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THE DISPERSION AND POSSIBLE BIOLOGICAL UPTAKE OF AMMONIA IN A WASTEFIELD, POINT LOMA, MAY 1972

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INTRODUCTION

During 1971 and 1972, Dr. William Thomas, Scripps Institution of Oceanography, conducted a series of cruises for the Coastal Water Project and the National Science Foundation to determine the effect of nutrient inputs from marine outfalls on the growth and abundance of marine phytoplankton (Thomas 1972). At approximately the same time, a simple numerical model using phytoplankton uptake kinetics was developed at the Project (Southern California Coastal Water Research Project 1973). Comparison of the model predictions and the field observations showed the estimated and observed phytoplankton enhancements to be of the same general magnitude; however, there was poor agreement regarding the spatial distribution of the enhancement. The field data showed only local enhancement, which disappeared a few kilometers from the outfall. The model, on the other hand, predicted that, in the presence of a moderate current, the maximum response would occur several kilometers "downstream" from the outfall. Several hypotheses could be advanced to account for the discrepancy, but the available data was insufficient to test them.

In May 1972, the Project conducted a 2-day cruise in an attempt to directly test the model predictions. The site was the Point Loma outfall off San Diego, which discharges approximately 90 million gallons of primary treated sewage per day through a large multiport diffuser in 60 m of water. The diffuser is designed to produce a subsurface wastefield during most of the year, and the wastefield observed during the cruise confirmed this expectation.

Unfortunately, the results of the May 1972 study could not be used to test the model because the model was developed for diatoms, and the data suggest the presence of motile phytoplankton. In spite of this failure, the cruise did provide information on (1) the ability of large drogues to follow a submerged wastefield; (2) the suitability of ammonia as a wastefield tracer and as a means for estimating the initial dilution of the wastewater discharge; (3) the decrease in concentration of the wastefield (following initial dilution) because of gravitational spreading and oceanic dispersion; (4) the wind, surface, and subthermocline currents (simultaneous measurements); and (5) the possible uptake rates and behavior of marine phytoplankton. These observations form the basis for this memorandum.

METHODS

The vertical position of the wastefield in the water column was determined from an ammonia profile obtained at a position slightly downstream from the outfall diffusers; the wastefield was found to extend from 30 to 50 m (in a total water depth of about 60 m). Three 30-ft parachute drogues were then placed in the submerged wastefield (at a depth of 39 m). The subsequent motion of the surface floats (consisting of an innertube, a 12-ft bamboo staff, and a small flag and light) was used to follow the motion of this subsurface parcel of water.

At approximately 5-hr intervals, water samples were taken from the water column defined by the centroid of the drogues. In addition, samples were taken at two positions approximately 300 m to either side of the central station on a line perpendicular to the motion of the drogues. Samples were taken at depths of 0, 7, 15, 21, 27, 33, 39, 45, and 51 m. At regular intervals, wind velocity was also measured using the ship's anemometer, and the motion of surface water was estimated from short-term (1 to 2 hr) observations of the motion of a surface drogue of approximately 1.5 sq m effective cross-sectional area.

Nutrients (ammonia, nitrite, nitrate, phosphate, and silicate) were measured at a shore-based laboratory by Mr. Don Sibert, under the direction of Dr. Thomas. Chlorophyll-a determinations, corrected for the presence of pheophytin-a, were also made at this laboratory.

RESULTS

Winds and Currents

The wind direction and strength during the duration of the cruise are shown in Figure 1. The speed ranged from near 0 to 12 kn, principally from the west to northwest, and averaged approximately 5 kn from 210 degrees, magnetic heading.

Both the surface and subthermocline currents had strong southerly trends, as is shown in Figure 1. The surface currents were much stronger, ranging from 15 to 71 cm/sec (0.3 to 1.4 kn) and averaging 45 cm/sec (0.9 kn); the deeper currents ranged from 3.1 to 12 cm/sec (0.06 to 0.24 kn) and averaged 7.3 cm/sec (0.14 kn). The weakest surface current was stronger than the strongest observed subthermocline current, and on occasion, there was more than 1 kn of shear between the two layers. As a result, the water in the mixed layer above the drogues was essentially replaced by a new parcel in the interval between samplings.

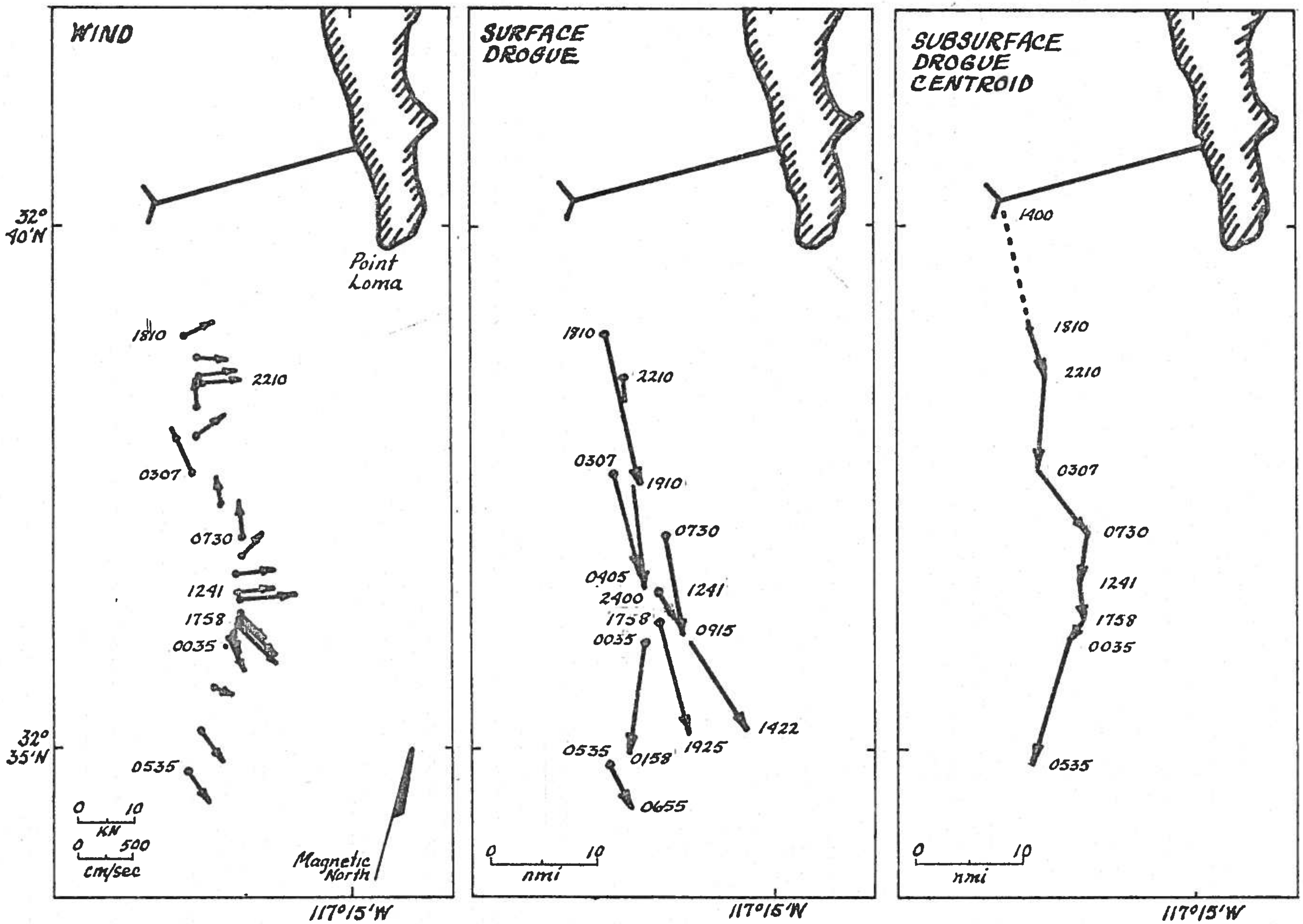

Figure 1. Wind, surface, and subsurface currents, Pt. Loma, May 1972.

This tendency for the average water movement to persist in one direction for extended periods of time was also observed earlier in the Point Loma outfall area (periodicity: >4.5 days) and more recently, in the Whites Point outfall area (periodicity: ≈14-21 days); Lamb[1] noticed a similar current pattern in considerably deeper water off La Jolla.

The total distance traveled by the parachute drogue system during the study was 9 km (5.5 mi.).

Dispersion of Drogues and Ammonia

The rate of dispersion resulting from horizontal "diffusion" processes can, in principle, be estimated by the time rate of separation of pairs of drogues in a system containing a large number of drogues. Three drogues alone will not permit a statistically significant estimate of these rates; nevertheless, we have examined the relative separation of the drogues with time and found that the separation was proportional to the cube of the elapsed time. This would correspond to a dispersion mechanism predicted by the Richardson "Four-Thirds Law." If, however, an average "diffusion velocity" is calculated from the total separation, we obtain a value of about 1 cm/sec, which corresponds well with values reported for the southern California coastal area.

Data obtained in earlier cruises by Dr. Thomas[2] indicated that ammonia might be useful in tracing submerged sewage fields. In addition, it can readily be taken up by phytoplankton and utilized as a source of nitrogen. In this study, we used ammonia to test a simple dispersion model and to see if deviations from the dispersion model predictions could be related to biological uptake.

The vertical distributions of ammonia in the water column for each sampling period during the study are shown in Figure 2. The solid line represents the water column concentrations at the centroid of the drogue system, while the two broken lines correspond to two lateral stations. Because the peak ammonia concentration for the first 29 hours of the study was observed at the central station, it appears that the drogue system was moving with the wastefield.

The peak ammonia concentration observed immediately downstream from the outfall was 11.3 μ-moles N/L. Unfortunately, samples of effluent were not taken for ammonia analysis at the time of the study; hence, estimates of the initial dilution cannot be made. If a nitrogen concentration of 28 mg/L (2,000 μ-moles/L) is assumed, this would give a dilution of about 175:1, which agrees well with theoretical estimates. The ease with which the samples can be obtained and the minimal field equipment necessary (a small drogue and sampling bottles) suggest that this may be an efficient method for determining the initial dilution.[3] In

1. R. Lamb, University of Washington, personal communication.
2. Dr. W. H. Thomas, Scripps Institution of Oceanography, unpublished data.
3. The quantitative portion of the analysis can be done on shore.

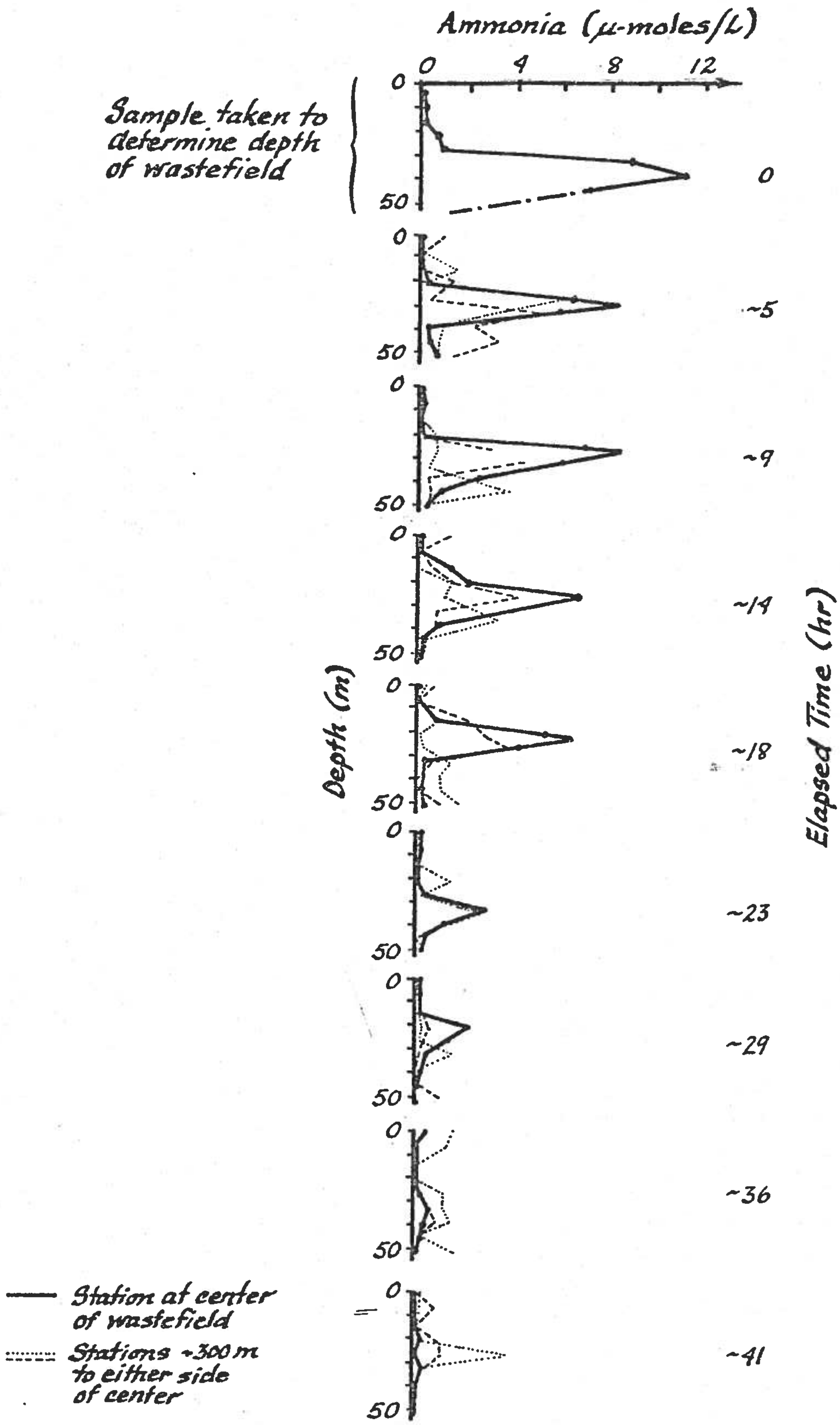

Figure 2. Ammonia with depth, Pt. Loma, May 1972.

addition, direct measurements of the wastefield thickness can be obtained and compared with theoretical estimates (which, at present, have a large uncertainty).

Some vertical displacement of the ammonia enhancement in the water column is evident in Figure 2. Analysis of other nutrient concentrations in the water column suggests that at least part of this movement was due to internal waves.

Figure 3 illustrates the change in time of the (estimated) peak ammonia concentration: As would be expected, this concentration monotically decreased with increasing elapsed time. The solid curve in the figure represents the ammonia concentration predicted by a simple "diffusion velocity" dispersion model.[4] In general, there is a fairly good correspondence between the predicted and observed concentrations until 1200 hours on 25 May, when an abrupt decrease in the measured value was observed. If, however, the model value is "renormalized" to this anomalous value, there is good agreement again at 1800 hours. At 0300 hours on 26 May, a second anomalously low value was observed and, as before, renormalization gives good agreement at the next sampling time (0600 hours).

An obvious question is, "Do these discrepancies reflect deficiencies in the dispersive mechanisms incorporated into the model or inadequate input data for the model or might they be indicative of the existence of additional nonconservative processes that alter the chemical state of the ammonia nitrogen?" The two most likely candidates for the latter process are:

A. The oxidation of ammonia to nitrite or nitrate.

B. The biological uptake of ammonia by marine algae.

If ammonia is lost by oxidation processes, the concentrations of nitrite and/or nitrate should increase. No significant change in nitrite concentrations were observed; however, the change would not have been obvious if the conversion rate of nitrite to nitrate is rapid. The fluctuations in the ambient nitrate concentrations were large enough to mask ammonia-associated changes. Nevertheless, the oxidation of ammonia probably cannot account for the observed decrease because these processes would not produce "discontinuous" changes in the ammonia concentrations, but would instead augment the overall rate of decrease. Therefore, we considered the possibility that the anomalous changes we observed were due to biological uptake.

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4. Assume similarity. Then $c(t)/c(t = 0) = \sigma(t = 0)/\sigma(t)$, where $\sigma(t) = \sigma(t = 0) + v_D t$ and, for Case A, $\sigma(t = 0) = 500$ m and $v_D = 0.01$ m/sec and, for Case B, $\sigma(t = 0) = 300$ m and $v_D = 0.007$ m/sec.

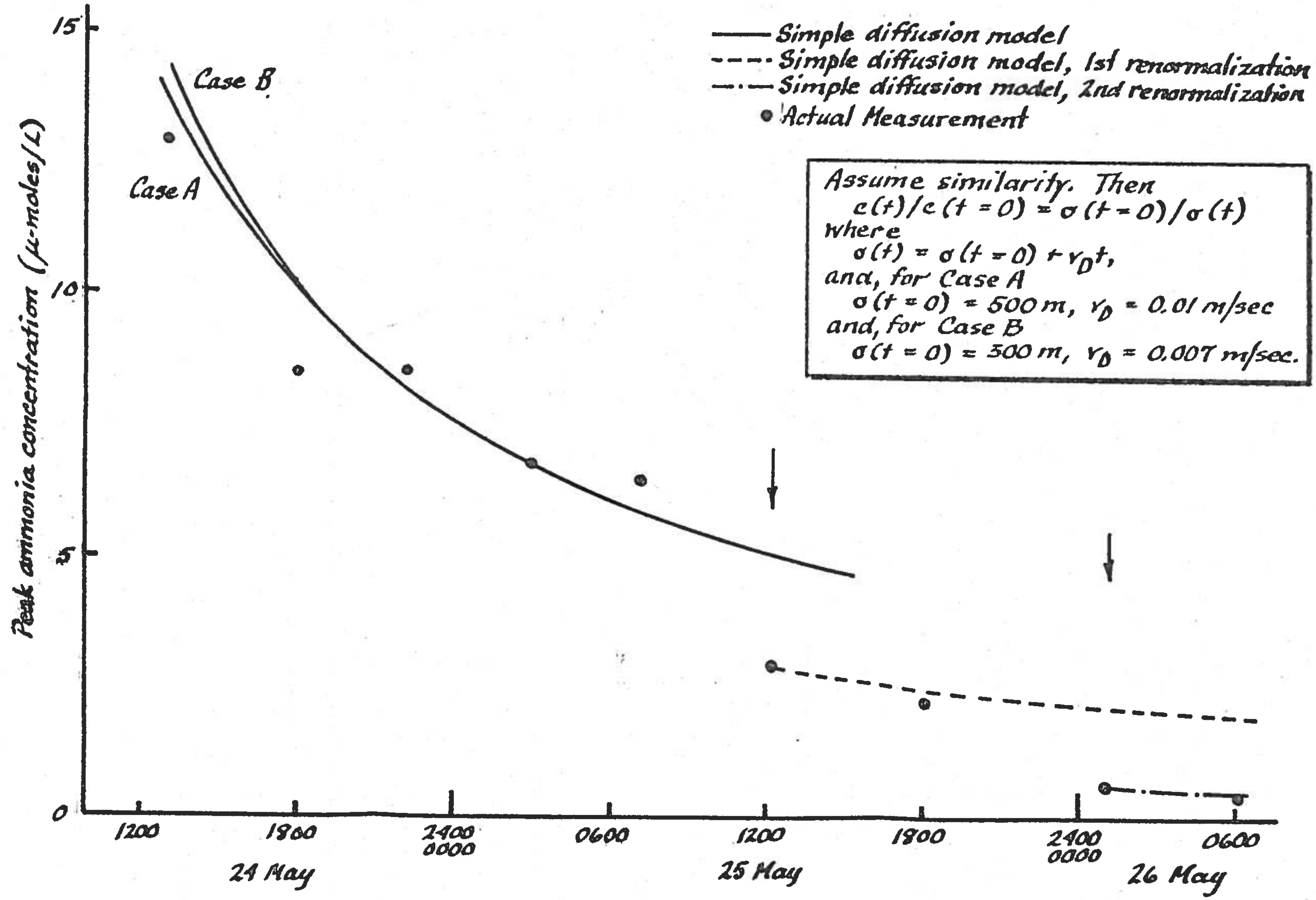

Figure 3. Peak ammonia concentrations, Pt. Loma, May 1972.

Phytoplankton

The time evolution of chlorophyll-a concentrations in the water column, for each depth down to 33 m, is shown in Figure 4. In general, depths greater than 15 m were below the thermocline, and water less than 7 m was in the mixed layer. The two most interesting features in the figure are the two subthermocline chlorophyll enhancements that occurred at approximately noon and midnight on 25 May. This variation is particularly striking in the 21-m sample, where the chlorophyll increased about 30 times, changing from 0.15 mg/cu m at 1800 hours on 25 May to 4.5 mg/cu m at 0045 hours on 26 May. If this change were the result of nutrient uptake and growth of phytoplankton, it would correspond to a growth rate of about 17 or 18 doublings/day. But, because laboratory and field studies indicate growth rates of about 1 to 3 doublings/day, it is unlikely that growth was the cause of the observed change.

The "enhancement" may have simply been a change in the mixed layer depth as a result of internal wave activity. Comparison of Figures 2 and 4 indicates that downward displacements of the wastefield are correlated with increased chlorophyll concentrations at the four lower depths. For example, the wastefield was deepest at elapsed times of 23 and 36 hours, and these times correspond (approximately) to 1200 and 2400 hours on 25 May. Although this hypothesis could account for the observed changes in chlorophyll concentrations, it does not explain the abrupt changes in the ammonia values.

An alternate hypothesis is that the enhancement was a result of the migration of motile phytoplankton. Presumably, the noon migration would result from the avoidance of high levels of light, and the midnight migration would represent an effort to take up nutrients for subsequent utilization. In this case, the apparent downward displacement of the wastefield would actually be the result of ammonia uptake in the upper part of the wastefield. If migration is to account for the change, the migration speeds must exceed 1 m/hr, and speeds of 2 to 4 m/hr might be required. Although these values are relatively large, they do not appear to be incompatible with estimates of migration speeds. A direct test of this hypothesis would be a mass balance calculation of the chlorophyll in the water column; however, the large current shear that was present across the thermocline during the cruise makes it impossible to perform this calculation.

Chlorophyll and Ammonia Correlations

Figures 3 and 4 show anomalous decreases in ammonia concentrations in the wastefield occurring at the same time as enhancements in chlorophyll; this suggests that the ammonia decrease resulted from biological uptake. However, observed growth rates for phytoplankton argue against the rapid growth of the crop: Thus, for this hypothesis, the ammonia loss must be due to uptake and storage. To

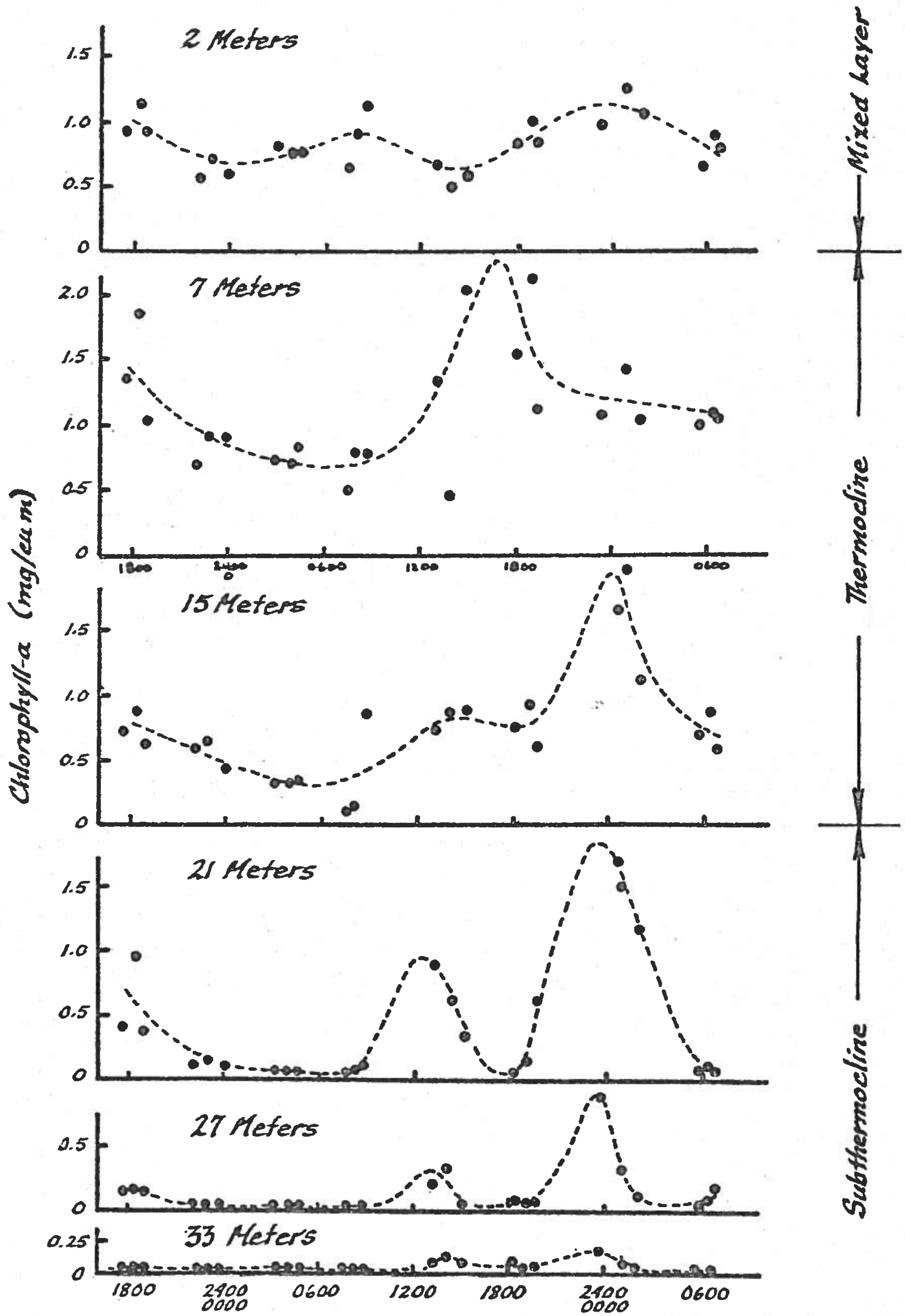

Figure 4. Chlorophyll-a with depth, Pt. Loma, May 1972.

test the validity of this hypothesis, we have estimated the ammonia uptake rate and storage capacity that would be required to explain the observed ammonia decrease. The required uptake rates were 2.5 doublings/day[5] for the midnight enhancement and 9 doublings/day for the noon enhancement. This latter value is substantially greater than is observed in steady-state culture studies, but quite compatible with the uptake rates observed when phytoplankton are removed from a nutrient-depleted environment and placed in a nutrient-rich environment (where uptake rates corresponding to 12 to 13 doublings/day have been measured). Similarly, the corresponding mass of nitrogen that would be taken up by the phytoplankton is 0.33 (midnight) and 2.3 (noon) times the normal, steady-state mass. Again, this is compatible with the values observed for nutrient-starved phytoplankton.

Thus, although there is no conclusive evidence that the ammonia reduction observed in the May 1972 cruise was the result of biological uptake, this hypothesis does supply a possible explanation for the observations.

DISCUSSION

If the biological uptake and storage of ammonia by motile phytoplankton was the cause of the abrupt changes in ammonia concentrations observed in the May 1972 cruise, this mechanism could figure significantly in models of phytoplankton enhancement. The simulation model developed by the Project (1973) suggests that the magnitude of a wastewater-related enhancement of nonmotile phytoplankton is limited, in part, by the dispersal of the nutrients in the discharge as a result of diffusion. If nutrient uptake is rapid, and the nutrients are stored for subsequent growth, the enhancement could be larger than predicted by the model. On the other hand, if this process occurs in an environment in which there is substantial current shear because of a divergence in the surface and subthermocline water movements, the growth may take place over a much larger area, and the enhancement may be reduced.

Shear sometimes results from two layers of water moving in opposite directions; this condition has been observed in the Whites Point area on occasion. In this situation, a wastewater-related enhancement of phytoplankton could occur near the outfalls in that the affected organisms would be carried first away from--and then back into--the outfall area by the water movements.

If, however, correlations between phytoplankton abundance and anomalous decreases in ammonia concentration are accidental, the data suggest that a simple diffusion model, based on similarity, may be inadequate to account for dispersive processes occurring in a wastefield.

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5. In terms of the equilibrium mass of nitrogen in the phytoplankton crop.

CONCLUSIONS

1. The vertical position, thickness, and initial dilution of wastewaters discharged from an outfall system producing a submerged wastefield can readily be estimated from ammonia concentrations in the wastefield and effluent.

2. At some outfall sites, parachute drogue systems may be capable of following the wastefield for elapsed times exceeding 1 day, or distances greater than 8 km.

3. The uptake of ammonia by motile phytoplankton could be an important process in reducing the concentration of ammonia in a wastefield.

   a. The rate at which ammonia concentrations could be reduced by this mechanism may be comparable to the maximum reduction rates produced by physical dispersion processes.

   b. The possibility that motile phytoplankton are present should be considered in interpreting the predictions of plankton enhancement made by models developed for nonmotile phytoplankton.

4. Simple diffusion models, based on similarity, may provide adequate explanations of the wastefield dispersion during periods of unidirectional flow, but additional investigation will be required to demonstrate this conclusion.

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