Current Flow Patterns in the San Diego Bight

During 1987, staff oceanographers Terry Hendricks and Niels Christensen developed methods to identify and quantify the flow patterns in the San Diego Bight. This information was required to ensure that the discharge from a proposed new ocean outfall would not contaminate the nearshore waters with bacteria.

A new ocean outfall may be constructed in the San Diego bight near the border with Mexico. Bathing water standards for total coliform bacteria must be met nearshore and in *Macrocystis pyrifera* kelp beds, so the treatment method, outfall design, and outfall location must be selected to meet these requirements. A variety of factors affects the presence of outfall-related bacteria in these protected waters. These include the concentration of bacteria in the effluent, the magnitude of the initial dilution, subsequent dilution by oceanic processes, die-off of the bacteria, and the rate and frequency of transport of wastewaters into the protected areas by ocean currents. The SCCWRP researchers were asked to quantify one element of this analysis: transport by ocean currents.

Figure 1 shows the study area. The indentation south of Point Loma and San Diego Bay forms the San Diego Bight. The dashed line extending offshore from the coast delineates the border with Mexico. The two solid lines near the border indicate possible alignments for the proposed outfall; the line extending offshore from Point Loma (terminating in a "vee") indicates the location of the existing outfall. The dashed line roughly paralleling the coast marks the offshore boundary of the area to be protected from bacterial contamination.

During 1986-87, Engineering Science obtained about one year of current meter data from the seven moorings indicated by the circles in Figure 1. Previous, but limited, measurements of currents in this area by SCCWRP (Hendricks 1981) have indicated that the presence of the bight introduces additional complexity into the coastal flow patterns. In view of this complexity, it would have been desirable to obtain information on the circulation in the middle and upper portion of the bight from additional current meter moorings. Unfortunately, this region lies within a U.S. Navy restricted area (indicated by the trapezoidal area in Figure 1).

The task faced by the SCCWRP researchers was to use this mass of current meter data to provide estimates of the frequency and rate of transport of wastewaters into the protected nearshore area for various possible termination locations of the proposed outfall. In order to do this, they developed the following five-step process.

(1) The currents were partitioned into two components--tidal (and shorter period fluctuations) and non-tidal flows. The latter dominate the transport between the proposed outfall terminus and the protected area; the former have the effect of additional dispersion superimposed on the flow.

(2) The non-tidal flows were examined for reoccurring patterns. Each observed flow pattern can be approximated as a combination of these elemental flow patterns.

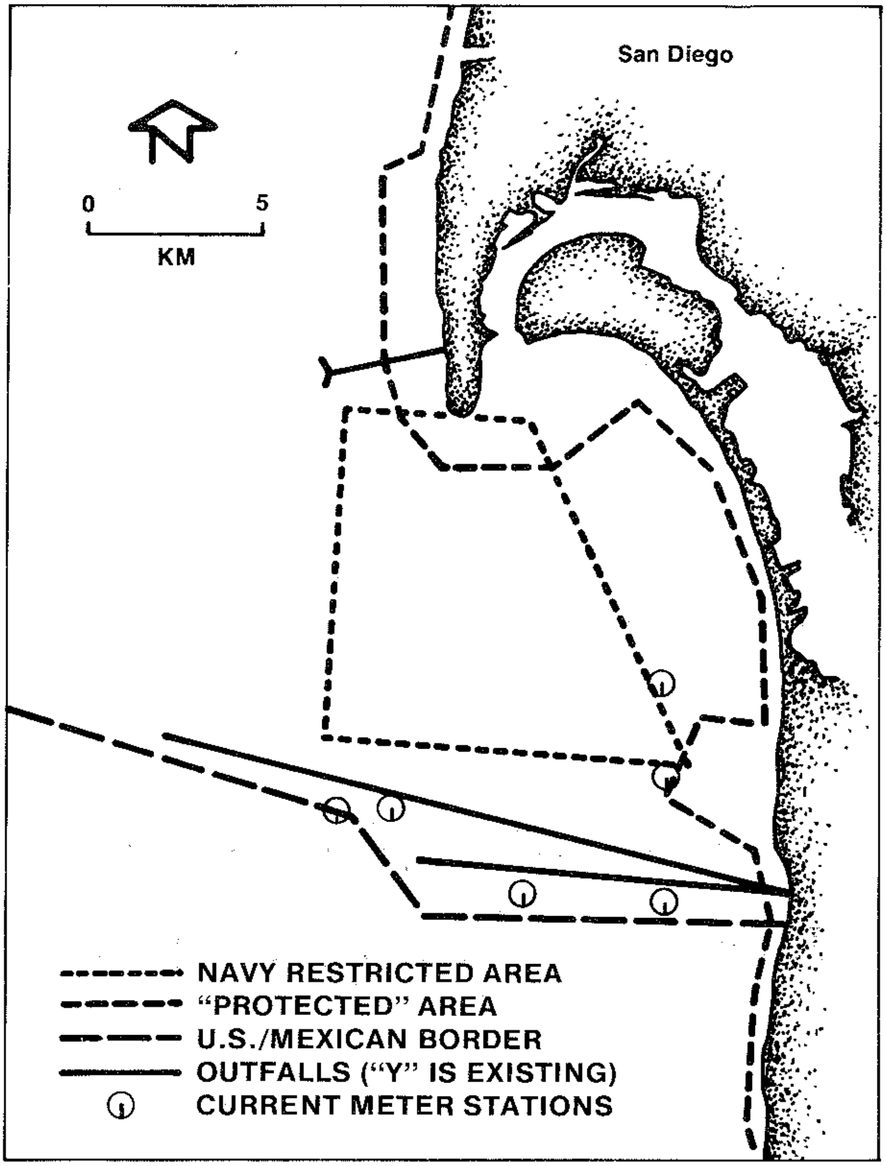

Figure 1. Study area.

(3) The variations in time for the strength of each elemental flow pattern were used to quantify the probability of occurrence for each composite flow pattern.
(4) The general characteristics of coastal flows were used in a numerical flow model to extend the composite flow patterns away from the current meter moorings and into other areas of the bight.
(5) The dispersion of wastewater associated with tidal (and shorter period) fluctuations was reintroduced to the transport estimates.

Through the use of this technique, it was possible to reduce the total of approximately 150,000 observations from the 10 meters used in the analysis to a few tens of circulation patterns, and to quantify the frequency of occurrence of each pattern.

A pair of velocity component (e.g., N-S and E-W) time-series was constructed from the speed-direction time-series for each current meter. A simple filter was applied to these series to remove fluctuations with tidal, or higher, frequency. Cross-correlation coefficients were then computed for each pair of the residual time-series. A mathematical technique, empirical orthogonal function (EOF) analysis, was used to identify statistically independent patterns in the correlations. For 10 current meters, and two components to the flow at each meter, 20 possible "elemental" flow patterns will be produced by this analysis. All the observed flows in the original time-series can be represented as a (time-varying) combination of these 20 elemental patterns. Up to this point, nothing has been gained by this analysis from the standpoint of reducing the number of observations required for the analysis.

It frequently happens, however, that most of the observed flows can be adequately represented as a combination of only a few of the elemental patterns. This turned out to be the case in the San Diego Bight. Two patterns, a more-or-less longshore flow and an eddy, were found to account for about 82% of the total observed variance (variability). Therefore, it was possible to approximate the observed flows as the combination of just two elemental flow patterns instead of the original 20.

So far, the flow patterns only describe the flows in the immediate vicinity of the current meter

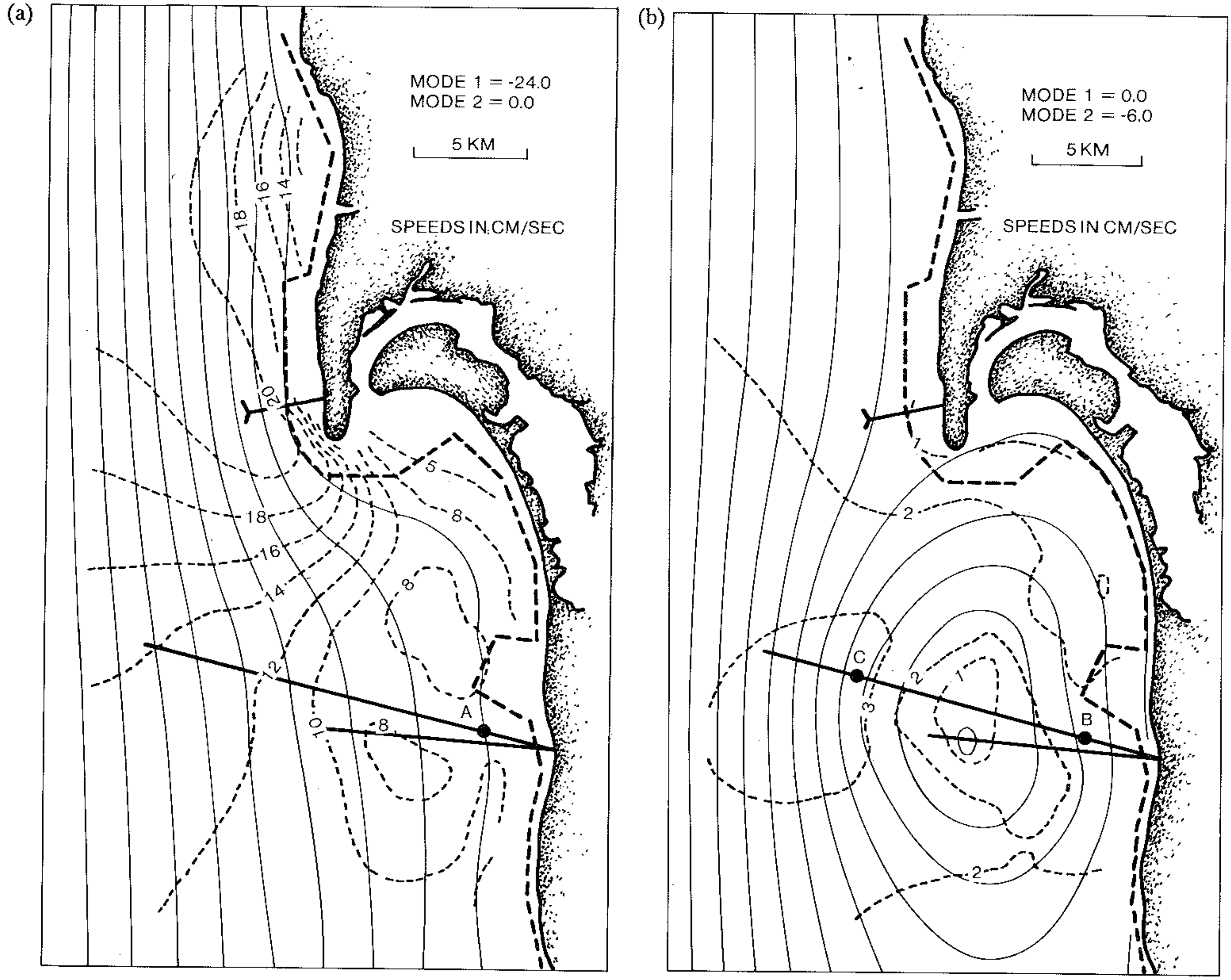

Figure 2. Two elemental flow patterns: (a) longshore flow and (b) eddy.

moorings. The presence of the coast can be expected to change the direction and strength of the currents from location to location, and it is necessary to estimate these variations to assess the frequency and rate of transport into the nearshore protected waters.

In order to do this, Hendricks and Christensen made a number of assumptions. First, they assumed that far offshore, the flow was essentially parallel to the general trend of the coastline. In addition, they noted that coastal flows frequently appear to be nearly in geostrophic balance--that is, the "force" associated with the earth's rotation is roughly balanced by the pressure gradients associated with the density stratification of the water column and the slope of the sea surface. They combined these assumptions with the requirement that the simulated flows reproduce the observed flows at each of the current meter moorings in a numerical model to simulate the circulation patterns over a larger area.

With these approximations, the circulations associated with the two elemental flow patterns identified from the EOF analysis are shown in Figures 2a (longshore flow) and 2b (eddy). In these figures, the light solid lines represent the trajectories of water as they move through the area. Where the lines are closer together, the currents move

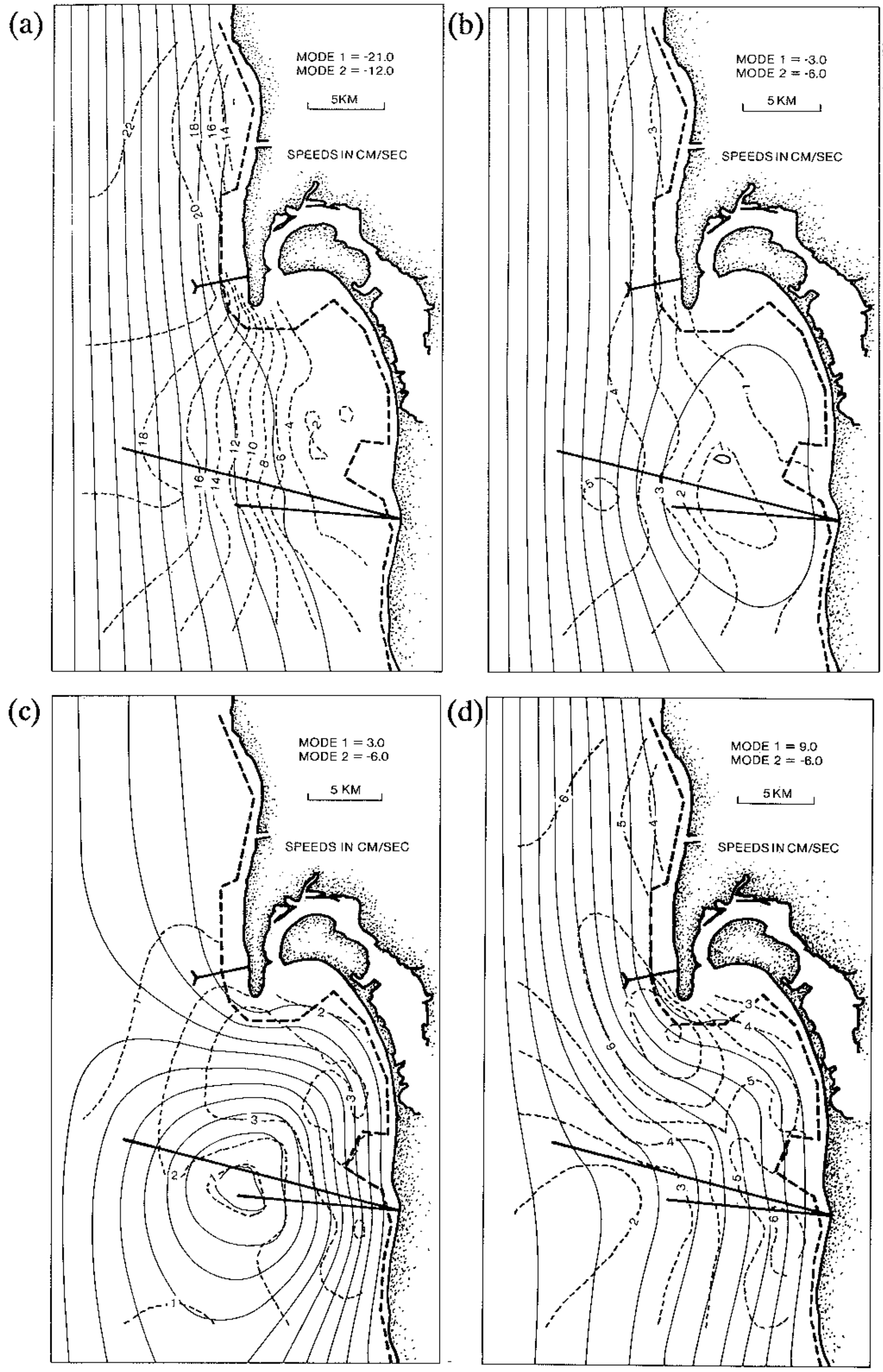

Figure 3. Four possible combinations of the two elemental flow patterns.

faster; where they are farther apart, the flows are weaker. From Figure 2a, it is immediately evident that if only the longshore flow pattern is present, wastewater discharged from the outfall offshore of point A will not come into contact with the protected area (actually, the dispersion associated with tidal motions still needs to be taken into account). On the other hand, only discharge from inshore of point B, or offshore of point C, in Figure 2b will impact the protected area. Thus these streamline diagrams provide a convenient method for analyzing the flow trajectories.

One should also note that these same trajectories exist whether the flow is strong or weak--only the rate and direction (e.g., upcoast/downcoast, clockwise/counterclockwise) of the flow depend on the magnitude and sign of the strength of the elemental flow.

As noted above, each of the observations during the course of the year-long study can be approximated as a simple combination of these two elemental patterns. Examples are shown in Figures 3a-3d for various strengths of the two elemental flow patterns. However, the strength of the contributions from each of two patterns will change during the passage of time and little would be gained by the previous analysis if a composite flow pattern must be generated for each observation time.

The time-series describing each of the elemental flow patterns can be generated from the original time-series for each current meter. It is convenient to describe the amplitude of each flow at each point in time in terms of the plot shown in Figure 4. In this plot, only a single point, corresponding to an amplitude of +10 and +5 for the two

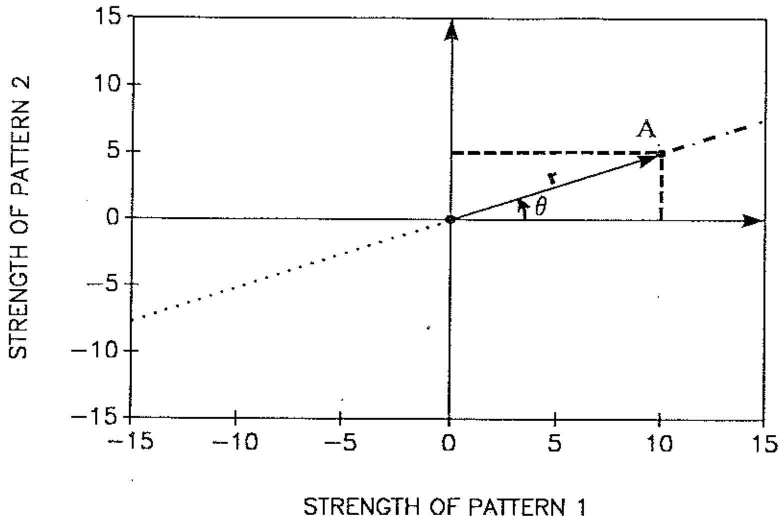

Figure 4. Representation of observations by the strength of the two patterns. Point A represents one observation in the time-series of observations.

components (respectively) is shown for clarity. However, the actual plot would contain as many points as there were observations in the original time-series used to compute the correlation coefficients.

The location of any point in this plot can be described in either rectangular coordinates (e.g., pattern 1, pattern 2), or by a radius and angle (as shown in Figure 4). The advantage of the latter approach is that all dots that lie along a line with the same angle have the same flow pattern and the same trajectory plot. The only difference between two flows lying at different distances from the origin along the line shown in Figure 4 is the strength (speed) of the flow. Moreover, dots lying along the same line extended through the origin also have the same trajectories--but with the flow in the opposite direction. Analysis also shows that dots lying close to this line have flow trajectories that are only slightly different from those lying on the line.

As a result, it is not only possible to substantially reduce the number of flow patterns that must be simulated, but to compute the probability of occurrence of each of the simulated flow patterns. Approximately 50 flow patterns were generated in the analysis (Figures 3a-3d represent 4 of the 50). This number was more than sufficient to describe the range of circulations contained in the original time series. Without this similarity analysis, it would have been necessary to generate more than 2600 flow patterns.

All the preceding analysis neglected the transport of wastewater by tidal currents. These motions were treated as a dispersion that is superimposed on the trajectories obtained from the previously described methods. The cross-shore component of the currents associated with tidal (and shorter period) motions (initially removed from the analysis) was used to compute this dispersion. It was found that the cross-shore distribution was essentially independent of time for elapsed times (i.e., the time since discharge from the outfall) of more than about 6 h. Approximately 50% of the time, the tidal motions would move the wastewater less than 0.5 km from the computed trajectory; about 90% of the time it would lie within 1 km of the trajectory; and virtually 100% of the time it would be within 2 km. These dispersion factors are easily applied to the trajectory diagrams to take into account the tidal motions.

The products of this study have been twofold. A new method has been developed to simplify the analysis of massive amounts of current meter data, and this method has been used to overcome the geographical constraints on the collection of oceanographic data required for siting the south San Diego outfall.

Acknowledgment

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Reference

Hendricks, T. J. 1985. Current measurements: City of San Diego dedesignation study. Final report to CH2M Hill Inc. Southern California Coastal Water Research Project, Long Beach, CA.