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CURRENT VELOCITIES REQUIRED TO MOVE SEDIMENTS

The distribution of effluent-related sediments around an outfall, and the changes that have been observed in the properties of these sediments (Page 91), suggest that the sediments may undergo substantial reworking by the near-bottom currents. Two obvious questions are (1) what is the minimum water velocity required to resuspend the sediments in the water and (2) how frequently do the currents reach or exceed this threshold velocity?

The answer to the first question depends on a number of factors, including the size distribution, shape, and density of the particles, the amount of consolidation of the sediments that has taken place, and the extent of reworking by benthic organisms. These factors are difficult to reproduce in the laboratory, so we decided to measure the required velocities in-situ in the actual sediments.

For this purpose, we devised and constructed a "sediment stirrer"—a plexiglass water tunnel that is lowered to the sea floor, with the sediments forming the bottom wall of the tunnel (Figure 1). A variable speed motor (controlled remotely from a surface vessel) drives a propeller that draws water through a convergent entrance section into the tunnel. The water speed within the tunnel is obtained from the voltage applied to the motor using a laboratory calibration and can be checked with a small current meter. An underwater television camera and light system, which transmits a picture to a monitor and tape recorder on the surface vessel, is attached to the steel frame that supports the tunnel.

The operation of the tunnel at sea is very simple. The tunnel is lowered to the bottom, with the operator watching the monitor to make sure the tunnel edges are well seated into the bottom sand or mud. The motor voltage is then gradually increased until particulates are set into motion. This occurs rather abruptly because the stress on the sediments increases at a rate proportional to the square of the velocity. The speed at which motion commences is labeled V_{IM} in the subsequent discussion. These velocities are remarkably reproducible between samples within a small area, the variation between measurements being about 1 cm/sec. The speed is then increased until a definite turbid movement is observed within the tunnel. We have termed this latter speed the "resuspension velocity," or V_{RS}.

We have used the "stirrer" apparatus to make measurements in the sediments around the Whites Point and Orange County outfalls, and have found that both V_{IM} and V_{RS} are reduced near the outfalls. Figure 2 illustrates the distribution of V_{IM} and V_{RS} in the Whites Point and Orange County outfall areas and shows this trend. This means that the outfall sediments can be moved by slower currents than the natural sediments.

Grab samples were also taken at each site and analyzed for organic content of the surface sediments (as measured by percent volatile solids) and particle size distribution. No significant correlation was found between the V_{IM} and sediment grain size, but V_{IM} decreases when percent volatile solids increases (Figure 3).

A striking feature observed at both outfalls was that the resuspension velocity, V_{RS}, was almost the same as the initiation of motion velocity, V_{IM}, at sites close to the outfall; away from the outfall, V_{RS} was substantially larger than V_{IM} (Figure 2). Thus if the currents are sufficiently strong to initiate motion in the sediments near the diffuser, resuspension is also likely.

To estimate the current speeds that can occur near the bottom, we made direct measurements of the near-bottom currents with a current meter and also calculated the bottom currents produced by ocean waves.

The current measurements were made off Encinitas during March of 1976, using a Savonius rotor current meter situated about 50 cm above the bottom in 56 m of water. The distribution of observed speeds, shown in Figure 4, indicates that if similar speeds exist in the Whites Point area, resuspension will occur ($V > 6$ cm/sec) about 24 percent of the time in the area extending 3 kilometers to the northwest of the outfall. The maximum observed speed was about 12 cm/sec during this record.

Wave data taken off the Torrey Pines area (near San Diego) in 10 m of water by Pawka* were used to calculate the associated bottom currents at a depth of 60 m. The frequency of occurrence of speeds in excess of 6 cm/sec, and the speeds that will occur 1 percent of the time, are shown in Table 1. These calculations suggest that the sediments near the Whites Point outfall may be reworked during 150 days out of the year.

The calculations indicate that, during the spring, velocities greater than 6 cm/sec should be observed 39 percent of the time. However, speeds greater than this occurred only 24 percent of the time during our 2 weeks of current meter observations off Encinitas. The discrepancy may reflect uncertainties in the velocity calculations or actual differences between the Torrey Pines and Encinitas areas--the characteristics of swell can change appreciably from area to area due to refraction by bottom topography or "shadowing" effects of offshore islands. It is also possible that the swell during the current measurements period was below normal, since large swell is usually present at irregular intervals. Episodic occurrences of exceptionally large swell may produce a substantial reworking of all the sediments at the 60 m depth. For example, arough estimate of the bottom currents associated with a swell that occurred during December 1969 indicates that the speeds may have exceeded 1 knot (51 cm/sec). It should be noted that, although these wave-associated currents are oscillatory in nature, once the particulates are resuspended (and kept in suspension by these currents), distribution over a large area can be produced by the weaker, but longer period flows.

In summary, the substantially reduced resuspension (V_{RS}) and initiation of motion (V_{IM}) velocities observed near the outfalls, relative to the more distant sediments in the same depth of water, suggest that outfall-related sediments may be reworked more frequently by the bottom currents, particularly as the organic content of these sediments increases. Measurements of the near-bottom currents in 56 m of water and calculations of the currents associated with waves in this area bear out this observation. These estimates indicate that resuspension may occur during more than one-third of the year near the Whites Point outfall. Infrequent, large swell--perhaps occurring only a few times each decade--can rework all the sediments at this depth. At this time, the more organic, lighter weight, sewage particulates are more likely to be swept away and dispersed over a much larger area than natural particulates.

* S. Pawka, Scripps Institution of Oceanography,
La Jolla, unpublished data.

Table 1. Summary of calculated properties of wave-associated currents in 60 m of water*.

Season	Percent of Times Speed Exceeds 6 cm/sec	Maximum Speed** (cm/sec)
Spring	39	22
Summer	23-29	16
Fall	37	17
Winter	74	25

*Based on wave data from Torrey Pines.
**Occurs 1 percent of the time.

Figure 1. Sediment stirring device.

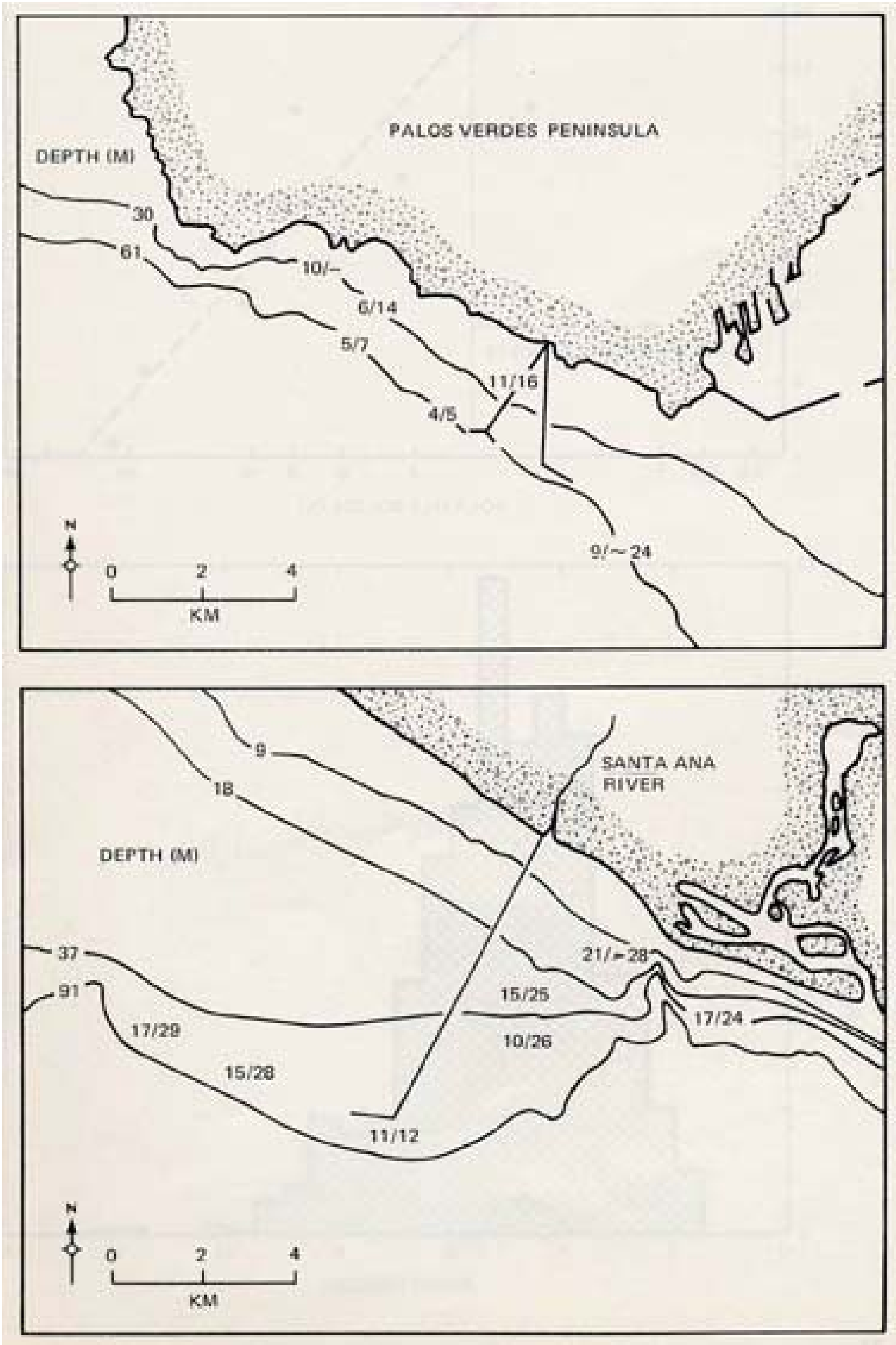

Figure 2. Measurements of currents (cm/sec) required to move and resuspend bottom sediments in the Whites Point and Orange County outfall areas. The number preceding the slash is the speed at which movement in the sediments is initiated; the number following the slash is the speed at which the sediments are resuspended.

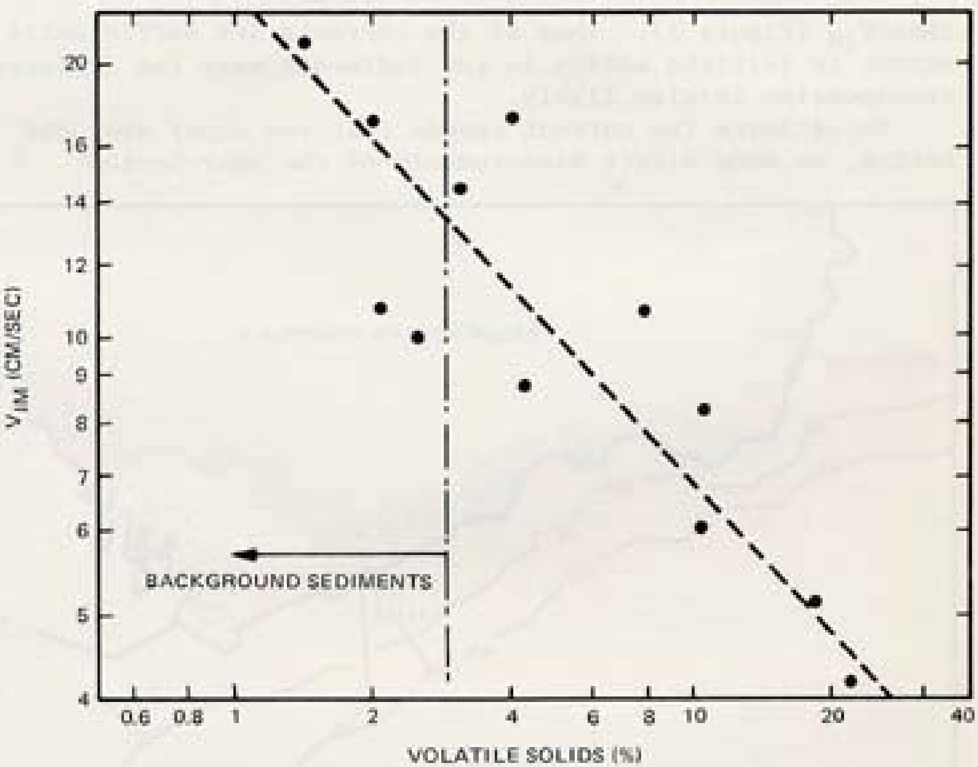

Figure 3. Relationship between the speed required to initiate motion of the bottom sediments (VIM) and the volatile solids content of these sediments. Data from both Whites Point and Orange County outfall areas.

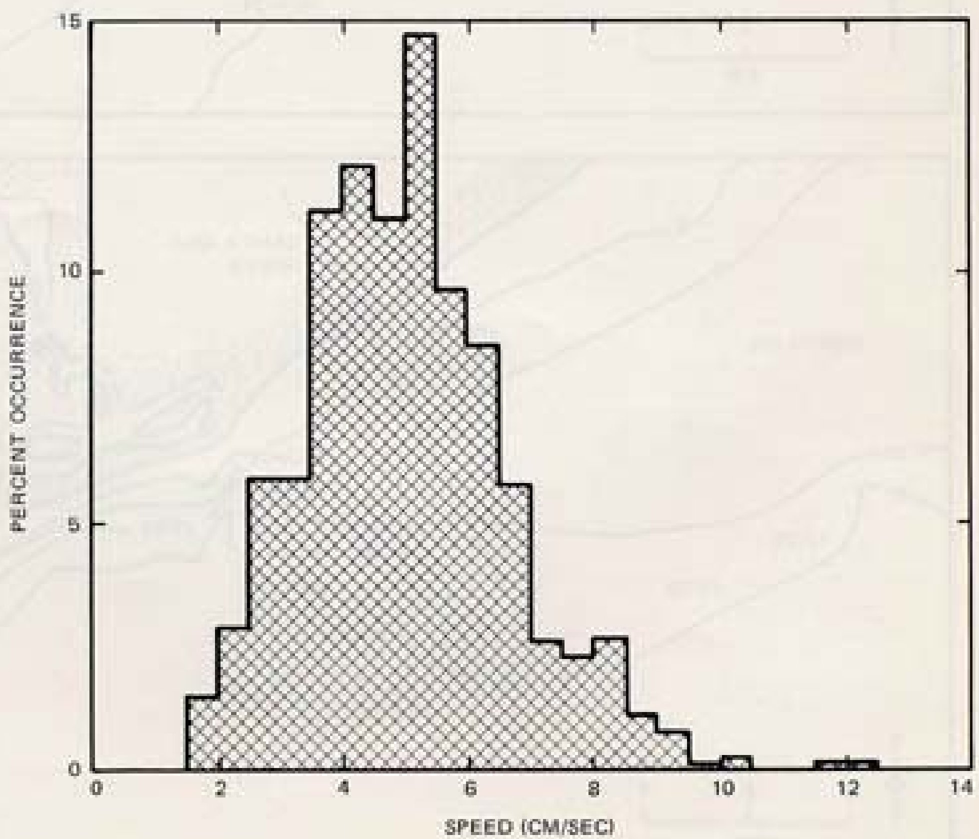

Figure 4. Distribution of speeds observed 50 cm above the bottom in 56 m of water during March 1976 at a station off Encinitas.