PROCEEDINGS

OF THE

SIXTH SYMPOSIUM

ON

WATER POLLUTION RESEARCH

TOPIC

OCEANOGRAPHY AND RELATED

ESTUARIAL POLLUTION PROBLEMS

OF THE NORTHWEST

Compiled by
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Region IX
Portland, Oregon

November, 1959

There is a great need today for more basic knowledge in all areas of water pollution and water quality protection. Our country's waters are vital to its continuing economic growth and to the health and welfare of its citizens. The amount of research we have been able to do in this field is small in relation to the growing problems. This is especially true with respect to problems in marine and estuarial waters.

The accomplishment of the vast amount of research that is needed will require the combined efforts of researchers everywhere. Symposiums of this type provide for a free exchange of ideas. They can do much to stimulate expanded programs in non-Federal research establishments. These programs, complementing Federal research activities, are essential if we are to solve the complex problems resulting from our growing nation.

The Public Health Service is grateful to those in the Pacific Northwest who have given their time to participate in this symposium.

Gordon E. McCallum

Gordon E. McCallum, Chief
Division of Water Supply
and Pollution Control

SIXTH SYMPOSIUM ON WATER POLLUTION RESEARCH, PACIFIC NORTHWEST

SUBJECT: OCEANOGRAPHIC AND RELATED ESTUARIAL POLLUTION PROBLEMS OF THE NORTHWEST

DATE: November 17, 1959

PLACE: Room 104, U. S. Court House, Main and Broadway, Portland, Oregon

AGENDA

9:30 am Introductions

9:40 am Purpose and scope of symposium - Edward F. Eldridge.

9:45 am FACTORS RELATING TO FLUSHING AND EXCHANGE - Leader, Dr. Clifford Barnes

Prepared remarks by:

Dr. W. Bruce McAlister - CLASSIFICATION OF ESTUARIES.

Dr. Wayne V. Burt - POTENTIAL SIGNIFICANCE OF UPWELLING.

Dr. Joseph S. Creager - SIGNIFICANCE OF BOTTOM TOPOGRAPHY

11:45 am Lunch

1:00 pm BIOLOGICAL FACTORS - Leader, Dr. H. F. Froelander

Prepared remarks by:

Dr. J. A. Macnab - DISTRIBUTION OF MARINE ORGANISMS IN ESTUARIES.

Dr. Albert Sparks - WASTE DISPOSAL IN THE MARINE ENVIRONMENT.

Mr. L. D. Marriage - RELATION OF THE ESTUARY TO MARINE PRODUCTION.

3:00 pm MEASUREMENTS - Leader, Professor Robert Sylvester

Prepared remarks by:

Dr. Maurice Rattray - MODELS, THEIR USE AND LIMITATIONS.

Dr. John Dermody - VALIDITY OF MEASUREMENTS.

5:00 pm Adjournment.

FOREWORD

In May 1957 the Public Health Service initiated a project in the Pacific Northwest for the purpose of testing an idea for a program by which to better reach and serve those engaged in water pollution research in this area. This project was given the title "Technical and Research Consultation Project." Its major objectives are to encourage, guide, co-ordinate and develop research in this field.

A series of symposiums is one of the devices used to accomplish these objectives. The following subjects have been covered by the six symposiums in this series:

1. Research on Water Pollution in the Northwest
2. Financing Research Projects
3. The Sphaerotilus (Slime) Problems
4. Short-Term Bioassay
5. Siltation - Its Sources and Effects on Aquatic Life
6. Oceanography and Related Estuarial Pollution Problems in the Northwest

The material which follows is a compilation of prepared statements and discussions from the sixth water-pollution research symposium held at Portland, Oregon on November 17, 1959. This symposium was followed on November 18, 1959 by an informal meeting to discuss various research projects. The meetings were arranged and conducted by Edward F. Eldridge, Physical Sciences Administrator.

The agenda for this sixth symposium was divided into three parts, each having a discussion leader and a panel of outstanding persons in the fields covered. Following the presentation of the prepared remarks by the leader and panel, the meeting was opened to general discussion. The discussions have been abstracted in order to reduce the job of publication.

The meeting was attended by fifty-five persons representing educational institutions and other organizations from Washington, Oregon, Alaska, California and British Columbia. The list of those attending is contained on the last page of this report.

PROCEEDINGS OF THE
SIXTH SYMPOSIUM
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ESTUARIAL POLLUTION PROBLEMS
OF THE NORTHWEST

November 17, 1959
Assembled by
Edward F. Eldridge

<u>Opening Remarks</u> - E. F. Eldridge

This is the sixth of a series of symposiums which have been held in this area on subjects related to water-pollution research. Today we are discussing certain phases of salt-water estuary problems.

For some reason, until recently at least, we have not given adequate attention to estuaries and estuarial problems. Consequently there is a definite lack of fundamental background information on which to base judgment as to the effects of pollution in these areas.

Centers of population in coastal states are usually located on estuaries (harbors) because of the availability of water transportation and shipping. For much the same reasons, major industries locate in these areas. As a result, the sewage, treated and untreated, from about thirty million people and the industrial wastes from an unknown but large segment of industry in this country are discharged into estuarial waters. Also, estuarial waters are the final recipients of the effects of land use on the streams which discharge into estuaries.

It was recently called to my attention that one of the meetings in connection with the Twelfth General Assembly, American Geophysical Union to be held in Helsinki, Finland this coming summer will be on the subject of "tidal rivers." The following is a quote from the description of the meeting:

> The maritime part of the river (that which is subject to tide) poses multiple and generally very difficult problems: variations of heights and currents caused by tide, influence of upstream supply, influence of the form of estuaries, problems of sedimentation, questions of salinity, etc."

Thus, our subject today is becoming recognized as one of international importance.

Most of us who are gathered here today are interested in research and its application to practical problems. These estuarial problems are an open field for research especially in the Northwest. The suggestion was made that perhaps some of you might be interested in discussing this phase of the subject. Therefore, arrangements have been made for the use of this room for tomorrow morning when we can, in a very informal way, talk about the research needs in this area.

Now, just a word about the pattern we have followed in these symposiums--you will notice that we have listed three items and that each has a leader. It is expected that the leader will open the discussions with certain statements. We have asked a panel to prepare remarks on phases of the item since we feel that this will give us the advantage of some preliminary thinking. Open discussions will follow the presentation of prepared material.

The first item for discussion is "FACTORS RELATING TO FLUSHING AND EXCHANGE." The leader is Dr. Clifford Barnes, Professor of Oceanography, University of Washington.

ITEM I

FACTORS RELATING TO FLUSHING AND EXCHANGE - Dr. Clifford Barnes

First, I would like to go back to some of the earlier considerations of our estuarial systems. These date back in this area about thirty-five or forty years. Dr. Thompson of our Chemistry Department at the University of Washington became interested in the intrusion of salt water into Lake Union and Lake Washington after the construction of the shipping canal and locks connecting these lakes with Puget Sound. Here we have a normal tide situation in which a counter-current of salt water is working in the fresh water ponds. This is characteristic of many of our estuaries. In these first studies Dr. Thompson attempted to get some idea of how this penetration took place.

Then we go along for another period of about fifteen or twenty years and find that Dr. Tulley of Nanaimo, British Columbia made a study in the Albernay Canal. His interest was largely in the material discharged into this canal. He determined how long this material stayed in the estuary and worked out certain fundamental concepts of the exchange in deep water estuaries. From this work and other studies he made on the East Coast and particularly at Woods Hole he tried to formulate certain basic rules by which to estime the flushing time in various kinds of estuaries. These rules were based upon assumptions that he made of the mixing. Where the mixing was not perfect, he simplified the functions using only the upper layers.

Pritchard and his co-workers at Chespeake Bay examined the shallow waters and arrived at some very good explanations of the factors involved wherein the gradients were more lateral than they were vertical.

So we have here a brief background for estimating some of the exchange rates in our bays and estuarial systems, but we find that when we start working at it very closely we really know very little about them. Whenever we try to apply the equations, they are generally so simple that we cannot take into consideration the topography of the systems, the varying winds, and the varying range of tide. We find that we have to take average conditions and we know that some of our greatest difficulties come from the extremes.

As we look at various estuaries, we find that they are all types. In order to clarify our subsequent discussions, as we speak of estuaries we have asked Dr. McAlister to tell us about the classification of these estuarial types. Dr. McAlister has had considerable experience in Puget Sound regions, Alaskan waters, and in the bays and estuaries here on the Oregon Coast.

CLASSIFICATION OF ESTUARIES - Dr. W. Bruce McAlister

In many respects our lakes and oceans are better understood than are the marine processes which occur along the shore and in the coastal estuaries. The open sea and many lakes represent a relatively unchanging environment. A water sample taken at a particular location at a particular time may be considered characteristic both of adjacent water and a reasonable span of time. Investigations conducted over a period of years may be fitted together to describe the properties of lakes and streams and the oceans which remain nearly constant year to year. The same is not true of estuaries; here the variability is much greater. The circulation, and the physical and chemical properties of the water change due to rapid variation in tides, fresh water runoff, and meterological conditions. Different seasons may be accompanied by changes great enough to completely alter the character of the estuary. Estuaries as well have been the sites of intensive industrial and population developments. The result has been to add new factors to make estuarine conditions even more variable.

While each estuary has certain individual characteristics which set it apart from any other estuary, these so called boundary conditions govern the details of the circulation, but study has shown that estuaries may be grouped into certain classes within which the circulation and salinity patterns may be reasonably inferred, within rather broad limits, from our knowledge of the physical characteristics of the estuary.

Types of Estuaries

A general definition which has gained wide acceptance is the one given by Pritchard (1952) who defines an estuary as a "semi-enclosed coastal body of water having a free connection with the open sea and containing a measurable quantity of sea salt." Estuaries have been divided into classes on the relationship between evaporation and fresh water inflow; on their size and shape; and on the circulation patterns observed.

Estuaries in which precipitation and fresh water inflow exceed evaporation, so as to produce a measurable dilution of sea water are termed positive. When evaporation exceeds the combined total of precipitation and land drainage, the estuary is termed inverse. Neutral estuaries are those in which neither fresh water inflow or evaporation predominate. All of the estuaries along the northwest coast are of the positive type.

A further classification is made on the basis of structure. Coastal plain estuaries are usually relatively shallow estuaries with dendritic shorelines formed by the drowning of river valleys, either from subsidence of the land, or from a rise in sea level. The deep basin or fiord estuary has steep sides, a deep basin, and may, or may not have a shallow sill at the mouth. In general, Oregon and Washington coastal estuaries are of the coastal plain type, while British Columbia and Alaska have predominately fiord estuaries.

Both fiord and coastal plain estuaries may be arranged according to the particular circulation patterns and salinity distributions which are observed. The transition from one class to another is associated with changes in the width and depth of the estuary, with river flow, and with the tidal range. The estuaries may generally be placed in one of three types: a two-layer or stratified estuary; a partly mixed estuary; and the vertically homogeneous or well-mixed estuary.

One of the factors that determines the type of mixing pattern present is the river flow-tidal prism ratio. This is the ratio of fresh water discharge during a half tidal cycle of 12.4 hours to the tidal prism, which is the volume of the estuary between mean high water and mean low water. This has been called the flow ratio. High river runoff with a flow ratio of the order of 1.0 or more provides a large volume of fresh water at the surface which helps to maintain the sharp vertical salinity gradients typical of the two-layered estuary. With smaller runoff and a flow ratio between 0.2 and 0.5, the estuary is probably of the partly mixed type. When river flow is low and flow ratio is less than 0.1, the estuary is probably the well-mixed vertically homogeneous type. Thus, a given estuary may change types with changes in river flow.

The tidal range can be very important. In any estuary the energy required to mix the salt and fresh water is largely supplied by the tidal forces. As an approximation, the energy present in a tidal cycle may be considered as propotional to the square of the tidal range. In the Mississippi River estuary on the Gulf Coast, the tidal range is 0.5 feet, compared with an average in excess of five feet off the northwest coast. This is a ten-fold difference in tidal range, corresponding to a hundred-fold difference in energy, and explains the greater mixing found locally than along the Gulf Coast, other conditions being the same.

A third important factor is size and shape of the estuary. A two layer flow may be established in deep narrow estuaries, which would not occur in a shallow, wide estuary under the same conditions of tides and run-off.

Two-Layered System (Figure 1)

This system consists of a layer of almost fresh water overlying a layer of saltier, oceanic water. The fresh water from the river inflow is spread out on the surface while the more dense salt water forms a layer of salt water under the fresh water, in the case of river commonly referred to as a salt wedge, along the bottom. At the interface of the salt and the fresh water, some of the salt water mixes upward into the fresh water of the upper layer, where it is carried back to the sea in diluted form. With a two layer system, there is typically a large flow of water in the upper layer, essentially running downhill over the lower layer. Salt mixed from below the upper layer remains nearly fresh. Due to vertical stability, very little, or none, of the lighter, fresh water mixes in the denser salt

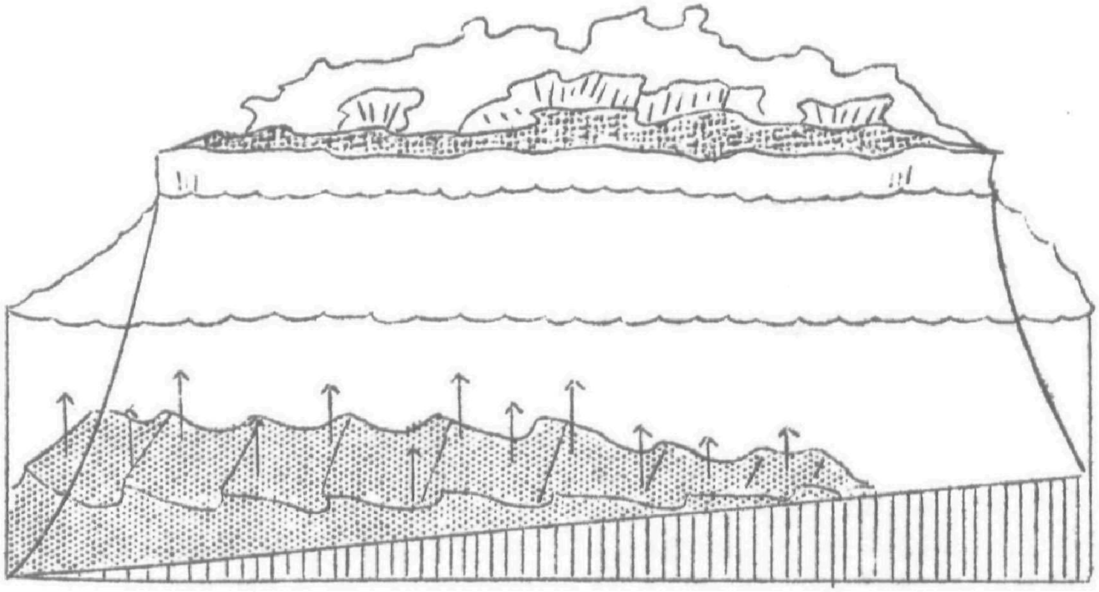


Fig. 1

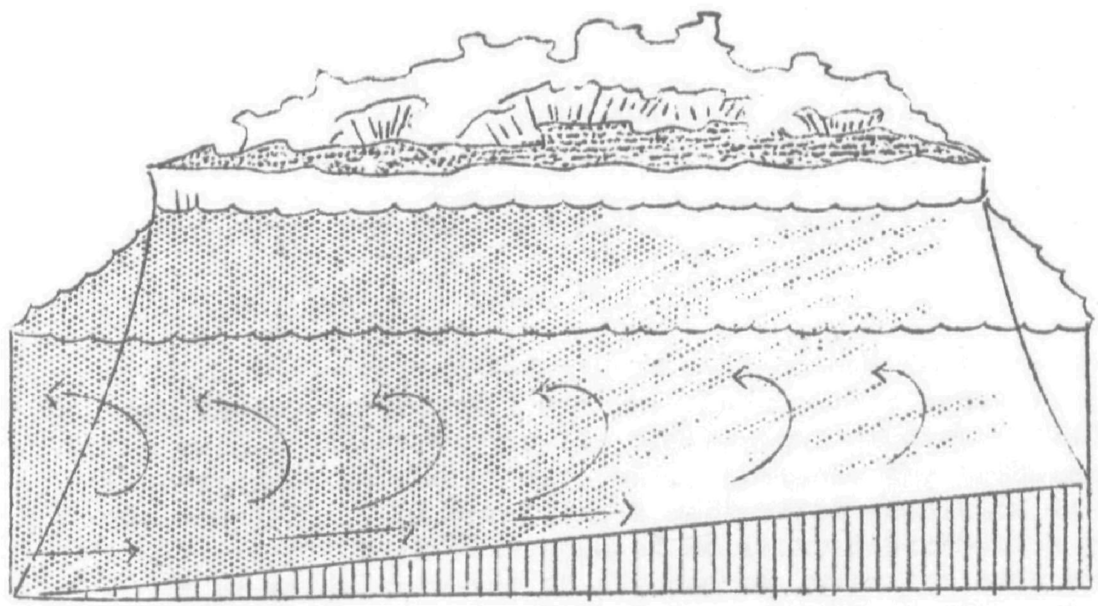


Fig. 2

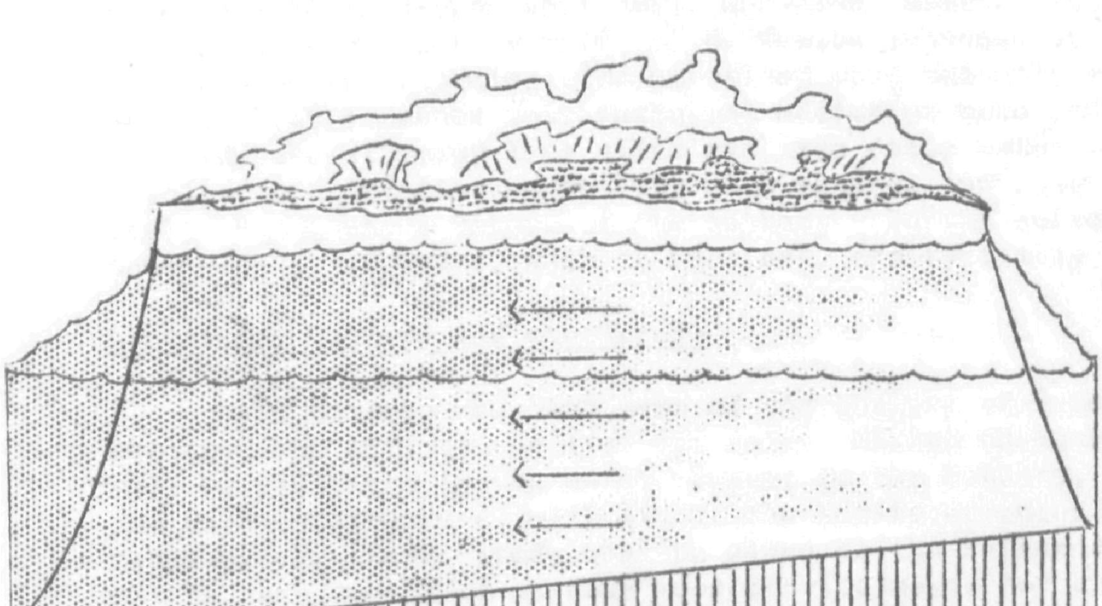


Fig. 3

layer. The layer of salt water may move back and forth with the tides, but will maintain some mean position. Since some of the water in the salt layer is constantly being lost to the upper, fresh water layer, there must be some net upstream movement in the salt layer, if it is to maintain itself.

Two layer flows are characteristic of the Alaska and British Columbia estuaries, but are uncommon in Oregon and Washington coastal streams. Along the Oregon coast, only the Umpqua and Columbia rivers approach the two layer system, and then only during extended periods of high runoff in regions near the mouth of the river.

<u>Partly-Mixed System</u> (Figure 2)

As runoff becomes more moderate, or as shallower estuaries are considered, the circulation will change to a partly mixed system. Vertical mixing becomes sufficient, such that the salt and fresh water layers are no longer sharply defined. At any location, however, the water near the bottom is still more saline than the surface water. The strongest ebb, or outflowing current is near the surface, and, in general, we find a stronger flooding tidal current near the bottom. Since more salt is transported out of the estuary in the upper layer on the ebb tide than enters on the flood tide, there is a compensating net upstream flow of salt water along the bottom. The partly mixed pattern is common in the coastal streams.

<u>Well-Mixed System</u> (Figure 3)

The partly mixed system will change further; under the influence of high tides, low runoff, and shallower, wider estuaries; to give rise to the well mixed or vertically homogeneous estuary. Sudden obstructions or restrictions in the channel which increase the turbulence will also enhance the possibility of obtaining a well-mixed condition in the vicinity of the obstruction. With this type of salinity distribution there is a slow net drift of water outwards at all depths, with the back and forth tidal movement superimposed upon this small non-tidal drift. The salt moves upstream against this current by means of diffusion enhanced by the tidal mixing. On occasion the incoming tide may flood most strongly at the surface, or eddy in such a manner that turbulent eddies of more saline water temporarily override the slightly less aline and less dense water underneath. This results in immediate instability with mixing, and contributes to the vertically homogeneous nature of the estuary. During periods of low runoff, some Oregon estuaries, such as Coos Bay, are typically well mixed.

<u>Additional factors and conclusion</u>

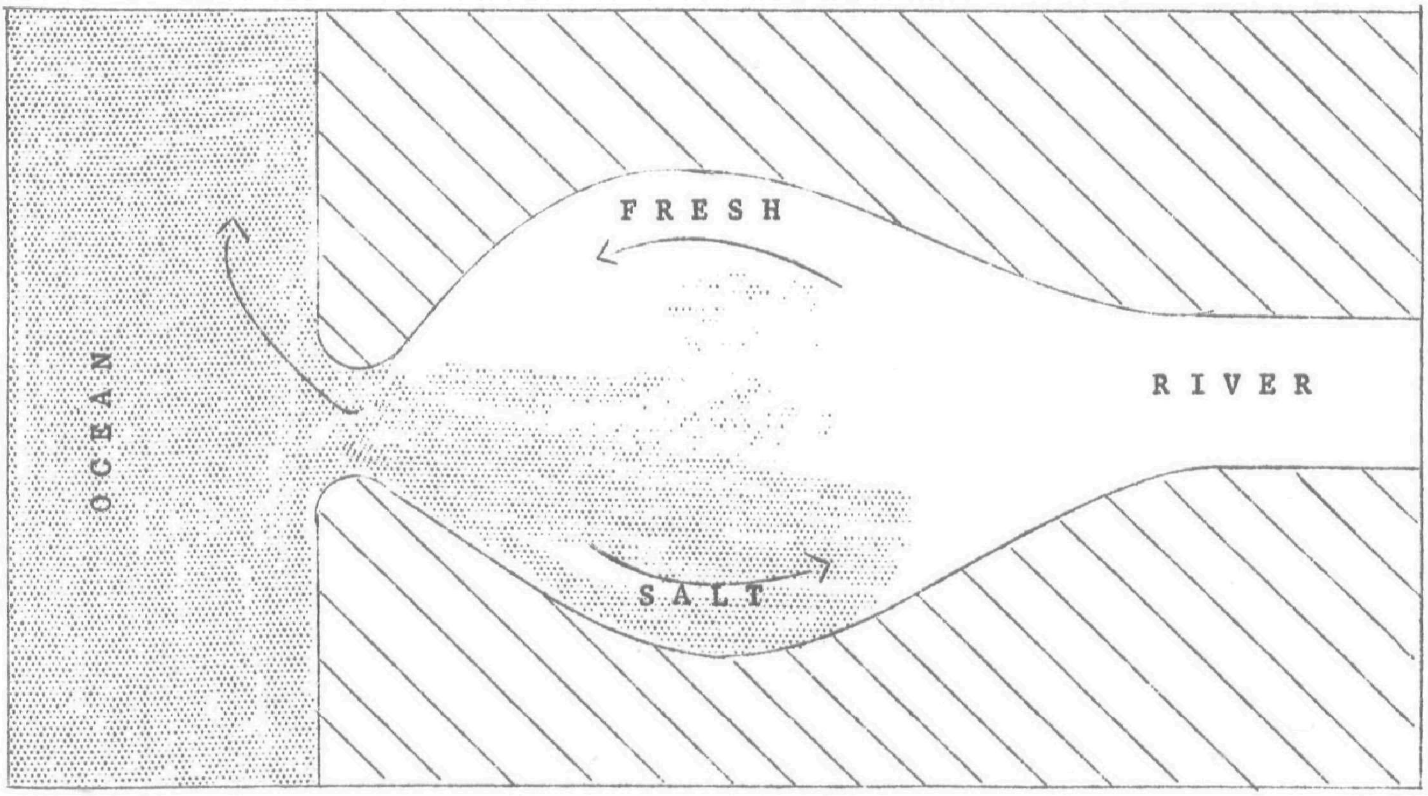
No mention has been made of the quality of water entering into the estuary from offshore or from upstream. Marked changes in the source water will be reflected in the water present in the estuary, and, as they affect the density structure, will affect the entire circulation pattern of the estuary. Important study must be given to the bottom currents. Tidal mixing, and two layer systems must provide means for transport of dissolved or suspended material upstream for large distances against the apparent current.

Material discharged at depth into a two layer regime near the mouth of the estuary will distribute itself throughout the estuary, with accordingly large flushing periods, while the same discharge at or near the surface might be quickly flushed away.

Thus, for an estuary which derives its source water both from upstream and oceanic sources, the properties of the oceanic water must also be carefully considered.

In large estuaries, the effects of the earth's rotation will cause a lateral distribution of salinity along the estuary, with saltier water generally being found on the left of the estuary, looking seawards. (Figure 4). This effect is not apparent in our local coastal estuaries, but becomes more prominent in wider estuaries such as the Strait of Juan de Fuca.

The conclusion to be drawn is that effective utilization of an estuary requires knowledge of the topography, tidal patterns, runoff, and offshore conditions as well as immediate observed circulation patterns.



LATERAL SALINITY DIFFERENCES

Figure 4

COMMENTS - DR. BARNES

What happens in any estuary is largely influenced by the nature of the feed waters. These feed waters are from two general sources each of which may vary over a wide range. These sources are the fresh waters from the streams which feed the estuary and the salt water entering from the ocean. The system at best is complicated and in cases such as Puget Sound where numerous feed waters are involved the system is very complex.

In the next discussion we are to consider some of the factors involved in salt water feeding in from the ocean. Dr. Burt is well acquainted with this particular problem. His topic has to do with upwelling and its influence on estuarial waters.

POTENTIAL SIGNIFICANCE OF UPWELLING - Dr. Wayne V. Burt

One of the primary factors that distinguishes the problem of waste disposal in estuaries from waste disposal in rivers is the presence of salt water in the estuaries. Tidal currents and currents associated with the density difference between fresh and salt water bring salt water from the oceans into estuaries. There it mixes with fresh river water and eventually returns to the ocean again.

The inflowing salt water comes from near the surface for the shallow estuaries of the west coast of the United States. The assumption is usually made that this salt water from the surface layer of the ocean is at or near saturation with dissolved oxygen. This is a reasonable assumption because of surface mixing and the contact of the surface waters with the atmosphere. Thus, in any computation on oxygen consumption within the estuary, the salt water may be automatically credited with being full saturated with oxygen.

The purpose of the present talk is to show that although the last assumption may be valid most of the time, the researcher must be continually on the lookout for significant deviations from the average picture. The largest deviations are probably due to wind-driven upwelling of sub-surface layers of coastal waters or similar upwelling caused by underwater topography.

My attention was first focused on this problem by a paper by Erman Pearson, a sanitary engineer at Berkeley. He presented the paper at the 1958 meetings of the American Society of Limnology and Oceanography in Logan, Utah, 1958. Using data from Grays Harbor, Washington, Pearson clearly showed that the salt water coming into the estuary was at times very low in its oxygen content. He attributed this low oxygen content to upwelling in coastal waters.

Upwelling

The theory of upwelling due to surface winds is presented in most oceanography texts. According to the theory, North and Northwest winds blowing over the waters on the west coast of the United States combine with the rotation of the earth to cause the surface water to flow away from the coast. If any appreciable water is blown away, it must be replaced by upwelled water from sub-surface layers. This upwelled water is usually low in oxygen and high in dissolved nutrient material.

Reid, Roden, and Wyllie (1958) have made a study of the current systems off the west coast in which they pay particular attention to upwelling. They show that the oceanic wind systems are such that upwelling should be at a maximum off Southern California in May and June, off Northern California in June and July, and off Oregon in August. Southern Washington waters should have their maximum upwelling about the same time as Oregon waters. They point out that there may be major exceptions to the mean or average picture of upwelling due to unseasonal wind distributions or topographic effects. Topographic upwelling appears to occur quite often near sharp breaks in the coast line such as Point Conception or Cape Mendocino. In these regions spots of upwelled water may appear at the sea surface at any time of the year. A combination of coastal currents and topographic effects may set up large scale vertical turbulent eddies. The exact process of how this occurs has not been explained. It is evident from their report that the occurrence of upwelling is more complicated than the simple theory would predict.

An examination of Scripps Cruise data off the Oregon Coast from April to October 1949, brings out evidence of upwelled water with lowered oxygen content from April through July. No upwelling was apparent during August, September, or October. The upwelled water seems to occur in large patches that may move in location from cruise to cruise. The patches of upwelled water were absent during one cruise in early August when upwelling should be a maximum in the local waters. The lowest surface layer (surface to 10 feet) oxygen value was recorded in April instead of August as would be expected from the mean wind distribution.

The conclusion that can be drawn from the Scripps report and from their cruise data is that some low oxygen upwelled water may be expected anywhere along the west coast at any time during spring and summer. It may, however, be completely absent during the most likely time of its occurrence. In some areas upwelling may occur at other times of the year, but this is less likely.

<u>Local Oxygen Data</u>

For the past sixteen months, the Department of Oceanography at Oregon State College has been making approximately monthly cruises on a line running west from Newport, Oregon. The stations are ten miles apart, beginning five miles from the coast and estending from 15 to 45 miles offshore, depending on the weather. Some evidence of the upwelling of water with a reduced oxygen content shows up at individual stations in September, October, 1958 and June, 1959. The September and October cruises this year did not show evidence of strong upwelling.

The only extensive data available aside from Pearson's data for Grays Harbor is a large amount of data taken by John Queen in and near Coos Bay.

He took samples at approximately bi-weekly intervals on 47 days over a 27 month period in 1930, 1931, and 1932. (The oxygen data collected during this study are shown in Fig. 5). The data of interest to us here were obtained in the surf on two pocket beaches located 1½ and 3/4 miles south of the entrance to the Coos Estuary. Data from these two stations were grouped together and plotted on this diagram. Each point represents the mean of 7.8 observations during the day that samples were taken.

Consistently low oxygen concentrations were found in the surf from January to the middle of May each year. Relatively high concentrations were recorded during the rest of the year. Only a few of the mean concentrations are near the saturation range of 5.5 to 6.5 ml/l. The highest concentrations occurred during August and September. The mean per cent saturation for the whole 27 months was approximately 65 per cent.

The individual minimum observations each day approached 2 ml/l during January, February, and March down in the range where damage may occur to some organisms.

One possible source of water low in oxygen is the estuary. The oxygen data from the two stations located 8 and 11 nautical miles up the channel in the estuary were averaged together for each day and plotted as circles on the top of Figure 6. Both surface and bottom data were used to give an average of 16.8 individual observations each day or a total of almost 900 for the whole period. Note the lack of correlation between the surf and estuary data. It is apparent that the estuary is not the major source of de-oxygenated water during the late winter and spring.

It has also been suggested that the anomalously low oxygen concentrations may be due to the oxygen demand of decaying organic matter, but it is hard to estimate the source of the large amounts of material needed to bring about the observed conditions during the winter months.

No matter where the low oxygen water came from the results of its presence in the estuary are quite startling. During January 1931, John Queen made a series of 24 hour stations at several locations in the Coos Bay Estuary. On January 3 and 4 hourly surface oxygen data were collected near North Bend, 10 miles up the estuary, Fig. 7. These data show a clear inverse relationship between oxygen concentration and tidal height. At higher high water, when the water at the station contained the highest percentage of ocean water, the oxygen content was a low 2.62 ml/l. At the following lower low water when the highest percentage of river water was present the oxygen content had gone up to 6.30 ml/l. At lower high water the oxygen content was 2.84 ml/l and at higher low water, 4.90 ml/l.

A second twenty-four hour station was occupied nearer the ocean on the same day. Lower oxygen content was measured than at North Bend.

A third twenty-four hour station had been occupied ten miles up the estuary from North Bend on January 1 and 2. Here the water was fresh at low

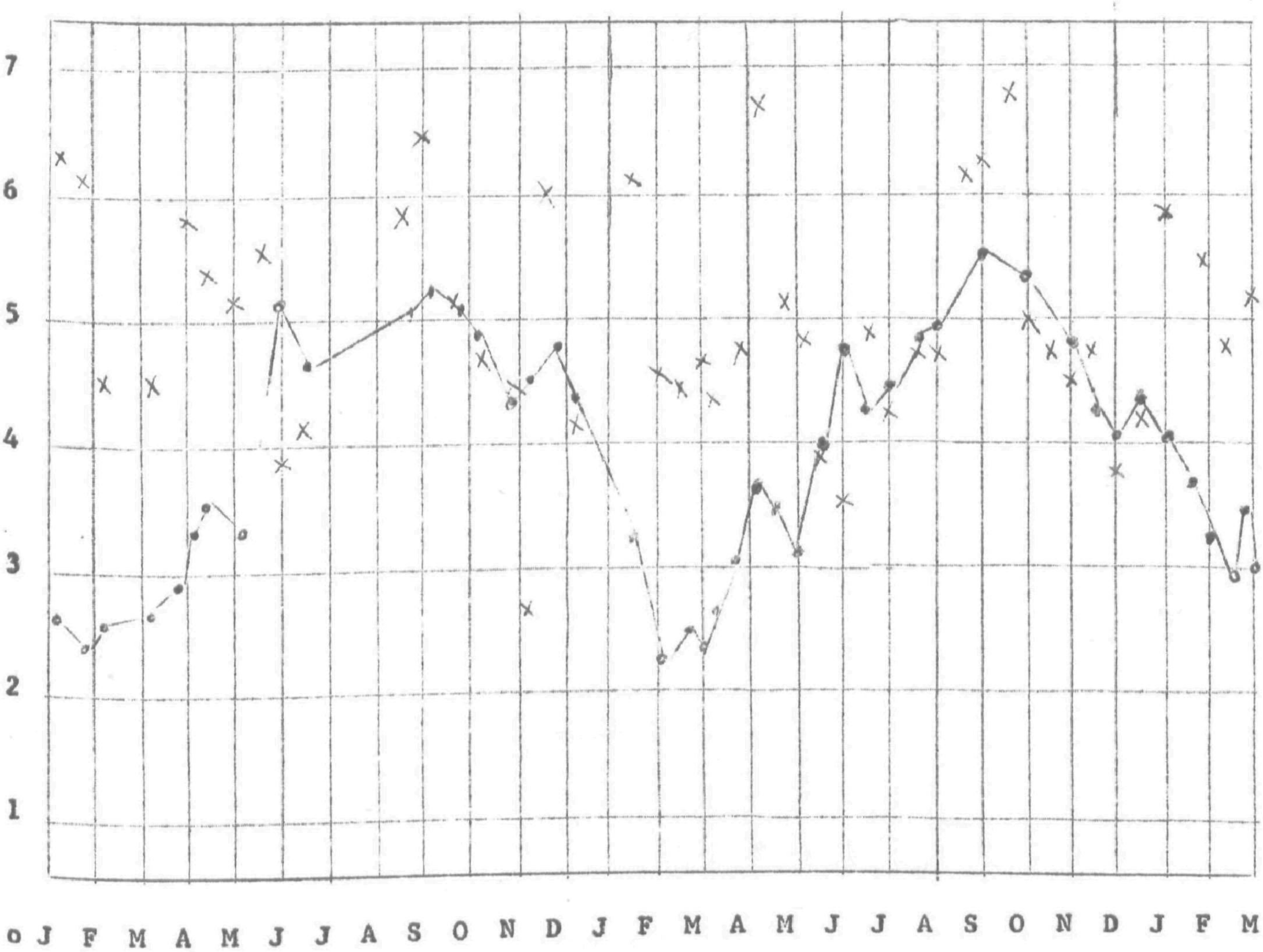


Figure 5

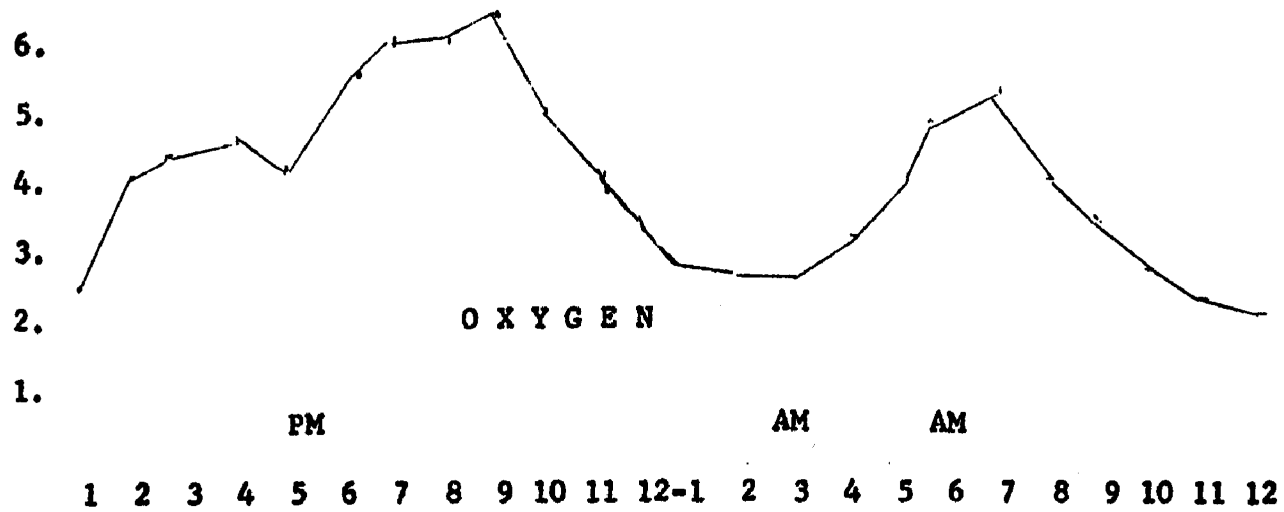


Figure 6

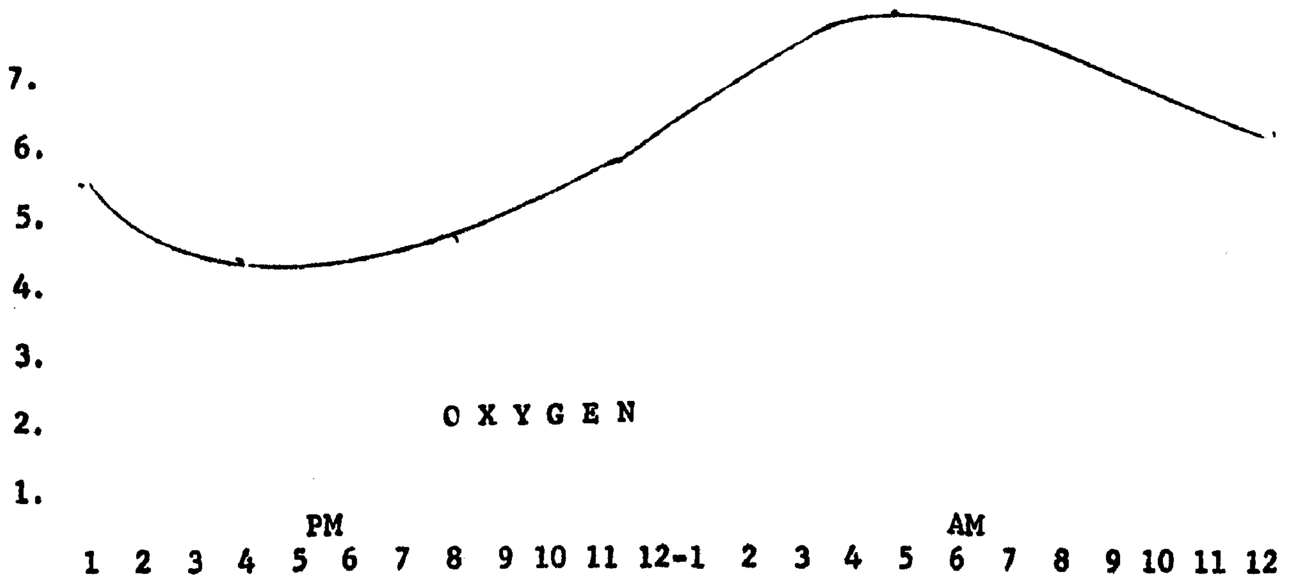


Figure 7

water and was only 1/10 sea water at high water. The range in oxygen concentraion was from 6.70 to 8.1 ml/l.

The above data clearly show the potential that upwelled water may have in helping to establish the oxygen pattern within an estuary.

Queen did not make any 24 hour stations during the summer. His data runs from before daylight on some days until after dark on others. From these data a twenty four hour composite curve Figure may be drawn showing the normal minimum at daybreak and maximum in the afternoon. None of his data show a marked tidal effect in the summer.

Conclusions

(1) Insufficient data are available to predict when and where upwelling will occur to the extent that it will be a factor in pollution work in estuaries.

(2) Presently available data indicates that the effects of upwelling could be significant at times.

(3) A large amount of data must be taken and analyzed before the effe effects of upwelling can be handled quantitatively. In the meantime, we should measure the oxygen content of the ocean surface water entering estuaries to be on guard for upwelled water.

References

Reid, J. L., G. I. Roden and J. G. Wyllie (1958) Studies of the California Current System, California Cooperative Oceanic Fisheries Investigators, Progress Report 1 July 1956 to 1 January 1958.

Contribution from Scripps Institution of Oceanography No. 998.

COMMENTS - Dr. Barnes

Dr. Burt in his discussion referred to oxygen concentration on a volume basis. Many of use use the weight basis or parts per million which will account for the differences in the units shown on the charts.

Dr. Burt has indicated the importance of looking at each of the sources of feed water. The condition in the estuary depends on the quality of the water fed into it, the length of time it remains and the changes which occur while it is in the estuary.

In deeper estuaries the surface waters may change in character rapidly with changes in the fresh water feed. At the same time the deeper waters may remain fairly constant. As we approach the bottom we again have a different set of influencing factors. Dr. Creager will discuss the effects of the geological structure on currents, exchange and water characteristics.

SIGNIFICANCE OF BOTTOM TOPOGRAPHY - Dr. J. S. Creager

The estuarial water pollution problem is most influenced by geological factors in those estuaries that receive appreciable quantities of fresh-water drainage. In general, those estuaries with small drainage areas and little or no fresh-water discharge are "clean" estuaries, in that they have relatively stable bottoms. The flood and ebb are in balance with respect to magnitude and duration of flow.

The direct effect of bottom configuration on tidal volumes, current direction and velocity, turbulence, and flushing and exchange rates, although not always regarded quantitatively, has been taken into account in most estuarine studies. Many generalizations are made. Other things being equal, as the depth to width ratio of an estuary increases the water masses tend to become more stratified and the bottom water becomes more stable. We find that, as is so often the case when dealing with estuaries, such generalizations must be applied with caution. For example, Schultz and Simmons (1957) report lower Charleston Harbor as having "considerable difference in density between the upper and lower strata" and "excessive cross-sectional area"; the depth-to-width ratio in this case is on the order of 1:300. A safer generalization is made if we speak of the influence of depth and width separately. If we change the cross-sectional area by increasing the width while holding depth, tidal velocities, and river flow constant, we are effectively changing the ratio of tidal volume to river flow which will result in a greater mixing of fresh and saline waters. If we change the cross-sectional area by increasing the depth while holding the width, tidal velocities, and river flow constant, we have increased the cross-sectional area but we have not increased the area of the fresh-water salt-water interface across which we can get mixing. The increase in depth results in lowering the effectiveness of the tidal velocities in promoting vertical mixing, and the system tends to become more highly stratified (Pritchard, 1955).

Lateral constrictions both near the mouth and in the central portion of an estuary may exert strong influences on circulation and mixing. Obstruction of the mouth of an estuary by bars and spits induces intense mixing in the vicinity of the mouth but will cause reduced tidal volumes within the estuary, resulting in reduced mixing away from the mouth. Horizontal mixing may also be increased by mid-estuary constrictions. Such constrictions will tend to increase the velocities and to form horizontal eddies, both of which will increase mixing of fresh and saline waters. As pointed out by Stommel (1953) we may also get another type of vertical mixing induced by transitions in width. At the beginning of the ebb flow fresh, almost vertically mixed, less-dense water, upstream from a constriction, in progressing downstream through the constriction "does not push the heavy water back downstream but, because of the control action of the sudden widening in the channel, passes through critical velocity and flows out over the lower, heavier water with supercritical velocity, probably forming somewhere downstream an internal hydraulic jump." This supercritical flow may induce mixing between the faster-flowing fresher water above and the slower-moving saline layers below.

The influence of bottom type and configuration on vertical turbulence and eddies is more difficult to predict because of the complexities encountered in working with conditions at the boundary. It is extremely difficult to make the necessary measurements in the field and almost impossible to introduce all the necessary variables into a laboratory experiment. This is one area that could profitably be given a great deal more attention. Small-scale roughness elements on the bottom must enhance vertical mixing through increased turbulence and eddy action. This would be particularly important as the depth of the estuary is decreased and as the velocity of tidal currents is increased.

Secondary sills within an estuary must also be considered. If the sill rises above the bottom to such a level that the salt-water wedge is completely intercepted, the hydraulic regime will be different on the two sides of the sill. Upstream from the sill, conditions would be much the same as in the rivers supplying fresh water to the system. Downstream from the constriction, mixing may be brought about in much the same way as proposed earlier by Stommel for mixing downstream from areas of lateral constriction. If, during periods of flood flow, the salt-wedge is able to extend across the barrier then, during the ebb flow when fresh water again extends to the bottom, mixing may be very intense upstream. The possibility of the salt-wedge extending upstream across the barrier is increased during periods of low fresh-water discharge. Under such conditions salt water upstream from the barrier may stagnate and become a pollution problem, if rapidly mixed with overlying waters during seasonal freshets.

As mentioned earlier those estuaries with small drainage areas and with little or no fresh-water discharge are "clean" estuaries. That is to say, the water in the estuary is not continuously charged with sediment and the bottom is not being rapidly shoaled through siltation. Most estuaries, including those referred to as "clean", are subject to shoaling near the mouth. Tidal currents in flood stage bring sediment into the estuary and deposit this material as their velocity decreases. In estuaries having a constriction across the mouth the deposition will tend to be localized just inside the constriction, where the flood current flows into quieter water.

As the amount of fresh water discharged into an estuary increases, two other types of shoaling become apparent. In the regions where rivers are discharging into the estuary, shoals will be built up through deposition of the larger or denser sediments that were being transported by the river. Such deposition will be dependent on changes in velocity within the fresh-water flow. The remainder of the sediment will be transported seaward. The second type of shoaling (Schultz and Simmons, 1957) occurs somewhere in the middle reaches of the estuary. The normal patterns of clastic sedimentation are not obvious in this region. The interaction of the fresh water and the saline water becomes a dominant factor in controlling deposition. In estuaries that are classed as vertically stratified or partly mixed, this interaction factor is most pronounced. In highly stratified estuaries the currents above the fresh-water-salt-water interface have a predominant downstream direction, while those below have a predominant upstream direction. Sometimes the flow above the interface may be entirely in a downstream direction and the flow below the interface entirely in an upstream direction. In this case any sediment still being moved as bottom load by the fresh water will be deposited at the point where the fresh-water salt-water interface intersects the estuary bottom. The colloidal clays being carried in suspension will not be affected until salt water becomes mixed with the fresh-water transporting agent. Flocculation of clay particles occurs on contact with sea water and will be most pronounced at the interface, where mixing is most intense. The flocculated clay particles will settle into the salt-water wedge and be carried upstream and deposited where the interface intersects the bottom of the estuary. In estuaries having a relatively fixed position of the salt-water wedge the shoal may become quite large. If the upstream limit of the salt-wedge fluctuates, the deposit will be more dispersed. These shoals in the mid-reaches of an estuary tend to be relatively stable. They are stirred and moved about only during periods of increased fresh-water discharge or storms. Such periods in the Pacific Northwest will occur during the winter and spring.

The degree to which this mid-estuary sedimentation problem affects pollution problems is unknown. In the case of sewage disposal the lighter particles are considered to be dispersed by wind, wave, and current action to the extent that they are no longer regarded as a problem. However, if the sewage particulate matter and sewage bacteria are flocculated with the clay particles on contact with sea water they may be reconcentrated on deposition. Such reconcentration could conceivably cause contamination of the overlying water during these periods when the sediment in the shoal is agitated. Certainly, should reducing conditions exist in an estuary, the area in the vicinity of the mid-estuary shoal should be a reducing environment. If this shoal area is also an area of deposition of organic and nutrient material, bacterial growth may even be stimulated. If for any reason the sewage sludge was not deposited in the vicinity of the outfall but was transported as bed load, its final deposition area would be in the mid-estuary shoal, thus adding to the possible contamination problem in that region.

Another source of contaminating material may exist in estuaries with extensive mud or tidal flats that are alternately covered and uncovered during the tidal cycle. Anaerobic conditions and the production of hydrogen sulfide may exist in tidal-flat sediments at depths of less than five centimeters below the sediment surface. The greater the range of the tide the greater the hydraulic head produced between the level of the interstitial water of the tidal-flat sediment and the low-tide level. If the interstitial flow is not too great to reduce the level of anaerobic conditions, a continuing source of water with low oxygen and high sulfur content may be provided. The effects of such a supply of low quality water to estuaries is a subject that should be given more attention.

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DISCUSSION - Lead by Dr. Barnes

Dr. Creager has contributed to our general food for thought, concerning some of the effects of topography, constrictions and type of bottom on exchange in estuaries. When we consider this along with the different types of estuaries as discussed by Dr. McAlister, and of the varied conditions of feed water as indicated by Dr. Burt, we realize that we have in the estuary a very complex system and in order to define it we must make a great number of field measurements. We have theories which guide us especially in our considerations of estuaries of smooth sides and which conform ordinarily to simple geometric patterns in which there is rather well defined flow. In such cases we come out with reasonable solutions. However, even in these cases solutions to many of the problems are not possible from a theoretical basis alone; hence the major need for field work.

Dr. McAlister mentioned that in Oregon estuaries he did not see evidence of Coriolis Force (force of earth's rotation) because of their small size and the cross channel mixing. However, in larger systems, such as the Straits of Juan De Fuca the effect of this force is readily apparent. It shows up in a dominate movement of fresh water toward the sea on the northern side of the Straits, and in the difference in the height of the tide on the two sides. This force is, of course, more evident as friction and other forces play a lesser part in the motion of the water.

In the Straits of Juan De Fuca we have rather extensive records of upwelling. In this case upwelling is not only caused by wind, but is influenced by the flow of surface water out to sea which is quite strong. There is considerable mixing of fresh water and salt at the sills where the Straits join Puget Sound and the Straits of Georgia. This uses up a considerable amount of salt water and transfers it from the bottom layers into the less dense upper layers where it is sent out to sea. This increases the rate of flow in the bottom layers to make up the deficiency; thus water is pulled from lower depths of the sea. This occurrence is greatest in summer months because of the increased run-off of fresh water due to the melting of the snow-pack during the warm weather period. Added to this is the force of the prevailing north and northeast winds. The result is upwelling.

Oxygen concentrations in the deeper waters of the Straits often are as low as 10% of saturation during these periods. This low oxygen water does not appear in all areas or at all times because in passing across the mixing zone it mixes with a considerable portion of the high oxygen surface waters before it feeds into the interface. The upper layers of the Straits are normally high in oxygen.

Another factor causing upwelling is the jet stream of rivers and estuaries which is pushing out and mixing some of the deeper waters with surface water causing a rise to fill the deficiency. This is evident at the mouth rivers, for instance the Snohomish River in Washington. At the neck of the jet stream as it enters the Sound, very frequently there will be a flow of high salinity and low oxygen water due to upwelling caused by the movement of the water.

A limited study has been made of natural oxygen utilization in the deep waters of certain bays off of Puget Sound. In these areas the rate of oxygen utilization has been shown to be 0.02 ppm per day. These deep waters do not move from the system (due to the existance of a sill at the entrance) unless upwelling occurs. At the rate of 0.02 ppm the oxygen will be essentially exhausted in less than a year. Hence, when movement toward the surface occurs these low oxygen waters may appear near the surface. (The rate is not specific since utilization is reduced as the concentration is lessened). This upwelling is associated with higher salinity in the surface waters and the season coincides with that of upwelling in other areas. This water is also cold. (It is of interest to note that the coldest water of the year in the Straits is in August, not in the winter). When this occurs in the bays the deeper water is displaced by deep water from the Sound and the surface water leaves the systems in the upper layers. This I call displacement flushing of the estuary in contrast to turbulent flushing which causes a varying amount of mixing. The deep water simply rises to the surface and the surface water flows out of the bay.

In such cases water within a few meters of the surface has been found to contain oxygen in concentrations of 15% saturation. This condition will show up most prominently at the head of the system near the mouths of the rivers. It does not often appear in the surface because of the flow of fresh water from the river. Thus there is a film of fresh water with higher oxygen on the surface over the low oxygen strata, unless the jet stream causes turbulent mixing.

A different condition exists in estuaries north of the Columbia than in those south of the river mouth. North of the Columbia the surface water is made up of river flow and land drainage throughout the summer since the drainage areas are large and are influenced by snow melt in the Cascades and Olympia mountains. Because of this higher flow the low oxygen upwelling water is not as often found as it is south of the Columbia. The drainage areas on the Oregon coast are smaller and are not influenced by snow melt as are those in Washington. Hence the layer of surface water is not as deep and upwelling may be more apparent. This situation is also influenced by the currents off the coast which in turn are influenced inshore by the jet of the Columbia River.

Another point influencing exchange in certain estuaries is that of orientation with respect to wind. In some cases wind is very effective in swishing out surface water and increasing exchange rate. In others they are such irregular shapes and so oriented that wind may have no appreciable affect, or may reduce the exchange rate. Wind is therefore an important consideration.

Water flushed out of an estuary does not normally return in the same condition that it left. The reaction is irreversible because once the water is mixed outside it cannot return to its original condition. Here again the shape and orientation of the estuary are controlling factors. Estuaries with a long outside approach have essentially dead spots in the entrance where mixing is of low order. In such cases the return water is more nearly of the same nature as that passing out during the ebb tide.

Change in orientation has a profound influence on the exchange and flushing.

Other inlets may have a long approach so that there is considerable dead space at the entrance and water that goes out on the ebb returns on the flood and the efficiency of flushing is very low.

Another factor influencing efficiency of flushing is the tendency to entrap material on the bottom or in surface pockets. This is especially the case where there are extensive tide flats. Here a comparatively low volume of water covers the flats during flood, much of which is retained in the muds when the tide ebbs. Thus the cleaning efficiency is low.

A technique for measuring inflow and outflow and direction of flow in stratified clear water was discussed. A nail dipped in dye is dropped point down into the water. As it sinks it leaves a column of dye. The direction and rate of spread of this dye can be observed.

Dredging affects exchange and flushing by the change in bottom contours. In most cases dredged estuaries tend to return to normal.

There is a need for improvement of methods by which to measure exchange rates and flushing. Oceanographers for the most part use changes in salt concentration, which method is not adequate for all situations. A great many measurements are necessary before a flow pattern can be established

The suggestion was made that radiological methods be investigated as indicators of flow and distribution. One disadvantage in the use of radiological isotopes is the pick up by organisms. In this connection the selection of the proper isotope and the element of time are important. The use of radiological methods are not hazardous if handling is understood. Radio isotopes have been used in California and other areas. The use of isotopes of the alkali metals was suggested as a possibility. Dr. El Wardani furnished the following table of isotopes which might be used.

POTENTIAL ISOTOPES FOR MARINE POLLUTION STUDIES

ISOTOPE	$t_{1/2}$	cost/curie	Specific activity	Gamma Energy MEV
RB^{86}	19.5d	$1,000.	9mc/g	1.1
I^{131}	8.0d	750.	Carrier-free	0.36 and 0.72
Ba^{140}	12.8d	500.	Carrier-free	0.16 and 0.54

Temperature has an effect on upwelling of deep ocean waters and on exchange and flushing. Since temperature affects density there is a build up of density difference between the cold and warm water layers. When the dynamics of this condition reach a certain level, there is an exchange between the layers. During this exchange the entire stability of the system is altered, in fact, at certain periods there is no stability.

Temperature also affects the solubility of the gases in water. As water is warmed gases are released which tends to create an unstable condition. This, of course, assumes a saturated condition so far as gases are concerned.

This discussion indicates the many factors which are involved with exchange, flushing, upwelling and other physical conditions in estuaries.

ITEM II

BIOLOGICAL FACTORS - Leader Dr. H. F. Frolander

Estuaries have represented convenient and sometimes rich waterways for man, providing in the early history of our country a wealth of food supply. Entrance to estuaries provided sheltered access to the sea and relatively safe harbor facilities. As a natural habitat such areas provide spawning regions for marine species and a kind of proving ground of sharp variations of salinity and temperature with ideal opportunities to study these variations in relation to biological organisms; the large fluctuations, unlike conditions present in nearby neritic coastal areas, allow a clearer insight of the direct effect of these factors on the organisms. From an aesthetic point of view vacation resorts tend to occur in proximity to such areas.

As a natural kind of evolution the very attractiveness and convenience associated with such areas tend to lead to their destruction. They are used for the disposal of sewage. Industries discharge wastes which are sometimes toxic or which cause the depletion of oxygen. Predation by man of natural biological populations may occur. In more recent times the estuaries are often used for the disposal of radioactive waste products. These are but a few of the problems confronting us.

In many such regions the usual chain of events is that such an area has progressed to one of the latter conditions before public opinion and health problems arise and demand a study to correct the situation. Usually, and unfortunately, the highly desirable background of a study before such conditions arise, is lacking. It reminds one of the story of locking the barn after the horse is stolen. However, a different type of ending to the story is possible, as with corrective measures the natural conditions may be restored to allow normal population. The disappearance of textile mills from estuaries and rivers leading to the sea in New England and the subsequent reappearance of various types of fish and associated food chain organisms, is a case in point. A happier solution might be to do a little planning with foresight to conserve natural conditions, and make the best possible use of our resources before the situation has completely deteriorated.

Those on this afternoon's program have a variety of topics to cover. Dr. Macnab is interested in the organisms which occur in estuaries. In talking to Dr. Macnab he emphasized the difficulties involved in estuarial studies and the large amounts of time, money and energy which must be expended. This is a situation which will exist in all marine projects due to the variable weather conditions, cost of equipment, the cost of transportation by boat or ship into the areas involved.

THE DISTRIBUTION OF MARINE ORGANISMS IN ESTUARIES - Dr. J. A. MacNab

It is quite probable that estuarine animals have been occupying this type of environment for over a billion years or ever since the Archeozoic or Proterozoic eras of paleontology. At first they were possibly represented by soft-bodied larval types that could not leave traces as fossils. Some of these may have burrowed in the soft muds of these ancient estuaries, like simple worms or types like Amphioxus or Balanoglossus. Others may have crawled over the surface, like flatworms and others were probably feeble swimmers, like jellyfish, Ctenophores and other planktonic forms.

As Hedgepeth points out in his treatise on Marine Ecology "the organisms which become adapted to the fluctuations in estuaries have found an environment which may actually be comparatively stable in the geological sense." Certainly such habitats have esisted since the first rivers started flowing into the sea. During this long history of estuaries some organisms such as worms, algae and molluscs have undoubtedly clung to an estuarine environment for most of the millions of years involved, others have migrated into fresh water or to land, and new recruits have been added from time to time mainly from the sea.

Estuarine habitats have probably been the refuge or stronghold of the toughest animals from the standpoint of tolerance to wide variations in temperatures, salinities, turbidity, etc. As continents rose and fell estuaries became eliminated by sedimentation and new estuaries developed as the contour of the land masses changed.

There is little doubt that from estuarine animals certain terrestrial forms developed due to their abilities to withstand wide fluctuations in environment. Still, in all the long history of estuaries, animals have never encountered anything like the concentrated, widespread, wellnigh universal pollution that has been pouring into estuaries in rapidly increasing concentrations since the industrial revolution of that aggressive, inquisitive, tool using ape, who, as one geologist stated, is exerting more influence on erosion than any force since the ice age. Or, as Life recently put it, man "the unique, tempestuous, rational, passionate, esthetic, irrascible, proud, anxious, toolmaking, trouble make animal that has dominated the planet for the last half million years.

This creeping, insidious, miasmic fog of pollution has developed so gradually and has been so intimately a part of man's developing civilization that man has paid little attention to it until practically every fresh water stream, estuary, bay and inlet has been contaminated. Oyster beds, clam beds and spawning areas have been quietly eliminated. Estuaries have been scoured by dredges and wastes piled high in appropriately termed spoil areas to smother out whole communities of organisms. Even less attention than has been given to pollution in fresh water has been given to control or treatment of sewage and industrial waste freely poured into the waters of estuaries. The ocean has come to looked upon as the ideal depository for all kinds of wastes and it must be said that it does a remarkable job of neutralizing, detoxifying and diluting pollutants with tidal scouring, wave action, currents and its complex mixtures of salts. There are evidences, however, to those who have the time, money and opportunity to investigate conditions carefully, that even the sea is showing signs of indigestion from this contamination.

Pitifully little work has been done on estuaries along our Pacific Coast or for that matter in any part of the world to determine quantitatively and qualitatively the populations of (especially) bottom animals. In most places it is already too late to find out exactly what the normal communities were before civilization altered environmental conditions. We shall soon be in the position of grassland ecologists who have to resort to the railroads' right-of-way or graveyards to find what they hope may be a sample of the original native vegetation. Along our thousands of miles of Pacific Coast line only two people seem to have been doing anything like an exhaustive survey of bottom animals with an eye to the possible effects of pollution. These are Francis P. Felice, studying the effects of wastes on bottom animals in San Francisco Bay, and Donald J. Reish, along the Lower San Gabriel River and in Long Beach Harbor. Even in these comparatively detailed studies many phases of the work have had to be slighted or neglected altogether. Otherwise investigations have been in the nature of special studies on the effects of pollution on oysters or other restricted phases of the problem.

It is easy to see why little work has been done in estuaries. Anyone who has battled wave, winds, currents and tides, in rather cramped quarters, with consequent grounding on sand bars or mud flats, realizes the difficulties involved. Very little can be done by only one or two persons. A good boat and trained crew are essential. In shore work at low tide slime on rocks and oozy sticky mud make work very slow and tiring. All work has to be done in definite relation to tidal action which is nowhere so strong as in estuaries.

In general at the mouths of the estuaries, the animal life is practically that of an open sea coast with certain modifications. One interesting feature just off the mouth of Coos Bay is the presence of a large and populous sand dollar bed about two by three miles in extent. This bed is associated with many olive shells, some worms and juvenile edible crabs. In fact it seems to be a sort of nursery for these crabs. It would be interesting to know whether such beds lie off the entrance to other estuaries and whether they have any relation to the nutrients that may be washed out of the bay or stirred up by dredging in the bay. Usually such things as crabs, flounders, sand dabs, olive shells, clams, worms and even razor clams can be found just inside at least the Coos Bay estuary.

As one moves up the bay the effects of pollution and fresh water begins to be evident. The olive shells drop out and the clams are of the smaller bay varieties, worms and crabs may still be numerous. Shells and rocks may be covered with barnacles.

Up the estuary life becomes much less varied. There may be mud flats with worms and bay clams. Colonies of animals forming an almost pure population may be found such as a haul that produced nothing but bark and grey shrimp near North Bend. As the water freshens, the Zuider Zee crab and soft shelled clam MVa arenaria may be found. Tide pools along the shore may be inhabited by a mixture of fresh water and salt water animals.

Several problems arise in connection with animal life in estuaries. One that has intrigued me is the relation between the plankton which enters an estuary in large numbers and rich variety on a flow tide. On an ebb tide a plankton sample may yield little but algae, an occasional ctenophore, copepods, etc. It seems likely that much of this planktonic food must die in the estuary due to increased temperature and slackened currents to say nothing of pollution. Possibly a large part of this contributes to the cozy muck of the tide flats and furnishes food for many bottom invertebrates. It would be interesting to obtain quantitative figures on this.

Reish and Felice find that in the upper parts of an estuary where pollution is maximum, life is practically eliminated, especially by industrial wastes. A few animals seem quite tolerant to domestic pollution. These and other resistant or tolerant forms may even be increased in numbers at a distance from the source of concentrated wastes. The trouble is that these animals which are so tolerant and which seem to thrive on at least domestic pollutants are for the most part weed species that are of less or little economic importance as compared to native species and in many cases have been imports from elsewhere such as the soft-shelled clam and the Zuider Zee crab. In some places, other small clams such as Gemma may even replace Mya. Are we producing by pollution the same situation that prevails on overgrazed pastures where foreign weeds came in to replace valuable native species? This seems to be the case in Coos Bay where a large Empire clam bed was smothered by a spoil area produced by dredging opposite the city of Coos Bay. Now only small grey shrimp, worms, and other inedible invertebrates are left. Apparently even this far up Coos Bay in former times the native oyster was abundant. At least the bottom yields numerous shells. These native oysters were killed out by a great forest fire in the early pioneer days. It is possible that the largely unrecognized forms of pollution connected with mills and logging may have played a larger part than we realize. Now even the Japanese oysters cannot be raised in the vicinity of North Bend or Coos Bay.

Another question that occurs to me is to what extent are we eliminating the nursery grounds or food of economically valuable fish such as the striped bass by pollution and disturbance of estuarine shore lines?

COMMENTS - by Dr. Frolander.

Several items mentioned bring to mind problems in estuaries as regards populations. There is a significant difference between the populations found in estuaries on the east coast and those in this area. For instance the best place for the soft shell clam on the east coast is the wide mud flats exposed at low tides. But similar areas on the west coast are usually void of clams. There may be a few other species but they are sometimes very lean. Here they appear to grow in a very narrow area at a certain tidal level. The type of distribution, sediment, etc. is entirely different than on the east coast. They would never be found in a rocky area.

Another point is that of distinguishing between pollution which is detrimental and that which may be beneficial. Sometimes sewage solids are beneficial. For instance, one of the problems on the east coast is to keep people out of areas contaminated by sewage. The clams there are big and fat. They do very well on certain types of material in sewage.

There are important relationships between sediment size and growth rate of shellfish. The coarser the sediment the better the growth rate. This might be related to the mechanism of pumping and expulsion of sediment.

There are many problems in estuaries that need investigation. Dr. Sparks has been interested in economically important forms such as types of mollusks. He has worked in the Gulf Coast area on problems of the effects of pollution on shellfish. He is also interested in the training of people in this field.

WASTE DISPOSAL IN THE MARINE ENVIRONMENT - Dr. Albert K. Sparks

Since the origin of American industry, waterways have been utilized as the principle method of disposal of industrial wastes. I do not intend to debate the right or wrong of this point, but simply to point out the historical precedence. There have been in recent years great advances in industrial pollution abatement, largely for economic gain in secondary recovery of valuable products which were formerly lost through the effluent streams. These improvements have been overshadowed, however, by the tremendous increase in industrialization. This growth of industry in areas where the same waters receiving industrial discharges must also provide for the community uses, has resulted in increasingly strict pollution control laws.

Because of the much greater dilution in estuarine and oceanic situations, conditions have not been so critical nor controls so stringent as in fresh-water streams. In recent years, however, attention has been focused upon estuarine and oceanic pollution.

Industry's Reactions to Controls

To meet these controls, industry has developed methods for handling and disposing of objectionable waste materials and, in many cases, have developed methods of testing their effectiveness. The general tendency has been, however, to develop methods of testing and monitoring based on chemical determinations with no biological assessment attempted. This has been largely because few industrial concerns have biologists on their staffs. Many organizations have spent millions of dollars for equipment to improve the quality of their waste water. The quality of the effluent, and the improvements in the quality have been measured in terms provided by standard laboratory test procedures. Although these procedures are invaluable in improving the effluent, the data thus obtained provides insufficient information as to the actual effect of the waste stream on the marine life in the estuary. In recent years some industries have financed studies designed to determine this affect, either by ecological surveys or bioassay, or a combination of the two.

<u>Problems of Biological Studies</u>

It is particularly difficult to assess the biological cost of waste disposal in estuaries because of the neglect of this ecosystem by both limnologists and oceanographers. Several investigators, particularly Lyman and Fleming (1940), have pointed out the unreliability of chlorinity determinations in estuaries because of the upset of ionic ratios in river-diluted sea water. When effluent streams from oil refineries, petrochemical plants and the like are added to the already upset ion ratio, the chlorinity relationship becomes even more confusing.

Another problem is the seasonal and even short-term changes in the chlorinities because of rainfall and river discharge. At times of heavy rainfall, great dilution of the estuaries occur, fresh-water fish and invertebrates are swept into the area, storm sewers add discharge that is often highly toxic, and many industrial waste treatment units are unavoidably flushed. Rapid and extreme changes occur in the hydrographic and faunal picture at such times and the task of analyzing the role of each factor is difficult.

When mortalities of fish or economically important invertebrates occur in an industrialized estuary, industry is almost universally blamed for the condition. Actually, of course, this stigma may be, in individual cases, deserved or be grossly unfair to an organization that is faithfully fulfilling the letter of the law from a pollution standpoint. We may be sure that in any such instance, study should replace hysteria.

Some time ago I was retained by the Research and Development Division of a large oil refinery to set up a program designed to determine the effect of their effluent on the ecology of the area into which it is discharged. In addition to a series of bioassays, an ecological survey of the area, the Houston Ship Channel and adjacent bays, was initiated. (Chambers and Sparks in press).

The Houston Ship Channel is located between Galveston Bay and the City of Houston and is, actually, an artificial channel formed by straightening and dredging a bayon and it is maintained by periodic dredging. A number of streams of various sizes empty into it and it receives a slight tidal exchange. The

City of Houston and communities along the banks, totaling approximately a million people discharge sanitary wastes, after varying degrees of treatment, into it and, additionally, it is heavily industrialized with several oil refineries, chemical and petrochemical plants, a steel mill and a paper mill lining the banks and discharging their effluents into it. Under these conditions it is virtually inevitable that the upper part of this stream is heavily polluted. The area routinely studied consisted of about nine miles of the channel, extending two miles below the company outfall and seven miles above it and a series of bays adjacent to this section. Approximately sixteen stations were set up and weekly determinations of dissolved oxygen, chlorinity, temperature and certain chemical constituents were obtained. Population studies of the fishes and larger invertebrates were made at certain stations each week by means of a small otter trawl and plankton studies were also conducted. Additionally, current studies were routinely conducted by several methods including a Price Meter and a current cross and a study of the bottom conditions utilizing cores and dredges was made.

Results of this ecological survey demonstrate, I think, some points of interest in estuarine studies. We found that all measured hydrographic conditions varied seasonally, and, also fluctuated over short term periods.

A large concentration of fishes of many species exist at all times in the bays off the Ship Channel, varying from predominately fresh-water fishes in the winter to predominately marine fishes in the summer season. Quite often, however, fresh-water fishes and marine fishes would be collected in the same haul.

In addition to seasonal fluctuations, it was learned that a dissolved oxygen gradient existed within the area, being high at the lower end of the survey area and low in the upper area where the bulk of industry is concentrated. This is of particular interest because dissolved oxygen concentration was found to be the most critical factor in the ecology of the area. A temperature gradient was also found to exist, with temperatures increasing with distance up the channel. There was also a decrease in number of species and individuals of fishes with distance up the channel. These phenomena have been listed to illustrate the necessity for extensive sampling at frequent intervals over at least one year before a reliable picture of an estuary can be shown.

Disposal Problems

Since the bulk of my own experience in waste disposal in estuaries has been involved with the petroleum industry, I would like to illustrate the disposal problem by a discussion of this industry's problem.

As stated in American Petroleum Institutes Manual on Disposal of Refinery Wastes, "Petroleum is a highly complex mixture of hydrocarbons and their sulfur, nitrogen, and oxygen derivatives." Any one of these may enter the effluent stream and affect the recipient water body. These losses may occur during drilling or pumping, in the field, or at the refinery during receiving, transferring, storing or refining. Often losses occur as a result of breakdowns or overflows in treatment plants or from unintentional flushing of storm sewers or effluent storage tanks by sudden thaws of snow or torrential rainstorms. Many of the non-petroleum substances used in treatment of petroleum may also appear in the effluent stream and many by-products of catalytic cracking of petroleum are difficult to recover from the waste stream.

It seems to me that the real question in waste disposal in estuaries is not so much "what is in the effluent," but, rather, what is its effect on fish and other marine life. A total effluent which will, as in the case of the company I have mentioned previously, usually cause no mortality to fish in 100 per cent concentration is obviously not affecting the ecology of the estuary. An effluent that is shown by bioassay to be toxic in low concentrations is in obvious need of improvement.

I would like to stress, in conclusion, the need for hydrographic and biological monitoring in addition to bioassay determinations as the necessary steps in determining the biological costs of waste disposal in the marine environment.

COMMENTS by Dr. Frolander

One of the problems in estuaries is related to multiple vs single use. The question is--whatis the best use that should be made for the benefit of the most people. Certain areas should be enjoyed by people for recreation--fishing, etc. Areas should be used by people for living purposes. Certain areas are ideal for industrial sites. In most cases we come face to face with good economics. The sensible thing to do is to put on a good conservation program which will take care of most of the factors. In most cases, however, someone will be hurt.

The decision as to what uses should be made requires the establishment of a program to study the specific problem. The question is who is to make this study and what facilities are needed. University people are expected to teach and do a normal amount of research. However, to study most of these problems a good staff full time is needed. It might take people from numerous fields. Considerable time may be involved. Even after top flight people have spent a long period on a study, there may still be unanswered questions. This is research and the difficulties that Universities have in conducting studies of large scope.

Research in the marine areas are made difficult because it is not always possible to go into areas because of weather. This may break the continuity of study and often make repetition necessary, if such is possible. The facilities to do this type of work are specific and costly. This has to be recognized by those who supply the funds for such studies. In spite of these difficulties and the cost, this research is an absolute must.

Without this basic information, we will never be able to make proper decisions on the uses of our waterways. Whether or not the deterioration of the marine population in given areas is due to material discharged by industry or to natural change in circulation or several other factors--we are not always sure.

I can think of several problems in bays in Washington where this is basically the case. Planktons grow well in some of these regions at times, but at other times they don't grow so well. Materials are discharged by industries and the question is how much effect does this material have on the growth of oysters. The circulation tends to be comparable to the situations on the east coast where the currents and the load of sediment might as easily explain the end result as the effect of the particular effluent that was discharged. We need a more direct approach in getting some of these materials closer to the animals.

Mr. Marriage has been interested in the organisms in estuaries that might be commercially important.

RELATION OF THE ESTUARY TO MARINE PRODUCTION - L. D. Marriage

The things that I will mention are applicable principally to Oregon although they may be to some extent applicable elsewhere. My mental picture of an estuary is a depression in the coastline with a river discharging into the head end and the ocean exerting its effect on the other--in between is the mixture of the two--the proportions being dependent upon the ratio of the river flow to the tides.

On the floor of the estuaries are sediments laid down by the checking of the river currents by the ocean tides and the precipitating effect of salt water. The intrusion of salt water is dependent upon the range of the tides, the configuration of the estuary and the quantity of fresh water being discharged into the estuary. The degree of mixing of fresh and salt water varies from very well mixed to a high degree of stratification. Temperature regiments vary accordingly to climate, shape of the estuary, incoming water temperatures and related factors. Nutrients are carried into the estuary by the river where they form the basis for a complex food change including plants and animals

Within this changing physical environment communities of animals and plants are established which are capable of surviving and thriving under a wide range of conditions. They are distributed depending upon their individual tolerances and so we find an estuary as a source of food for resident as well as anadromous and visiting fish. Predatory fish find smaller fish and other marine animals to prey upon. The Ling cod and salmon are examples of predator fish who make feeding trips into these areas in search of food. Other fish and shellfish feed upon smaller forms of life ad infinitum. Some fish utilize estuaries as nursery grounds to a greater or lesser extent. It is the habit of the English sole young to reinvade an area up to a year's time before migrating to the ocean. To a greater or lesser extent herring have similar habits.

Anadromous fish utilize estuaries as a transition zone between salt and fresh water, either during their migration to the ocean or to the river. Salmon and shad and certain trout are examples. These species are of great economic value to man, both commercially and sports-wise.

The Dungeness crab utilizes some of the estuaries on feeding excursions from the oceans and in a limited way as a nursery. Studies have shown some crabs to move from one estuary to another along the Oregon coast. Large numbers of crabs have been tagged off the Oregon coast to study migration habits. Also tagged crabs have been released within bays to observe their migration habits. These crabs appear to move off-shore. Conversely crabs found and tagged off-shore move into the bays. Also crabs will move from one estuary to another; so movement is considerable. We have not been able to show to any large extent a contribution of bay to the off-shore crab stock although there is undoubtedly some contribution in this line. Similar movements apply to animals that are of less direct economic importance.

Resident plant and animal life in various forms and stages of development contribute to a class called plankton. These are generally macroscopic and microscopic forms on which selected larger animals feed. The resident plankton of an estuary are supplemented by ocean plankton on incoming tides. Together these ocean and estuarine plankton play an extremely important part in the food chain of an estuary.

The study of all these organisms living together harmoniously and advantageously is called ecology. Occasionally man upsets the ecology of an estuary by adding pollutants or excessive nutrients to the waters. When this happens the food chain is broken. The more adaptable species replace the less adaptable ones and a whole new ecology results which may or may not be in the interest of man's wants or desires.

Dr. Creager spoke of man made changes within estuaries--for example breakwaters and similar structures change the flow pattern of the bay. Pollutants could change the distribution of fish in a bay, particularly shellfish. This factor has not been given adequate consideration in Oregon in so far as harbors and estuaries are concerned.

Collectively the animals found in estuaries can be of great economic and esthethic value to man. Hundreds of thousands of pounds of salmon, stripped bass, trout, crabs, oysters, clams, herring, shad, sole, sturgeon, ling cod, perch, rock fish, etc. are harvested annually in marine waters of Oregon. As the population of humans increase, the easily accessible marine animals assume a proportionally greater value. It can be said with assurance that esturaries play an important role in marine production--and yet very few specifics are known about the chain and relationship of the chain to these animals. Management activities on economically important species are employed which limit the catch or harvest, prohibit the landing of females, the catch, the season for harvesting, etc.

Biological and ecological studies are desperately needed to define the habitat where the economically important species live. Studies are needed to define food chains within each respective bay, show the existing relationship among the various contributors and the limiting physical, ecological and biological factors. These factors may far outweigh any effective management practices and need to be further understood.

One of the problems peculiar to Oregon is the ownership of the tide lands in our bays. The greater percentage of Oregon's tide lands are owned by private concerns and the State has very little control over the development or use. Harbor improvements in Coos Bay were across from the towns of Coos Bay and North Bend. Animal communities have been covered with waste from channel deepening, etc. On the same side as the town of Charlestown on Coos Bay, one whole very productive clam flat has been covered. The decision to cover this area was made on the basis that it is of more economic importance to develop a small boats basin than to save clams in that area.

Fisheries interests need to get together with the port commissions and those responsible for various developments within bays along the Oregon coast to discuss these problems. The possibility has been suggested to use the

the spoils from dredging operations to create clam beds where non-productive beds now exist. I was reminded in the discussions of changes of ecology within bays, for example the oyster kill in Yaquina Bay in 1953 and 1954 where a tide flat of approximately 200 acres was innundated, so to speak, by a very profuse growth of green algae called Ulva and enteromorpho of the family of Ulvaceae. This apparently was a result of a combination of factors during the early summer months which were advantageous to the growth of the algae and as far as you could see for the 200 acres, it looked just like a golf course under which were the oyster beds. This created a cover for the sun to beat down on and for the various chemical processes and great mortality for the oysters took place--even 100% mortality in some places. Nutrition was a great part in this with sewage being discharged into the bay and the nitrogen deposits reused by the algae and resulting in profuse growth.

DISCUSSIONS led by Dr. Frolander.

We have a category covered by Mr. Marriage of the role of estuaries in what we might call natural relationships--that of the estuaries providing a nursery ground or a site for certain species of organisms to develop and feed out into surrounding areas. These estuaries are then important as regions that replenish the stock in the more open areas and which may be periodically removed or destroyed depending upon conditions existing there. This region then acts as a feed dispersing zone. These same zones act in a reverse way, because of their richness in growth, as hunting grounds for predatory forms and as a result of this, various forms come in from the sea to feed on the juicy morsels within these shallow areas and we have (as we have in a few states) a multi-million dollar sport which is of great benefit to the state. One always has to weight the pros and cons of this factor.

In one eastern state the value of the sporting industry is some six million dollars. That alone is quite an industry and one has to take this into consideration in deciding upon these multiple uses of estuaries.

Anadromous fish use the estuary as a transition zone. This is an area where biological studies can be made on problems such as: how these fish move up into the stream, what are the natural barriers, and how the fish get around them. This is of great use to marine ecologists when they try to decide later why there is a particular distribution of fish such as ? which have such a strange distribution about the ocean.

One has to realize that somewhere along the line there are certain limits to tolerances that may control distributions and one can learn a lot about this in the study of forms from the transition zones in places like an estuary.

The other point--what happens when you upset one of these regions. In certain rivers natural salmon runs have disappeared. Dr. Edmundson, University of Washington Zoology Department has been interested for several years in the reestablishment of salmon in an area in Bear Lake, Alaska. This is a region where a good salmon run had disappeared and where an attempt was made to reestablish the run. They could supply fish to the region, but this was not enoughtbecause for the stock to grow and develop some form of food supply is needed. What is it that the young salmon feed on? Considerable is known about what they feed on in the hatchery but the information as to what they feed on in nature is lacking. Since they obviously feed on something, probably in the plankton category, in the young stages in the streams, as they move downstream toward the ocean, this implies that there was in the past a supply of phytoplankton to support the zooplankton level. This in turn implies the need for nutrients to start them growing. Therefore, to replenish the adult fish something must be done about the concentration of nutrients in the region. A natural step follows to supply the nutrients. Bear Lake is not readily accessible and to fly the nutrients in is expensive on the chance that it might work. Once the nutrients are there, how can they be applied? They cannot be dumped into the lake at one time since timing has been found important; otherwise the plankton bloom will appear at the wrong time for the young fish. All the food in the world two weeks late will do very little good. The sequence of the nutrients is a big factor. One of the easiest ways was to introduce the materials around the edges of the lake and let natural spring melt carry it in. This occurred at an ideal time since increased temperature and light provided ideal conditions for photo-synthetic activity.

Another point that was brought up in the study of estuaries, is that it is not enough to do biological work. A group of well-trained people working simultaneously taking physical and chemical measurements are needed to work along with the biologist.

One other point mentioned here and there in the various talks has been this problem of looking at everything except Man as the cause of the ills in estuaries. This is illustrated by the controversy regarding salmon population versus seal herds. In years past the salmon populations were quite good and the seal herds were quite good. There wasn't any particular problem till Man showed up.

Indicator organisms are valuable adjuncts to biological studies. However, they are found only as a result of much basic information and many years of intensive research. There must be a long range of biological data supplemented by physical and chemical data in order to relate any particular organism to specific conditions.

There is some question as to what constitutes an indicator organism. It depends upon what condition is to be indicated. The meaning of "Indicator organisms" as applied to estuaries is one or more that will be related to the aquatic environment, good or bad. Indicator organisms cannot be relied upon to tell the entire story. They are only valuable as tools to bioassay.

An example of indicator organisms in wide use is the coloform organism used to indicate bacterial contamination of human origin. Even in this case, supplemental information is needed on which to base judgement of the health hazard associated with the specific situation.

Radioactive material and its take-up by marine organisms can be adapted as a tool for study in the marine environment. Information regarding the selectivity of organisms for radioactive substances, how it is concentrated and how they get rid of it would be valuable to the marine biologist.

Reference was made to a study of flotation of marine diatoms. Through ionic selection these organisms regulate their buoyancy to a particular level in the sea. If some of these ions were radioactive, valuable information could be collected regarding distribution and travel.

How can the collection of basic background data be implemented? In many cases industry has played an important role in the collection of such data. For example, the hydrographic and biological studies supported by the oil refineries in north Puget Sound supplied before and after the refineries were placed in operation. With this data any change in the environment resulting from the wastes from these operations was readily apparent. (No significant change was indicated in this case). The work was done by the University of Washington.

Too much emphasis cannot be placed on the need for studies of seasonal cycles prior to the existence of a pollution problem. Without these data it is difficult to decide what the original ecology of the area was.

A large segment of industry is presently doing research and making surveys in this field. Much of this should have been done twenty years ago. There is a tremendous amount of this type of work to be done in the Northwest, in order that the same situation as exists today will not be faced twenty years from now.

What is meant by the word "pollution"? There is some confusion in the minds of the general public as to this term. For instance the overly large bloom of plankton in Lake Washington is called "pollution" since it interfere with swimming and other recreational uses. In the same area the term is applied to the bacterial contamination of beaches which cause them to be closed. Salt water intrusion in Lake Washington through Government locks retards circulation and anaerobic bacteria take over. As a result many beautiful yachts are blackened. Salt in irrigation water interfers with its use and is called pollution. Toxic substances in water may affect fish. In cases where fish are a consideration, this condition would be pollution. The run-off of land which affects water supplies may be pollution.

In all cases, the use made of the water is involved. Hence, pollution can be defined as a condition of water quality which interfers with the use to be made of the water. It is not necessary to identify the degree or source in the definition of the term.

ITEM III

<u>MEASUREMENTS</u> - Leader Professor Robert Sylvester

Measurements are the foundation for all of the studies of estuarial problems. The oceanographer is involved with physical factors and the biologist with the ecology and the disturbance of the environment. The engineer usually is required to use the data supplied by the above and others to do the best he can to fullfill his responsibility. Often the engineer must proceed without adequate data. To all of these, methods for measuring pertinent factors are a must.

In evaluating the effects of actual or possible pollutants in a tidal estuary, it is necessary that water mass movements in the estuary be fully understood and that generalizations not be made since no two estuaries are alike and, in a given estuary, the dynamics involved preclude a steady state condition existing for any prolonged period of time.

The principal objectives in the study of a tidal estuary in relation to water pollution control are to determine:

1. The distribution and concentration of river water in various parts of the estuary.

2. The net seaward transport of the river water.

3. The accumulation of river water within the area and the time required to flush a day's river flow through the area.

4. Existing water quality conditions in the river as it enters the estuary, within the estuary and in the entering sea water.

5. The effect of future pollutants can be predicted by using the fresh water concentrations and transport in the estuary as a tracer, or guide, to the possible behavior of additional entrained waters.

Some of the variables affecting estuarial behavior on which data must be obtained are:

1. Topography

2. Fresh water flow variation

3. Sea and fresh water temperatures and salinities.

4. Wind direction and velocities.

5. Water depths and volume in different segments of the estuary.

6. Tidal ranges.

7. Coastal currents

8. Stratification under different river flows or the existence of a salt water wedge.

The approach to an estuarial study can take several forms:

1. An analyst can obtain data from charts and maps, river discharge records, tide tables and normal salinity-temperature data and apply Ketchum's (or some other) method of rational analysis which assumes:

a. A constant river flow

b. Uniform mixing in a segmented estuary.

c. Steady state distribution of salt and fresh water

d. Uniform tidal movement.

e. Definite limit of salt water intrusion.

Field data must be obtained to check the validity of this method. If it proves valid, data are obtained on where in the estuary monitoring stations might best be located and the effect of future pollutants may be calculated.

2. A large number of water quality data are obtained under all estuarial conditions of behavior. Transport times and concentrations may then be calculated from the salinity and fresh water flow relationships. Current meter readings can be used to augment these calculations. This approach gives the existing water quality conditions and it permits prediction of future conditions. In a large estuary, a very great number of samples must be collected over a long period of time, involving considerable expense and manpower.

3. A model may be built of the estuary that will permit, in a relatively short period of time, studies of water mass movement, exchange and water quality. Models may be expensive and time-consuming to build and their distortion, viscous and surface tension effects may limit their usefulness to over-all effects only.

Dr. Maurice Rattray will discuss the use of models in water pollution studies.

ESTUARINE MODELS - THEIR USE AND LIMITATIONS - Dr. Maurice Rattray, Jr.

I. General statements on modelling and similarity

A. Need for models

A model of a natural waterway is constructed for use in solving a problem, or a group of problems, which are too difficult (or practically impossible) to solve on the waterway itself. Often the answer desired for a particular application, such as pollution, may be just yes or no, but the mechanism which controls the system is still extremely complicated.

The kinds of problems for which a model is useful can be divided into two categories:

1. Conditions for which the physical laws governing the motion or behavior are not completely known.

2. Conditions for which the physical laws are known, but the system is too complicated for a solution to be obtained by analytic means. In this case the model operates as an analogue computer.

B. Modelling laws

Before a model can be properly designed and used, it is necessary to know what questions are to be asked of it and what mechanisms will control the answer. To put this in another way: one is interested in the answer to a problem, and it is necessary to properly specify the problem.

Model scaling laws will be determined by the totality of equations (for example, the differential equations and boundary conditions) which uniquely determine the desired answer. The requirement of similarity between model and prototype can only be met when a number of restrictions between the different scale factors are satisfied. When these conditions are fulfilled, it means that the set of equations relating the prototype variables is identical to that relating the model variables, and therefore results obtained by measurement on the model can be directly related to the prototype.

Unfortunately for models utilizing water, similarity cannot be satisfied for the general equations of fluid motion (Navier Stokes) except at full scale. This is usually expressed by stating that the Froude number characterising the gravitational effects on the flow, and the Reynolds number, characterising the viscous effect on the flow, cannot simultaneously be made the simultaneously be made the same in model and prototype for any model scales other than unity. It is just this fact which makes the modelling of hydrodynamic phenomena difficult and often misunderstood. It is also evident that different scales will be required to model different aspects of water motion. For this purpose 'dimensional analysis' will be rather limited in use and actually not useful at all for the "distorted" models commonly found.

Before similarity considerations can be applied it is necessary to simplify the general equations by retaining only those terms which are important for the particular phenomenon under investigation and setting the others equal to zero. This must be done such that and prototype satisfy the same simplified equations. Otherwise, the use of scale models to investigate natural flows would be impossible. Once the appropriate simplified equations and the conditions under which they are valid are obtained, then a straightforward application of the similarity criteria will determine the necessary scale restrictions for the model.

It has often been said that the use of models is part an art and part a science. It is a science. What was considered to be art, was nothing more than a physical insight enabling the investigator to see what terms in the equations would be important without explicitly writing the equations. In addition, there was often an investigation of the laws of behavior utilizing the model and then the application of these laws for scaling to the prototype. This was called "trial and error" but was really an application of the basic principles outlined above.

II. Examples of modelling

A. Conditions for which the physical laws governing the motion or behavior are unknown

When the laws of motion or behavior of a system are unknown, similarity cannot be applied and modelling laws are unknown. It is necessary to use either the natural system or a model to determine the appropriate laws, and in many cases the use of a model is advantageous. Simple geometry usually will be used as the laws themselves will be independent of the boundary's shape.

1. Dr. Garbis H. Kenlegan has performed a comprehensive series of experiments of this type which give model laws for various density current phenomena. The work has been primarily concerned with various aspects of the intrusion of salt water wedges into rivers. The laws of behavior were determined by investigations in several different flumes under varying conditions of runoff, density difference, etc. His results, where they are uninfluenced by viscosity, could be directly applied to rivers with rectangular cross sections. For non-rectangular sections the model laws he obtains can be used to build an appropriate model of the river system.

The fact that work is being carried on to determine the model laws for certain density phenomena should provide warning that all estuarine problems are not yet ready to be solved by the use of models.

B. Conditions for which the physical laws are known

1. Distorted tide and river flow models

These are the most commonly used type of estuarine model. They are based on the laws for fully turbulent, almost horizontal flow. That is, the effects of viscosity, vertical acceleration,surface tension and Coliolis force must be negligible in both the model and the prototype. The equations governing this system are available.

It is worthwhile to consider the condition for the scale of bottom roughness. The relation used for bottom stress is valid for turbulent flow over a rough bottom. It is always necessary to make the roughness Reynolds number in the model sufficiently large for this condition to be satisfied. This can be done by increasing velocities or roughness and is usually accomplished by distorting the scales. Increasing the depth scale immediately increases the velocity scale and must be continued until it is sufficiently high for turbulence in the channel.

In the Puget Sound model at the Department of Oceanography, University of Washington, the roughness elements consist of large irregularities in the channels. In this case they are already sufficiently large in the model to insure a turbulent boundary layer for the main channel flow. Actually it is uncertain that the bottom stress needs to be included for this model. For the tidal motion the stress terms in the equations of motion will be relatively small, and for the mean motion the bottom stress will be negligible.

2. Mean salinity distribution

When the mean salinity distribution is to be studied, equations must be included for the salt balance and the density and salinity changes. These equations can be written.

In the salt balance the vertical transport of salt due to turbulence is generally important, and yet an original assumption was that the flow be almost horizontal for a distorted model. It will be generally necessary to consider the nature of the turbulence in order to ensure that the modelling will be correct. Since the largest scale turbulence will be the major factor in the turbulent exchanges important to the mean salinity distribution, the following conditions will suffice for adequate modelling with distortion:

a. The largest scale turbulence is generated by large scale roughness and therefore is distorted to the same extent as the length scales. Since turbulence will tend towards isotropy, it is important that the turbulent effects become insignificant away from the turbulence generating regions.

b. Turbulent exchange will be modelled satisfactorily even with isotropic turbulence, if the horizontal exchange is negligible and the vertical turbulent components are scaled correctly.

C. Mixing and dispersion problems

Large scale distributions of any material will follow the same laws as the salinity. Thus the same modelling will be adequate for both. However, small scale distributions may be influenced by the smaller scales of turbulence and also to an important amount by the horizontal components of turbulence. It is improper to assume correct behavior for small-scale dispersion just because a model gives the proper mean salinity distribution.

An example of this difficulty is found in a study of flushing in the Delaware model carried out by Dr. D. W. Pritchard. This model had been artificially roughened by the addition of bottom roughness elements and vertical rods so that the mean current and salinity distributions compared adequately with the prototype. However, the initial spread of any contaminant was unrealistic.

D. Wind circulations

When a wind blows over an estuary a wind circulation will be caused due to the action of the wind stress on the free surface. The modelling for stress will be the same as given before, and satisfactory results can be obtained if the proper stress is obtained from the model wind, and if there is no important turbulence generated by the wind. If there are important turbulent effects due to the wind action these would also have to be reproduced.

In conclusion the use of models is very valuable in solving many estuarine problems. However, if the laws of behavior for the mechanism under study are unknown, they must first be found before an adequate model can be designed. It is important to recognize this restriction and to realize that a single model may not answer all the questions that might be asked about a single system.

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DISCUSSION - Led by Prof. Sylvester

Reference was made to two models of Puget Sound constructed by the Oceanographic Department of the University of Washington. The question was asked - in models of this type what valid measurements can be obtained in relation to currents and water quality and wherein are erroneous results possible?

Dr. Rattray indicated that proper current distribution was obtained and the tidal current is reporduced adequately. Because of the small amount of water representing the flow of rivers viscous effect are important in the model while they are not so in nature. In order to reproduce the salinity which would be found in river mouths water in the model at the mouths of the rivers is artifically stirred. The effects of viscosity in the main body of the model are not important.

All important factors of the model have been scaled to fit the equations. Field studies indicate that these equations are proper. Actually the model works better than was originally expected. It has been constantly refined. For instance much smaller salinity variations than originally expected are measurable. To do this it was necessary to maintain a constant temperature in the inflow from the ocean for any set of studies. This model allows studies under constant and controlled conditions which is not possible in the actual body of water. This allows formation of the laws of distribution.

A plastic sheet has been installed over the surface to eliminate the effects of warm air in the room, such as evaporation etc.

There are limitations in the use of the model for pollution studies in that it does not contain the biological systems found in nature. Therefore, any changes in composition resulting from biological action cannot be duplicated.

It is usually necessary to add an excessive amount of indicators to represent the flow of waste from a specific source. However, unless this amount is significant as regards the volume of water in the model and affects the flow, the dynamics of the model are not changed. Therefore it will disperse and be transported like a smaller volume would be. Concentrations are not measurable. Several dispersions are adequately represented. Local dispersions may not be. Larger scale models of the local area are necessary to show such effects.

The model is an excellent tool for background studies. However, it requires a great deal of field work before it can be scaled. It is necessary to have sufficient information by which to write the equations. The model solves these equations. The model can also be used for studying the equations. For instance flumes have been used to obtain the laws for salt-water wedges, the way they intrude into rivers, rate of exchange, etc.

Computer systems are often possible in river models but difficult to use in estuarial models.

Cost is governed by size and what is required to be reproduced. The University has about $16,000. in the present Puget Sound model. Experience can reduce the cost. The cost of field investigations is not included in the above estimate.

The question was asked if it would be practical for states, Federal government and educational institutions to join to build models of desirable estuaries in which all could participate in studies.

Results do not mean anything unless the results are valid. Dr. John Dermody will discuss this subject.

VALIDITY OF MEASUREMENTS - Mr. John Dermody

It has been shown that one needs field measurements of currents in order to properly construct a model of an estuary.

It can also be said that one must have a model in order to intelligently measure currents in the field; at least one must construct a "mental image" model (using available theory and data) in order to equip the field party with adequate instruments--instruments capable of measuring the currents expected to be found.

There are two methods of measuring currents--each differs markedly from the other:

1. The "Path" method of Lagrange, in which a particle of water is "tagged" in some say, and its path traced as it moves through space, e.g., a free-drifting drogue or pole.

2. The "Flow" method of Euler, in which the motion of water is observed as it passes a given point, e.g., an anchored current meter.

Data from these two methods can be correlated; however, for turbulent flow with complex boundary conditions it is impossible to infer one type data from the other.

At first glance, it might seem that the path method might be best adapted to studies of estuarial flushing, where the track of water mass throughout its identifiable existence is of primary interest.

However, the path method alone will not answer all questions. The devices used to measure the path of a water mass must, inherently, integrate the motion both with time and with space. Remember that we assume that motion is steady during the interval between fixes (positions), and we assume that the water mass causing the motion in the drogue or drift pole, is uniformly moving with it. The short term variations of velocity and direction both in time and in space that mean so much in mixing processes cannot be detected, therefore, by the path method.

The flow method of measuring currents complements, rather than competes with, the path method. It is by this method that one can get some idea of the short term variations with time, and of the variations with depth, within a water mass. One assumes that the point past which one measures currents is representative.

The data from the flow method is in a form more adapted to analyses; analyses, for example, for tidal components, runoff components, turbulence within the water mass, etc.

It would seem therefore, that to adequately define circulation patterns in an estuary, field measurements with both flow and path techniques should be used.

The mention of analyses to resolve various components of a current brings us to the consideration of causes of currents in an estuary.

Two concepts should be stressed here:

1. Without some knowledge of the causes (or "driving forces") behind the currents measured, one can only report what the currents were at the time and under the conditions of the field study. It is seldom safe to predict what will happen under differing conditions without knowledge of causes and their interrelationships. Validity of a current study therefore, is a function not only of the accuracy of the field measurements, but also of the thoroughness of analysis of the data.

2. The second concept to be stressed is this: whether we want to know (and predict) average conditons, or extremes. Very often, it is apparent after only a relatively short field study that the average currents in an estuary are conducive to adequate flushing. The question then is: does adequate flushing take place at all times, or, does the estuary flush under all conditions? It is, more often than not, I suspect, the extremes that give us crises in pollution problems.

In practice, there are usually many restrictions which determine which technique of field measurement to use, and how thoroughly the data can be analyzed.

Besides budgetary restrictions, very often limitations on available instruments and manpower are the governing criteria in planning a field study.

Let us look at the main instruments used in the two methods of current measurements. There are probably as many current measuring devices as there are men who measure currents.

1. The path method:

a. Areal - introducing dye, or a large number of floats - recording the movement by periodic air photos. This adapts well in models--in the prototype, aircraft time becomes expensive. Usually surface movement only can be measured in this way.

b. End point - introducing drift bottles or cards which can be recovered later when they come ashore. This method gives no data on the "perambulations" the bottles might have taken enroute. Can be quite useful, however, to furnish negative information. Again, surface movement only are measured.

c. Trajectory - introducing poles and/or drogues at assorted depths and periodically (and frequently) observing their positions - usually observed visually (3 point fixes) but radar can be used if wind is low. If short term variations will be important, positions must be obtained frequently. Weather can bring this type of study to a premature close.

2. For the flow method, the main instruments are classified as follows:

a. Instruments which operate on some sort of rotating element, such as a Price meter, with rotating cups, or an Ekman meter with a propeller--suject to ships motion errors.

b. Those which utilize the pressure of moving water on a plate or pendulum distorts the moving water mass it is measuring.

c. The GEK (Geomagnetic Electro Kinetograph) which measures the electromotive force produced when a conductor (sea-water) moves through a field (the earth's magnetic field). Not too well adapted to small bodies of water. Does measure net transport directly.

d. Ultrasonic device that measures velocity of sound as a function of velocity of water through which the sound is traveling.

A more realistic subdivision of current meters might be:

1. Those which integrate the total velocity over a period of time, e.g. Ekman.

2. Those which indicate immediately the short term variations of velocity and direction. e.g. Mangnesyn-Hotwire.

References:

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Spec. Publication 225, U. S. C. & G. Survey - Tide and Current Glossary

Spec. Publication 98, U. S. C. & G. Survey - Manual of Harmonic Analysis and Prediction of Tides.

Tidal Hydraulics - G. P. Pillsbury, 1939. U. S. G. P. O. Corps of Eng. Professional Paper No. 34.

DISCUSSIONS - Led by Prof. Sylvester

To measure currents of low magnitude in deep water it is best, if possible, to anchor the meter to the bottom. The ships motion is a source of considerable error. The ship would move around with even greater velocities than are often being measured. Meter can be mounted on a tripod and anchored to the bottom.

Important to have tight meter when used in deep water to avoid necessity of frequently raising it for drying.

Vertical motion of the ship may cause errors in horizontal current measurements which will have to be taken into account when measurements are in the order of hundredths of knots.

(Note: Dr. J. H. Carpenter of John Hopkins University has used Rhodamine B Dye and the Aminco-Turner Fluorometer for tracing the movement of water in Baltimore Harbor. The dye is dissolved in water of a density of that of the depth where the tests are made. This mixture is pumped into the harbor at the desired level. The pattern of dispersion of the dye is followed by continuous readings on the Fluorometer from a boat moving about the harbor.)

FINALE - E. F. Eldridge

The general theme running through the discussions today emphasizes the complex nature of the estuarial problem. A lack of knowledge was indicated, but by no means is there a complete lack of knowledge. This is very well indicated by the excellent discussions of the various items of the agenda.

It is apparent that the oceanographer has knowledge in certain areas, the marine biologist in another and the engineer in still another. There appears to be a major need for compiling this information from the various sources and pointing it to the problems of water pollution.

As stated at the beginning of this symposium, estuaries are used in a major way for the disposal of sewage and wastes. The table which is attached to this finale indicates the magnitude of the sewage problems in salt water areas. These together with the problems of industrial waste disposal, land run-off etc. produce problems of a magnitude requiring a major research effort, if solutions are to be adequate.

Research is the key. This is the challenge. Knowledge, and knowledge alone will dispel the controversies and make possible an effective pollution control program.

SEWAGE EFFLUENT DISCHARGES TO SALT WATER
Number of Facilities and Population Served by Degree of Treatment

STATE	NO TREATMENT No.	NO TREATMENT Population Served	PRIMARY No.	PRIMARY Population Served	SECONDARY No.	SECONDARY Population Served	TOTAL No.	TOTAL Population Served
REGION I								
Connecticut	6	53,400	25	549,150	5	14,950	36	617,500
Maine	59	164,950	7	43,505	-	-	66	208,455
Massachusetts	17	625,110	6	984,640	9	688,600	32	2298,350
New Hampshire	4	28,500	2	5,400	1	200	7	34,100
Rhode Island	3	13,540	8	172,160	5	289,350	16	475,050
REGION II								
Delaware	4	7,250	4	22,600	3	1,100	11	30,950
New Jersey	12	114,833	61	2122,908	9	172,555	82	2410,296
New York	15	3172,400	47	1102,590	25	4935,600	87	9210,590
REGION III								
Maryland	4	14,450	16	52,438	13	830,950	33	897,838
North Carolina	18	113,348	11	110,142	4	39,884	33	263,374
Virginia	4	18,525	12	546,390	10	22,400	26	587,315
REGION IV								
Alabama	2	90,000	4	26,100	2	16,900	8	133,000
Florida	16	401,230	43	459,910	54	381,772	113	1242,912
Georgia	3	91,000	3	8,000	2	15,500	8	114,500
Mississippi	-	-	1	16,000	8	62,600	9	78,600
South Carolina	20	131,150	2	2,300	3	7,000	25	140,450
REGION VII								
Louisiana	-	-	2	4,200	1	1,940	3	6,140
Texas	6	76,000	6	126,000	20	291,325	32	493,325
REGION IX								
Alaska	18	49,911	-	-	-	-	18	49,911
California	35	289,406	95	5135,599	49	1187,628	178	6612,633
Oregon	11	21,450	11	27,950	7	11,050	29	60,450
Washington	43	708,038	23	201,420	3	3,000	69	912,458
U.S.TOTAL	300	6184,491	389	11719,402	230	8974,304	921	26878.197

Data taken from 1957 Inventory of Municipal and Industrial Wastes.
Salt Water defined as having more than 5,000 parts per million.

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