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PLANKTON AND ASSOCIATED NUTRIENTS IN THE WATERS SURROUNDING THREE SEWER OUTFALLS IN SOUTHERN CALIFORNIA

by

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A Final Report
submitted to the
Hyperion Engineers, Inc.
by the
Geology Department
University of Southern California

September 4, 1956

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PLANKTON AND ASSOCIATED NUTRIENTS IN THE WATERS SURROUNDING THREE SEWER OUTFALLS IN SOUTHERN CALIFORNIA

INTRODUCTION

The discharge of sewage through ocean outfalls has been investigated as to its possible role in causing an increase of phytoplankton production in the coastal waters of the Los Angeles region. The frequent amber-colored water off the Playa del Rey-Santa Monica shoreline has been quite apparent to local residents during the past decade, and has given rise to the colloquial terminology of "beer-colored breakers". Laymen have attributed this discoloration directly to the sewage effluent, apparently unaware of its more likely origin from plankton blooms. The "red water" is, of course, objectionable to those who frequent the shore, mainly because of the supposed origin, but also due to the distastefulness of swimming and bathing in water that is not "clean and blue".

Of greater significance is the possibility of the particulate organic matter contributed by plankton acting as "sanctuaries" for coliform bacteria and allowing the bacteria to persist in the marine environment for periods of time longer than normal. Such a possibility would have little importance if the plankton populations were normal in abundance and occurred in a natural cycle. However, with a constant inflow of available nutrients in proportions many times greater than normal, significant numbers of phytoplankton could conceivably exist throughout the year even though visible blooms are infrequent.

In August and September 1955 and May 1956, three small, but intense blooms along the Orange County coast were followed by unusually high bacterial populations on the adjacent beaches. Beach counts of coliform bacteria had been greater than normal during the summer of 1955, but were 60 to 80% higher immediately following the blooms. Numbers of coliforms had also been lower preceding the May occurrence. This apparent correlation was at least suggestive, particularly because the blooms were restricted to those waters through which the sewage flowed. There are no bacterial data relating to discolored water areas in Santa Monica Bay due to the chlorination of the effluent by the Bureau of Sanitation, Los Angeles, during the period of plankton sampling.

In conjunction with investigations to establish the rate of coliform disappearance from sea water, many series of nutrient determinations were conducted in the water surrounding ocean outfalls. It was believed that before speculations on the amount and result of nutrients contributed by sewage were carried further, some chemical data were necessary. By making repeated plankton counts, it was conceivable that the nutrient, phytoplankton, and bacteria data could be related. Therefore, around the Orange County, Los Angeles County, and Hyperion outfalls the vertical and horizontal distribution of phosphate, silicate, nitrate, and ammonia were investigated. The most detailed work was accomplished near the Orange County outfall, but enough was learned of the other two areas to show at least the relative nutrient conditions.

The contribution that plankton make to the turbidity of the water is also an important consideration in the discharge of

sewage into the sea, and was an added inducement to the study of this problem. During the warm months of 1955 (July, August, and September) many areas having yellow-green discoloration were noted south of El Segundo. The patches, extending two to three miles seaward, were sampled on several occasions. Phytoplankton numbers were high and consisted chiefly of Ceratium furca, although many other dinoflagellates as well as diatoms were present. However, the water was not nearly as intensely colored, nor populations as high as in the waters north of El Segundo between Venice and Santa Monica. Along the latter shore and extending from 0.5 to 1.0 mile from the coast was a reddish-brown discoloration which persisted for periods of 10-20 days. This water contained the same organisms in about the same ratios, but in numbers many times greater. The normal path of the effluent-enriched waters during these months is north from the outfall, striking the shore in the Venice area, the same area of abundant plankton.

THE NUTRIENT SALTS

Phosphate, nitrate, silicate, and iron are among the most important of the various compounds dissolved in sea water, as limiting factors in phytoplankton growth. Many experiments have been conducted under laboratory conditions on pure cultures to determine the reactions and requirements of plankton for nutrients (Harvey, 1955). Few experiments have been conducted using more than one type of organism or with other than sterile sea water. None have approached the multitude of complexities involved in the sea with a vast variety of plankton using and

reusing the available nutrients, and with the variations in temperature, light, predators, turbulence, etc., which exist. The problems of determining the in situ requirements for plankton reproduction are innumerable, and certainly unanswerable at this time. Nevertheless, the relationship between the available nutrients and plankton is unquestionable (Sverdrup, Johnson, and Fleming, 1942).

Methods

Oceanographic

On cruises to the Orange County, Hyperion, and Whites Point outfalls during December 1955 and January and February 1956, two days in sequence were generally spent making vertical profiles. Stations were occupied in the immediate vicinity of the outfall and in the surrounding waters to determine to some extent the areal distribution of the nutrient fields. The enrichment of nutrients around the outfalls and their diminution with unit distance from the outfall were compared to surrounding normal shelf water.

Laboratory

Standard chemical methods were used to determine the concentrations of silicate-silicon, phosphate-phosphorus, nitrate-nitrogen, ammonia-nitrogen, and dissolved oxygen.

The silicate-silicon concentration was measured by the Dienert and Wanderbulcke method as modified by Robinson and Thompson (1948a). The water samples were stored in polyethylene bottles and the colorimetric comparison made two to

three days later in the laboratory. Ammonium molybdate and sulphuric acid was then added to the sample, converting the silicate to a yellow-colored compound which was compared visually with standards of known silicate concentration. The results of the silicate-silicon determinations were not corrected for salt error.

Phosphate-phosphorus was determined by the Robinson and Thompson (1948b) modification of the method of Denigès. A solution of sulphuric acid and ammonium molybdate was added to the sea water sample, forming a complex phosphomolybdic acid. Stannous chloride was then added to reduce the complex acid to a blue substance whose color is proportional to the concentration of phosphate. The water samples were treated aboard ship just after removal from the Nansen bottles and a colorimetric comparison was made in Nessler tubes.

The nitrate-nitrogen concentration was determined colorimetrically by comparing the color produced in sea water with a reduced strychnine reagent against a previously calibrated standard of methyl orange in N/100 HCL (Wattenberg, 1937). The methyl orange solution is standardized by comparison with known concentrations of nitrate in sea water. To avoid the salt effect, nitrate-free sea water was used. As soon as possible after collection aboard ship, the strychnine reagent was added to the sample of sea water, and 24 hours later the sample was visually compared with the methyl orange standard. Both nitrite and nitrate are measured by this method; however, the former is in small enough quantities in ordinary surface sea water to fall within the experimental error of the method.

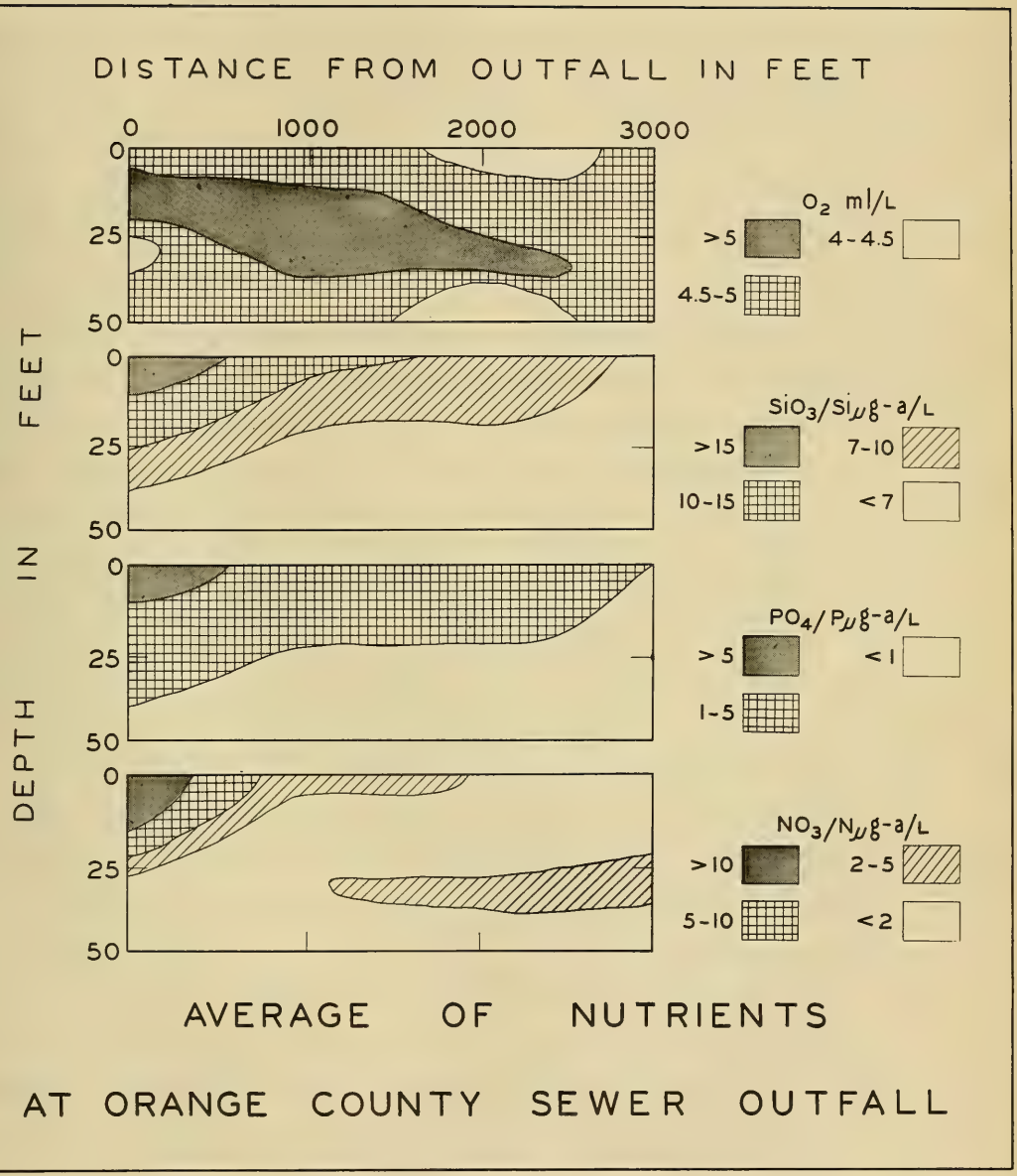
The tartaric acid method of Wattenberg as modified by Cooper was used to determine ammonia-nitrogen on cruises made in 1956 (Wattenberg, 1937). Tartaric acid was added to the sample after removal from the Nansen bottles to prevent the formation of a precipitate on the addition of Nessler's reagent. A colorimetric comparison with standards of known ammonia concentration was then made. Ammonia-free sea water was used in the preparation of the standards. Previous determinations had been made by the method of Witting-Buch. These proved unsatisfactory as some of the samples became turbid when the reagents were added after the necessary three day storage.

The dissolved oxygen in sea water was determined by the Pomeroy-Kirschman modification of the Winkler method (Pomeroy and Kirschman, 1945). Manganous sulfate and sodium iodide added to the water sample liberated iodine equivalent to the oxygen dissolved in the water. The quantity of iodine is then determined by titration with sodium thiosulfate. The 52 ml samples were drawn in glass-stoppered bottles of exact volume, immediately treated with the reagents, and titrated within ten minutes of recovery in the Nansen bottles.

Orange County Outfall

The vertical and horizontal distribution of nutrients is simplest around the Orange County outfall where the effluent rises directly to the surface with no benefit from diffusion. In Figure 1 are shown the average nutrient values versus distance from the outfall on December 19 and 20, 1955. The

Figure 1. The average nutrient values around the Orange County outfall on December 19 and 20, 1955.



AVERAGE OF NUTRIENTS

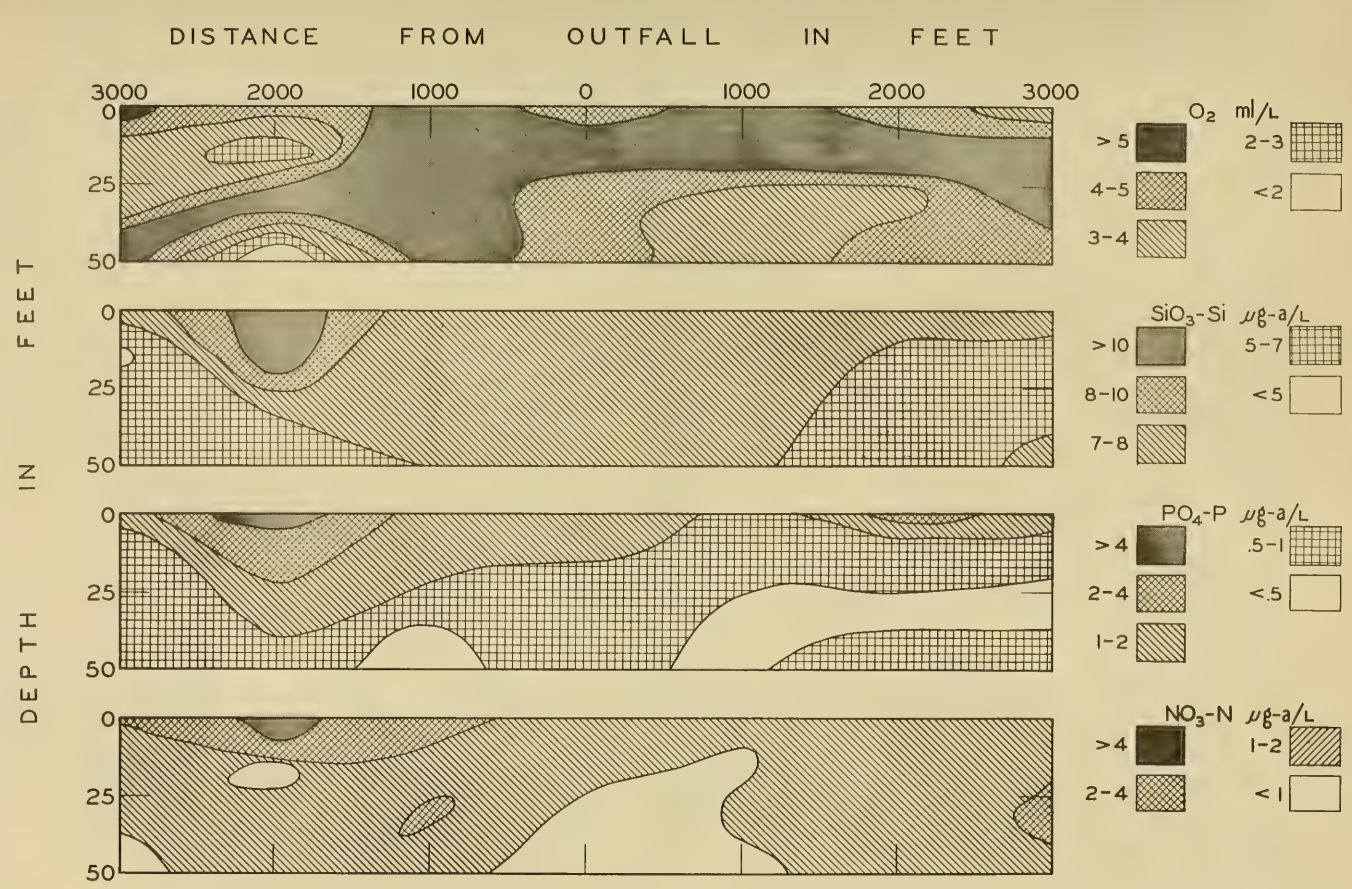
AT ORANGE COUNTY SEWER OUTFALL

nutrients rise to the surface with the effluent column and then spread and diffuse into the surrounding sea water. The silicate and nitrate persist for greater distances and through a much greater thickness of water than around the other outfalls. But even these approach normal shelf values within 9,000 feet of the outfall area under most conditions. From the nutrient profiles there is little indication of sedimentation, so it appears reasonable to assume that here, at least, the available nutrients are concentrated in the fluid portion of the effluent and not with the particulate matter. The oxygen profile is a better indication of sedimentation, showing an upper and lower layer of relatively low oxygen which meet at an average distance of 2,700 feet. The lower values are probably due to the oxygen demand of the particulate matter discharged and thus indicate to a certain extent the sedimentation profile of the debris.

On December 19 and 20 there was a fairly uniform and recognizable distribution pattern of nutrient salts (Figures 2 and 3). Differences existed each day, however, with respect to concentration, location, and extent of the nutrient fields.

The silicate on December 19 was most concentrated approximately 2,000 feet west of the boil. On December 20 the area of concentration was about 500 feet east of the boil, and the movement of the field (due to changing wind direction) is considered responsible for this shift. Concentrations were more than double on December 20, and field of dispersion was considerably larger than on the 19th. Also on 20th, a silicate-silicon concentration of 10 μg-a/L or more extended over a

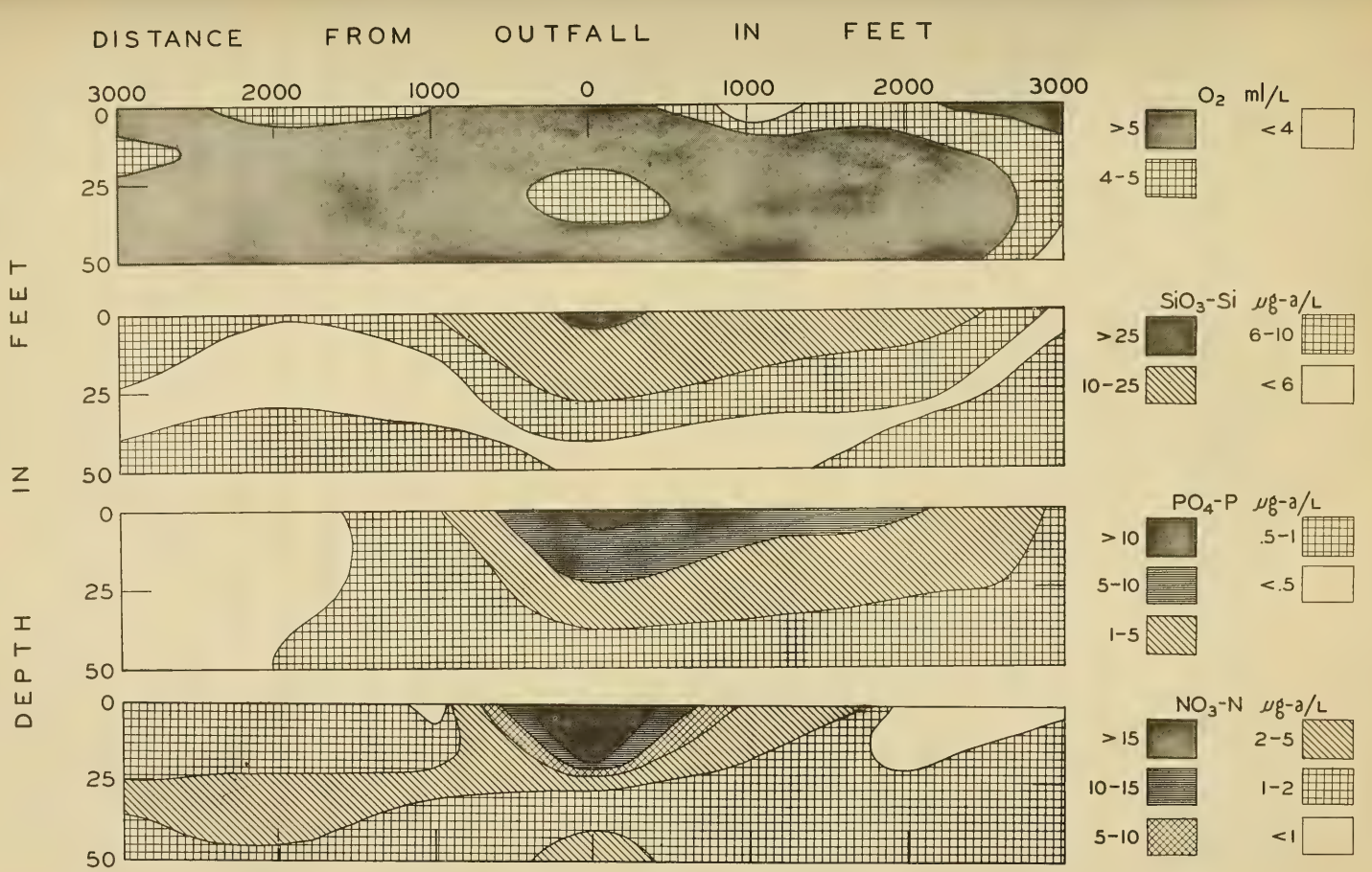
Figure 2. Vertical distribution of nutrients around the Orange County outfall on December 19, 1955.



ORANGE COUNTY SEWER OUTFALL

19 DECEMBER 1955

Figure 3. Vertical distribution of nutrients around the Orange County outfall on December 20, 1955.



ORANGE COUNTY SEWER OUTFALL

20 DECEMBER 1955

distance of 4,000 feet with an average surface concentration which was five times the value found at the bottom near the outfall.

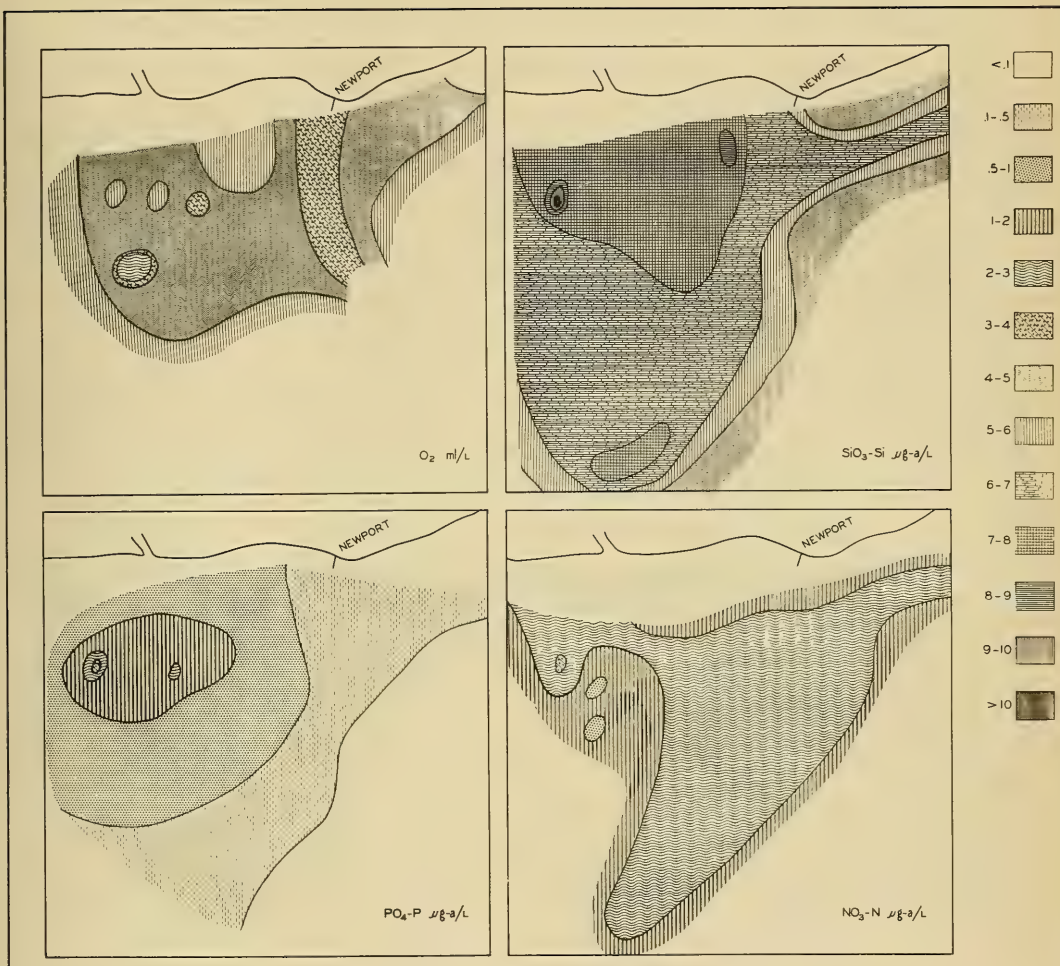
The phosphate and nitrate reflect the same distribution; the shift of the area of concentration, the increase of concentration on December 20, and the similar location of the areas of high concentration.

The surface distribution of the nutrients on December 19 had a lobate character extending generally to the southeast and east (Figure 4). The influence of the silicate and nitrate fields were still apparent almost 25,000 feet from the outfall; even though the average concentration of the nutrient salts for both days, plotted against depth and distance from the outfall, reveal the simple form of dispersion in the surface layers (Figure 1).

Hyperion Outfall

The vertical distribution of the nutrients around the Hyperion outfall on January 12 and 13, 1956, were different than those near the Orange County outfall (Figure 5). In addition to that portion of the nutrients which rose to the surface with the effluent, a subsurface layer was present for all except ammonia. It is believed that this striking dissimilarity between the two areas is due to the chemical and physical differences of the two effluents. Although only four paramaters had been measured in the Orange County effluent, (chlorinity, suspended solids, phosphate, and coliforms) and three in the Hyperion effluent (chlorinity, suspended solids,

Figure 4. Surface distribution of nutrients around the Orange County outfall on December 19, 1955.

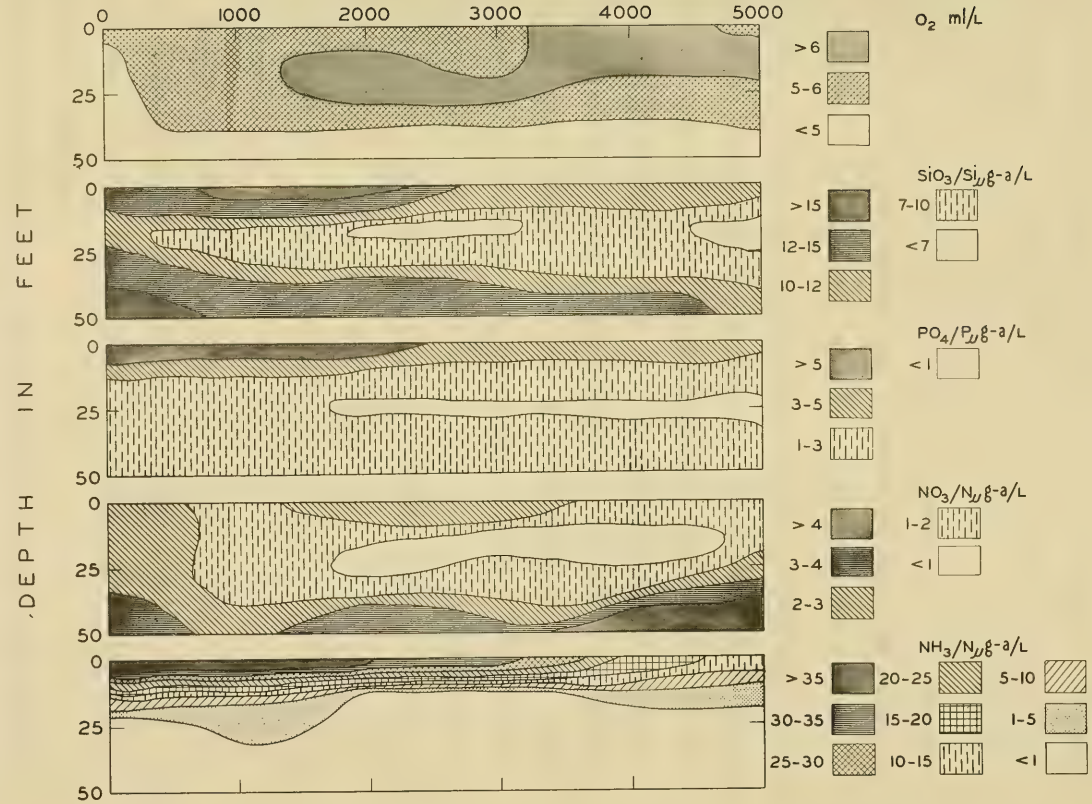


SURFACE DISTRIBUTIONS

ORANGE COUNTY

19 DECEMBER 1955

Figure 5. Average distribution of nutrients around Hyperion outfall on January 12 and 13, 1956.



AVERAGE OF NUTRIENTS AT HYPERION SEWER OUTFALL

and coliforms), the differences are marked and may be important.

The nitrate, silicate, and to a certain extent the phosphate show double layers of high concentration, one at the surface and one near or at the bottom. From about 2,000 feet to 4,500 feet from the boil there is an intermediate layer at a depth of 20 feet having low concentrations. The two layers of high nutrient values meet at about 4,500 feet. At greater distances the concentrations are relatively uniform with depth but continually decrease by dilution and diffusion.

The average profiles for oxygen and ammonia differ from those of other nutrients, and are in themselves different. The oxygen profile shows an unsaturated layer extending from the outfall along the bottom for all distances samples (9,000 feet). The oxygen content in the upper 40 feet, except near the outfall is high, and from a distance of 1,200 feet is at or near saturation. The ammonia concentrations, which are perhaps the best indication of sewage, are greatest in the boil and from the surface to a depth of 10 or 15 feet. Below 15 feet ammonia is low and approaches the normal value for shelf waters. High ammonia concentrations, 50 to 100 times that of normal water, occur as far as 9,000 feet north of the outfall, and it is probable that these high concentrations extend even farther.

The average values for both days emphasize the character of the dispersion of the nutrients. Generally, silicate and nitrate show strong concentrations in the top and bottom layers; phosphate high at the surface and a moderate concen-

tration with depth; ammonia essentially concentrated in the surface water and decreasing to zero at depth. Silicate, phosphate, and nitrate all show patchy areas of low concentration in the intermediate layer.

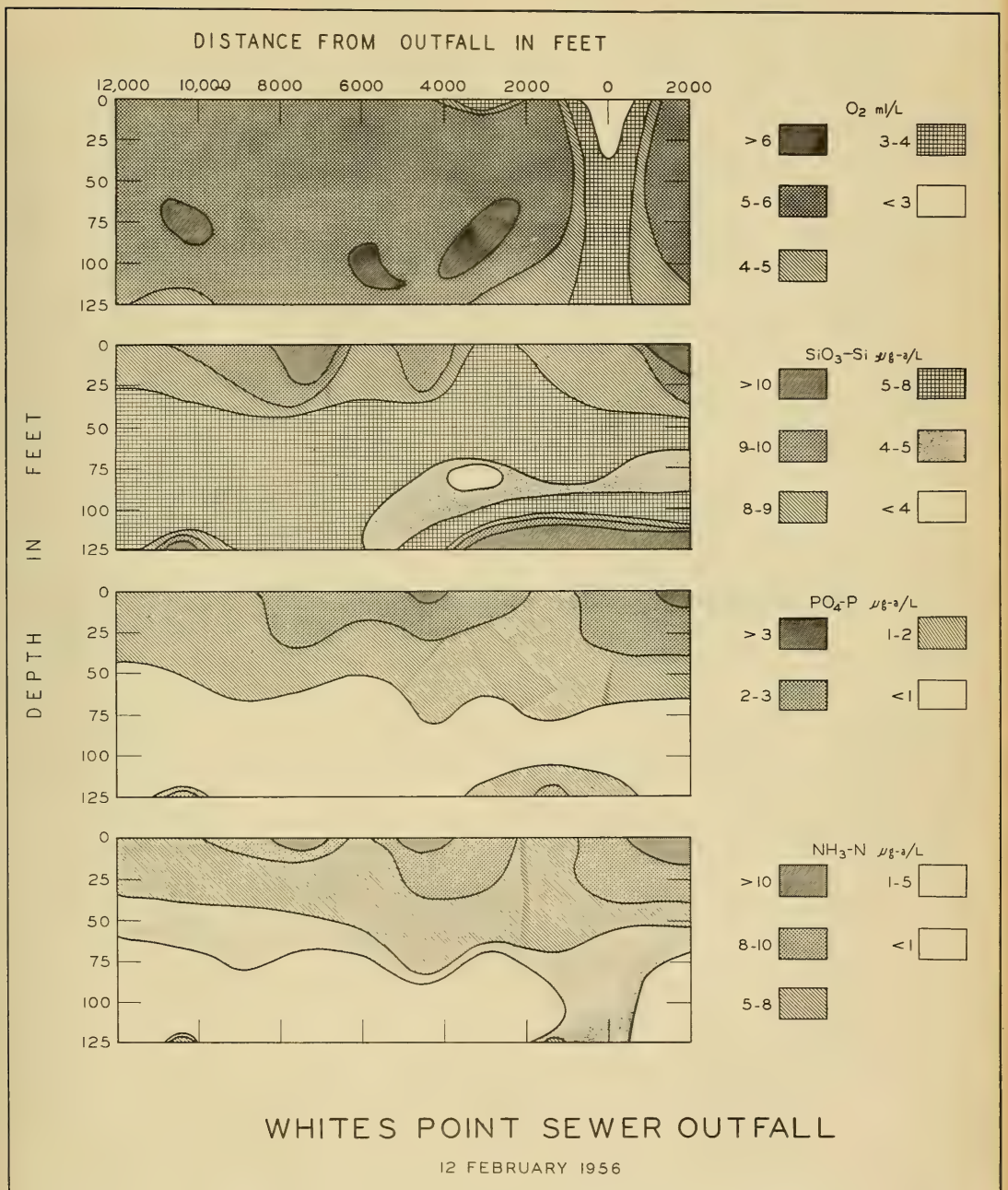
Whites Point Outfall

The vertical and horizontal distribution of nutrients in the water surrounding the Los Angeles County outfall at Whites Point differ significantly from the other two areas. The difference appears to be due to (1) a different type of treatment, (2) the depth of discharge, and (3) the mechanical method of discharge. The nutrient concentrations are lower in any given mass of water, spread through a greater thickness of water, and extend for greater distances (Figure 6). For example, low and high oxygen concentrations are generally less extreme than at the other two outfalls, the values remaining in a median range throughout the entire water column and for distances as much as six miles from the outfall.

Ammonia values decrease with depth, as at Orange County and Hyperion, but no areas of normal concentration occur within 11,000 feet of the outfall, and reasonably high ammonia has been measured near Point Vicente. The same is true with silicate and phosphate, although the silicate concentrations are greater on the bottom than at the surface and there is an intermediate layer of lower values.

From the nutrient averages (Figure 7) a variable decrease in ammonia with depth is noted, as well as pockets of concentration in the bottom layer which is otherwise low. The

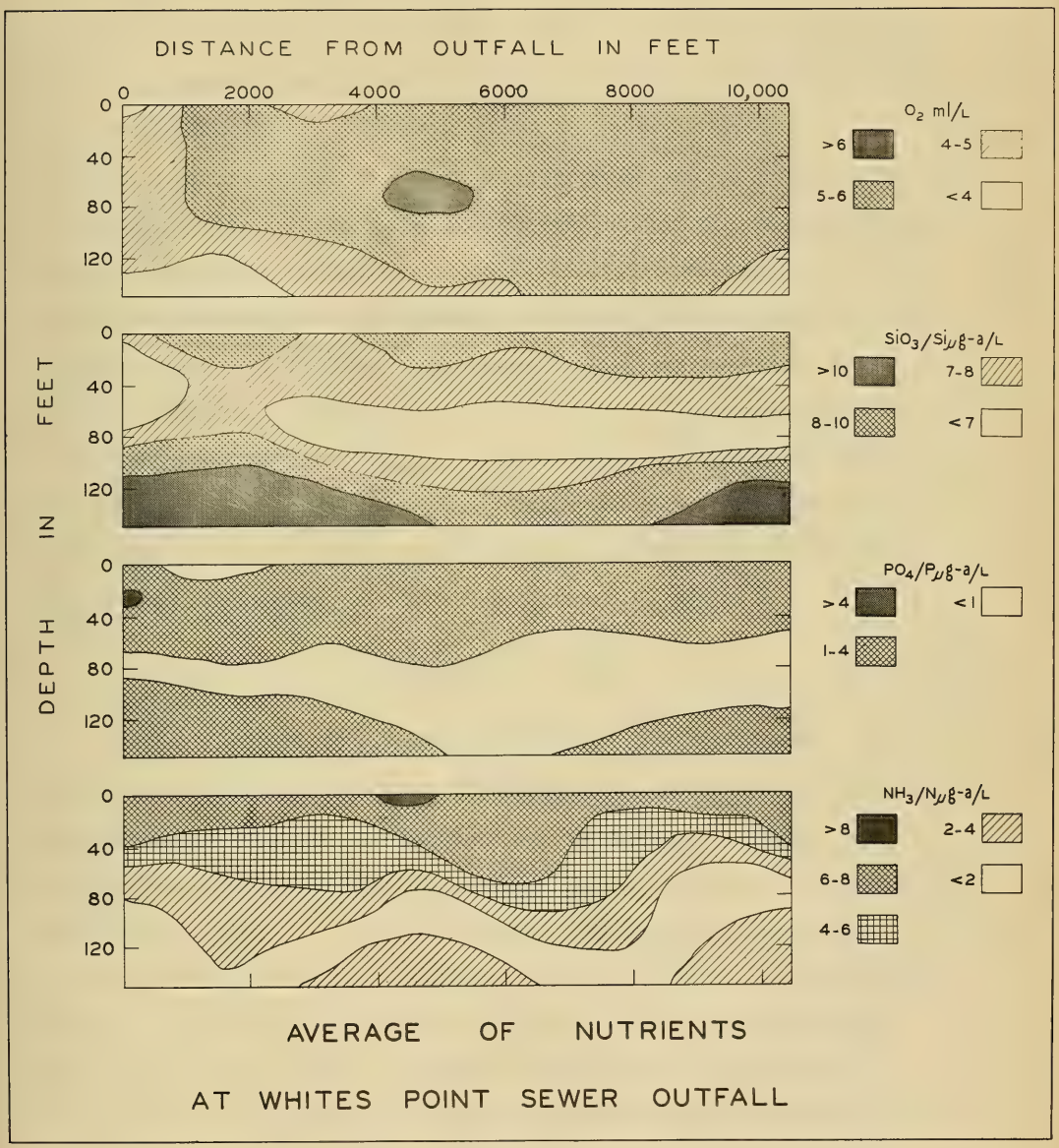
Figure 6. Vertical distribution of nutrients around Whites Point outfall on February 12, 1956.



WHITES POINT SEWER OUTFALL

12 FEBRUARY 1956

Figure 7. Average nutrient distribution around Whites Point outfall in February 1956.



AVERAGE OF NUTRIENTS

AT WHITES POINT SEWER OUTFALL

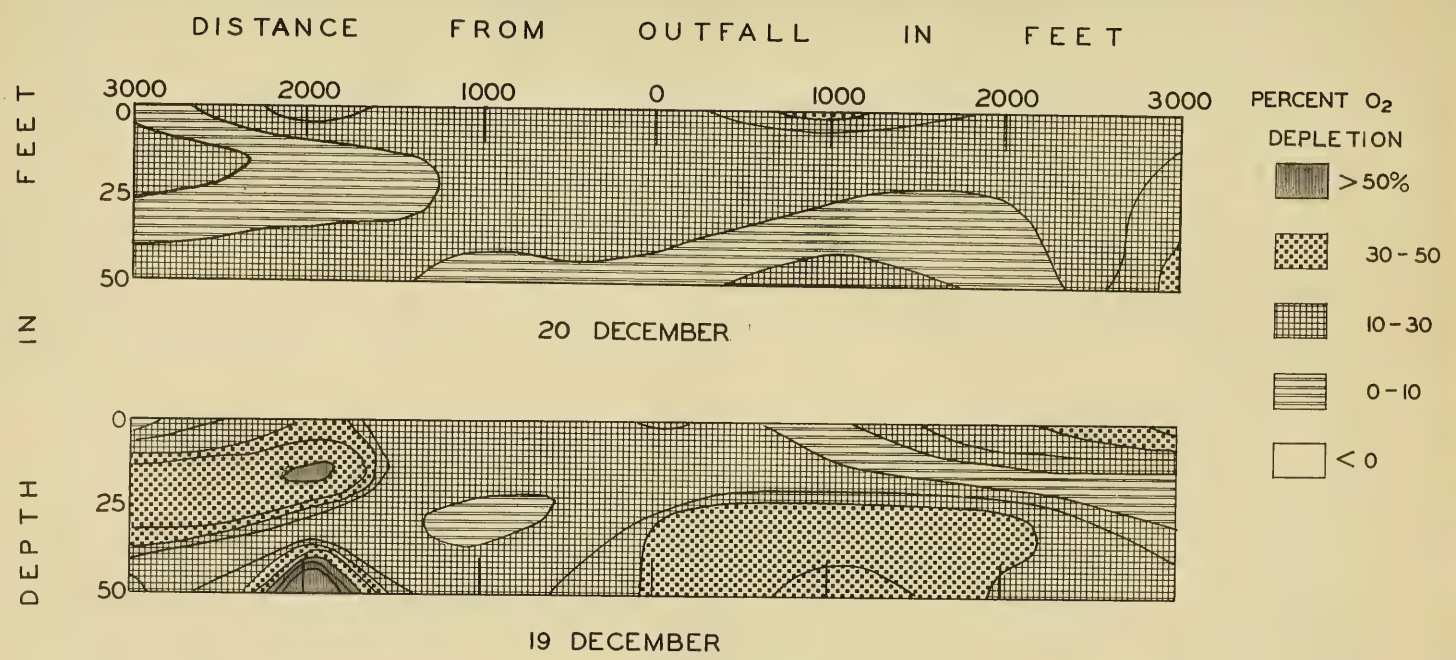
concentration of phosphate formed a top and bottom layer of moderate quantity. Silicate was highest near the bottom, low in the intermediate layers, and showed a moderate concentration at the surface

From the average profiles at the three outfall areas, it is apparent that there is a great increase in the concentrations of the nutrients in waters surrounding sewer outfalls. The distance that high values persist from the outfall appears to be determined by (1) the type of effluent (or treatment), (2) the mode of discharge, (3) the depth of discharge, and (4) the volume of discharge. (These conditions are not necessarily in order of importance.) Concentrations are increased measurably and sometimes appreciably as far as six miles from the discharge pipe.

Dissolved Oxygen

The dissolved oxygen concentration around the three outfalls was determined on each cast made for nutrient analyses. The deficiency in per cent below the saturated value (determined from the concurrent chlorinity and temperature) is shown in Figures 8 and 9, and was prepared by interpolation from data by Harvey (1954). The oxygen demand of the organic matter, ammonia, and BOD in the effluent is apparent at all outfalls The pattern developed by immediate oxidation is especially noticeable in the oxygen profile at Whites Point on February 12, 1956, where the bottom waters were moved to the surface by the rising effluent and the minimal value of 2.82 ml/L occurred (Figure 6). Pockets critically low in oxygen have

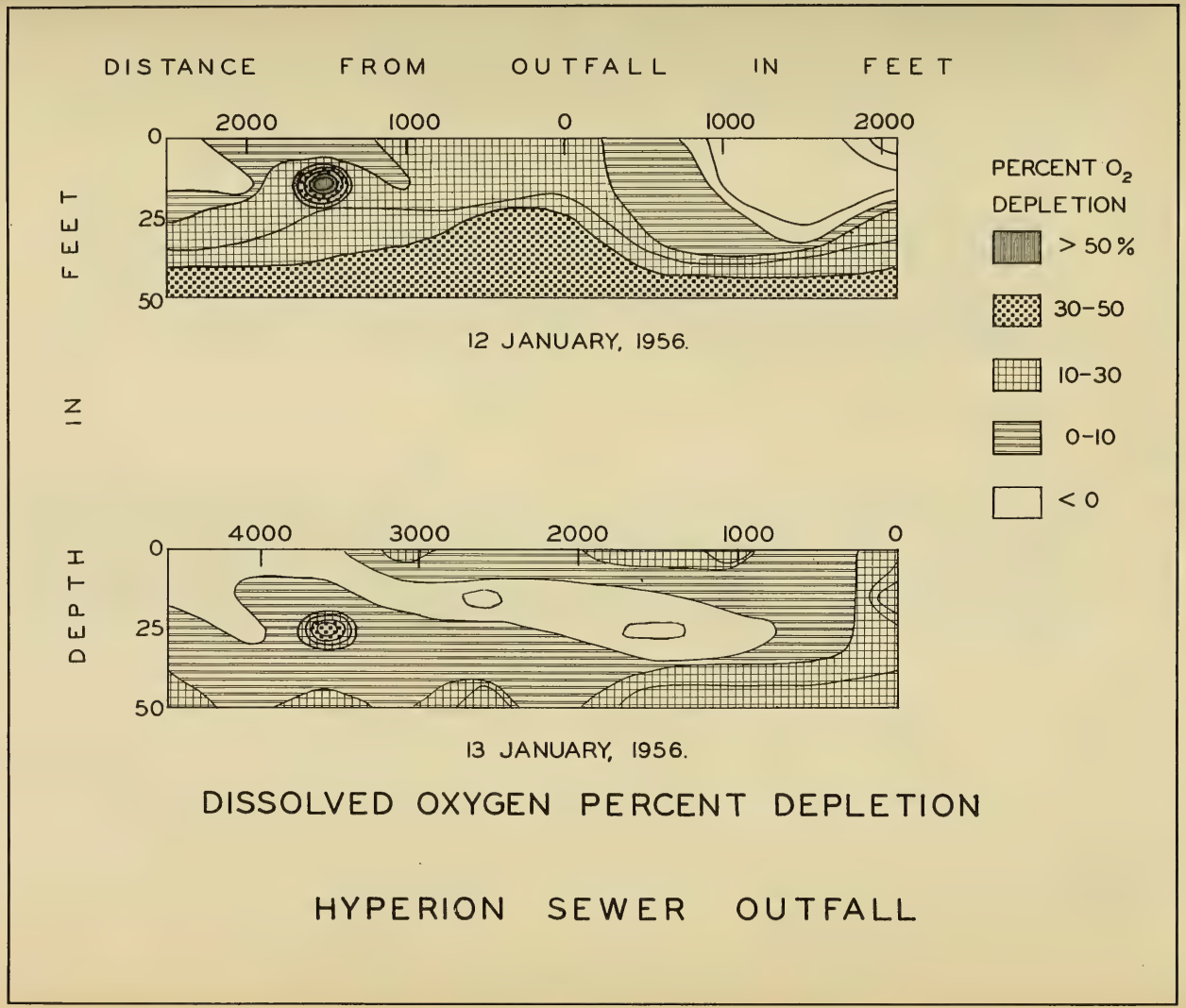
Figure 8. The deficiency of oxygen around Orange County outfall on December 19 and 20, 1955.



DISSOLVED OXYGEN PERCENT DEPLETION

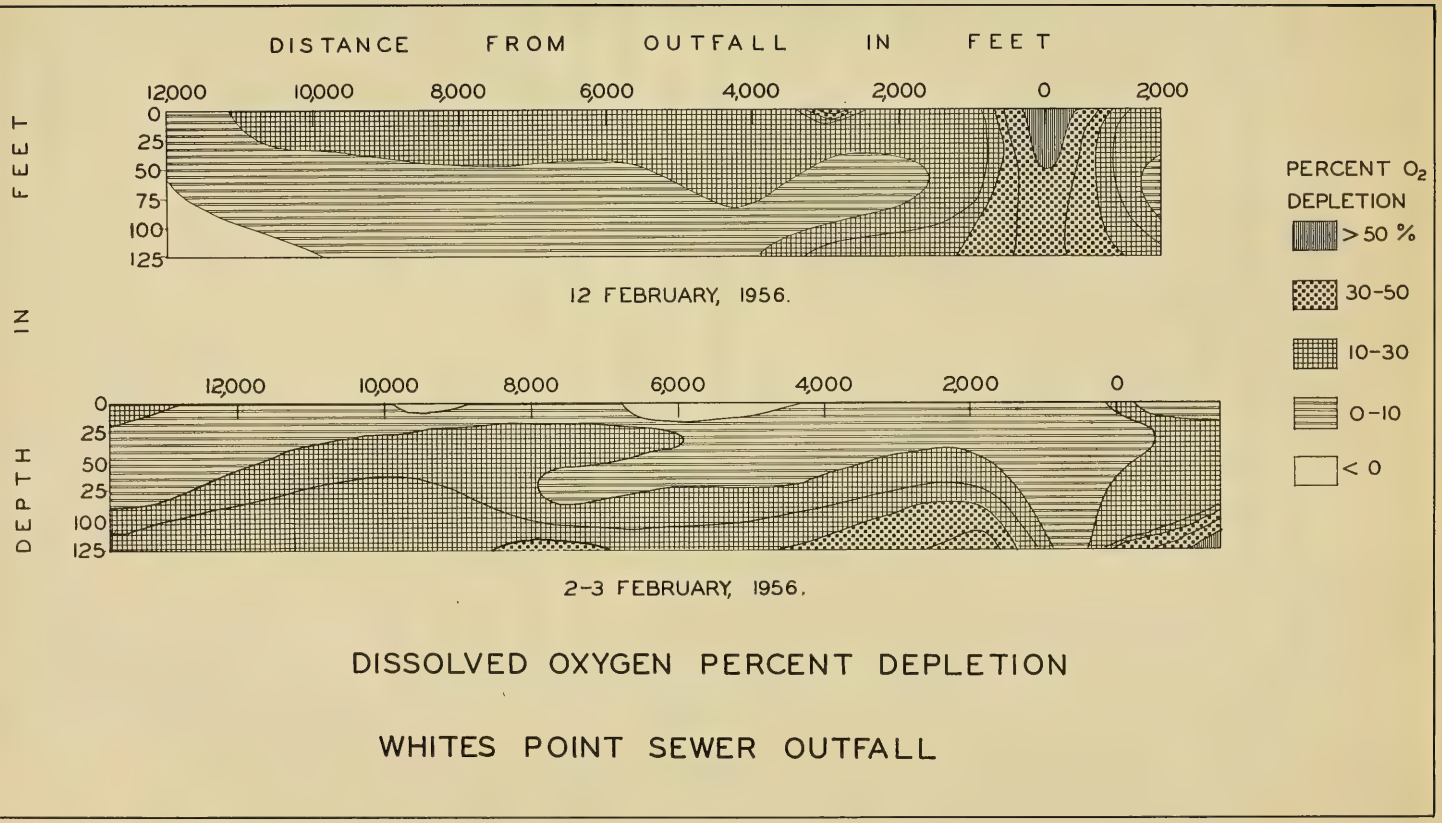
ORANGE COUNTY SEWER OUTFALL

Figure 9. The deficiency of oxygen at Whites Point outfall on February 12, 1956, and at Hyperion on January 12 and 13, 1956.



DISSOLVED OXYGEN PERCENT DEPLETION

HYPERION SEWER OUTFALL



DISSOLVED OXYGEN PERCENT DEPLETION

WHITES POINT SEWER OUTFALL

been found at various depths at Orange County and Hyperion. However, on occupying the same traverse on the following day these areas of high oxygen depletion were not found. For example, at the Orange County outfall on December 19, a column of water 2,000 feet west of the boil showed a depletion of 52% for the intermediate water and 77% below saturation for the bottom water. The latter is the minimum value (1.38 ml/L) found at any of the outfalls. On December 20, the intermediate water was only 6% and the bottom water 13% below saturation. The pockets of low oxygen depletion, as well as areas of high nutrient content, are ascribed to the hourly variations in the character of the effluent, and inadequate mixing of the effluent on discharge. From an examination of the average distribution of the dissolved oxygen, it is apparent that adequate ventialation occurs in all outfall areas.

The vicinity of the Hyperion outfall generally shows the highest oxygen values, whereas Orange County has the lowest. Of interest in the vertical sections showing oxygen deficiency (average values for January 12 and 13, 1956) is the tongue of supersaturated water that extended from the surface diagonally into the intermediate water about 1,500 feet from the boil at Hyperion (Figure 5). Saturated areas were also found around the Whites Point outfall at the surface, but at the Orange County outfall there was no water approaching saturation.

Discussion

The methods of diffusion at Whites Point and Hyperion probably account for the difference in the nutrient distri-

butions around these two outfalls from the simple pattern of surface dispersion that exists at the Orange County outfall. The character of the effluent, the oceanographic conditions, and the depth of water at Whites Point also contribute to form a still different pattern than at the other two outfalls.

The patchy distribution or pockets of high concentration of nutrients noted at considerable distances from the outfalls is explained by variations in the effluent as well as inadequate mixing on discharge. Phosphate determinations on the effluent before discharge were made at Orange County on December 19 and 20, by Mr. William Henderson, County Sanitation District of Orange County. On December 19, the phosphate determination showed a fairly even distribution in parts per thousand over the eight hour period that determinations were made. The range on this day was from 3.2 o/oo to 4.8 o/oo. On the other hand, the phosphate in the effluent on December 20 ranged from 0 o/oo to 16.0 o/oo throughout the same period of time. Although the analyst has stated that some trouble was experienced with the method of determination and the data are not necessarily to be considered completely reliable, the observations do indicate that not only a wide diurnal range, but a large hourly range does occur in the phosphate content of the effluent. The increase in phosphate on December 20 in the effluent also aids in explaining the great increase in phosphate observed at sea on this day, and the erratic distribution of the maximum concentrations.

Maxima and Minima

Maxima and minima values were selected from the data at all depths within 3,000 feet of the outfall. They give an indication of the dispersion of nutrients in the vicinity of the outfall areas (Table I).

Around the Orange County outfall occurred two of the highest concentrations and two of the second highest of the four nutrients determined. Whites Point, on the other hand, had three of the lowest values and one of the highest. The former are attributed to the simple dispersion of the nutrients at Orange County; the latter, among other previously mentioned factors, the better diffusion through a longer water column and the characteristics of the effluent. The chance that sampling at the various outfalls has missed the areas of very high concentration in the boil must also be considered.

Enrichment of the Outfall Area in Nutrients

An accurate calculation of dilution in the boil and the dimunition of nutrients with distance cannot be made because of the lack of information on the concentrations in the sewage. A comparison is made, however, with the concentration of salts in the surrounding shelf water at a sufficient distance from the outfall area to be free from the influence of the effluent. The factor in Table II gives the increase of maximum nutrient values in the vicinity of the outfall over the values obtained in normal sea water. With the exception of nitrate-nitrogen, the increase above the surrounding sea water is lowest at

TABLE I

MAXIMA AND MINIMA CONCENTRATIONS OF NUTRIENT SALTS AT ALL DEPTHS WITHIN 3,000 FEET OF THE OUTFALL

OUTFALL	DATE	MAXIMA μg-a/L	MINIMA μg-a/L
		SiO_3-Si	
Orange County	Dec 19	10.0	4.5
Orange County	Dec 20	26.0	5.0
Hyperion	Jan 12	21.0	5.0
Hyperion	Jan 13	23.0	5.0
Whites Point	Feb 2	16.0	6.0
Whites Point	Feb 12	13.0	4.5
		PO_4-P	
Orange County	Dec 19	4.4	0.2
Orange County	Dec 20	13.0	0.3
Hyperion	Jan 12	7.6	0.5
Hyperion	Jan 13	10.0	0.6
Whites Point	Feb 2	3.8	0.6
Whites Point	Feb 12	3.2	0.3
		NO_3-N	
Orange County	Dec 19	4.5	1.5
Orange County	Dec 20	18.0	1.5
Hyperion	Jan 12	6.5	0.0
Hyperion	Jan 13	4.5	0.0
Whites Point	Nov 3	18.0	0.7
Whites Point	Feb 2	20.0	0.0
		NH_3-N	
Orange County	Nov 18	32.0	0.0
Hyperion	Jan 12	46.0	0.0
Hyperion	Jan 13	68.0	0.0
Whites Point	Feb 2	15.0	0.0
Whites Point	Feb 12	11.5	1.5

TABLE II

ENRICHMENT FACTORS OF THE MAXIMUM NUTRIENT CONCENTRATIONS BASED ON SURROUNDING NORMAL SEA WATER

Nutrient	Distance from outfall	Depth	µg-a/L	Enrichment factor
		ORANGE COUNTY December		
SiO_3-Si	outfall	surface	26.0	4.3
PO_4-P	outfall	surface	13.0	21.6
NO_3-N	outfall	surface	18.0	12.0
NH_3-N	outfall	surface	32.0	80.0
		HYPERION January		
SiO_3-Si	2,000'	surface	23.0	5.7
PO_4-P	2,000'	surface	10.0	25.0
NO_3-N	1,000'	45'	6.5	13.0
NH_3-N	3,000'	surface	68.0	170.0
		WHITES POINT February		
SiO_3-Si	700'	125'	16.0	2.9
PO_4-P	700'	125'	3.8	7.6
NO_3-N	1,500'	125'	20.0	20.0
NH_3-N	1,500'	surface	15.0	37.5

Whites Point. The maximum increase is at Hyperion where ammonia-nitrogen was concentrated 170 times over normal, 3,000 feet from the outfall at the surface.

In Table III the enrichment of the surface water at 1,000 foot intervals from the outfall was made from the average values of the nutrients on both days of sampling and on both sides of the boil. Since factors are computed from the averages, the decrease with distance appears small.

PLANKTON NEAR THE OCEAN OUTFALLS

On all cruises for bacterial studies, plankton casts were made at each hydrographic station. The waters surrounding the Orange County and Los Angeles County outfalls were relatively free of plankton prior to December 19, 1955. Average volumes recovered were less than 0.5 ml, and there was no increase in the area of the sewage boil. None of these samples was retained, but the volume was noted at each station.

On December 19 and 20, 1955, near the Orange County outfall, the volume of plankton in each haul was markedly greater than earlier in the year. Many recoveries contained 10-14 times the earlier volume of plankton and at 3 stations the volume was 30 times greater. The most abundant organisms were diatoms (53% average) and dinoflagellates (31% average). Within the diatom group, Chaetoceros sp. was most numerous followed closely by Ditylum sp. and Coscinodiscus sp. Of the dinoflagellates, Ceratium furca was the most common and Ceratium tripos the next. Zooplankton average 14% of each haul and were mainly nauplius larvae (Table IV).

TABLE III

SURFACE ENRICHMENT FACTORS OF THE AVERAGE NUTRIENT CONCENTRATIONS AT 1,000 FOOT INTERVALS FROM OUTFALL BASED ON SURROUNDING NORMAL SEA WATER

ORANGE COUNTY
December

Nutrient	Outfall	1,000'	2,000'	3,000'	4,000'
SiO_3-Si	2.8	1.8	1.1	1.0	
PO_4-P	12.0	4.5	5.0	1.5	
NO_3-N	9.8	2.2	2.1	1.5	

HYPERION
January

SiO_3-Si	3.2	4.1	4.0	2.8	2.9
PO_4-P	17.5	15.0	15.0	8.7	8.5
NO_3-N	2.2	1.8	2.1	2.0	1.3
NH_3-N	97.5	142.5	82.7	78.2	43.5

WHITES POINT
February

Nutrient	Outfall	700'	1,500'	1,800'	2,000'	3,000'
SiO_3-Si	1.7	1.5	2.6	1.8	1.8	1.8
PO_4-P	3.2	2.0	4.7	2.0	2.5	5.0
NO_3-N	0.0	3.5	5.0	4.5	0.0	---
NH_3-N	17.5	12.5	22.7	13.7	26.2	20.0

TABLE IV

MONTHLY AVERAGE
PER CENT OF PLANKTON

Classification	J	F	M	A	M	J	J	A	S	O	N	D
Dinoflagellata	25	42			6	54		35	35			29
Ceratium furca	13	15			<1	1		7	7			11
C. fusus	--	1			<1	1		1	<1			<1
C. tripos	3	18			<1	33		11	6			10
Dinophysis sp.	<1	<1			--	<1		4	3			1
Noctiluca sp.	2	4			1	<1		<1	<1			1
Peridinium sp.	7	4			5	19		12	19			6
Diatomacae	66	35			79	17		20	23			56
Asterionella sp.	<1	<1			<1	<1		<1	--			<1
Biddulphia sp.	<1	<1			--	--		--	--			2
Chaetoceros sp.	37	24			71	10		9	10			19
Coscinodiscus sp.	11	5			2	5		4	1			12
Ditylum sp.	13	3			<1	<1		3	9			16
Rhizosolenia sp.	3	3			5	2		3	2			6
Stephanopyxis sp.	<1	<1			--	<1		<1	<1			1
Thalassiosira sp.	2	<1			<1	<1		1	1			<1
Zooplankton	9	23			15	29		45	42			15
Arrow worm	--	<1			--	--		<1	<1			--
Branchiopod	<1	<1			--	<1		1	<1			<1
Copepod	1	6			2	5		8	8			2
Eggs and egg cases	<1	2			<1	4		3	5			<1
Globigerina sp.	<1	3			<1	1		2	<1			1
Heliozoan (?)	3	3			4	4		7	10			2
Larvae												
Annelid larvae	<1	<1			<1	<1		<1	1			<1
Nauplius (copepod and barnacle)	4	7			6	11		15	10			7
Pluteus (brittlestar)	--	<1			--	<1		--	<1			<1
Veliger (gastropod)	--	<1			--	<1		--	<1			--
Pelecypod (embryonic)	--	<1			<1	<1		--	--			--
Radiolaria	--	--						--	--			--
Tintinnid (favella sp.)	1	<1			1	<1		3	2			2
Tunicate	<1	2			1	4		5	6			1

During the days of January 12 and 13, 1956, similar volumes of plankton were in the waters near the Hyperion outfall in Santa Monica Bay. The volumes did not equal those along the Orange County coast except in the boil, but were still 8-10 times that noted in Santa Monica Bay in the fall months. Again the most abundant forms were the diatoms, which averaged 66% of the total plankton, whereas the dinoflagellate volume was 23%. The diatom Chaetoceros sp. was by far the most common, being 42% of the average haul. Ceratium furca was again the most abundant dinoflagellate. Of the zooplankton, nauplius larvae constituted 4% of the population.

These quantities of planktonic forms continued to be present in the waters of the Los Angeles area through February. In this month on the 2nd, 3rd, and 12th, equivalent volumes were recovered near the Whites Point outfall. As before, the volume was greatest in the boil area, but remained relatively high at distances of several thousand feet. Diatoms remained the most abundant group (60%), but on these days and in this area, zooplankton were more common than the dinoflagellates (Figure 10). Copepods represented 10% of each haul and the Foraminifera Globigerina sp. was present, averaging 4% of the total numbers.

The plankton population was low in March and April and the first part of May 1956, the volumes in net hauls being similar to those obtained during October and November 1955. In the latter part of May the numbers increased. Diatoms composed 79% of each net haul, Chaetoceros sp. representing

Figure 10. Plankton abundance in the waters of the Los Angeles area during the winter of 1955-1956.

PER CENT PLANKTON IN COASTAL WATERS OF THE LOS ANGELES BASIN

72% of the population. The remaining diatoms were Coscinodiscus sp. and Rhizosolenia sp. Zooplankton were next in abundance (15% of each net haul), and of the zooplankton, nauplius larvae constituted 6% of the population.

High plankton numbers remained in the waters of Santa Monica Bay and the Orange County coast through the months of June and July. In the latter part of May and in the months of June and July, though, dinoflagellates made up the bulk of the population. During this period, the dinoflagellates constituted 66% of the total, with Ceratium tripos the most abundant form (30%). The dinoflagellate Peridinium sp. represented 18% of each net haul, and the remaining dinoflagellates were other species of Ceratium. The diatoms during this period represented only 12% of the total population, whereas zooplankton represented 21%. This trend followed through June until in July, the dinoflagellates made up 73% of the total plankton. In this month, the dinoflagellate Ceratium fusus was the most common, comprising 33% of each net haul. Diatoms were more abundant than zooplankton (16%) and Chaetoceros sp. represented 15% of the population.

Ocean Conditions

Temperature

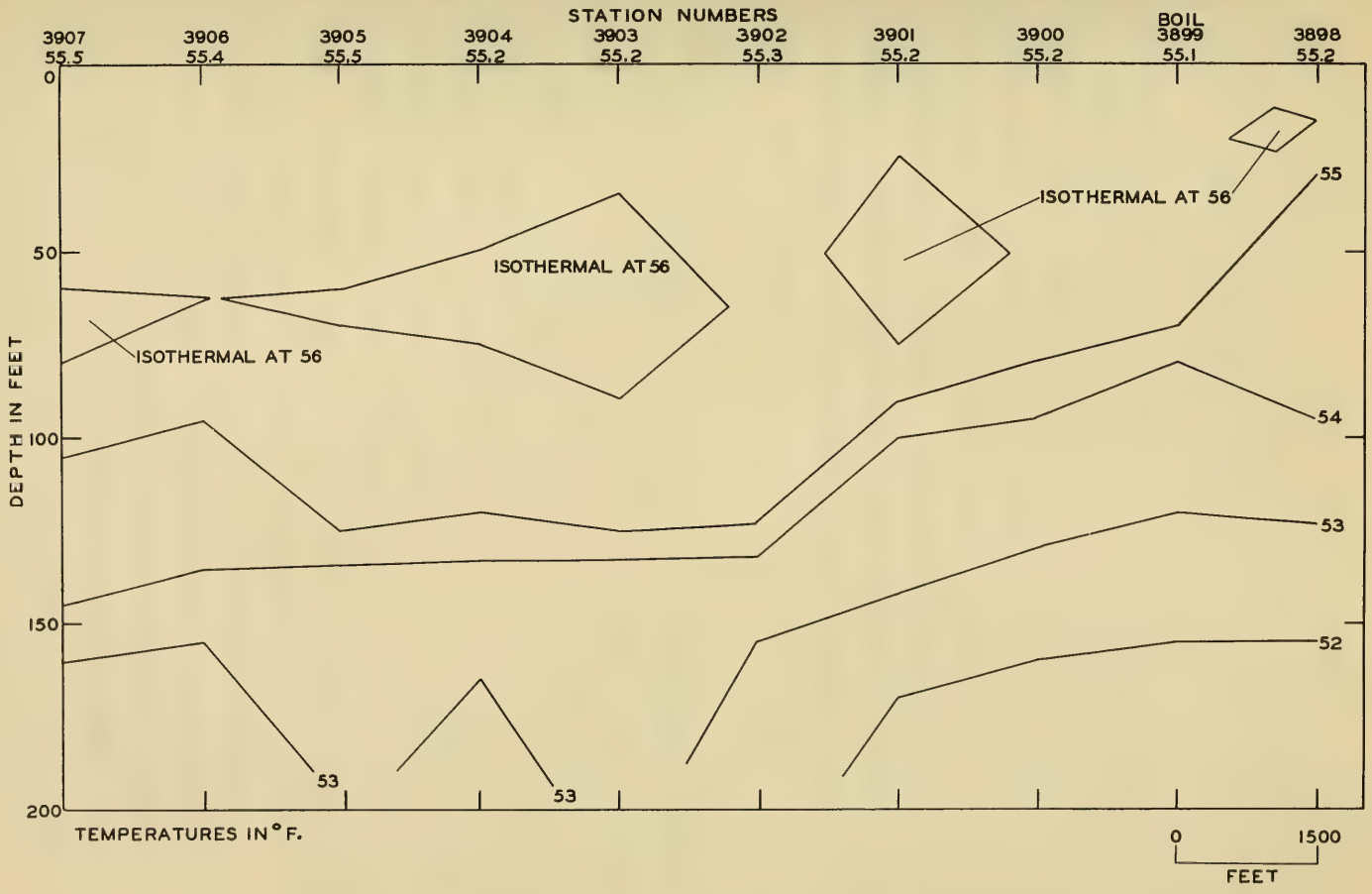
In the winter months, surface temperatures ranged from a low of 55.4°F near Hyperion to a high of 57.9°F near Orange County. At these two outfalls the water was nearly isothermal, there being a 2 to 3°F range from 55 feet to the surface. Near the Whites Point outfall the surface temperatures were

similar to those in Santa Monica Bay, averaging 55.5°F, and the range from 150 feet to the surface was about 3°. True isothermal conditions extended below 50 feet, where a tendency toward a thermocline occurred. At or slightly below this depth, several masses of warm water were noted. On February 12, these subsurface inversion layers were distinct and more or less continuous for two miles north of the outfall area (Figure 11).

During March the surface water temperatures rose to a maximum of 58°F. Subsurface temperatures were still more or less isothermal in the vicinity of the Orange County and the Hyperion outfalls. Near Whites Point, however, there was a range of from 7 to 8°, from 150 feet to the surface, and maximum surface temperatures were slightly lower (57.2°F). In April, maximum surface temperatures reached 63°. In the vicinity of the two shallower outfalls the subsurface temperature range averaged 8°, and the greatest range was 10°F. At the Whites Point outfall, a range of 10° was common and 11 and 12° frequent.

In the latter part of May, when increased numbers of plankton began to occur in the waters, surface temperatures remained at approximately 63°, but the temperature spread from 55 feet and from 150 feet increased sharply. In June the maximum surface temperature was 65°. In the vicinity of the two shallower outfalls, temperatures at the bottom began to rise so that again more or less isothermal conditions existed. At Whites Point, on the other hand, an increased spread was noted from that of the other months. For example,

Figure 11. Vertical temperature distribution at Whites Point outfall on February 12, 1956.



TEMPERATURE CROSS-SECTION AT WHITES POINT ON FEB. 12, 1956

on June 19, the temperature on the bottom was 52° and at the surface, 64.5°, a spread of 14.5°F.

Salinity

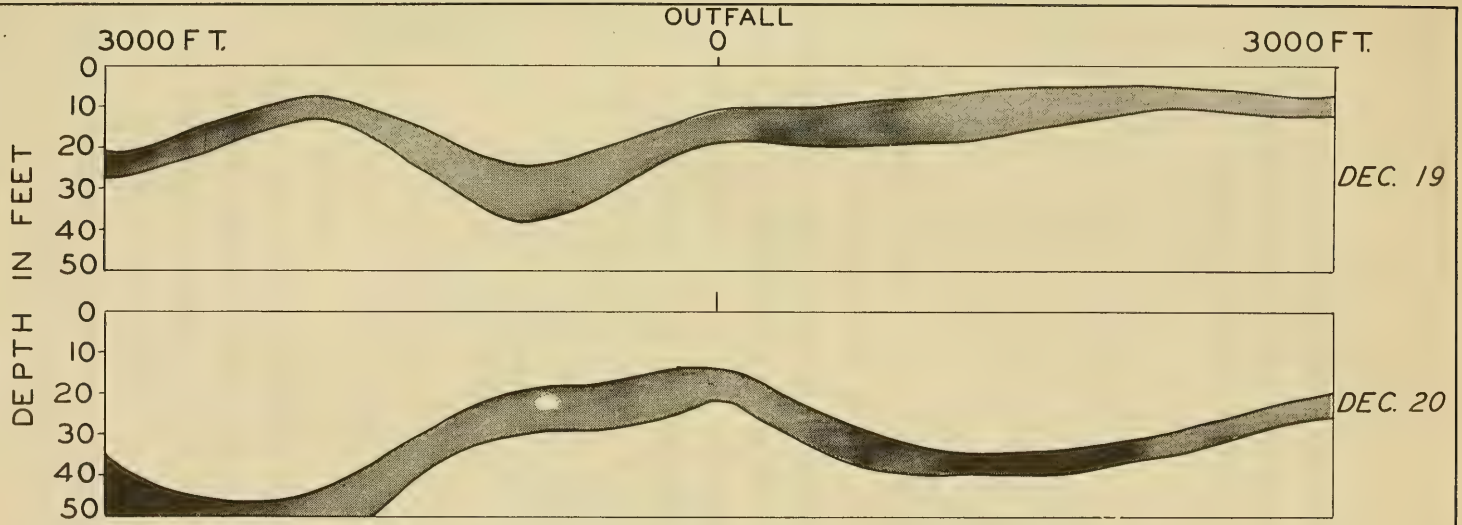
Except in the immediate vicinity of the boil, surface salinities were normal on all days of increased plankton growth around Orange County and Hyperion outfalls. Near Whites Point, lower salinities during the winter months are attributable to surface drainage following moderate rainfall. Subsurface salinities were also normal, except near Whites Point where isothermal layers and rain runoff caused mild variations.

Water Transparency

There was no unusual discoloration of the surface waters near the three outfalls during the winter months, even though the recovered plankton samples were rust or reddish-brown in color. During May and June, a tinge of brown could be detected when high plankton numbers were present. This discoloration was slight and not visible to some observers. Surface transparencies frequently gave a Secchi disc reading of 20 to 25 feet, and at Orange County, 30 to 35 feet. Such transparencies were, of course, present outside the sewage field. Within the field typical readings of 4 to 10 feet were obtained.

Subsurface transparencies taken with the hydrophotometer were typical, except at Orange County on December 19 and 20, 1955. On these two days, a distinct subsurface layer of low light transmission occurred and is attributed to the concentration of plankton (Figure 12). On the 19th, the layer

Figure 12. Subsurface layers of low light transmission around the Orange County outfall on December 19 and 20, 1956.



DEPTH AND THICKNESS OF PLANKTON LAYER
DECEMBER 19 & 20, 1955
VICINITY OF ORANGE COUNTY SEWER OUTFALL
SECTIONS PARALLEL TO COAST

varied from 10 to 25 feet deep, averaging about 15 feet. On the 20th, the stratum settled in the water to depths of 20 to 45 feet, but remained about the same thickness.

Plankton Distribution

The study of plankton distribution in time and space and the oceanographic conditions responsible for the generation of plankton blooms have been the subject of much research by many observers and in many areas (Harvey, 1955; Allen, 1941). In certain areas, such as the west coast of Florida, the destruction to fish populations by blooms is often disasterous, and has therefore demanded extensive research. But with all the work, both in the laboratory and in the field, there is today no definite evidence as to the oceanographic conditions responsible for generating rapid reproduction amongst plankton. During the course of this survey, a detailed attempt was made to determine if a correlation exists between the growth of phytoplankton and increased nutrients discharged by sewer outfalls. It is believed that some confirming evidence has been gathered, but so many inconsistencies still exist that certainly no definitive conclusions can be reached on all phases of the problem.

Under natural conditions (no sewage discharge) oceanic waters may enter the nearshore zone without being greatly influenced by conditions peculiar to the immediate surrounding region. Allen (1941) has noted that it is unwise to suppose that the phytoplankton is necessarily a product of the nearshore area, or a resultant of the environmental conditions

there. In a period of long continued calm, or in a whole year of mild weather, the local influence may be notable. However, in most years there must be long periods in which the local influence is relatively negligible in determining the condition of the populations. Doubtless, many of the striking peculiarities of occurrence and abundance in different seasons and years are due to differences in degrees of dominance of local influences. The only reliable conclusion possible seems to be that the coastal waters may or may not exert noticeable influence upon the population within its limits, depending on the extent to which water movements permit its conditions to operate before the populations shift to other localities or disappear.

In the sea, a dense population of a particular phytoplankton may appear in a locality for a few hours or days, and not be strongly represented again for years. A plant or population may appear at a level at which it is not usually found, or it may be found most often at a certain level in one locality and at a different level in another. Populations nearshore and at considerable distances offshore may be closely similar, although recognizable differences are more likely to be found. Inasmuch as the shallow depth of water is sufficient to constitute a fundamental difference from any offshore habitat, it is probable that the presence of similar populations in places more or less distant from each other is not necessarily an indication that habitat conditions are also similar. Certain circumstances may be responsible for such an irregularity. Particular environmental features may be so prominent over a wide area at a given

time that they cause production of definitive populations in spite of local dissimilarities of other features which are recognizable but not detrimental. Two populations, inshore and offshore, may have drifted into separate localities from a region of common origin so recently that they appear to retain the earlier likenesses in recognizable form, although already acquiring important differences. A population may develop in an offshore area and expand into nearshore waters, adapting itself to environmental features of the new area as the expansion progresses. Thus, the constant movements of the plants in one direction or another add enormously to the difficulty of conducting researches and of understanding the results.

Considering all of these conditions, the wonder may be not the inconsistencies of plankton near the three outfalls during the past year, but rather the constancy of their occurrence.

Distribution with Distance from the Outfall. The noted distribution of plankton with distance from the three outfalls apparently corresponds to the increased nutrients in the discharge area. In Figure 13, the average volume of plankton in the winter has been plotted against distance from the boils, and in Figure 14, the average numbers in June and July at Orange County. Each shows a remarkable increase within 1,000 feet of the boil, an increase which is greatest at Whites Point. The average volume at distances greater than 5,000 feet was 1.1 ml per net haul when the data for these curves were gathered. This was double the amount in the waters prior to

Figure 13. The average volume of plankton in the winter of 1955-1956 versus distance from the sewer outfalls.

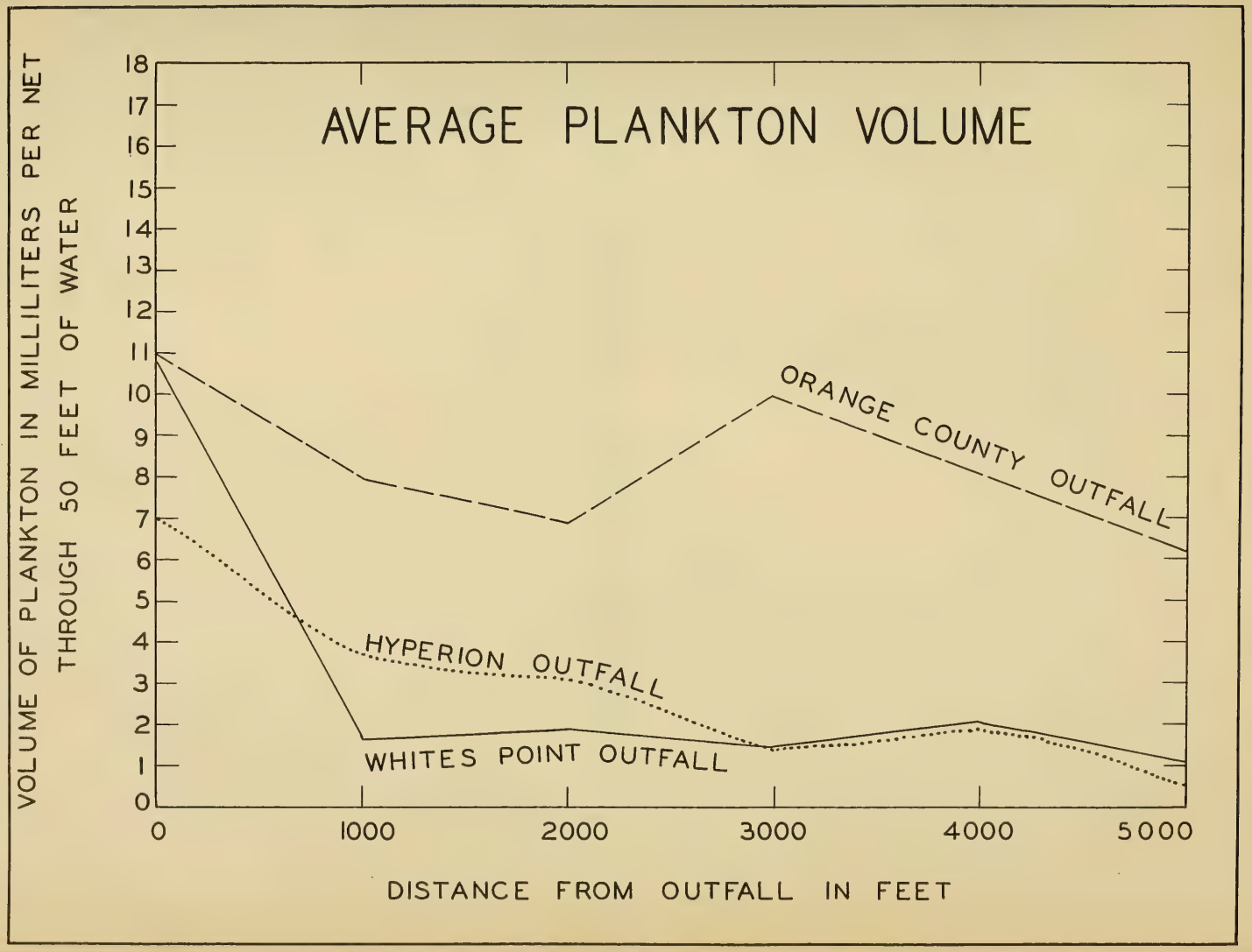
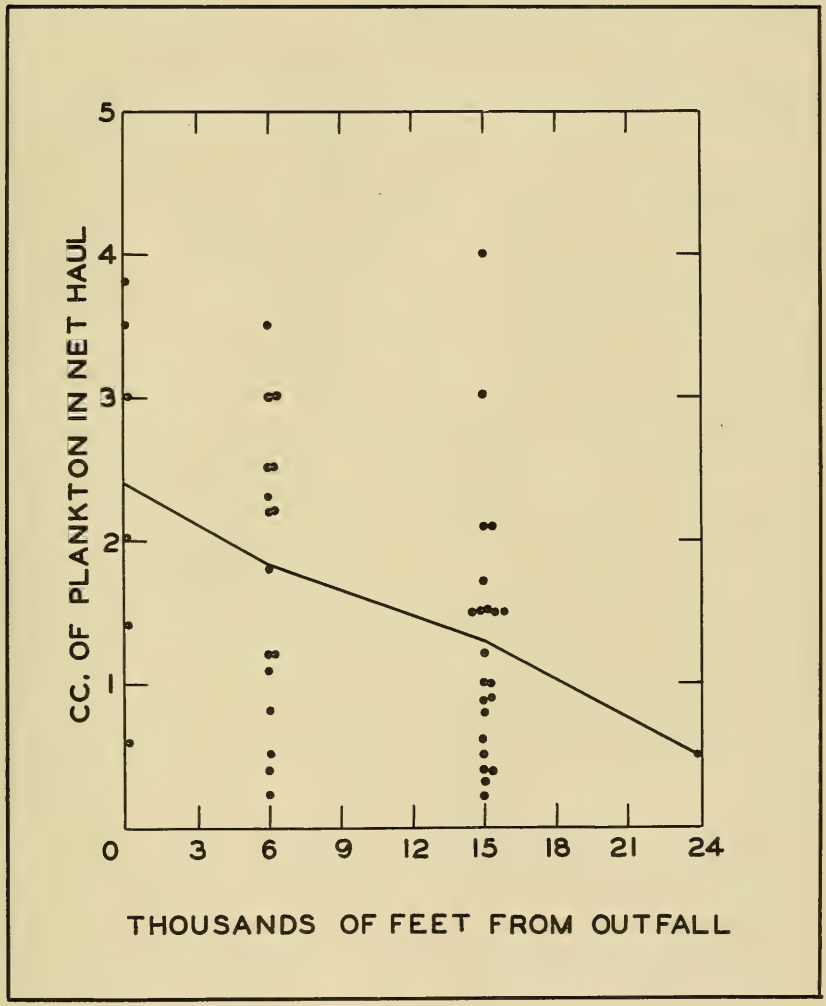

AVERAGE PLANKTON VOLUME
VOLUME OF PLANKTON IN MILLILITERS PER NET THROUGH 50 FEET OF WATER
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1000
2000
3000
4000
5000
DISTANCE FROM OUTFALL IN FEET
ORANGE COUNTY OUTFALL
HYPERION OUTFALL
WHITES POINT OUTFALL

Figure 14. The average plankton numbers in June and July 1956 versus distance from the Orange County outfall.

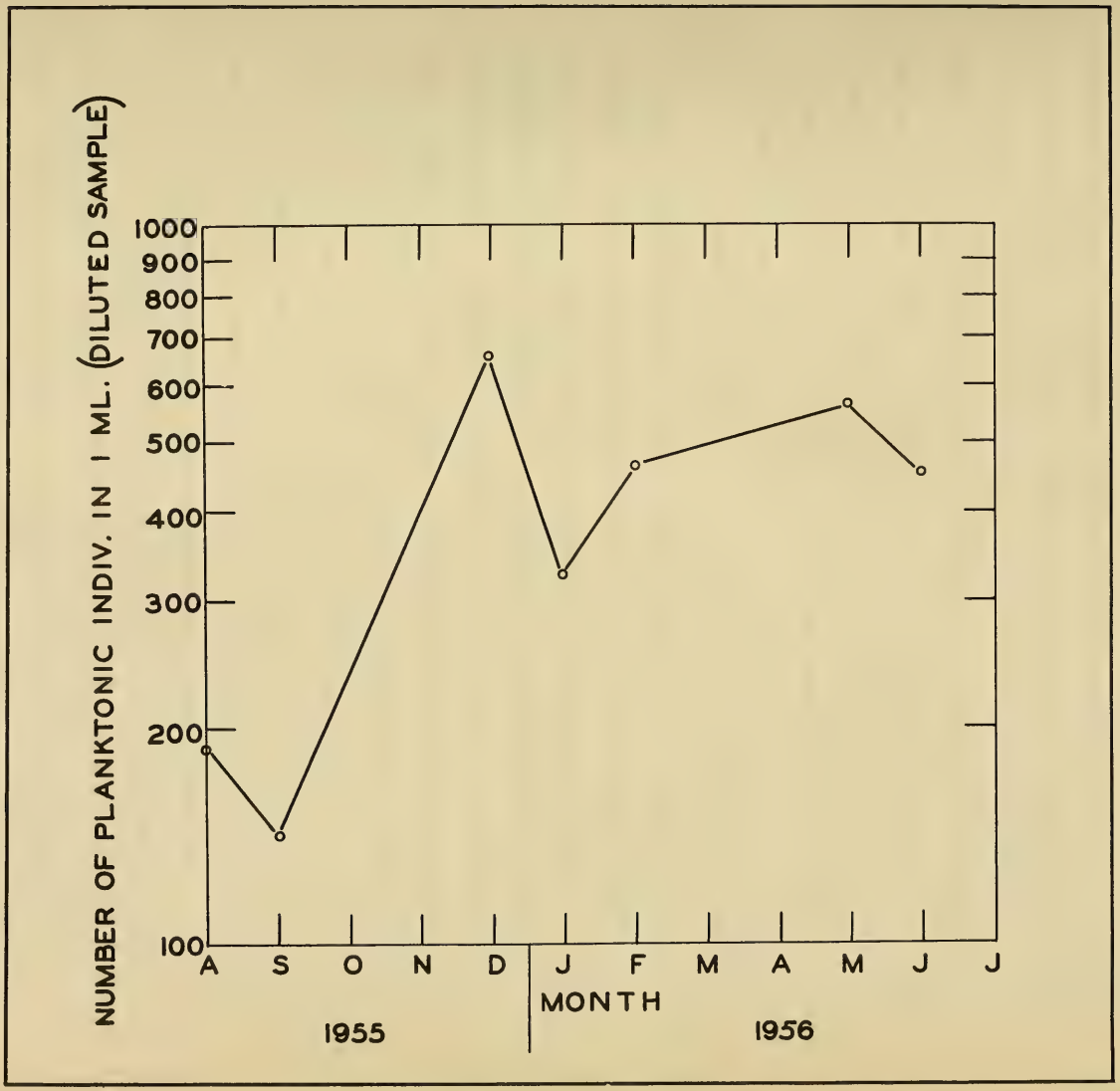

CC. OF PLANKTON IN NET HAUL
5
4
3
2
1
0
3
6
9
12
15
18
21
24
THOUSANDS OF FEET FROM OUTFALL

December 19, 1955, and in March and April, 1956. The average increase in volume at Orange County and Whites Point was about eleven times that in the surrounding waters, and at Hyperion the increase was seven times. Furthermore, at Orange County, there were stations where the increase was 30 to 40 times that in the nearby waters.

In several samples, the greater volume in the boil was accompanied by an increase in the percentage of zooplankton. The increase was due to fewer numbers of dinoflagellates; the diatom numbers remaining more or less constant. All samples from boil areas did not show this increase. Some, particularly those at Orange County, showed no change from samples taken several thousand feet from the outfall.

Distribution with Time. The average number of plankton for each month from August 1955 through July 1956 are shown in Figure 15. The lowest numbers occurred in the latter part of September and in October 1955; the maximum for the year in December. There was a secondary low in January and then began a general rise to the secondary maximum in May. This seasonal distribution does not correlate with the average for southern California noted by Allen (1941) in his studies extending over a period of 20 years. His normal distribution showed a peak abundance in April; in general decrease through October followed by a slight increase in November; then a rapid drop to the winter low. However, in 1932, numbers of dinoflagellates in December were nearly as high as the maximum in April. A similar condition occurred at Oceanside in 1922 and 1924, when diatoms were high in December, although not at maximum concen-

Figure 15. The average number of plankton for each month from August 1955 through July 1956.

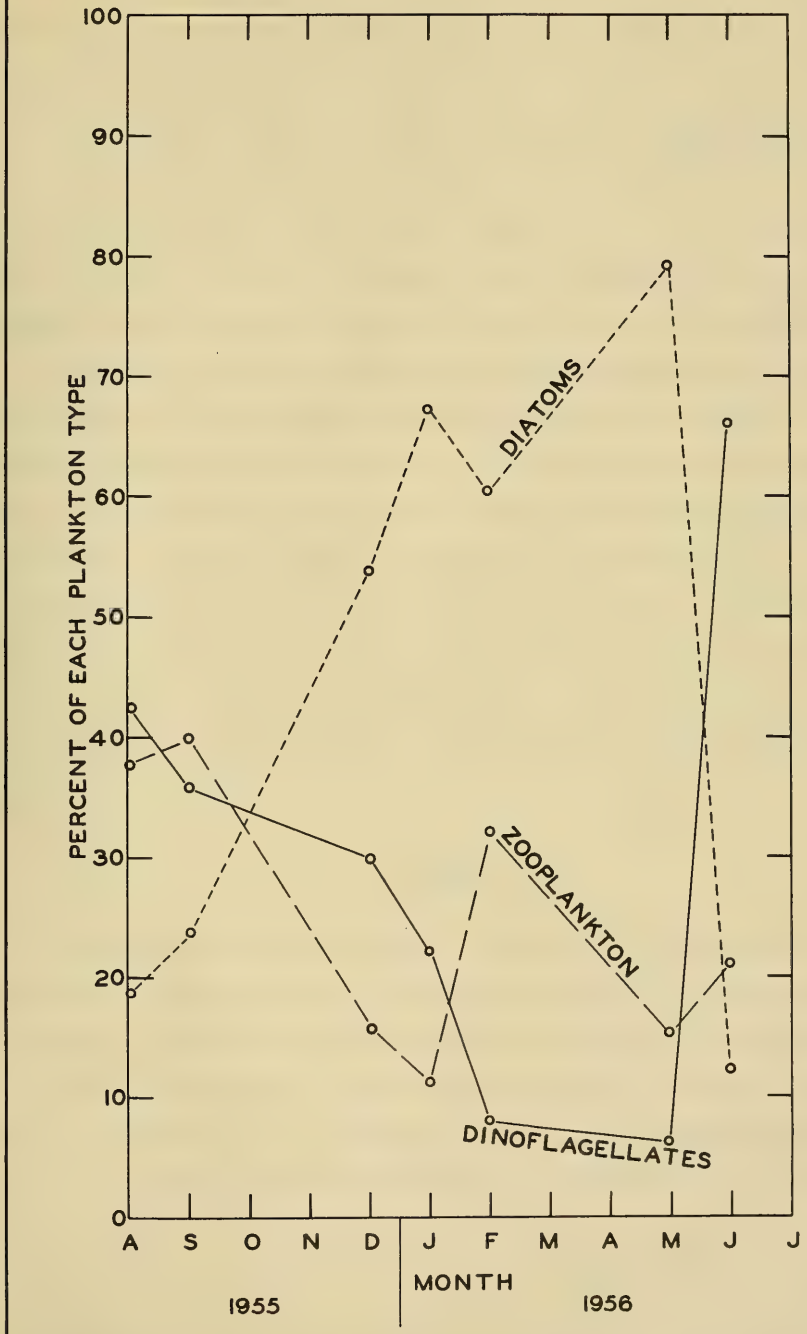

NUMBER OF PLANKTONIC INDIV. IN 1 ML. (DILUTED SAMPLE)
1000
900
800
700
600
500
400
300
200
100
A
S
O
N
D
J
F
M
A
M
J
J
MONTH
1955
1956

tration. It appears, therefore, that in some years increased populations may be expected in the winter months. It is conceivable that the great quantities of nutrients contributed by the sewer outfalls may result in this distinction between what is the norm for seasonal distribution and the distribution during the past year. If this were so, however, one would expect to find a variation in the distribution of nutrients during this period, or differences in the sewage constituents. Such are not the case.

The nutrients are more or less in a steady state condition in their contribution to the coastal waters. In Biscayne Bay, Florida, where sewage is discharged into the upper end of the bay, such a condition leads to plankton volumes that are uniformly higher in the upper portion of the bay than in the lower (Smith, Williams, and Davis, 1950). However, due to the many variations existing in the water and currents in the open ocean, as noted above, steady state plankton growth could not be expected except in such a confined environment.

The variation in the different groups of plankton through the past year is shown in Figure 16. The greatest per cent of dinoflagellates occurs in the month of June. This is followed by a continual but gradual decrease through May. The diatoms are greatest in percentage in the cold months of the year, decrease in June, and then follow a gradual rise to their greatest numbers in January. Zooplankton reach their peak in September, where they constitute a greater percentage than either of the other two groups. When diatoms are the most abundant plankton type, the diatoms Chaetoceros spp. are

Figure 16. Variation in the three groups of plankton from August 1955 through July 1956.


100
90
80
70
60
50
40
30
20
10
0
PERCENT OF EACH PLANKTON TYPE
DIATOMS
ZOOPLANKTON
DINOFLAGELLATES
A
S
O
N
D
J
F
M
A
M
J
J
MONTH
1955
1956

always the most common. On the other hand, when dinoflagellates constitute the greatest numbers, several species may contribute. The main contributors are Ceratium tripos and Ceratium fusus. The greatest number of organisms within the zooplankton group are normally nauplius larvae and copepods. All others are generally low. However, in August and September 1955, radiolarians were as numerous or more so than the other zooplankton.

Although continuous sampling was not conducted in each area, because of the similarity of oceanographic conditions and the proximity of the outfalls to each other, it is likely that no major differences existed in the dominant organisms in the three areas. Allen found this to be the case in localities as far apart as La Jolla and Oceanside. Therefore, it is believed that differences which may have been noted in the percentages at the different outfall areas during the year were probably due to seasonal variations rather than differences due to locality.

SUMMARY

It is apparent both from the increase and volume of plankton and the increase in nutrient salts in the proximity of the boil that the presence of sewage has a great effect on the reproductive rate of planktonic organisms. The question arises, therefore, as to whether or not the increased nutrients initiate a rapid reproductive growth of plankton or a plankton bloom. It can be seen that there is by no means a steady state of plankton numbers in the vicinity of sewage outfalls. There is, however, a steady state condition of the nutrient concen-

trations. Although there are variations that may be daily, weekly, or annual, these variations are minor in comparison with the great quantities of nutrients in the waters immediately surrounding the discharge point. In all cases, when numbers of plankton were high in the vicinity of a sewer boil, the numbers were also reasonably high in the waters which were not affected by the sewage discharge. On days when there were no plankton, or at least relatively few plankton, in the surrounding waters, there were also few plankton in the immediate vicinity of the discharge point. At times when discolored water was noted in Santa Monica Bay or surrounding Orange County outfall area, discolored water did not appear to originate in the waters enriched by the sewage discharge. On the other hand, discolored water frequently appeared many miles away and gradually spread to the enriched waters. Once these waters nearshore gained high numbers of plankton, the discoloration increased markedly, and could be more or less related to, visually at least, the flow of the sewage field.

It is reasonable to assume, therefore, that the increase of nutrients in nearshore waters from the discharge of sewage does not in itself initiate a plankton bloom. The initiation of a bloom must be due to some other condition, a condition which is undoubtedly a natural characteristic of the nearshore waters. Once rapid plankton reproduction is initiated in continental shelf waters, the nutrients contributed by the effluent markedly increase the reproductive rate, and thus the numbers of plankton. Depending on the discharge volume, ocean currents, and other oceanographic conditions, the effect

of the increased reproductive rate by the effluent is noticeable as much as 12,000 feet or more from the outfall.

Increased numbers of phytoplankton in the water obviously increases turbidity, and consequently decreases transparency. This is due not only to the discoloration of the water as a result of increased numbers, but also to the mere addition of great quantities of particulate matter; in this case, the organisms. Although turbidity may be increased by the addition of dissolved compounds in the water, the major cause in nearshore areas is from the particles of silt, clay, and sand, or any other solid debris which can be kept in suspension by turbulence. In the case of plankton, only exceptionally minor turbulence is necessary, for even in calm waters floating mechanisms inherent to the organisms will keep them in suspension for indefinite periods of time.

The question then arises as to whether the occurrence of plankton in waters enriched by the effluent can be directly attributed to the sewer outfall, or is it a natural phenomenon which can therefore be disregarded when measuring transparency in any monitoring program? Perhaps in order to apply the condition to the water quality standards established on May 2, 1956, by the State Water Pollution Control Board, a legal definition of what constitutes sewage origin is necessary. However, there is no doubt that under certain conditions, the waters within 2 to 3 miles of these three sewer outfalls contain higher numbers of plankton than the surrounding waters, and that the greater numbers are due to the enrichment of the local ocean by the effluent.

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