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COASTAL CURRENTS

For several years, the Coastal Water Research Project has conducted current studies to obtain a basic understanding of subthermocline water motions, to estimate residence times (or flushing rates) of these waters, and to obtain information needed in the formulation of models of the transport and dispersion of municipal wastewater discharges. During 1976, current meter and drogue studies were carried out in the San Diego area. The objectives of this work were (1) to determine the mean speed and direction of subthermocline currents over a period of a year, (2) to examine the long-term variability in these currents, (3) to determine the length of the segment of coast that can be described by the currents recorded at a single location, and (4) to explore possible correlations between these currents and winds and tides. During the year, we also made short-duration measurements of currents at several depths in the water column near four southern California municipal wastewater outfalls as part of our continuing studies of initial dilution of wastewater discharges.

Current meter records were collected with in-situ film-recording current meters on taut-line moorings. At the Point Loma meter station, 290 days of data were recorded between 11 January and 31 December 1976. During this period, the net movement of the subthermocline currents was upcoast at a mean speed of 3 cm/sec; however, a great deal of variability was superimposed on this mean flow. In the alongshore direction, the energy associated with the fluctuating component of the flow was about 18 times greater than the energy associated with the mean flow; in the onshore/offshore direction, the mean flow was essentially zero. This large amount of variability means that current meter records for periods of at least 2 months are required to be able to determine if the mean flow is upcoast or downcoast.

A comparison of the currents recorded at the Point Loma station and at stations 6.5 and 13.5 km upcoast shows a high correlation between the daily average currents at the three locations. This correlation suggest that the movements of the currents over this segment of the coast can be inferred from the Point Loma current meter record and that there is probably minimal offshore/onshore exchange of water by large eddies or gyres in this region. The correlation—combined with drogue observations, which also indicate that the primary direction of flow is along the contours of constant depth (isobaths)—also supports the assumptions used in developing the model of the alongshore transport of waste-water materials described in the Project's 1975 annual report (Hendricks 1975).

SPEED AND DIRECTION OF SUBTHERMOCLINE CURRENTS

Most of the current meter records were collected just north of Point Loma outfall (Figure 1). During February, currents at a depth of 11 meters at this station were also measured. In March, meters were deployed at two stations off Encinitas— at depths of 41 and 55 meters in 56 meters of water and at a depth of 15 meters in 42 meters of water (Figure 1). During this investigation, drogue observations were also carried out in the Torrey Pines and Encinitas areas. Current meters were placed off Mission Beach and La Jolla during August and September, and short-term records (of a few hours duration) were collected at several depths at the Point Loma, Orange County, Whites Point, and Hyperion outfall locations during the initial dilution studies carried out in October.

Figure 2 shows the average currents over 2-week periods at weekly intervals at the Point Loma current meter station. It is apparent that the net motion in the alongshore direction is upcoast and that the 2-week average currents in the onshore/offshore direction are generally much weaker. The alongshore flow averaged 2.0 cm/sec for the first half of this record and 4.0 cm/sec for the last half, yielding a "yearly" mean current of 3.0 cm/sec. A crude analysis of the variability in the average daily flows suggests that records of 2 months duration would be required to determine whether the mean flow is upcoast or downcoast at the 90 percent confidence level and that a 1-year record would have an uncertainty in the strength of the mean flow of approximately ±50 percent at the 90 percent confidence level. As the year 1976 appears to have been atypical from the standpoint of weather and California Current flow, these mean flows may also deviate from the norm, although it is unlikely that the direction of the mean flow would change. An average speed of 3 cm/sec corresponds to a travel time of approximately 150 days from the Mexican border to Point Conception (if the flow continues at this same speed along the entire intervening section of coast).

SURFACE AND NEAR-BOTTOM WATER MOVEMENTS

Technical problems inhibit the collection of long-term current meter records of near-surface flows (0- to 3-meter depths). However, drogue measurements and visual observations, as well as discussions with oceanographers, fishermen, and yachtsmen, indicate that the surface currents flow predominantly downcoast at speeds that are probably on the order of 25 cm/sec. As the mean motion of the subthermocline currents is upcoast, the "frictional" forces associated with the exchange of water across the thermocline must be small in comparison with the other forces driving these two water motions. It is, however, possible that the exchange, although small, is important in the dispersion of effluent in that there is a large shear in the currents and a potentially steep vertical concentration gradient of effluent in the water column.

Although we have only a limited number of days of current meter observations at a depth approximately 0.6 meter above the bottom, the data offer evidence that the near-bottom water may also move in a direction that differs considerably from the flow 15 meters above the bottom. In general, the near-bottom water flows appear to have a significant offshore component and may also have an alongshore component that is in the opposite direction to that of midwater currents. Even in relatively deep water, the speed near the bottom can be comparable with the speed near the middle of the water column: During a few hours of current measurements near the Orange County out-fall in October, the near-bottom currents (which reached a maximum speed of 20 cm/sec) averaged 15 cm/sec; this speed is comparable with the speeds observed at 13 meters (20.2 cm/sec) and 27 meters (16.6 cm/sec) above the bottom in 55 meters of water. These near-bottom speeds exceed the 12 cm/sec velocity required to resuspend the sediments near the diffuser (Hendricks 1976a) and approach the resuspension velocities of the sediments at stations away from the outfall (24 to 29 cm/sec).

VARIABILITY IN SUBTHERMOCLINE CURRENTS

Previous observations have demonstrated that large fluctuations in the current speed and direction are super-imposed on the mean flow. Spectral analysis (described in Hendricks 1976b) is a convenient tool for investigating the properties of this variable part of the total flow; the spectral energy distribution for the first half of 1976 is illustrated in Figure 3. As was noted in earlier studies, the largest fluctuations are associated with variations that occur more slowly than the diurnal or semidiurnal tides, with the peak of the energy spectrum occurring at "periodicities" on the order of 10 to 20 days.

There appears to be only a slow decline in the spectral energy density associated with even slower fluctuations. For these long-period variations, the ratio of the along-shore energy to the energy associated with the onshore/offshore motions is approximately 15 to 1. For the 290-day mean motions, this ratio increases to 25 to 1 and cannot be distinguished from a value of Infinity (only alongshore flow) if the experimental uncertainty in recording the direction of flow is taken into account. As was noted earlier, this anisotrophy disappears near the tidal periodicities, and the onshore/offshore motions may even be dominant at the higher frequencies (shorter periods). Although the energy density in the alongshore direction is greater for fluctuations with periodicities longer than 10 days than it is for fluctuations with periodicities between 1 and 10 days, the energy associated with each band is about the same—35 percent of the total energy. Periodicities near the tidal periods contribute about 20 percent, and the mean flow and fluctuations more rapid than the tidal oscillations each contribute approximately 5 percent of the total. In the onshore/offshore direction, the contribution by the mean flow is negligible, with the tidal periodicities accounting for about 50 percent of the total energy, and the higher and lower frequencies contributing about 25 percent each.

REGIONAL COHERENCE OF SUBTHERMOCLINE CURRENTS

Drogue observations conducted during previous years have also indicated that the alongshore motions are generally much stronger than the onshore/offshore movement. In these earlier studies, the drogues were deployed at a single station and followed for a period of time. In March 1976, we deployed four 5-meter-diameter parachute drogues at a depth of 41 meters along a 6-km section of the coast off Torrey Pines so that we could synoptically compare the currents along this section of the coast. All of these drogues moved upcoast at similar speeds (7 to 10 cm/sec) and roughly along the local isobaths (Figure 4), indicating substantial coherence in the currents within this region. During this same time period, observation of a surface drogue indicated that the near-surface water was moving downcoast at a speed of about 26 cm/sec. It was somewhat surprising to observe so much similarity in the movements of the drogues at depth since they were deployed downstream from La Jolla Canyon and Point La Jolla, which might have been expected to produce local eddies and gyres or other disturbances in the flow.

Further studies of the possible coherence in the along-shore flows were carried out during late July, August, and September, when current meters were placed in 56 meters of water off Mission Beach and La Jolla (Figure 1). A 25-hour running average was used to calculate "daily" average flows; the daily averages for these stations and for the Point Loma station were then compared. The high coherence between the three records (Figure 5) suggests that long-period movements (greater than 1 day) are related to events or processes that extend over distances exceeding 15 km and that the Point Loma current meter record is probably a good representation of the overall movement of the subthermocline currents along this segment of the coast. As drogue observations and current meter records have indicated that the currents tend to follow the local contours of constant depth, it appears likely that effluent from the Point Loma outfall moves Pines so that we could synoptically compare the currents along this section of the coast. All of these drogues moved upcoast at similar speeds (7 to 10 cm/sec) and roughly along the local isobaths (Figure 4), indicating substantial coherence in the currents within this region. During this same time period, observation of a surface drogue indicated that the near-surface water was moving downcoast at a speed of about 26 cm/sec. It was somewhat surprising to observe predominantly upcoast past La Jolla before significant advective onshore or offshore movement occurs. Further investigation will be required to determine how far up the coast this coherence persists. The March record taken off Encinitas suggests that significant coherence in large fluctuations in the currents may exist for distances up to 35 km since a sharp reversal in the flow (from upcoast to downcoast) was noted in both the Point Loma and Encinitas records near the end of March.

This indication that current meter records taken at a single location can be combined with the drogue observations and used to estimate the alongshore movement over an ex-tended area of the coast, and the observation that there are strong similarities in the spectra of records taken at different times of the year, lend support to the dispersion model mentioned in the Project's 1975 annual report (Hendricks 1975) in connection with the prediction of the deposition of effluent particulates around the Whites Point outfall. As this model estimates the probability that a volume of wastewater will be moved alongshore a distance "x" from the outfall in the time "t," it may be a useful tool in estimating the alongshore distributions of a variety of wastewater constituents, such as bacterial densities, that change their properties with the passage of time. A more sophisticated model will, however, apparently be required to predict the onshore/offshore movement of these materials with any high degree of reliability.

SUMMARY

The mean motion of the subthermocline currents in the area of the Point Loma outfall over a 290-day period was upcoast at a speed of 3 cm/sec. This net upcoast motion is in agreement with the distribution of effluent-related sediments in this area and, in fact, with the distribution of sediments off the Whites Point outfall as well. If this mean flow continued along the entire coast between Mexico and Point Conception, it would correspond to a transit time for that region of about 150 days.

Current meter records collected along a 15-km segment of the coast indicate that the average dally currents are similar within this region, and there is evidence that this similarity extends to some degree to a 35-km segment of the coast.

Superimposed on the alongshore mean motion are much larger fluctuating motions that generally vary more slowly than the tidal oscillations for the alongshore component of the flow. The onshore/offshore motions are much weaker, and are dominated by fluctuations of tidal periodicity. Fluctuations that are of shorter period than the tidal oscillations and those that are of longer period contribute equally and, in combination, are about equal to the tidal oscillation.

The subthermocline mean motion was upcoast, or in the opposite direction to the mean motion of the surface cur-rents. There was also some evidence that the near-bottom currents (within 1 meter of the bottom) move in a different direction than the midwater currents and have a significant offshore component. At Orange County, these near-bottom currents were observed to reach 20 cm/sec, which is com-parable to the midwater speeds and sufficiently strong to resuspend the sediments in the vicinity of the diffuser and move them offshore.

REFERENCES

Hendricks, T. 1975. A model of the dispersion of wastewater constituents. In Annual report. Coastal Water Research Project, pp. 173-77, El Segundo, California.

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______. 1976b. Measurement of subthermocline currents. In Annual report. Coastal Water Research Project, pp. 63-70, El Segundo, California.

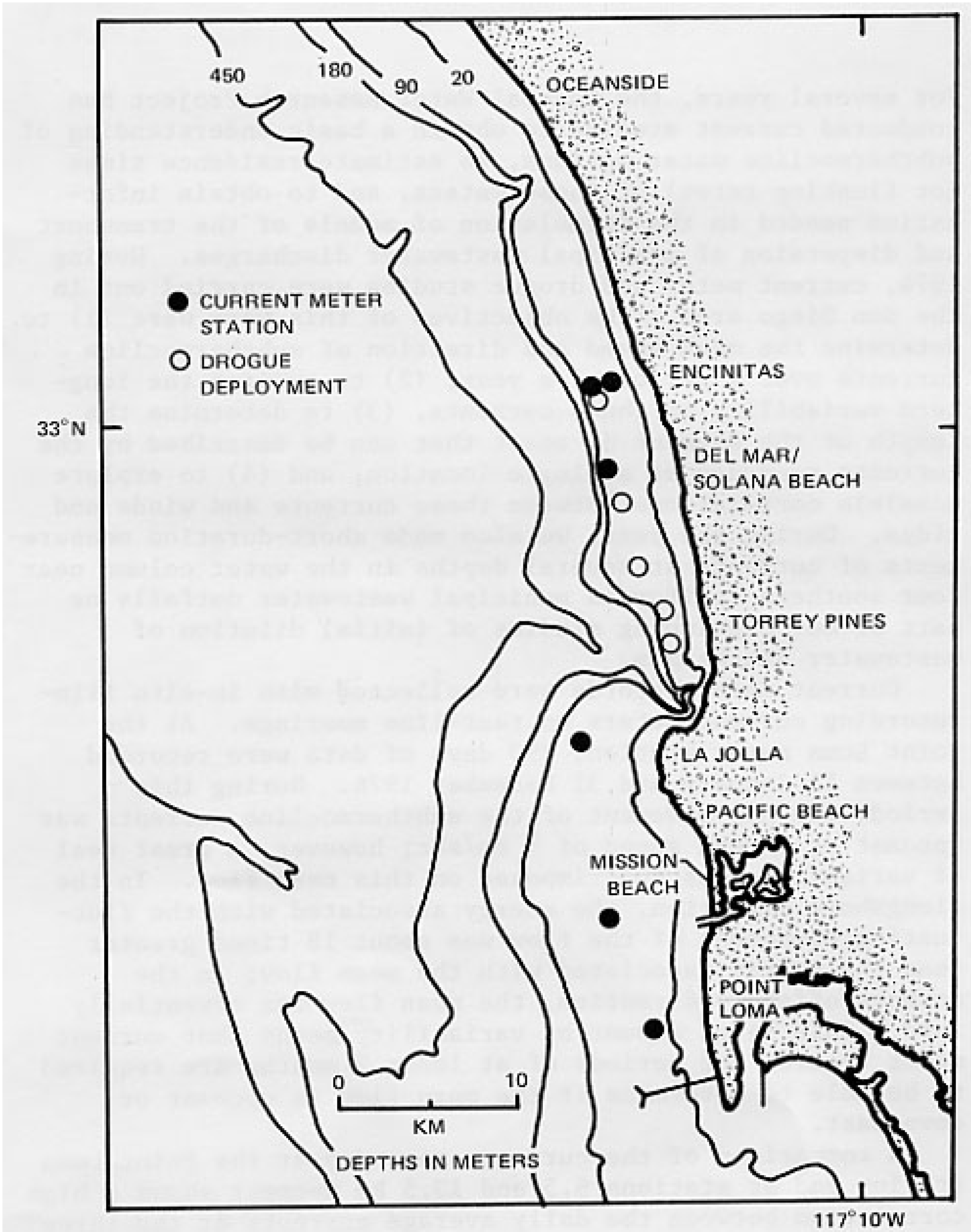

Figure 1. Current meter stations and drogue deployment locations for studies during 1976.

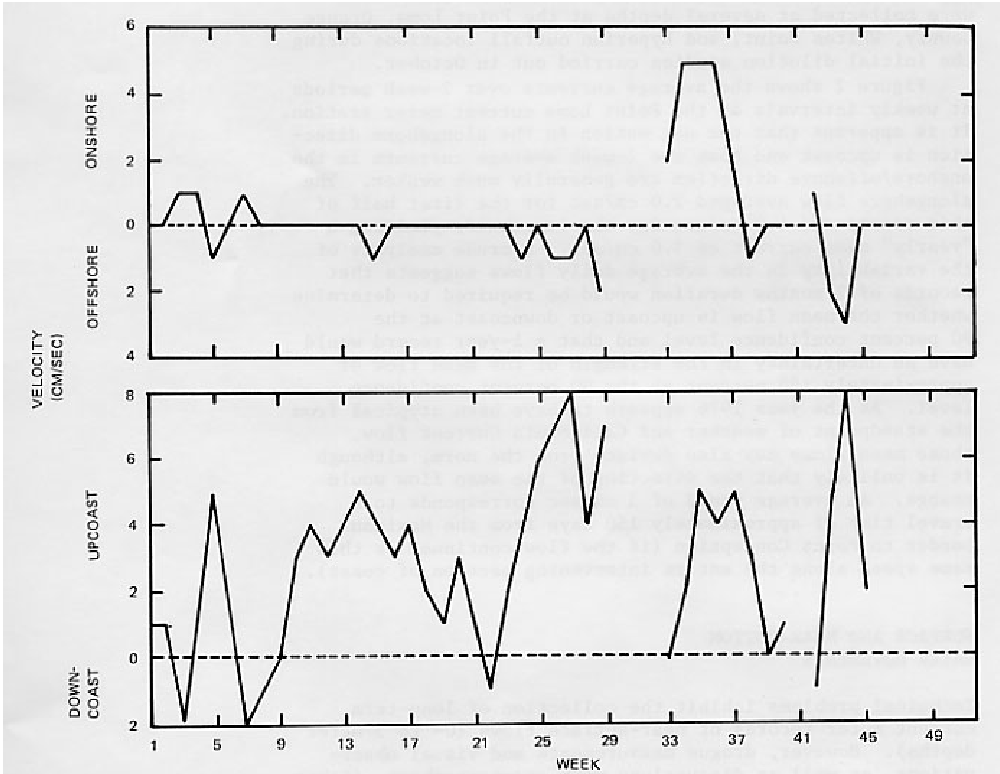

Figure 2. The onshore/offshore alongshore components of the currents measured at the Point Loma current meter station at a depth of 41 meters in 56 meters of water during 1976. The values represent the net current over 2-week periods calculated at weekly intervals.

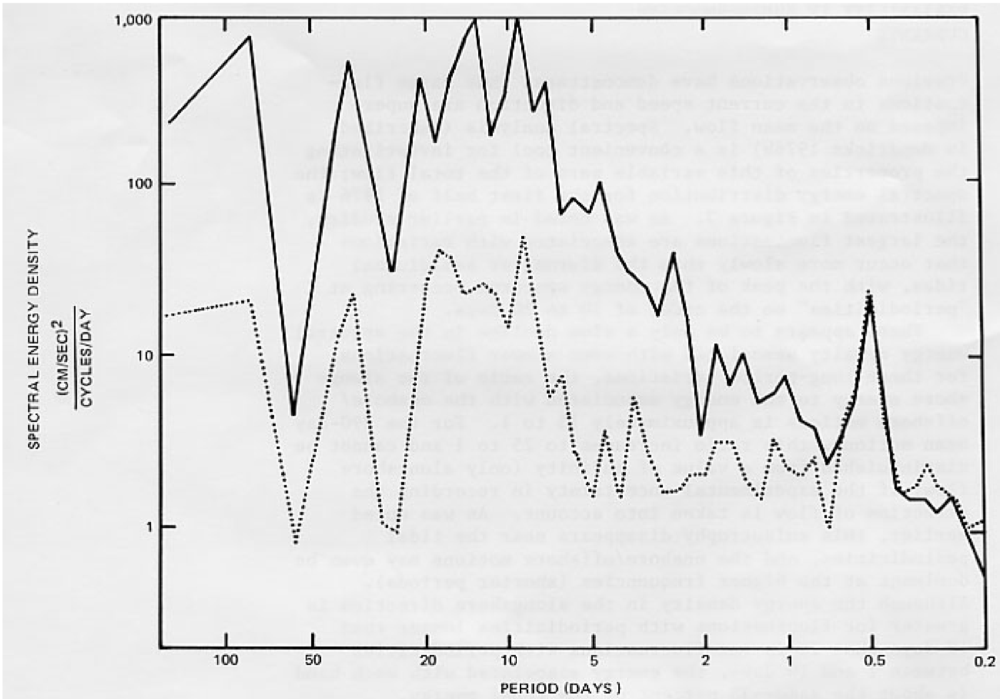

Figure 3. Spectral energy density as a function of "periodicity" for the 41-meter deep records from Point Loma, 1976. The solid line represents the alongshore component; the dotted line, the onshore/offshore component.

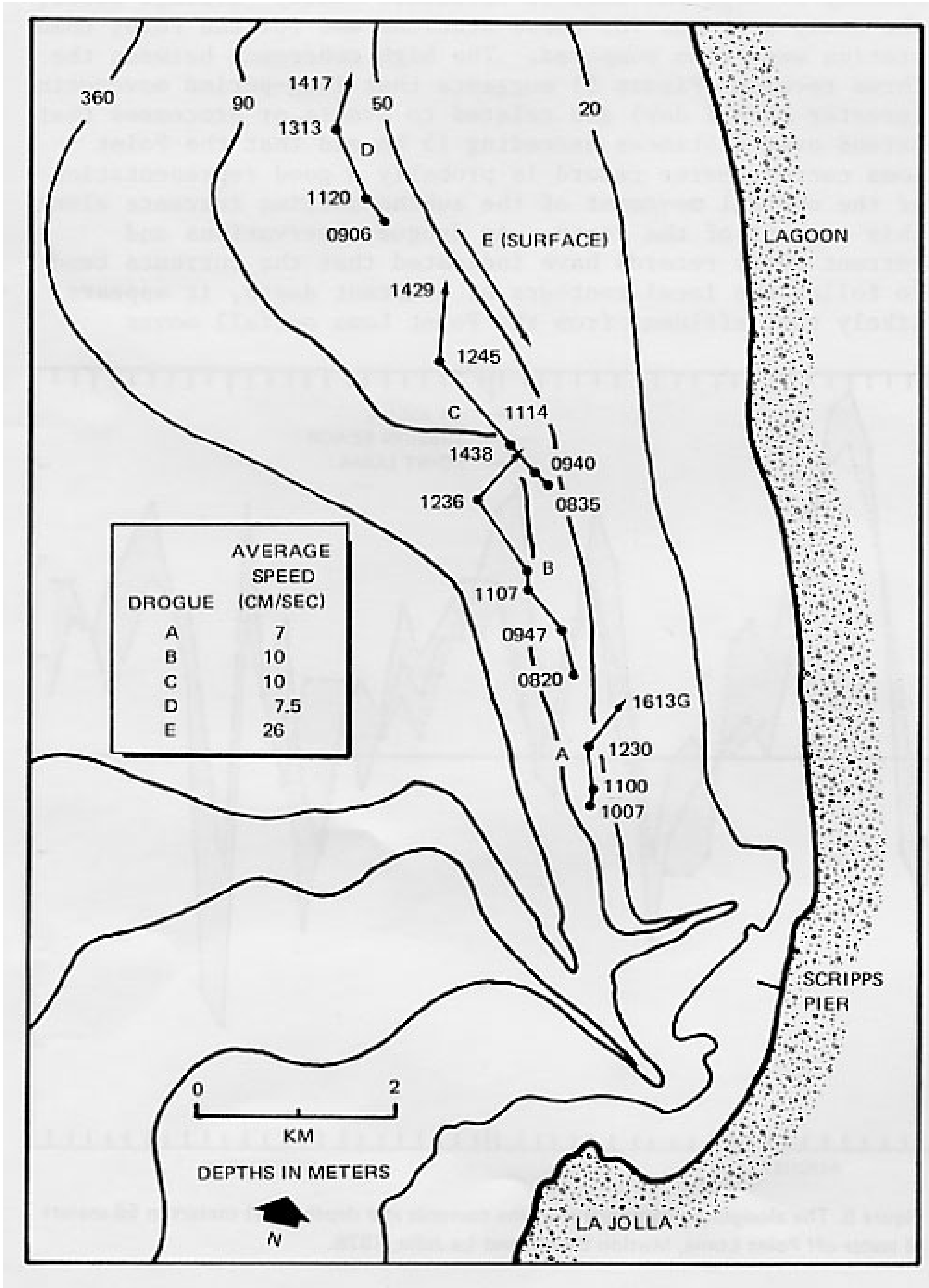

Figure 4. Drogue movements off Torrey Pines Beach (north of La Jolla) during March 1976. The time of observation is noted for each point; the symbol "G" (lower drogue) indicates grounding on the bottom. The speeds are the average speed over the observation period.

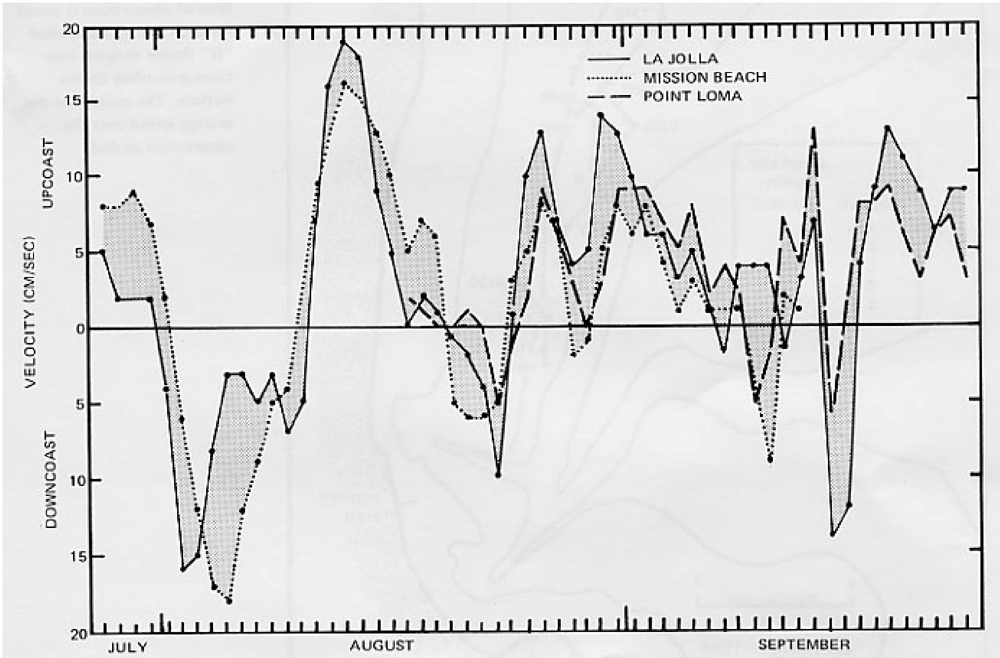

Figure 5. The alongshore component of the currents at a depth of 41 meters in 56 meters of water off Point Loma, Mission Beach, and La Jolla, 1976.