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MEASUREMENTS OF SUBTHERMOCLINE CURRENTS

We have continued and expanded our studies of the currents flowing over the nearshore shelf areas off southern California. Records have been collected over all four seasons from nine current meter stations near and away from municipal wastewater outfalls. The stations ranged from Santa Barbara to San Diego. Most of these measurements were made at a water depth that is representative of the portion of the water column occupied by a submerged wastefield.

A number of factors can influence the coastal currents, including both area-wide conditions (such as the tides, the weather, or the California Current and its associated eddies and gyres) and localized influences (such as the bottom topography and local winds). Thus, we were not surprised to find that some features of the currents appear to be common to almost all of the sites we surveyed, while other features vary from area to area. The speeds of the currents in some areas appear to be significantly different from those in other areas (Table 1). For example, the highest mean speed observed at the Point Loma (San Diego) location was less than the average mean speed observed off La Jolla and Whites Point. Nevertheless, when we calculated and compared the average mean speed for each current meter site, we found no values that differed by more than 20 percent from the area-wide average speed of 9.8 cm/sec.*

We also found considerable similarities in the statistical properties relating to the time variability of the currents at various areas. To examine time variabilities, we separated the currents into two components--the flow parallel to the local contours of constant depth (the "alongshore" component) , and the flow perpendicular to the contours (the "onshore/offshore" component). In last year's annual report, we reported that the primary movement of water was in the alongshore direction, and this observation has been confirmed by our recent data. We have also been able to determine that the predominance of

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*Mean speeds of this type have been used in a number of wastewater dispersion calculations that do not take into account the time variability of the flows. Although these mean speeds are probably representative of the strength of the currents past the diffuser, they are not necessarily representative of the net movement of water out of the outfall area.

alongshore flow can be associated with certain features in the time variability of the currents. To discuss these features, it is convenient to divide the fluctuations observed in the currents with time into three categories:

- Tidal oscillations, in which the current flows in one direction for 6 (or 12) hours and then reverses direction for another 6 (or 12) hours. The strength of the tidal frequency currents varies from area to area; however, in the alongshore direction, about 15 to 20 percent of the total kinetic energy associated with the currents is in these frequencies.
- Low-frequency fluctuations, less defined oscillations that occur more slowly than the tidal fluctuations. These slowly varying portions of the currents, which are presumably related to area-wide influences, are particularly important since they account for about 75 to 80 percent of the total kinetic energy.
- High-frequency fluctuations, the rapidly varying portions of the currents, which contribute less than 6 percent of the total kinetic energy.

The relationship between the energy and the variability of the flows in time is illustrated in Figure 1, using Point Loma data. In creating this figure (or spectrum), the sequence of speeds in each of the two directions is represented by a series of the form:

$$Sn = \sum_{K=1}^{N/2+1} V_k \cdot \cos(2\pi f_k \cdot n\Delta t + \phi_k),$$

where

S_n = the nth observation in the sequence composed of N total measurements (n = 1,2,3,….,N),
V_k = amplitude of kth harmonic,
f_k = frequency of kth harmonic,
ϕ_k = phase of kth harmonic, and
Δ_t = the time elapsed between each observation.

After determining the value of V^ (and (f)^) for each frequency, the kinetic energy (V2) associated with each frequency is plotted versus the frequency. The plot reveals that a major portion of the kinetic energy (and hence the time variability) in the alongshore direction comes from two sources—the slowly varying portion of the flows with frequencies less than 1 cycle/day, and the two tidal oscillations at about 1 and 2 cycles/day.

Figure 1 shows that the alongshore component dominates the low frequency currents, while the energy associated with the alongshore and onshore/offshore components becomes comparable at the high frequencies. Therefore it is the slowly varying, presumably large-scale (i.e., extending over a considerable area) flows that produce the observed dominance of flow in the alongshore direction.

Similar spectra have been observed during other seasons and at other current meter locations. Figure 2 is a composite spectrum based on measurements of the alongshore component of the currents at Whites Point (fall), La Jolla (fall), and Point Loma (winter, spring, and summer). The individual records have been scaled so that the mean speeds for each record are the same. At frequencies below the tidal frequency of 1 to 2 cycles/day, there is a regular increase in the kinetic energy with decreasing frequency. This rate of increase is such that the amount of variability contributed by each frequency to the total variability in the original measurements is proportional to the periodicity ($T_k = 1/f_k$) associated with that frequency. A similar relationship may exist at the high frequencies above the tidal frequencies. At the present time, our records are too short to determine the lower frequencies at which this relationship must begin to break down. The comparatively slow net flows observed during all of our longer records suggest, however, that the energy may again start to decrease as the frequency falls below 0.05 cycles/day (corresponding to periodicities of 20 days). We are presently carrying out extended measurements to resolve this question and ascertain the net direction of flow.

The ensemble average shown in Figure 2 appears to be a reasonable representation of the spectra obtained from each of the individual records. This is important because, in the model for dispersion of wastewaters described in last year's report, we had made the assumption that the spectra obtained from a series of measurements at a single location would be similar. The fact that the spectra for different areas are also similar (after a suitable scaling of the speeds) suggests that a single dispersion calculation may be sufficient to describe the dispersion in a number of areas, provided that the calculation is only used to describe dispersion of the effluent 1 day or more after discharge. For shorter times, it will be necessary to include the particular characteristics of the tidal currents associated with each area into the calculations.

Each record of 4 weeks duration or longer has been analyzed to determine the contribution of six tidal frequencies to the observed variation in each of the two component directions. The results show that there is a considerable variation in the properties of the tidal period fluctuations from area to area. In general, the tidal oscillations are strongest in the alongshore direction and dominated by the principal lunar semidiurnal harmonic (which has a period of 12.42 hours). At the Orange County outfall site, however, this oscillation was strongest in the onshore/offshore direction (the Orange County semidiurnal harmonic, with an amplitude of 6 cm/sec, was also the strongest harmonic noted at any site). In contrast, the luni-solar diurnal harmonic (with a period of 23.93 hours) was the dominant oscillation at the Santa Barbara site, where the flow was predominantly in the alongshore direction. We have some doubt about attributing the fluctuations of tidal periodicity to the tidal changes in water level, because a comparison of several records taken at the Point Loma site showed that the strength of the flows associated with each harmonic could vary considerably from record to record. This variation suggests that a portion of these oscillations may be associated with internal wave fluctuations of tidal periodicity.

A substantial correlation was found between the variations in the flows at different depths in the water column. Figure 3 shows the variation in the speed of the alongshore component recorded by current meters at depths of 10.5 and 41 m at a 56-m-deep site off Point Loma during February 1976. In the top graph, variations due to tidal or high frequency currents have been suppressed by mathematical processing. The variations in the flows at the two depths correlate to a high degree.

The Point Loma results confirm previous observations made off Encinitas. However, at the latter site, there was substantially stronger density stratification of the water column, and differences in the flows at different depths due to changes in this stratification were also evident. Pairs of meters placed offshore in 183 m of water and inshore in 30 m of water at Encinitas also showed this correlation.

When the higher frequencies of the alongshore component of the currents off Point Loma during 1 week in February are unsuppressed (Figure 3, bottom graph), we find muchless correlation between the flows at the two points in the water column. Initially, there appears to be a substantial correlation between the records, particularly in the fluctuations of tidal periodicity; but this correlation disappears 4 days later in the record. This is consistent with the hypothesis that internal wave fluctuations can affect the currents of tidal periodicity.

Our investigations of the coherence, or correlation, between flows at several alongshore locations are still in progress. Measurements to date indicate that, along a "smooth" coastline, significant correlation may exist between sites up to 10 km apart. On the other hand, simultaneous 4-week records from Point Loma and Oceanside, about 60 km apart, revealed net flows in opposing directions, suggesting that the correlation may be low at such distances and that substantial onshore/offshore flow may have occurred in the intervening region.

In summary, measurements made at a number of sites over the nearshore shelf area off southern California show similarities in the currents:

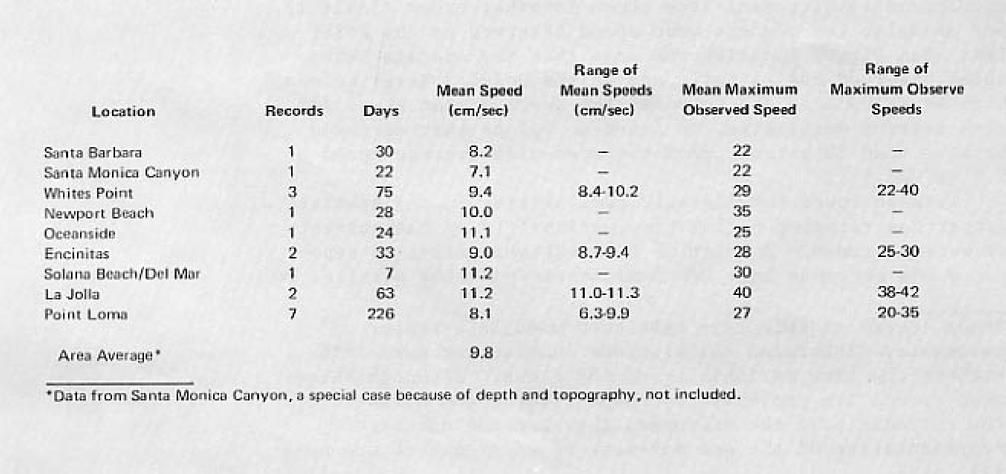
- The mean of the speeds at all sites at a depth of 41 m in 56 m of water was 9.8 cm/sec; the mean speed for each site differed from the area-wide value by less than 20 percent.
- The predominant direction of flow is alongshore—approximately parallel to the local contours of constant depth.
- The statistical properties of the time variability existing in the flows is similar from area to area. More than 75 percent of the kinetic energy in the alongshore component of the currents is associated with the portion of the flow that fluctuates more slowly in time than the tidal oscillations. This slow-varying portion is responsible for the predominance of the alongshore component of the currents over the onshore/offshore component.

- The similarity in these statistical properties supports one of the assumptions in the dispersion model we developed last year and indicates that a single calculation may be applicable to a number of areas.

Some differences between sites were, however, also evident:

- Although the mean speed for a particular site did not greatly differ from the area-wide average, there appeared to be definite differences among sites.
- Tidal currents varied significantly from site to site, not only in the speed and predominant direction of flow, but also in the ranking of importance of the various tidal harmonics.

Table 1. Summary of current meter records.



Location	Records	Days	Mean Speed (cm/sec)	Range of Mean Speeds (cm/sec)	Mean Maximum Observed Speed	Range of Maximum Observe Speeds
Santa Barbara	1	30	8.2	–	22	–
Santa Monica Canyon	1	22	7.1	–	22	–
Whites Point	3	75	9.4	8.4-10.2	29	22-40
Newport Beach	1	28	10.0	–	35	–
Oceanside	1	24	11.1	–	25	–
Encinitas	2	33	9.0	8.7-9.4	28	25-30
Solana Beach/Del Mar	1	7	11.2	–	30	–
La Jolla	2	63	11.2	11.0-11.3	40	38-42
Point Loma	7	226	8.1	6.3-9.9	27	20-35
Area Average*			9.8			

*Data from Santa Monica Canyon, a special case because of depth and topography, not included.

Figure 1. Spectrum of the currents observed of Point Loma from April to July 1975 at a depth of 41 m in 57 m of water. The greatest energy is associated with the very slowly changing fluctuations and the diurnal and semidiurnal tides (at 1 to 2 cycles/day). The along-shore component has about ten times the energy of the onshore/offshore component at the lower frequencies at the high frequencies the two energies are comparable.

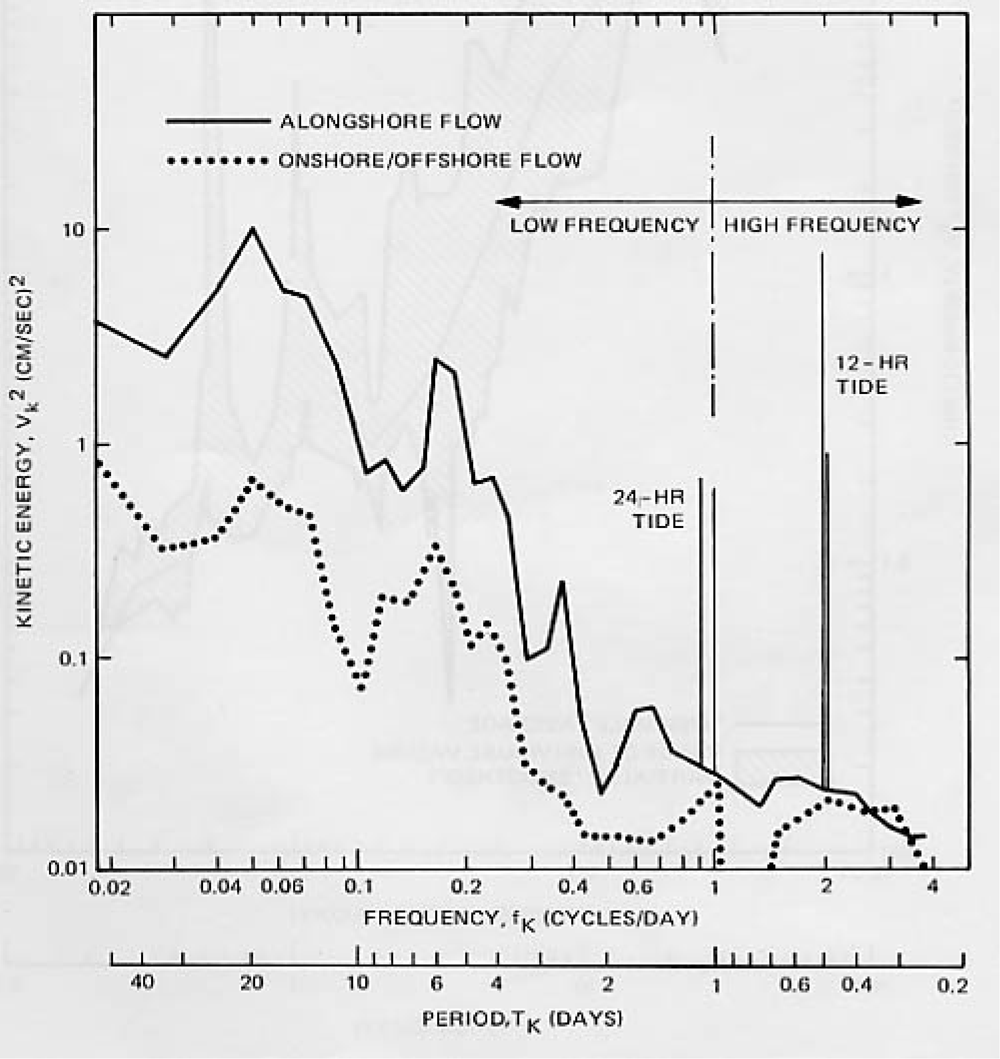


Figure 2. The composite spectrum created from five individual spectra for the alongshore component of currents observed off Point Loma, La Jolla and Whites Point.

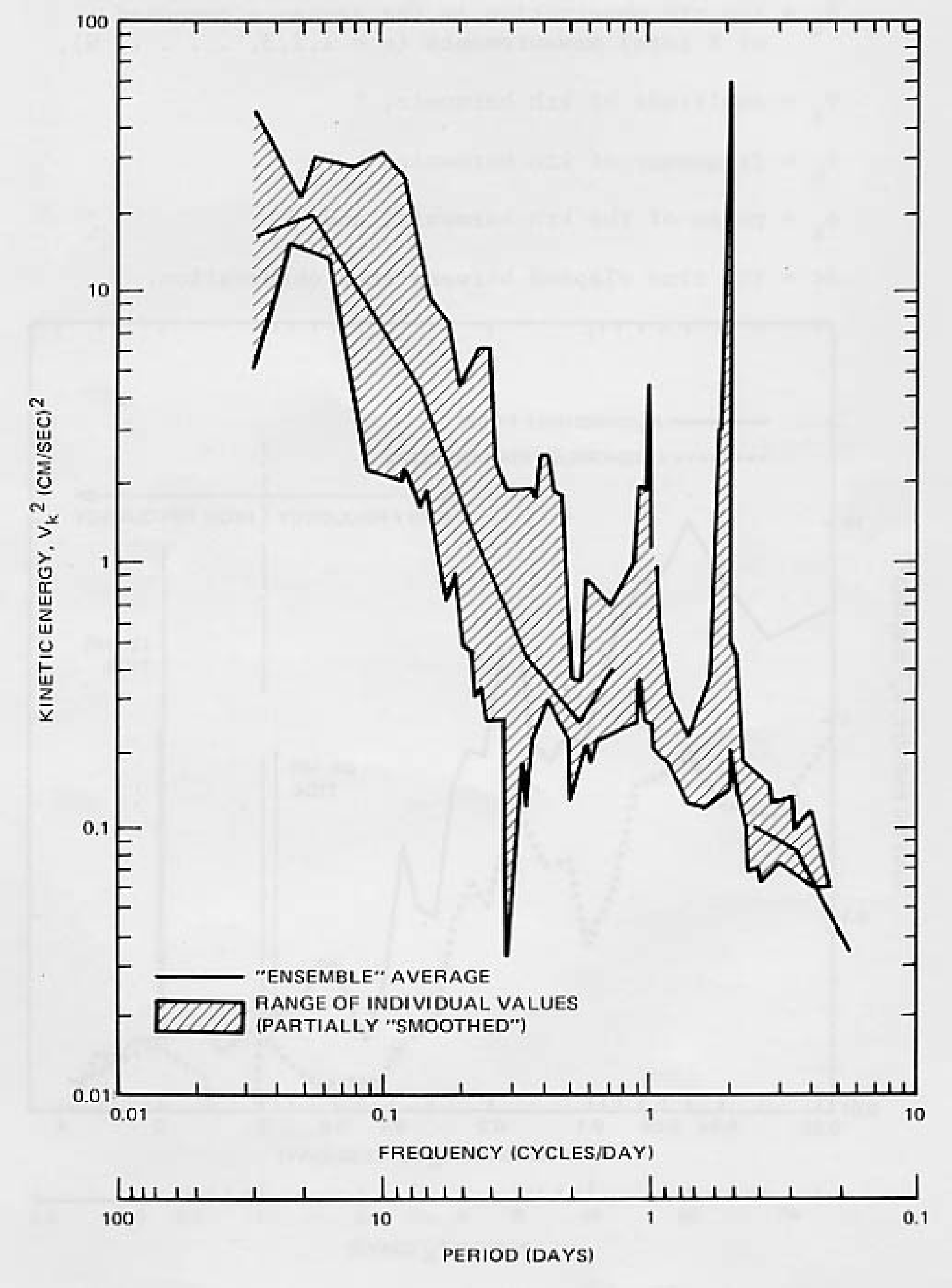


Figure 3. The alongshore component of the currents at a 56-m deep site off Point Loma, 1976.