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THE EFFECTS OF SLUDGE DISPOSAL IN SANTA MONICA BAY

This report contains a summary of scientific findings that relate to the effects of discharging sludge from the Hyperion Wastewater Treatment Plant via the "7 mile pipe" into Santa Monica Bay. Most of the data used here were obtained in 1978 and 1979, but the situation does not appear to have changed much during the previous 5 years and thus probably will not change greatly in the next few years regardless of what action is taken.

Nothing in this report should be construed as an argument for or against the continuation of sludge discharge. Hopefully the existence of well-documented measurements of the present physical, chemical, and biological situation will contribute to a rational decision. At least it will make it possible to compare the ecological advantages and disadvantages of the present site with those of alternative sludge disposal sites or methods.

The findings described in this report are generally similar to those in the "Interim Report on the Effects of Sludge in Santa Monica Bay"(Coastal Water Research Project· 1977). The differences result mainly from improved navigation (which permitted precise canyon mapping and sample loction), collection of more samples from more carefully distributed stations, improved biological techniques that permitted the examination of more samples and more qualitative descriptions. The composition of the material discharged from the outfall, the size of the area affected, and the number of animals in the discharge area are approximately the same, This description of the situation is simply more detailed and better documented than our previous reports.

SANTA MONICA BAY

Geography

Santa Monica Bay, immediately west of Los Angeles, extends over 40 km (27 miles) between headlands; its total area is about 500 sq km or 230 sq miles. The sea floor of much of the Bay is flat and muddy, but there are several areas of low-relief rocky outcrops. Two large submarine canyons are the most prominent hydrographic feature of the bay. The shoreline is composed mainly of sandy beaches, which are much used for recreation, especially in the summer when waves are low and water temperatures are high. The tide range is from 4 to 7 feet so that tidal currents are superimposed on the general coastal currents.

Several cities, including Santa Monica, Malibu, Marina del Rey, El Segundo, and Redondo Beach, ring the bay. Their inhabitants want the water quality to be maintained at a high level, especially within several kilometers of beaches where it is likely to be used by swimmers and fishermen.

Santa Monica Bay is part of the "open coastal waters" of southern California, but it is not immediately adjacent to the deep Pacific Ocean. Rather, it opens into a continental borderland, which is characterized by a series of alternating basins (with depths to 2000 meters) and mountain ranges that occasionally break the surface to form the channel islands. The distance from shore to the abrupt continental slope into deep water, which is called the Patton Escarpment, is about 240 km (150 miles). The very large open embayment between the escarpment and the shore and extending from Point Conception to Cabo Colnet is known as the Southern California Bight. Its area is about 100,000 sq km. Thus, Santa Monica Bay is part of this large Bight and receives some protection from north Pacific swell because it faces southwest and is partly in the lee of offshore islands.

In September 1957, after extensive design studies that paid particular attention to the effects of waste discharge on the adjacent water and sea life (by the standards and available information of the late 1950's), the 7-mile sludge outfall was put into operation. This small pipe (2 feet in diameter) extends 10 km offshore from the Hyperion Treatment Plant in El Segundo to a point near the head of Santa Monica submarine canyon, almost in the center of the bay where the water depth is 100 meters. The intention was to dispose of waste solids well offshore in this steep-sided trench in the sea bottom where they would create only minor problems and have a reasonable chance of being carried further offshore by currents so that organic buildup on the bottom would be minimal.

Redondo Canyon, about 15 km further south, is a similar but larger hydrographic feature. Because its head comes closer to shore, it traps much of the sand and natural organic material moving along the coast in the Redondo area. The offshore end on this canyon intercepts some of the excess organic material moving northward along the Palos Verdes peninsula from the Los Angeles County outfall.

The water quality in Santa Monica Bay as a whole is influenced by many factors, including two large wastewater outfalls (in addition to the sludge outfall): These are the Hyperion outfall, which discharges 5 miles offshore--only about 2 miles from the sludge discharge point, and the Los Angeles County outfall, which discharges about 8 miles southeast of Point Palos Verdes. Some of the latter's (greatly diluted) wastes are carried by currents into the southern end of the Bay. The Project's Annual Reports give details on the concentation and amounts of materials discharged by these two outfalls each year. The bay is also affected by discharges from power plants and an oil refinery as well as land washoff by rain storms, harbor discharges, aerial fallout, and the effects of many people using the beaches and small boats.

The position of the sludge particles on the bottom is largely controlled by the topography of the bottom and by the currents that flow in and above the canyon. Therefore, to understand why the effects observed are where they are, it was necessary to have an accurate chart of the canyon and the surrounding terrain. The official charts, made before the present electronic positioning methods and high-frequency echo sounders became available, were not satisfactory. We found it necessary to rechart the area using LORAN C for position and a 50-kHz echo sounder for depth. These devices were also used to confirm positions of all trawls and grabs. Therefore we have confidence that the samples were taken exactly where they are shown on our chart. In the past when sample positions were not so precisely known, it was not possible to make accurate comparisons of small differences or abruptly changing conditions. Now as a result of our new survey, the patterns of pollutants and of animal responses can be reexamined at appropriate intervals to determine if changes have occurred.

Oceanography

The southward-moving California current (the major current off our coast) flows well offshore, but some of its water turns toward the coast opposite the Mexican border to become part of a great counterclockwise eddy that mixes with warm waters moving up from the south. This mixture flows northward through the Bight and along the outer edge of Santa Monica Bay. The residence time of water (the average time that a particle of water stays in Santa Monica Bay) at the depth of the wastefield is believed to be about 1 month. For the mixed-layer waters of the Southern Calfornia Bight as a whole, the residence time is about 3 months.

The motion of the water over the relatively flat bottom of Santa Monica Bay is less consistent than along the relatively steep offshore slopes of the open coast, which tend to organize water motion. We have measured currents in the bay at various times by means of current meters, which continuously recorded for periods of 1 month at depths ranging from 40 to 384 meters in the canyon. Drogue measurements of surface and subsurface currents were made on several occasions. Temperature scans made by satellites were examined because the relative surface temperatures are often an indication of the circulation (Hendricks 1977). The currents in the bay often change direction and speed; sometimes there is one large gyre (rotational water motion), and sometimes there are two small gyres.

When there is an abrupt change in density caused by a layer of warmer water overlying a cooler layer, the zone of change is called a thermocline. The two layers of water often move in different directions. The water below the thermocline is most likely to be subject to regional currents; that above is often wind driven. When there are strong easterly winds (Santa Anas), the surface waters are blown offshore and replaced by cooler waters from beneath. This condition is called upwelling, and it is generally believed to be beneficial to sea life because the deeper waters contain nitrates and other nutrients.

The density of the water at various depths in the bay, which controls the height to which the waste plume from a pipe rises, depends not only on the water temperature but on its salinity. Both of these change with the season; Figure 6 shows the position of the outfall "plume", which consists of discharged waste diluted with seawater, in the usual condition and during the two most extreme cases yet measured. When the water is mixed by winds and waves, it is nearly the same density from the bottom to the surface. When this occurs, the plume rises higher and breaks the surface; under these conditions, the dilution increases to as much as 300 to 1. This condition rarely exists for more than 3 weeks at a time; it generally occurs in the winter months but not every year. The other extreme is a large difference in density between surface and bottom water; this is a "highly stratified" condition, which may or may not have an abrupt change in density at mid depth. During this condition the plume does not rise very far above the bottom, and there is less dilution (perhaps 100:1). Most of the year ocean density conditions allow the plume to rise to mid depth and the dilution is about 200:1.

Dr. Terry Hendricks has measured currents (1) on the shelf inshore of the outfall both at the bottom and 15 meters above the bottom, (2) at the depth of the shelf edge (80 meters) but over the canyon, (3) near the bottom of the canyon at two depths, and (4) on the slope away from the canyon. The records were of 2 to 5 weeks duration.

The strongest observed subsurface currents were found over the shelf inshore of the 7-mile outfall, where maximum speeds were about 35 cm/sec, and the median speed was about 10 cm/sec. The weakest currents were observed near the bottom on the shelf and deep (about 385 meters) in the canyon. Closer to the outfall, in 168 meters of water, the near-bottom currents in the canyon reached speeds as high as 45 cm/sec, but the median speed, at 8 cm/sec, was weaker than that on the shelf.

In all areas, the shape of the sea floor appears to play an important role in the direction of movement of the currents. Generally the principal direction of movement is approximately parallel to the local contours. The exception to this occurred in near-bottom waters on the flat shelf, where the primary motion was directed toward the head of the canyon. Water movements above the canyon at the depth of the adjacent shelf area are in some ways similar to both the shelf and the canyon currents; this is probably a transition region. The net movement 3 meters above the bottom in a depth of 168 meters of water in the canyon was up-canyon; in a different year, at 385 meters of water, it was down-canyon. We do not know whether this reversal is representative of a systematic flow within the canyon or simply indicative of long-term variability. On both occasions, the net speeds were 3 to 4 cm/sec.

Variability is often greater than mean motion, and it changes from area to area. Typical variations are likely to be 10 cm/sec over the shelf and in the shallow part of the canyon; 7 cm/sec in the deep canyon and over the slope; and 3 cm/sec near the bottom on the shelf. Over the shelf and on the slope most of the variations occur over periods longer than 1 day. Near the bottom at the deeper canyon station, the variation is predominately of tidal periodicity, but at the shallow canyon station it is largely composed of harmonics of the semidiurnal tidal period. These data support the hypothesis that canyons can "trap" internal waves and intensify the near-bottom currents up and down the canyon.

The levels of dissolved oxygen (DO) in the water near the outfall are of interest, because oxygen is available to sea animals only in this form. There has been concern in the past (especially in restricted inland waters) that wastes that require oxygen for chemical or biological reactions (COD or BOD) would use up the oxygen in the water that is needed by sea life. However, in Santa Monica Bay and elsewhere on this coast, the water usually contains far more oxygen than needed to support both the animals and the chemical reactions. The DO levels are about 8 to 9 parts per million near the surface and 4 to 5 ppm near the bottom. If the temperature is low, as it is on the deep slopes, the sea animals live well at 2 ppm DO; others live in the nearby basins where natural conditions produce only 1 ppm DO (Mearns and Word 1975).

In the canyon bottom where the percentage of volatile solids and the biochemical oxygen demand of the waste sediments is very high (up to 27,000 ppm), we find a 30% decrease in the biomass of the benthic animals. However, the presence of large numbers of fish in this area suggests that there is adequate oxygen in the near-bottom water for most animals in spite of the large BOD of the sediments.

The natural question that arises about any ecological data, including that generated by a detailed look at the area of the 7-mile sludge discharge, is: Relative to what? The answer is that three previous surveys were made specifically to establish a basis for ecologial comparisons. SCCWRP's <u>60 Meter Control Survey</u> of the southern California coast from Point Conception to the Mexican border established 29 stations at a depth of 60 meters that are believed to represent original pristine conditions. (Word and Mearns 1978). The following year, a 300-station survey of <u>Life in the Bottom</u> was made that extends from Point Dume to Dana Point for depths of 20 to 500 meters (Bascom 1978). More recently a survey of life in submarine canyons (referred to in Table 8) has been partially finished and will be reported in a subsequent paper by this author and others.

Ecological conclusions expressed in this paper were reached relative to these other data bases. "Normal" conditions are further defined and the combined data are presented by Bascom, Mearns, and Word (1978).

In all of these, we have relied on the Infaunal Trophic Index devised by Jack Word of our staff as a means of numerically describing the feeding habits of a community of small animals that live in muddy bottoms (Word 1978). This index uses 52 indicator species that are divided into four categories based on their feeding preferences. They obtain their food immediately above the bottom, on the bottom, just below the surface and deep in the bottom. The number of individuals in each of these four categories in any sample of mud is determined and the result used in a simple equation. The index number is high where the first group (water-column feeders) is dominant and low when most animals are in the last group (deep in the bottom). The result of this method is that it is possible to obtain consistent results that have a numerical value and can be used to chart variations in bottom conditions.

<u>Material Discharged and Where it Goes</u>

The average daily discharge from the 7-mile sludge line for the last few years in millions of gallons per day (MGD) is as follows:

1.2 MGD of screened, digested primary sludge
1.0 MGD of waste-activated anaerobically-digested secondary sludge
2.5 MGD of secondary effluent
4.7 MGD total

The average solids content over the last 8 years has been 8,900 mg/liter (parts per million), somewhat less than 1 percent by volume of the material discharged. Details of the average yearly concentrations and tonnages of possible pollutants are given in Tables 1 and 2. These are taken from our recent annual reports. Table 3 gives the concentrations of EPA Priority Pollutants in the 7-mile discharge for one day in July 1978. This is similar to the data in Table 1 except that it is for the volatile or extractable man-made organic materials in a single sample.

About 57,000 metric tons (dry weight) of solids with an approximate (wet) volume of 285,000 cu m is discharged each year. Over the 22 years of operation, a total of approximately 1,250,000 metric tons of solids or about 6

Table 1. Average concentration of constituents discharged through the 7-mile outfall (1971-1979) as measured by the Hyperion Treatment Plant laboratory (H. Schafer).

	1971	1972	1973	1974	1975*	1976	1977	1978	1979	Average
Flow (mgd)	5	4.6	4.8	4.7	4.3	4.1	4.6	4.6	4.8	4.6
mg/liter dry weight										
Total solids	7,900	8,600	8,500	8,400	*10,300	9,900	4,400	8,400	7,100	8,700
Oil and grease	760	636	922	900	970	697	608	511	400	710
Ammonic nitrogen	160			300		411	349	302	230	290
Total phosphorus	130			663	80	141	189	247	266	240
Cyanide (CN)		0.10	0.11	0.53	0.67	0.44	0.70	0.24	0.18	0.37
Phenols					0.029	0.61	0.58	0.46	0.53	0.41
Silver	0.03	0.29	0.8	0.4	0.8	0.86	1.88	0.69	0.70	0.72
Arsenic		0.03	0.27	0.18	0.29	0.28	0.26	0.24	0.22	0.22
Cadmium	0.23	0.42	0.98	1.28	1.17	1.31	1.30	1.25	0.80	0.96
Chromium	2.1	8.23	18.2	15.1	11.7	11.66	12.8	4.9	5.3	10.0
Copper	12.2	7.58	13.6	13.9	16.8	16.8	15.5	14.7	8.7	13.2
Mercury	0.1	0.125	1.4	0.15	0.108	0.098	0.131	0.059	0.062	0.25
Magnanese	1.6	0.67	0.37		0.19					
Nickel	2.6	2.04	3.7	3.1	3.1	3.6	4.1	5.3	3.4	3.4
Lead	0.51	1.8	1.57	1.13	2.05	1.65	2.14	5.99	4.89	2.42
Zinc	16.5	10.74	27.0	23.0	23.1	21.1	28.6	22.8	15.0	21.0
Selenium		0.25	0.45	0.4	0.27	1.16	1.68	0.69	0.05	0.63
μg/1										
DDT			4.03	2.59	6.49	6.78	1.40	2.72	0.9	3.7
PCB			25.4	3.30	15.3	34.8	20.3	31	10.8	20.4

*Digester cleaning in 1975 significantly but temporarily raised the average suspended solids.

million cu m of (wet) solid material have been discharged from this pipe.

Upon discharge, the momentum of the effluent flowing from the pipe carries it outward while its relative warmth and low salinity cause it to rise. As this jet of waste moves out over the canyon and the water deepens, diffusion and mixing with the surrounding water cause it to expand while currents modify the direction of the resulting plume. Dilution by a factor of 50 to 150 probably takes place in the first 200 meters. Note that the 7-mile outfall discharge point is not at the head of the canyon, which is nearly a kilometer farther north, but at a point along the canyon where the walls are much steeper (see Figures 1,2 and 3).

To determine where the discharged material goes, Project personnel directly sampled and measured bottom materials over a wide area. We also collected data for use in theoretical estimates by measuring the currents in the area and conducting settling- velocity experiments in the laboratory using effluent-seawater mixtures to determine how rapidly the particulates fall to the bottom. The latter measurements were used in a mathematical model to obtain a computer solution to the question of how much solid material would be deposited on a flat bottom at outfall depth.

Table 2. Material Discharged from the 7-Mile Outfall (H. Schafer).

	Number of Years Measured	Average Per Year for Last 8 Years	Approx. Total in 22 Years
		(Metric Tons Dry Wt)	
Total solids	22	56,700	1,250,000
Oil and grease	22	4,800	106,000
Ammonic nitrogen	5	1,930	42,000
Total phosphorus	6	1,530	34,000
Cyanide (CN)	7	2.5	55
Phenols	4	2.7	59
Silver	7	4.6	101
Arsenic	7	1.4	31
Cadmium	7	6.3	139
Chromium	7	67	1,470
Copper	7	88	1,940
Mercury	7	1.72	38
Manganese	4	4.2	92
Nickel	7	21.0	480
Lead	7	13.4	295
Zinc	7	138	3,040
Selenium	7	4.4	97
Chlorinated Hydrocarbons		(Kilograms)	
DDT*	7	25	550
PCB*	7	138	3,040

*Based on average after 1972

Because currents in the canyon often have a different speed and direction from those on the shelf, the theoretical fallout patterns for a flat bottom at 100 meters depth are not directly applicable. However, Figure 5, which shows the relation between actual and theoretical patterns, is instructive.

We have combined the measurements of volatile solids in the canyon area with our observations (TV, photos, cores) and experience to estimate the amount of sludge remaining near the discharge point. We believe the volume of excess volatile solids (above natural levels) is about 200,000 cu m of wet material or between 66,000 and 93,000 tons, dry weight. As shown in Figure 7, we plotted sludge depths and volatile solids measurements and worked out the volume within contour lines. The total volume is about equivalent to 10 ± 2 percent of all the solids discharged over the last 22 years. Presumably a larger percentage originally settled, much of which has since been consumed by the sea life in the canyon.

Table 3. Concentrations of EPA Priority Pollutants (mean ± standard error) in 24-hour composites of the 7-mile effluent collected July 1978 (D. Young). Note that none of the volatile organics have been found in sediments or marine animals.

Flow (liters/yr x 10^{11})	0.064	Extractable Organics (μg/liter)	
pH	7.3*	2-chlorophenol	8 ± 3
General Constituents (mg/liter)		4-nitrophenol	90 ± 80
Total suspended solids	12,000	Phenol	700 ± 60
Oil and grease	610*	Pentachlorophenol	<10
Ammonia nitrogen	280	Bis (2-ethylhexyl) phthalate	13 ± 8
Total (K) nitrogen	740	Miscellaneous	
BOD	4,700**	Asbestos (10^6/liter)	11,000 ± 0
COD	8,700**	Cyanide (μg/liter)	300
Fecal coliform (MPN/100 m1)	3.9×10^6	Phenol (mg/liter)	0.24
Volatile Organics (μg/liter)		Trace Metals (mg/liter)	
Benzene	<10	Antimony	0.23
1,1-dichloroethane	<10	Arsenic	0.26**
1,1,1-trichlorethane	<10	Beryllium	0.002
1,1,2-trichlorethane	<10	Cadmium	1.3*
Chloroform	<10	Chromium	12.8*
1,1-dichloroethylene	<10	Copper	15.5*
1,2-trans-dichloroethylene	145 ± 5	Mercury	0.13*
Ethylbenzene	16 ± 0	Manganese	0.80*
Methylene chloride	<10	Nickel	4.1*
Tetrachloroethylene	<10	Lead	2.2*
Toluene	30 ± 13	Selenium	0.069
Trichloroethylene	<10	Silver	1.9*
		Thallium	0.065
		Zinc	28*

*1977 average from treatment plant monitoring data.

**Sample collected 18 Jan 1972.

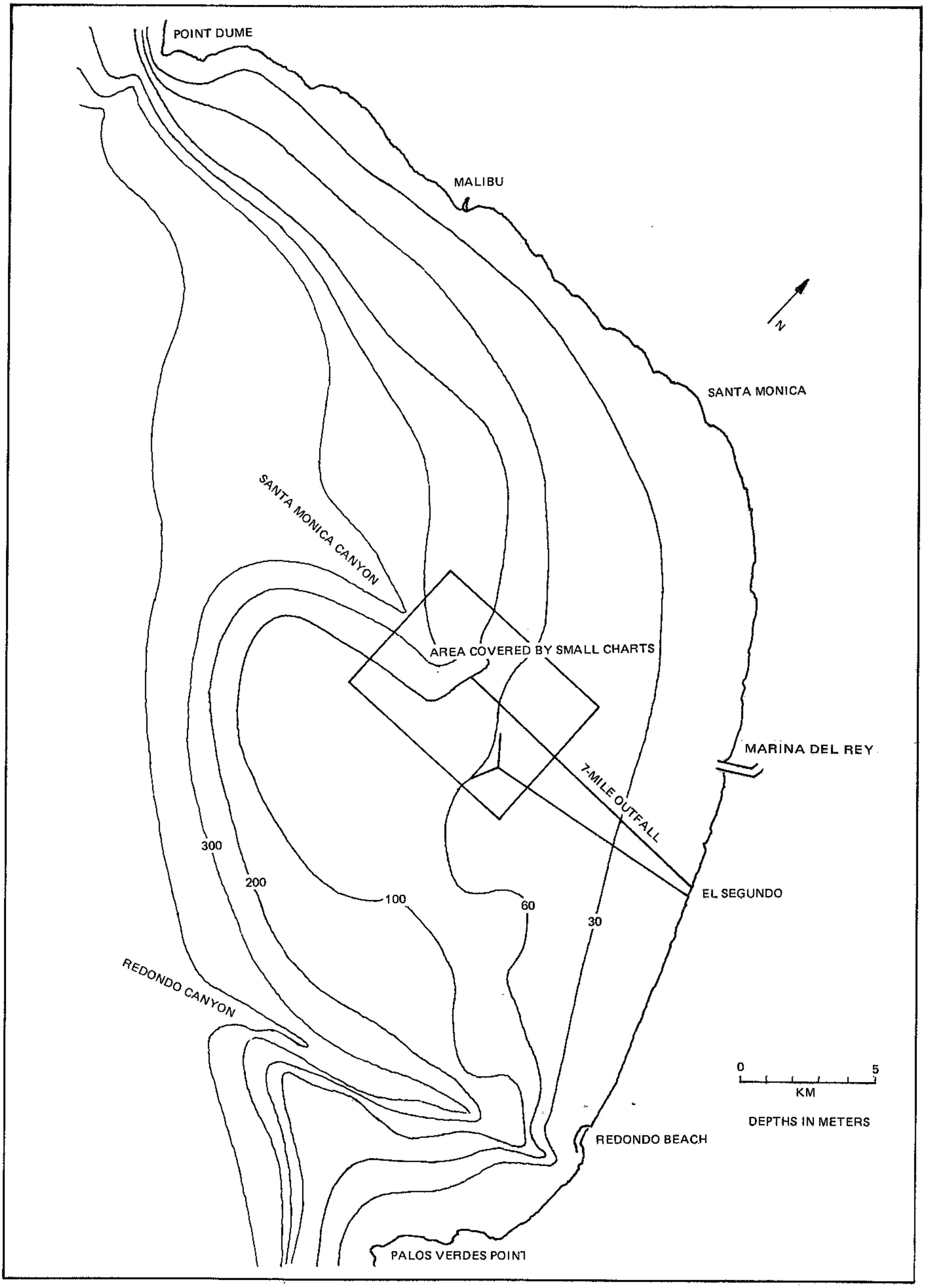


Figure 1. Santa Monica Bay.

Laboratory settling velocity measurements by Dr. Allan Abati were made by mixing the effluent with seawater at 1:500 and weighing the amounts that settled to the bottom of glass cylinders at increasing time intervals. As shown in Figure 4, one quarter of the solids settled (in the test) in 1/2 hour. This is equivalent to 2.5 days in the ocean for particles falling 40 meters (height of plume bottom above a theoretical flat surface).

Figure 5 shows that the predicted sediment field differs in several ways from the actual sediment field determined from survey data. Nevertheless, it is significant that the differences between the two patterns

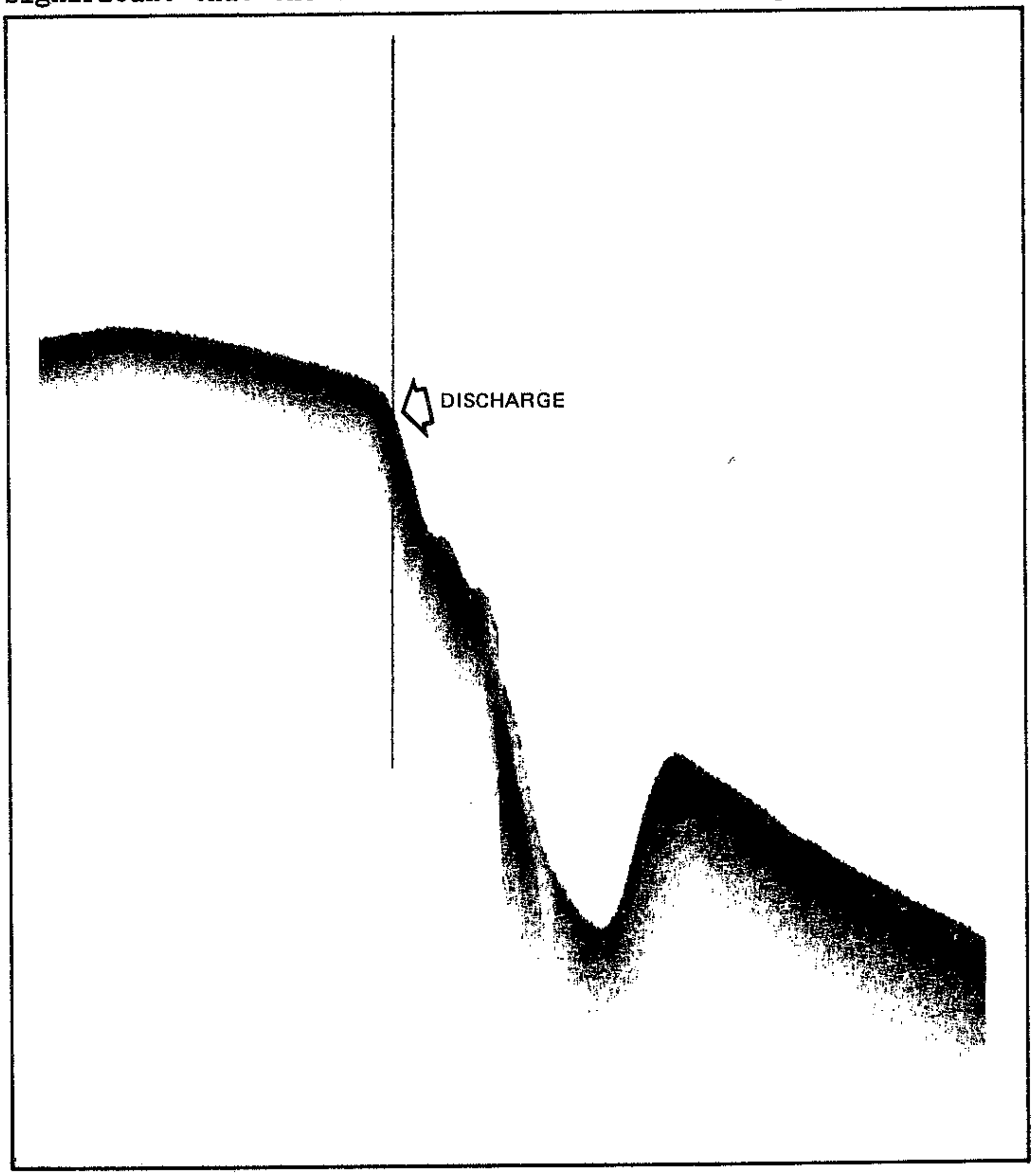


Figure 2. Echogram of the Santa Monica Submarine Canyon along the line of the 7-mile pipe, which comes from the left across the relatively flat shelf. Larger sludge particles fall into the deep canyon (H. Stubbs).

are qualitatively consistent with the observed properties of the currents in the outfall area.

For example:

1. The heaviest sedimentation is near the head of the canyon. This is consistent with the up-canyon movement of the near-bottom currents just below the outfall. These currents would carry particulates settling into the canyon toward the head of the canyon.
2. During periods of internal wave activity, the near-bottom currents in the inshore end of the canyon are sufficiently strong to resuspend particulates that have settled in the canyon. These particulates also would be carried toward the canyon head.
3. Low-density waste particulates deposited on the shelf inshore from the canyon are likely to be carried into the canyon during periods when water motion near the bottom is sufficiently strong to initiate resuspension.

All of these processes tend to modify the predicted depositional pattern so that the maximum buildup of effluent

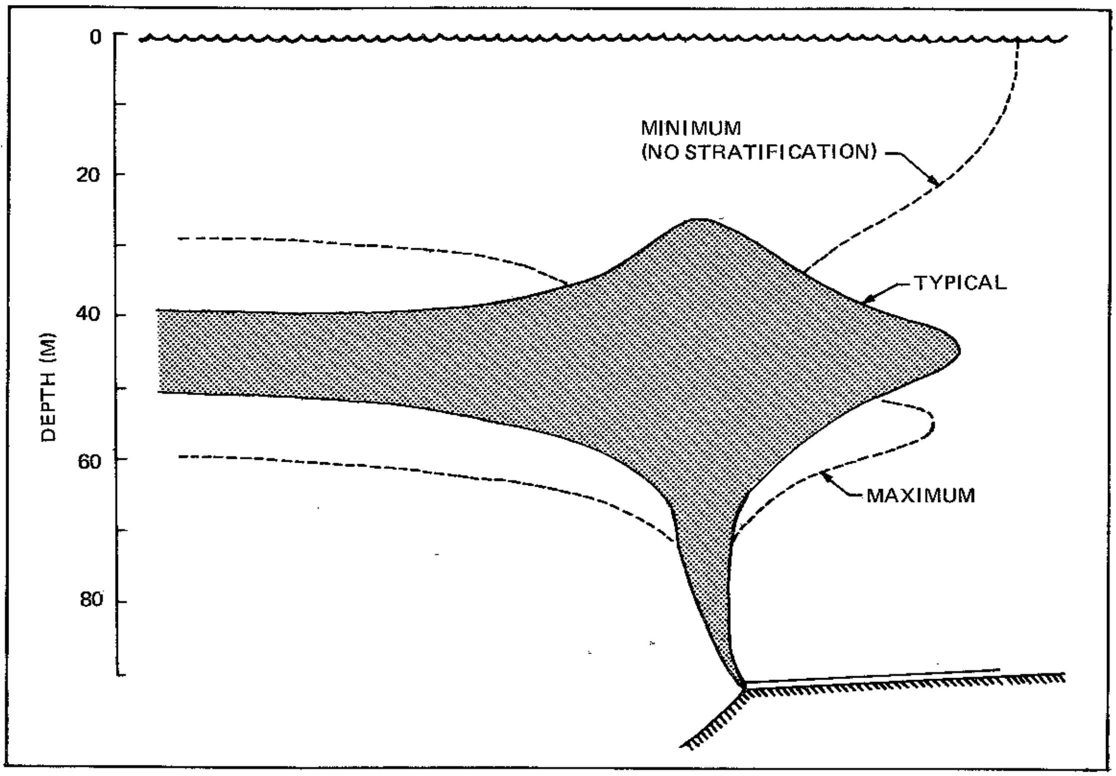


Figure 3. Schematic illustration of particulates settling from the wastefield produced by the 7-mile outfall during periods of typical stratification of the water column and weak offshore currents. The vertical position of the wastefield depends on the nature of this stratification; the two dashed lines indicate the boundaries for its extremes (T. Hendricks).

particulates will occur near the head of the canyon either by up-canyon movement of particulates in the canyon, or by the offshore movement of particulates on the shelf above.

This theoretical pattern worked out by Dr. Terry Hendricks indicates that 10% of the discharged solids fall within an oval area covering about 2 sq km around the outfall. If the currents on the shelf swept those particles into the deeper part of the canyon, the deposit would take on a shape closely approximating that of the 10% volatile solids isoline shown in Figure 5.

The bulk of the solid material discharged with the effluent is very fine particles (96% of the solids will pass through a 0.25 mm screen) of neutral density that neither sink nor float. These remain suspended in midwater for many days, and most are probably carried out to much deeper water offshore by the currents that flow along the edge of the shelf in a generally north westerly direction. Many are probably consumed by sea animals, but in any case they are very widely dispersed.

Particles larger than 1 mm are often of much greater density than the water. These represent about 1 percent of the solids discharged, and they are assumed to fall out immediately (Table 4). There is actually a pile of such material, which looks much like dark grass cuttings, directly in front of the discharge. On close inspection, this sludge material is seen to include watermelon and tomato seeds, plant fibers, and bits of leaves. In addition, there is a considerable number (but very small percentage by weight) of artifacts such as band-aids, cigarette filters, bits of aluminum foil, and small rubber or plastic objects. Particles between 0.25 and 1.0 mm in size make up about three percent of the solids discharged.

Table 4. Size distribution of sludge particles and approximate amounts of each size class settling to the bottom within the first 3 hours after discharge (or about 1 Km from discharge point) (H. Schafer).

	Effluent solids in 7-mile discharge		
Particle size	Percent of solids	Tonnage per year	Tonnage falling to bottom within 3 hours of discharge
Greater than 4 mm	.09	60	60
4-2 mm	.24	136	136
2-1 mm	.69	390	390
1-0.5 mm	1.80	1,020	1,020
0.5-0.25 mm	1.12	680	680
Smaller than 0.25 mm	96.00	54,400	2,760
		56,700	5,046

Most of these probably fall nearby and doubtless account for much of the sludge that remains in the canyon.

Other factors besides the 7-mile discharge also influence the amount of sludge in the canyon. For example, some small part of the solids released from the far larger 5-mile pipe have, at various times in the past (during equipment breakdown or floods), discharged settleable solids onto the shelf, some of which were swept by currents into the canyon. It is also likely that natural particles such as the fecal material of the large number of fish, which is indistinguishable from discharged particles, contribute substantially to the material in the upper canyon. A rough estimate of the amount of fish droppings in the canyon is 20 g/sq m/yr. The discharged sludge particles are mixed with these and other natural particles and churned by the bottom animals to form the very light and fluffy bottom deposit seen in the bottom television pictures.

It has also been suggested that occasional rapid slides of bottom material called turbidity currents, which have been observed in other submarine canyons, transport the detritus and sludge down the steep (10:1) slope into the basin below. We have found no clear evidence of turbidity

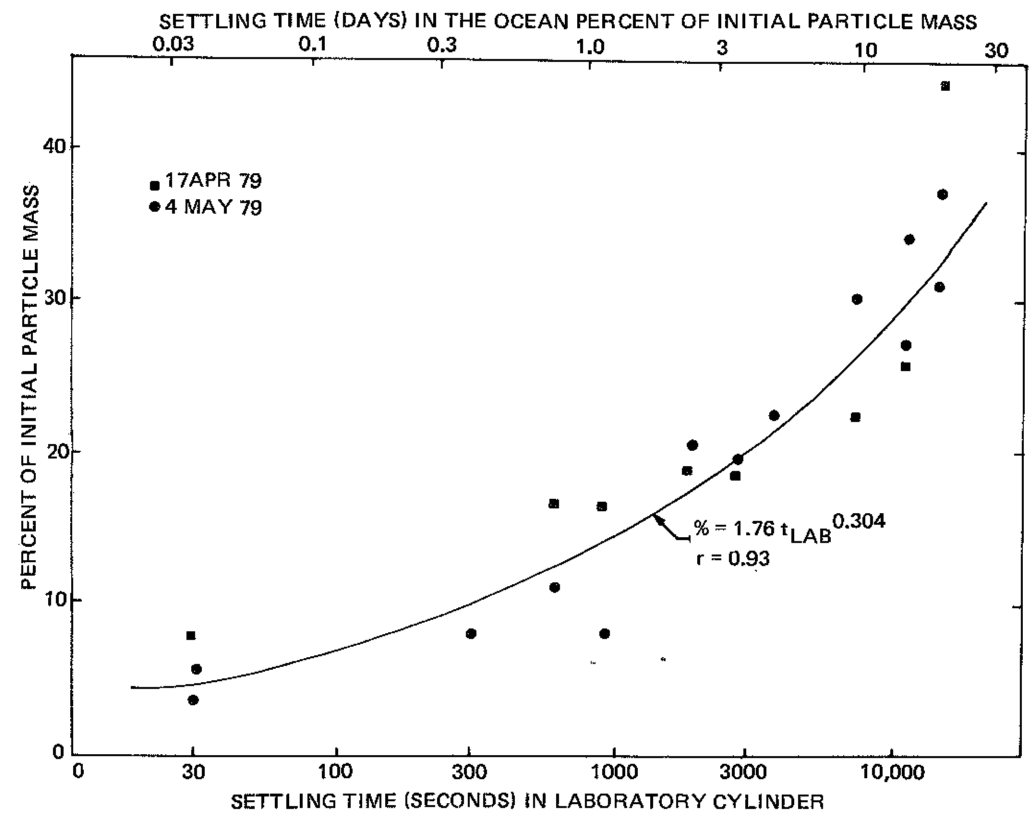


Figure 4. Settling time measurements, showing that about 5% of the solids fall to the bottom in the first hour, 20% in three days, and 30% in 2 weeks (A. Abati, T. Hendricks).

currents in Santa Monica Canyon, but these could be a factor in the amount of sludge present.

Life on and Near the Pipe

The 7-mile pipe ends in a sled-like steel structure that was used to tow the pipe into place when it was installed in

Table 5. Fish species and number of individuals of each species taken in 7-mile outfall trawls (A. Mearns).

	No. of Individuals					
	1976	1977	1978	1979F	1979W	Total
Depth (m)	128	183	152	149	124	
Tow time (minutes)	20	10	10	9	10	
Dover Sole	329	232	597	120	177	1455
White Croaker	312	96		1	9	418
Slender Sole		49	177	108	58	392
Pacific Sanddab	28	96	18	11	179	332
Pink Sea Perch	195	4				199
Long Spine Combfish	182	2				184
Speckled Sanddab	93	8				101
Stripetail Rockfish	35	3	3		31	72
Splitnose Rockfish			26	24		50
Shiner Perch	38					38
Plainfin Midshipman	16	1		1	12	30
English Sole	5	13		1	7	26
Rex Sole			20			20
Green Blotched Rockfish	5	4			5	14
Shortbelly Rockfish	2	11				13
Ratfish	13					13
Green Spotted Rockfish			1		11	12
Spotted Cuskeel	3	3	4	1	1	12
Blackbelly Eelpout		1	10			11
Shortspine Combfish	3	1			6	10
Sablefish			7	1	1	9
Pacific Electric Ray	8				1	9
Greenstriped Rockfish					4	4
Curlfin Sole	4					4
Hornyhead Turbot	3					3
Blacktip Poacher			3			3
Cow Rockfish	1	1			1	3
Bocaccia		1			1	2
Hundredfathom Codling					2	2
Pigmy Poacher					2	2
Spiny Dogfish			1	1		2
Longfin Sanddab			2			2
Gulf Sanddab	1		1			2
Bigmouth Sole	1					1
California Tonguefish	1					1
Squarespot Rockfish		1				1
Calico Rockfish		1				1
Halfbanded Rockfish		1				1
Shortspine Thornyhead				1		1
Lizardfish	1					1
Smooth Stargazer					1	1
Total 41 species	1279	529	871	269	509	3457

1957. (Full use for sludge began in 1959). The depth at that point is about 100 meters, and the echo sounder profile (Figure 2) shows that this sled is a little below the flat bay bottom near the inner rim of the canyon. A few years ago, James Allen of our staff analyzed 57 photographs of the last few hundred meters of pipe and the terminal structure, taken by Harry Pecorelli of Aqua-Contractors and Oceanographers, Inc., to make the summary shown in Table 7 and the sketch of Figure 8 (Allen et al. 1976).

The pipe offers a hard substrate, and sea animals that usually live on rocky bottoms are present there in substantial numbers. The sea anemone *Metridium senile* almost covers the terminal structure. The starfishes, *Astropectin verrilli* and *Luidia foliolata*, are very common

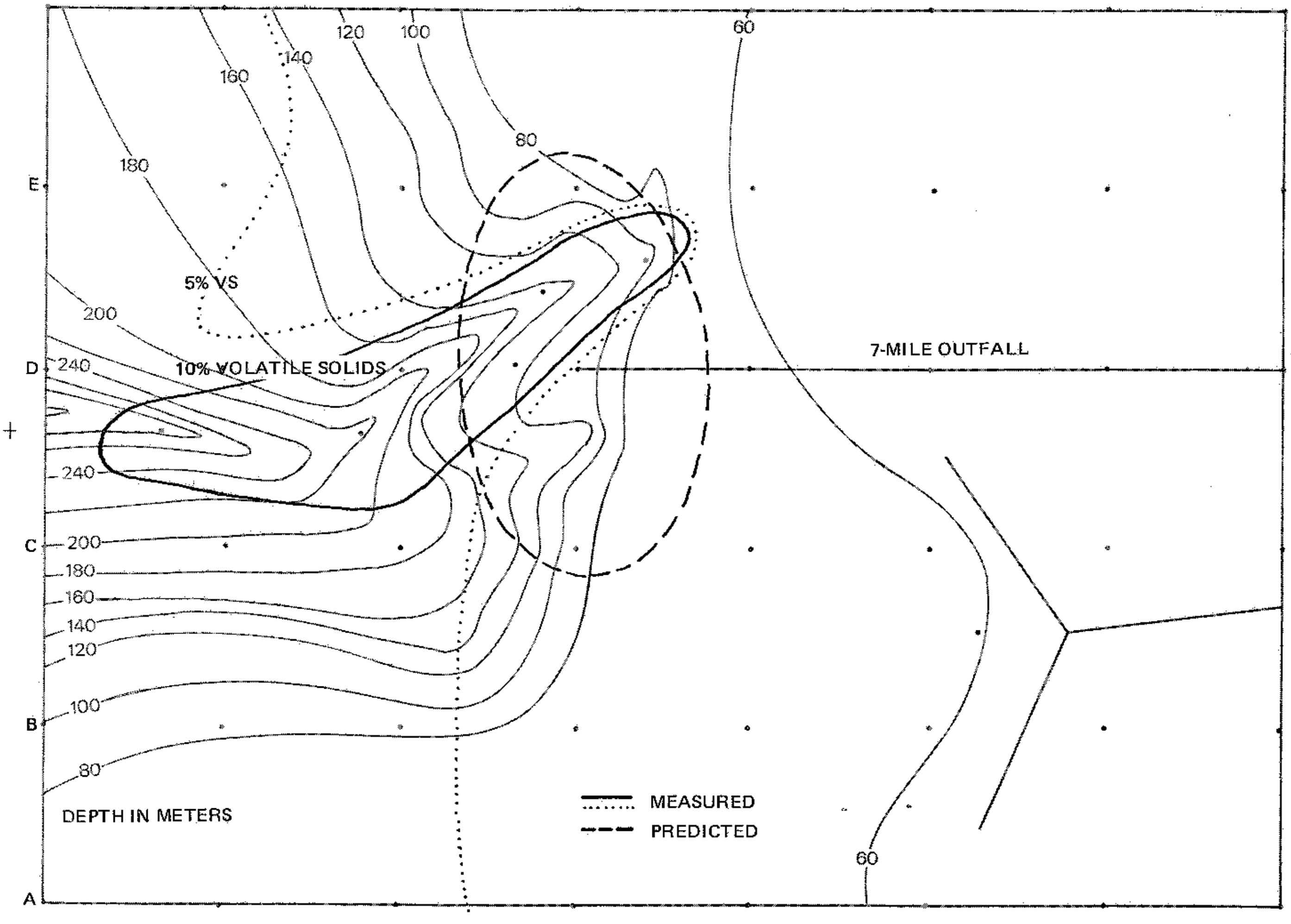


Figure 5. Relationship between the theoretical pattern predicted by Hendricks if 10% of the solids discharged fell on a plane surface the depth of the shelf edge (80 m) in the measured current field and the area in which total volatile solids exceed 10%. Currents on the shelf are believed to sweep the particles into the canyon (T. Hendricks, W. Bascom).

on the surrounding soft bottom (especially on the north side of the pipe). The gastropods, *Kelletia kellite*, *Megasercula carpenteriana*, and *Terebra* sp., were also common on the soft bottom nearby.

The larger rockfish utilize the pipe as a point of reference for schooling; schools of bocaccio (*Sebastes paucispinis*) and vermillion rockfish (*Sebastes miniatus*) are common near the end, and individual bocaccio have been seen cruising along the pipe. Schools of the smaller shortbelly rockfish (*Sebastes jordani*) were also frequently observed above the pipe. Individual cow rockfish (*Sebastes levis*) occurred near the *Metridium*, and Dover sole (*Microstomus pacificus*) were noted on the soft bottom and on the pipe, particularly near the region where it is buried.

The bottom in the vicinity of the 7-mile discharge and at the head of Santa Monica Canyon was examined by towing a

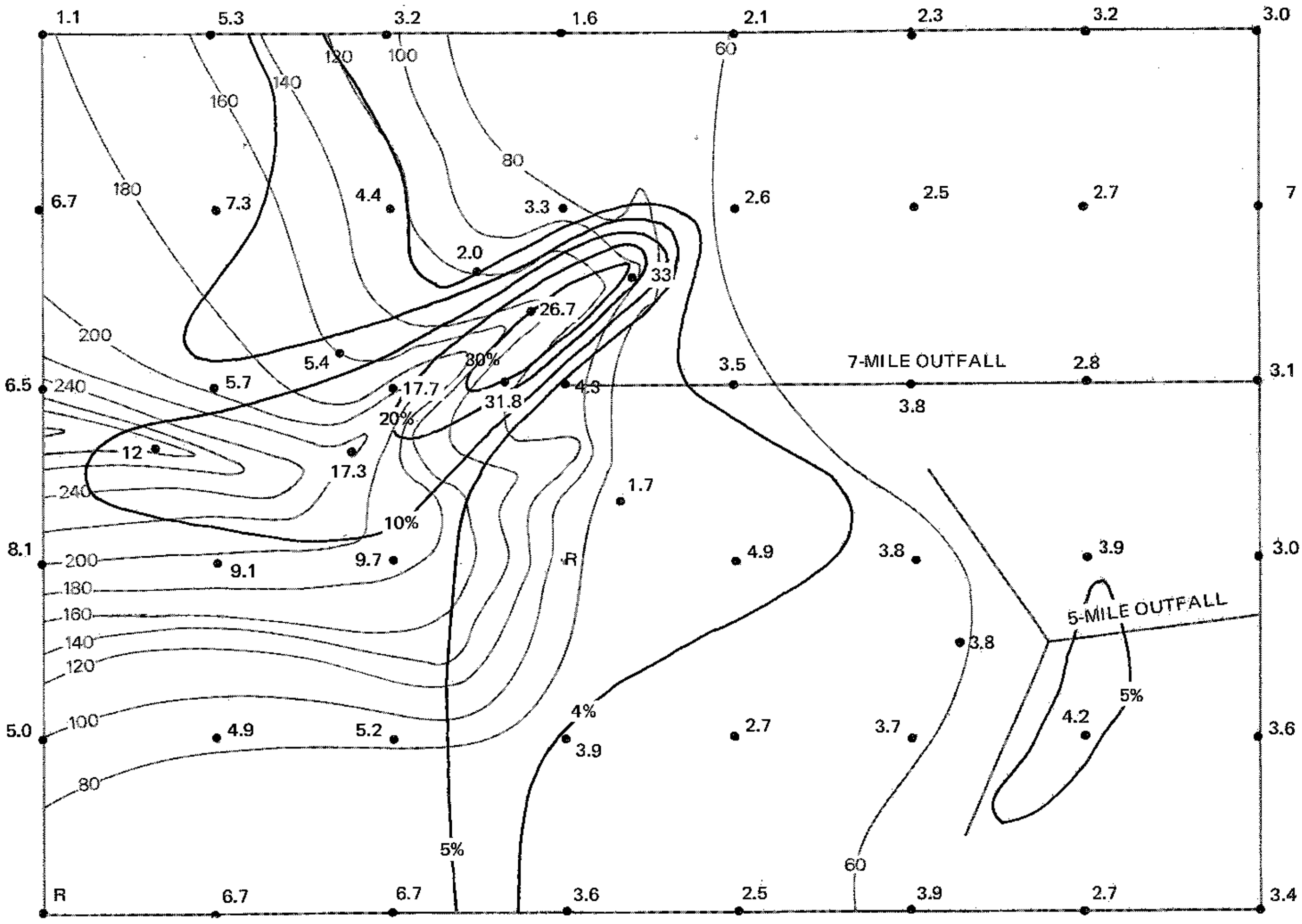
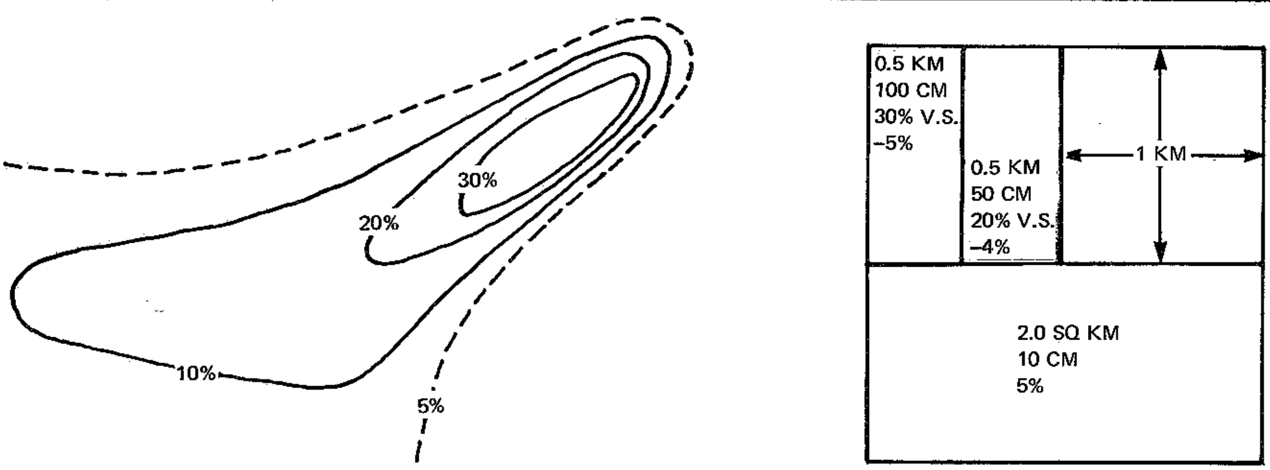


Figure 6. Volatile solids in sediment (H. Schafer, W. Bascom).

television camera along the bottom. Sediments were generally firm on the shelf inshore of the canyon, becoming softer along the pipe and very soft within the canyon where the television sled sank to a depth of a least 0.6 meter in material directly in front of the discharge point that seemed to be largely sludge particulates. Bottom materials in the upper part of the canyon consisted of large particulates that, when disturbed, were suspended briefly before settling; water with a refractive index different from the surroundings was observed near the water-sediment interface when the bottom was disturbed.

The water was moderately clear away from the pipe and either very clear or very turbid immdiately above the sludge field. Sea pens (*Virgularidae*) and sand stars (*Astropectin verrili*), which were common but not abundant on the flat



100 CM x 1000 M x 500 M = 500,000 CU M
25% SLUDGE = 125,000 CU M
ADJUSTED FOR DENSITY =
35,000–45,000 METRIC TONS

50 CM x 1000 M x 500 M = 250,000 CU M
16% SLUDGE = 40,000 CU M
15,000–23,000 METRIC TONS

10 CM x 1000 M x 2000 M = 200,000 CU M
8% SLUDGE = 16,000 CU M
11,000–15,000 METRIC TONS

5 CM x 1000 M x 5000 M = 250,000 CU M
2% SLUDGE = 5,000 CU M
5,000–10,000 METRIC TONS

TOTAL = 186,000 CU M (66,000 TO 93,000 METRIC TONS)
OR 8.8 TO 12.5% OF ALL SOLIDS DISCHARGED

Figure 7. Calculation based on measurements and estimates of the amount of excess volatile solids (sludge) now in Santa Monica Canyon. It is about 10% ± 2% of the total discharged over 22 years (W. Bascom).

above the canyon, were not observed in the sludge fields. Fishes were more abundant in the sludge field than inshore of the canyon (0.42/sq m vs 0.05/sq m); dominant species in the sludge field were white croaker (*Genyonemus lineatus*) and shiner perch (*Cymatogaster aggregata*) with densities of 0.18 and 0.06/sq m, respectively. Dominant species outside the sludge field were longspine comfish (*Zaniolepis latipinnis*), pink sea perch (*Zalembius rosaceus*) and sanddabs (*Citharichthys* sp.) with densities of 0.02, 0.01, and 0.01/sq m , respectively. Pacific electric rays (*Torpedo californica*) occurrred in high densities (0.04/sq m) in the sludge field, presumably feeding on schooling fishes. Schools of northern anchovy (*Engraulis mordax*) were observed in the canyon area near the bottom. Both white croaker and shiner perch were observed picking at the bottom, presumably obtaining food. The fact that the water in the canyon above the sludge was clear enough for effective use of bottom television in counting fishes is an indication of water conditions.

Life in the Bottom

The project's 1978 Annual Report contained charts of the central southern California coastal waters, including Santa

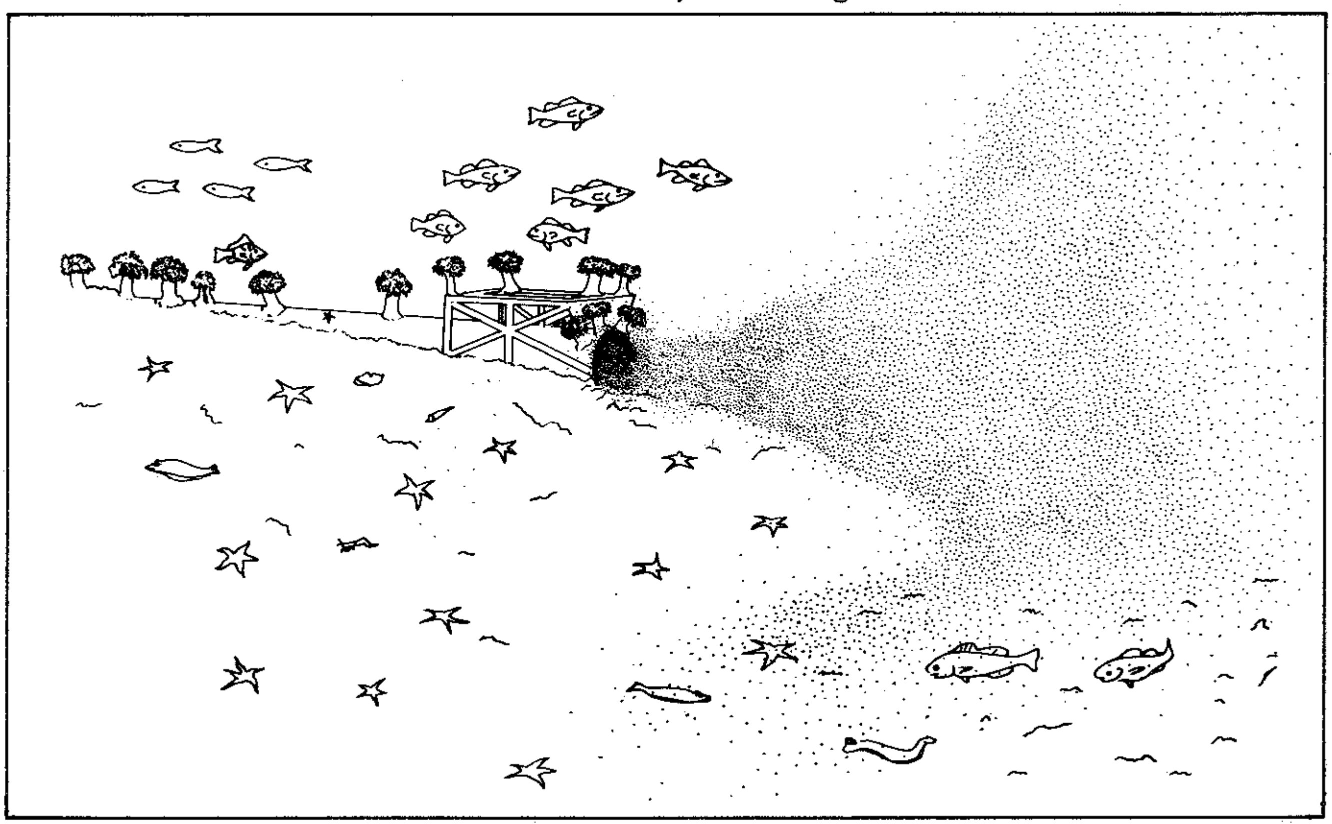


Figure 8. A biologists concept of the 7-mile discharge (M.J. Allen).

Monica Bay and canyon, showing Infaunal Trophic Index distribution and biomass of benthic invertebrates (Bascom 1978). Some of these charts are presented here with changes resulting from new data. Where the original 1-km grid points put us on a rocky bottom, we previously reported NA for "not applicable", since the index was intended only for soft bottom dwellers. Recently we have added five new stations (54 through 58) by taking grab samples of the soft bottom nearest to the grid point. This changes the isolines so that they more realistically represent the situation.

The Infaunal Trophic Index, previously mentioned, which numerically rates community structure of the benthic infauna on a scale of 0 to 100, is the most useful indicator of the bottom. An ITI of 60 usually represents the lowest "normal" level and 30 to 60 is the region of change (Bascom et al. 1978). Infaunal index numbers below 30 indicate very substantial changes in benthic animal communities. Figures 9 and 10 show that, in the upper part of the canyon, the

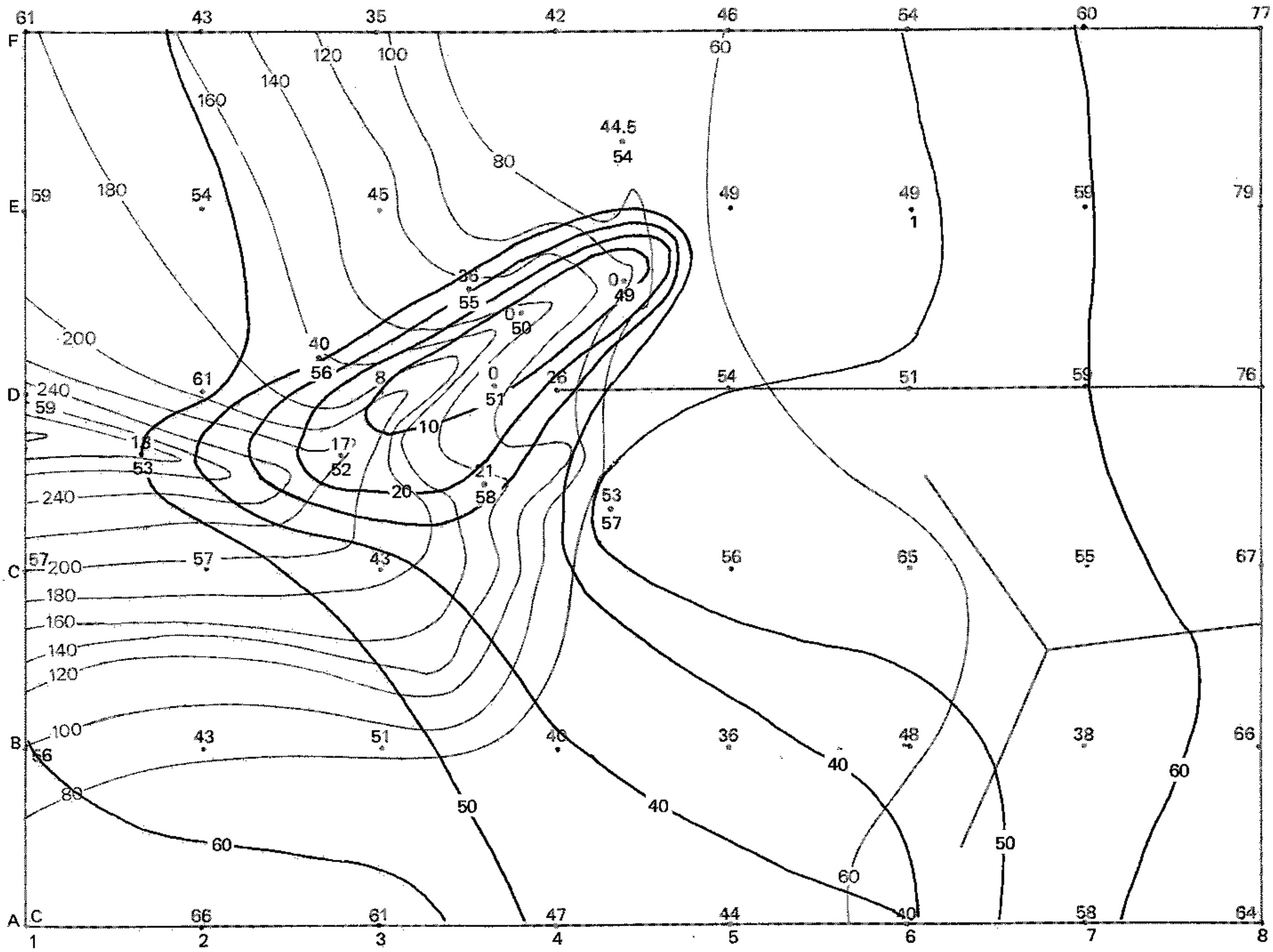


Figure 9. Infaunal Trophic Index in the region of the outfall, showing that the greatly depressed area is confined to the canyon (J. Word, J. Roney).

number of species is greatly reduced (perhaps as few as ten); Infaunal Trophic Index is often zero.

The bottom animals in the 0 to 30 area are largely those of Groups III and IV, which live and feed in the soft mud. These include polychaete and dorvellid worms, two Group III molluscs (*Parvalucina tenuisculpta* and *Macoma carlotensis*), and a Group II mollusc (*Axinopsida serricata*), which usually feeds in the water column. There are about 15 to 20 species present when the Infaunal Trophic Index is 30, as it is along the edge of the inner canyon.

The number of individuals present and the biomass in most of these canyon stations is about double the number at control stations. This ecological result is often seen when

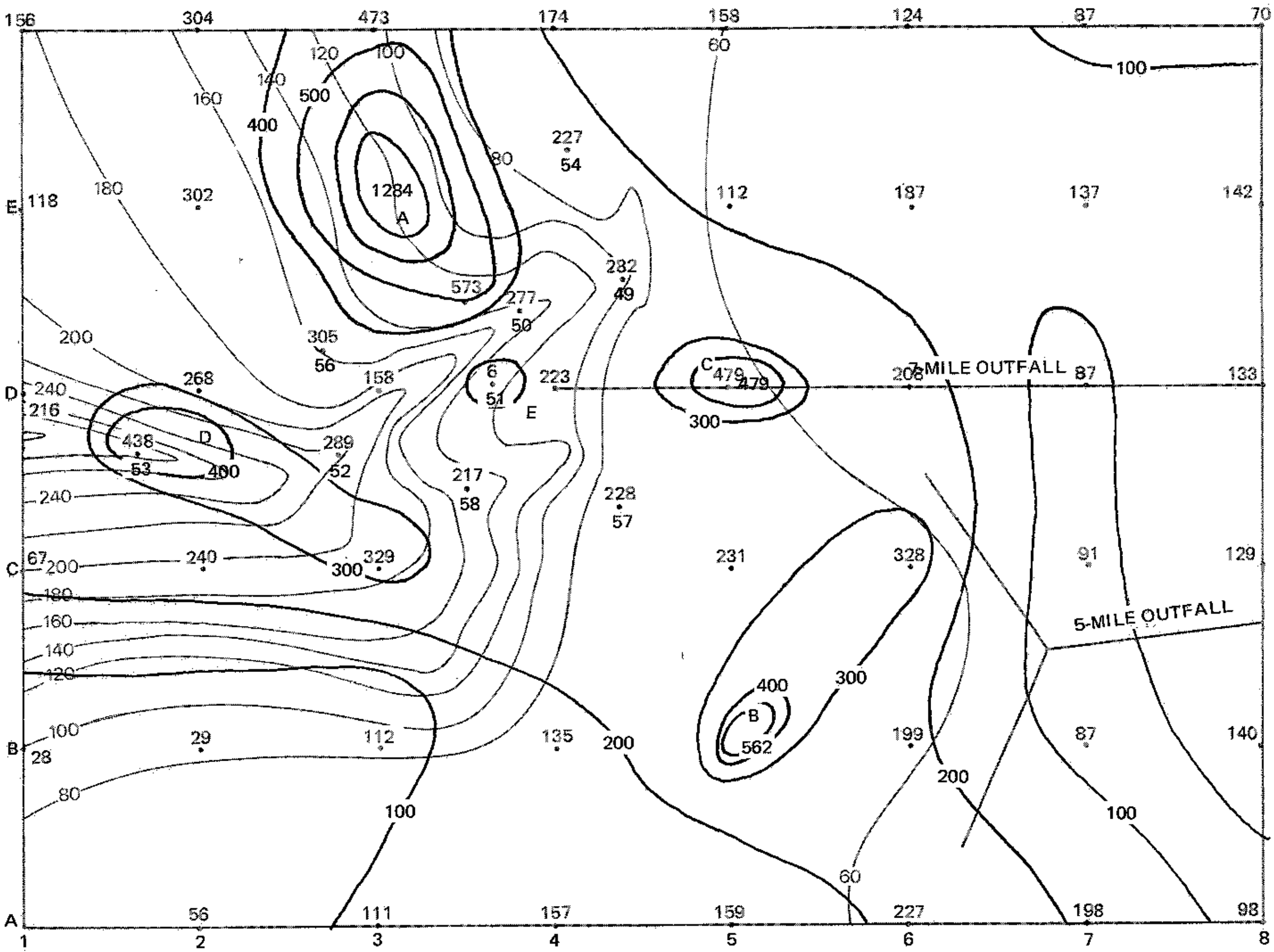


Figure 10. Infaunal biomass in grams per square meter, showing the great increases (above the norm of 70) caused by outfall effects. Dominant animals in areas of enhancement are: (A) echiuroid, *Listriolobus;* clam *Parvalucina;* (B) mollusks, *Bittium, Parvalucina; Listriolobus;* (C) polychaete worms and *Listriolobus;* (D) echinoderm *Brisaster;* clam *Parvalucina.* (E) is small area of depressed biomass (J. Word, J. Roney, W. Bascom).

there is a large specific food supply. The number of species is reduced to the few who can utilize the food; those grow and reproduce exeedingly well.

Life on the Bottom

Trawls and observations made repeatedly in Santa Monica Canyon immediately in front of the sludge discharge show that there is an abundance of fish and invertebrate life above the sludge. Our problem was to find ecologically equivalent control areas with which we could compare the data. In that endeavor, we have only been partly successful because Santa Monica Canyon is unique; it begins well offshore and its bottom has few rocks. Other canyons, such as that at Point Dume, come much closer to shore and are generally too rocky to trawl. For comparison, we have used data from equivalent depths in Redondo Canyon, San Pedro Sea Valley, and off Coal Oil Point and Point Conception.

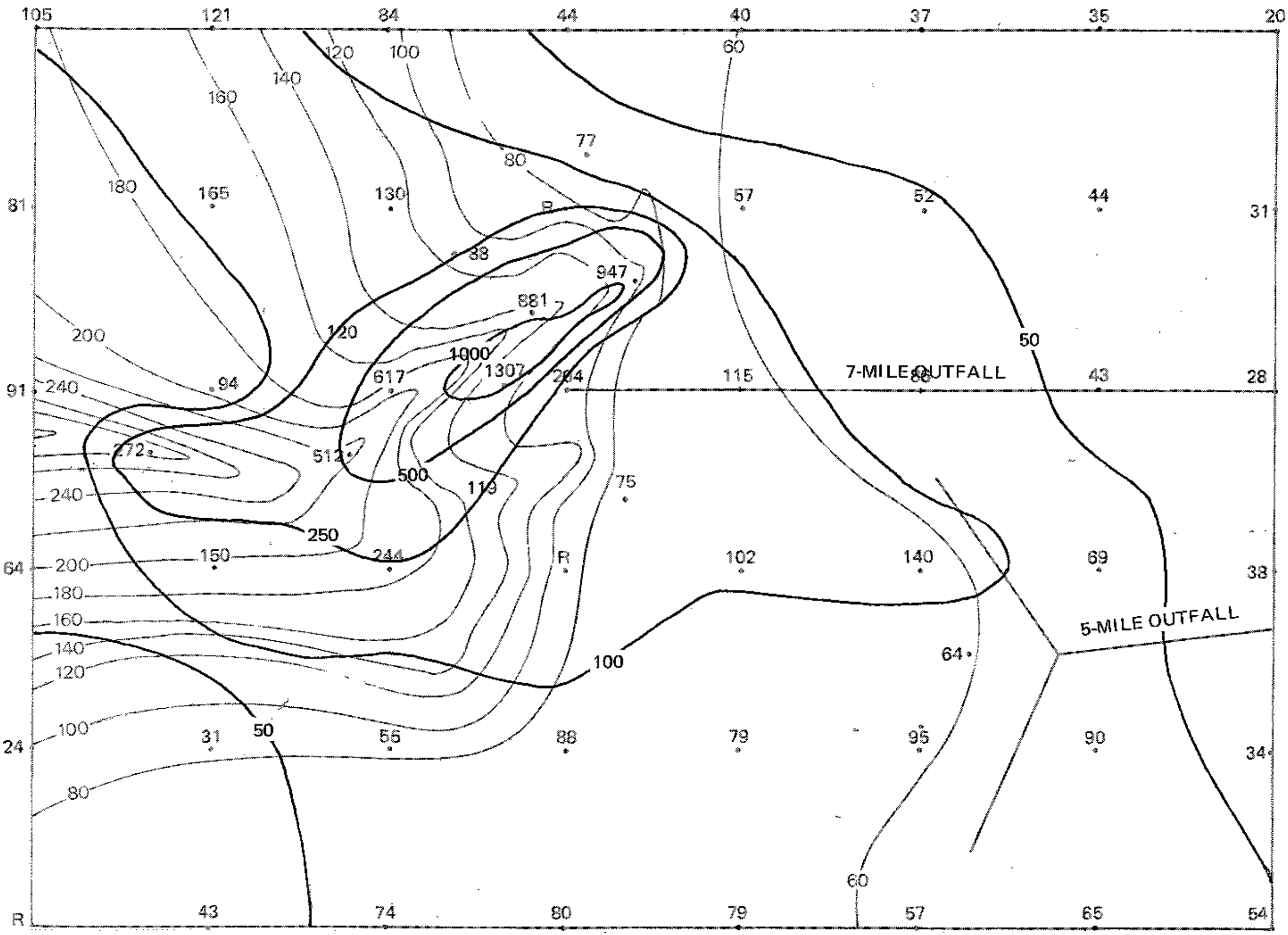


Figure 11. Copper in the upper 2 cm of sediments in ppm, dry weight (P. Hershelman, T.K. Jan).

During the period from 1976 through 1979, five trawls were made in the canyon sludge area at depths ranging from 124 to 183 meters. As can be seen on Table 8, there are more species of fish (17.4), more biomass (40.7 kg), and larger individual fish (59 grams) in the sludge area than at the stations chosen for comparison. There is an even greater excess over the average numbers found in our 60-meter control survey, where the average was 14 species of fish and 347 individuals per trawl.

The invertebrates are not quite comparable because the two trawls to the west were twice the duration and brought up rocks and kelp drifters on which many tiny invertebrates were found that would not ordinarily be taken or counted in a routine trawl in a canyon. However, the average number of species of invertebrates taken in Santa Monica Canyon is more than the 11 found on the 60-meter control survey; the number of individuals (734) compares with 455 in the control survey (Table 6).

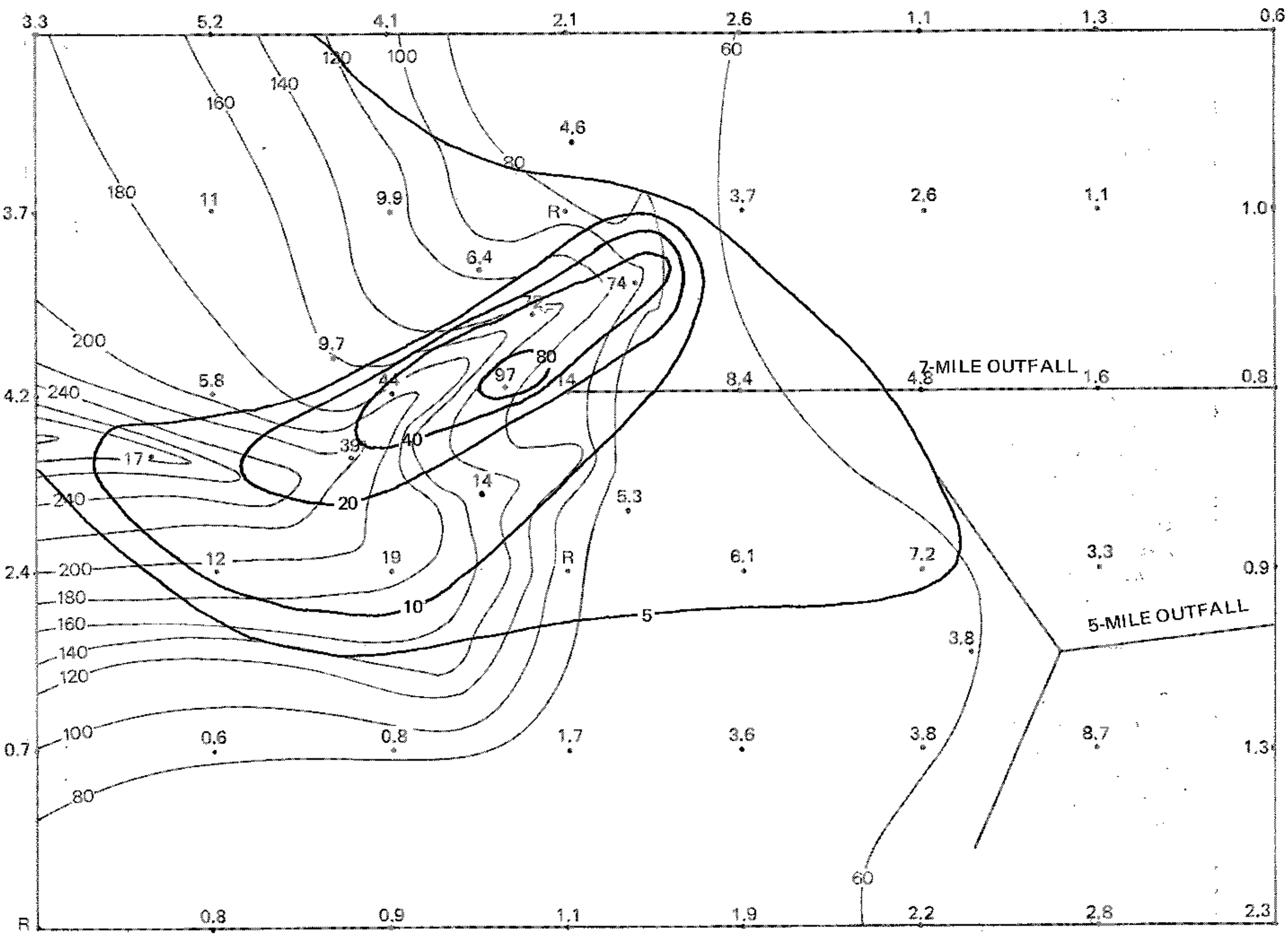


Figure 12. Cadmium in the upper 2 cm of sediments in ppm, dry weight (P. Hershelman, T.K. Jan).

Overall, a total of 41 species of fish and 40 species of macroinvertebrates have been captured by trawl at the sludge outfall (Table 5). Catches are dominated by Dover sole (*Microstomus pacificus*), white croaker (*Genyonemus lineatus*), slender sole (*Lyopsetta exilis*), Pacific sanddab (*Citharichthys sordidus*), the star *Astropectin verrilli*, the prawn *Sycionia ingentis* and sea pens (*Acenthoptillum* sp.).

Table 6. Invertebrate species taken in 7-mile outfall trawls (A. Mearns).

	No. of Individuals					
	1976	1977	1978	1979F	79W	Total
Depth (m)	128	183	152	146		
Tow time (minutes)	20	10	10	9		
Astropecten verrilli	718	1188			140	2046
Sicyonia ingentis	340	5	105	13	21	484
Acanthoptilum sp.*		300-500		P	P	400+
Simnia sp.*	50-100	13			2	~90+
Solemya sp.	80					80
Seapen UI*	50-100					~75
Pandalus platyceros	1		63			64
*Crangon alaskensis**	~50	1				~51
Pandalus jordani			44			44
Metridium senile	2	4	33		3	42
*Listriolobus pelodes**	1-10	31				~38
Allocentrotus fragilis		1	10		24	35
Armina californica	24	3				27
Parastichopus californicus	12		8		5	25
Pleurobranchaea californica	11			2	7	20
Mediaster aequalis	7	3			1	11
*Lironeca vulgaris**	1-10	1			P	~8+
Cancer anthonyi	7					7
Luidia foliolata		1		1	5	7
Calinaticina oldroydii		2	4			6
Pinnixa sp.*	2-5	1				~5
Parvilucina tenuisculpta			2	3		5
Lytechinus anamesus					3	3
Mursia gaudichaudii	1		2			3
Cistena californiensis		3				3
Ophiura lutkeni		3				3
Octopus ?rubescens	2					2
Nassarius mendicus				2		2
Crangon zacae			1	1		2
Cancer productus	1					1
Tritonia exsulans	1					1
Heptacarpus tenuissimus	1					1
Cerebratulus sp.	1					1
Glycera americana	1					1
Lucinoma annulatus	1					1
Luidia asthenosoma		1				1
Sergestes similis				1		1
Nereidae UI				1		1
Acila sp.					1	1
Metridium sp.					1	1
Total* 40 species	1211	1214	273	24	210	

*Those species with ranges on approximate numbers were not used in calculations.

There is no question but that sea life is very abundant above the bottom in the area of the sludge deposit.

Life in Mid Water

Animals caught in the trawls described in the previous section live within 1 meter of the bottom. Large populations of other species live higher in the water column throughout the Bay.

Santa Monica Bay is very productive and contains an astonishing amount of sea life--at least 70,000 tons--which itself produces about 25,000 tons of fecal material a year (wet weight). The outfalls undoubtedly influence this figure somewhat, presumably enhancing it by providing food and nutrients and perhaps diminishing it by adding toxicants. Alan Mearns of the Project estimates the increase in benthic invertebrate biomass caused by the two Hyperion outfalls (5-mile and 7-mile) at 5,600 metric tons or about 8 percent of the total in the Bay.

The average chlorophyll level in the bay is about 12 mg/liter relative to 4 mg/liter in nearby ocean waters. This indicates the amount of photo-synthesis by phytoplankton (diatoms and dinoflagellates), which form the base of the food web. Minute animals, including copepods and larval fish live on these microscopic plants. These, in turn, are consumed by larger animals including anchovies and mackerel, which are in turn consumed by still larger fish, sea lions, and birds.

The outfalls do not appear to have much effect on this primary productivity because the nutrients they release (mainly ammonia nitrogen) usually do not reach the euphotic (sunlit) level of water where photosynthesis can take place and chlorophyll form. If the outfall nutrients reached the surface waters, we would expect to see a local enhancement

Table 7. Marine organisms appearing in 5 percent or more of 57 photographs taken at 100m in Santa Monica Bay in 1975, on or near the 7-mile pipe (M. J. Allen).

Species	Common Name	Frequency of Occurrence (%)
Metridium senile	Sea Anemone	45.6
Astropectin verrilli	Sand Star	45.6
Sebastes paucispinis	Bocaccio	19.3
Luidia foliolata	Star	14.0
Sebastes levis	Cow Rockfish	12.3
Sebastes minatus	Vermilion Rockfish	12.3
Kelletia kelletii	Kellet's Whelk	7.0
Megasercula carpenteriana	Snail	7.0
Sebastes jordani	Shortbelly Rockfish	7.0
Microstomus pacificus	Dover Sole	7.0
Terebra sp.	Snail	5.3

of phytoplankton that is not observed. Rather the increased chlorophyll seems to come from nitrogen in nitrates from upwelled water that moves into the shallow, lighted water of the Bay when easterly winds push the surface water offshore.

Fish Diseases

Over the past 20 years, numerous diseased fish have been collected from Santa Monica Bay and elsewhere in southern California. Project scientists have examined over 300,000 fish of 151 species taken from Ventura to San Diego and at some of the offshore islands. The objective was to determine the types and frequency of diseases, which species are affected, and whether or not wastewater outfalls are a likely cause of disease. In addition, a variety of laboratory experiments have been conducted to learn more about the causes of fish diseases. Two types of diseases have received most attention: external tumors on croakers and flatfishes and fin erosion diseases in a variety of fishes.

Present evidence indicates that, in southern California, skin tumors occur commonly in young Dover sole.

Table 8. Summary of trawl catch statistics in depths of 150 ± 20 m. Santa Monica Canyon has the most species of fish as well as the most biomass and the largest individual fish. Note that the three canyon trawls were only about half the duration of the controls (A. Mearns).

	1977	1977	1976-1979	1976-1977	1979
	Point Conception	Coal Oil Point	Santa Monica Canyon	San Pedro Sea Valley Canyon	Redondo Canyon
No. of samples	3	3	5	3	2
Depth (m)	152 ± 27	149 ± 21	145 ± 27	139 ± 2.5	164 ± 51
Tow time (minutes)	22 ± 5.7	21 ± 3.8	11.8 ± 4.6	10.0 ± 1.0	10 ± 0
Fish					
No. of individuals	168 ± 102	342 ± 314	691 ± 392	200 ± 189	841 ± 590
No. of species	14.0 ± 3.6	15.0 ± 3.5	17.4 ± 5.0	8.3 ± 1.5	17.0 ± 9.9
Biomass (kg)	6.9 ± 4.2	4.1 ± 3.6	40.7 ± 29.9	6.3 ± 5.6	28.8 ± 12.7
Avg. wt./fish (g)	5.4	12.0	58.9	31.0	38.4
Shannon-Weaver Diversity	1.80 ± 0.20	1.92 ± 0.07	1.69 ± 0.38	0.99 ± 0.60	1.75 ± 0.41
Invertebrates					
No. of individuals	527 ± 664	400 ± 379	734 ± 774	75 ± 70.7	634 ± 276
No. of species	53 ± 27[1]	25.3 ± 8.6	15.2 ± 6.0	10 ± 2.8	18.0 ± 7.1
Biomass (kg)	7.0 ± 6.6	65.0 ± 23	13.0 ± 8.0	6.5 ± 8.1	6.6 ± 0.63
Avg. wt./invert. (g)	13.3	163.0	4.1	20.8	11.2

[1] Two trawls with many invertebrates attached to drift kelp, sea weeds, and rocks. These are not comparable with soft bottom fauna in other trawls.

The tumors are similar to a disease affecting very young flatfishes in Japan, Alaska, British Columbia, Washington, Oregon, and northern California. Prevalence of tumors is low in young Dover sole from southern California compared with those in other species from sites in the Pacific Northwest and Alaska; diseased Dover sole have been captured as far south as Cedros Island in Baja California. The cause of the disease is unknown but whatever it is, it is widespread and has been present in coastal areas of the north Pacific for many years. The disease does not appear to be caused by southern California sewage or sludge discharges.

Few white croaker with lip papillomas have been reported since 1970. This growth has been described as nonmalignant and possibly a response to an irritant or an injury (Russell and Kotin 1957). Because of the relatively wide coastal distribution of the condition and the nature of the growth, the lip papilloma disease does not appear to be related to the discharge of municipal wastewaters (Mearns and Sherwood 1977).

The second type of disease, commonly known as fin erosion syndrome, does seem to be related to sewage

Table 9. Prevalence of fin erosion and skin tumors in Dover sole collected near the 7-mile outfall in Santa Monica Canyon (M. Sherwood).

	1977	1978	1979	1979
Day	29 Sep	2 Oct	7 Aug	7 Aug
Depth (m)	183	152	149	124
Tow Time (minute)	10	10	9	10
No. of Dover sole	232	597	120	172
No. with fin erosion	38	86	13	56
% with fin erosion	16%	14%	11%	32%
No. with tumors	3	1	1	1
% with tumors	1.3%	0.17%	0.83%	0.58%
No. < 120 mm SL	71	28	30	1
No. with tumors < 120 mm SL	2	1	1	0
% with tumors < 120 mm SL	2.8%	3.6%	3.3%	0

Table 10. Concentrations of organic compounds in livers of flatfish collected at Station 51 in the upper part of the Santa Monica Canyon (D. Young).

	μg/wet kg				mg/wet kg		
		1234	135			PCB	
	p-DCB	TCB	TCB	HCB	1242	1254	Total
Median	<1.2	29	0.0	24	3.3	19	27
Mean	< 67	26	3.2	25	3.5	19	26
SE	±52	±6.2	±3.2	±3	±0.7	±5	±4

discharges although the specific cause is unknown. Many reports by this project (including Sherwood 1978) have described this disease, its epicenter off Palos Verdes, and its prevalence relative to other parts of the world.

Fishes with fin erosion disease have been collected in the vicinity of the 7-mile outfall. The Dover sole (*Microstomus pacificus*) is the species most frequently affected, both at this site and on the Palos Verdes shelf some 20 kilometers to the southeast.

The proximity of Santa Monica Bay to the Palos Verdes shelf and the less frequent surveys of the canyon area have made it difficult to estimate the extent to which migration could be responsible for the presence of Dover sole with fin erosion in the canyon. From September 1976 to May 1977, a series of trawls ranging in depth from 200 to 610 meters were made off the Palos Verdes shelf, in Santa Monica Bay, and along the 460 meter isobath connecting the two locations. One objective of this survey was to determine if diseased Dover sole were moving northwest from Palos Verdes and if they could be collected between the two discharge sites. Fin erosion in Dover sole was found at depths of up to 460 meters off Palos Verdes, although the number of fish affected decreased with increasing depth (52% at 140 m and 23% at 460 m). No fish with fin erosion were taken along the isobath between Palos Verdes and Santa Monica Canyon suggesting that this was not a major pathway for the movement of diseased fish from one area to the other. The disease was seen in one of six Dover sole taken at 460 meters in Santa Monica Canyon on 6 April 1977. In addition, 14 percent of the slender sole taken on 7 April 1977 at a depth of 180 meters in Santa Monica Canyon had eroded fins.

The trawl of 21 December 1976 through the sludge deposit in Santa Monica Canyon at a depth of about 130 meters produced 1279 fish of which five individuals were diseased. Four of 329 Dover sole (mostly young fish) had skin tumors, and one of 312 white croaker had a lip papilloma. All remaining fishes appeared healthy and showed no signs of fin erosion or other external disease.

A trawl sample taken at the end of the 7-mile pipe in September 1977 contained large Dover sole both with and without eroded fins (Table 9). A comparison of trace contaminants in the tissue of these and smaller Dover sole (described in the trace contaminant section) suggested that fin erosion was being initiated in bottom fishes in the vicinity of the 7-mile pipe. The three October 1978 trawl samples suggested the same thing. Prevalence of fin erosion in Dover sole in the first sample near the 5-mile pipe was 4.2 percent (1 of 24); in the second sample, directly off the 7-mile pipe, 14 percent (86 of 597); and in the third sample, 4.25 km northwest of the 7-mile pipe, 0 percent (0 of 33).

Fin erosion in Dover sole and several other species with similar disease distribution patterns appears to be the result of exposure to contaminated sediments. Although a correlation exists between occurrence of fin erosion and elevated levels of total PCB in sediments, a cause-and-effect relationship between the two has not been demonstrated (Sherwood and Mearns 1977). Liver enlargement found in specimens with and without eroded fins collected in the vicinity of the 7-mile pipe is discussed in the trace contaminant section.

Chemistry and Toxicity

Virtually all of the possible pollutants in the city's discharged waste are present in the sediments in upper Santa Monica Canyon, some at high levels. This is because the tiny particles of these pollutants are attached to particles of organic solids that are discharged, about 10% of which

Table 11. Estimate of unionized ammonia from the sea animals of Santa Monica Bay.

Animals

500 km^2 of bay bottom contains:

80 gm/m^2 of benthic infauna (>1mm)	or	4×10^7 kg
40 gm/m^2 of fish, birds, mammals	or	2×10^7kg
10 gm/m^2 of infauna and microbes (<1mm)	or	$.5 \times 10^7$kg
and smaller animals that metabolize the detritus	or	$.5 \times 10^7$kg
	total	7×10^7kg

or 70,000 tons of animals.

Assume benthic animals excrete 0.001 part of body weight per day of total NH_3 and the higher animals produce twice that ammount. Assume salinity of 35 ppt, pH of 7.6, temperature of 15° C, then 0.831 of 1% of the total ammonia is unionized, (say 1%), thus:

$$7 \times 10^7 \text{ kg} \times 0.001 \times 0.01 = 700 \text{ kg/day}$$

or

$$365 \times 700 \times 0.001 = 255 \text{ tons/year}$$

of unionized ammonia is produced by animals.

Outfalls

The 7 mile outfall releases 1650 tons of ammonia nitrogen each year and the 5 mile outfall releases 7590 tons of ammonia nitrogen each year, a total of 9240 tons

or

$$9240/0.82 = 11{,}000 \text{ tons}$$

of total ammonia of which 1% or 110 tons is unionized, thus:

$$255/110 = 2.3 \text{ times}$$

more unionized ammonia comes from the animals than from the outfalls.

Note on solids released

If total fecal material is 1% of body weight per day of the 70,000 tons of animals present, then 365 x 700 tons = 255,000 tons of fecal material (wet weight) or about 25,000 tons (dry weight) is produced by the animals in the bay each year. This is relative to the 56,700 tons released by the 7 mile outfall of which about 90% leaves the outfall area.

Table 12. Inner grid of sampling stations covering the Hyperion outfalls and Santa Monica Canyon region at 1-km intervals.

Station	LORAN-C Position LOP 1	LOP 2	1978 Date	Depth (m)	Bottom Material	In-faunal Trophic Index	Bio-mass (g/ sq m)	% Vola-tile Solids	BOD (mg/ kg)
Santa Monica Bay Inner Grid									
A1	28152.2	41141.1	15 May	80	Rocks	NA	NA	NA	NA
A2	28153.9	41137.8	6 Feb	80	Sand, gravel	65.9	56	6.7	800
A3	28155.6	41134.6	6 Feb	76	Sand	61.0	111	6.7	850
A4	28157.3	41131.5	6 Feb	70	Sand, gravel	47.0	157	3.6	500
A5	28159.0	41128.4	6 Feb	62	Sand, gravel	44.0	159	2.5	920
A6	28160.7	41125.4	17 Feb	61	Sand	39.6	227	3.9	850
A7	28162.4	41122.2	17 Feb	58	Sandy silt	57.8	198	2.7	1,170
A8	28164.1	41119.2	17 Feb	57	Silty clay	63.5	98	3.4	1,340
B1	28152.7	41143.2	6 Feb	138	Sand, gravel, rocks	55.7	28	5.0	750
B2	28154.4	41139.9	6 Feb	84	Sand	43.4	29	4.9	440
B3	28156.1	41136.7	6 Mar	80	Sand, gravel	50.8	112	5.2	610
B4	28157.8	41133.6	6 Mar	77	Sand, gravel	39.6	135	3.9	620
B5	28159.4	41130.4	15 May	65	Sand	35.7	562	2.7	920
B6	28161.2	41127.3	27 Feb	62	Silty sand, gravel	47.8	199	3.7	1,520
B7	28162.9	41124.2	27 Feb	61	Silty clay	37.5	87	4.2	2,210
B8	28164.6	41121.1	17 Feb	55	Silty clay	66.2	140	3.0	980
C1	28153.2	41145.3	6 Feb	240	Clay	56.6	67	8.1	1,720
C2	28154.9	41142.1	15 May	217	Silty clay	56.7	240	9.1	2,750
C3	28156.5	41138.8	15 May	191	Silty clay	42.7	329	9.7	3,060
C4	28158.3	41135.6	6 Mar	89	Rocks	NA	NA	NA	NA
C5	28160.0	41132.5	27 Feb	68	Sandy silt	56.0	231	4.9	1,535
C6	28161.7	41129.4	27 Feb	62	Silty clay, gravel	65.1	328	3.8	2,150
C7	28163.3	41126.5	27 Feb	58	Silty clay, gravel	55.1	91	3.9	1,400
C8	28165.1	41123.2	17 Feb	53	Silty clay	67.2	129	3.7	760
D1	28153.7	41147.4	6 Feb	210	Clay	59.3	216	6.5	960
D2	28155.4	41144.2	6 Feb	195	Silty clay	58.1	268	5.9	1,320
D3	28157.1	41140.9	6 Mar	201	Sludge	8.1	158	17.7	10,550
D4	28158.8	41137.7	6 Mar	95	Silty sand, rocks	25.9	223	4.3	1,780
D5	28160.5	41134.6	15 May	65	Silt, sludge	53.8	479	3.5	2,190
D6	28162.2	41131.4	27 Feb	60	Sandy silt	51.2	208	3.8	1,580
D7	28163.9	41128.3	27 Feb	54	Silt, gravel	59.0	87	2.8	960
D8	28165.6	41124.9	17 Feb	50	Silty clay	75.8	133	3.1	600
E1	28154.2	41149.4	6 Feb	195	Silty clay	59.1	118	6.7	1,070
E2	28159.9	41146.2	15 May	173	Silty clay	54.3	302	7.3	1,900
E3	28157.6	41143.1	6 Mar	132	Sandy silt	45.0	1,284	4.4	2,240
E4	28159.3	41139.8	15 May	95	Rocks	NA	NA	NA	NA
E5	28161.0	41136.6	27 Feb	60	Sand	48.7	112	2.6	1,080
E6	28162.7	41133.5	27 Feb	57	Sand	48.7	187	2.5	870
E7	28164.4	41130.4	27 Feb	51	Sandy silt	58.9	137	2.7	750
E8	28166.1	41127.3	17 Feb	45	Silty clay	79.4	142	3.2	890
F1	28154.7	41151.4	15 May	185	Silty clay	60.8	157	6.6	1,440
F2	28156.4	41148.3	6 Feb	147	Sandy silt	42.9	304	5.3	1,480
F3	28158.1	41145.1	6 Mar	96	Silt, sand, gravel	35.1	473	3.2	1,050
F4	28159.8	41141.9	6 Mar	63	Sand	42.4	174	1.6	580
F5	28161.5	41138.7	27 Feb	58	Sand	46.2	158	2.1	1,850
F6	28163.2	41135.6	15 May	53	Sandy silt	54.0	124	2.3	1,230
F7	28164.9	41132.4	27 Feb	50	Silty clay	59.5	87	3.2	830
F8	28166.6	41129.3	17 Feb	42	Silty clay	77.2	70	3.0	450
49	28159.7	41137.8	30 Jan	111	Sludge	0.0	282	33.0	27,700
50	28158.7	41139.2	30 Jan	153	Sludge, sand rocks	0.3	277	26.7	20,600
Special stations in and near the canyon									
51	28158.2	41138.8	27 Feb	136	Sludge	0.0	6	31.8	22,500
52	28156.6	41140.9	30 Jan	198	Sandy silt	16.8	289	17.3	12,100
53	28154.6	41144.5	30 Jan	246	Silty clay	48.2	438	12.0	3,890
54	28159.6	41140.2	2/13/80	73	Silty sand	44.5	227	3.3	1,030
55	28158.3	41140.5	2/13/80	87	Silty sand	36.1	573	2.0	920
56	28156.8	41142.2	2/13/80	160	Silt	39.9	305	5.9	1,590
57	28158.8	41135.5	2/25/80	78	Coarse sand	53.4	228	1.7	990
58	28157.6	41138.2	2/25/80	155	Silty sand	21.1	217	4.6	1,400

fall to the bottom in the discharge area. The result of this is that all pollutants correlate reasonably well with each other and with volatile solids. The correlation with the number of species of marine life is inverse; that is, numbers of species decrease as pollutants increase. However, the biomass and number of animals may increase substantially in spite of the presence of possible toxicants. We do not know which of the nutrients, chemicals or pollutants cause the reductions and/or increases.

An examination of the results of chemical analyses of bottom samples shows that the most convenient and reliable indicator of sewage solids is an increase of volatile solids above the normal levels. Figure 7 shows the distribution of volatile solids around the outfalls. The natural range of volatile solids, as determined by our control survey for outer shelf depths is 1.8 to 3.8 percent (Word and Mearns 1978). Thus, it can be seen that the flat area above the canyon shows little increase above normal. In the canyon, however, the levels rise abruptly to as much as 33% in a pile of large sludge particles immediately in front of the discharge point.

Figure 11 shows a similar pattern for increased copper in the bottom with levels in the upper canyon reaching as much as 1300 ppm relative to the control range of 2.8 to 31 ppm. Cadmium (Figure 12) in the bottom also has the same pattern and range of values. These metals are bound to the particles and there is no evidence that they are biologically available to any great extent. Sometimes the natural metal level in invertebrates will rise to 5 or 10 times normal, but there is no known toxic effect at these levels. The fish that feed on these invertebrates have metal levels that are slightly below normal. The extent to which these pollutants can be made biologically available by microbial action that destroys the underlying organic particles to which they are attached is unknown.

The levels of polychlorinated biphenyls (PCB's) in the canyon sediments are mostly in the range of 1 to 3 ppm (dry weight); levels of PCB's on the shelf immediately above the canyon are about one-tenth that level, and these decrease towards shore (Figure 13). Often fish accumulate PCB's in muscle tissue at about two-tenths the level of that in the sediment. This means that the dry weight in sediments is often about the same as the dry weight in fish muscle. The highest level measured (3.1 ppm) in sediment is only slightly above the permissible level in fish for human consumption.

The concentrations of the total chlorinated benzenes in waste effluents are generally higher than those of PCB's, and they can be detected and measured at the same levels as PCB, or about 0.1 ppb (Young 1978). Around other outfalls, dichlorobenzene has been detected in sediments at about the same level as PCB. Fish taken in trawls of the upper canyon were found to have certain chlorinated benzenes in their livers. Speckled sanddabs were found to have trichlorobenzene and hexachlorobenzene in their livers, each at about 25 ppb. No para- or ortho- dichlorobenzene was detected. Generally the levels of the chlorobenzene in muscle tissue (the edible part) of such fish are about one-twentieth the level in the liver, although we did not make that measurement in the fish from the canyon. When this level is compared with the FDA standard of 300 ppb HCB in meat products, no danger is indicated.

Thus, although the chlorinated benzenes are dominant in effluent and are prominent in sediments, they do not appear to bioaccumulate to any important extent, either here or elsewhere.

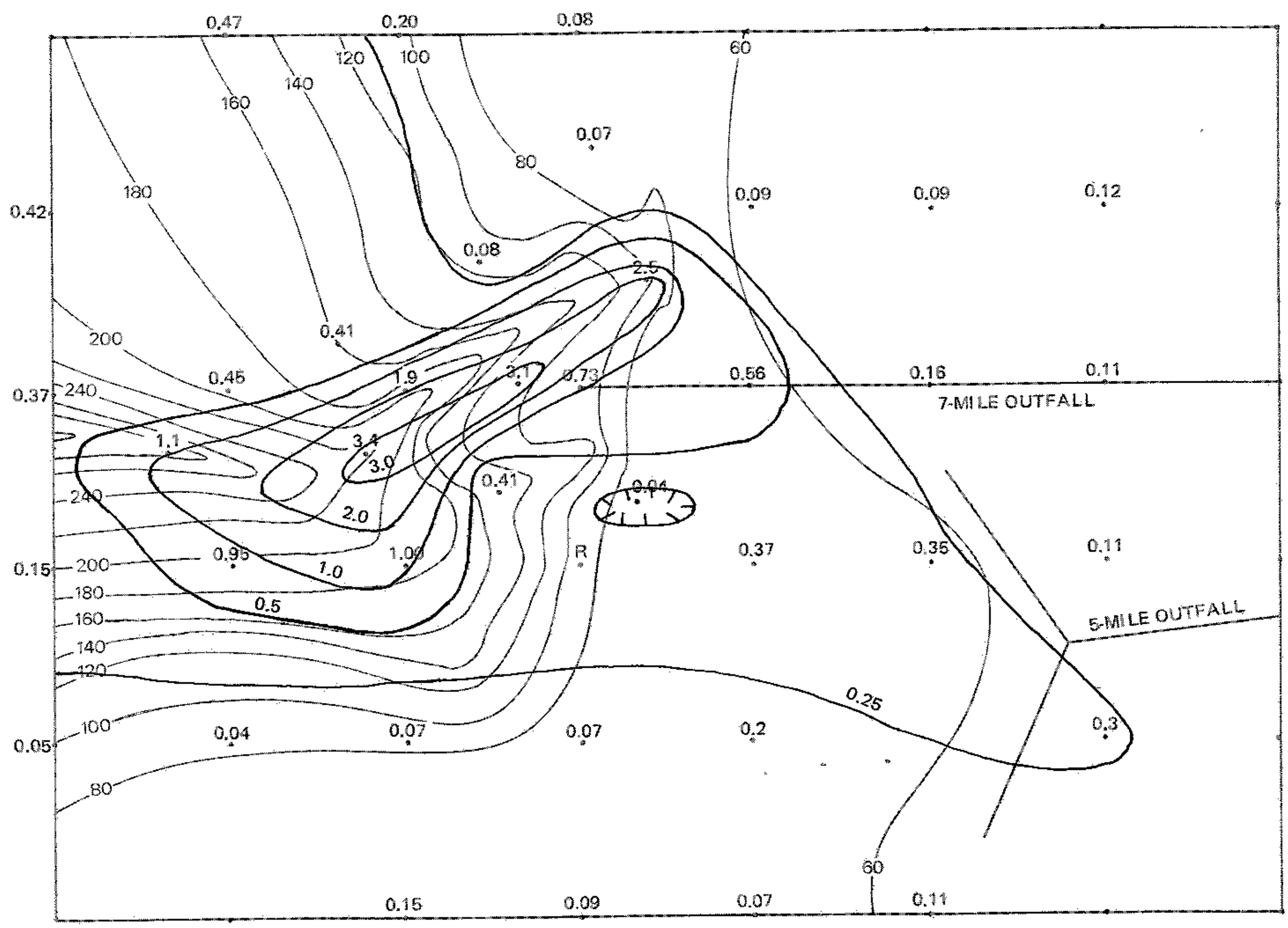


Figure 13. Concentrations of total PCB in the upper 2 cm of sediments in ppm, dry weight. (P. Hershelman, R. Gossett)

Preliminary toxicity studies have been made on the 7-mile effluent using both sea urchin fertilization and embryo development techniques developed by Philip Oshida of this Project. Samples of sludge taken on 13 February and 6 March 1979 were 1-hour early-morning composites, rather than the usual 24-hour composites, and the effect was greater than anticipated.

The tests were made at dilutions ranging from 100:1 to 1000:1. On 6 March, fertilizations were not significantly reduced at dilutions of 700:1 but at a dilution of 600:1, the discharge was slightly toxic to the development of sea urchin embryos (Oshida, this volume). This means that on these dates, about seven times as much dilution as usual would have been required to render the effluent nontoxic to these embryos within a few hundered meters of the discharge point. This condition is representative of the core of plume, which is at middepth and does not affect the near-surface or near-bottom animals. This toxicity continues to decrease as the wastefield moves away and becomes further diluted so that a relatively small volume of seawater is hazardous to tiny organisms. Since the sea urchin reaction is a measurement of overall toxicity, it is not possible to say which of the many constituents in the discharge is responsible.

CONCLUSION

At some time over the past 10 years, nearly every scientist on the staff of the Project has made some measurement relating to the 7-mile sludge outfall and its effects on the bottom or on sea life. All the important data have been summarized in this paper. The nature of the material discharged, how it is distributed by the currents, where it deposits and why, the extent to which animals are affected, the incidence of pollutants in the bottom, the statistics on fish diseases and toxicity of the plume have all been described.

We find that the area seriously affected is entirely in the canyon at depths greater than 100 meters (300 feet) and that the area seriously involved is about 3 sq km--a little more than a square mile or about 0.4% of the Bay. However distasteful it may seem to humans, this sludge-lined canyon attracts sea animals. Although the community structure in this small region is greatly changed, some animals have taken advantage of the situation and proliferated. Others have disappeared, and some rare forms have grown unusually large. The benefits and the detriments of discharging sludge from the 7-mile pipe are mixed.

We hope that any alternative proposal will receive equal study so that any changes made will be an ecological improvement.

SUMMARY

For 22 years, the city of Los Angeles has been disposing of sewage sludge by mixing it with various effluents, transporting it through a 7-mile long pipe, and discharging it at the brink of the Santa Monica submarine canyon. Sludge is used here to mean the residual solids from mixed primary-secondary wastewater treatment that have been anaerobically digested and passed through a 3.35-mm screen. The end of the pipe is 100 meters deep; immediately below it, the steep-sided canyon drops away to 200 meters, which is twice the maximum depth of the floor of Santa Monica Bay. The dissolved materials and most of the fine particles discharged are diluted, dispersed, and carried out to sea by the currents, but about 10 percent of the sludge particles discharged have accumulated in the canyon. The soft sediments covering about 3 sq km of the upper part of the canyon are now composed of 10 to 30% volatile solids, largely sludge. This material has a high biological oxygen demand, and its concentrations of metals and other possible pollutants are very high.

In this 3 sq km region of greatest disturbance, the Infaunal Trophic Index, which ecologists use as an indicator of community structure, falls below 30 relative to that of "normal" conditions, which has an index value of 60 and above. Normal conditions are defined as those in which the number of species, biomass, and the number of individuals are equal to or greater than those at the control stations. In the region around the outfall, some of the benthic animals that might be expected are missing. However, some molluscs, echinoderms, echiuroids, and polychaetes are present in large numbers. At four locations near the discharge point, three of which are above the rim of the canyon, the biomass is 435 to 1284 g/sq m, relative to the normal biomass of 70 g/sq m.

Fish are much more abundant in the upper canyon, there being more species, twice as many adult fish, and twice the biomass of other canyons at similar depths on the slope where there is no discharge. Fin erosion disease has been found in Dover sole (11-32 percent in canyon trawls over a 3-year period) and slender sole. This disease is somehow related to outfall effects, but the specific cause is not known.

Some of the particles of sludge that do not fall into the canyon are believed to land on the flat shelf above the canyon rim (according to a computer model that takes settling velocity and current speeds and directions into account) but are soon swept by currents into the canyon. Sludge particles do not seem to be moving shoreward as evidenced by measurements of PCB, which is high in the

canyon, low in the sediments immediately above the canyon, and very low several kilometers nearer to shore.

Bioassays of the 7-mile effluent show that it can be toxic to sea urchin fertilization and embryos at dilutions of 600:1 to 1000:1. Since the actual dilution is only 50:1 to 150:1, this means that the waste plume, which is suspended in midwater above the canyon, can be toxic to certain embryonic animals.

In spite of the high levels of pollutants present in the bottom and the toxicity of the water to certain delicate forms, it is apparent that sea life is attracted to the discharge area and is abundant there. Fishing is excellent as attested by frequent visits of party boats to the site, which is commonly known as the Volcanic or 7-mile reef.

Thus, both environmental benefits and environmental problems result from the 7-mile sludge discharge.

Samples to be used for volatile solids and BOD analysis or for metals analyses are put in 120-ml plastic jars; samples to be analyzed for chlorinated hydrocarbons are put in glass jars with aluminum foil covers. All are presterilized, labeled, and refrigerated at once.

LABORATORY METHODS

The plastic bags full of animals and bottom material larger than 1 mm were delivered to our taxonomy group, whereupon the following steps were taken. The samples were rescreened under a freshwater spray that removed the formalin; the solid material was transferred to jars containing 70 percent ethanol solution. The invertebrates were sorted into seven categories and placed in glass vials (polychaetes, molluscs, crustaceans, ophiuroid fragments, ophiuroid discs, other echinoderms, and miscellaneous organisms). Debris was placed in another vial (shells of long-dead animals fall into the category of debris, along with small rocks, worm tubes, grass cuttings, twigs, plastic bits, fish line, aluminum foil, etc.).

Each of these vials was sorted for Infaunal Index animals, which were then counted. The total weight of each of the seven groups was obtained by placing the damp animals in a tared plastic tube with a screen on the bottom end. Five minutes were allowed for moisture at the bottom of the tube to be transferred to the blotter-like paper towel on which it was placed. Then the total weight of the tube and animals was obtained to the nearest milligram. Total biomass is then the sum of all the weights of the amimals collected (including their shells) less the weights of their containers. Relatively large animals, such as urchins, starfish, and fish, were weighed separately; their weights are not included in the total biomass values.

After the results were logged, the vials of animals in alcohol from each site were wrapped together and stored for possible future use. These samples could be of value to some future scientist who wants information about some aspects of this survey on which we are not reporting.

The plastic bag of sediment intended for volatile solids and BOD measurements is usually frozen when it arrives in the laboratory. The sample is then homogenized, and a 5- to 10-gram subsample is placed in a tared beaker, dried for 24 hours at 105°C and weighed again, the result being the dry weight of the sample. The beaker is then placed in a muffle furnace at 550°C for 1 hour to volatilize the organic fraction and then weighed a third time. The difference between this weight and the dry weight permits the calculation of the percent volatile solids.

For the BOD measurement, a 0.5- to 2-gram sample of the homogenized sediment is weighed in a tared aluminum pan. The sample is placed in a 300-ml BOD bottle, which is then filled with oxygen-saturated seawater (at 20°C under standard conditions, it contains 8 parts per million of dissolved oxygen). One milliliter of bacterial seed solution (a culture of ocean bottom bacteria maintained on digested sludge) is added. The bottle is then sealed and stored for 5 days in the dark at 20°C with 15 seconds of agitation per day. At the end of the 5 days, dissolved oxygen is determined by the Winkler-azide method, and the amount of oxygen remaining is calculated in milligrams of oxygen per kilogram of sediment (dry weight).

Appendix 1
METHODS AND MATERIALS

SAMPLING EQUIPMENT AND METHODS

The equipment and methods used for this survey have been tested by this project as well as by others over a period of years; they have been reported elsewhere, but a short review may be helpful.

Through the courtesy of the City of Los Angeles, we were able to use their 20-meter long survey ship Marine Surveyor. All navigation was done with LORAN C, which gives position (and sample location) within about 20 meters. Once equipped with this precise and convenient navigational device and a high-quality echo sounder, we were able to improve the charts of the Santa Monica submarine canyon. In doing this, we found numerous variations from the depths given in official charts (No. 13746 and 18744). Therefore, some of the depth contours shown on the charts in this paper were revised by us and do not coincide with those on the official charts.

The principal sampling device used was a chain-rigged Van Veen grab originally developed elsewhere and revised by our group after much usage. We find that this grab takes virtually undisturbed 0.1-sq-meter samples of mud bottoms, mounds and tracks made by animals usually reach deck level intact, and the light surface constituents of the mud are still present. Tests made for the U.S. Environmentsal Protection Agency (Contract No. R801152; Word et al. 1976; Word 1977) demonstrated the superiority of this sampler to other types. It is about equivalent to a box corer for the purpose of capturing the infauna or protecting sample surfaces, and it is much more convenient to use.

Two grab samples were taken at each station, one for biology and the other for chemistry; water depth given by the ship's echo sounder was confirmed by means of a metering wheel on the winch.

When a biology grab is retrieved, it is placed in a rectangular plastic basin. The hinged top of the grab, which consists of a 0.5-cm screen and a rubber flap, is raised so that the surface of the sea bottom lies revealed, still covered with water. At this time, any special bottom features (including smell, texture, color, unusual animals or materials, etc,) are noted. The grab jaws are then opened so that the mud flows into the plastic basin whence it is then washed into a box with a bottom made of 1-mm screen. The animals and other matter remaining on the screen are removed, preserved in plastic bags partly filled with 5 percent formalin/seawater solution buffered with borax, and returned to the laboratory.

The grab sample to be used for chemical analysis is brought aboard and opened in a similar way to expose the undisturbed bottom. Then a syringe-type corer 2.6 cm in diameter is used to sample the upper 2 cm of mud (usually four such small cores are taken and composited).

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