others who are tampering with this great natural system. Yet it was all clearly understood a generation before, when Grove Karl Gilbert published in 1917 the finest paper ever written about San Francisco Bay --a study that started out as an examination of the problem of hydraulic mining debris in the foothills and interior valleys of the mining country. But to understand this process it became necessary to work out the problems of tidal action and sedimentation in San Francisco Bay, the end reservoir of the millions of cubic yards of dirt washed down from the mines. This paper is still worth studying today as an ideal environmental impact report.

The keystone of California's water system is Shasta Dam. When this dam was started in the late 1930's it was assumed there were no fish left in the Sacramento River that were worth saving. But after they started the dam it was discovered that the salmon run was increasing, coming back from almost complete obliteration. Unfortunately we cannot document the reasons for this resurgence of the salmon runs. We can only speculate. It looks as if possibly the salmon had become adjusted to what was left of their original environment in the Sacramento-San Joaquin system and were on their way to recovery when man was about to strike the *coup de grace* with a new series of even bigger dams to cut off what was left of the streams. But as the runs began to increase while Shasta Dam was being built it was obvious that something would have to be done to save the runs as they were a greater resource than anticipated in the original planning. Such difficulties as this arise out of our capacity to do big things, like Shasta Dam, Grand Coulee, and Boulder--or Hoover--dam. In the long run all these big things we are doing may become a hazard to human life. All good engineers are sworn to do nothing that is hazardous to human life to obtain their license to practice, but it might also be a good idea if we tried to think less grandiosely. For a change we might think about how things could be done on a smaller scale instead of the largest possible scale.

It also seems difficult for people, especially from such a distance as Washington, D.C. to understand the problems of a semi-arid region with intermittent stream flows. When we failed to include Cottonwood Creek, south of Redding, in our suggestions for possible salvage streams to replace the lost reaches of the rivers above Shasta Dam, we had to demonstrate by photographs of the dry stream bed that an annual statement of large stream flow did not guarantee water during the period of the salmon run. Water problems have been the main theme of most western movies and novels; in how many such stories is there a scene about fishing, catching fish or a reference to fish? Diversion ditches without fish screens have long been part of the western scene.

Up to the time the big canal south from Tracy across the Tehachapi to Los Angeles was built, the biggest California ditch of all was the Owens Valley aqueduct and pipeline for the city of Los Angeles. This was not achieved without bitterness and rancor, and overt sabotage, as anyone familiar with the history of California can easily remember. It was because of this rape of the Owens valley that Mary Austin predicted that no good end would come to Los Angeles, that in time the earth would speak out against this violation. And so it has, perhaps not exactly as she might have anticipated. Parts of the Owens Valley have gone back to sagebrush and jackrabbits, but Mary Austin did not know how right she was about Los Angeles. It is a place for leaving, too large for its own ecological base and unlivable. By some outrageous quirk of fate, however, the regional office of the Los Angeles Water and Light Bureau is just across the street from Mary Austin's house in Independence. Of course my own family tradition conditioned me to the implicit understanding that what went on south of the Tehachapi was simply not part of California. I suppose somehow this idea came from my mother's harrowing story about the over-endowed friend who was burned to death in a train wreck on the Tehachapi because she got stuck in the train window trying to escape. Somehow I got the impression that the moral of this episode was that she deserved this unfortunate fate for having gone to Los Angeles.

There are various grandiose schemes that may be even bigger than the water system of dams and canals, in keeping with our tendency to think big, such as that to build an enormous plastic hose to lay along the bottom of the ocean to take the waters of the Klamath River from their mouth and carry them to Los Angeles. Ultimately, such a super king-sized plastic hose might go to the Columbia River. But at the rate people are leaving Los Angeles these days this may all become academic, like those Pentagon plans for the invasion of Canada or other unlikely places, since all possible contingencies must be thought of. I hope this is such an unrealistic contingency plan. And grandiose schemes do fall of their own weight, sometimes. However, one has to be careful about saying unkind things about private developments, however ill-advised their construction may be, as you can be sued. Nevertheless, although a condominium may be falling down before one's eyes, you are not supposed to say too much specific about it. Yet there are development interests who would like to see the Oregon coast built up like the Rio de la Plata or the Riviera, with solid rows of high buildings along the shore. I suppose their ultimate dream would be the submerged hose to Los Angeles and all the rest of the seascape obscured by high-rise buildings. Everybody would be spending lots of money to keep these things up, eating in expensive places and consuming energy beyond our means--and everybody would be happy, I suppose. And the ocean, the bays and the streams would be treated alike as the universal sink, just places to dump whatever we want to forget.

Even where our interests are scientific or esthetic, we endanger our seashores. Once a rich site for class trips like Moss Beach is now almost bare rock surface, with hardly any of its former diversity of life remaining. This is the result of countless visits by hordes of students. The same sort of thing is happening to Oregon beaches, especially the area on the south side of Yaquina Head. It is possible for most of us to realize that rivers and bays may be endangered by developments that fail to heed the rights of water as part of a natural system, but the seashore itself is just as vulnerable. The value of seashore property may be due in part to the idea that seashores are invulnerable, that the tide will always come in and clean away all the stuff that accumulates on them during the day. But this may not be true. The system involving the waves and currents near the shore is in some ways separate from the great oceanic system, and mixing goes on slowly. Concentrations may be built up along the shore that will in time be as offensive as those on a neglected estuary mud flat. And nature lovers are no less responsible than crass industrialists. It is amusing, in a morbid sort of way, to hear objections from a bird-loving society that a certain seaside development will endanger the birds while at the same time they would build a bird watching convention and teaching center that might well frighten away more birds than a motel.

As an approach to recognizing when our environmental assaults may reach a critical stage, it has been proposed that we adopt a concept from theoretical ecology about the ratio of kinds of organisms to their total numbers. The idea is that the more kinds there are the better off the system is, that is, its diversity is a sign of health or stability of some such. Hence all we have to do is sample it and estimate how diverse it may be after identifying the kinds of animals and plants we find there. We can compute an index for this, and if the index tells us things are approaching a more monotonous condition of only a few kinds of animals, then we are damaging the environment and should change our ways. It does sound straight-forward and simple except that the number derived should not be accepted as more than a general indication because of the difficulty of being sure about the kinds of plants and animals that go into the calculation of this index. We are not certain that our theory is applicable in all cases, but the principal proponent of this sort of thing is an engineer characterized by one of my colleagues as a man "who is often wrong but never in doubt." The danger in this sort of thing is that it sounds simple and practical and might be adopted as a standard by public bodies. But because the basic data may be very variable, a slight change in numbers might produce a value below the required standard and result in curtailment, or, conversely, a favorable index might justify an ill-advised increase in activity.

One is tempted to ask, since we already know that what we are doing is bad for our environment, why not stop it? That is too simple, also. But we can ask, what--or who --are we trying to save our environment for? For the small boy who can play explorer in a neglected bit of marshland, chasing butterflies with his net, or rank upon rank of condominiums full of people with no place to go? Must we build up everything, pipe all the water elsewhere and close the beaches until even a well-known religious leader would know he is not welcome, as the little sign of Casparilla Beach, Florida, suggests: "Please don't walk on the water."? I would hope such thoughts as these would occur to engineers as often as they do to common people, for if we forget to respect our waters as the essence of our living system, our end may be nearer than we think.

Fluid Dynamic Flow Around Pipelines

Tokuo Yamamoto, Research Associate
Department of Civil Engineering
John H. Nath, Professor
Mechanical Engineering and Oceanography
Oregon State University, Corvallis

The subject of the dynamics of fluid flow around cylinders seems to be constantly in question. The reasons are twofold: 1) quantitative knowledge on the subject is necessary for the rational design of ocean and nearshore structures using cylindrical supports, for the design of pipes and cables submerged in different flow conditions and other applications; 2) the subject has been difficult to understand thoroughly because of the complicated flow regimes which depend on the ambient velocity distribution, turbulence, nearby boundary conditions, cylinder shape, direction and time variation of the flow, presence of a free surface, and the motion response of the cylinder itself. The somewhat random phenomenon of vortex shedding adds further difficulty. (Probably other aspects have been omitted from the foregoing list.) Hopefully this paper will add to the fund of usable information that is growing on this subject.

Only rigid cylinders subjected to flow which is perpendicular to the central axis were considered in this study. In addition, the cylinders were circular, horizontal at a varying distance from a horizontal plane boundary and at a relatively large distance from the free water surface as shown in the inset of Fig. 2. Experimentally the cylinders were subjected to waves and the total horizontal and vertical forces were measured. Theoretically, steady flow was considered as well as the unsteady flow characterized by surface waves. The purpose of this paper is to review the theoretical considerations, particularly the influence of the nearby plane boundary on vertical and horizontal forces, and to show the comparisons of the theory with experimental results.

The theory is based on a common assumption that the total force can be considered as the sum of components due to water particle acceleration and water particle velocity. Basic flows for uniform ambient conditions, both steady and unsteady, are first considered and later combined to

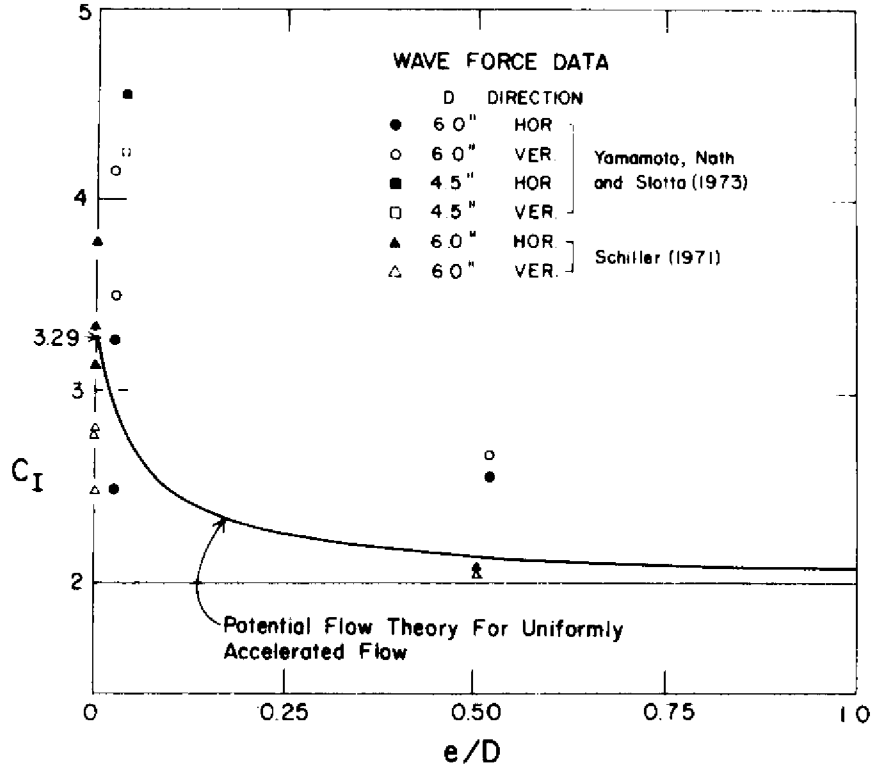

FIGURE 1. Inertia Coefficient

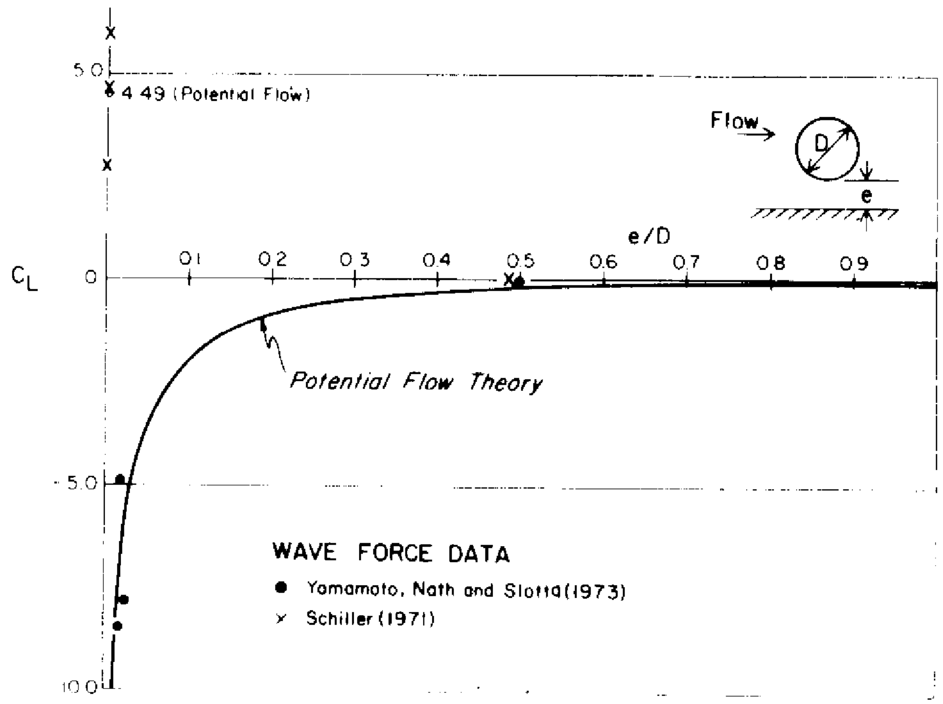

FIGURE 2. Lift Coefficient

approximate the actual condition of water wave forces on horizontal cylinders.

THEORETICAL CONSIDERATIONS

It is assumed that both the vertical and horizontal forces are acceleration and velocity dependent. It is recognized that certain drag and lift forces are dependent on the square of the velocity and if such forces act at some angle other than 0° or 90° with the horizontal plane, that there is an interaction between the horizontal and vertical components. However the experimentation was in a regime of flow where such action was negligible.

Forces Dependent on Particle Acceleration

As the fluid accelerates around a rigid cylinder, a pressure distribution is created, the area integration of which is usually characterized by an equivalent added mass multiplied by the acceleration the water particles would have at the center of the cylinder if the cylinder were not present. The ambient flow regime, and thus the fluid acceleration, is influenced by a nearby boundary. In addition, the acceleration should be taken as the total, or substantive derivative of the velocity. Often the convective acceleration is neglected and it is shown here that it can have a significant value.

Bottom boundary effects on added mass. One classical theoretical approach for a cylinder in an infinite acceleratory fluid is to locate a doublet at the center of the cylinder (2). Integration of the resulting pressure distribution on the cylinder is found to be equivalent to the mass of the displaced fluid, times the acceleration, times a coefficient, which is 1.0 for a circular cylinder. In addition there exists a pressure field which accelerates the fluid. The additional pressure on the cylinder is equivalent to the mass of the displaced fluid times the acceleration. The sum of the added mass coefficient, C_M, and 1.0 (the coefficient for the pressure field) is hereby termed the inertia coefficient as follows,

$$C_I = 1.0 + C_M. \tag{1}$$

However, the proximity of a plane boundary will modify the added mass coefficient (8). Considerations were given for flows accelerating both perpendicular and parallel to a plane boundary. It was determined that the value of C_M depended on the distance of the cylinder from the boundary, but was the same for a circular cylinder whether the flow was parallel or perpendicular to the boundary. (Interestingly, it was noted that a sphere accelerated normal to a wall has a larger added mass than when accelerated parallel to the wall [2,3]).

Applying the method of images, the motion against the wall may be approximated with the two doublets moving against each other with the axes in the direction of motion. When the two doublets approach each other they no longer represent circular cylinders, because of mutual influence. In order to eliminate the influence a distribution of an infinite series of doublets of converging strengths along the cylinder radius is required. Therefore a circular cylinder moving perpendicular to a wall can be expressed as an infinite series of doublets, properly distributed. The complex potential is written as,

$$W = -i\sum_{j=0}^{\infty} m_j\left(\frac{1}{z-i(s-aq_j)} - \frac{1}{z+i(s-aq_j)}\right) \tag{2}$$

where $m_n = Ua^2q_1^2q_2^2q_3^2\ldots q_n^2, \quad m_0 = Ua^2$ (3)

and $q_n = \dfrac{1}{\frac{2s}{a} - q_{n-1}}, \quad q_0 = 0$ (4)

and where a is the cylinder radius, s is the distance between the center of the cylinder and the wall, and U is the velocity of the cylinder. In addition, $z = x + iy$, where x is the distance along the wall from the point of symmetry and y is the distance from the wall, and $W = \phi + i\psi$, where ϕ is the velocity potential and ψ is the stream function. The added mass coefficient is then obtained with

$$C_M = \frac{1}{\pi a\dot{U}}\int_0^{2\pi} \frac{\partial\phi}{\partial t}\cos\theta \, d\theta \tag{5}$$

where $\dot{U}$ is the acceleration of the cylinder, $\partial\phi/\partial t$ is evaluated at the cylinder surface, and t is time.

Numerical computations, using the first 40 terms, were made of Equations 2 and 5 and the inertia coefficient ($C_I = 1.0 + C_M$) was plotted as a function of e/D, the ratio of the gap between the cylinder and the wall to the cylinder diameter as shown in Fig. 1.

Effects from convective acceleration. The foregoing was for an ambient fluid velocity which is not a function of space. Often the convective acceleration (when the ambient fluid velocity *is* a function of space) is neglected for computing wave forces on cylinders. This section will show that the convective term can be significant for horizontal cylinders for some conditions.

Now let u and v be the velocities in the x and y directions respectively in two-dimensional flow. Consider motions in the positive x direction for the case where the convective acceleration term varies linearly so that an inertia coefficient, C_A, can be defined from,

$$F = \rho\pi a^2 C_A \left(u\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y}\right) \tag{6}$$

Such a flow is approximated by the near stagnation flow close to the nose of a blunt body where the diameter of the cylinder is much smaller than the characteristic dimension of the blunt body (8). In the citation the force on the cylinder was expressed analytically with potential flow theory. The expression is very lengthy and is not reproduced here. The inertia coefficient, C_A, was found to be constant with distance from the boundary, in contrast to C_I. Therefore, in general the force on a cylinder from the total acceleration should be written as,

$$f(t) = \rho\pi a^2 [C_I \dot{u} + C_A (u\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y})] \tag{7}$$

where $\dot{u}$ is $\partial u/\partial t$. In this paper forces varying with time are designated by f(t) and steady-state forces and the amplitudes of time dependent forces are designated by F.

Equation 7 was used to determine the acceleration force on a cylinder with $e/D > 2.0$ and with a wave height to water depth ratio of 0.6, using solitary wave theory, and it was found that the convective term was 30 percent of the total force.

Forces Dependent on Water Particle Velocity

The orbits of the water particles in waves are eliptical. Thus velocity dependent on drag forces from waves rotate around a horizontal circular cylinder and can be portrayed with a Lissajous figure (4). In addition, lift forces will exist from circulation and vortex shedding and a rather confused flow state will exist as the wake is swept around the cylinder. The following development attempts to approximate the horizontal and vertical forces for velocity dependent forces.

Lift forces from circulation. The proximity of a solid bottom boundary causes a flow asymmetry which then induces a circulation around the body. Besides the circulation due to the potential flow outside the boundary layer, the vortex in the wake behind the body also creates a circulation. Therefore the lift force F_L due to a uniform steady, U, flow may be given by the Kutta-Joukowski theorem as,

$$F_L = \rho(\Gamma_{pot} + \Gamma_{vor})U \tag{8}$$

where ρ is the density of fluid, Γ is the circulation around the body and the suffices pot and vor denote the potential flow and vortex influence. Because in this paper only two-dimensional flows are considered, all forces considered have units of force per length. It has been reported that the actual circulation around the body due to a vortex was one order of magnitude smaller than the circulation of the vortex formed in the wake (1). The mechanism of vortex formation is not completely known. Therefore the experimental determination of Γ_{vor} is left for future efforts. This paper will consider only the effect of the bottom plane boundary on the lift force.

For potential flow, no net drag force exists on the cylinder parallel to the bottom boundary for a uniform flow, U. However, the near proximity of the plane boundary induces a force on the cylinder which acts perpendicularly to the ambient flow direction.

When the cylinder touches the boundary a net force exists away from the wall (3). However, if even a very small gap exists between the cylinder and the wall then a large net force exists toward the wall. The solution is obtained by imposing a distribution of doublets on the cylinder radius between the center and the edge below (5,8). The results are:

$$F_L = 4\pi\rho \sum_{j=0}^{\infty} \sum_{k=0}^{\infty} \frac{m_j m_k}{[2s - a(q_j + q_k)]^3}, \quad k \neq j, \quad e > 0 \tag{9}$$

At the wall (e=o), the lift force per unit length of cylinder is given in closed form (5) as $F_L = \rho a U^2 \pi(\pi^2+3)/9$. Usually the lift coefficient, C_L, is defined from $F_L = C_L \rho a U^2$. Based on Equation 9, C_L was calculated as a function of e/D and plotted in Fig. 2.

Drag forces from oscillating flow. No general exact theory has been developed to predict the velocity dependent drag forces in unsteady flow. However, as a first approximation, consider the boundary layer developed near the surface of a cylinder oscillating perpendicular to its axis for laminar flow. For this case the frictional drag on the cylinder may be obtained in closed form. The velocity profile for the above problem has been established (7) and based on the solution, the total frictional drag on the oscillating cylinder can be obtained (8).

For a cylinder moving in a direction perpendicular to its axis with a velocity $u = U \cos \omega t$, the total frictional drag can be obtained as,

$$f(t) = 2\pi a U \rho \sqrt{\nu\omega} \cos(\omega t + \pi/4) \quad (10)$$

where ν is the kinematic viscosity of the fluid and ω is the angular frequency. Thus, the total drag on an oscillating cylinder is 45° out of phase with respect to the cylinder velocity; the same as the case for the oscillating flat plate. It is likely that a similar phase shift exists for turbulent flow. This suggests that past techniques for evaluating inertia coefficients from wave force data, where the drag force is assumed to be zero because the wave particle velocities are zero, can be in serious error.

Wave Forces for Particular Cases of Negligible Drag and Convective Acceleration

The forces from waves on a submerged cylinder can be considered as the sum of the acceleration force, the lift force and the drag force. As discussed in a previous section the drag force is very complicated in nature and cannot easily be analyzed theoretically. However, there are cases where the drag force and the convective acceleration force are negligible with respect to the other forces. Thus, the situation considered in this section will be the one where the vertical force is due to lift from circulation and the temporal acceleration from the waves and the horizontal force will be due only to wave temporal acceleration. This is done because the data gathered do fall into this category (8).

In the experimental work for this study the wave forms were fairly close to sinusoidal. Therefore, as the usual first approximation, the Airy wave theory was utilized in the theory. It was also assumed that the cylinder did not affect the wave shape. For future reference let the amplitudes of the horizontal particle velocity, the horizontal temporal acceleration and the vertical temporal acceleration be defined at the center of the cylinder and be expressed as U, $\dot{U}$, and $\dot{V}$, respectively.

It can be shown from theoretical considerations that the Morison equation will be adequate to estimate the temporal acceleration forces provided that the inertia coefficients are properly selected and that the submergence is greater than one cylinder diameter and the cylinder diameter is less than about one-third of the wave length (8). The present experimental condition and the usual structures in the ocean, such as pipelines and cables, are usually well within the above conditions.

Given the water surface at the cylinder is $\eta = H/2 \cos \omega t$, where H is wave height, then,

$$f_H(t) = \rho \pi a^2 C_I \dot{U} \sin \omega t \quad (11)$$

where the horizontal force f_H, is shown qualitatively in Fig. 3. Note that the maximum horizontal force occurs at a zero-crossing (phases 2 and 4 in Fig. 3).

The vertical force $f_V(t)$, is the sum of the acceleration force, $f_{VA}(t)$, and the lift force, $f_L(t)$, as

$$f_V(t) = \rho \pi a^2 C_I \dot{V} \cos \omega t + \rho a C_L U^2 \cos^2 \omega t \quad (12)$$

where f_{VA} and f_L are also shown qualitatively for a negative value of C_L in Fig. 3. It has also been assumed that no phase lag exists between the horizontal velocity and vertical lift force, although it is entirely possible. Note that f_L occurs at a double frequency of the wave and has only a negative direction, assuming there is some gap between the cylinder and the bottom boundary. The force f_V is shown in Fig. 3 for the special case where the amplitudes of the two components are equal.

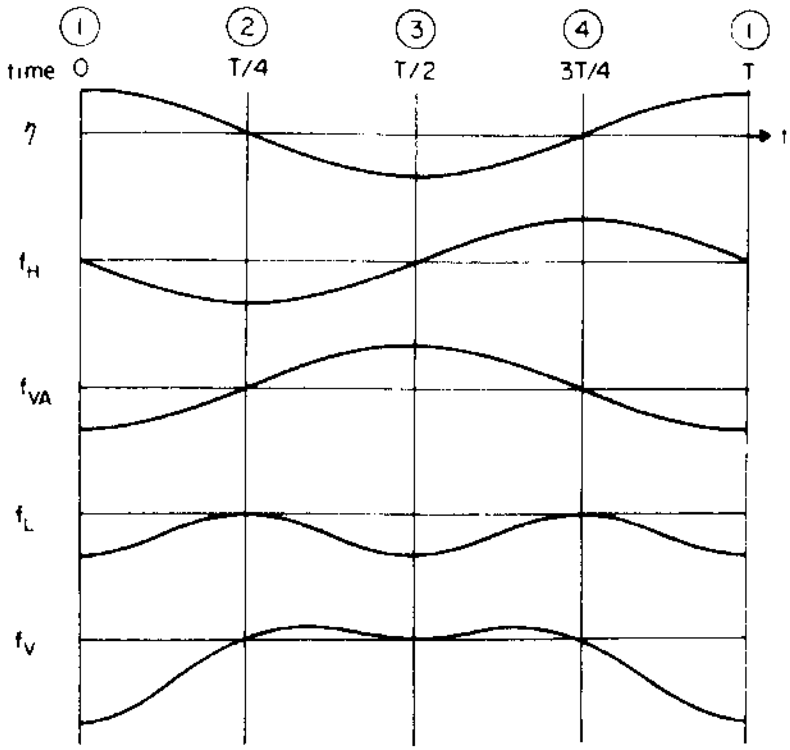

FIGURE 3. Theoretical Wave Forces

For the case shown, both the acceleration force component and the lift component are maximum in absolute value and both are in the negative direction (or downward) at the wave crests. For future reference, let the amplitudes of the fluctuating forces be expressed by the corresponding upper-case letters.

At the wave troughs, the vertical acceleration force component is maximum and upward but the lift force is maximum and downward. Therefore, the two components tend to cancel each other and the total vertical force is small at the wave troughs. If there is no gap between the cylinder and the bottom boundary, the left force is always positive and upward. For this case, the total vertical force is maximum and upward at the wave crests, but small at the wave trough. Therefore, the two components may be separated by either one of the following two techniques:

Technique 1: If the vertical forces are measured when the wave crest and the wave trough pass over the cylinder, the vertical acceleration component can be separated from the lift force by taking the difference between one-half the sum and the measured wave forces.

Technique 2: If only the maximum vertical force is measured, the separation of the two components is still possible., The lift force is zero for zero U^-, whereas the acceleration force is linearly dependent on wave amplitude. Therefore, only the acceleration component is important for very small waves. If the total vertical force is plotted versus the vertical acceleration, the plot should have a single straight line portion through the origin near the origin. Assuming the straight line portion (or actually the tangent at the origin) to be the vertical acceleration component, the lift force component can be separated from the vertical acceleration component.

EXPERIMENTATION AND RESULTS

Experiments were made at Oregon State University in a wave basin 28 feet long, 18 feet wide and 2 feet deep. Two cylinders with different diameters, namely 6 and 4 1/2 inches, were used. The gap between the cylinder and the bed varied from 1/8 inch to 3 1/8 inches. Two water depths, 14 1/8 and 10 inches, were used. The test cylinder consisted of a three-foot test section and a one-foot dummy section, each end located about midway between the wave generator and the beach, with the axis parallel to the wave generator paddle. A series of waves with various wave lengths (about 2 to 8 feet) and with various wave heights (about 1 to 4 inches) were generated.

A strain gauge force dynamometer was used for wave force measurements. A pair of resistance-type wave meters were used to measure the waves. Continuous simultaneous records of the strain gauge outputs and wave meter outputs were made. Wave forces under the third or fourth wave were used for analysis. A sample of the recorded results is given as Fig. 4.

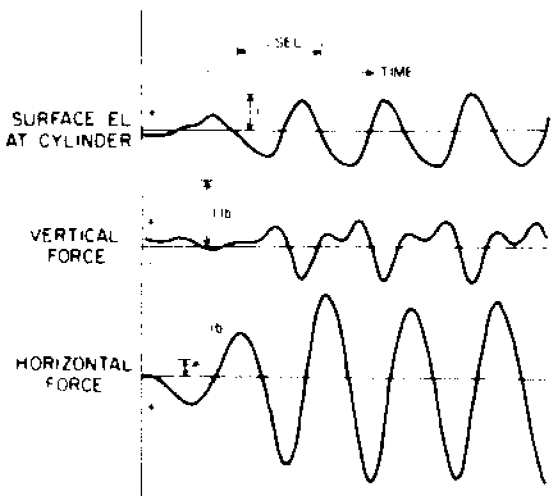

FIGURE 4. Sample Record

In order to check out the proposed method for analysis of wave force data and to gain some more information, experimental data found in the literature were also analyzed with the proposed method. Laboratory measurements of wave forces on a horizontal cylinder (6 inches in diameter and 14 7/8 inches long) with no gap as well as with a gap of 3 inches were used [6]). Wave data (height, period, and length) and force data (maximum horizontal force and maximum vertical force) were given for the following four combinations of diameter-gap-water depth in inches: 6-0-12, 6-0-15, 6-0-18, and 6-3-18. For the first three combinations, a barrier was placed between the cylinder and the bed so that no flow was allowed beneath the cylinder.

Wave and Force Records

Figure 4 shows the experimental results D = 6 inches, e = 1/8 inch, and h = 10 inches. The wave is approximately sinusoidal in shape at the cylinder, which was a typical result. The peaks of the horizontal forces are about at zero-crossings; i.e., the horizontal force is about 90° out of phase to the surface wave. This characteristic agrees very well with the theoretical curve of horizontal acceleration force in Fig. 3. Thus, it might be said that under the experimental conditions illustrated the drag force is very small or negligible and the horizontal force is essentially from the wave temporal acceleration.

For a larger e/D, the vertical force was sinusoidal. An important phenomenon is the difference in the vertical forces between Fig. 4 and the sinusoidal response. For e = 3 1/8 inches the vertical force is very smooth and sinusoidal; the upward peak occurred at the trough, and the downward peak at the crest, i.e., the force was 180° out of phase to the surface wave. This agrees with the theoretical vertical acceleration force in Fig. 3. For e = 1/8 inch, the vertical force variation is no longer sinusoidal as seen from Fig. 4. Very large downward forces occur at the crests, whereas some downward component is superimposed on the essentially upward peak at the trough. This characteristic is very similar to the theoretical vertical force curve in Fig. 3.

From the above observations, it may be said that the drag forces are negligible and the lift force becomes important when the gap between the cylinder and the bottom boundary is small.

Forces from Particle Acceleration

The experimental data for this study were processed in the following manner. For a given set of recorder readouts, the wave data were processed to obtain the wave period, T, the wave length, L, and the wave height, H. The horizontal force at the zero-crossing was taken as the magnitude of the horizontal force, F_H, which practically was the maximum force. The vertical forces were read both at the wave crest and at the wave trough; then the magnitude of the vertical acceleration force, F_{VA}, and the magnitude of the lift force, F_L were separated by Technique 1.

A plot of the results for the vertical acceleration force is shown as Fig. 5. The inertia coefficient, C_I, can be derived from the slope of the line, which was fitted by eye. Plots similar to Fig. 5 were constructed for the other test conditions and the results are plotted

Lift Forces from Particle Velocity

The total vertical forces were separated into the vertical acceleration forces, F_{VA}, and the lift forces, F_L, as mentioned before.

The plots of F_L versus U^2 are shown in Fig. 7. Although there is some scattering, the plots come out approximately as a straight line through the origin. In other words, the lift force is proportional to the square of the horizontal velocity and almost independent of the wave length. The lift coefficient, C_L, can be evaluated from the slope of the straight line. The coefficient C_L, thus obtained, is -7.83 for the case illustrated and was plotted on Fig. 2. Other cases for the OSU data and the data from (6) are also plotted on Fig. 2.

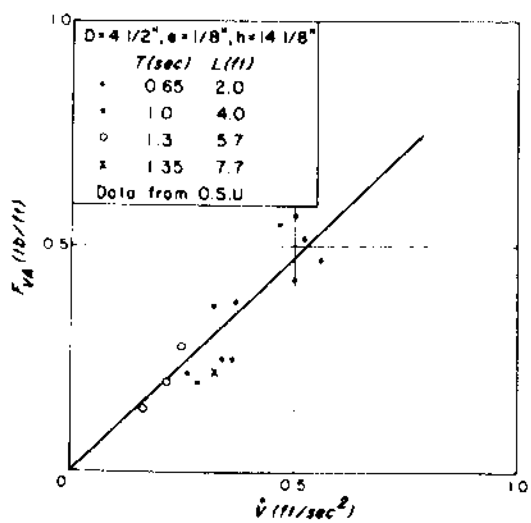

FIGURE 5. Vertical Acceleration Force

CONCLUSIONS

Acceleration and velocity dependent forces can be considered separately, and then superimposed for determining wave forces on horizontal cylinders with good results for engineering purposes, provided the proper coefficient values are used. The coefficients can be properly evaluated from potential flow theory if the drag forces and vortex forces are negligible with respect to the added mass effects and the circulation lift forces.

Experimental results with waves agree fairly well with the theory that the horizontal and vertical acceleration forces are equal for a cylinder close to a plane boundary.

The convective acceleration should not be neglected in some cases when determining the horizontal force due to fluid acceleration. For one case investigated it was equal to 30 percent of the total acting horizontal acceleration force.

Lift forces on horizontal cylinders from circulation can be accurately estimated for waves. For uniform steady flow it was shown that the lift force on a cylinder touching the bottom boundary is large and directed away from the boundary. However, if a small gap exists between the cylinder and the boundary, such as from lifting the cylinder from the boundary, then a large force is exerted on the cylinder toward the boundary. This suggests a possible failure mechanism of alternating positive and negative lift forces for cylinders resting on the bottom boundary.

A phase shift probably exists between maximum velocity and maximum drag force for cylinders subjected to waves. It was shown that the phase shift is 45° for laminar flow and is unknown for turbulent flow. This shows that some past evaluations of the inertia coefficient or the added mass coefficient, where the drag force was assumed to be zero when the ambient velocity was zero, could be in serious error.

ACKNOWLEDGEMENT

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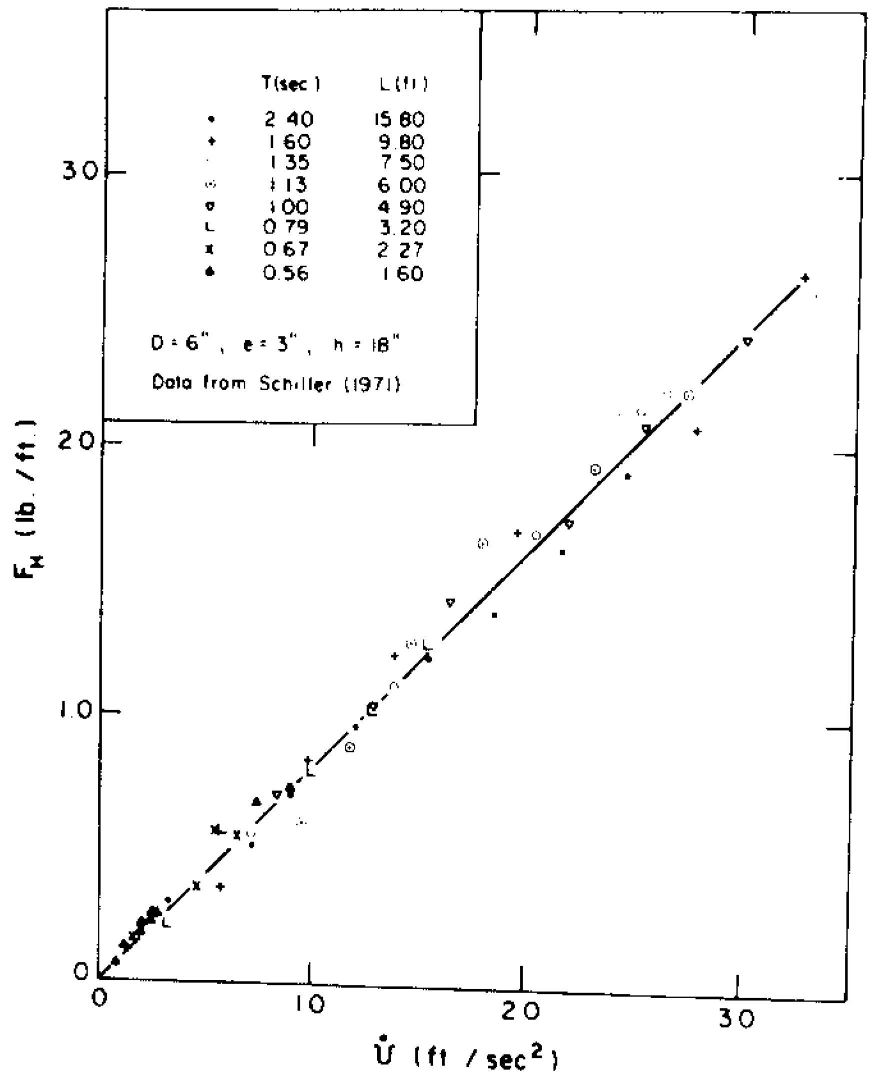

FIGURE 6. Horizontal Acceleration Force

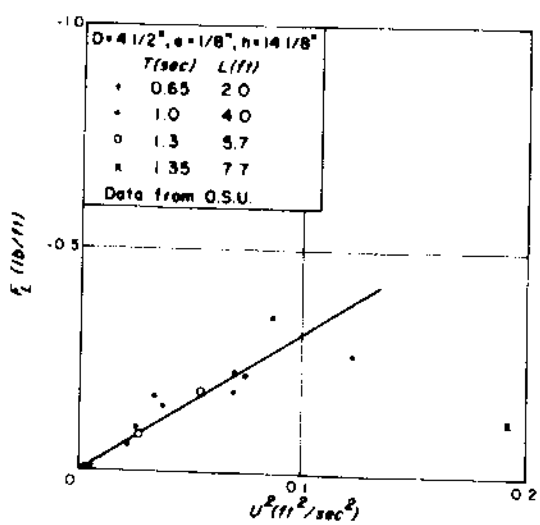

FIGURE 7. Vertical Lift Force

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Evaluation of Flotables of Wastewater Origin in the Vicinity of Marine Outfalls

Robert E. Selleck, Professor
Division of Hydraulics & Sanitary Engineering
University of California, Berkeley

The major objectives of this study were to measure and evaluate the flotables of wastewater origin found on the surface of coastal waters within the vicinity of marine wastewater outfalls, and to determine the net transport of such materials shoreward during periods of calm weather. This study remains in progress and the discussion presented herein describes the work accomplished in the first year of the study on the first major objective only; i.e., the measurement and evaluation of flotables of wastewater origin in coastal waters.

To achieve this objective it was necessary first to develop methods of sampling flotage quantitatively on the ocean surface as well as in wastewater effluents and, if possible, to develop methods of analysis which would indicate the fractions of the flotage derived from wastewater discharges.

SAMPLING METHODS

The flotage may be either in the form of particulates or molecules present at the water-air interface. The latter group are termed "film substances" herein. The sampling methods devised to collect the flotage on the ocean surface captured particulates either greater or smaller than 0.5 mm in size; consequently, particulates greater than 0.5 mm are arbitrarily termed herein "macro-particulates" and those smaller than 0.5 mm "micro-particulates."

It was decided early in the course of the study that the sampling methods should be as quantitative as possible. The macro-particulates could be sampled relatively easily by straining the surface water through a net connected to a surface trawl once a trawl had been designed to sweep a water layer of reasonably constant depth in calm water. The trawl finally utilized sieved a layer approximately 3 cm deep through a 500 u nylon screen when towed at speeds of 1.5 knots or less. Care had to be taken in the trawling operations to avoid clogging the screen because a clogged screen would not permit the free passage of water.

It is not easy to sample film substances and micro-particulates quantitatively. After considerable consideration of the methods employed by other investigators it was decided to employ flexible screens which could collect a very thin surface layer of water from a reasonably well-defined surface area by capillary action. Aside from flexibility, the material from which the screen was constructed had to have the following properties: insignificant background concentrations of the substances being measured; the ability to adsorb tightly the flotage because inevitably some of the water contained in a screen was lost when the screen was inserted into a sample container; and simplicity and cheapness because only limited areas (~0.1 sq m) could be sampled quantitatively by such means, requiring a relatively large number of samples to be taken in any ocean survey. A number of metal, paper and cloth materials were tested and it was found that glass cloth possessed the best overall properties. Ordinary nylon cloth also demonstrated good sampling properties but the nylons tested contained surprisingly large amounts of hexane extractables which could not be extracted reliably; consequently, nylon was deemed inadequate for surface sampling of hexane extractables.

Laboratory tests showed that the glass cloth screens collected a surface layer of salt water about 0.1 mm deep under quiescent conditions. The surface area sampled in most of the work at sea was 0.10 m square.

To ascertain fully the origins of the flotage collected on the ocean surface it was necessary to examine the characteristics of the flotage existing in the wastewater being discharged to the region under study. This was done approximately by separating all flotage from the bulk liquid by agitation in a funnel but significant improvements in the procedure could have been made by bringing the film substances and micro-particulates to the surface of appropriate samples with agitation and then screening from the surface in a manner equivalent to the ocean work. Macro-particulates, on the other hand, could have been best collected by sieving a portion of the effluent stream. Obviously, much work remains to ascertain the extent of agitation required, the effect of dilution with salt water on the flotage being collected, and the best means of collecting a bulk liquid sample from a wastewater stream.

OCEAN SURVEYS OF 1971

Two separate ocean surveys were conducted in the spring and late summer of 1971 to determine the presence and significance of surface flotage derived from the large marine wastewater outfalls located in the vicinity of the City of Los Angeles, California. A control area was selected at the northern end of Santa Catalina Island as shown in Figure 1.

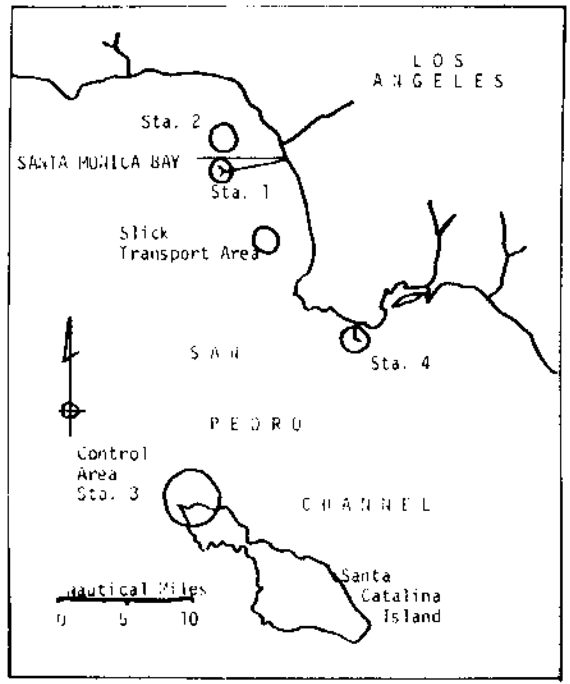

Figure 1. Location of study area.

Trawl and screen samples were collected primarily in the region of the 300 mgd Hyperion wastewater marine outfall (Stations 1 and 2) and the control area (Station 3). The Hyperion discharge was an unchlorinated partial secondary effluent with the characteristics shown in Table 1.

As noted previously, the dry weights and weights of hexane extractables shown above were determined on all flotage collected in a funnel. Thus they could not be separated into the macro-particulate and film forming substances categories. It is believed that much of the hexane extractables was derived from a very few macro-particulates, however.

The hyperion effluent was released from a Y-shaped diffuser having an overall length

TABLE 1

ANALYSIS OF 24-HR COMPOSITE SAMPLES OF HYPERION EFFLUENT[a]

Measure	April 6-7 1971	Aug. 30-31 1971
Measured by Hyperion Staff		
Grease and Oil	12 mg/l	9 mg/l
Suspended Solids	64 mg/l	81 mg/l
Volume of Suspended Solids	50 mg/l	76 mg/l
Coliform Organisms[b]		
AM	260,000/ml	430,000/ml
PM	186,000/ml	930,000/ml
Measured by this Project Staff		
Bulk Hexane Extractables	10.7 mg/l	8.2 mg/l
Dry Weight of Flotables	4.8 mg/l	3.1 mg/l
Hexane Extractables in Flotables	0.15 mg/l	0.30 mg/l

[a]Mean plant flow in 1970 was 330 mgd.

[b]Determined from grab samples.

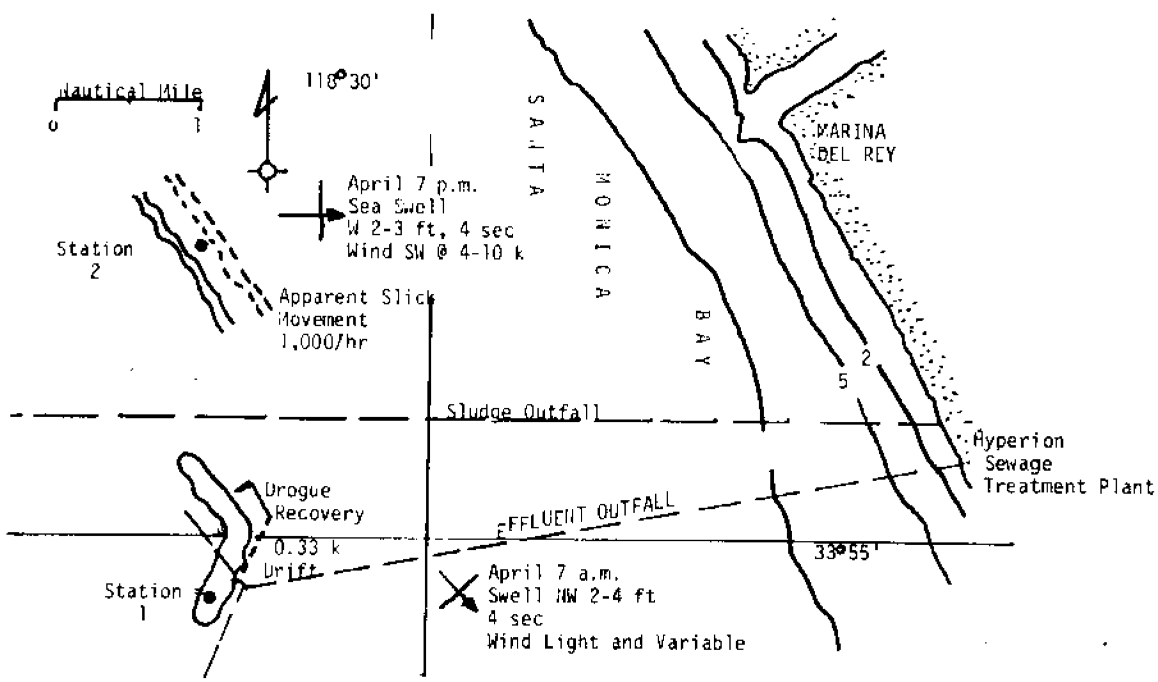

Figure 2.

of 8000 feet and a depth of approximately 200 feet. *During the times of the ocean surveys the effluent plumes were always submerged beneath well-defined ocean thermoclines*, but a sea slick outlining the outfall diffuser was observed in the spring survey as shown in Figure 2. This type of slick was not observed in the summer survey.

STUDY RESULTS

Macro-Particulates: Three to four surface trawls were made at Stations 1, 2, and 3 in each survey. The length of each trawl varied from 25 to 620 m depending on the amount of material collected on the sieve. The total number of particulates captured varied from 5.4/100 sq m at the control to a maximum of 1790/100 sq m in one trawl made in the slick area observed at Station 1 in the spring survey. (One hundred sq m of surface area trawled was equivalent to a volume of approximately three cu m of sea water sieved. Thus, 100 particulates/100 sq m would be equal to 33 particulates/cu m.) Average values for all trawls and surveys are shown in Table 2.

TABLE 2

MACRO-PARTICULATES: No./100 sq m

	Average	Range
Station 1	430	37-1790
Station 2	88	30-163
Control	23	5.4-96

Inspection of the particulates captured soon showed that many were derived from sources other than wastewater discharge (pieces of kelp, tar, insects, etc.), but others could have been of wastewater origin (seeds, plastic, rubber, bits of grease and wax, fibers, etc.) and the latter were classed somewhat arbitrarily as "sewage types."

The kelp and other sea weeds were captured in large quantities in some trawls and not at all in others. They tended to contain adhering pieces of grease and other particulates if such particulates occurred in the area; consequently, they tended to bias the data somewhat. The average concentrations of particulates found in various categories are shown in Table 3.

Measurement of the length of particulates captured in the summer survey with the 500 u screen trawl showed that the grease and wax particulates, the most predominant kind of "sewage type" particulate, had lengths ranging from 0.5 to 10 mm with an average of 1.3 mm. The pastic pieces ranged generally from 2 to 5 mm in length with pieces as long as 50 mm being captured occasionally. The seeds were 2 to 3 mm in length. The kelp pieces varied widely in length, as might be expected, ranging from 1 to 150 mm with a median value of approximately 5 mm. (It should be recalled that particulates smaller than 0.5 mm were not captured with the surface trawl.)

Other analyses conducted on the macro-particulates included dry weight, weight of hexane extractables, and coliform organisms. Making allowance for the larger pieces of sea weed which would influence the dry weight of flotage collected unduly, the average dry weights, weights of hexane extractables and concentrations of coliform organisms observed during the surveys are presented in Table 4.

The above shows that the mg of hexane extractables per 100 sq m decreased rapidly with distance from the Hyperion outfall diffuser. The hexane extractables were related closely with the number of grease and wax particulates captured in each trawl as shown in Figure 3.

Figure 3 indicates that the mg of hexane extractables found per unit of surface area had nearly a 1 to 1 correspondence with the number of grease and wax particulates found per unit area. Because the grease and wax particulates had an average size of 1.3 mm

TABLE 3

MACRO-PARTICULATES: No./100 sq m

	"Sewage Types"		Pieces of	Other
	Plastic	Total	Sea Weed	(Insects, Tar, Charcoal, etc.)
Station 1	5	384	11	35
Station 2	0.7	63	11	14
Control	0.2	2	10	11

TABLE 4

MACRO-PARTICULATES

	Dry Wt. mg/100 sq m	Wt. of Hex. Extract. mg/100 sq m	Coliform Bact. No./sq m
Station 1	1090	560	6,500
Station 2	1160	24	3,400
Control	210	2*	nil

*Exclusive of one large piece of tar 35 mm long.

their volumes might have averaged 1 x 10^{-3} cc or approximately one mg in weight; consequently, it would appear that a large fraction of the grease and wax particulates were directly soluble in hexane.

Bulk water coliform bacteria samples were collected 10 cm beneath the ocean surface at all the stations. No coliform bacteria were found in any of those samples, indicating counts of less than one organism or so per 100 ml. Large numbers were found in the macro-particulates collected on the surface, however, as shown in the above table.

The average values for coliform bacteria listed in the table are geometric means which equal approximately the 50 percent value. Because one sq m of surface trawled was equivalent to approximately 30 liters of water strained, the values may be divided by 300 to obtain counts per 100 ml. Thus, the 50 percent values were approximately 22/100 ml at Station 1, 11/100 ml

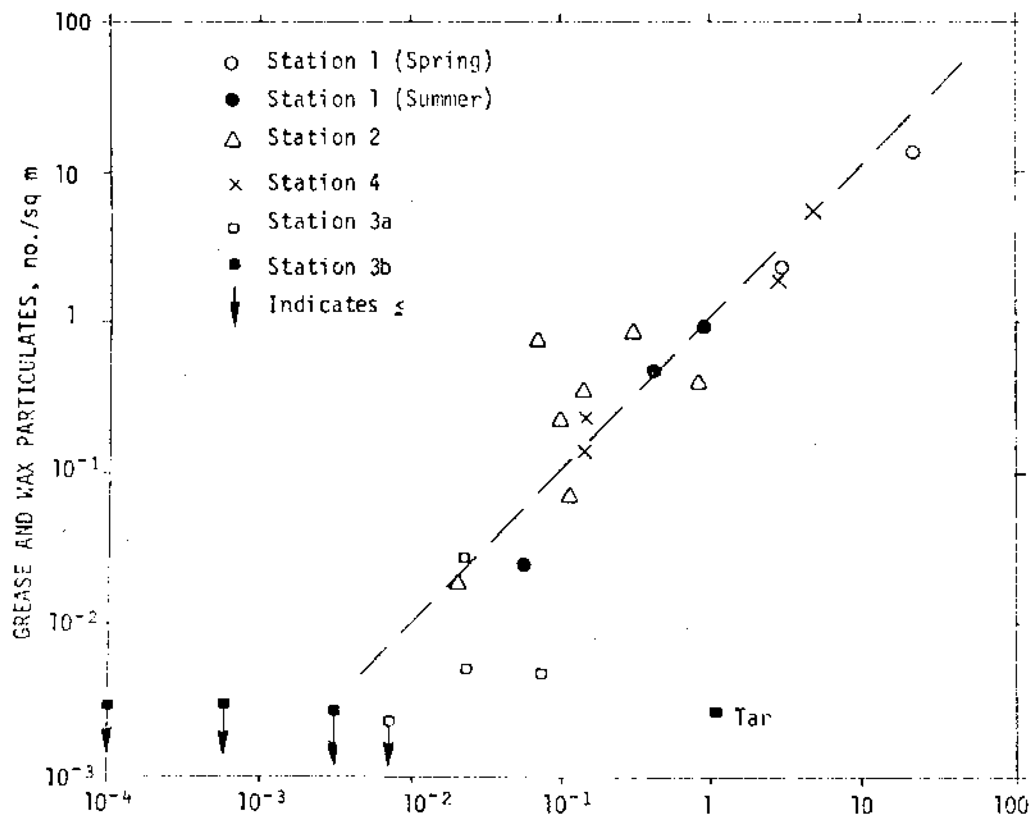

Figure 3. Macro-particulates (Trawl Samples) Spring-Summer, 1971.

at Station 2, and very small at Station 3 (<1/116 cu m). Generally a total of about five separate coliform bacteria trawls were made at each station, with maximum counts of 500/100 ml and 60/100 ml being observed at Stations 1 and 2, respectively.

The presence of coliform bacteria in the macro-particulates proved that some of the flotage must have been of wastewater origin. The grease and wax particulates correlated reasonably well with other "sewage types" of particulates as shown in Figure 4, and the grease and wax particulates corresponded closely with the weight of hexane extractables as shown in Figure 3. The latter decreased appreciably with distance from the Hyperion outfall as shown in a previous table. From all of this it was concluded that most of the particulates classified as "sewage types" in this work were derived from wastewater discharge, and that hexane extractables provided a convenient means of measuring such particulates quantitatively as long as bits of tar were not too prevalent.

Micro-Particulates and Film Substances: The capillary screens used in this work captured particulates down to the limits of resolution at 430 power. The maximum size taken with reliability has not as yet been ascertained but the particles captured probably could not exceed the dimensions between the weave of the cloths employed (~0.1 mm). The minimum size captured by the surface trawl sieve was about 0.5 mm, thus particulates ranging in size from 0.1 to 0.5 mm probably have not been sampled accurately in the studies conducted to date.

The screens collect samples to a depth of about 0.1 mm, 30 times less than that strained by the surface trawl. Thus, in terms of volume of water sampled, the screens collected about 30 times less water per unit of surface area than strained by the surface trawl.

Counting and measuring the micro-particulates was difficult because much of the fine debris was clumped together as aggregates containing a various number

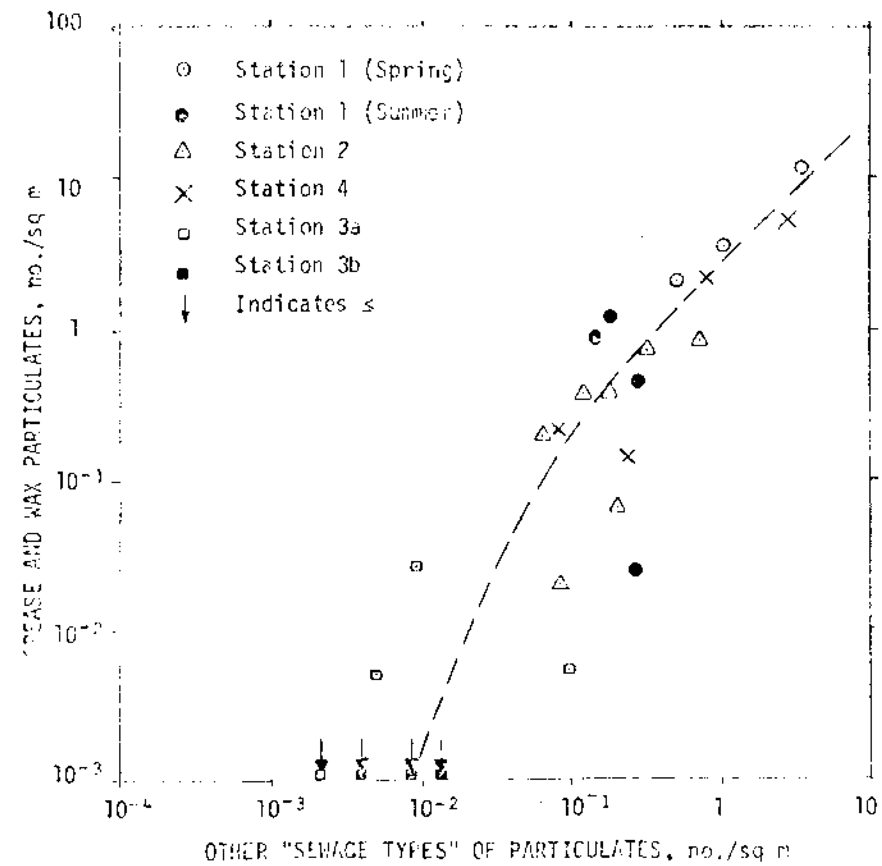

Figure 4. Macro-particulates (Trawl Samples) Spring-Summer, 1971.

of individual particles. Such aggregates were considered to be only one particle in the enumeration procedures.

Unlike the macro-particulates, the micro-particulates demonstrated no clearcut distribution over the ocean surface, and even those which seemed to be of an artificial nature (fibers, colored bits of material, etc.) appeared to be distributed in a more or less random manner. In addition, the character of the fine particulates changed radically from the spring to summer surveys. The station average densities of the micro-particulates are summarized in Table 5, excluding the surface plankton which were found in relatively numerous quantities in both surveys.

Table 5 does indicate that the micro-particulates may have been more dense over the Hyperion outfall than elsewhere, but no analysis of variance has as yet been conducted on the data so it is not known if the differences are significant at any reasonable confidence level.

A significant portion of the micro-particulates captured in the summer survey were individual, black graphite-like particles having an average size of 5.5 u. Their distribution tended to parallel that observed for all of the micro-particulates as shown in the above table.

A few of the micro-particulates captured over the Hyperion outfall (Station 1) must have been derived from the wastewater discharge, however, because coliform bacteria were found in three of the eight screen samples collected at that point during the surveys, giving an overall average count of about 330 organisms per 100 ml of water sampled. The maximum count in one of the eight screen samples taken was 5,200/100ml, appreciably above the ocean bathing water standard of 1000 coliform organisms/100 ml or less 80 percent of the time. Because none of the bulk water samples taken 10 cm beneath the ocean surface contained any coliform bacteria, it is apparent that some coliform organisms were being concentrated on the ocean surface even when the wastewater plume itself was not surfacing.

Some of the capillary screen samples were extracted with hexane and the results indicated that the hexane extractables were distributed more or less randomly across the ocean surface with a large variance in individual samples taken at a given site. Thus, the distributions were somewhat similar to those observed for the micro-particulates. Average values observed at the various stations are shown in Table 6. No definitive explanation can be offered at this time concerning the large variations observed between samples taken at a given station. The results

TABLE 5

MICRO-PARTICULATES: No./sq cm

	Spring (200x) (-4 samples added together)	Overall Total	Summer (430x) Black Particulates Total	Summer (430x) Black Particulates Range
Station 1	6.1	120	17	(3.5-41)
Station 2	4.8	39	2.5	(1.4-15.4)
Control	1.3	53	4.2	(1.6-42)

TABLE 6

HEXANE EXTRACTABLES IN CAPILLARY SCREEN SAMPLES
mg/100 sq m
(Areas sampled 0.1 sq m)

	Spring Mean	Spring Range	Summer Mean	Summer Range
Station 1	390	(25-1260)	150	(30-305)
Station 2	220	(120-575)	150	(75-330)
Control	200	(130-280)	140	(75-335)

appeared to be nearly independent of whether or not a slick was present at the time of sampling. It should be realized, however, that the amount of hexane extractables recovered per sample for 0.1 sq m cloth screens was generally in the range of 0.1 to 0.2 mg, a relatively small quantity to measure and analyze when it is considered that background from the cloth itself or storage vessels could be much greater than this if not cleaned carefully prior to use.

DISCUSSION OF RESULTS TO DATE

Trawl Samples: Macro-particulates can be sampled relatively accurately using surface trawls. Particulates smaller than 0.5 mm could be collected using a screen finer than that employed in this study but problems might arise with the screen clogging too quickly.

The evidence indicates that a substantial portion of the macro-particulates derived from a partial secondary wastewater effluent were of the grease and wax category, and that they and possibly other wastewater flotage contained appreciable numbers of coliform organisms. The grease and wax particulates could be measured rather precisely by extraction with hexane.

Factors remaining to be investigated for macro-particulates include the development of means to sample the macro-particulates accurately in the effluent stream itself in order to determine a reliable mass balance between the weight of hexane extractables released from the outfall and those found on the ocean surface. Such effluent samples cannot be collected easily in such a large outfall as the Hyperion outfall because access to the pipe is difficult and the character of the grease may change as it flows through miles long outfall pipes. Also, the number of macro-particulates in the Hyperion effluent was relatively scarce, amounting to only one or two particulates per liter of effluent. Thus, a relatively large volume of the effluent has to be screened to measure the concentration of macro-particulates accurately. Even so, an approximate first generation analysis of the data shown in Table 1 and the results of the trawl samples taken over the Hyperion outfall in the spring survey indicated a reasonable balance between the hexane extractables released as flotage and those found on the ocean surface (13 mg/sq m of hexane extractables computed vs. 11 mg/sq m observed on the average). For methods of computation the reader should refer to Ref. (1).

The character of the hexane extractables contained in the macro-particulates remains to be ascertained. A precise method of analysis for long chain fatty acids has been developed employing gas-liquid chromatography and ion detection. It is also planned to analyze the extracts for PCB compounds and possibly pesticides. Finally, the effects of initial hydrolysis of the fatty acids also remains to be studied. Once these studies have been completed much about the nature of the hexane extractables portion of the macro-particulates found on the ocean surface can be ascertained. It is expected that the characteristics of such extractables will differ considerably from those derived from particulates having origins other than domestic wastewater discharges.

Capillary Screens: A problem with the surface screening technique developed in this study is that quantitative samples cannot be collected for cloths having areas in excess of approximately 0.1 m square, but such a small cloth yielded a comparatively small amount of hexane extractables in the coastal water surveys (~0.1 mg). This means that either very sensitive analytical procedures have to be employed with all the attendant problems of possible sample contamination, or a large number of such samples have to be collected and pooled together.

A few capillary screen samples taken in San Francisco Bay produced much higher surface concentrations than found in the Southern California waters. For example, a surfacing primary wastewater effluent plume demonstrated surface concentrations on the order of 10 to 15 mg of hexane extractables/sq m, and a heavy bunker oil spill gave concentrations ranging up to 270 mg of hexane extractables/sq m. In those cases analysis of the hexane extracts became much easier.

Tests conducted on pure long chain free fatty acids added to sea water under quiescent conditions indicated a reproducibility in the sampling method of ±5 percent at low concentration. *In situ* measurements taken in the coastal waters of Southern California indicated a much greater variation than this between replicates. The cause of this variation is unknown but it may be related to the fact that the samples were not hydrolyzed first before extracting with hexane. This factor is to be investigated in the second year of this work as well as the exact fatty acid composition of the surface films. Aside from the possible reduction in sample variation between replicates, this approach may indicate the sources of the film substances once comparison is made directly with the flotage collected from the wastewater effluents themselves. Other analyses which will be attempted in the second year of this study will be PCB and pesticide analyses.

The samples collected to date from the Southern California waters indicated that the total weight of hexane extractables taken alone was not sufficient to distinguish between capillary screen flotage of natural and wastewater origins, or possibly even between slick and non-slick areas found in the region, though it did suffice to measure gross surface pollution as demonstrated by the samples taken in San Francisco Bay. This does not necessarily mean that such flotage did not reach the surface because it may have surfaced well downstream from an outfall diffuser, but if it reached the surface in relatively insignificant amounts within the vicinity of the outfall, then the slick observed outlining the Hyperion outfall diffuser in the spring survey (see Figure 2) must have been formed by some hydraulic surface compression created by the sewage boil underlying the surface. This in turn implies that the surface film materials throughout the area needed little incentive to form slicks; consequently, little differences in surface concentrations between slick and non-slick areas would have been observed.

ACKNOWLEDGMENTS

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The actual costs of the ocean surveys conducted in the coastal waters of Southern California including ship time, oceanographic equipment other than that developed in this project, travel expenses and some general assistance was borne by the Southern California Coastal Water Research Project under the direction of Dr. George Hlavka. Their aid and encouragement is gratefully acknowledged.

REFERENCE

Final Report: "Surface Phenomena Study" for the Southern California Water Research Project, Sanitary Engineering Research Laboratory Report No. 72-9, University of California, Berkeley, California (June, 1972).

The Development and Destruction of Bayocean Spit, Oregon

Thomas Terich, Assistant Professor
Department of Geography
Western Washington State College, Bellingham
Paul D. Komar, Assistant Professor
School of Oceanography
Oregon State University, Corvallis

Bayocean sand spit lies approximately seventy miles south of the Columbia River along the northern Oregon coast and separates the Pacific Ocean from Tillamook Bay. Early in the century, work was begun on a large beach resort on the spit. Financial problems caused the decline of the resort which was abandoned in 1952 as severe erosion and breaching of the spit threatened the few remaining residents. The rapid sand deposition and beach progradation north of a north jetty at the Tillamook Bay channel was believed to have deprived Bayocean spit of sand, thus causing erosion.

The purposes of this study are: 1) to recount the growth and decline of Bayocean Park, the resort development on Bayocean spit; 2) investigate the erosion of Bayocean spit; 3) to interpret the erosional and depositional patterns on the spit and neighboring beaches to determine the causes of the severe erosion of Bayocean spit.

BAYOCEAN PARK

Tillamook County deed records show land claims for portions of Bayocean spit dating back to 1867. One of the early land holders was A.B. Hallock, who named his holdings Barnegat, after a popular Atlantic beach resort. Hallock welcomed visitors and tourists to the spit.

While visiting the Tillamook area in the early 1900's, T.B. Potter, president and general manager of the T.B. Potter Realty Company of San Francisco and Kansas City, recognized the recreational potential of the sand spit. Potter decided to establish an elegant resort on the spit, which he called Bayocean. He put his plan into action by purchasing much of the sand spit. In 1907 a plat map was completed and submitted to Tillamook County (Tillamook County, 1907). The map was an impressive display of approximately 3,000 50x100 foot lots with a large block of land in the middle of the spit reserved for a future hotel and bathhouse. The only access to Bayocean Park was by boat. Therefore a pier, pavilion and boathouse were planned on the bayward side of the spit. The same day the plat map was recorded, a four column article appeared in the Sunday *Oregonian* detailing the splendor of the planned beach resort (*Oregonian*, June 24, 1907):

"This most attractive vacation spot eclipsing all the resorts for tourist travel in Europe, excelling anything on the Atlantic coast and outstripping the best on the Pacific shores, is to be only a bit over a couple of hours ride from the very heart of this city [Portland]. E.E. Lytle, who is building the Pacific Railway and Navigation Company's line, states that he is under obligation to complete the road next year, and places himself on record by saying that his trains will be able to run to Tillamook Bay in less than two and a half hours from the heart of Portland."

It was clear to Potter that the success of Bayocean Park depended to a large measure upon the completion of Lytle's railroad. The train would run as far as Bay City. Wharves had been built at Bay City and Garibaldi to accommodate the passenger traffic. At Bay City, Bayocean visitors would have a 15-minute ferry ride to the resort.

The fame of Bayocean spread as Potter advertised widely. In spite of Bayocean Park's isolation, lots sold readily. Enthusiasm regarding the future of the resort grew as investors announced plans for the construction of a heated salt water natatorium on the beach.

BAYOCEAN PARK 1910-1914

Lytle's railroad did not arrive in Tillamook as planned in 1908, or even 1909, postponing the full promotion of the resort. Property continued to be sold, but not at the desired pace. The plans of investors declined. Physical improvements promised to the property owners were curtailed, initiating dissent among the property owners.

On October 9, 1911, three years late, Lytle's railroad at long last reached Bay City. Bayocean Park took on renewed life. The arrival of the railroad finally allowed the scheduling of an official opening for June, 1912. Advertisements of Bayocean Park illustrated wide, sandy beaches, the new salt water natatorium constructed on the beach and the Bayocean Hotel (Figures 1 and 2). Other humble, yet adequate, temporary bungalow housing and tents were available to the visitor. Many large, private vacation homes and permanent residences were also scattered throughout the park.

CONSTRUCTION OF THE NORTH JETTY

Nearly concurrent with the coming of the railroad to Tillamook was the approval of the construction of a north jetty to the Tillamook channel. Lumber interests in the Tillamook area had lobbied for several years for the improvement of the channel entrance to Tillamook Bay. The anticipated increase in shipping trade with the coming

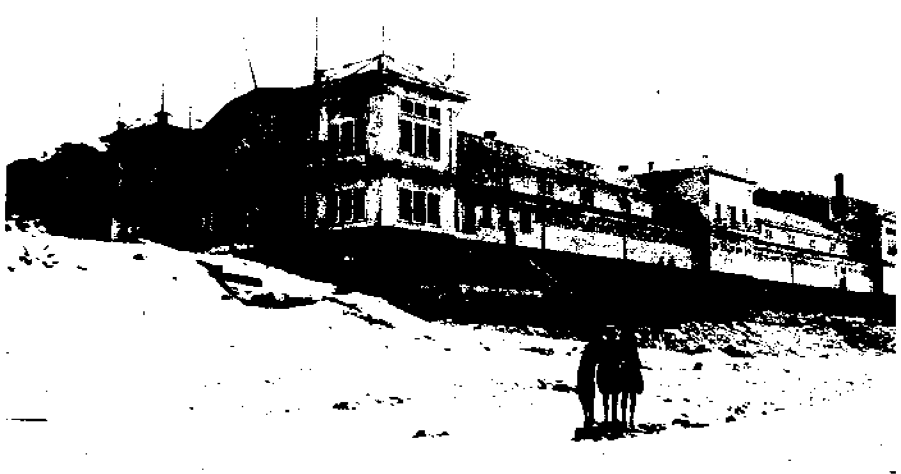


Figure 1.

of the railroad justified the construction of a 5,400 foot long jetty on the north side of the channel to stabilize the entrance to Tillamook Bay. Work on the jetty commenced in June 1914 and was complete in October of 1917.

DECLINE OF BAYOCEAN PARK

All outward signs pointed to the future prosperity of Tillamook and Bayocean Park; however, as time passed, the comparative prosperity and improvements to the resort were apparently not sufficient as there numerous complaints by investors. The complaints culminated in charges that the enterprise was bankrupt, a petition was instituted in 1914 for a receiver. Potter fought the case; however, the plaintiff's evidence was apparently convincing, for a receiver was appointed (*Oregonian*, December 11, 1914).

Years of litigation and claims of fraudulent practices followed. The alleged practices on behalf of T.B. Potter undoubtedly downgraded the credibility of his company and value of Bayocean Park. Improvements to the resort came haltingly. The depressed resort was in operation; however its isolation to the automobile during an era of road building and increased auto access to other resorts further depressed Bayocean Park (Olsen, 1972).

In 1927 a group of prominent Tillamook residents organized under the name of the Tillamook-Bayocean Company and assumed the entire assets of the T.B. Potter Company's holdings on Bayocean Spit (*Oregonian*, July 13, 1927). They, with the aid of F.D. Mitchell, a long-time resident of the spit, completed a road along the southern side of the bay to Bayocean Park. The future of the resort again brightened, but only for a short time as the Depression of 1929 halted all hopes for the revival of the resort. One by one the cottages were abandoned, the hotel closed and numerous other structures were vacated.

During the Depression some of the structures within the park were used temporarily by groups of drifters, products of the Depression. However, they, too, abandoned the deteriorating remains of Bayocean Park.

EROSION OF BAYOCEAN SPIT

It is difficult to assess when noticeable erosion began on the spit. Residents of Bayocean argued that erosion of the spit was the direct result of the Corps of Engineers' reconstruction and 300 foot lengthening of the north jetty in 1932-33. The residents maintained that there was no erosion or property loss prior to 1932. The U.S. Army Corps of Engineers maintained that the north jetty lengthening had little impact upon Bayocean Spit. They countered the claims of the residents with geomorphological evidence that the Oregon coast is undergoing a recessional change without the influence of man-made structures and that erosion may be normally expected anywhere on the coast (War Dept. Dist. Eng., 1940).

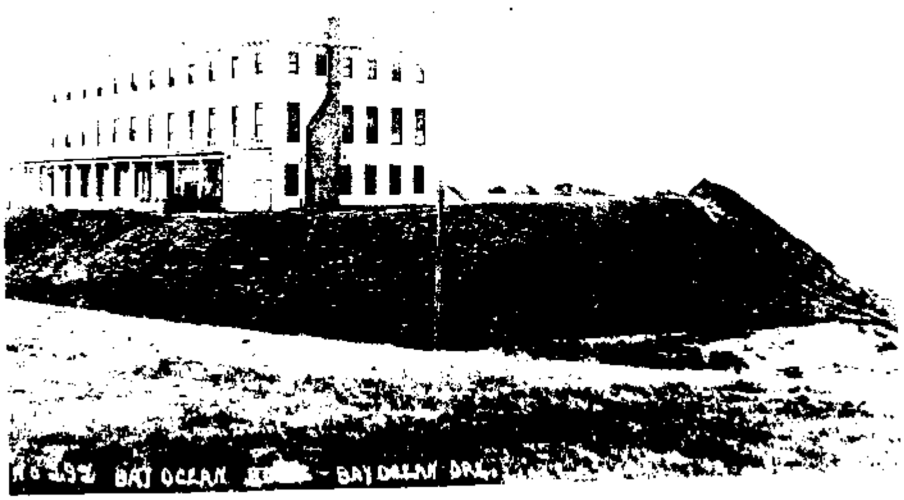


Figure 2.

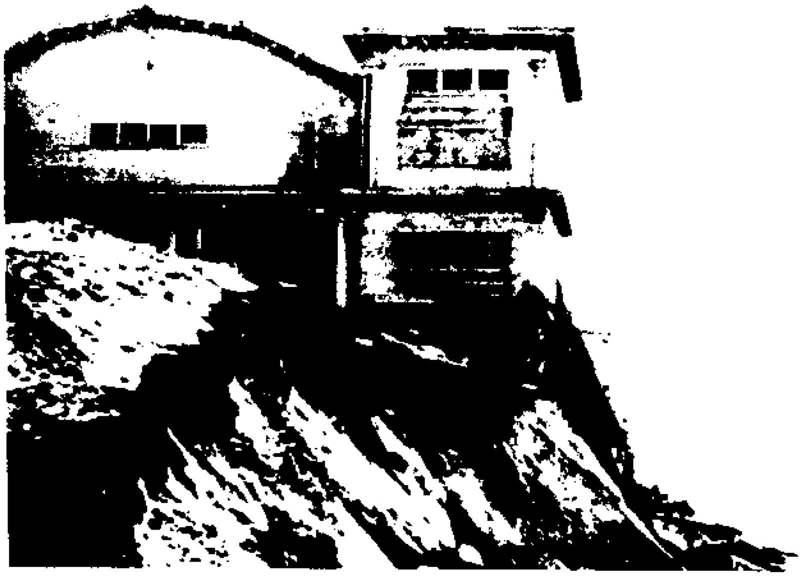
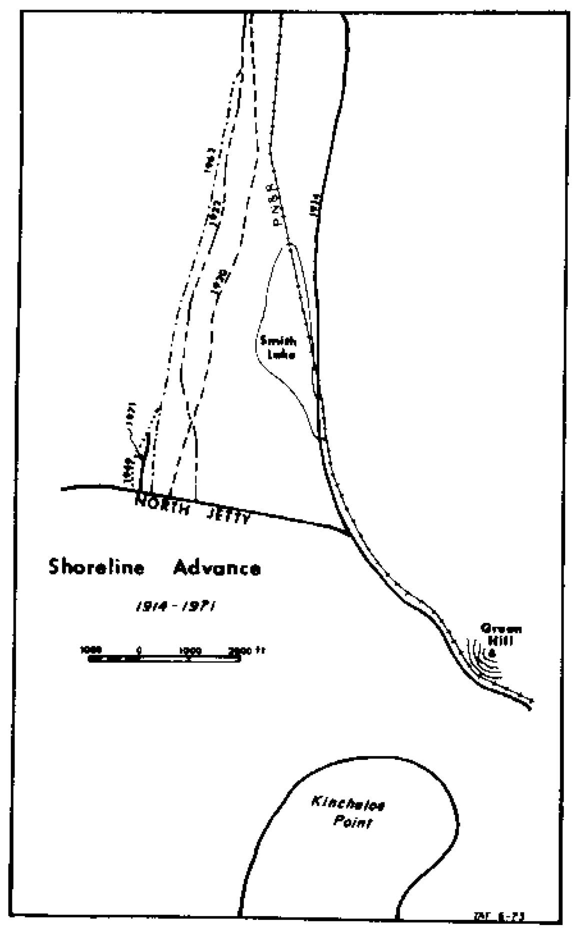


Figure 3.

There are some indications that erosion of Bayocean Spit had begun prior to 1932-33. Figure 3 is an undated photograph of the natatorium already showing erosional undermining of the structure. The photo is known to have been taken after 1932 when erosion first began to undermine a sidewalk fronting the building and before 1936, when the structur'e roof collapsed.

It is clear that the north jetty had trapped large amounts of sand resulting in the rapid progradation of its northern shoreline (Figure 4). The residents insisted that not only had the north jetty trapped large amounts of sand, but also had created currents and offshore eddies leading to increased erosion of the spit (*Oregonian*, February 19, 1939). The residents proposed the construction of a south jetty, which they believed would trap sand to the south along Bayocean's beach front and replenish sand losses. Moreover, they contended a south jetty would benefit navigation in the channel and drive the erosive effects of offshore eddies created by the north jetty farther out to sea. The Corps of Engineers explained that they believed a south jetty would create only local accretion south of its land connection and would be of no value to the protection of the inhabited portion of the spit (War Dept. Dist. Eng., 1941).

Figure 4.



EROSION - 1939

Erosion of Bayocean spit during the winter of 1939 was particularly severe and caused considerable damage. On January 3, 4, and 5, 1939, a severe storm and high tide combined to lash the spit. Small gaps along the narrow southern sector of the spit were awash with waves carrying debris and gravel into Tillamook Bay. Considerable damage had been inflicted upon the paved road along the foredune between the village of Cape Meares and the Bayocean resort. The natatorium, which had been constructed at the base of a foredune, had been completely destroyed (Figure 5).

Subsequent high tides and storms in January and February of 1939 continued the destruction (*Oregonian*, February 19, 1939). Maximum recession of the top of the dune bank was twenty-five feet with an average recession of 7.3 feet for that part of the spit with foredunes (War Dept. Dist. Eng., 1940). Four houses had been undermined and destroyed, nine houses were in precarious positions and six had been moved back from the foredune (War Dept. Dist. Eng., 1939). There still remained approximately thirty dwellings at Bayocean, ten of which were permanently occupied. There were two small stores and an auto camp with thirty-five cottages located midway on the bay side of the spit. The 1940 population was thirty-two permanent and approximately 150 peak population during the summer (War. Dept. Dist. Eng., 1940).

The destructive erosion of the winter of 1939 initiated much concern and fear, not only among residents and investors in Bayocean Park, but also Tillamook citizens. The fear was not only of further erosional destruction, but also of possible breaching of the spit. A breach in the spit would allow sand and gravel to enter the bay, covering shellfish beds, and would permit wave activity to disrupt shipping and flood low farmlands. A group of concerned citizens organized the Bayocean Erosion Committee, whose purpose was to lobby government officials to come to their aid.

EROSION - 1940-1948

In January, 1940, winter storm waves continued to gnaw at the spit and widen the gaps cut by the preceding year's storms. The Bayocean Erosion Committee appealed to their state and federal representatives; however, they received little support. The war years postponed discussion of aid.

In 1946 the U.S. Army Corps of Engineers appraised some possible actions to retard the erosion (Dept. of Army Corps of Eng., 1946). They concluded that the proposed measures would either have little effect on reducing the erosion or could not be economically justified.

On November 2, 1948, another severe storm lashed the spit. Two new gaps were cut through the narrow neck of the spit, undermining roads and severed utility lines to Bayocean Park. Storm winds and high waves reappeared November 5, 1948 to further erode the spit and isolate its eighty residents from the mainland (*Oregonian*, November 7, 1948). Food and water were ferried to the residents. Water service was later restored by attaching fire hoses to each side of the severed pipe and suspending it over the gap. A telephone cable was installed in the event the resi-

Figure 5.


KINCHELOE POINT
TILLAMOOK BAY, OREGON
SCALE
KINCHELOE POINT
TILLAMOOK BAY, OREGON
SCALE
KINCHELOE POINT
TILLAMOOK BAY, OREGON
AUG 10, 1963
SCALE

Figure 6.

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dents of the spit were isolated (*Oregonian*, November 25, 1948). The storms of 1948 certainly pointed to the doomed fate of Bayocean Park.

BREACHING OF THE SPIT

The 1939 fears of the spit's breaching became a reality on November 13, 1952. Storm waves aided by high tides penetrated the gaps, weakened and finally destroyed a 4,000 foot long segment of the spit's narrow sand ridge neck (Figure 6). At high tide the water-filled breach was nearly three-quarters of a mile wide. At low tide the break became several small channels, the largest about 500 feet wide with a water depth of six feet (*Oregonian*, November 23, 1952). The ebb and flow of subsequent tidal periods deepened and widened the breach. Eight residents reamined on the spit through November. In December two were evacuated, leaving the total resident population of Bayocean to six (*Oregonian*, January 18, 1953).

The breach assumed the major tidal flow causing the navigation channel with its jetty to shoal, due to loss of the scouring tidal current. Waves rolled through the breach and produced swells within the bay. Sand carried into the bay created new shoals within the bay, endangering shipping and covering nearly 1000 acres of former oyster beds (Brown, 1958).

DIKING THE BREACH

In 1956, four years after the spit's breaching, work was begun to dike the opening. The alignment of the breakwater was set back from the beach line of the spit. It was anticipated that the pocket in the shorline formed by the setback would fill chiefly by erosion material from the spit. With the pocket filled, it was expected that a more or less uniform shoreline would be re-established forming a protective sand beach in front of the breakwater. Figure 7 shows that this assumption proved to be correct.

Immediately following the closure of the breach, commercial fishermen reported marked increases in tidal velocities in the navigation channel and rapid erosion of sand bars, which had been building inside the bay since 1952 (Brown, 1958).

RECENT EROSION

The shoreline between Kincheloe Point and the former breach site has continued to erode. U.S. Army Corps of Engineers (1971) data from 1957 to 1971 shows the shoreline has retreated roughly twenty feet per year. There is some concern that continued erosion will again breach the spit. However, the Corps of Engineers foresees the average rate of erosion declining as sand accretes south of the new south jetty, extending seaward from Kincheloe Point. It is believed that sand will be trapped south of the new jetty, causing accretion of the shoreline near the jetty and slowing erosion farther down the beach.

SOUTH JETTY

Comparison of United States Coast and Geodetic Survey maps (Figure 8) shows the growth of shoals within the channel entrance to Tillamook Bay. The shoals extend northwesterly from Kincheloe Point, migrating within the channel entrance causing increased wave activity and turbulence. Winter conditions are most severe as southwesterly storm waves break over the shoals, making the chan-

Figure 7.

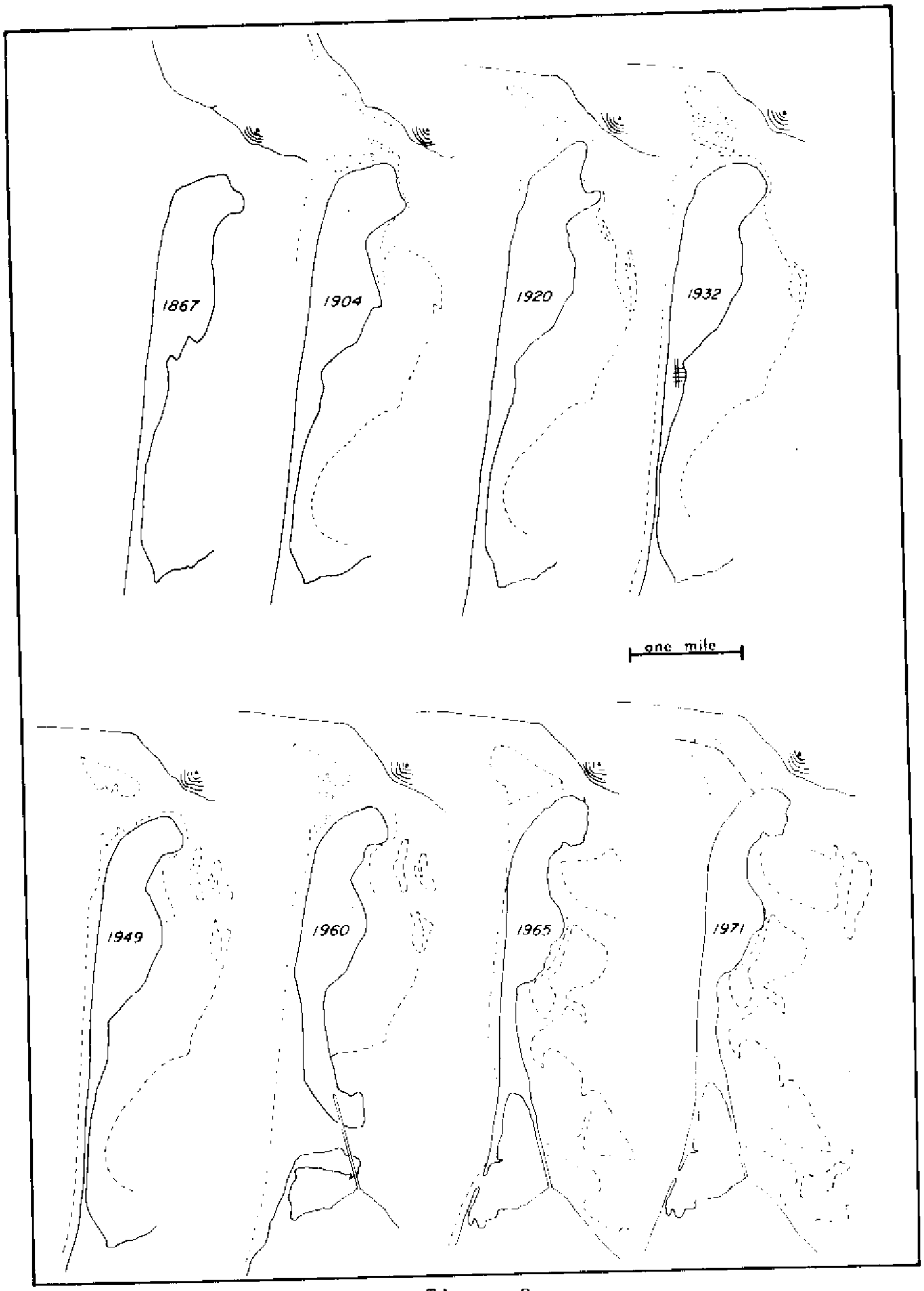

Figure 8.

nel impassible for periods ranging up to ten days (U.S. Cong. Sen. Docs., 1965). The vessel delay had forced concellation of water carrier service; moreover, the unpredictable channel conditions discouraged many fishing boats from basing at Garibaldi. As a result, Tillamook Bay suffered a decline in waterborne transport and fishing activities (U.S. Cong. Sen. Docs., 1965).

The hazardous channel conditions prompted renewed consideration and eventual approval for the construction of a south jetty at the channel entrance to Tillamook Bay. Construction of a 3,700 foot long jetty westerly from Kincheloe Point was begun in April 1969 (Figure 7). As the construction progressed, it was recognized that the large shoal the jetty was designed to contain extended well beyond the proposed length of the jetty. The jetty had to be lengthened for more complete protection within the channel. Work is now underway to extend the south jetty by 2,830 feet to a total length of 6,525 feet with a projected completion date of October 1974.

Beyond aiding navigation of the channel, the Corps of Engineers (1965) expects the south jetty to reduce the continuing loss of sand into the channel and consequently deposit sand for a short distance south of the jetty and reduce erosion rates south to Cape Meares.

SHORELINE CHANGES 1939-1973

Figure 9 represents shoreline changes to Bayocean spit as taken from 1939 and 1973 aerial photography. Most of the seaward face of the spit has retreated several hundred feet since 1939. The most severe recession has occurred where the former narrow sand ridge connected Bayocean to Cape Meares. The breach destroyed nearly a mile-long stretch of the ridge. The diking of the breach and subsequent formation of a new shoreline repositioned the entire southern part of the sand spit 800 to 900 feet east of its former location. Tillamook County tax assessor records show that people still hold claim and pay nominal taxes on land formerly located on the narrow sand ridge, but is now under several feet of water. Beach erosion is still continuing for several hundred yards north of the former breach site and will probably continue to do so. This eroded sand probably moves northward along the beach to be deposited in the wave protected area south of the new south jetty.

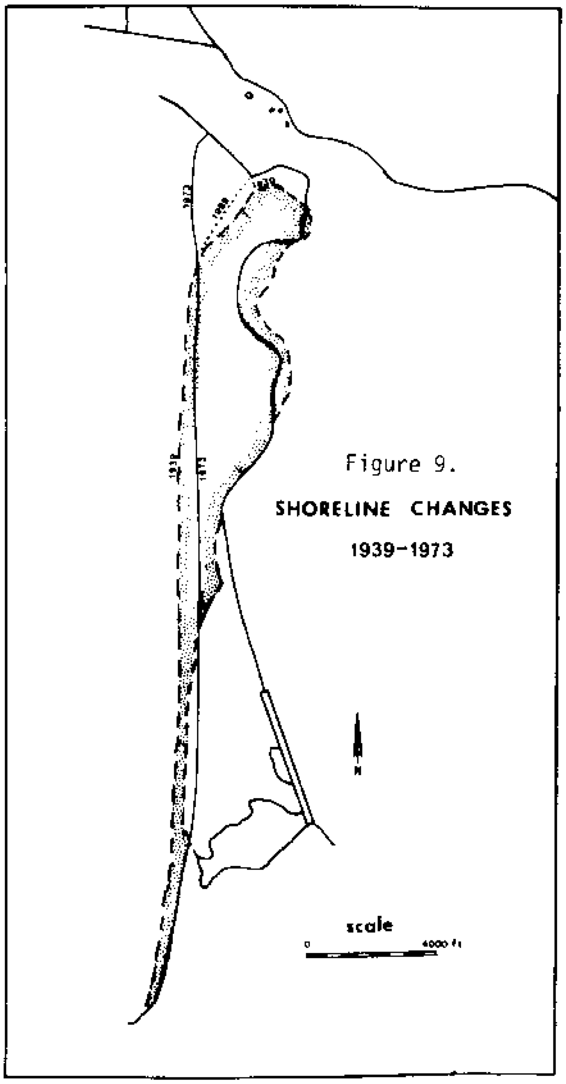

Figure 9.
SHORELINE CHANGES
1939-1973

The most rapid change in the shoreline configuration has occurred due to sand deposition and shoreline progradation south of the south jetty. Since its construction in 1969, the shoreline immediately to the south has advanced approximately 1,500 feet. The shoreline advance is likely to continue as the jetty is lengthened.

SEDIMENT SOURCES AND THE EROSION AND DEPOSITIONAL SHORELINE PATTERN

Inspection of charts and aerial photographs for the Bayocean spit area has revealed rapid sand deposition immediately north of the north jetty and within the Tillamook Channel to the south of the north jetty (Figure 10). Rockaway-Manhattan beaches, four to six miles north of Bayocean spit, have likely been the source area for sand deposited north of the north jetty as the aerial photographs demonstrate that these beaches have been eroding. Concurrently, sand has been deposited south of the north jetty within the channel entrance to Tillamook Bay. The major source area for these sands are more difficult to identify. Various possible sources will be discussed in order to account for the relative importance of each as a sediment source for the channel shoals.

TILLAMOOK BAY

The five rivers that empty into Tillamook Bay discharge much sedimentary material. Using the Langbein and Schumm (1958) method, an estimate of the fluvial sediment discharge was made. The Langbein and Schummn (1958) method provides an estimate of total sediment discharge for drainage basins by correlating this sediment supply with the effective annual precipitation for basins of differing climatic and vegetation conditions and with the drainage basin area. The effective precipitation

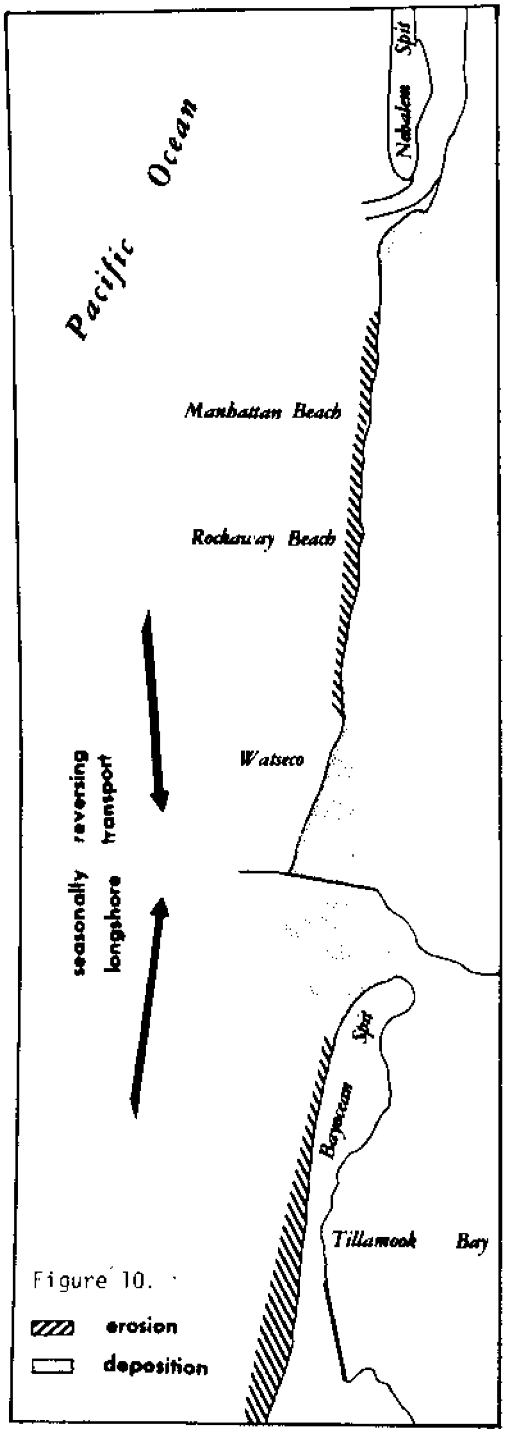

Figure 10.

eliminates that portion of the precipitation which is lost through evaporation and transportation. Table I is the estimated fluvial sediment discharge as predicted by the Langbein and Schumm (1958) method for the five rivers which enter Tillamook Bay.

TABLE 1

River	Drainage Area (mi^2)	Annual Sediment Yield (yd^3/yr)
Miami River	36	79,300
Tillamook River	61	125,600
Kilchis River	67	136,000
Wilson River	195	337,500
Trask River	175	308,700
	534	987,100

Comparison of U.S. Coast and Geodetic Survey charts for 1869 with present-day charts show that most of the fluvial sediments are contributing to the filling of the bay. Could sediment discharges out of Tillamook Bay account for the channel shoals which developed south of the north jetty? Two lines of evidence indicate that Tillamook Bay is not a major source of sediments for the channel shoals. Avolio (1973) has recently found very well sorted sand extending from the channel well into northern Tillamook Bay covering an area approximately one square kilometer. This evidence indicates that beach sand is flowing into and being deposited within Tillamook Bay. This suggests that Tillamook Bay is a "sink" rather than a source of sediments to the channel and nearshore. Similar conditions were found by Kulm and Byrne (1966) at Yaquina Bay, approximately sixty miles south of Tillamook Bay. Beach sand was found to enter the bay through the channel when the bay circulation assumed a two-layered system. A two-layered system develops within the water of the estuary when freshwater overlies a salt water wedge at the bottom of the estuary. The rapidly outflowing upper layers of freshwater carries with it some of the salt water at the boundary. The removal and outflow of this salt water is balanced by a low level inflow of salt water near the bottom within the salt wager wedge. Thus, the two-layered system creates bottom current velocities flowing from the ocean into the bay, causing the movement of beach sand into the bay. The result is a net accumulation of both fluvial and beach sediments in the bay. The evidence found at Tillamook Bay suggests that similar processes occur leading to the filling of the bay from marine as well as fluvial sediment sources. Thus, rather than contributing sand, Tillamook Bay probably extracts sand from the channel and Bayocean nearshore.

HEADLAND EROSION AND LANDSLIDING

The Corps of Engineers (War Dept. Dist. Eng., 1940) and Twenhofel (1946) suggested that Cape Meares, immediately south of Bayocean spit, has probably served as a sediment source for Bayocean spit. Basalt boulders and cobbles along the southern end of the spit were probably derived from the basalt capping the Cape.

On the north side of Cape Meares is a large landslide described by North (1964) and Schlicker (1972). Study of aerial photographs indicate the slide has become active some time after 1955. The toe of the slide has moved beyond the former beach line. Trees leaning 20 to 30 degrees seaward at the toe of the slide indicate recent ground movement. The slide is undoubtedly contributing sediment to the longshore drift as waves erode and remove the advancing soil and rock.

EROSIONAL LOSSES FROM BAYOCEAN SPIT

Bayocean spit's known shoreline retreat since 1939, as shown in Figure 9, offers the possibility of quantifying the volume of sand loss from the spit. Corps of Engineers' surveys show that erosion has occurred along approximately 3.5 miles of the spit with accretion at the northern extreme. The eroded portion of the spit has receded on the average 550 feet since 1939. Given an average sea cliff height of 20 feet, the total volume of erosion since 1939 has amounted to roughly 7,400,000 cubic yards of sand or 220,000 cubic yards per year. These eroded sands have entered the littoral currents to be transported and deposited elsewhere. The progradation of Kincheloe Point and sand deposition within Tillamook channel coinciding with the construction of the north jetty (Figure 8) suggest that much of the sand eroded from Bayocean spit has been deposited in those locations.

A rough estimate of the channel shoal volume was made to see if there was a correlation between the accumulated volume of sand within the channel shoal extending from Kincheloe Point and the volume sand loss from Bayocean spit since 1939. Undoubtedly some of this sand has been deposited within Tillamook Bay; however, that portion was omitted from the estimate. Table II presents the approximate shoal volumes using the estimated surface area 0.63 square miles and a variety of reasonable depths of accumulation.

TABLE 2

ESTIMATED SHOAL VOLUMES

Depth (ft)	Cubic Yards
8	5,240,000
9	5,890,000
10	6,550,000
11	7,200,000
11.3	* 7,400,000
12	7,860,000
13	8,500,000

*Estimated sand loss to Bayocean spit (yd^3) 1939-1971.

Table II shows that an average 11.3 feet of sand deposition within the channel shoal would account for all of the estimated sand eroded from Bayocean spit since 1939. Since some of this eroded sand entered Tillamook Bay, a shoal thickness somewhat less than this value could actually account for the sand eroded from the spit. Comparisons of Coast and Geodetic Survey charts indicate deposition within the channel on the order of ten feet thickness or more. This indicates then that erosion from Bayocean spit has probably served as the major source of sands deposited within the Tillamook Bay channel following construction of the north jetty.

LONGSHORE SAND TRANSPORT

National Marine Consultants (1961) presents wave hindcast data which suggests that longshore sediment transport for much of the Oregon coast reverses with the seasons. During the spring and summer a south longshore transport predominates reversing to a north transport during autumn and winter. Longshore current observations conducted along Bayocean spit by the Corps of Engineers (War Dept. Dist. Eng., 1940) during 1939 and 1940 agree with the longshore current predictions as indicated by the National Marine Consultans (1961) information.

Although sand moves north during one season and south during another, the available information indicates that the overall annual net drift of sand along the beach is nearly zero. This is first suggested by the approximate balance of the longshore component of the wave energy flux to which the sand transport rate can be correlated (Komar and Inman, 1970). It is also indicated by local geomorphologic evidence. Although Bayocean spit is attached to the mainland mass at its south end and extends to the north, a configuration generally taken to indicate a northward growth and littoral transport, Nehalem spit, just a few miles to the north has grown in a southerly direction. Along the Oregon coast, spit growth does not provide a clear indication of the net littoral drift direction. If a net drift of sand did exist, Cape Meares at the south end of Bayocean spit should act as a long-term "jetty" or "groin" and block this drift so that the beach would build out on the updrift side and erode on the downdrift side. No such pattern is found, the beaches on the north and south sides of the Cape being approximately symmetrical.

Utilizing heavy minerals found within sands as natural tracers of the sand movement, Scheidegger, *et al.* (1971) found a long-term net drift predominantly to the north along the Oregon coast and offshore. This drift is long-term in geologic sense, however, so that the net annual drift of sand along the coast is still nearly zero.

As will be seen in a moment, the pattern of erosion and deposition along Bayocean spit and neighboring beaches can also be interpreted as indicating a seasonally reversing longshore transport with a near-zero net drift.

IMPACT OF THE NORTH JETTY UPON LONGSHORE SEDIMENT TRANSPORT AND SHORELINE CONFIGURATION

The very rapid sand deposition and beach progradation north of the north jetty and simultaneous erosion of Bayocean spit caused the U.S. Army Corps of Engineers (1970) to identify a predominant net north to south littoral sand transport of 800,000 cubic yards for the area. Their conclusion appears to have been based on comparable examples such as the breakwater at Santa Barbara, California, which blocks a strong unidirectional longshore drift, sand deposition and shoreline advancement occurring on the updrift side of the jetty or breakwater and erosion occurring in the downdrift side. Such an interpretation for the Bayocean area of course conflicts with the evidence against a strong net drift of sand. In addition, a closer scrutiny of the patterns of erosion and deposition around the Tillamook jetty reveal a distinct difference from this unidirectional drift model. Simultaneous with the noticeable deposition north of the north jetty, there has been sand deposition to the immediate south of the jetty. This deposition occurred as a comparatively small advancement of the shoreline at Kincheloe Point, but more important as the development of a large system of shoals in the mouth of the harbor entrance. In addition to the erosion of Bayocean spit, erosion also took place at Manhattan-Rockaway beaches farther north of the jetty. A somewhat different pattern of deposition-erosion around the jetty therefore emerges. Near the jetty itself, both to the north and south, deposition of sand occurred (Figure 10), while at greater distances from the jetty erosion took place. The reason for this distribution is that the jetty provides small areas on either side which are partially shielded from the waves. When sand moves to the south it accumulates on the north side of the jetty in the usual fashion. When the waves subsequently arrive from the south, moving sand to the north, sand is blocked on the south side, but due to the protective shielding of the jetty, only weak diffracted waves can reach the shadow zone behind the jetty to transport the sand previously deposited there by the south transport. Therefore, this sand is not removed from the shadow zone and the long-term effect is an accumulation of sand near the jetty, both on the north and south sides, within the sheltered zones, and erosion of the beach at greater distance away from the jetty to supply the sand to the areas of deposition. In the case of the jetty at Tillamook Bay, the erosion to Bayocean spit aas made more severe in that the length of the beach is relatively small, there being a large rocky headland to the south, so that the erosion per unit length of shoreline had to be large to supply the required sand. In contrast, there is a long stretch of beach to the north of the jetty so that only a small amount of sand had to be supplied by each unit length of shoreline.

CONCLUSIONS

Most studies of man-made structures in the nearshore have emphasized beach erosion and deposition resulting from the construction of jetties transverse to a unidirectional sand transport. The typical pattern that emerges is sand deposition and shoreline progradation on the updrift side; erosion and beach recession on the downdrift side of the structure. At first glance, one would expect little or no erosion and deposition to occur along a shoreline by the construction of a structure transverse to a seasonally reversing longshore sand transport but with little or no net annual drift. However, as shown by the Bayocean example, even with a near zero net drift jetty construction may upset the natural movements of beach sand and thereby cause severe erosion.

ACKNOWLEDGEMENTS

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Fjord Estuary Modeling in Alaska

J. Brian Matthews, Associate Professor
Institute of Marine Science
University of Alaska, Fairbanks

In 1967 work was begun on a ten-year program with the ultimate objective of developing a numerical fjord circulation model. The project was funded by the Office of Naval Research and based at the Institute of Marine Science of the University of Alaska. Effort was directed at evaluating the important factors influencing circulation in Alaskan fjords via a field program in the fjord inlets of southeast Alaska while, at the same time, carrying out investigations into numerical techniques.

When this project was initiated there was not a great amount of interest in the fjord estuaries of northwest America. Yet the northeast Pacific coastline contains many deep fjord-like inlets stretching in a complex network from Tacoma, Washington, to Cook Inlet, Alaska, a span of more than 10° latitude. The region provides an invaluable international asset for multipurpose uses. The recent threat of the pipeline-tanker route from Prince William Sound to Puget Sound has served to focus on the potential damage to this unique coastline which might follow poor management procedures. We believe that thorough understanding of fjord inlet circulation mechanisms is a necessary preliminary to the development of wise management procedures for multipurpose uses.

In some respects it is advantageous to develop numerical model procedures for fjord inlets because some of the problems in other estuaries are absent. Fjords occur in mountainous coastlines at higher latitudes and are believed to be gouged by glacial action along natural valleys or fault zones. Subsequent flooding from the sea results in typically steepsided U-shaped long narrow inlets which sometimes have restrictive sills. It is because of their bathtub-like shapes that we feel they offer good possibilities for preliminary work in numerically modeling their circulation patterns. Tidal flats and shoal regions are generally absent from fjord estuaries unlike many coastal plain or bar-built estuaries.

FJORD CATALOG

As part of a long-range goal of designing a model applicable to any fjord estuary we wished to know where fjords occurred and what properties could be systematized. Accordingly an attempt has been made to list the fjords of the world according to their location and topographic features.

Fjords occur in Alaska, British Columbia, Washington, and Arctic Canada. Greenland, Iceland, Norway, Chile, and New Zealand also have fjord inlets. Work is progressing on the catalog. All regions except Greenland have been compiled to date and the northeast Pacific region is presently undergoing final checking and revision. The catalog will be printed in volumes by region as they become available.

Inlets are listed by country and latitude, longitude and marsden square locations are given. The depths of the major sills and basins are listed as well as the surface area. Connecting bodies of water and special terminations such as in glaciers or major rivers are listed. The catalog is stored on computer desk file and is designed to be compatible with oceanographic data files.

FJORD CIRCULATION

During compilation of the fjord catalog and other literature searches it became apparent that the fjord regions of the world have received remarkably little attention from oceanographers. Although the fjords of Norway have been settled for at least two thousand years only a handful have received attention from oceanographers (Gade, 1963; Saelen, 1967). Greenland, Arctic Canada (Nutt and Coachman, 1956), Chile (Pickard, 1971) and New Zealand (Skerman, 1964) have been similarly neglected.

By contrast the inlets of the Pacific Northwest have been quite well surveyed and their oceanographic features described. Pickard and his collaborators have documented the oceanography of the major British Columbian inlets (Tully, 1949; Tabata and Pickard, 1957; Waldichuk, 1957 and 1958; Herlinveaux and Tully, 1961; Pickard, 1961; Herlinveaux, 1962, and Gilmartin, 1962). The fjord region of Washington State, the Puget Sound system has been worked on by University of Washington oceanographers and some of their work has been published (University of Washington, 1953, and Collias *et al.*, 1966).

The Alaskan inlets have been investigated in seasonal studies (McAlister, Rattray and Barnes, 1959; Jones, 1964, and Pickard, 1967). More recently the University of Alaska has carried out annual surveys of certain Alaskan inlets and some of this work has been published as M.S. theses or reports (Quinlan, 1969; Gleason, 1972, and Nebert and Matthews, 1962).

Most of the studies mentioned above reveal that fjord inlets are generally stratified with a seaward-moving brackish layer at the surface. The deep water is believed to be entrained by these surface layers and is renewed from the ocean. In some inlets wind mixing plays an important role (Farmer, 1972).

In Alaskan inlets we find the stratified condition in summer and fall whereas the water mass is homogeneous in winter and spring. This appears to be a consequence of the runoff which has a high double peak in summer and falling to very small amounts in winter. The first peak occurs in May due to spring runoff and the October peak from a precipitation peak. Winter precipitation is mainly in the form of snow. However, circulation appears to continue year-round and large surface currents have been observed in February with very homogeneous conditions from top to bottom of the inlet in Endicott Arm (Gleason and Matthews, 1972). In this particular inlet, which has a 50 m entrance sill, tides are believed to be the indirect mechanism driving the observed circulation (Nebert and Matthews, 1972).

REQUIREMENTS FOR A MODEL

At a workshop on fjord circulation convened by Dr. E.L. Lewis of the Frozen Sea research group in 1972, the present knowledge on fjord circulation dynamics and associated problems was reviewed. Although the principal factors influencing circulation could be enumerated and specific problems formulated for solution it was reluctantly concluded that we have insufficient information at the present time to attempt large scale modeling efforts. An experiment has been proposed to help fill the gap and this will be detailed below. First, however, it will be useful to summarize the requirements of a numerical model.

A numerical model should be able to predict circulation patterns in fjord inlets and describe the distribution of properties such as temperature, salinity and dissolved oxygen. There is a need for both time dependent and steady state solutions. These models can have uses from many agencies such as those concerned with fisheries, pollution control, or transport. Fjord models will ultimately need to be coupled to larger ocean models which may themselves be coupled to global ocean/atmosphere models.

The factors isolated as important to fjord models fall roughly into topographic and physical classes. Topographic features to consider are (1) sills, (2) sinuosity, (3) islands, and (4) shape of sides. Sills have a major influence on mixing and serve to restrict the basin so that deep water may not freely enter the inlet if it be restricted by a sill. The inner basin of the Norwegian Nordfjord is renewed only every seven or eight years when exceptionally cold dense water is introduced into the outer basin (Saelen, 1964). Saanich Inlet in British Columbia seems to be dependent on a similar mechanism for flushing (Herlinveaux, 1962). No Alaskan inlets become anoxic but our work on Alaskan inlets demonstrates the importance of the entrance sill on circulation (Quinland, 1969; Nebert and Matthews, 1972). The other three topographic features listed affect circulation to a lesser extent than the sills but are nonetheless important. Sinuosity leads to cross-channel circulation and possibly to upwelling and mixing across the pycnocline.

Nine meteorological or oceanographic factors appear to be significant. These are (1) temperature and salinity just outside the inlet, (2) tides, (3) winds, (4) runoff, (5) radiation, (6) air characteristics, (7) freezing and melting, (8) icebergs, and (9) sediments. The list is roughly in order of importance for temperate fjords although seasonally and from inlet to inlet their importance does vary. Outside water characteristics determine what is available to mix with inlet waters-Norwegian inlets for example, generally have water 2‰ more saline than North American inlets (Matthews, 1971). Temperature of the external water appears to be the variable which is critical to fjord flushing in Norway whereas salinity variations are equally important to North American inlets.

Tides play an important role in many estuaries and fjords are no exception. We have suggested that it is the tides which transport water in and out of some Alaskan fjords and together with density differences and sill depth controls much of the circulation (Nebert and Matthews, 1972). Because fjords are generally deep and stratified simple depth-mean tidal numerical models cannot readily be applied. We have, however, worked with such models in order to gain expertise in modeling and have applied well mixed estuaries such as Cook Inlet (Matthews and Mungall, 1972, and Mungall, 1973). Winds, often of the Föhn type, funneled between the steep sides of a fjord inlet can play an important role in circulation. Farmer (1971) has shown the wind to be of major importance in spring in Alberni Inlet on Vancouver Island.

Runoff determines the density in the upper layers of the inlet and provides the necessary dilution whereby density differences are set up. Generally the world's fjord regions have low runoff in winter and high runoff in spring and summer. Radiation and air characteristics affect the surface of the inlet and may lead to thermohaline convectio due to freezing or evaporation. In the inlets of southeast Alaska and British Columbia these effects are not usually large. In the Canadian Arctic, Greenland or Chile, however, they may be important for the seasonal cycle. Icebergs generally result from glaciers calving directly into an inlet. Because they may extend over 200 m below the surface (Gleason and Mathews, 1972), they can serve as a heat sink and source of fresh water and play an important role in bringing deep waters to the surface. Alaska, Greenland, Arctic Candaian and Chilean inlets have tidewater glaciers; Norwegian and British Columbian inlets do not. Fjords are often fed by glacial streams carrying heavy sediment loads. The sediments may lead to strong turbidity currents which influence mixing and also cut light penetration, thus modifying phytoplankton behavior.

In the foregoing paragraphs we have enumerated what are believed to be the major factors influencing fjord inlet circulation. Any numerical model which strives to predict circulation must be able to use each of all of these. The state of the art in estuarine modeling has recently been reviewed (Ward and Espey, 1971) and applications of some models to Pacific Northwest estuaries was ably discussed by Callaway (1971) at the first of these conferences. The author as briefly reviewed numerical models in the light of fjord needs and presented a scheme for a ten-layer baroclinic free surface model (Matthews, 1972). In the proposed model the approach was taken that it is simpler in the long term to design a full three dimensional model first and simplify it later than to build small models and attempt to enlarge them.

The proposed model is driven by salinity, temperature and tide specified at open boundaries. Topography is built in as initial conditions. The scheme allows ten depths to be specified corresponding to the ten layers of the model. This does not allow for smooth contours as can be achieved by building the vertical ordinate into the scheme as in the sigma-t approach (e.g., Gilchrist *et al.*, and Freeman *et al.*, 1972). However, it allows the major topographic features to be included while making model results easy to fit to observations.

In designing the finite difference scheme the boundary conditions to be applied were kept in mind. The computer programs are still under development but provision for specifying many conditions has been allowed for so that maximum flexibility can be achieved. Disk stoarge of array variables has been set up so that input/output operations occur simultaneously with computation but are not limiting factors. The scheme allows two dimensional (vertical or horizontal) and one dimensional subsets to be operated with the consequent serving of computation time. At the present time the one dimensional model is being evaluated.

The model uses eight equations solved sequentially in slabs along an inlet. Marchuk time splitting procedures are used throughout to give a stabilization to the numerical scheme. The equations solved are for vertical velocity, surface elevation, temperature, salinity, density and pressure equations and two equations of horizontal motion. Cartesian coordinates are used with fixed latitude and the Boussinesque approximation assumed.

The major problem in such models as the one given above is that no analytical solutions are available for them nor are the mixing and turbulence parameters known. Thus, unlike the two dimensional tidal numerical models for well-mixed estuaries the more general models cannot be adequately tested at present. Because the remedy requires time series synoptic data which requires a large effort too great for individual researchers or even single agencies. It was to overcome these problems that the proposed Joint International Fjord Experiment was originated.

JOINT INTERNATIONAL FJORD EXPERIMENT (JIFE)

To overcome the lack of time-series synoptic data for fjord estuaries a joint experiment by agencies with a long-time interest in fjord inlets has been proposed. We plan to conduct detailed survey of a topographically simple inlet using multiple current meter arrays, ships' tide guages and weather stations. The Universities of Alaksa, Washington and Oregon State, NOAA and EPA are presently planning to participate in the first experigmnt. The first field experiment will be in April 1974 in Hood Canal, Washington. This site was chosen for its simple topography, wealth of background data and location convenient for most participants.

The central idea of the proposed experiment is that it will be carried out with existing equipment as inexpensively as possible. All the present participants have ongoing projects concerned with fjords and have specific needs for the results of the experiment. The 1974 experiment is designed as a preliminary to a major experiment in 1975. In the first year we hope to find the optimal spacing and arrangement of current meters so that coherence is observed and first and second order gradients can be computed. From these current measurements and the time-series STD results we hope to evaluate spatial and temporal variations of turbulent diffusion coefficients. Values of these coefficients are essential to circulation models such as proposed by Matthews (1972) or Winter and Banse (1972).

MODEL RESULTS

The philosophy behind the fjord numerical modeling program that the University of Alaska has been briefly reviewed above and the present state-of-the-art given. We are continuing our work on trying to find the best methods to test and evaluate model performance and different methods of examining the great volumes of data that can be accumulated with or for numerical models.

From our steady state tidal numerical models we have customarily stored every computed value of tide height and currents during the final tidal cycle. This is stored on tape and examined later by analytical programs. To achieve any kind of understanding of the results one must go to some kind of visual display. For tides we have used cotidal and cophase contours or plots of current vectors. Perhaps the most graphic presentation is the exag-

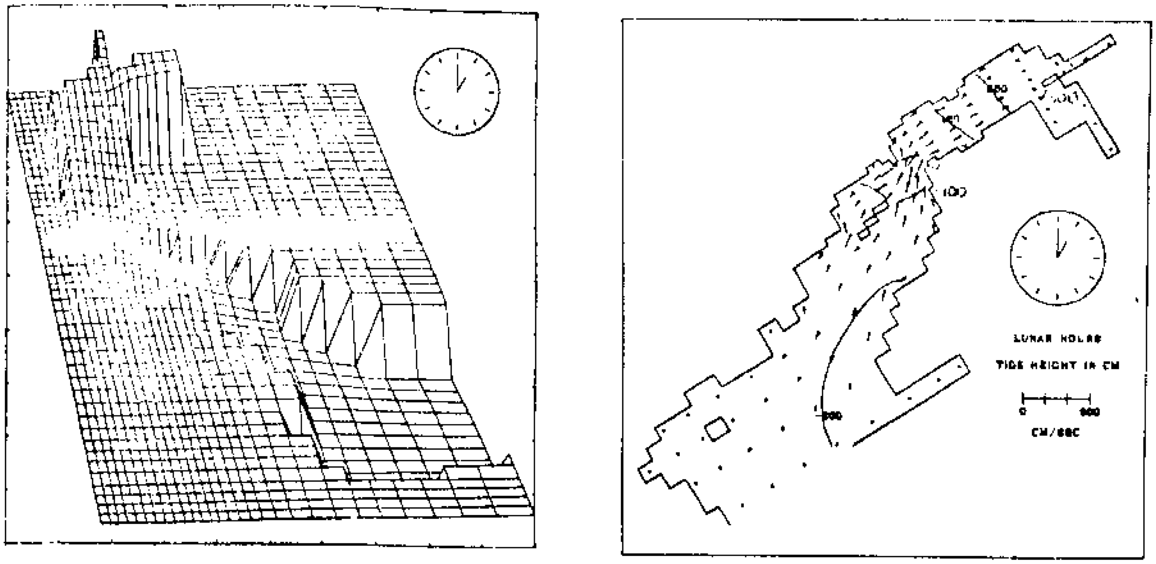

Figure 1. Two frames from a movie of the M2 tide of Cook Inlet showing left, an exaggerated sea level perspective and right, superimposed current vectors and cotidal lines.

gerated perspectives plot such as the one shown in Figure 1.

However, even for a relatively simple tidal solution one rapidly becomes inundated with plots and has difficulty in following the dynamics involved. We have used the film technique which has been employed by several ocean modelers with considerable effect. In this technique plots of some property distribution with time are photographed on consecutive frames of movie film. The resulting film when projected shows the movement of the property with time, usually at a faster-than-normal rate.

Using this technique we have produced a movie of the M2 tides of Cook Inlet, Alaska, and the Irish Sea. Sequences of both perspective plots and superimposed current vectors and cotidal lines were produced in color. Examples of both types of frames are shown for Cook Inlet one hour after high tide at Anchorage in Figure 1. The dynamics of the tidal movement came through very clearly in this kind of presentation. It is very simple to see how the Coriolis effect results in a larger tidal range on the south bank of Cook Inlet than on the north bank for example.

Our future plans after successful development of the 3D model and testing against JIFE data include experimentation with visual technqiues for displaying temperature-salinity, density and other water quality properties. It is not improbable that such experiments could lead to the real time display on cathode ray tubes, of, for example, oil spill plumes or other results of environmental disasters. We in Alaska will be very happy if our work can contribute in some small way to this goal.

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Effect of Pulpmill Effluent on Dissolved Oxygen in a Stratified Estuary

R.R. Parker and J. Sibert, Research Scientists
Pacific Biological Station, Nanaimo, B.C.

Dissolved oxygen (DO) levels of receiving waters are often used as criteria to judge the effects of industrial discharges on environmental quality. Port Alberni (Figure 1), a highly stratified fjord estuary, is such a case. A large integrated pulp and paper complex is situated in Port Alberni at the mouth of the Somass River (Figure 2). There is at least tacit agreement among industry and regulating agencies that DO should be maintained above 5 mg/l. Our study attempted to identify and quantify the functional relationships comprising the system responsible for DO levels in the estuary. In this paper we state conclusions relative to the main theme but supporting evidence is generally not included. A full treatment of all aspects is available in several manuscript and technical reports, e.g., Kask and Park, MS 1972; Parker and Sibert, MS 1972; Sibert and Parker, MS 1972; Parker, Sibert and Terhune, MS 1972; Anon., MS 1957. These may be obtained by request from the Pacific Biological Station, Nanaimo, B.C.

THE BLACK CLOUD HYPOTHESIS

Prior to construction of the pulp mill, dissolved oxygen concentrations were near saturation in the upper zone (Figure 3). Deep water contained relatively little O_2, generally about 4 mg/l. Immediately under the halocline there was usually more O_2 present than might be expected from mixing processes alone. Supersaturation often was observed in this stratum. These surpluses could exist only if sufficient solar energy penetrated to that level making photosynthetic oxygen production possible.

In 1970 the upper zone was characterized by lower DO, an obvious response to the bacterial biomass feeding on mill waste. When the mill was not operating, DO values in that stratum increased to saturation,

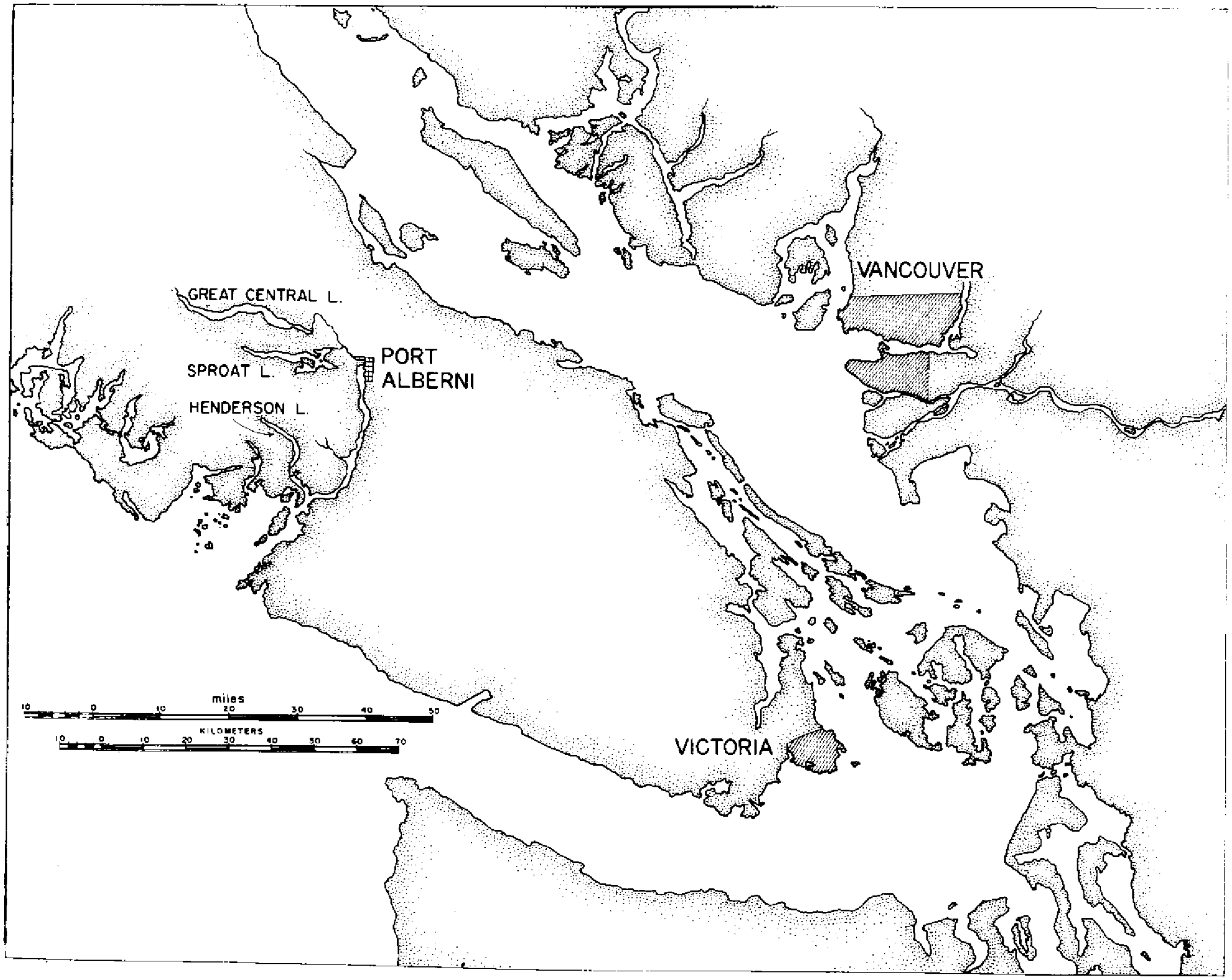

Figure 1. Map of southern Vancouver Island, B.D., showing location of study.

Figure 2. Aeriel photograph of Port Alberni and the Somass River mouth. Courtesy of MacMillan Bloedel Ltd.

and decreased again when the mill resumed activity. The sharpest contrast in this "before and after" comparison is between DO values immediately under the halocline. The mill effluent apparently had altered the balance between O_2 production and consumption at that level, even though the non-particulate component of the mill waste is confined to the halocline and upper zones. An important source of oxygen to the upper zone, through entrainment, has been eliminated. Thus the observed decrease in DO in the upper zone is due to two dissimilar immediate causes: One, the biochemical oxygen demand (BOD) of the mill effluent discharged with the fresh water component; the other, the low (often less than 2 mg O_2/1) DO level of the marine water being entrained.

We call this our "Black Cloud Hypothesis" because we believe the later phenomenon is caused by blockage of light penetration by humic stain in the mill waste. While a small amount of net production is possible in the upper zone, the compensation depth (Figure 4) rarely extends to the stratum under the halocline while the mill is operating.

A NUMERICAL MODEL

The Black Cloud Hypothesis has three components: (1) blockage of photosynthesis due to the shading effect of the mill stain, (2) respiration, and (3) estuarine circulation. To test whether the consequences of such a hypothesis are quantitatively consistent with the observations, a simple numerical model was developed.

The model is based on the well-known concept of the chemostat or continuous culture apparatus (Herbert *et al.*, 1956). To simulate the oxygen dynamics system of Alberni Inlet with a numerical model, 16 chemostat units are coupled vertically so that the output of each unit is the input of the unit directly above. In addition, each unit has a second input and output in the horizontal direction (Figure 5). The basic equation expressing the rate of change of a solute in any single unit is:

$$\frac{dX}{dt} = f_1X_1 + f_2X_2 - (f_1 + f_2)X + \Sigma S_x$$

where X is the concentration of the solute in the unit, X_1 is the concentration in the reservoir (R_1) associated with the flow rate f_1, X_2 is the concentration of the solute in the underlying unit associated with the flow rate f_2, and ΣS_x represents the sum of all sources and sinks of X associated with non-conservative processes. In the case of the bottom chemostat unit X^2 is the concentration of the solute in the reservoir, R_2.

The model consists of five such equations representing the states of dissolved oxygen, bacterial biomass, bacterial nutrient, algal biomass and mill stain. Pulp mill effluent is considered to have two components, bacterial nutrient and stain, which are related to measurements of BOD and effluent color made tt the mill.

The non-conservative terms, S_x, contain models of biological processes. For oxygen there are two non-conservative terms, bacterial respiration and net algal production. Bacterial respiration is related to the biomass of bacteria. Net algal production

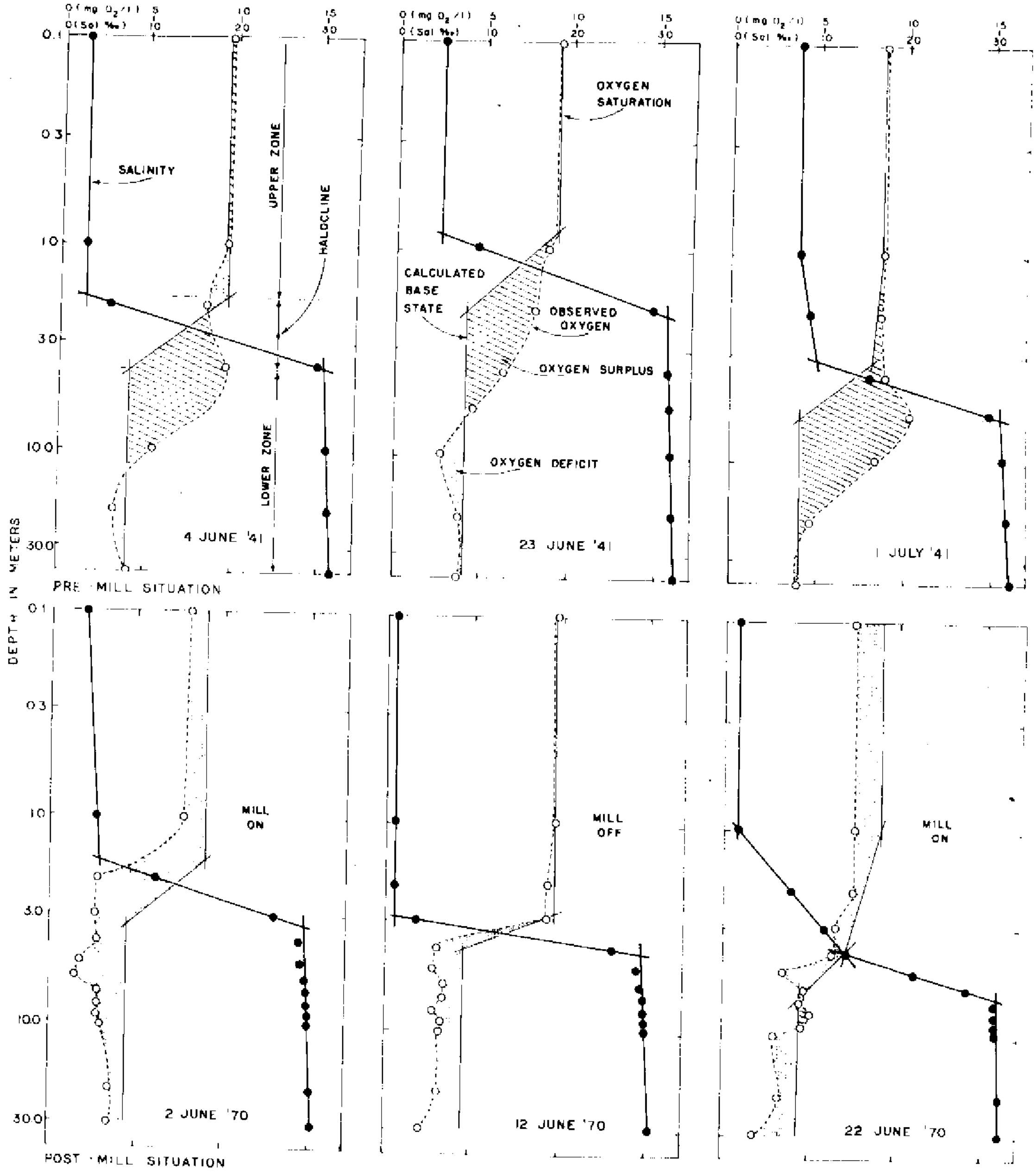

Figure 3. Comparisons of observed oxygen profiles with predicted base states for pre- and post-mill operation periods.

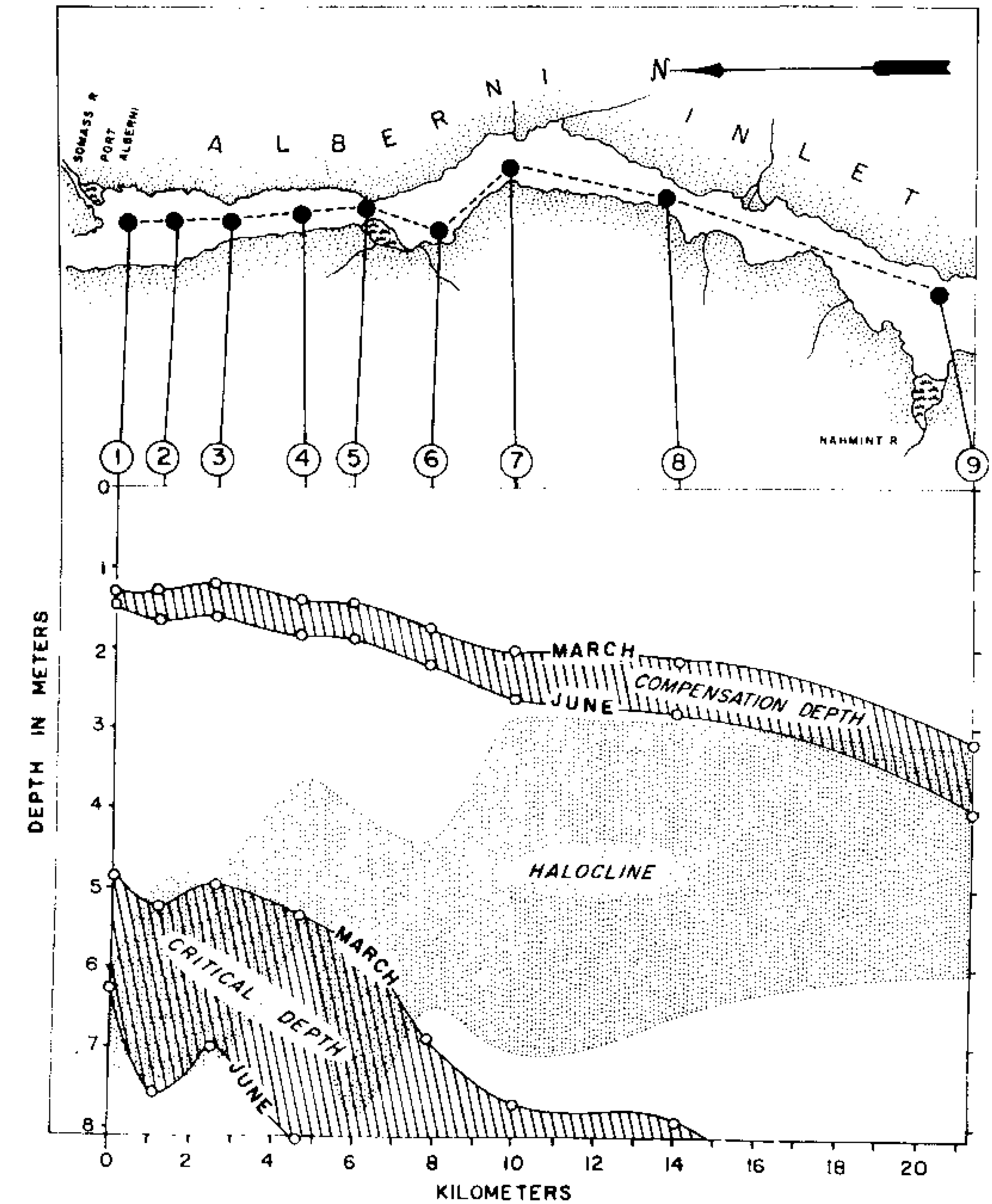

Figure 4. Horizontal distribution of compensation and critical depths in relation to the halocline 6 August 1970.

is a function of algal biomass and light intensity only. Light intensity decreases exponentially with depth according to the transparency of the water. Transparency is decreased by "natural" turbidity, mill stain, and algal biomass.

An example of the output produced by the model is shown in Figure 6. In this run, there was no mill effluent entering the model, and after 12 days, a steady state is achieved. The resultant O_2 profile is not unlike those observed in the Inlet with near saturation concentrations above the halocline. At day 13, mill effluent is introduced. Immediately, the oxygen concentration and the algal biomass decrease, and the bacterial biomass increases. By day 15, a new steady state is achieved. Primary production is practically nil and O_2 concentrations are less than 4 and generally between 2 and 3 mg/l throughout the water column. On day 19, the concentration of BOD is reduced from 200 to 100 units resulting in a decrease of the bacterial biomass and restoration of some of the oxygen above the halocline. Primary production remains nil and there is little O_2 below the halocline. During the next few simulated days, the stain content of the effluent is gradually reduced from the initial value of 800 units. Not until iteration day 45, where the stain is 75 units, do anything like normal production and DO levels return to the water column. On day 51, the effluent is removed and productivity is restored to the pre-mill level.

The model effectively demonstrates that the large amount of stain introduced into the surface waters of the estuary can practically eliminate primary production both in the upper mixed zone and below the halocline. As a result, the DO remaining in the water column is rapidly respired by bacteria and other organisms. The control or removal of BOD has no effect on the dissolved oxygen below the halocline. These results are consistent with the Black Cloud Hypothesis. The model further suggests that about 90 per cent of the stain must be removed in order to restore the oxygen generating system.

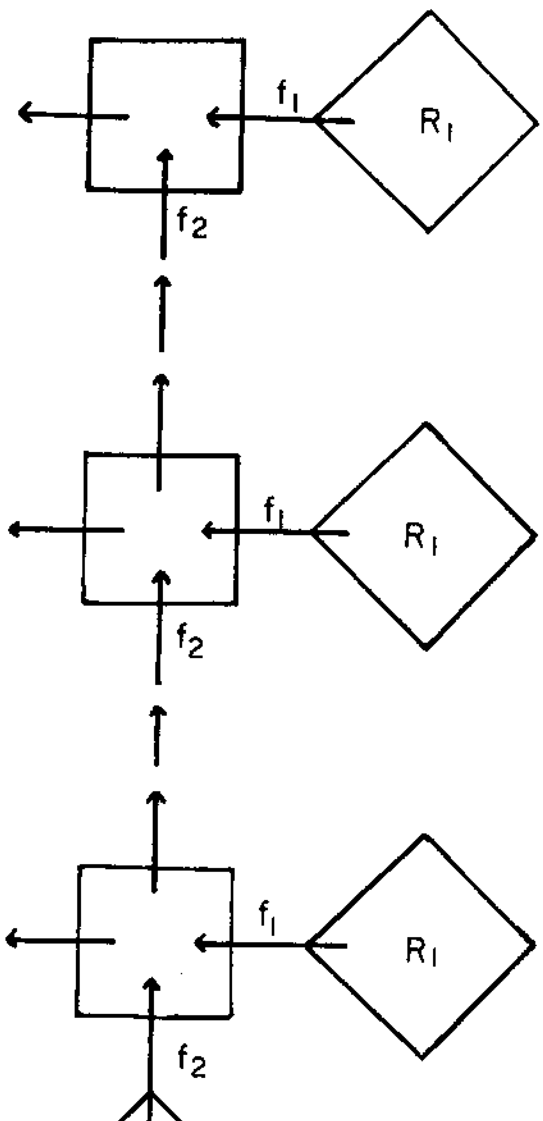

Figure 5. Schematic representation of the coupled chemostat model. Squares represent the chemostat units, diamonds the reservoirs (R_1 and R_2), and arrows the flow of material (f_1 and f_2).

SOURCE WATER FOR ENTRAINMENT

Alternative systems, quite different in the extreme, may be visualized in the entrainment process. At one extreme,

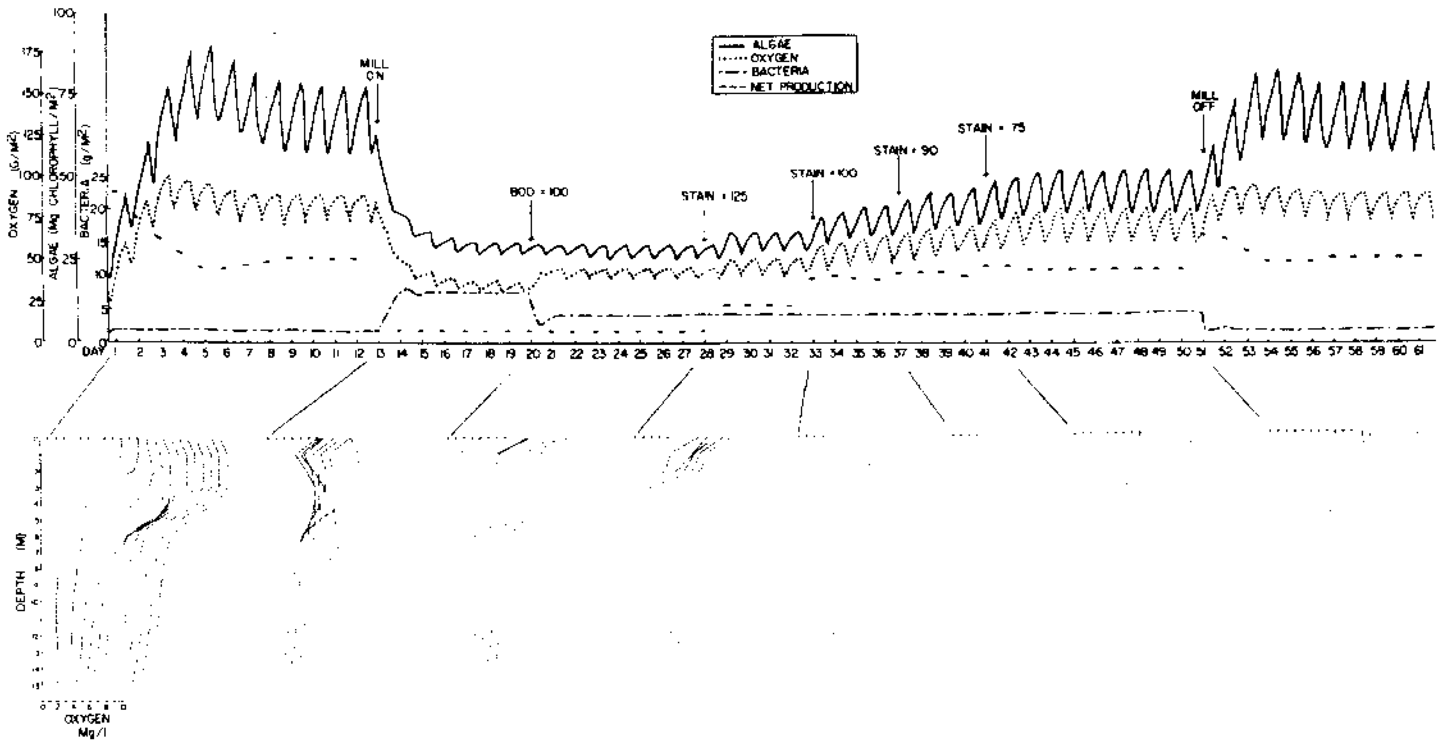

Figure 6. Output from the coupled chemostat model. Upper part shows the totals of algal biomass, oxygen concentration, bacterial biomass, and net production summed over the 16 chemostat units at the end of each iteration. The lower part shows profiles of oxygen concentration at noon of each simulated day in the 16 chemostat units corresponding to different depths in the inlet. The origin for each successive plot, indicated by the cross (+), has been displaced to the right along the abcissa by the equivalent of 1 g/m^3 of oxygen on the scale.

the sea water entrained into the upper zone is carried up inlet in a relatively intense current immediately under the halocline. In this case, the water would be submerged below the halocline for a relatively short period, depending on the length of the fjord, and would remain within the euphotic zone (given clear water in the upper zone). At the other extreme, up inlet transport is a gradual process involving slow, up inlet movement of water well below the euphotic zone. In this case, source water to the head of the inlet would be deep water, and would remain submerged for a relatively long period. In the first, case, photosynthesis would tend to maintain and supplement a high oxygen content in source water; in the second case, source water would re-enter the euphotic zone in an oxygen depleted state from the depths. These two transport systems may be associated with different rates of river discharge, with high river discharge associated with the first system and low river discharge with the second (Rattray, 1967).

The importance of this distinction for Alberni Inlet lies in the presence of mill stain in the upper mixed layer. This stain prevents photosynthesis from maintaining the DO concentration in landward flowing water below the halocline. If the landward flowing water is very deep, much more stain must be removed from the upper mixed layer in order to restore oxygen production below the halocline than if the landward flowing water is confined to a relatively thin stratum immediately below the halocline. Furthermore, respiration can remove more oxygen from the water if it is moving slowly and thus out of contact with the surface for a longer period than if it were moved rapidly.

Results of a current study made from a single station 4 km seaward of the mill 21-22 July 1971, are shown in Figure 7. Vertical current profiles were measured hourly to a depth of 25 m over a 26-hour period, employing a Chesapeake Bay drogue (Pritchard and Burt, 1951). The main assumption implicit in this type of study is that current profiles measured at the station are reprsentative of the entire cross-section of the inlet at that point. Unfortunately, this assumption cannot easily be tested.

We accumulated transport volumes in respect to the position of the bottom of the halocline. The results clearly show that net transport was seaward or nil in all strata to nearly 15 meters below the halocline, i.e., to a depth of approximately 20 m. In other words, sea water was not moving landward in a well defined layer immediately below the halocline, but rather as a gradual movement of the deep water.

Further evidence on the question of depth of flow of source water for entrainment can come from an interpretation of the distribution of properties of the sea water in the inlet. Nitrate, while non-conservative, can serve as a useful indicator. Isopleths of nitrate concentration in two along-inlet vertical planes were estimated from measurements taken on 24 June 1971 and 9-10 August 1971.

The freshwater discharge of the Somass River is regulated to exceed 1000 cubic feet per second (CFS) and may occasionally exceed 15,000 CFS during peak flow. During the year 1971, discharge was generally greater than 2000 CFS. The nitrate measurements made on 24 June (Figure 8) were made during a period of relatively high river discharge--about 4500 CFS. The halocline is relatively deep, reflecting the large volume of the upper mixed zone. There is only a slight suggestion of upwelling at the head of the inlet and NO_3 values were less than 12 µg-at N/l in the top 20 m of the upper one-half of the inlet.

In contrast, NO_3 isopleths suggest a strong upwelling at the head of the inlet during the 9-10 August 1971 series (Figure 9). This was a period of relatively low river discharge--about 2300 CFS. The halocline was relativley shallow (2-3 m) and values of NO_3 greater than 14 µg-at N/l penetrated upward from below 20 m depth to the bottom of the halocline. The current drogue studies were made during 21-22 July, a period of moderate river discharge--about 4000 CFS. Thus at times of low to moderate river discharge the inflow of marine water to the head of Alberni Inlet appears to be a gradual process occurring well below 20 m depth.

Our conclusion from these studies is straightforward. Satisfactory oxygen levels cannot be maintained in the receiving waters at the head of Alberni Inlet unless a large proportion of the humic stain is removed from the mill effluent.

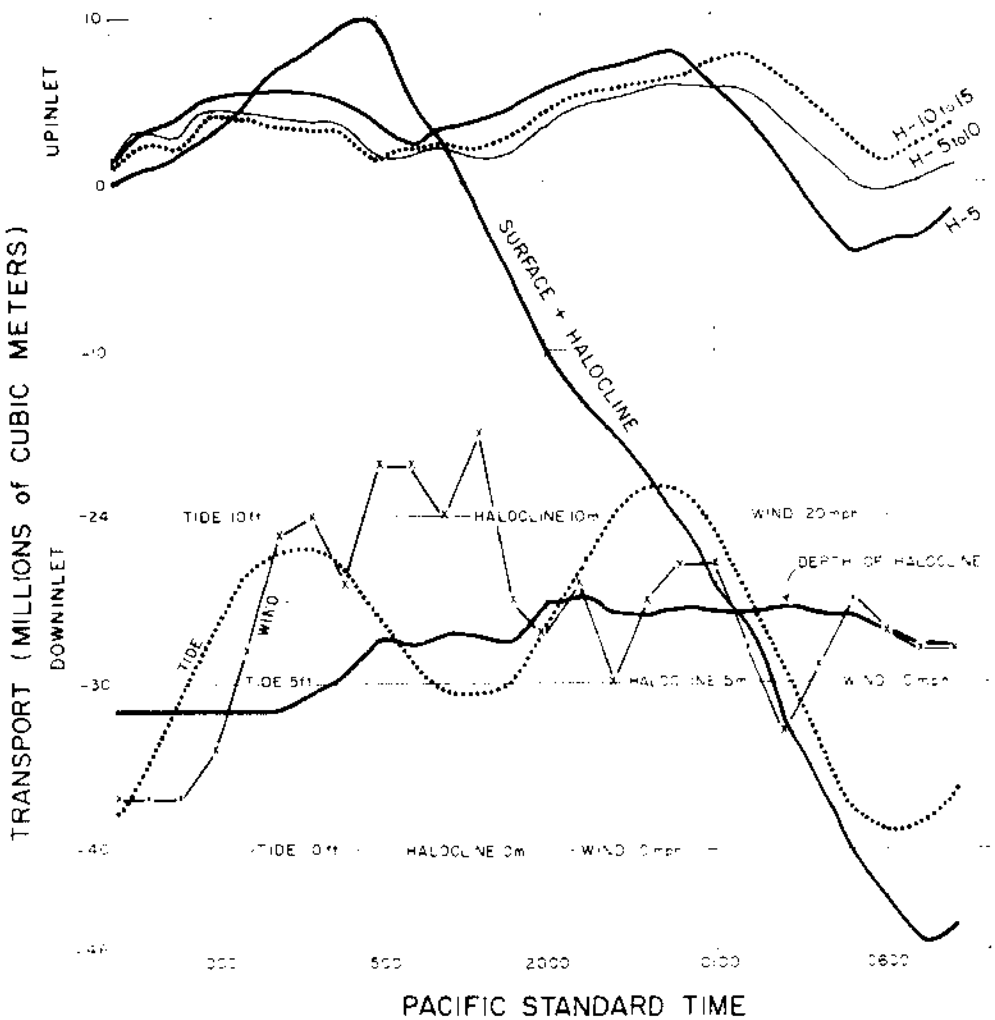

Figure 7. Accumulated transport ($10^6 m^3$) within the surface layer (to bottom of halocline) and three successive 5 metre layers underlying the halocline shown with reference to wind velocity, tidal height and depth to bottom of halocline. 21-22 July 1971.

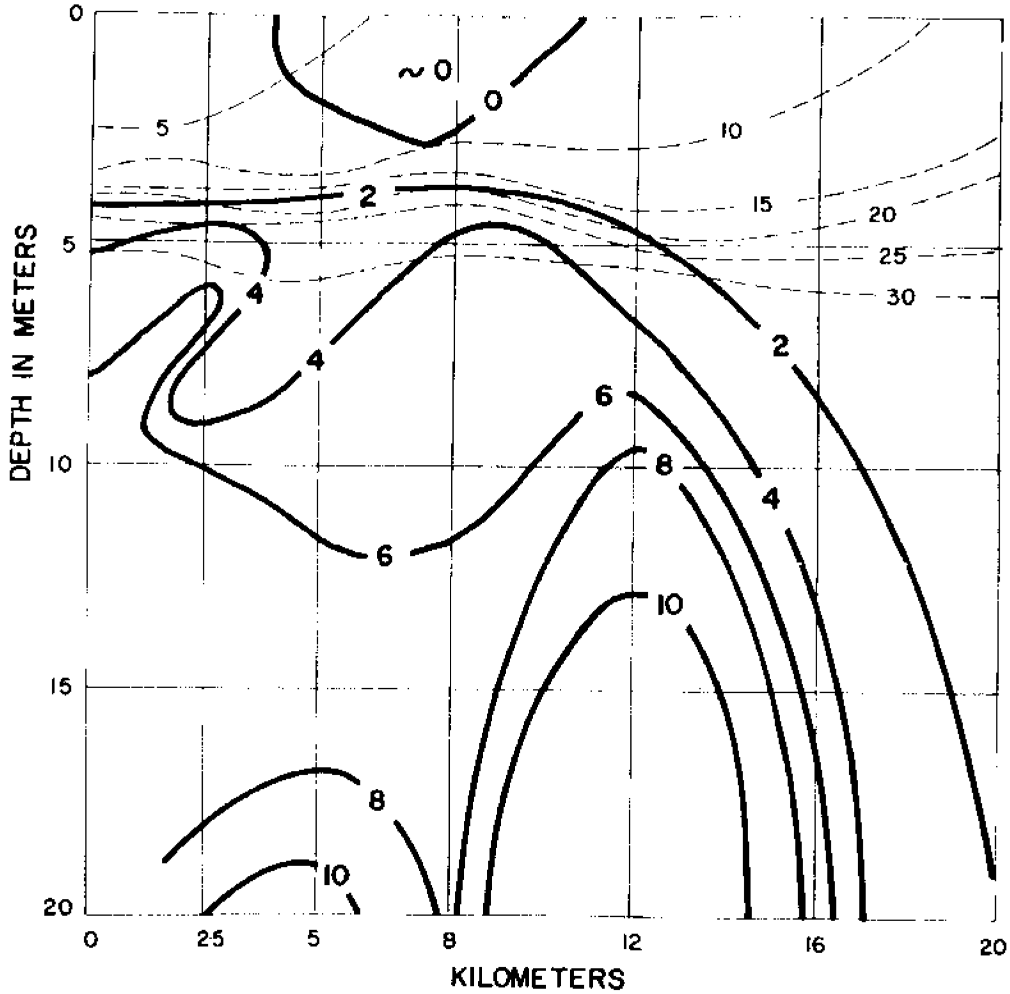

Figure 8. Distribution of nitrate (μg-at N/l) and conductivity (millimhos/cm) in Alberni Inlet, 24 June 1971.

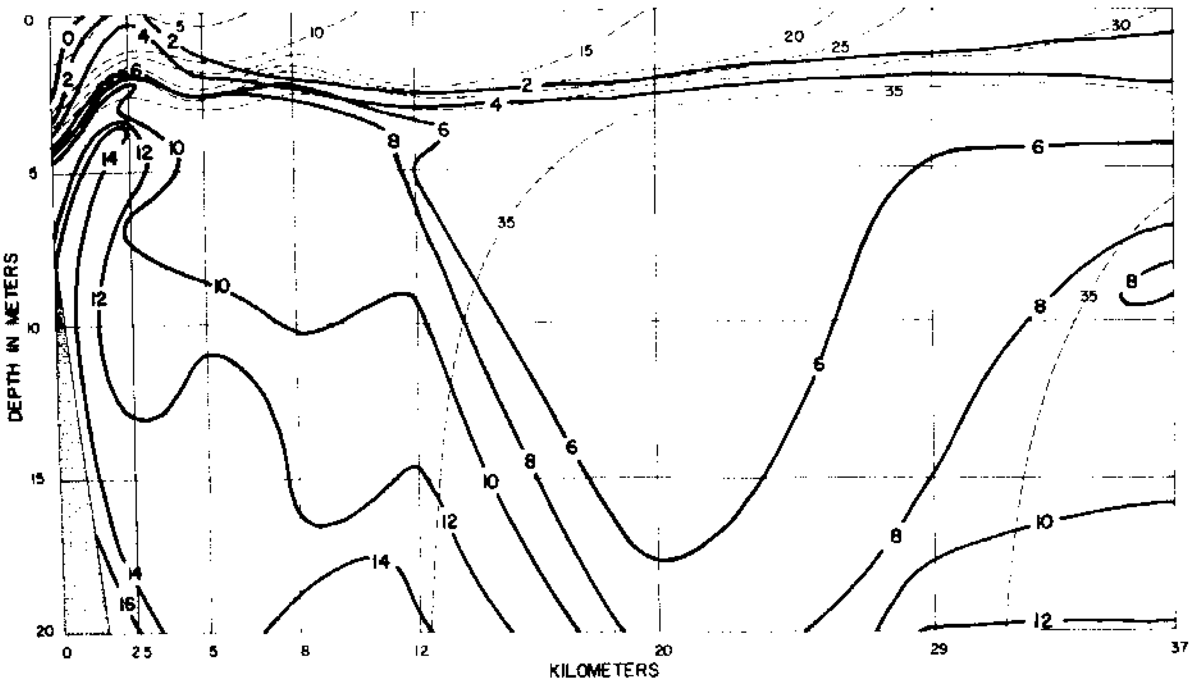

Figure 9. Distribution of nitrate (µg-at N/l) and conductivity (millimhos/cm) in Alberni Inlet, 9-10 August 1971.

SUMMARY

1) The level of dissolved oxygen in the upper mixed zone of Alberni Inlet is partially dependent on the supply of DO by the landward flowing marine water below the halocline. The oxygen content of this water is dependent on photoshythesis. Large amounts of humic stain within the upper mixed layer prevent net photosynthetic production of oxygen in the underlying stratum.

2) A numerical model of the oxygen dynamics of the inlet demonstrated that removal of BOD from the pulp mill waste only slightly increased the DO of the upper mixed layer. Approximately 90 per cent of the stain must be removed from the effluent to recover near-normal osygenation of the inlet.

3) Studies of currents and the distribution of nitrate suggest that marine water which is entrained into the upper mixed layer usually moves up the inlet slowly and at considerable depth. This kind of motion makes it of great importance to maintain the clarity of the upper mixed layer, particularly at the head of the inlet.

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3-D Measurement of Estuarine Circulation Using Tracer Dye

Terry Ewart and William Bendiner
Ocean Physics Group
Applied Physics Laboratory, Seattle

The complex uses to which we put inland waters must be governed by careful observation and modeling, and by the ability to predict the results of our activities and demands. As the demands increase, then, so must the sophistication of our understanding, if we expect to prevent the degradation of our surroundings. We present here a tracer technique for studying 3-D estuarine circulation and dispersion in more detail than previous methods have allowed. Using a towed instrument package, we have conducted one such study with reasonable success; we will try to point out the pitfalls we found, and to weigh the difficulties against the particular benefits of our method.

EXPERIMENTAL MODEL

Faced with the problem of designing an experiment, one hopes (ideally) for a model, or some conceptual framework, as a guide. Available models lag far behind the supply of complexities in natural systems; in the case at hand, very far behind, indeed. The area around Kiket Island, Wn., is characterized by extremely strong tidal flows, complex geometry, and seasonally changing stratification. It is principally connected to the Straits of Juan de Fuca through Deception Pass to the west and also to Possession Sound to the south. The mouth of the Skagit River lies just south of the study area. No mathematical model we know of can handle such a system. But certainly strong stratification and highly irregular geometry suggest that observations must be made in three dimensions. Furthermore, any significant unsteadiness or periodicity imposes certain sampling requirements: questions of suitable averages and the fluctuations around them will be important. In terms of realistic pollution control, the relevant question becomes not "What is the peak (or average) contamination in the system?" but "How dirty is a given volume in a given place likely to get, and how long will it stay that way?" Putting the question this way is of particular importance to biological studies, for often the impact of a contaminant on the biosphere is dependent not on the average concentration, but on the duration and frequency of local peaks.

Such sampling requirements would seem to limit the usefulness of some present techniques except in special cases. An airborne tracer-detection system[1] for instance, has the advantage of extremely fast sampling over wide areas, but sacrifices all the information about depth dependence. On the other hand, discrete water sampling would require huge numbers of samples; the next section suggests just how huge the number might be. Our method occupies something of a middle ground: slower than airborne systems, it still provides fairly fast 3-D sampling over a large volume, while avoiding the necessity of thousands of simultaneous discrete samples.

DATA REQUIREMENTS

It is instructive, in a depressing sort of way, to look at the data requirements implied in the previous section. Our method involves towing an instrument package around a fixed track in the area of interest, while cycling it between the surface and the bottom. Since tidal action is dominant, and we are generally interested in conditions on both ebb and flood, we should sample the entire track at least as often as every three hours. The towing speed is fixed by the power of the boat and currents, the drag of the instruments, the strength of the cable, etc., in our case at four knots (~2 m/sec); thus, the track length was limited to 12 n.m. A decision must be made as to whether the area can be sufficiently covered by such a track; in the case of the Kiket Island study, there was only one section which we could not cover, but we did not deem it essential. We found the maximum vertical lowering rate of our instrument package to be about 1 m/sec, while the average depth of the study area was about 25 m. Given our towing speed, this implied a sample every 50 m horizontally (at mid-depth). Since stratification and strong vertical gradients were expected, we felt it desirable to record a point every vertical meter, i.e. once per second. In a dye study, one would like to record at each point the concentration, temperature, salinity, depth, time, and a manual event number (to help sort the data), a total of six channels. In order to follow the buildup of the continuously released dye, to determine the steady-state condition if there is one, and to follow the decay after the end of the dye release (because the time constants thus obtained are interesting parameters), one is obliged to take data for something on the order of a week (this requirement, of course, depends on the system under study). At the end of six days, simple calculation tells us we have accumulated 3×10^6 data words. Several such experiments may be required to examine the seasonal variations; e.g. in the present case, we carried out experiments in March and June (1971). One must be prepared to deal with such accumulations.

Note that these requirements do not depend so much on a particular method but on the variability of the environment under study and the detail with which it is necessary to study it. Of course, if there is at hand a model in which we have confidence --whether it be based on simplifying assumptions suitable for simpler systems or on previous observations--then subsequent measurements do not need to be nearly as detailed. Leendertse *et al*[2] provide such a case in their study of Jamaica Bay, N.Y., in which observations over a modest length of time, at only a few locations, were sufficient to adjust their model. But the model must come first, and the less information it contains (i.e., the more primitive it is), the greater must be the observational effort. The observations will provide only phenomenological values and it must be shown in the subsequent analysis whether the data are sufficient to describe the system, in terms of, for example, distribution functions or temporal and spatial stability. From these general considerations, we now turn to the particular example under discussion and the techniques we used in that case.

ESTIMATION OF TEMPERATURE FIELD

Kiket Island, Wn. (see Figure 1), was the proposed site for a nuclear-powered generating station; the object of studies there was the assessment of the thermal impact of a once-through cooling system. Our immediate goal, then, was the estimation of the excess temperature field. The reactor was expected to release about 2.4×10^9 watts = 4.95×10^{13} calories/day to the coolant, which, with a planned pumping rate of 42.5 m^3/sec (1500 c.f.s.), implies a coolant temperature increase of about 11°C. We simulated this heat discharge by the continuous release

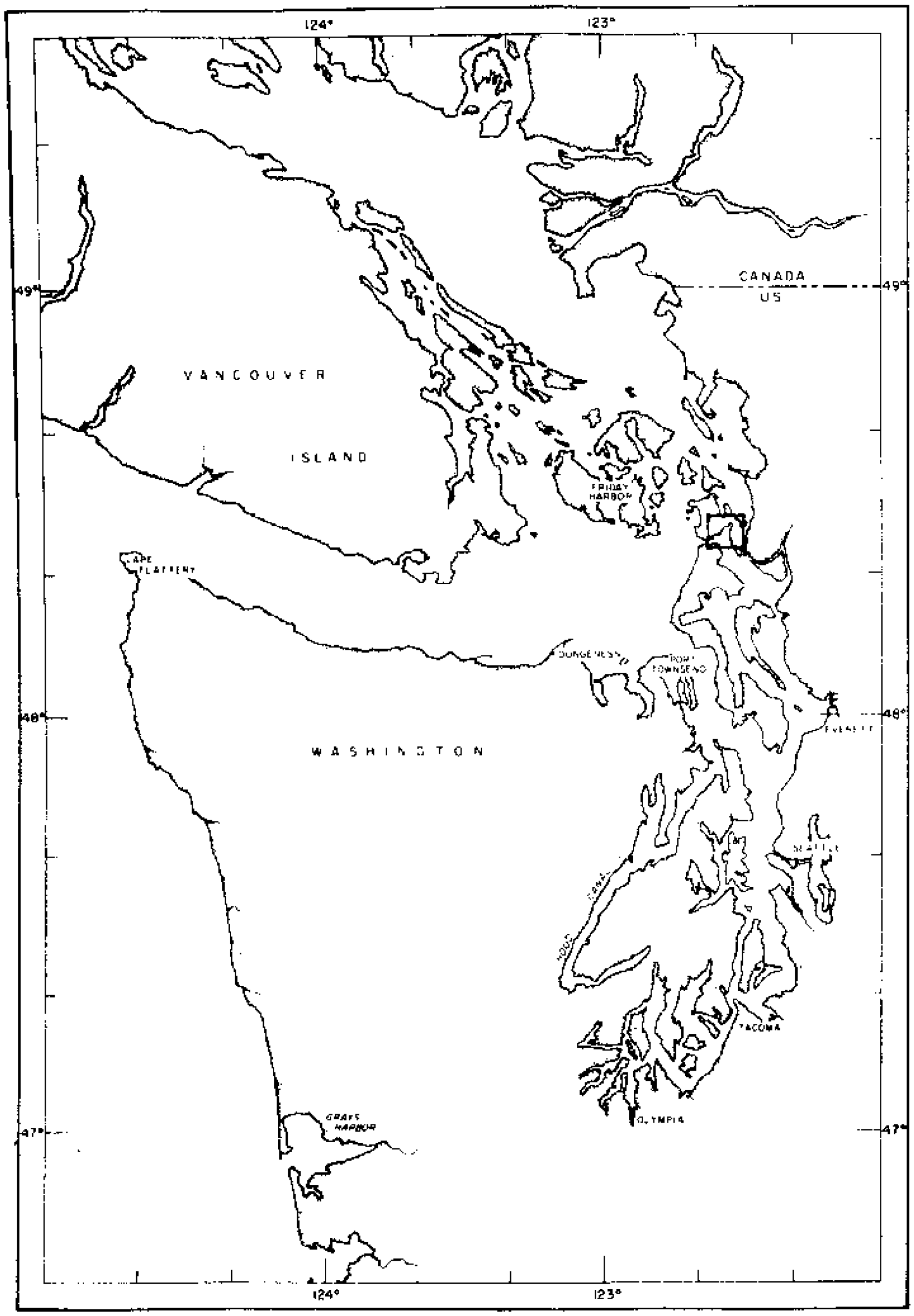

Figure 1. Location map, with box indicating the Kiket Island study region.

at a fixed point of 45.3 kg/day of Rhodamine B dye, so that, assuming conservation of heat and dye, 1 gram of dye = 1.09×10^9 calories, or 10^{-11}g/cm^3 = 0.011°C excess temperature. Since the background fluorescence detected by our *in situ* fluorometer at Kiket was equivalent to 3×10^{-11}g/cm^3, and full scale reading is 10^{-8}g/cm^3, we were able to detect equivalent excess temperatures in the range 0.03-11.0°C. The former temperature is near the accuracy limit of our ambient temperature measurement, while the latter is about the planned effluent release (excess) temperature.

Insofar as heat and dye behave identically in a natural system, we can predict the one as accurately as we can measure the other. One obvious difference in behavior lies in the loss of heat to the atmosphere. The work of Pritchard and Carter[3] and of Roesner[4], however, indicates that in our case, this will be at most a 5-10 per cent loss, which we have ignored. Also, Rhodamine B is subject to photo-decay and adsorption onto particulate matter, but measurements of these effects by Carter[5] indicate that they, too, can be safely ignored. Thus, the major problem is the simulation of the plume in size and buoyancy.

In order to come as close as possible to the dynamics of a buoyant thermal plume, we mixed the dye with fresh water and surface water, then released it from a 30 m diffuser pipe. The pipe was slung, at about 3 m depth beneath a barge taut-moored at one end (which held the fresh water and pumping apparatus), so that the diffuser moved very little but was always oriented perpendicular to the mean surface current. The dye solution was pumped

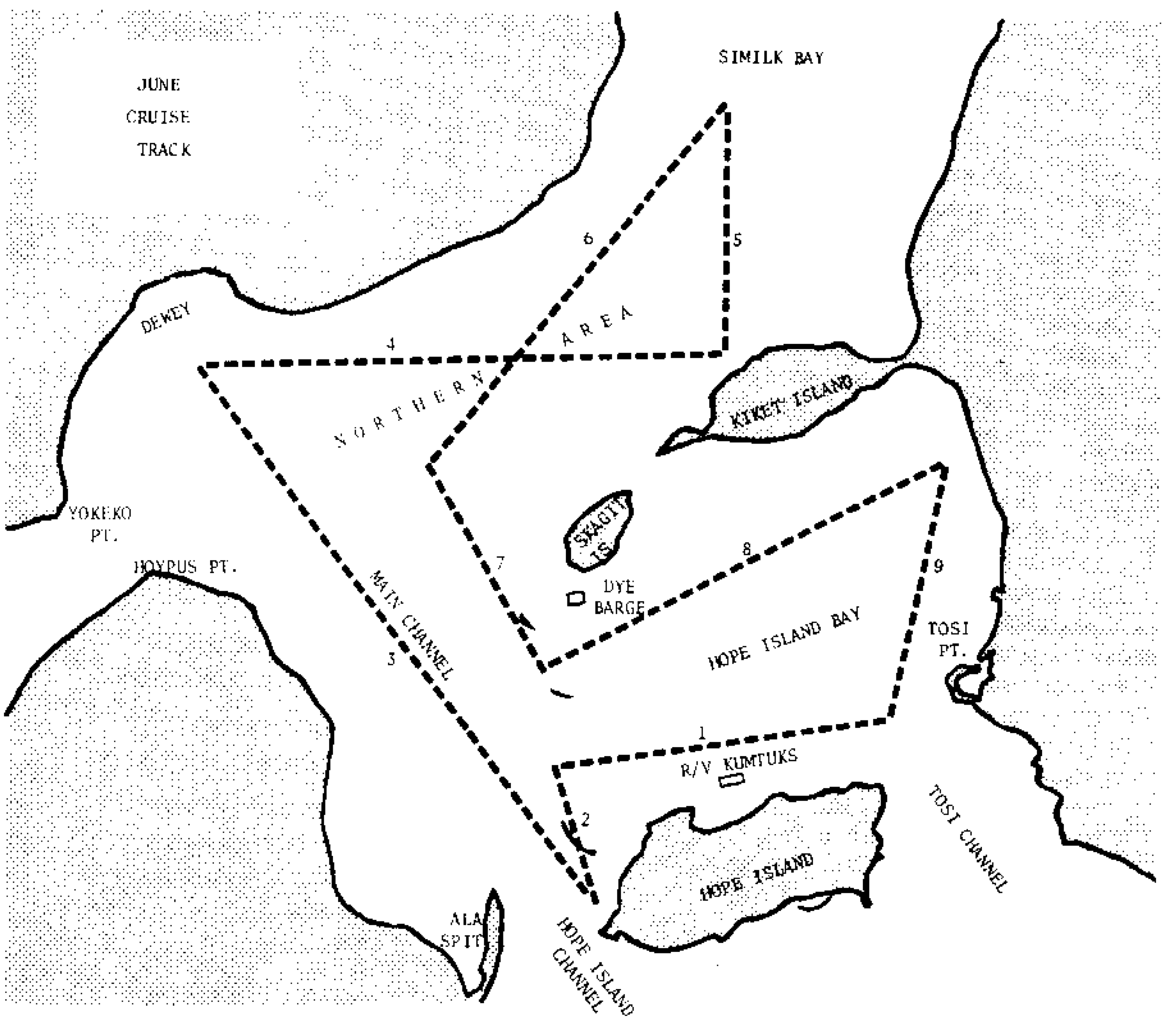

Figure 2. Detail map of Kiket Island study region.

at a rate of 1.4 x 10^4 cm^3/sec, and had, after mixing at the diffuser pipe, a density defect of about 5 x 10^4 per cent compared to surface water and an excess temperature equivalent of about 200°C. To come any closer to dynamic similarity to the planned reactor effluent was beyond practicality, since it is difficult to simulate a power plant without building one, but as we will see later, the details of the release are not too significant.

The selection of a discharge point for the plant being one of the desired results of the experiment, rather than an input, we were forced to choose a location for the dye release which looked reasonable from economic, navigational, and dynamic points of view, but the partially arbitrary nature of the choice must be recalled when interpreting the results. Our choice of release point, and the selected cruise track, are shown in Figure 2.

INSTRUMENTATION

We turn now to a description of the sensors which we used, of which the prime one is the *in situ* fluorometer. This instrument, developed by one of the authors (Dr. Terry Ewart), is shown in Figure 3. It is unique in several respects. First, interference filters (50Å bandwidth) provide extreme separation of the absorption and emission spectra, which helps to provide the maximum sensitivity of better than $10^{-12}g/cm^3$ Rhodamine. Second, the circuitry is very stable with respect to temperature and needs no adjustment for changes in the lamp intensity. Third, the instrument has a dynamic range of 10^3 on each of its four overlapping ranges, so that this experiment could be conducted without range-changing. The use of an *in situ* instrument eliminates the necessity of pumping samples to the surface, a procedure which would degrade spatial resolution at all but the shallowest depths.

Ambient temperature was measured with a glass bead thermistor incorporated into a Wien bridge oscillator circuit.[6] Resolution as about 0.9 mdeg C. Depth was measured by a bellows-and-potentiometer sensor which showed an unfortunate tendency toward hysteresis; this problem had to be dealt with in the course of data analysis. A sensor which didn't suffer from this defect would be a worthwhile improvement. Positioning was to have been provided by a Hastings-Raydist Type DM radio location system, involving two fixed shore stations and a shipboard unit. The system can,

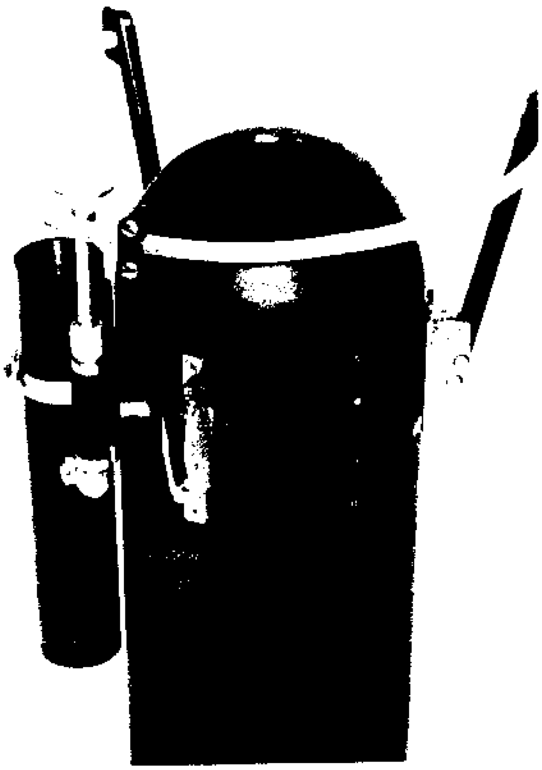

Figure 3. The APL fluorometer, with its guard ring, conical intake screen, and Venturi eductor. The eductor, on the suction side of the sample cell, was replaced for the Kiket Island cruises by a small submersible pump.

when working properly, give a fix to the nearest few feet, but it gave us instead a great deal of trouble, and most of its data--recorded along with the other measured variables--were not usable. In the final analysis, we depended on the accuracy of the radar navigation which we used to pilot the boat. This was aided by a number of buoys set along the track and fitted with radar transponders or reflectors. The passage of various legs of the cruise track and of the various buoys and landmarks (recorded in the manual event number channel), together with the real-time signal (also recorded), were used in lieu of the Raydist data.

All data were recorded on IBM-format digital magnetic tape through a specially designed data system. The system consists of 15 interchangeable channels, each of which can be tailored for type of signal (frequency, voltage, digital or some other). All data are converted into 10 or 12 bit words, and each channel is recorded sequentially once per second. As previously mentioned, real time (derived from a precision oscillator in the data system and available throughout the boat) and a manually entered event number are also recorded. In the Kiket experiments, we used 10 of the 15 channels, and found this system to be most satisfactory.

INSTRUMENT TOW

The steel cage containing the instruments (the "fish") was to be "flown" between bottom and surface as fast as possible over greatly varying bottom topography. In order to accomplish this safely, the winch operator was provided with a fathometer which had been modified to display the instrument depth (derived from the depth sensor) as well as water depth. A sample record is shown in Figure 4. The operator was also provided with readouts of fish depth, line out, and line speed (all recorded with the rest of the data). The winch itself was hydraulic and powered by a 14 h.p. gasoline engine. The addition of a hydraulic accumulator to the system

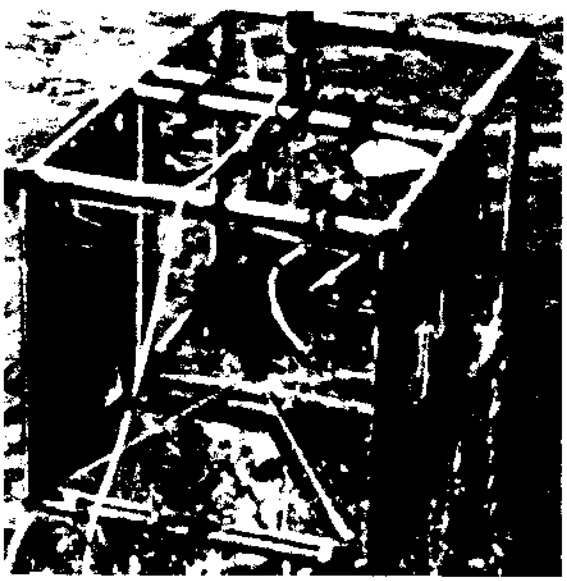

Figure 4. The instrument cage, or "fish." The gluorometer is tied into the center with nylon shock cord, along with the thermistor and vibrotron. The device at top right is a battery-operated sonic beacon which could be used to locate the cage if it were lost. The fluorometer pump, not visible here, is mounted under the beacon. A faired lead weight of about 250 lb hangs a few feet below the cage on a nylon line.

provided up to 50 h.p. output over several seconds, thereby allowing fast haul-in speed for emergencies. The operator was relieved every 30 minutes. With this system, the fish was cycled some 12,000 times in the course of the two experiments without mishap. A photograph of the "fish" is found in Figure 5.

The towing cable was a torpedo target towing cable, having 14 conductors and a center strain member. Although free, this cable was a poor choice. The large diameter (0.812") resulted in large drag which, combined with a modest 500 lb working load, severely limited the maximum towing speed. More serious, though, was the repeated breakage of conductors, which caused most of the lost time on both experiments. The breakage seemed to be the result of conductors sliding on the strain member as the cable passed repeatedly over the towing sheave. Multiplexing the signals onto a single (or few) conductor cable with an *outer* strain member would probably solve the problem.

One other difficulty, fortunately minor, is a common one in multi-sensor systems: the various sensors had different time constants, and were detected in the data system in different ways. (For example, the concentration signal, a frequency, was period-counted for one second, while the depth signal, a voltage, was sampled over a much shorter period.) More attention to uniformity in these respects would have eased the difficulties of processing the data.

This concludes the description of the experimental procedures. In the following sections, we take up the methods we used to look at the data, and note how the conclusions which we drew indeed indicate the necessity for extensive sampling in a system of this kind.

DATA ANALYSIS

The preliminary task of the data reduction included the elimination of bad points, extraneous (off-track) data, and conversion to real units. This involved about 150 man hours and 80 computer hours (on an IBM 1130). The March cruise (Kiket I) yielded 51 hours of good data (distributed over six days), the June cruise (Kiket II) 57 hours. We plotted vertical sections of dye and ambient temperature for each pass down the legs of the cruise track, as shown in Figures 6 and

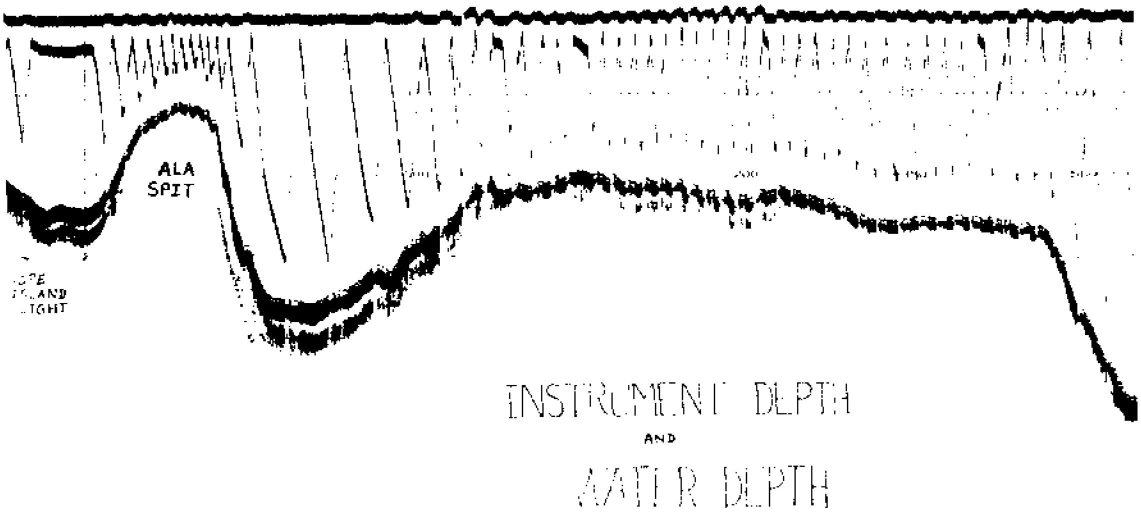

Figure 5. Winch control record used by the winch operator to fly the instrument package safely between the surface and the bottom.

7; the hexadecimal coding for excess and ambient temperatures is shown in each figure. These figures correspond to the fathometer record shown in Figure 5. Examination of a number of such sections shows, first of all, marked difference in stratification between March and June: the ambient temperature is nearly homogeneous with depth in March, and the dye distribution nearly so, away from the source. In June, on the other hand, both are strongly stratified. This, of course, is not unexpected; the March data reflect the low fresh water input from the Skagit, surface cooling, and stronger wind-induced mixing. But the difference suggests that we may proceed by dividing the system into depth zones for further comparison. On the basis of the June stratification, we chose the layers as 0-4, 4-8, 8-16, 16-bottom (all in meters). The vertical sections further show many sudden rises in concentration ("hot spots"), strongly stratified in June, much less so in March. Whether these are truly discrete spots, or rather, sections of continuous plumes or streamers cannot be determined from these sections alone, but we will return to this question shortly.

To proceed further, we averaged, within each layer, the concentrations in 150 m horizontal segments along the track. Now, averaging of data which displays variations on a continuum of scales must proceed cautiously and the results should be interpreted with care (see, for example, Jenkins and Watts[7]); in this case, we found the 150 m segment to be sufficiently small to avoid serious distortion of the results, but the averages are not all equally reliable, since the horizontal sampling interval varied with depth. These averages were then plotted, for each layer (for those occasions when we made a complete circuit), and contoured. Even more caution is necessary in interpreting these contours. In the first place, the data are not synoptic since the system changes considerably in the three hours necessary to complete the circuit. Secondly, we have drawn contours over an area which is thinly sampled by a linear track. These plots, therefore, can only be suggestions of what is really taking place. But they are carefully constructed taking into consideration the stage of the tide and what we already know from previous studies about circulation in the area, so we feel that they are qualitatively correct. They show a discontinuous array of plumes, jets, wakes and discrete spots, all highly variable in time. The dye plume emanating from the diffuser is broken into pieces which are advected around the area, diffusing independent of each other. Some examples from the March cruise are shown in Figures 8-11 (a detailed discussion is found in Bendiner, Ewart, and Linger[8]).

Scanning the vertical and horizontal sections yields the following general observations about the "patchiness" of the dye distribution. The spots and plumes

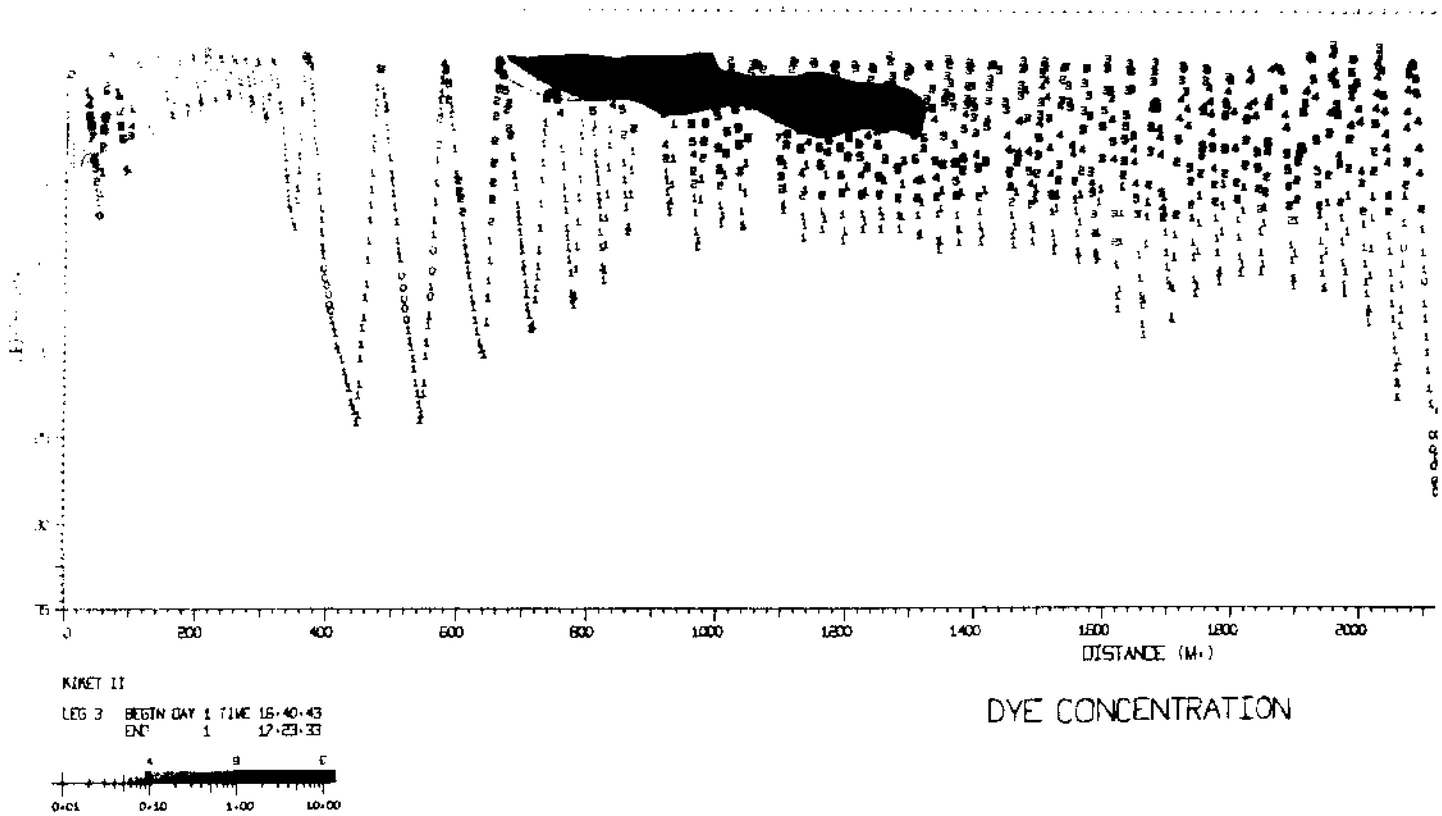

Figure 6. Dye concentration field measured on the leg shown in Figure 8. The hexadecimal digits, one for each recorded data point, represent concentration (in terms of excess temperature (^0C)) as shown in the legend.

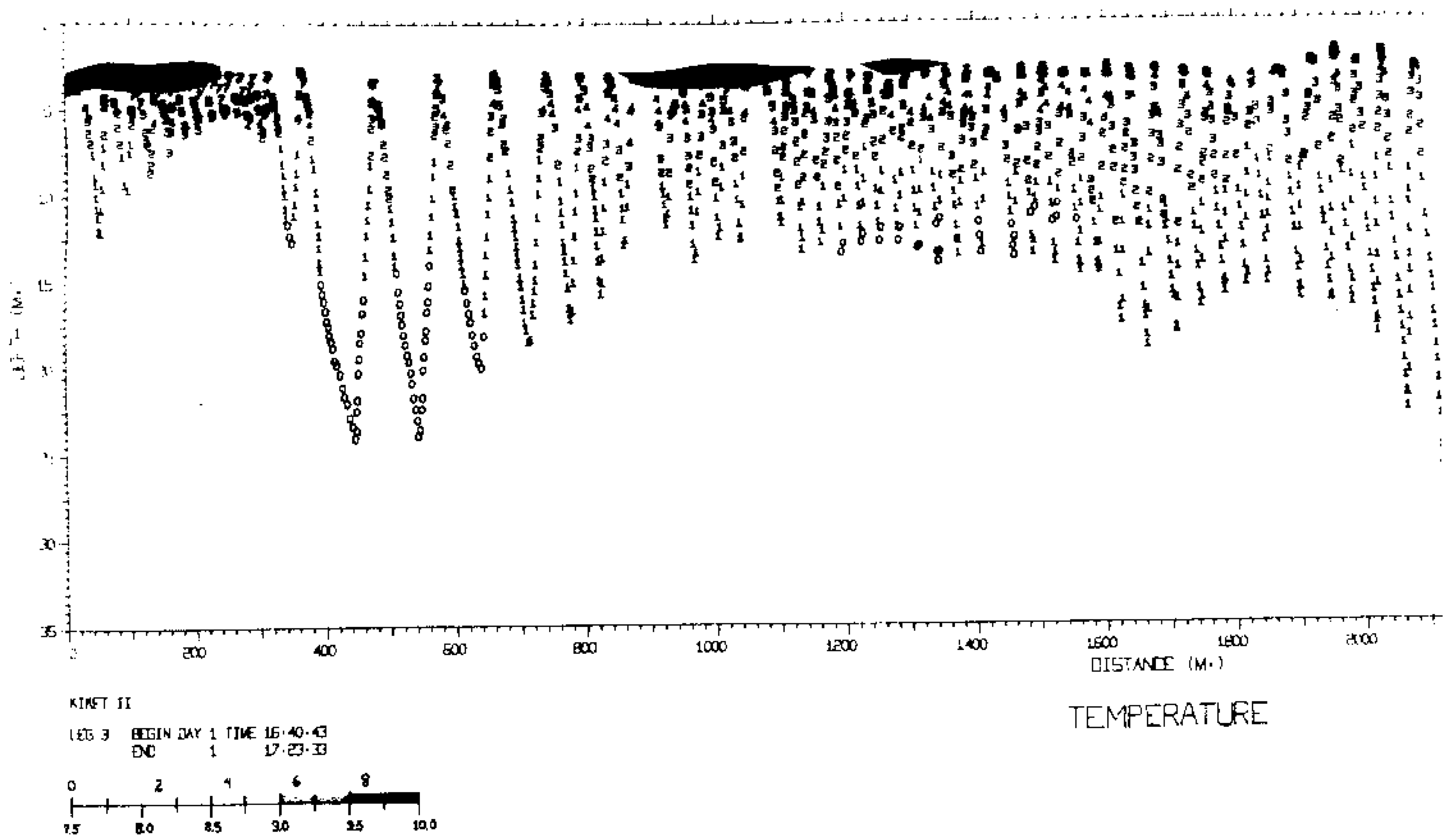

Figure 7. The ambient temperature data for the leg shown in Figures 8 and 9.

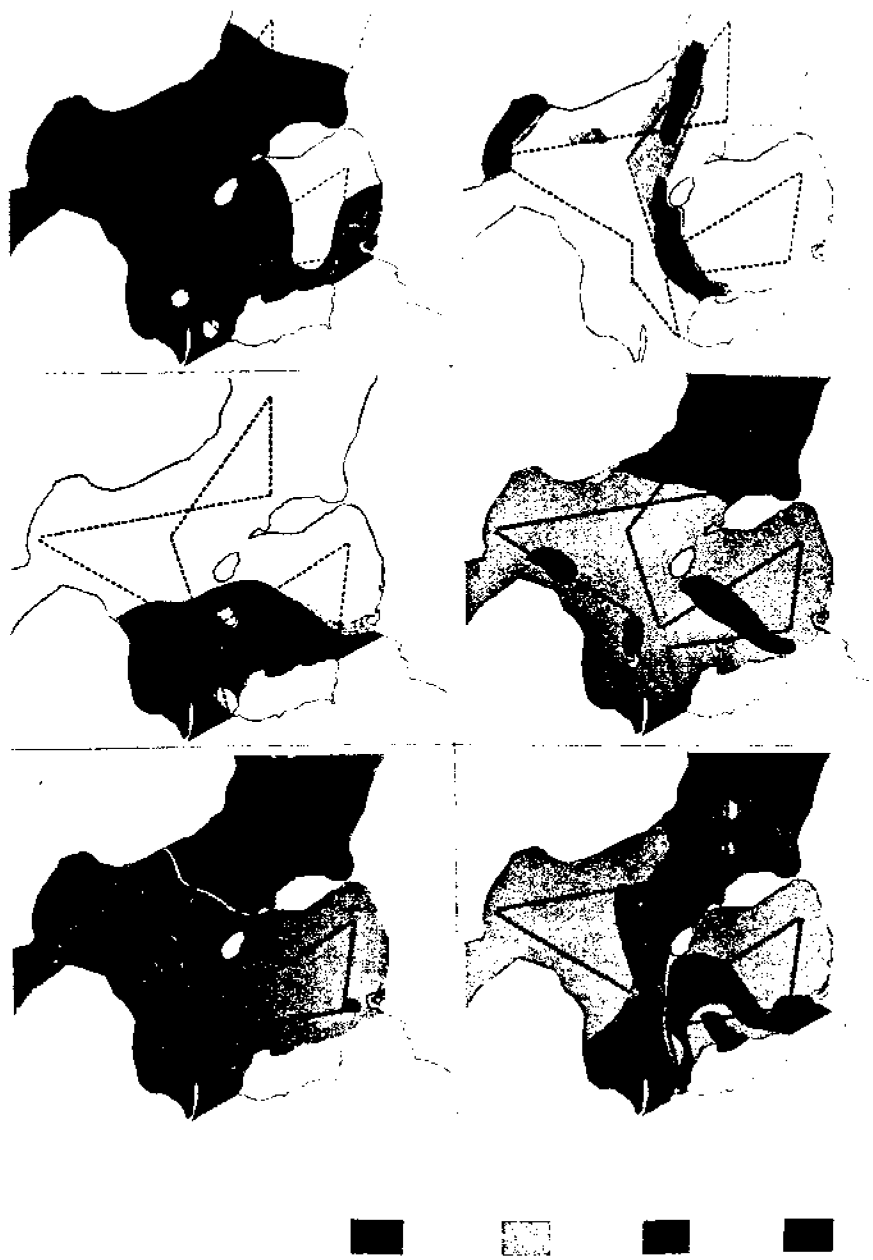

Figure 8.

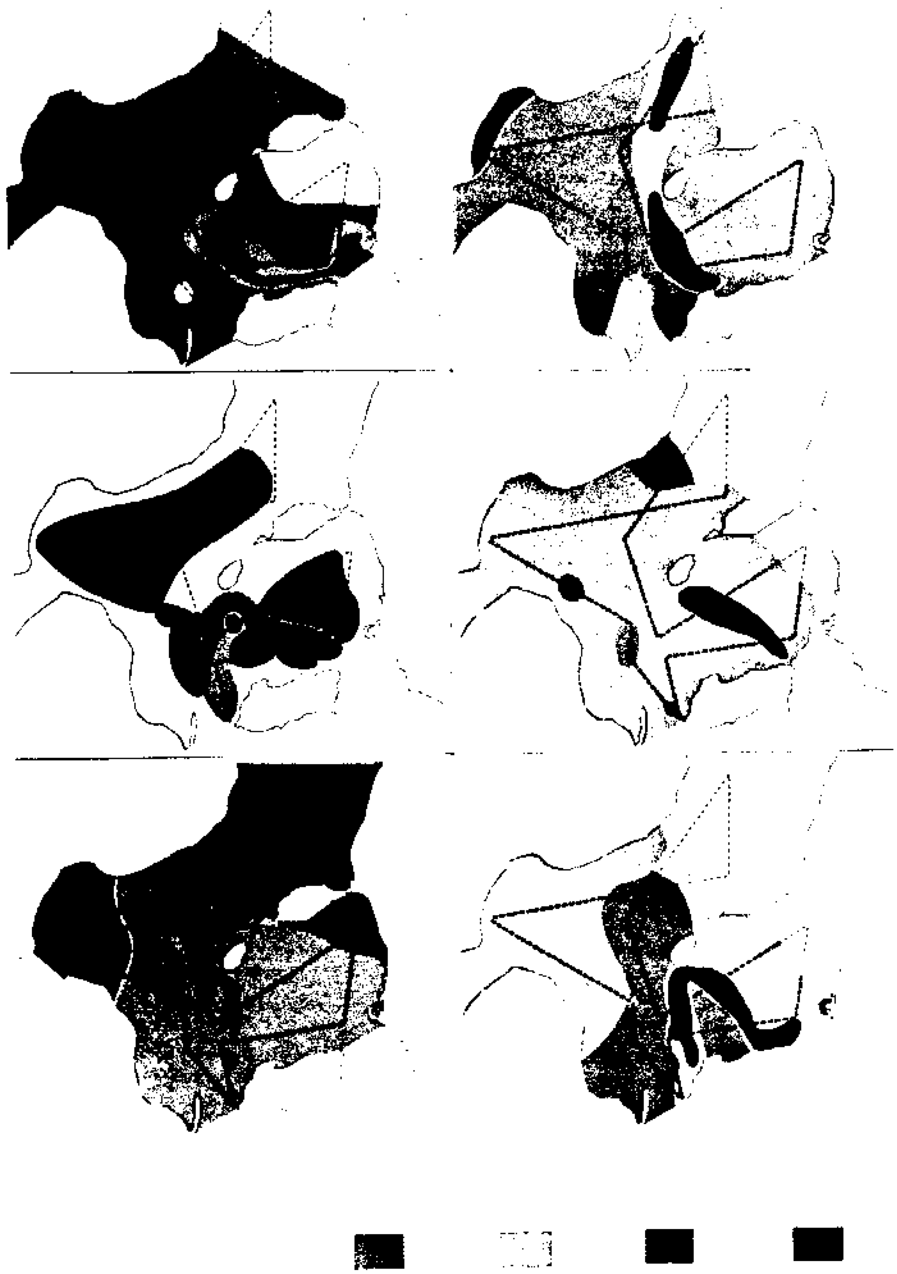

Figure 9.

Figure 10.

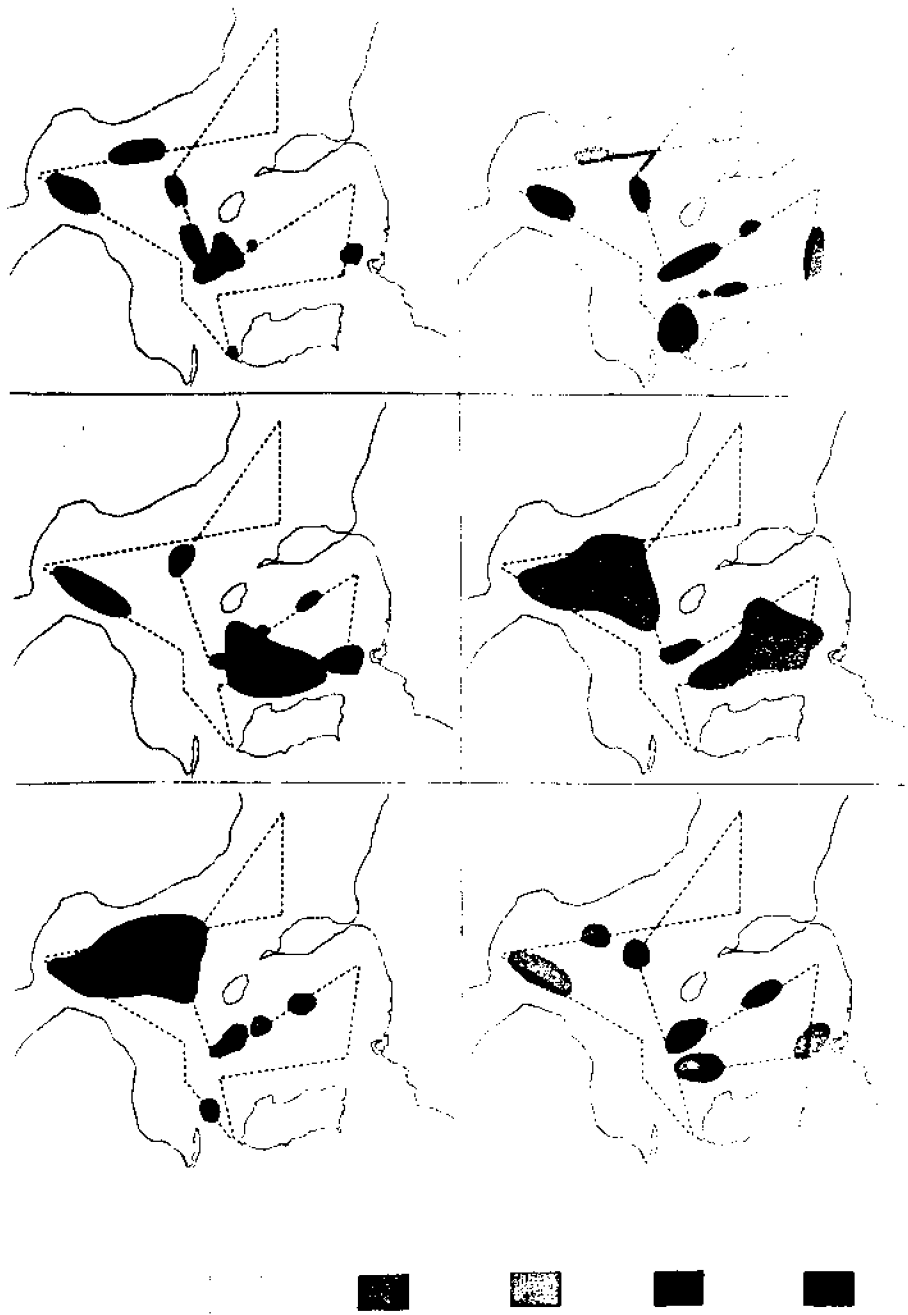

Figure 11.

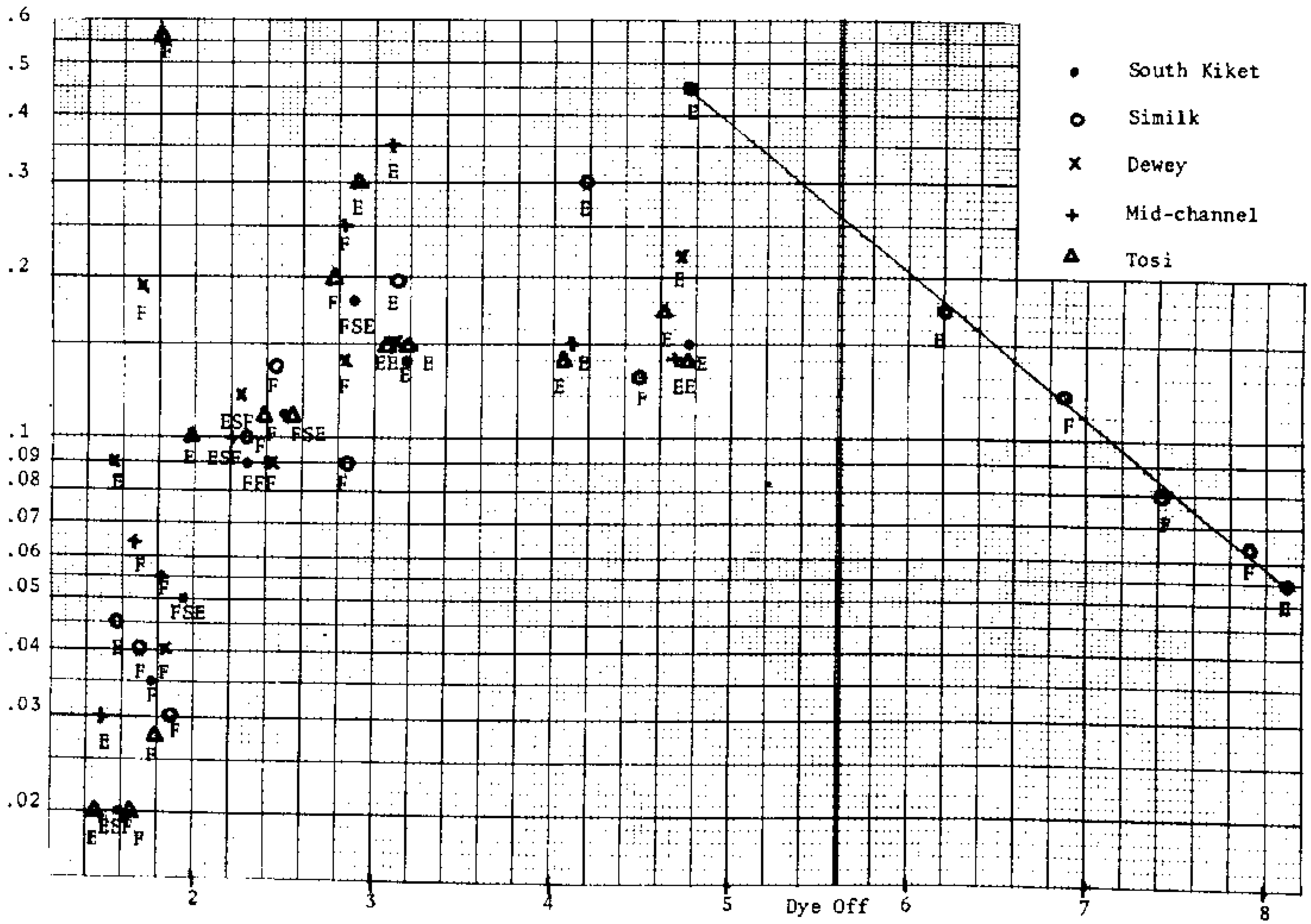

Figure 12. Buildup for Subdivisions of Kiket Area; Decay Curve for Similk Bay. E = Ebb; F = Flood; ESF = slack water following an ebb; FSE = slack water following a flood

have lateral dimensions from 50 m (about the lower limit of detection in this experiment) to 1500 m. Vertically they vary between a few meters and 30 m (top to bottom), with the June spots being more strongly depth-limited. None of the features was seen to last more than six hours--that is, they did not survive the turn of the tide--and the smaller features often did not last that long. The maximum excess temperatures in the barge plume were as high as the released effluent at times, even several hundred meters from the diffuser, but the discrete spots peaked at 7-8°C, with 2-3°C being more common. These maximum temperatures depend critically on the details of the release, and could, it seems, be reduced by diffuser design to almost any desired maximum. What is *not* dependent on such details is the *existence* of such spots everywhere in the system. Consequently, the concepts of "near field" and "far field," commonly encountered in plume studies, cannot be meaningfully defined in such a system.

We turn now from the detailed structure to more averaged quantities. The "time constants" of the various parts of the system are important, so we wished to observe the buildup of dye, the establishment of steady-state (if such a condition could be identified) and the decay period after the cessation of dye pumping. In order to see this in the data, we averaged the concentration over small areas along the track, trying not to include obvious hot spots. The result for Kiket II is shown in Figure 12, which plots excess temperature against time (days) for the various areas. Even though we tried to avoid hot spots in the averages, the buildup data is very noisy, and there is great variation with respect to tide. Nevertheless, most areas seem to have achieved some sort of average level, at 0.15-0.25°C depending on the area, after about 4 days. The possible exception was Similk Bay, a shallow region in the northern end of the system. Both the final high values there were on an ebb, however, with a lower flood concentration sandwiched in between; examination of plots like those of Figures 8-11 show that on ebb, jets of water sometimes squirt into Similk, to be dispersed on the following flood. (An example is visible in Figure 8, for Kiket I, Day 3, 02:43). It looks as if even Similk was close to equilibrium at the end of the dye release on Day 5.

The decay curve for Similk is also shown in the same semi-log plot (Figure 12) and is remarkably smooth and straight, allowing us to calculate a time constant of 35-40 hours. Notice that the decay line, extended back into the release region, passes through the last recorded ebb value. This suggests that dye was injected into that region on that last measured ebb, but *not* on the two ebbs which followed before the dye was shut off, indicating the highly variable nature of the circulation. Decay curves for other regions, as functions of depth and stage of tide (which made a difference in some locations but not in others) show variations from 7-35 hours, as shown in Table I, which includes all the cases for which we had sufficient data in the June cruise. (In March, bad weather prevented the decay measurements, but the severity of the storm seemed to cause very rapid flushing of the system.) Generally, (but with some exceptions), the deeper layers seem to flush more slowly, as might be expected, and where the stage of the tide made a difference, the direction of the variation was reasonable in terms of system geometry and the direction of flow.

Some of the data for these decay curves were pretty sparse. But strong support for their general validity came from an accidental spill from the barge of about two pounds of dye mixed with fresh water on Day 6 of the June cruise, 25 hours after the pump was shut off. This spill went unreported at the time, but was detected during analysis by a jump in the decay curve which suggested a small input

TABLE I

DECAY TIMES

	Ebb	Flood
Similk Bay	35-40 hrs	35-40 hrs
Hope Island Bay 0-4 m	13 hrs	7 hrs
Hope Island Bay 4-8 m	32 hrs	32 hrs
Hope Island Bay 8-16 m	28 hrs	28 hrs
Northern Area 0-4 m	7 hrs	26 hrs
Northern Area 4-8 m	11 hrs	44 hrs
Northern Area 8-16 m	11 hrs	75 hrs

of a few pounds into the surface layer (only) south of Kiket Island. Only after this analysis suggested checking with those who had been present did we discover the occurrence of the spill.

Carrying the averaging process now to its ultimate conclusion, we found that the space and time-averaged rise in excess temperature for the whole system in the equilibrium condition was 0.61°C in March and 0.28°C in June. We may explain the difference by the following argument: We have seen that the stratification in June inhibited the downward diffusion of dye from the layer in which it was introduced. We have seen, too, that the decay times generally increase from top to bottom (in June, at least, and it seem reasonable to expect the same in March), indicating more rapid flushing of the surface than the lower layers. These findings, taken together, would suggest more rapid elimination of dye from the system in June than in March. The averages (along entire legs) shown in Tables II and III indicate the distribution of dye with depth and its variation with tide. The ratio of top to bottom excess temperature is used as a (somewhat crude) measure of dye stratification. However, if the suggested explanation were complete, we would expect, on comparing the two experiments, to find the June values higher on the surface but lower toward the bottom than the corresponding March values. Table IV showing March/June (I/II) ratios does not show this; generally, the March values were higher at all depths. Some further explanation must be sought.

DEPTH-AVERAGED TIDAL MIXING MODEL

To this end, we construct the following simple depth-averaged tidal mixing model. Three terms determine the rate of concentration change: the injection rate, the dye loss due to the *net* flow of water through the region, and the loss due to the purely *oscillatory* (i.e., tidal) part of the flow. This last is non-zero because, although by definition as much water returns as leaves, it is not necessarily the same water, and some dye may be lost to the system. The fraction returning, P, enters the model as a parameter. We have, then,

$$V \frac{dC}{dt} = M - CT(1 - P) - CR \qquad (1)$$

where C is the concentration, M the injection rate (mass/time), T the oscillatory part of the volume transport, P the return fraction, R the net part of the volume transport, and V the volume of the system. After injection ceases, M=0, so that the time constant previously referred to is $1/\lambda$, where

$$\lambda = \frac{T(1 - P) + R}{V} \qquad (2)$$

In steady state, the lefthand side of (1) vanishes, so the equilibrium concentration is

$$C_e = \frac{M}{T(1 - P) + R} \qquad (3)$$

Applying these relations to the June case, with an average time constant of 25 hours, using oscillatory transport values given by Barnes[9] and volume and net transport values given by Rosebrook and Hammond[10], we estimate P = 54 per cent and $C_e = 1.9 \times 10^{-10}$ g/cm^3, or 0.21°C excess temperature, compared to the experimental 0.28°C. The return fraction of 54 per cent seems large until we realize that it includes the effects of *all* the "holes" in the system, the channels to the south as well as Deception Pass. In March, we don't have a decay time measured, but a very rough estimate based on the noisy buildup curve results in C_e = 0.54°C, compared with the measured 0.61°C. One difficulty with this model is that, since R is much smaller than T, we are effectively holding T or P responsible for the seasonal variation; neither of these seems too likely. The transports we used here may not be accurate (the measurements on which they are based are not conclusive) or the model may be too simple to apply to such a situation. Further measurements of transports would be needed to resolve this point.

DISCUSSION

In looking back over the preceding deductions and conjectures, it is clear that a few averaged observations would not have yielded much in the way of understanding, and probably would have been quite misleading. In order to begin to frame an explanation, even of the final averaged equilibrium temperatures, it was necessary to look at the three dimensional system, and to consider averages over much smaller units, and much smaller times. Furthermore, in order to assess the effects of excess temperature on marine life, the relevant figures are not only the averages,

TABLE 2

KIKET I EBB: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	.60	.60	.60	.50	.45	.60	.60	.67	.50
4-8	.62	.70	.64	.56	---	.70	.60	.90	.50
8-16	.67	.60	.50	.50	---	.50	.55	.75	---
>16	.55	---	.50	.50	---	---	.43	.40	---
Top to bottom ratio	1.1	1.0	1.2	1.3	---	1.2	1.4	1.7	

KIKET I FLOOD: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	.85	.80	.67	.53	.60	.46	.60	1.10	.62
4-8	.80	.60	.63	.52	---	.50	.70	.92	---
8-16	.50	.45	.70	.50	---	---	.60	.65	---
>16	.52	---	.60	---	---	---	.55	.48	---
Top to bottom ratio	1.6	1.8	1.1	1.0	---	---	1.1	2.3	---

TABLE 3

KIKET II EBB: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	.40	.19	.22	.30	.50	.40	.40	.23	.22
4-8	.35	.17	.22	.30	.45	.25	.38	.26	.21
8-16	.16	.11	.16	.21	---	.20	.21	.18	.20
>16	.10	---	.10	---	---	---	.10	.11	.13
Top to bottom ratio	4.0	1.7	2.2	1.4	---	2.0	4.0	3.0	1.7

KIKET II FLOOD: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	1.50	.31	.21	.30	.19	.16	.47	.30	.33
4-8	.80	.23	.19	.17	.12	.10	.21	.27	.18
8-16	.35	.10	.13	.08	---	.08	.10	.19	.10
>16	.12	---	.09	---	---	---	.06	.10	---
Top to bottom ratio	12.5	3.1	2.3	3.7	---	2.0	7.8	3.0	3.3

TABLE 4

KIKET I/KIKET II EBB: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	1.5	3.2	2.7	1.7	0.9	1.5	1.5	2.9	2.3
4-8	1.8	4.1	2.9	1.9	---	2.8	1.6	3.5	2.4
8-16	4.2	5.5	3.1	2.4	---	2.5	2.6	4.2	---
>16	5.5	---	5.0	---	---	---	4.3	3.6	---

KIKET I/KIKET II FLOOD: "BEST" EQUILIBRIUM VALUES

Leg	1	2	3	4	5	6	7	8	9
Depth (meters)									
0-4	0.6	2.6	3.2	1.8	1.2	2.9	1.3	3.7	1.9
4-8	1.0	2.6	3.4	3.1	---	5.0	3.3	3.4	---
8-16	1.4	4.5	5.4	6.-	---	---	6.0	3.4	---
>16	4.3	---	6.7	---	---	---	9.2	4.8	---

but also the spatial and temporal distribution of the peak values. Finally, the existence of a field of randomly drifting hot spots whose maxima are not obviously related to their distance from the source invalidates any pollution criteria based on fixed control volumes, independent of time; the use of such criteria could only be justified by the absence of anything else.

What is still missing from all the considerations presented here is a quantitative measure of mixing, related to the various scales of motion and based on a coherent physical theory. Such theories, applicable to complex natural systems, are hard to come by, and it would be useful to find a way to look at observations such as ours in such a way as to provide some input for the theoreticians. That problem we tackled, but it didn't fall, and remains to tax the ingenuity of future investigators.

We have described a technique for sampling and handling data which we applied to a dye diffusion study. There are ways in which the technique could be generalized. More, or different, sensors could be used. We are presently developing a suitable conductivity probe, and dissolved oxygen is another quantity which is of interest. Within the realm of fluorescent substances, there are other possibilities than Rhodamine: chlorophyll and lignin sulfonate, a waste product of paper manufacture, are two variables which the present fluorometer could easily detect. Furthermore, it would not be difficult to modify the instrument so that two substances could be detected in fast alternation: dye and another variable, perhaps, or two dyes released at different times, depths, or locations. Under some circumstances, it might be more revealing to institute a sudden point-source release of dye rather than the continuous technique described here; such studies are more closely tied to existing turbulent diffusion models. Whatever the measured variables, though, the technique allows us to amass and analyze sufficiently detailed data to study the patchiness of natural systems in three dimensions, over large volumes and long times, and that is its principle benefit.

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