Tareah Hendricks

AN ADVANCED SEDIMENT-QUALITY MODEL

The greatest impacts associated with the discharge of municipal effluent into the coastal waters, via deep ocean outfalls, are related to the dispersion and settling of effluent particulates. We want to be able to relate these impacts to the characteristics of the wastewater and outfall system, and the properties of the receiving water environment. We could then predict the effects of a new outfall on the marine environment, or estimate the changes that would occur as a result of modified treatment or method of discharge.

One of the methods we have chosen to use to obtain this predictive capability is to develop a numerical model to simulate the processes which determine the properties of the sediments. These processes include the sedimentation of natural and effluent particulates, biological "stirring" (bioturbation) of the sediments, the resuspension and redistribution of the sediments, and biological and chemical alterations. We constructed a model using these processes several years ago and used it to predict the changes that would be expected to occur around the Palos Verdes outfall(s) as the mass emission rate of suspended solids was reduced. Unfortunately, the formulation of the model was such that it could not be readily or reliably applied to other outfall areas.

In 1980, we received a grant from the National Oceanic and Atmospheric Administration (NOAA) to refine and test the model so that it could be used at other proposed or existing outfall areas. The model consists of two sub-models. The first of these estimates the distribution and mass flux rate of effluent particulates settling to the ocean bottom. The second deals with processes occurring close to (e.g. resuspension), or within (e.g. bioturbation) the sediments. This section describes the formulation and some results of the sedimentation flux sub-model, and briefly indicates some of the modifications that have been made in the benthic processes sub-model.

RESULTS

We have used the sedimentation sub-model to estimate the sedimentation fluxes and patterns in the Palos Verdes (White Point) and Newport Beach (Orange County) outfall areas. The maximum sedimentation rate in the Palos Verdes area was estimated to be about 380 mg/cm^2/yr in the immediate vicinity of the outfalls (at an annual suspended solids mass emission rate of 100,000 m-tons/yr). The sedimentation rate of natural particulates in this area is not well known, but has been estimated to be about 10 mg/cm^2 2/yr. The model predicts an area of approximately 21 sq. km will have effluent-related sedimentation rates in excess of this value.

Since the organic content of the effluent particulates is greater than in natural particulates, the effluent related flux of organic carbon will exceed the natural value over a somewhat greater area. Approximately 14 percent of the discharged solids are predicted to settle along a 16 kilometer section of the coast.

Off Newport Beach, the maximum sedimentation rate is predicted to be about 100 mg/cm^2 /yr in the immediate vicinity of the outfall diffuser (for an annual mass emission rate of 40,000 m-tons/yr), and fluxes in excess of 10 $mg/cm^2/yr$ cover an area of about 14 sq. km.

In the absence of any means to directly test the sedimentation sub-model predictions, we tested the qualitative characteristics of the predictions by comparing the predicted sedimentation flux patterns with the observed distributions of infaunal index (PV and NB), sediment volatile solids (PV), and sediment BOD (PV), with encouraging results.

Hypothetical outfalls, of identical design and wastewater characteristics, were also created at these two sites to see if one of the sites was a better outfall location from the standpoint of minimizing the effects on the benthos. The simulations suggested that under these identical conditions, the sedimentation rate around the Newport Beach site would be about one-half the rate of the Palos Verdes location. By substituting the currents observed in the Palos Verdes area for the currents actually observed in the Newport Beach area, it was found that the differences in the currents and in the bathymetry between the two areas were roughly equally important in creating this sedimentation rate difference.

SEDIMENTATION SUB-MODEL DESCRIPTION

The original sedimentation sub-model used in the 1978 sediment quality model predicted only the longshore distribution of particulate fluxes (i.e. the fluxes into transects extending offshore from the coast). This calculation could only be carried out if it was assumed that the water depth in the area was a constant. Variations in the sedimentation rate along the transects were included by assuming a modified Gaussian distribution. The "width" of the distribution was determined from a parameter fitting process involving the comparison of predicted onshore/offshore distributions of organic carbon with the observed distributions. This procedure has obvious limitations, for example, the procedure could only be used in areas where a discharge had occurred for some period of time. The new sedimentation sub-model estimates both the longshore and cross-shore distributions of the flux of settling effluent particulates, and does so in an area with varying water depths.

As with any complex process, a number of assumptions and approximations must be made to provide numerical representations of the dynamics of the real processes. These are required to keep the computation time and computer memory requirements within reasonable bounds, but also because of our incomplete understanding of the details of many of these processes. Several deficiencies are evident in our understanding of the processes which affect the flux of effluent particulates to the ocean bottom. These include:

1. A lack of detailed information on the ocean currents within the area of the simulation.
2. Minimal understanding of the aggregation of effluent particulates with other effluent and natural particulates after they are introduced into the marine environment.
3. A nearly total lack of information on the importance of biological processes to alter the settling and chemical properties of the particulates.

4. Insufficient information on the chemical properties of the particulates as a function of their settling speed.

In order to cope with these deficiencies, we made the following assumptions or approximations.

1. The movement of a parcel of water within the simulation area can be adequately predicted from the measurements of a single current meter located at an appropriate depth, provided some modifications are made to account for the influence of the coastal boundary.
2. The actual distribution of effluent particulate settling speeds is approximated by the distribution observed in the laboratory under quiescent conditions.
3. Biologically-induced changes in settling characteristics are assumed to be negligible.
4. All particulates are assumed to have the same concentrations of organic carbon, volatile solids, trace constituents, etc.

The simulation area is defined by two sets of grid points (and the corresponding cells). The outer grid dimensions correspond to the approximate coherence length-scales of the ocean currents; the inner grid, to the area expected to have large gradients in the sedimentation rates. "Parcels" of wastewater containing particulates are introducted at regular intervals from one or more points representing the ocean outfall(s). Each parcel then moves through the area according to the sequence of speeds and directions recorded by the current meter. At each time step, the water depth below the parcel of water is estimated from the values of the surrounding grid points, and the settling speed required for particulates to reach the bottom is calculated from the original wastefield depth, the local water depth, and the elapsed time since the parcel was "released." If any particulates in the wastewater parcel have settling speeds equal to, or in excess of this speed, they are removed from the parcel and "deposited" in the cell containing the parcel. Each of these "releases" is tracked until it leaves the simulation area. The "releases" continue until the current meter record is exhausted. Sedimentation rates into each cell are calculated from the fraction of the discharged mass deposited in the cell, the number of releases, the area of the cell, and the mass emission rate of particulates from the outfall.

It is necessary to modify the movements of the wastewater parcel, as predicted by the current meter record, to take into account the presence of the coast (actually the location of the isobath at the wastefield depth). If this is not done, the parcel is, on occasion, predicted to move "onshore," resulting in an anomalously high sedimentation rate at that location. Since this cannot occur in reality, we use an *ad hoc* approximation for the flow in the neighborhood of the coast to remove these artifacts.

Outside some reference distance to the "coast," the movement is given by the current meter record. Inside this distance, the meter-predicted movement is given reduced significance, and the requirement that the flow be parallel to the coast is given increasing importance, as the parcel approaches the coast. For calculation simplicity, only the distance to the coast in the cross-shore direction is used. This simplification has some undersirable characteristics in the presence of abrupt intrusions into the ocean, but most of the simulation areas do not contain features of this type. An example of the flow along a section of a hypothetical coastline, using this approximation, is shown in Figure 1.

We also construct the "longshore" axis of the grid of cells so that it approximately follows the general trend of the isobath corresponding to the wastefield diffuser depth. This procedure is motivated by the observation that drogues tend to move along the isobaths, and the dominant direction of movement in current meter records is also in this direction.

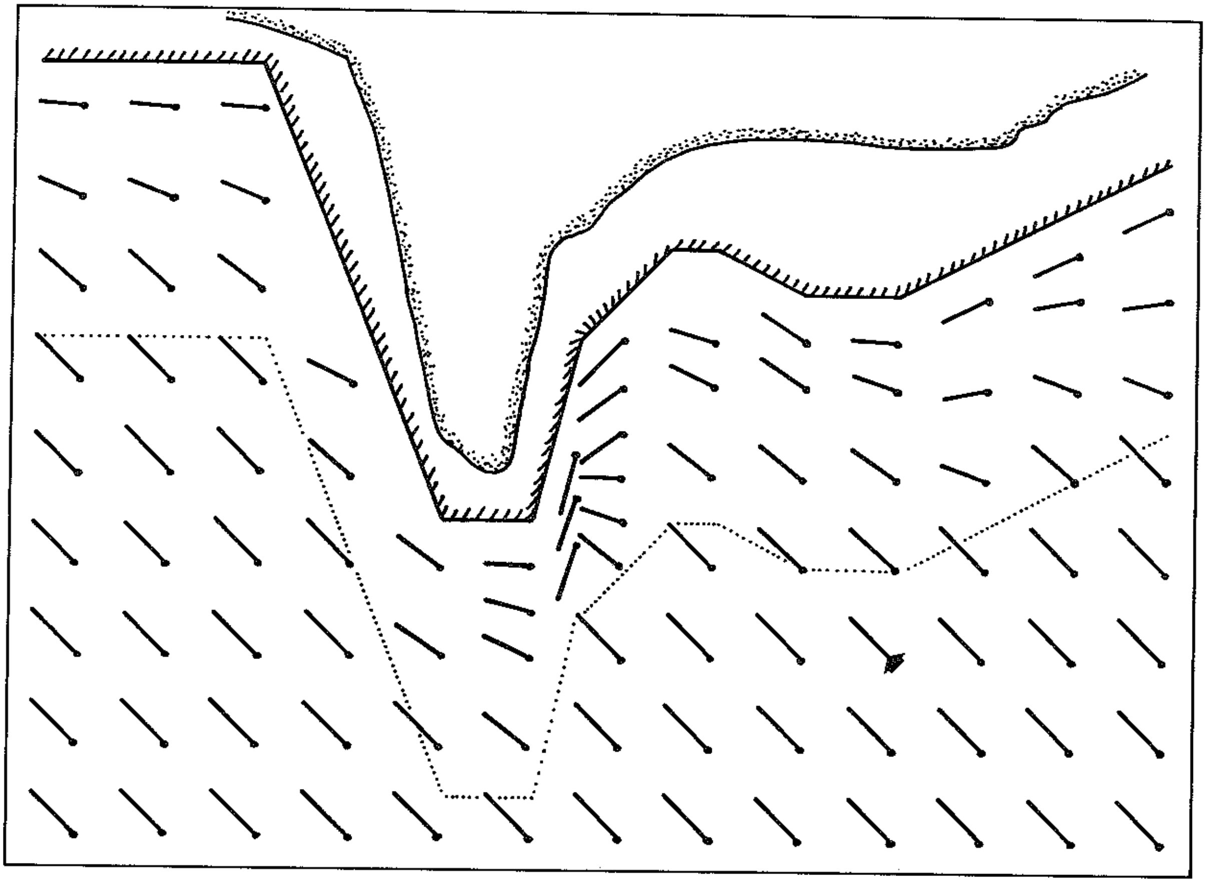

Figure 1. Flow Field with Boundary-Modification Algorithm. The direction of the "flag" represents the direction of the boundary-modified flow; the length, the speed of the flow. The "dot-shaded" boundary represents the actual coast; the "line-shaded" boundary, the "effective" coastline (isobath at the wastefield depth). The dotted line indicates the offshore extent of the reference distance in the algorithm. The current meter location is indicated by the bold arrow.

PALOS VERDES (WHITE POINT) SIMULATION

Sixteen cells in both the longshore and cross-shore directions were used to construct both the inner and outer grids. In the inner grid, the longshore and cross-shore cell dimensions were 1 km and 0.25 km, respectively; in the outer grid, they were twice as large. Three "release" points were used to simulate the three outfall diffuser sections on the two outfalls.
Since laboratory measurements of the distribution of effluent particulate settling speeds are difficult to make, and are prone to contain substantial errors, we constructed an "average primary settling speed distribution" from two measurements of White Point final effluent, and a single measurement of Orange County effluent. This distribution was used for both the White Point and Orange County simulations.

One and one-half hour intervals were used between sequential "release" times. Displacements were calculated at forty-five minute intervals. For a current meter record of approximately one month in extent, three "release" points, and the previously mentioned cell dimensions and time steps, approximately 24 hours of micro-computer time are required for the simulation with the present version of the program. This corresponds to about one-quarter of a million displacement/deposition calculations. An Industrial Micro-Systems 5000, using FORTRAN as the programming language is presently being used for these computations.

Since so much computation time is required, we do not simulate the deposition patterns for each month for which current meter data is available. Instead, we divide the records into two groups, according to the speed and direction of the net flow, and carry out the simulations using the average properties of each of these two groups. The two results are then combined after "weighing" the results by the number of monthly records in each group.

The results of this simulation process for the White Point outfall area is illustrated in Figure 2, and indicates a net bias in the upcoast and onshore directions, with the elongated contours roughly following the bathymetry. Maximum sedimentation rates occur at the 90 inch outfall, and correspond to about 380 mg/cm^2/yr for an annual mass emission rate of 100,000 metric tons of suspended solids.

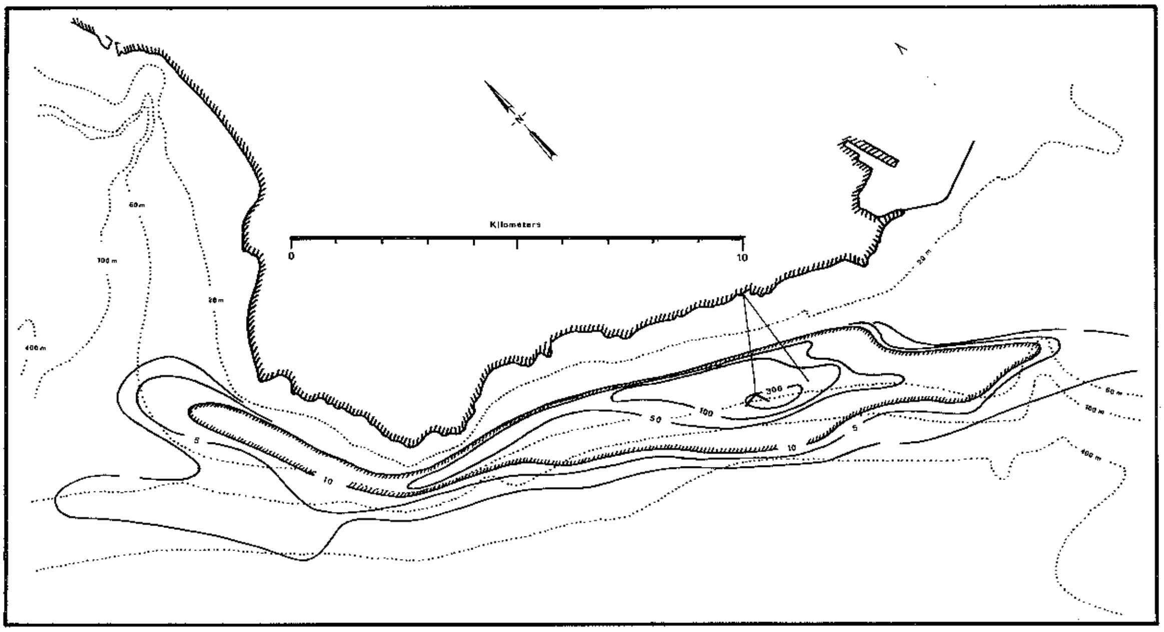

Figure 2. Predicted White Point Sedimentation Rates. The values are mg/cm^2/yr based on an annual mass emission rate of 100,000 m-tons of suspended solids. The contour corresponding to a flux of 10 mg/cm^2/yr is enhanced by shading.

Emery (1960) has estimated the natural sedimentation rate in this area to be about 10 mg/cm^2/yr, thus the peak sedimentation rate near the outfall is about 38 times the natural rate. Effluent-related sedimentation rates equal to, or in excess of, this estimated natural value occur in an area approximately 21 square kilometers in extent (indicated by the "shaded" contour line in Figure 2). Since the effluent particulates generally have a higher organic content than the natural particulates, the area of comparable organic input is somewhat larger. Approximately 14 percent of the discharged mass of effluent solids is predicted to settle within a 16 km long section of the coast. This percentage is similar to the value of 10-12 precent predicted by the earlier model.

In the absence of direct measurements of the sedimentation fluxes, there is no quantitative way to test the predictions of the sedimentation sub-model alone, since benthic processes (particularly resuspension) will modify the apparent sedimentation rates and composition of the sediments. From our earlier model work, however, we know that except for a net displacement in the direction of the predominant near-bottom mean flows, the sedimentation flux patterns and sediment quality patterns are similar. Therefore, we made a qualitative test of the model by comparing the predicted sedimentation patterns with the patterns of infaunal index (II), and sediment volatile solids (VS) and biological oxygen demand (BOD). Each of these is a measure of some property of the sediments. The predicted sedimentation pattern has considerable similarity to the collection of patterns associated with these sediment quality indicators (Figure 3). (Figure 3).

We also compared the longshore distribution of sedimentation rates predicted by the model with the distribution predicted by our earlier model. The two distributions are very similar--some of the differences are associated with the two different distribution of particulate speeds used in the two simulations.

ORANGE COUNTY SIMULATION

Two 16x16 grids of cells were also used for the Orange County simulations, but the cell dimensions were twice as large as those used in the White Point simulation. Two "release" points were used to represent the outfall diffuser.

The results of the simulation are shown in Figure 4, and the infaunal index distribution in this area is shown in Figure 5. The maximum sedimentation rate, which occurs in the immediate vicinity of the outfall, was predicted to be about 100 mg/cm^2 /yr, and values in excess of 10 mg/cm^2/yr cover an area of about 14 square kilometers. As in the White Point area, the predicted sedimentation patterns and the infaunal index patterns are similar, but some differences also appear to exist. This is paricularly true south of Newport Bay, where the predicted outfall-related effects appear to be larger than the observed effects. This is probably associated with the choice of the contour for the longshore axis of the cells. The latter was chosen to roughly follow the 55m isobath, but we are uncertain about how to extend the axis across Newport Canyon to the substantially narrower shelf on the southeast side.

PALOS VERDES/NEWPORT BEACH COMPARISON

The White Point outfall(s) lie in 55-60m of water on a narrow shelf. In contrast, the Orange County outfall, in 55m of water, lies on a relatively wide shelf. We wanted to see if either type of shelf had any advantages in minimizing the effects on the marine environment that relate to the discharge of suspended solids.

This type of comparison is difficult to make from direct observations since two outfalls exist in the White Point area, but only a single outfall off Newport Beach. In addition, the mass emission rates of suspended solids differ by more than a factor of two. It is, however, trivial to construct identical outfalls, effluents, and mass emission rates in the simulation model, and then compare the simulation results.

The results of this comparison are shown in Figure 6. The lower line (NB) indicates the fraction of the discharged material settling within some area around the Orange County outfall; the upper line (PV), the White Point outfall. The reference areas are defined by the sedimentation flux contours. Except in the immediate vicinity of the outfalls, where the sedimentation fluxes

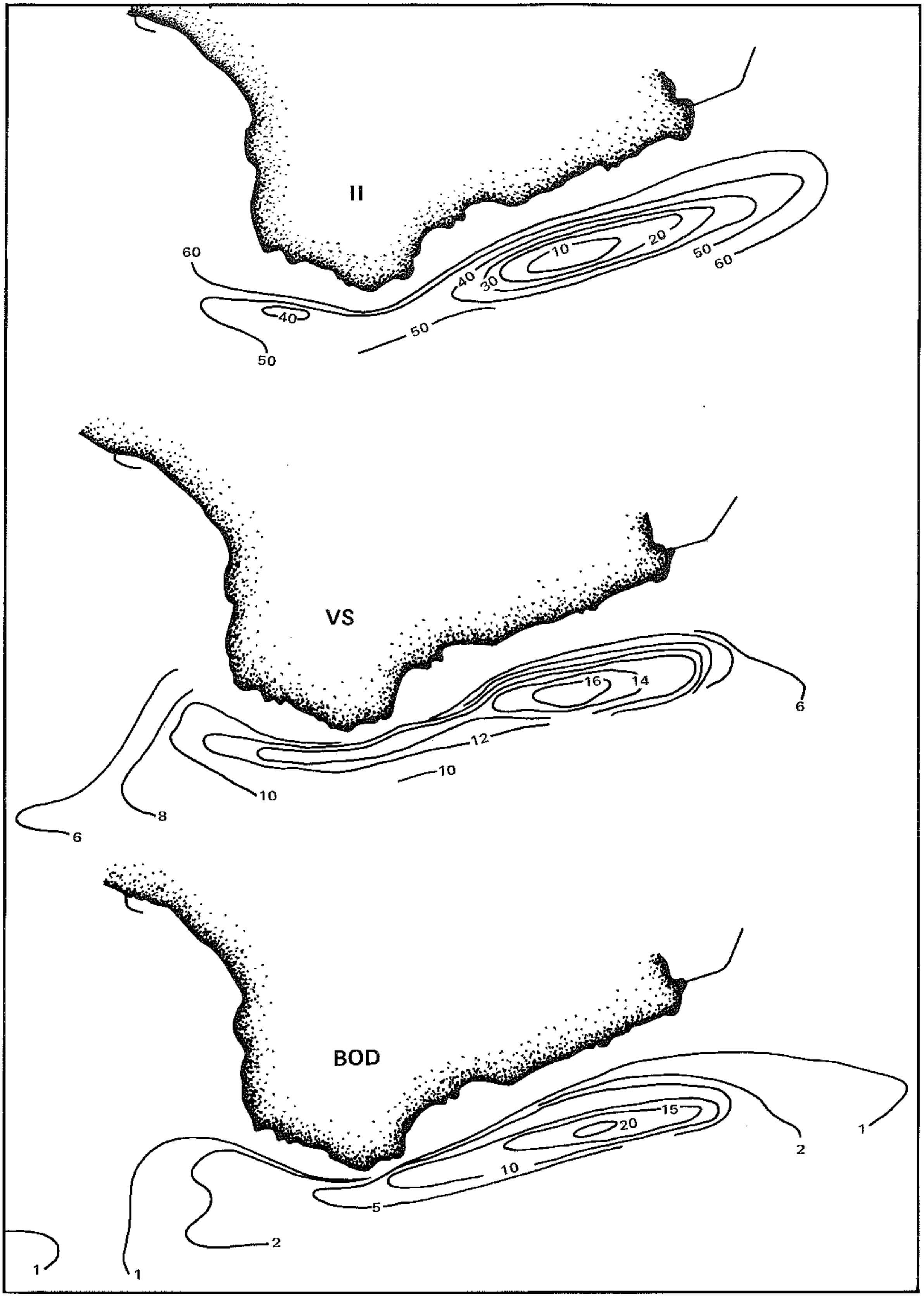

Figure 3. Observed Patterns of Infaunal Index, Sediment Volatile Solids, and Sediment BOD--White Point Area,
II = Infaunal Index; VS = Volatile Solids (percent);
BOD = Biological Oxygen Demand (gm/Kg).

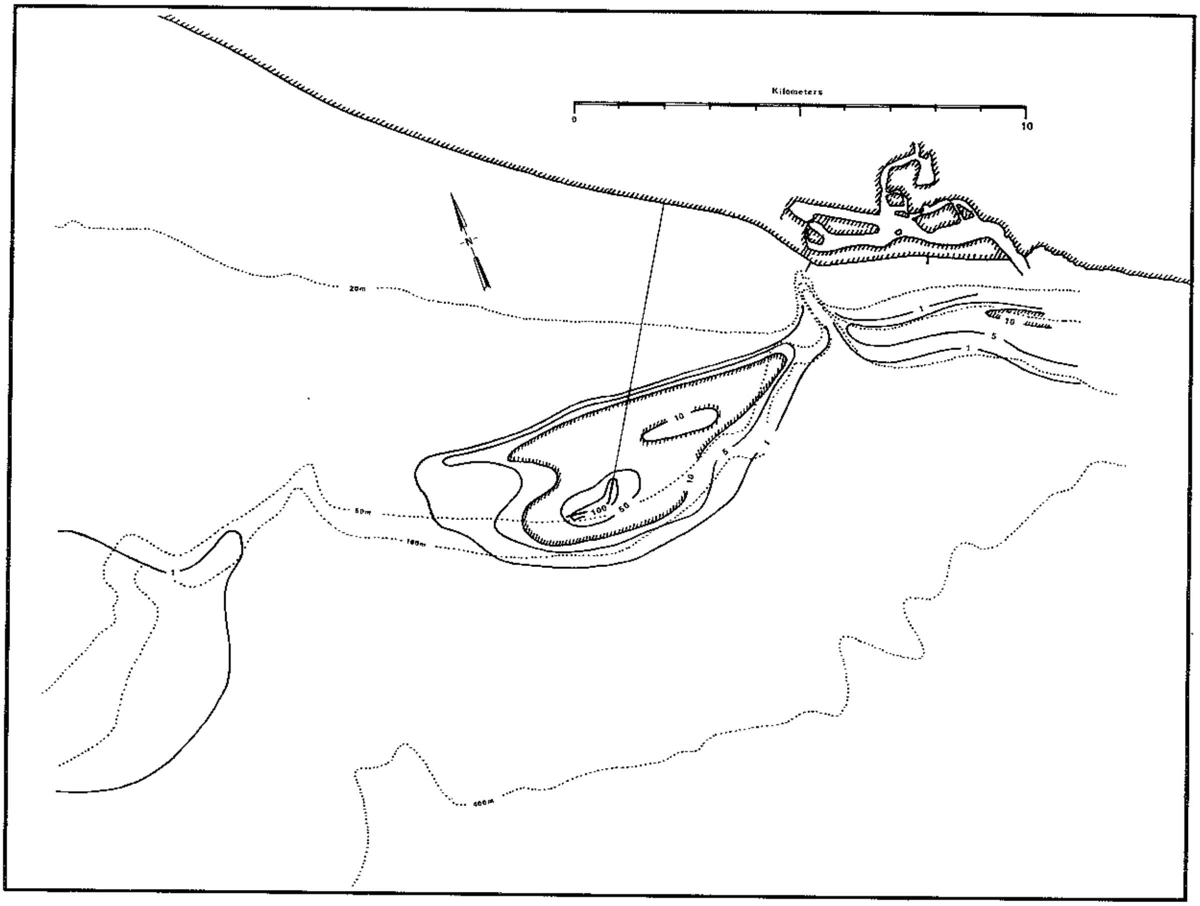

Figure 4. Predicted Orange County Sedimentation Rates. The values are mg/cm ^{2}/yr based on an annual mass emission rate of 40,000 m-tons of suspended solids. The 10 mg/cm ^{2}/yr contour (est. natural rate) is enhanced.

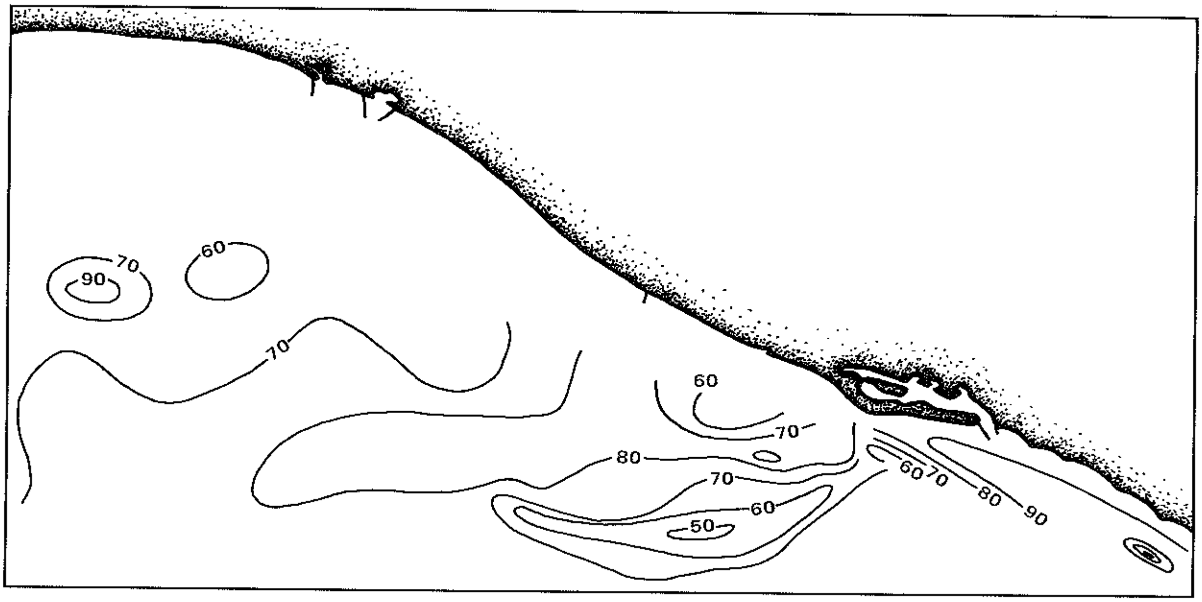

Figure 5. Observed Infaunal Index Pattern Around the Orange County Outfall.

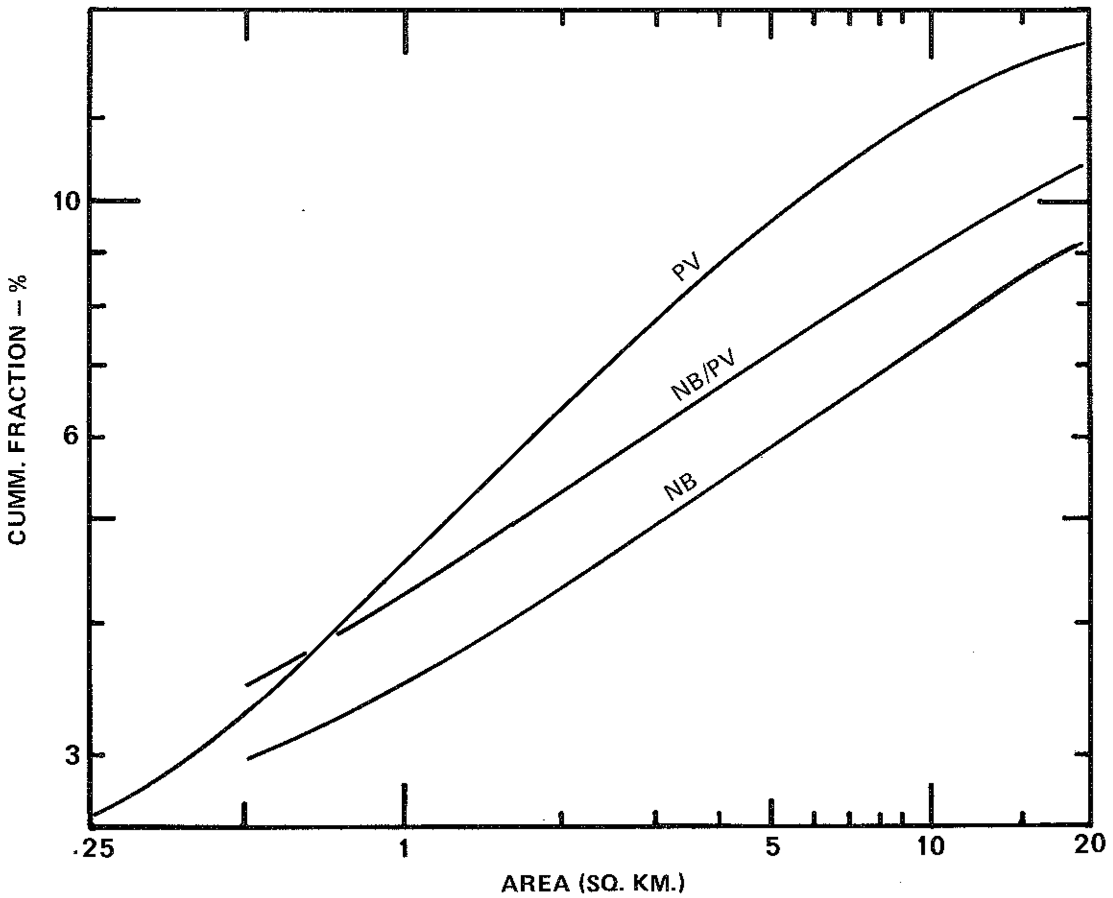

Figure 6. Fraction of Discharged Solids Settling in the Outfall Area.
The vertical axis indicates the fraction of the discharged solids that settle within the indicated area. The areas are chosen to coincide with sedimentation flux contours. NB indicates the Newport Beach/Orange County area; PV the Palos Verdes/White Point area; and NB/FV, the Newport Beach area using currents observed in the Palos Verdes area. The patterns are for identical, hypothetical outfall systems discharging identical effluents.

are essentially identical, approximately one-half as much material settles within a given area at the Newport Beach site as off Palos Verdes (i.e. the sedimentation rates are half as large). Since the currents are not the same in the two areas--the Newport Beach currents tend to be slightly stronger and persist for a longer period of time between reversals, it is not clear how much of this difference is associated with the bathymetry differences, and how much is related to the differences in the currents. Of course, the currents and bathymetry are undoubtedly related to some extent. In order to get some idea of the importance of just the bathymetric differences, we also simulated the Newport Beach area using the currents measured off the Palos Verdes area. The results, indicated by the middle line (NB/PV) in Figure 6, suggest that somewhat more than half of the increased flux of particulates in the Palos Verdes area is related to the bathymetry, with the remaining difference associated with the currents.

BENTHIC PROCESSES SUB-MODEL

The sedimentation fluxes predicted by the sedimentation sub-model are input information required by the benthic processes sub-model. Other processes included in the model are the sedimentation of natural particulates, resuspension and redistribution of sediments, bioturbation, and simple forms of biological decomposition of organic material and chemical mobilization of trace constituents in the sediments. These are the same processes included in our earlier model (Annual Report 1978). The principal difference between our earlier model and the current model is in the representations used for the resuspension and redistribution processes.

In the earlier model, the transport of resuspended sediment was only allowed in the offshore direction. This assumption was a reasonable one for the Palos Verdes area, with its highly elongated sedimentation patterns, but will not be suitable for other areas. The new model permits transport in all four directions (upcoast, downcoast, onshore, offshore), with the contributions weighted by the frequency of occurrence of net flows in each of the directions.

Resuspension is viewed as occurring as a series of "events." In the earlier model, the mass resuspended over some suitable period of time (e.g. one year) was assumed to be proportional to the fraction of the time that the bottom current speed exceeded the threshold resuspension speed. This is equivalent to assuming that equal masses of sediment are resuspended during each event. Intuition and laboratory studies, however, indicate that more material will be resuspended when the bottom speeds greatly exceed the threshold speed than when they are only slightly in excess. The new model, using the results of laboratory studies reported in the literature, relates the resuspended mass during each event to the relative excess bottom stress created by the currents.

In both models, it is assumed that immediately following resuspension, the resuspended sediments achieve a quasi-equilibrium between vertical diffusion and the settling of the resuspended particulates. In the earlier model, however, it was assumed that the thickness of the layer containing the resuspended particulates was the same for each event, and that the settling speeds were also the same. In the present model, we relate the vertical diffusivity to the near-bottom current speeds through the "shear velocity" and the thickness of the benthic boundary layer. We also assumed that the settling speed of the resuspended particulates is proportional to the threshold speed required for their resuspension so that particulates which are difficult to resuspend, such as sand, would settle faster than readily resuspended light organic material. The result of these improvements was that the computational scheme used in the original model could no longer be used, and an entirely new computational procedure was developed.

In principle, each combination of threshold resuspension speed, "instantaneous" near-bottom speed, and "net" near-bottom speed could be simulated at each cell and for each resuspension "event." However, since resuspension "events" occur over time-scales of hours, while sediment changes occur over time periods measured in years, this could require large amounts of computer time. Instead, we assumed that the "instantaneous" near-bottom current speeds (dominated by tidal and wave periods) were uncorrelated with the "net" speeds (associated with longer time periods), and noted that their probability distribution could be represented well by a Poisson distribution whose parameters depended on the water depth. The resulting equation for the deposition of material into the J(th) cell downstream from the cell of origin could then be integrated over the full range of "instantaneous" near-bottom current speeds occurring during time intervals comparable with the time scales required for changes to occur in the bottom sediments. If a similar integration over the full range of "net" near-bottom current speeds could also be carried out, it would be possible to have the model simulation time-step comparable with the sediment-change time scales, rather than the resuspension or transport time-scales. Unfortunately, we have not been able to analytically carry out this integration at the present time. In order to achieve the desired "long" time-steps for the simulation, we use an approximation to account for the range of "net" near-bottom speeds occurring during this interval.

The resulting equations have been programmed and the model is (at the time of this writing) being tested. We have made simulations with an interim version of the model (2-D and variable resuspended mass, but constant settling speed and layer thickness). Since the results of this interim model simulation are essentially identical to those described in the 1978 Annual Report, they will not be repeated here.

Four parameters are incorporated into the benthic processes sub-model. They are: (1) a resuspension mass parameter, (2) a characteristic length (relating to the benthic boundary layer thickness and settling speed/resuspension speed ratio), (3) a bioturbation depth and (4) the refractory fraction of the organic material. The first three parameters will be determined by comparing the predicted characteristics of the sediments in the Palos Verdes area with the observed characteristics in cores obtained from the area in a joint JWPCP (Los Angeles County) and SCCWRP sediment study. The model will then be tested by comparing predicted and observed characteristics at 3 or 4 other outfall sites. These test sites encompass a wide range of suspended solids mass emission rates, and the outfalls discharge in water depths ranging from about 20m to 56m. The results of the benthic processes sub-model, and the test site comparisons, will be described in the next bi-annual report.