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EFFLUENT PARTICLE DISPERSION

Particles emitted from municipal ocean outfalls are the subject of considerable concern since they often contain, or have attached to their surfaces, such potential pollutants as trace metals and chlorinated hydrocarbons. Effluent quality criteria for discharged solids are, in part, based on measurements of settleable solids. However, the usual measurement of settleable solids gives a volume relationship (milliliters per liter) rather than the mass of particles in the settled fraction. Hence, although such a measurement provides qualitative information about in-plant effluent consistency, it gives no information about the mass of material that reaches the sea bottom.

In an attempt to understand effluent particle dispersion in the ocean, we conducted a series of experiments to (1) determine the settling velocities of effluent particles in seawater; (2) determine the amount of chlorinated hydro-carbons and trace metals in rapid-settling effluent particles; (3) compare the settling characteristics of various effluent types in seawater; (4) predict the deposition rates of effluent particulate matter, trace metals, and chlorinated hydrocarbons in calculated outfall dispersion zones; and (5) test the calculated ocean dispersion of effluent particles by mixing fluorescent-labeled particles with effluent and detecting these in ocean sediments.

Our results show that, with the use of several relatively simple experimental procedures, one can successfully determine the settling characteristics of effluent particles in seawater and predict effluent particle dispersion and de-position in the ocean.

METHODS

Settling Velocity Experiment s

To determine the settling characteristics of wastewater effluents in seawater, we obtained 24-hour, flow-proportioned composite samples of the effluents of four dischargers—Los Angeles City (Hyperion Treatment Plant), Los Angeles County Sanitation Districts (Joint Water Pollution Control Plant, or JWPCP), Orange County Sanitation Districts, and San Diego City (Point Loma Treatment Plant). The samples were mixed with seawater in a dilution of 1 to 80 (effluent to sea-water) and placed in a series of 1-liter graduated cylinders. The cylinders were placed in a water bath, which was maintained at a temperature near that of ocean receiving waters. The maximum fall height for the settling particles was 35 cm. Unfiltered seawater was used in these experiments as it contains natural particles, which may interact with the effluent particles. Settling velocity experiments were simultaneously performed on unfiltered seawater to which no effluent was added; this allowed us to correct the results of the settled effluent/seawater experiments for the amounts of natural seawater particulates that settled in the same time periods.

At various times (ranging from 30 seconds to 4 hours) after homogenization of the effluent/seawater mixtures, the cylinders were removed from the water bath, and all but the bottom 50 ml of the mixtures were removed through a vacuum siphon. The remaining slurries of settled effluent and natural particulates were removed by pipette and filtered through tared Nuclepore filters of 0.2-micron pore size for gravimetric recovery of particle mass. The filters were rinsed with 30 ml of particle-free deionized water, folded, and sealed with 0.1 pi of chloroform. The filters were then dried overnight at 105°C and weighed to ±3 ug on a Cahn Gram Electrobalance (Cahn Instrument Company, Paramount, Calif.).

<u>PLOP Experiments</u>

PLOP (pollutant loading on particulates) experiments were conducted to determine the amount of trace elements and chlorinated hydrocarbons present in the rapid-settling fraction of effluent particles. In these experiments, effluent samples were mixed with unfiltered seawater in a dilution of 1 to 30 (effluent to seawater). The experiments were con-ducted in large (30-gal., 114-liter) trash cans. The effluent/seawater mixtures (approximately 25 gal.) were homogenized by stirring and then allowed to settle for 92 minutes. Since the maximum fall height for the settling particulates was 55 cm, the particles that settled within 92 minutes were those with settling velocities equal to or greater than 0.01 cm/sec.

The settled fraction of the particles was recovered by siphoning off the upper portion of the seawater/effluent mixture through a long siphon tube, which was placed in the trash can at the start of the experiment. The siphon tube was filled with seawater and plugged at the drain end to permit the start of the siphoning with a minimum of disturbance to the settled fraction. At the intake end, the siphon tube was capped; but a series of small intake holes were drilled between 5 and 10 cm from the capped end to allow siphoning and to prevent particles from being vacuumed off the bottom of the can. The resultant slurry (approximately 2 liters) was homogenized and analyzed for trace metals and chlorinated hydrocarbons by standard methods employed by our laboratory (Young et al. 1976; Hershelman et al. 1977).

PLOP experiments for trace metals were performed in plastic trash cans using plastic stirring rods and siphon tubes. All plastic surfaces were cleaned and soaked in a dilute nitric acid (1NHN03) solution to remove trace metal contaminants prior to the experiment. In contrast, chlorinated hydrocarbon experiments were conducted in galvanized metal trash cans using metallic stirring rods and siphon tubes. Before the experiment was initiated, all metal surfaces were cleaned and then rinsed in analytical reagent grade hexane to remove possible contaminants.

<u>Fluorescent Particle Tracer Experiment</u>

In an attempt to trace the dispersion of effluent particulates emitted from an ocean outfall, approximately 40 liters of a suspension of fluorescent organic particles were added over a period of 1 week to the final effluent of the City of San Diego's Point Loma Treatment Plant. The fluorescent particles were prepared by the Radiant Color Division of Hercules, Inc., Richmond, Calif, (orange red dispersion WD 16). The particles were insoluble in seawater and consisted of a base polymer of triazinealdehyde-amide with a specific gravity of 1.40. Analysis by scanning electron microscopy revealed the average particle size to be 5 microns, with a range from 0.5 to 30 microns. A previous investigation of eight Van Veen sediment grabs taken near the outfall site had revealed no particles of this type.

Following the week-long release of the fluorescent particles, 37 Van Veen grabs were taken at stations within the vicinity of the outfall over a period of 2 days. A sample of seawater and three sediment samples were taken from each of the grabs. The sediment was collected into a small glass vial by skimming the surface of the grab to a depth of 5 mm for a distance of 5 cm. The samples were added to 500 ml of glass-fiber-filtered deionized water and homogenized for 2 minutes in a Waring blender. After allowing the homogenized samples to settle for 1 minute to remove coarse debris, 20-ml aliquots were extracted by syringe and filtered through glass-fiber filters. Fluorescent pigment particles on the filter surfaces were detected and counted through a binocular dissecting microscope at a magnification of 26X. Excitation of the fluorescent particles was provided by ultraviolet light with a wavelength of 365 nanometers (nm); the wavelength of emitted fluorescence was 600 nm.

RESULTS AND DISCUSSION

Dispersion Zone Calculations

The calculation of a dispersion zone for rapid-settling effluent particles requires the use of local current measurement data. However, since detailed studies of current variations at all discharge sites have not been done, simplified dispersion zones for rapid-settling effluent fractions (those settling at rates equal to or greater than 0.01 cm/sec) have been calculated.

Upon discharge into marine waters, the outfall plume, being negatively buoyant, rises from its typical discharge depth of 60 meters to an average height of about 30 meters from the bottom. As the outfall plume rises with a velocity on the order of 30 cm/sec, all but the most rapidly settling components will be carried to the wastefield elevation. For effluent particles settling at velocities equal to or greater than 0.01 cm/sec, the fall time from the 30-meter height is 83.3 hours. If the net movement of subthermocline currents is taken to be upcoast at 3 cm/sec (Hendricks 1977), then the alongshore dimension for the calculated dispersion zone is 9 km.

The onshore/offshore dimension of the zone has been calculated by taking the length of the diffuser section (in the case of a Y-shaped diffuser, this is the sum of the legs times the cosine of the complement of the included angle) as the initial width of the wastefield. This width increases with time due to diffusion at a rate equal to approximately 0.4 cm/sec (Hendricks, this report): In the 83.3-hour settling period, the width would increase to 1.2 km. The resulting trapezoid-shaped simplified dispersion areas calculated for Orange County, JWPCP, and Hyperion are 21.6, 19, and 27 sq km, respectively (the dispersion zone for the JWPCP 120-inch diameter pipe is assumed to include the dispersion zone for the smaller 90-inch diameter pipe).

The dispersion zone for the San Diego Point Loma out-fall was calculated from unpublished current measurement data obtained from Dr. T. Hendricks of the Project.

The data made it possible not only to calculate the horizontal extent of the zone but also to determine, by estimation of current probability, that fraction of particulate material with a given settling velocity that will land within the zone. The dispersion zone characteristics of particles with fall velocities of 0.1 and 0.01 cm/sec for the Point Loma outfall are shown in Table 1. The locations of the Point Loma dispersion zones for particles settling at rates >0.1 cm/sec and >0.01 cm/sec are shown in Figure 1. In general, the fallout zone for the 0.01 cm/sec fraction is a narrow, north-trending strip 21 km long and ranging from approximately 0.4 km to 1.0 km in width. The 0.1 cm/sec fallout zone is, of course, contained within the 0.01 cm/sec zone.

The fallout zones described here are predicted, not measured, a fact to keep in mind in attempting to correlate fallout zones with observed field measurements. Each zone is intended to serve as a guide to where the particulate material should fall, not as a description of where it has been found. Small deviations in magnitude and/or direction of mean current will broaden the dispersion zone accordingly and proportionally reduce the particle deposition per unit area of the bottom sediments. In addition, the plume rise height, which is essentially a function of the density structure of the receiving waters at the time of discharge, may vary considerably over periods as short as 1 day because of such phenomena as the passage of storms, the upwelling of cold waters from greater depths, or the diurnal heating of surface waters by the sun. Therefore, any detailed forecast of particle dispersion must also allow for some variation in the average wastefield elevation of 30 meters.

Settling Velocity Data and Particle Mass Flux

Settling velocity experiments were designed to provide data on the percentage of effluent particulate material that would settle in seawater at various settling velocities. Settling velocity curves for various dischargers and effluents are shown in Figure 2. The data are expressed as the percent of initial effluent particulate mass that settled vs. time. The percent of material that would settle at any specific settling velocity may be determined using Figure 2. First, divide the maximum cylinder fall height (35 cm) by the settling velocity to get settling time, then locate the settling time on the abscissa of Figure 2; the percent of material that would be expected to settle in that time can be read on the ordinate.

It should be noted that the settling velocity curves presented herein represent single experimental runs. Hence, any calculations based on these data should be taken as approximations only. Replicate settling velocity determinations for each effluent would, of course, add statistical validity to any differences observed in the settling characteristics of the various effluents studied.

The Point Loma dispersion zone is relatively well characterized by current data; thus, detailed calculations of particle mass flux (deposition rate per unit area) could be made. Approximately 20,700 metric tons of solids are discharged yearly from the Point Loma outfall (Schafer 1977). Settling velocity data for this plant's effluent (Figure 2) indicate that about 10 percent of this material, or 2,070 metric tons/year, will have a settling velocity equal to or greater than 0.01 cm/sec. The water current probability model for Point Loma developed by Dr. Hendricks predicts that 50 percent of this material, or 1,035 metric tons/year, will settle into the 9.0-sq-km dispersion zone shown in Figure 1; thus, the mass flux to this area is predicted to be 1,035/9.0 metric tons/sq km/year, or 115 grams/sq meter/ year.

The settling velocity data (Figure 2) also indicated that 2 percent (or 414 metric tons) of the solids discharged annually off Point Loma are particles with settling velocities equal to or greater than 0.1 cm/sec. According to Dr. Hendricks' current probability model, 70 percent of these particles will settle in the 2.1-sq-km dispersion zone shown on Figure 1. Thus, the mass flux of the 0.1 cm/sec particles has been estimated to be (0.70)(414)/2.1 metric tons/sq km/year, or 138 grams/sq meter/year. The 2.1-sq-km area will also receive a contribution from particles settling at 0.01 cm/sec. Assuming that this material is evenly distributed throughout its depositional area, the total mass flux in the smaller area will be the sum of the fluxes for the 0.01 and 0.1 cm/sec material, or 253 g/sq meter/year. It should be noted, however, that falling particles are not evenly distributed, and that individual fluxes are undoubtedly larger close to the outfall and smaller towards the flanks of the dispersion zone. There will also be a minor contribution from effluent particles that have fall velocities of less than 0.01 cm/sec.

<u>PLOP Experiment Data</u>

PLOP experiments were designed to provide data on the mass of specific trace metal and chlorinated hydrocarbon species that fall through seawater with the rapid-settling particulate fraction (SO.01 cm/sec). By combining PLOP data with the annual effluent mass emission rates and calculated particle dispersion data for a particular discharge site, it was possible to calculate the rate of deposition of various constituents to the bottom sediments in the area of the discharge. The resultant deposition rates of specific rapid settling trace metals and chlorinated hydrocarbons for various dischargers are listed in Table 2. The mass flux (deposition rate per unit area) for each substance may be determined by dividing the deposition rate by the appropriate calculated dispersion area, which is also listed in Table 2.

PLOP experiments were also conducted on present final, advanced primary, and secondary wastewaters obtained from JWPCP; the data are summarized in Table 3. The actual concentrations of rapid-settling (>0.01 cm/sec) chlorinated hydrocarbons and trace metals in each effluent are presented. Hence, the data allows for specific comparisons between treatment types with respect to the amount of rapid-settling constituents present in the resulting effluents. For ex-ample, the data shows that rapid-settling DDT and PCB concentrations are approximately 68 and 67 percent lower, respectively, in the proposed advanced primary effluent than in the final effluent. Secondary treatment results in an approximate 10 percent further decrease in rapid-settling DDT and PCB concentrations to levels that are 78 and 79 per-cent lower, respectively, than in the present final effluent. Similar observations may be made for rapid-settling trace metals concentrations, although the amount and direction of change between treatments varies from metal to metal.

The projected emissions for the rapid-settling sub-stances listed in Table 3 may be determined for each effluent type by multiplying the effluent concentrations of the substances by the projected flow for that effluent type. If any combination of effluents is proposed, then the final effluent concentrations for each substance must be obtained by adding the individual effluent contributions in proportion to their flows. This assumes, of course, that there are no interactions occurring between the effluent types when mixed that would alter the settling characteristics of the various constituents.

The values listed in Table 3 are valid for JWPCP pro-posed and present effluent types only--comparative data on similar effluent types from other dischargers must be obtained in each case under the same rigorous experimental conditions.

Fluorescent Particle Tracer Experiment

The experiment involving the release, with San Diego waste-water effluent, of fluorescent-labeled particles with settling characteristics similar to those of typical effluent particulates permitted us to follow the dispersion and deposition of these particles in the ocean. We know of no previous attempts to label and trace effluent particulates from southern California municipal waste outfalls.

Figure 3 shows the number and distribution of fluorescent particles that were recovered from sediment grab samples. Several important observation's arise from this data. First, the maximum numbers of labeled particles were found at stations close to the 60-meter isobath, which is the discharge depth for the outfall and is approximately co-incident with the predicted dispersion zone (Figure 1). Second, there was considerably more onshore/offshore movement of the particles than was predicted by the current probability model of Dr. Hendricks (Figure 1). Although particle occurrence is low, the presence of particles at moderate widths normal to the principal transport direction suggests that either significant sediment resuspension has occurred within a few days after discharge or the principal current direction has meandered around a central isobath tendency. The implication of this latter possibility is important to considerations of the effluent particulate mass flux to the sediments. Based on the fluorescent particle data, it seems that the dispersion zone during the time of release is perhaps several times wider than that theoretically calculated and that fluxes should be reduced proportionally. Deposition, however, is still concentrated in the middle of the zones, as evidenced by the higher numbers of fluorescent particles per sample there. Finally, the ob- served dispersion zone agrees well with measurements of sub-thermocline current direction and velocity made during the release of the labeled particles. Current meter measurements during the release show a constant upcoast direction with slight offshore tendency; current velocities were generally around 10 cm/sec but occasionally decreased in intensity. Note that there are no particles south (downcoast) from the outfall or directly offshore from the diffuser. In summary, the agreement between the calculated and observed dispersion zones is quite good. Analogous future experiments with a more uniform size range of labeled particles would permit the calculation of actual particle flux to the sediment. In addition, resampling of the sediments over time should show the extent to which resuspension processes are important in spreading particles over larger areas.

SUMMARY

The results of these studies show that, with relatively simple laboratory techniques:

- It is possible to accurately characterize the settling properties of effluent particles in seawater and, thus, predict the deposition rates of these particles in calculated outfall dispersion zones.
- PLOP experiments can be used to determine the individual amounts of specific chemical species that are present in rapid-settling effluent particles and, hence, predict the amount of each substance that would fall to the bottom in the vicinity of an ocean outfall.
- The settling characteristics of different effluent types in seawater may be compared, especially with respect to the sizes of their rapid-settling particulate fractions. These comparisons would aid in the analysis of the effects of various proposed and present wastewater treatments on particle deposition around outfall areas.
- The dispersion of rapid-settling effluent particles in the ocean may be followed with the use of fluorescent-labeled particles.

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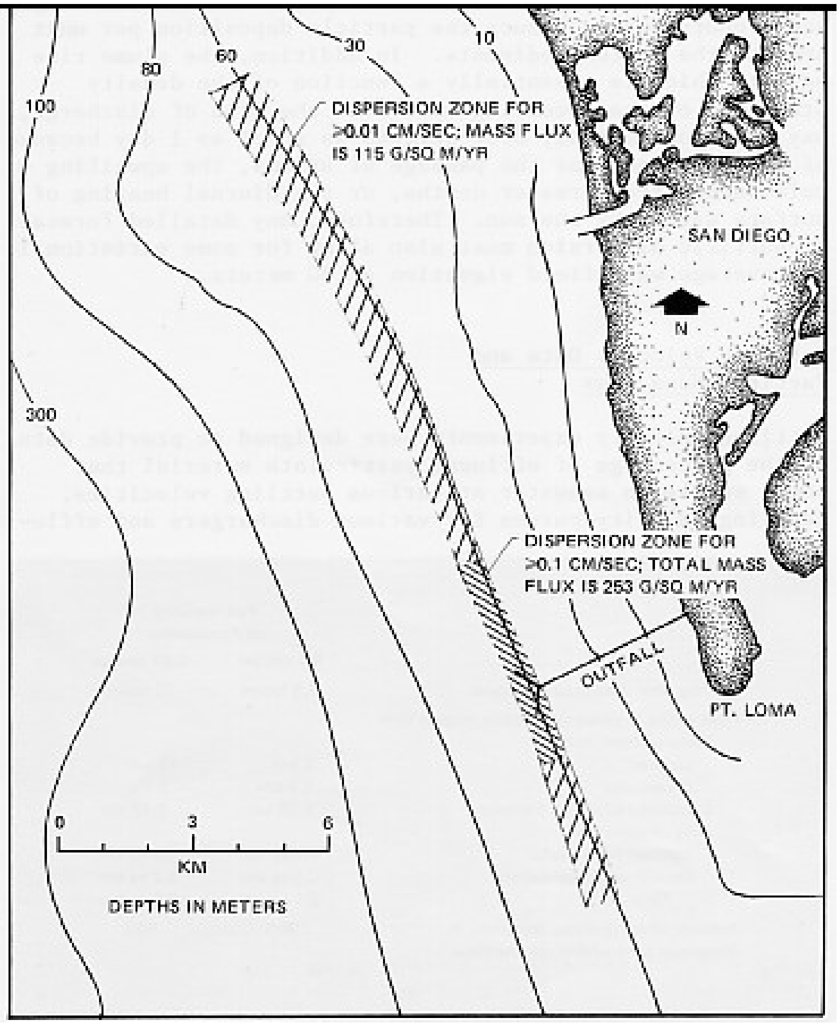
Figure 1. Point Loma dispersion zone locations and mass fluxes calculated for particles settling at velocities greater than or equal to 0.01 and 0.10 cm/sec.



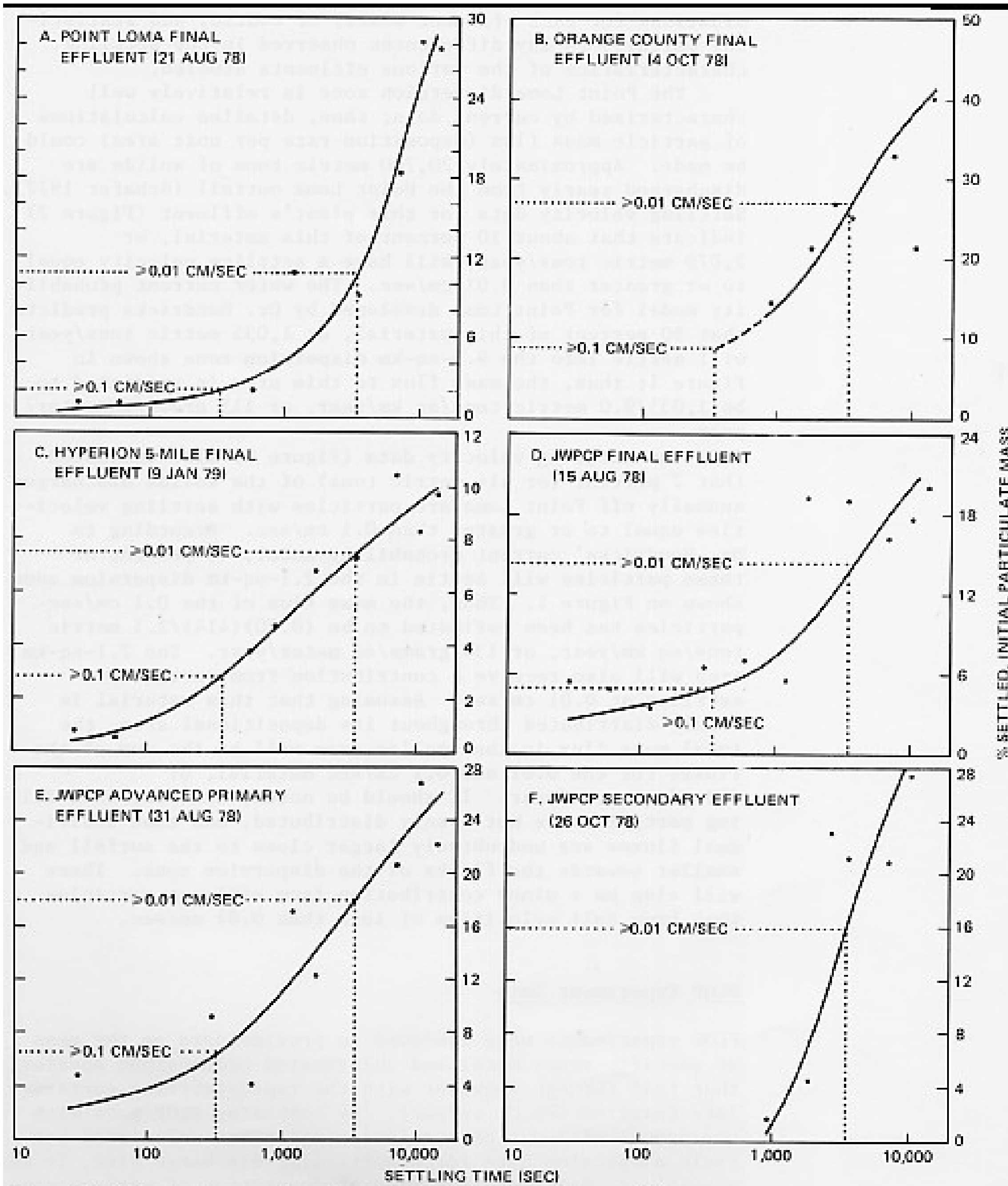


Figure 2. Settling velocity curves for various dischargers and effluent types. Each curve represents a single experimental run on a 24-hour, flow-proportioned composite effluent sample. The cylinder fall height for each experiment was 35 cm.

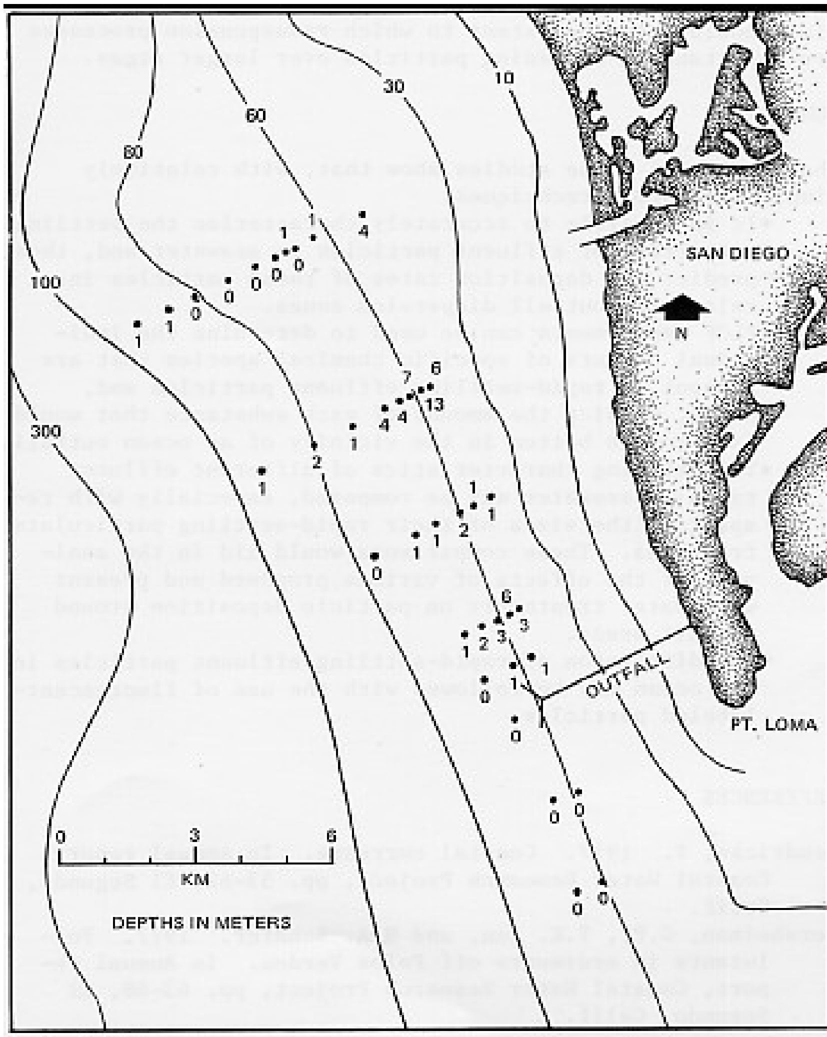


Figure 3. Fluorescent particle distribution near the Point Loma outfall.
The numbers represent the average number of particles detected per station sample.

	Fall Velocity of Particulates	
	0.1 cm/sec	0.01 cm/sec
Settling time used in calculations	7.5 hours	72 hours
Description of dispersion within settling time		
Distance from outfall		
Upcoast	3 km	16 km
Downcoast	1.5 km	5 km
Calculated width of dispersion	0.08 km	0.42 km
Area of dispersion		
Upcoast from outfall	1.4 sq km	6.8 sq km
Downcoast from outfall	0.7 sq km	2.2 sq km
Total	2.1 sq km	9.0 sq km
Amount of particulates deposited in dispersion zone within settling time	70%	50%

Table 1. Characteristics of calculated Point Loma outfall dispersion zone.

	Hyperion	JWPCP	Orange County	Point Loma
Annual flow (liters/yr × 10^{11})	4.96	4.88	2.51	1.62
Calculated dispersion area (sq km)	27.0	19.6	21.6	9.0
Chlorinated hydrocarbons (kg/yr)				
Total DDT	1.6	34	0.39	4.6
Total PCB	12	42	4.2	6.5
Trace metals (kg/yr)				
Silver	539	346	20	106
Cadmium	535	801	111	104
Chromium	4,820	14,640	462	927
Copper	6,070	5,900	772	1,590
Iron	64,000	273,000	15,900	5,180
Manganese	1,200	1,750	342	692
Nickel	1,470	3,660	261	437
Lead	2,650	4,980	309	903
Zinc	8,340	22,900	1,070	3,680

*Deposition rates were calculated using 1976 flow data (Schafer 1977) and data from single analyses of 24-hour composite samples of effluent; sampling was completed on the following dates: Hyperion, 11 Jan 79; JWPCP, 15 Aug 78; Orange County, 11 Aug 78; and Point Loma, 21 Aug 78. The mass flux (deposition rate/unit area) for each substance can be determined by dividing the deposition rate for the substance by the appropriate calculated dispersion area (second line on this table).

Table 2. Calculated deposition rates of chlorinated hydrocarbons and trace metals associated with the rapid-settling (≥0.01 cm/sec) fraction of effluents of four major southern California dischargers.*

	Final	Advanced Primary	Secondary
Chlorinated hydrocarbons (µg/liter)			
Total DDT	0.069	0.022	0.015
Total PCB	0.086**	0.028	0.018
Trace metals (µg/liter)			
Silver	0.71	0.97	0.33
Cadmium	1.64	1.49	0.21
Chromium	30.0	10.0	5.8
Copper	12.1	6.0	4.4
Iron	560	109	98
Manganese	3.60	1.88	2.14
Nickel	7.50	2.25	1.77
Lead	10.2	3.4	1.6
Zinc	47.0	35.5	19.0

*Projected emission rates may be determined by multiplying the effluent concentrations by the projected flow for that effluent type.

**Direct measurement was undeterminable; therefore, this value is based on average of the PCB/DDT ratios for the advanced primary and secondary effluents.

Table 3. Calculated concentrations of chlorinated hydrocarbons and trace metals associated with the rapid-settling (≥0.01 cm/sec) fraction of the various wastewaters of the JWPCP.*