

AUSTRALIAN ATOMIC ENERGY COMMISSION  
RESEARCH ESTABLISHMENT  
LUCAS HEIGHTS

A POWER STATION COOLING POND PERFORMANCE  
TEST WITH RADIOACTIVE TRACER IODINE 131  
SECOND EXPERIMENT AT MAITLAND, N. S. W.

by

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\*Electricity Commission of N. S. W.

First Issued Sydney, March 1960

Re-issued Sydney, April 1961





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ABSTRACT

A second tracer experiment to study the flow of power station cooling water in a cooling pond is described. Since the first experiment in March, 1958, the intake point had been deepened and extended into the pond in an attempt to avoid channelling.

The technique used in this test was similar to that used in the first but severe weather conditions were experienced. The results showed that even a moderate wind had more effect on the flow pattern than any other factor. Some aspects of this effect were studied quantitatively. The different weather conditions experienced in the two tests did not permit conclusive observation on the effect of the modified intake.

\* Electricity Commission of N.S.W.



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Figure 25 Movement of active front, first day

Figure 26 Activity passing through pumphouse

Figures 27 to 30 Average temperature and activity distribution with depth



## 1. INTRODUCTION

The radiotracer experiment using iodine 131 as iodide in solution, described in this report, is the second to be carried out on the Maitland Power Station Cooling Pond. The first experiment, carried out in March, 1958, showed the whole pattern of mixing of the condenser water over a period of 8 to 9 days in relatively stable weather conditions. However, it also yielded proof of considerable surface channelling of hot water back to the pumphouse intake\*. Subsequently, the depth of the intake pipe was increased from five feet to sixteen feet, in an effort to increase stratification and avoid channelling.

The purpose of the second experiment was to examine the effectiveness of the intake modification. Although the same quantity of iodine 131 was used in each experiment, a direct comparison of results was difficult, owing to seasonal variations in thermal stratification and different prevailing weather conditions.

During the experiment, the station was operating at a nominal rating of 20MW corresponding to a heat rejection of approximately  $100 \times 10^6$  B.t.u./hr with a cooling water flow of 14,000 gallons per minute.

## 2. RADIATION DETECTION AND TEMPERATURE MEASURING EQUIPMENT

Scintillation counters were used to detect the iodine 131 gamma rays. Each probe consisted of a  $1\frac{1}{2}$  inch diameter x 1 inch height NaI(Tl) crystal and a photomultiplier, mounted in a scintillation head. These were enclosed in watertight aluminium containers lacquered to prevent corrosion and adsorption of activity. They were connected directly by coaxial cable to one of the following units:

(a) Ericsson Telephones Ltd. portable  $\alpha\beta\gamma$  monitor type 145A .

\*\* (b) A.A.E.C. portable ratemeter.

(c) Burndept Ltd. type 1186 amplifier, with EKCO type 1037B ratemeter, and Leeds and Northrup Ltd. Speedimax chart recorder.

The latter instrument was permanently installed at the pumphouse, with the probe monitoring water pumped from the lake to the power station. The portable instruments were used to measure the activity of the tracer at various positions in the pond.

In this experiment, the water temperature was also measured using a thermistor unit mounted externally on the scintillation probe at a position corresponding to the level of the crystal. The thermistor formed part of one arm of a Wheatstone bridge circuit, and the out-of-balance current of the circuit was indicated on a 0-100  $\mu$ -ammeter. The unit measured temperatures within the range of 15°C to 50°C, with an accuracy of approximately 0.3° C.

## 3. CALIBRATION OF RADIATION DETECTION EQUIPMENT

All instruments were calibrated by the method previously described (Ellis et al. 1958). Almost identical results were obtained both for calibration curves and correction factors for readings near the surface.

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\* Ellis et al., 1958. The Use of a Radioactive Tracer (Iodine-131) in the Investigation of a Power Station Cooling Pond at Maitland, N.S.W. AAEC/E 8.

\*\* This instrument was developed by Mr. A. Klein of the Technical Physics Section of the A.A.E.C. Research Establishment. It is a fully transistorized battery-operated portable ratemeter with a range up to  $10^4$  counts per second.

#### 4. BACKGROUND MEASUREMENTS AT THE COOLING POND

Background levels at the pond were measured using the portable equipment and found to be identical with previous readings.

#### 5. DESCRIPTION OF EXPERIMENT

##### 5.1 Method of Addition of Tracer

The method used in the first experiment was again used with the additional precaution of preheating the carrier solution to the temperature of the outlet water to reduce density differences. 520mc of iodine I31 was used in this test with 10 lb. of potassium iodide carrier.

Twenty pounds of fluorescein dye was again added with the isotope to provide a visual indication of surface flow in the early stages. The isotope and fluorescein boundaries were found to coincide in all readings taken while the fluorescein was still visible, the interface being sharp and vertical.

##### 5.2 Detection of Radioactivity Distribution and Movement

Readings were taken as before, with boat movements in this experiment co-ordinated from the shore using two-way radios. This resulted in a better coverage of the movement of the activity with fewer readings. About 400 readings of activity and temperature were taken over a period of 3 days. Readings were taken from the surface down to the depth which showed no significant radioactivity above background, and recorded against position, time and depth. The interface between radioactive and inactive water was usually quite sharp and its position was recorded with each measurement.

##### 5.3 Correction of Activity Readings

After corrections for background, geometry factors near the surface, and decay, the calibration curves were used to convert counts per second to microcuries per gallon. All readings were corrected for activity decay to the time of introduction of the tracer, 6.20 a.m. on 3rd December, 1958.

#### 6. PRESENTATION OF RESULTS

During the first two days of this experiment moderate winds and occasional heavy showers were the prevailing weather conditions. It was obvious very early that the wind was having a considerable effect on the water movement and the results could not be effectively presented in the same way as in the first experiment.

The observations during the first day indicated a bulk movement of active water from the surface to a depth of several feet under wind influence and it was decided to present these results as cross-sections (Figures 10 to 24) as well as surface readings (Figures 1 to 9).

Three section lines were drawn from the end of the north arm to the intake area; the north and east arms were then divided into 36 areas of similar size by gridlines drawn normal to the three section lines. All readings occurring in an area over a given period of time were averaged, and these average activities plotted to a logarithmic scale on diagrams showing distance along section lines against depth. The interface of activity as found from readings and fluorescein observations was marked in wherever possible, a broken line being used to indicate inconclusive evidence. Maps showing the surface spread of activity were prepared for the same periods of time as the cross-section diagrams. A logarithmic scale was again used and boundaries shown by a broken line where their position was doubtful.

The advance of the active "front" with time was plotted for the period between injection and arrival of activity at the intake. The prevailing wind was averaged over a series of short intervals, and the wind component diametrically opposing flow determined and plotted on all the relevant figure

Activity/depth curves as used for presentation of results in the previous test were drawn up for the second and subsequent days. Activity readings were plotted against depth, and average curves for each of the three arms of the pond drawn. Corresponding temperature readings were also shown (Figures 27 to 30).

A scintillation head at the intake continuously monitored water entering the pumphouse. This activity was recorded over a period of nine days; after correction for background and decay, the activity in  $\mu\text{c/gallon}$  was plotted against time (Figure 26).

## 7. DISCUSSION OF RESULTS

### 7.1 Effect of Prevailing Wind

During the first and second days moderate to strong winds were experienced almost continuously. The wind came predominantly from the south east and therefore had a substantial component directly opposing the hydraulic flow in the pond. One of the most outstanding results arising from this experiment is the detailed information obtained on the very marked effect of wind on the movement of water after it enters the pond from the open channel. This wind effect is illustrated clearly in the observations of surface activity and in the cross-sectional activity diagrams.

The movement of the labelled water during the first day is shown in Figures 1 to 8 and 10 to 25. At all times during this day, even though the activity had penetrated to a considerable depth at the late stages, there was a sharp vertical and horizontal boundary between the active and inactive water.

In Figures 1 to 9 the movement of the active front and the surface concentrations during the day are shown. The wind strength remained moderate until 11 to 11.30 a.m. and during this period there was a slow spread of the active layer. However, the spread was much slower than in the previous experiment where the wind was, on the whole, negligible. Between 11.30 a.m. and 12.15 p.m. a wind component averaging 11 m.p.h. halted the spread and slowly forced the active water back along the north arm. A subsequent moderation in the wind allowed the labelled water to spread almost to the intake point during the next two hours and from Figure 6 it can be seen that the water started to spread into the south arm. However, a prolonged rise in the wind component between 4.30 p.m. and about 7.00 p.m. again forced the active water right back into the north arm leaving a small residue in the south arm (Figure 7).

At about 7.30 p.m. the wind dropped almost completely and the active water spread very rapidly over the whole area of the pond. As soon as this spread occurred and the labelled water reached the area over the intake point it commenced to enter the power station as shown in Figure 26. This was about 12 hours after injection of the tracer at the head of the outlet channel.

Figure 25 illustrates well the effect of wind action. In this graph the position of the active front is plotted with time, with an indication on the right-hand side of the average velocity of the wind component directly opposing the flow. It is clear that every advance is accompanied by a lower wind velocity and every retreat is accompanied by an increase in the average wind force. A careful study of the results showed that a wind component in excess of 9 to 9.5 m.p.h. caused a definite retreat while winds of lower velocity permitted flow in the normal direction. The magnitude of the variations shows also that even small wind velocity changes are very critical. The speed of movement of the active front was consistently zero at 9.0 to 9.5 m.p.h., and varied in a roughly linear fashion with wind component velocity. With a wind of 8 m.p.h. the front advanced at about 6 feet per minute and with a wind of 11 m.p.h. it receded at about 8 feet per minute.

These wind observations were made at the standard height of 10 metres above ground level at a weather station situated on ground about 20 ft. above the pond level and at a distance of 300 ft. from the water's edge. As would be expected, the actual wind velocity at the pond surface was somewhat less than at the weather station. Intermittent measurements of wind velocity taken at a height of about 4 ft. above the pond indicated that the velocity at this level was, on the average, about two thirds of the weather station reading.

In this experiment the maximum wind velocity component experienced was about 11 m.p.h. and it is interesting to consider the possible effects of higher wind velocities or winds from other quarters. A moderate wind velocity in the direction of flow would presumably cause channelling of the warm condenser water on the surface back to the power station in a very short time, resulting in almost complete by-passing of the pond. A strong prevailing wind in the opposite direction could hold up the movement for prolonged periods. It is clear that the location of intake and outlet in relation to prevailing winds is very important.

### 7.2 Vertical Movement of Labelled Water

It would be expected that the frequent oscillations of the active water caused by the wind variation would result in an appreciable mixing in depth in the pond. The sectional diagrams shown in Figures 10 to 24 illustrate the pattern of depth penetration.

During the first hour the active solution penetrated to a depth of about 4 to 5 ft. (Figure 10). This was a somewhat more rapid penetration than was observed in the first experiment. However, it is clear that practically no further vertical movement occurred during the subsequent seven hours and the boundary of inactive and active water remained sharply defined, (Figures 11 to 19). This is remarkable when it is considered that the labelled water showed three distinct and substantial reversals due to wind action in this period (Figure 25).

These results give no positive evidence that the backing up due to the wind produced a counterflow at depth. This would have caused considerable mixing and deep penetration of the activity. It is clear that a "raft" of labelled water of constant thickness oscillated backwards and forwards under the influence of the variable wind opposing the constant hydraulic head.

The maintenance of a constant depth of penetration for seven hours may be related to the temperature gradients. There is some evidence in the temperature scales shown in Figures 10 to 18 of a warmer layer existing to a depth of about four feet. However, the evidence is insufficient to conclusively explain the observed behaviour.

A further increase in depth occurred about seven to eight hours after injection when the boundary of the active layer suddenly dropped to about 10 ft. (Figure 20). An hour or two later there was the first evidence of activity in the south arm, extending to a depth of about 10 ft. After 14 to 15 hours this activity had penetrated to over 20 ft. (Figure 22) while it still remained substantially at about 10 ft. in the north and east arms. The fact that deep penetration more readily occurs in the south arm may be further evidence of the temperature gradient in the north and east arms opposing depth movement.

At about 6.30 p.m., 12 hours after injection, the active layer had spread to a point above the intake but at this time there is no evidence that the layer was deeper than 10 ft. Immediately the point above the intake was reached activity started to appear in the pump house (Figure 26). This indicated that the water was being drawn vertically down from above the intake which was at a depth of 16 ft. In fact, a slight vortex was observed in a calm period directly above the intake position.

The draw-off velocity in the submerged intake was much higher than the critical velocity for maintaining thermally stratified flow. A reduction in this velocity could easily be effected by intake design to overcome the draw-down effect which, however, is much less significant during warm weather conditions when stratification is more pronounced. By 11.00 p.m. on the first day (17 hours) there was a strong indication of extensive penetration to about 15 ft., (Figure 24).

In spite of the fact that fresh inactive warm water was entering the pond continuously during the observations recorded in Figures 10 to 24 there is no real evidence of this water spreading and diluting the immediate surface layer. This would indicate a rapid mixing of the intake water with the layer of the first four or five feet but as indicated earlier, very little mixing across the 5 ft. level of depth for some hours after entry into the pond.

Owing to the long delay in the activity reaching the intake the graph of intake activity against time (Figure 26) gives little additional information. It indicates that after about 16 hours, when the top of the rise was reached, the radioactive water had almost completely mixed with the pond water as the activity after this period was substantially constant for the period of observation (8 days).

While the active layer existed as a "raft" with clearly defined boundaries, no attempt was made to plot the variation of activity with depth. However, after the first 24 hours it was clear that the results could best be presented in this way and these are shown in Figures 27 to 30.

On the morning of the second day (Figures 27 and 28) the observations showed a very much lower activity in the north arm. This was almost certainly due to the events of the previous day when the wind prevented entry of the active water to the power station until the evening. Until then inactive water was passing through the station and was being deposited in the north arm, diluting the active solution remaining there. The slightly higher activity at the surface on the north arm in Figures 27 and 28 is probably due to the re-entry of the first of the active water to pass through the station on the previous evening. This relatively recently discharged warm water would be expected to appear at the surface.

Owing to the weather conditions it was not possible to do a complete survey of the pond in the afternoon of the second day to investigate this effect further. However, it is clear that by the morning of the third day, after approximately 36 hours of circulation of active solution through the power station, mixing was effectively complete with a uniform activity in each arm (Figure 30).

It will be noted that the temperature of the water in the north arm in Figure 27, while having the expected gradient, is unexpectedly lower than the temperatures in the east and south arms. This is probably explained by the very heavy rain in the early hours of the second day. The catchment of the reservoir drains almost entirely into the north arm and, from the rise in the reservoir level, it was estimated that seven million gallons of water flowed into the pond overnight. This would be sufficient to cause appreciable cooling of the north arm. However, within a few hours, the temperature distribution regained the more normal pattern (Figure 28).

The low surface activity shown in Figures 29 and 30 on the second day is difficult to explain. It could be due to rainfall diluting the surface layer but this effect was also seen during the first experiment.

### 7.3 Anomaly in Total Amount of Isotope Found in Pond

As in the previous experiment the same anomaly was found when the total amount of activity in the pond was calculated from the measured concentrations.

A quantity of 520 mc was added to the pond on the morning of the first day. On the second day when mixing was almost complete the average concentration, multiplied by the volume of the water containing the radio-isotope gave about 800 mc. On the following day the same calculation gave 680 mc. The accuracy of these estimates is not very great but the figures are again approximately 50 per cent. higher than the amount added. Subsequent investigations have shown that this anomaly is almost certainly due to deficiencies in the quantity of iodine 131 obtained for calibration of equipment used in both this and the previous experiment at Maitland. This had the effect of making the instruments appear less sensitive than they really were.

## 8. RADIATION PROTECTION

All working areas were carefully monitored during the handling of the radio-isotope and all staff wore film badges during the experiment. No significant radiation dose was indicated on any film badge. The radio-isotope in the water was rapidly diluted to well below I.C.R.P. drinking water tolerance level ( $0.27\mu\text{c/gallon}$ ). Only 47 of the 400 readings were above this level and only in the early period of the experiment.

## 9. CONCLUSIONS

Further valuable information on the flow pattern in the cooling pond was obtained from this experiment. The effect of wind was confirmed as a major factor influencing the flow and some quantitative aspects of this effect were revealed. A prevailing head wind appeared to hold up the mixing and flow rather than, as was expected, cause rapid mixing and vertical circulation of the water.

Because of the different prevailing weather conditions a strict comparison between this experiment and the first is somewhat difficult. However, it appears that the advantage gained by increasing the depth of the intake is not very great. In the prevailing cool conditions and severe winds the active water started to pass through the power station very soon after it appeared in the layers above the intake.

## 10. ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of the Power Development Branch of the Projects Division of the Electricity Commission of N.S.W. during the experiment. Thanks are also due to the Power Station Superintendent (Mr. J. Barratt) and his staff for valuable co-operation and for making available the necessary facilities.

The co-operation of the Director and staff of the Commonwealth X-Ray & Radium Laboratory for assistance in ordering and expediting the delivery of the radio-isotope from the United Kingdom is also acknowledged.

Thanks are also due to the Assistant Quarter-master General, Australian Military Forces, Eastern Command for the loan of the portable radio equipment used in this experiment.

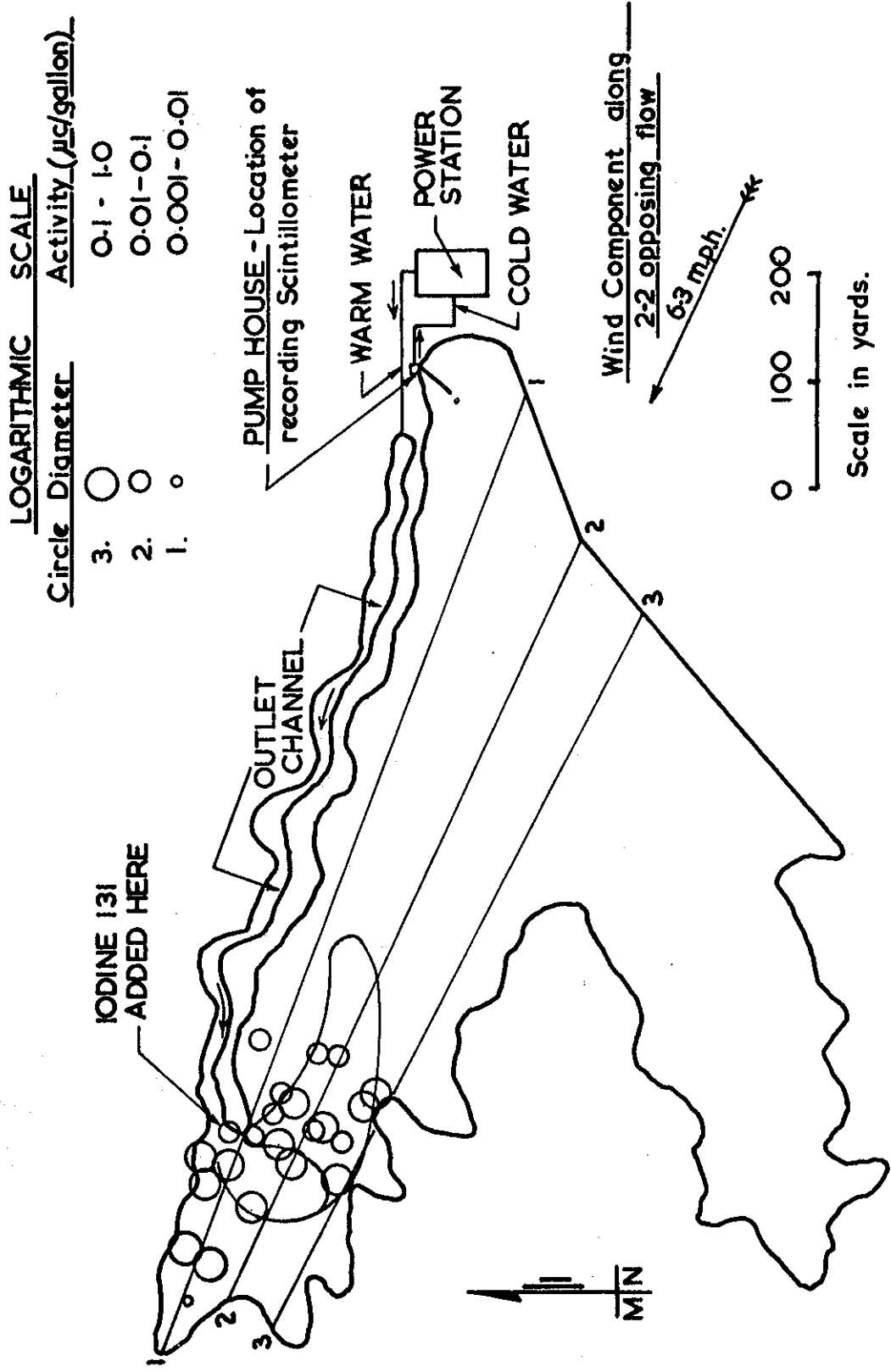


FIGURE 1. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 6.20 TO 7.15am.

SCALE  
See Fig. 1

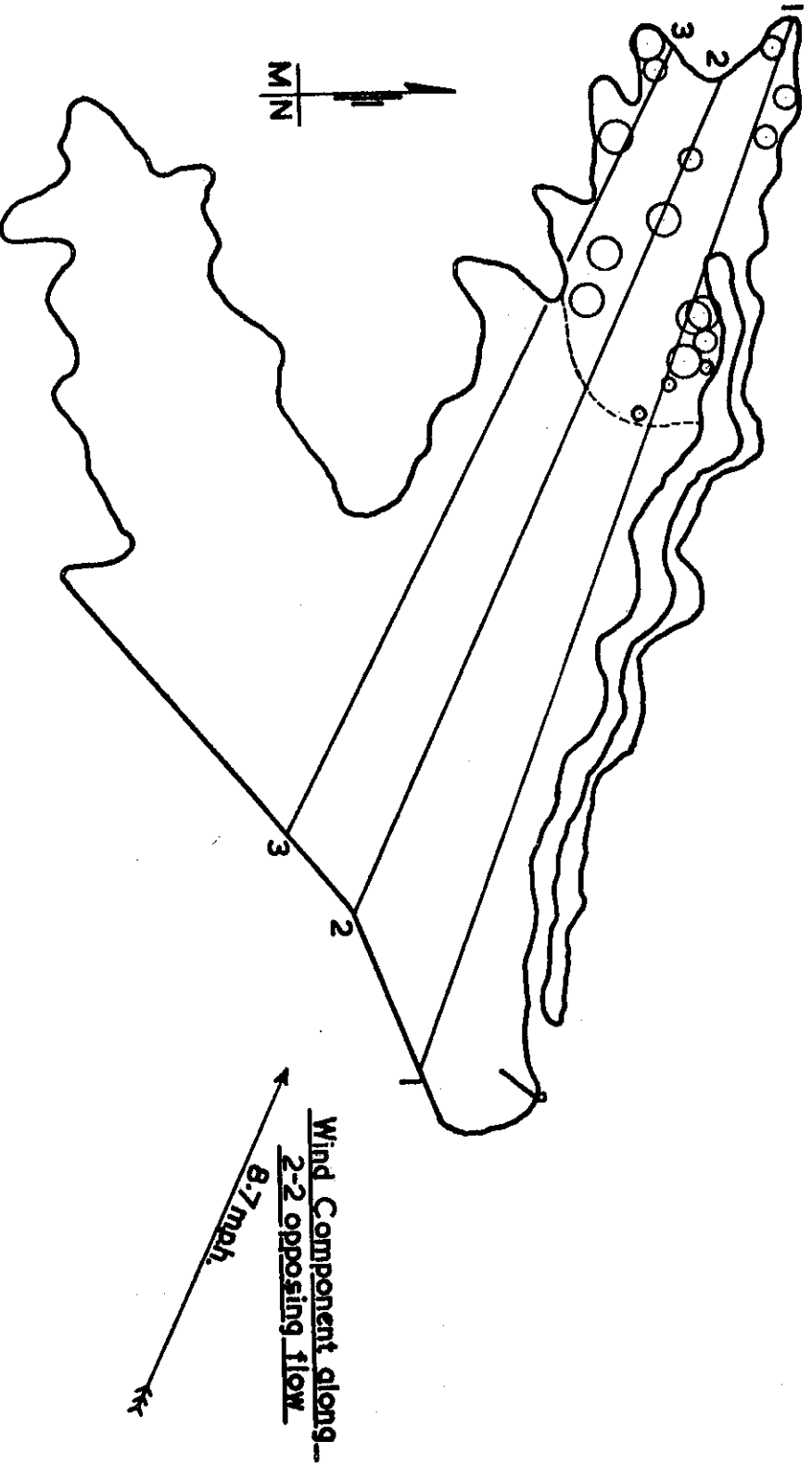


FIGURE 2. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 8.00 TO 8.30a.m.

SCALE  
See Fig. 1

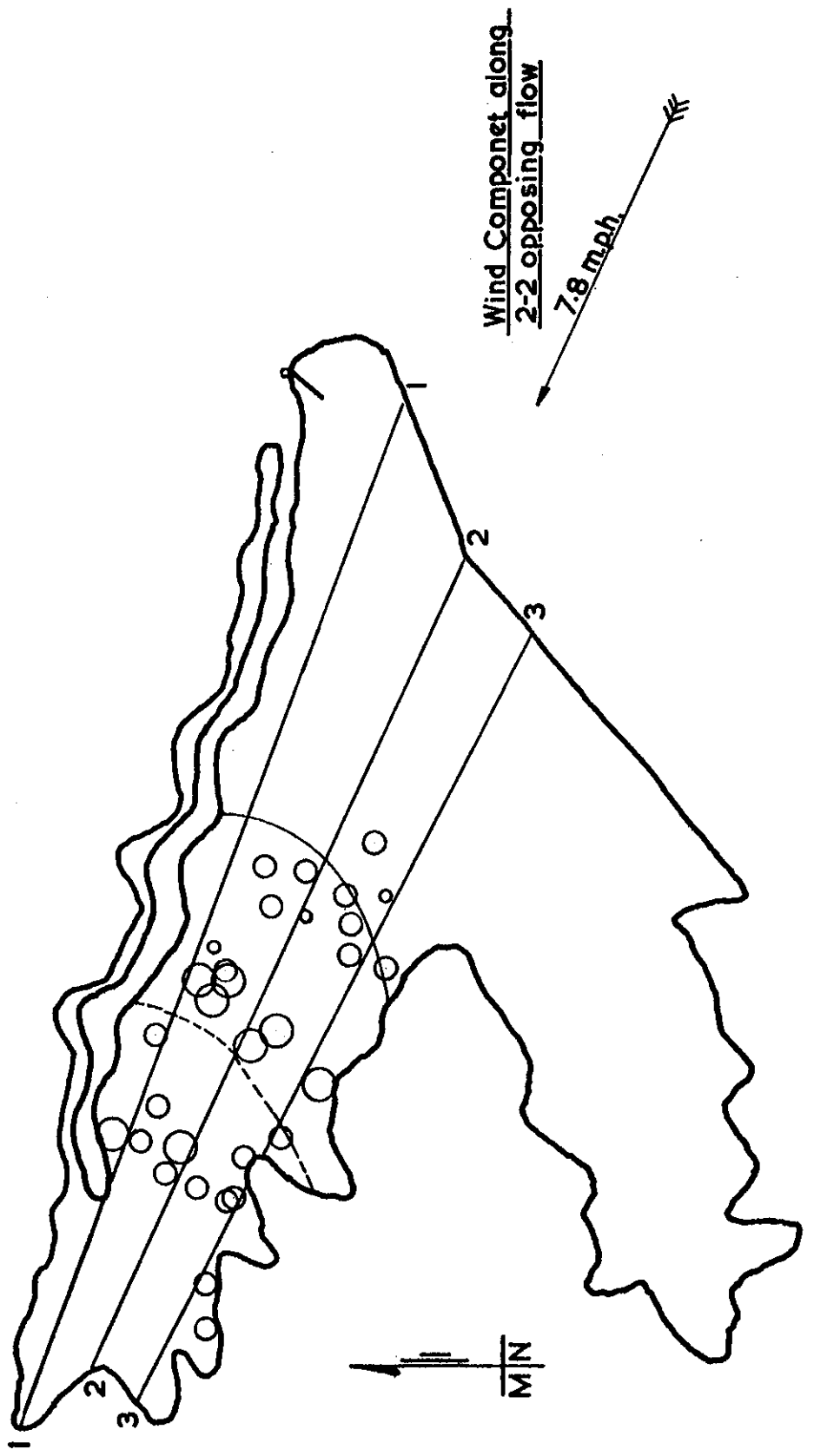


FIGURE 3 SURFACE DISTRIBUTION OF TRACER - FIRST DAY. 1000 TO 1100 a.m.

SCALE  
See Fig. 1

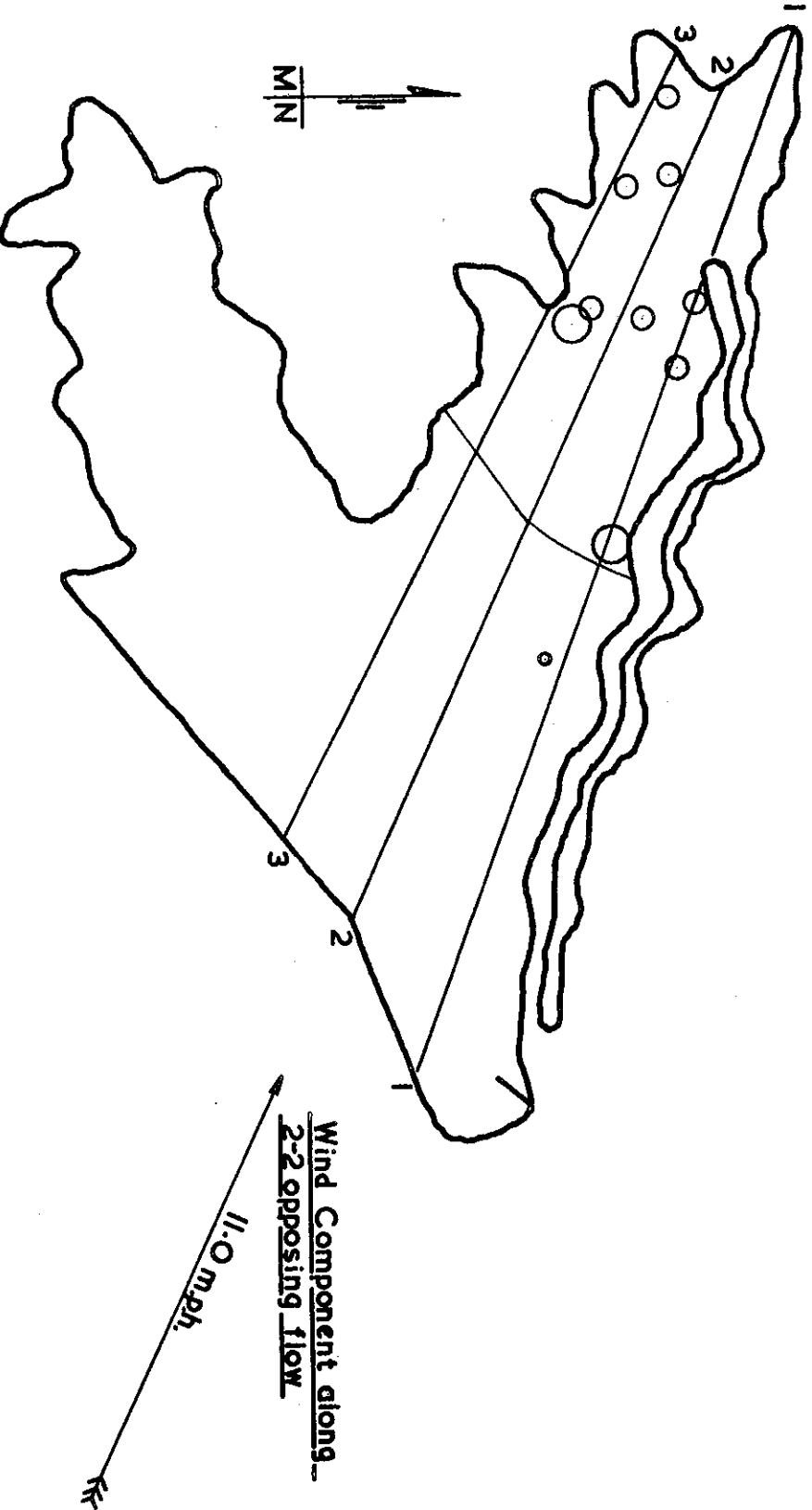


FIGURE 4. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 11.30 a.m. TO 12.15 p.m.

SCALE  
See Fig. 1

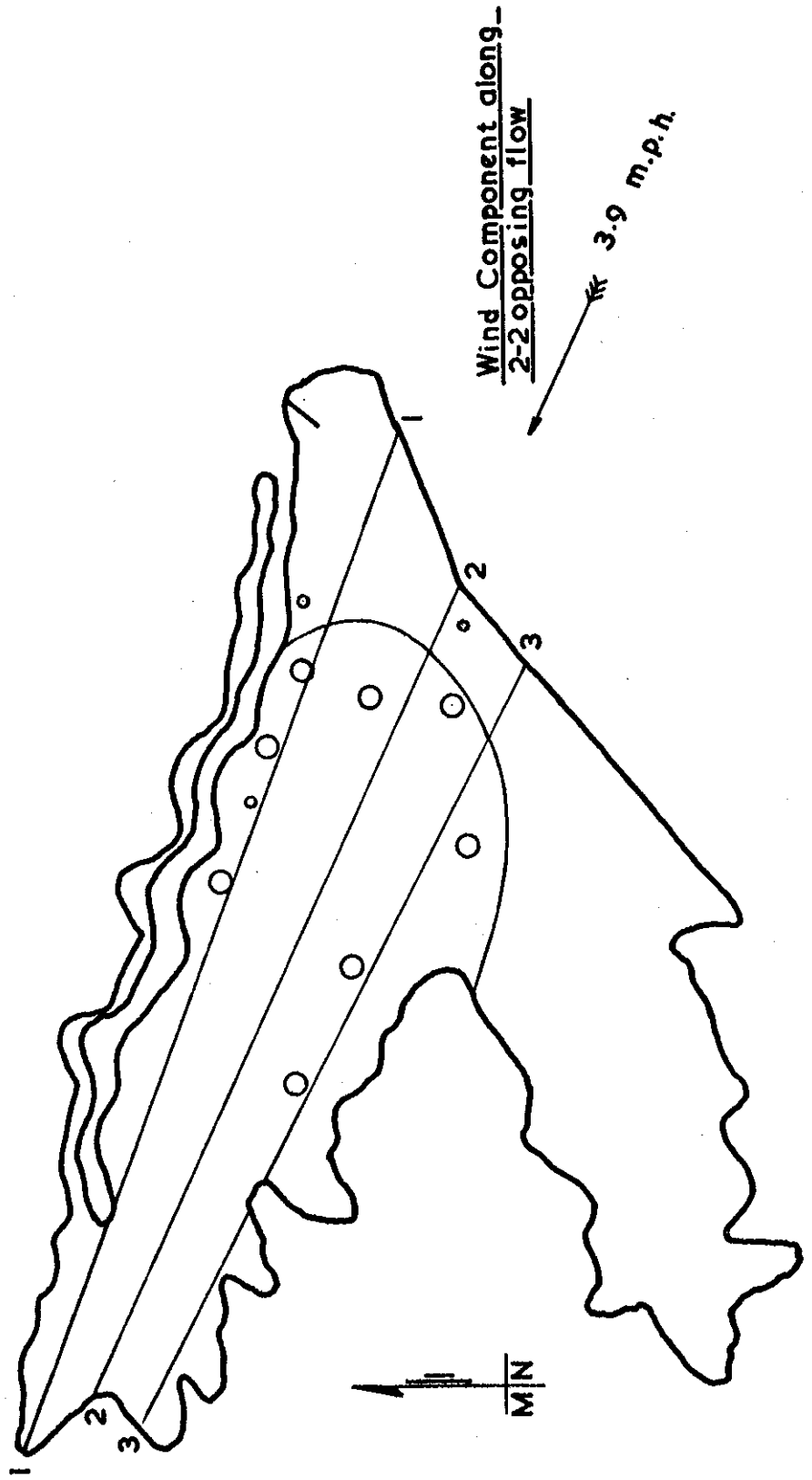


FIGURE 5. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 1.15 TO 2.00, P.M.

SCALE  
See Fig. 1

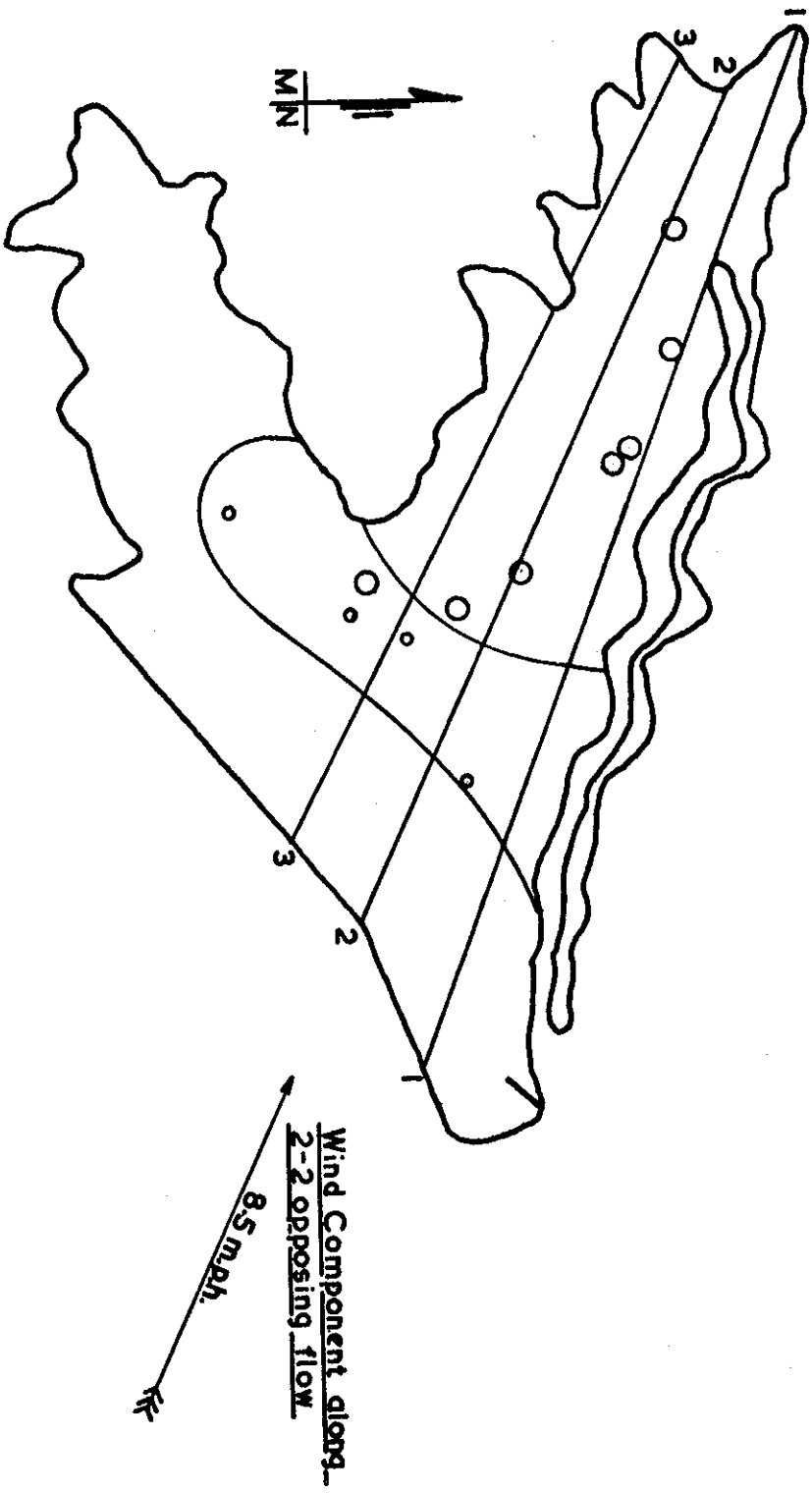


FIGURE 6. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 2.45. TO 3.30 P.M.

SCALE  
See Fig. 1

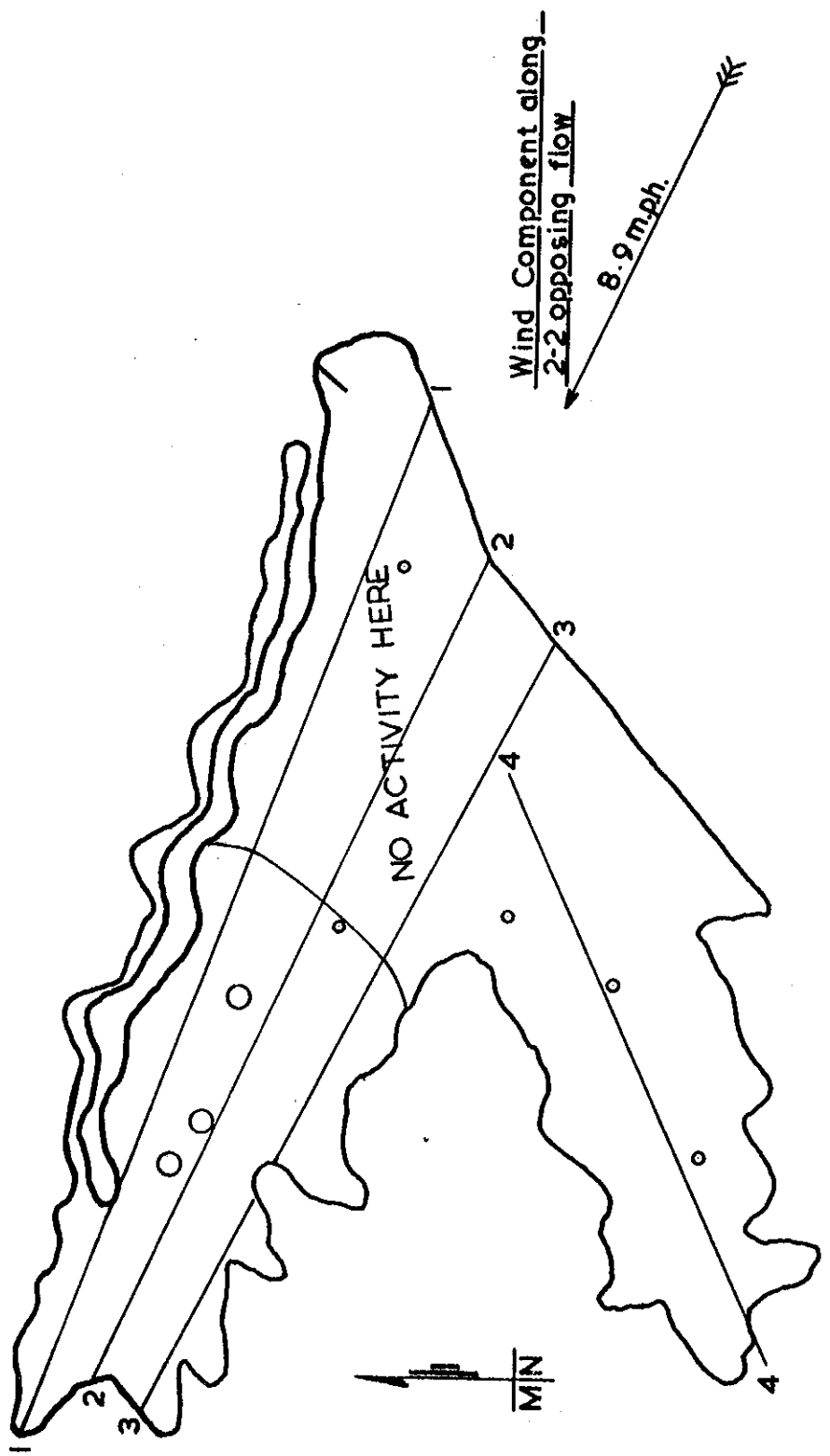


FIGURE 7. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 4.30 TO 5.30 p.m.

SCALE  
See Fig. 1

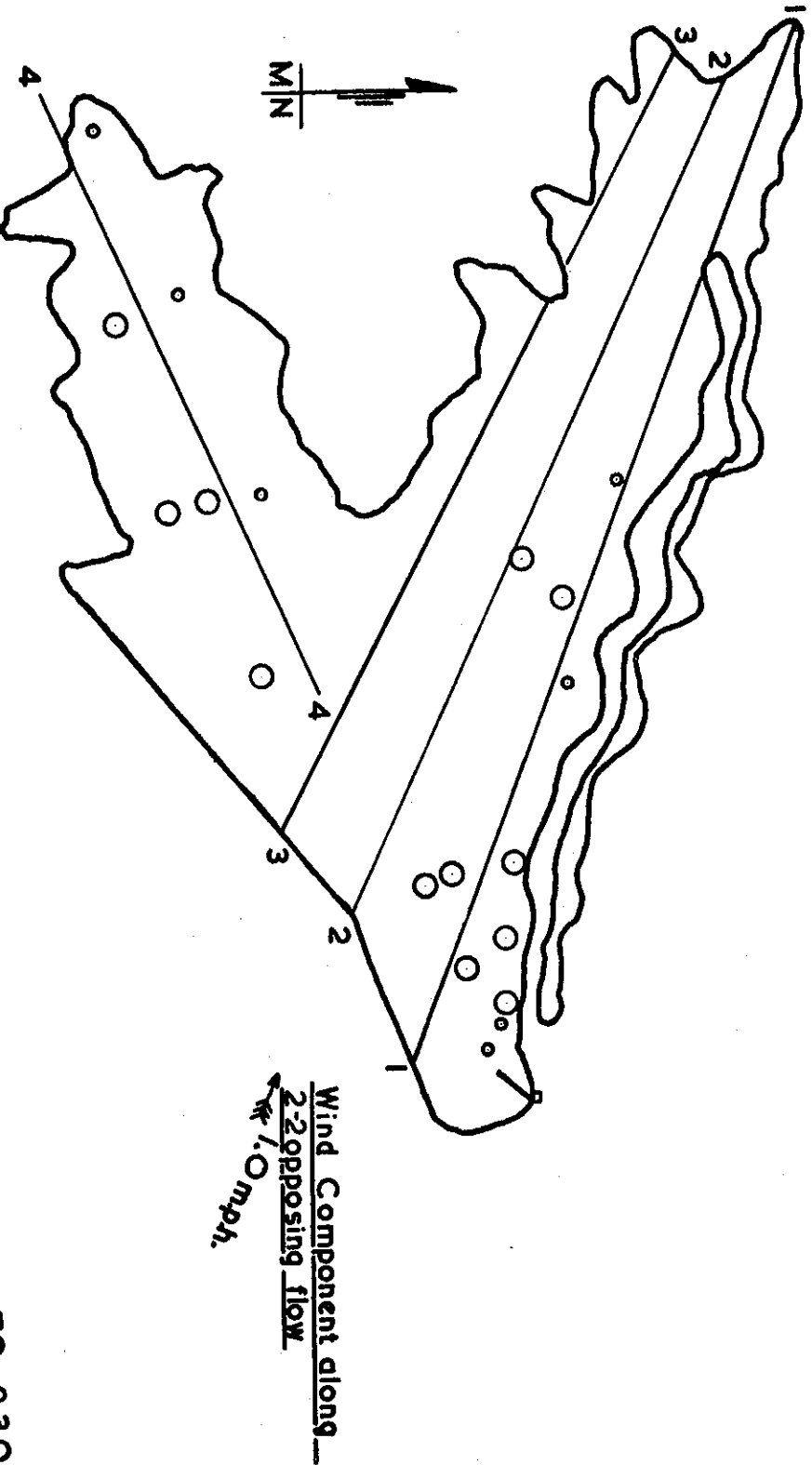


FIGURE 8. SURFACE DISTRIBUTION OF TRACER - FIRST DAY, 8.00 TO 9.30 p.m.

SCALE  
See Fig. 1

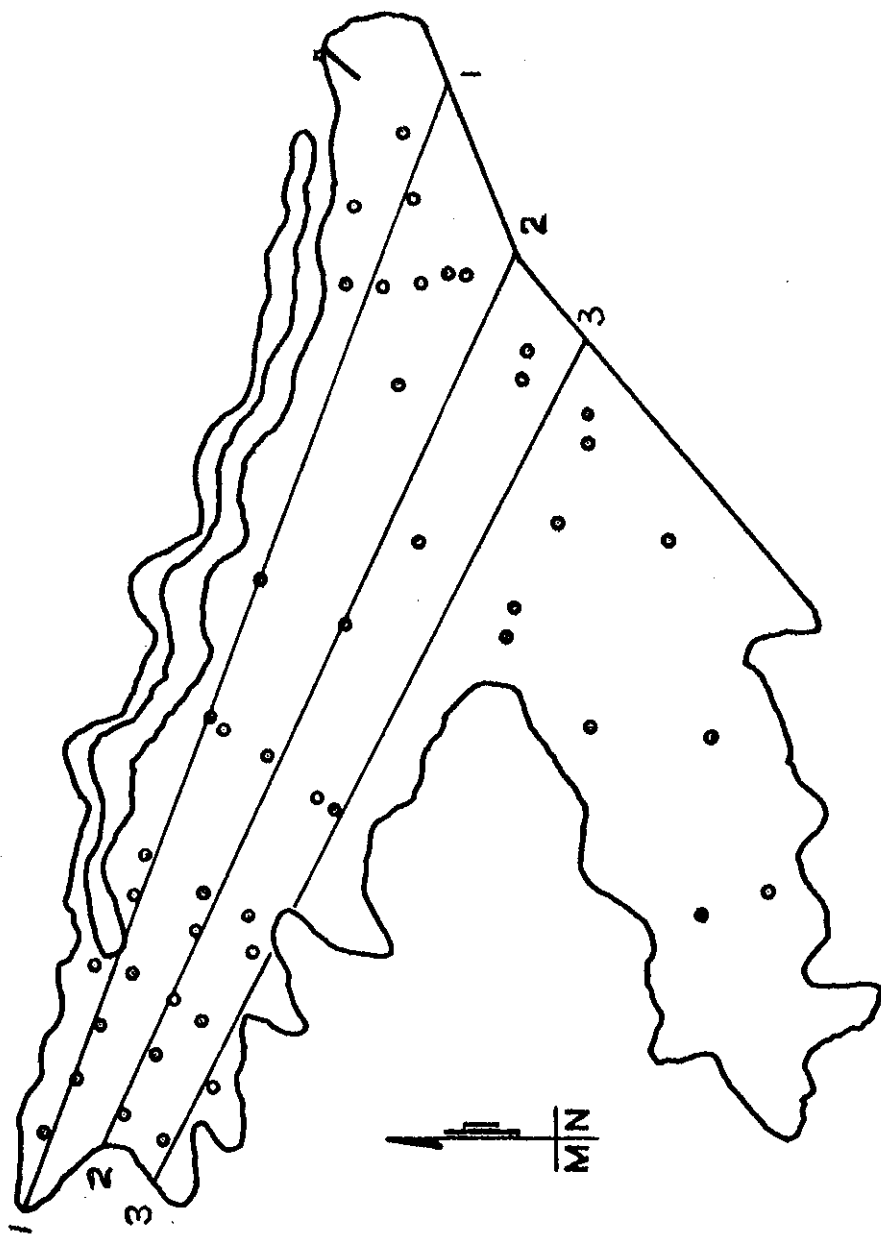


FIGURE 9. SURFACE DISTRIBUTION OF TRACER - SECOND DAY, 10.00 TO 12.00n.

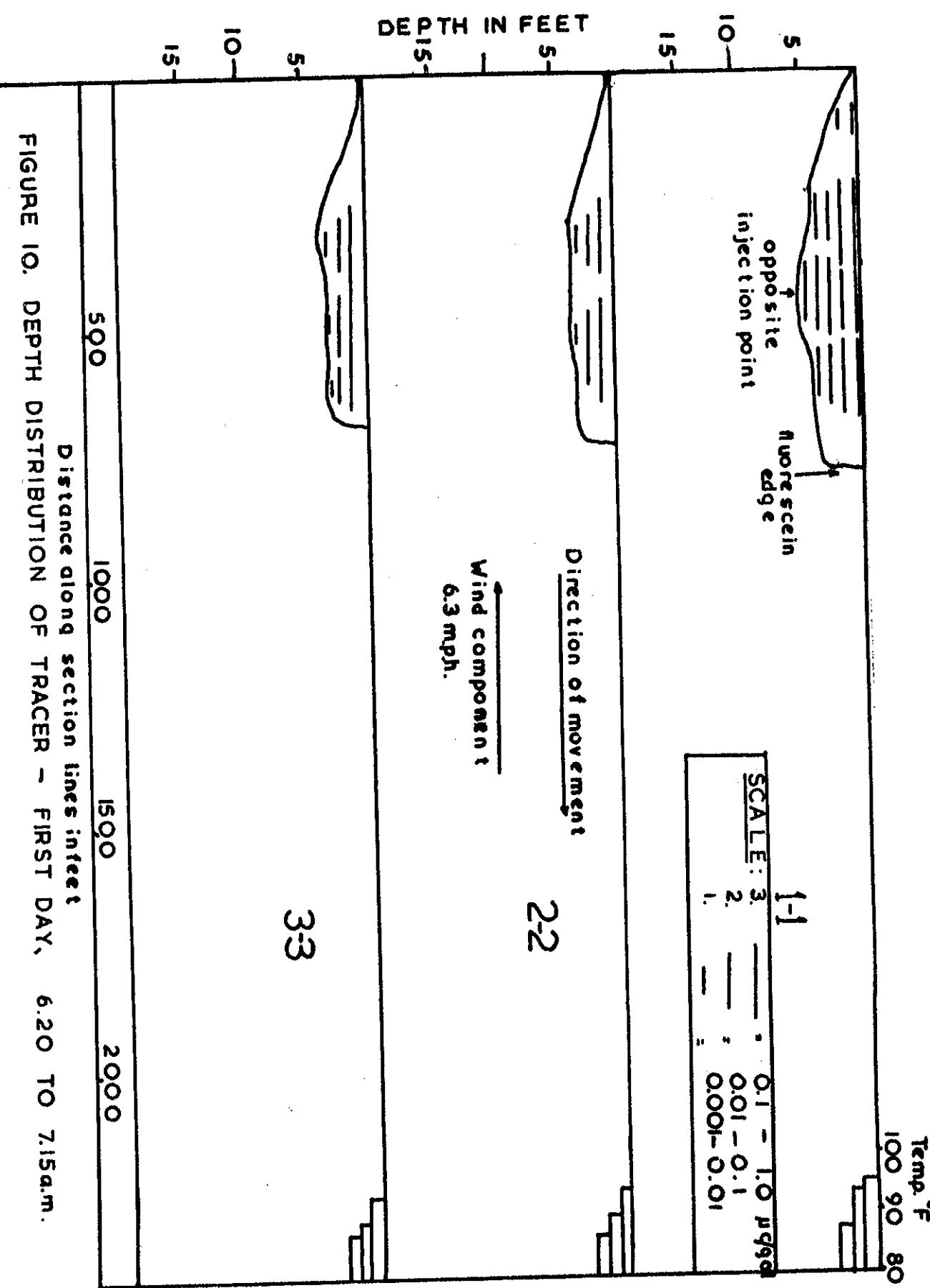
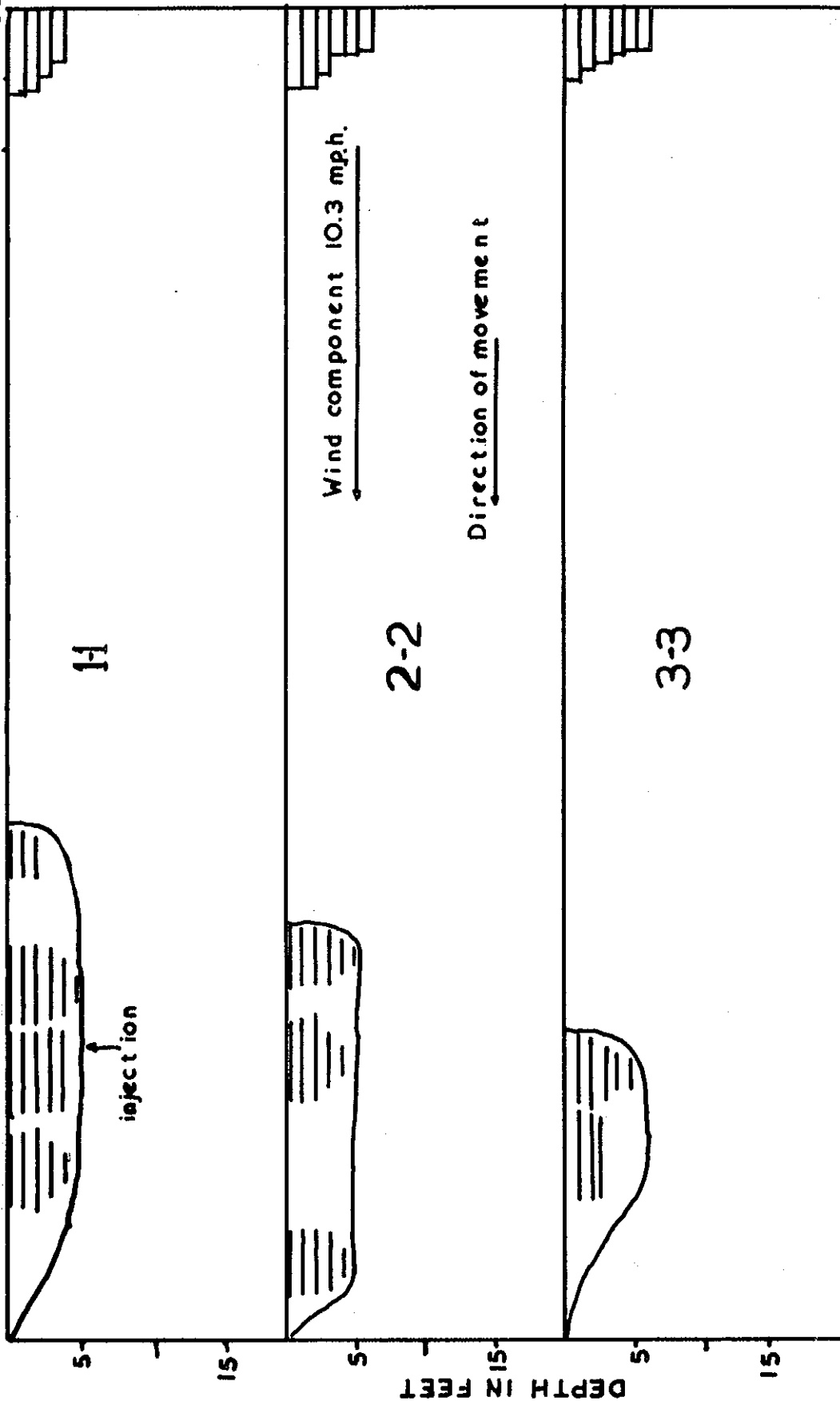


FIGURE 10. DEPTH DISTRIBUTION OF TRACER - FIRST DAY, 6.20 TO 7.15 a.m.

Temp °F  
100 90 80



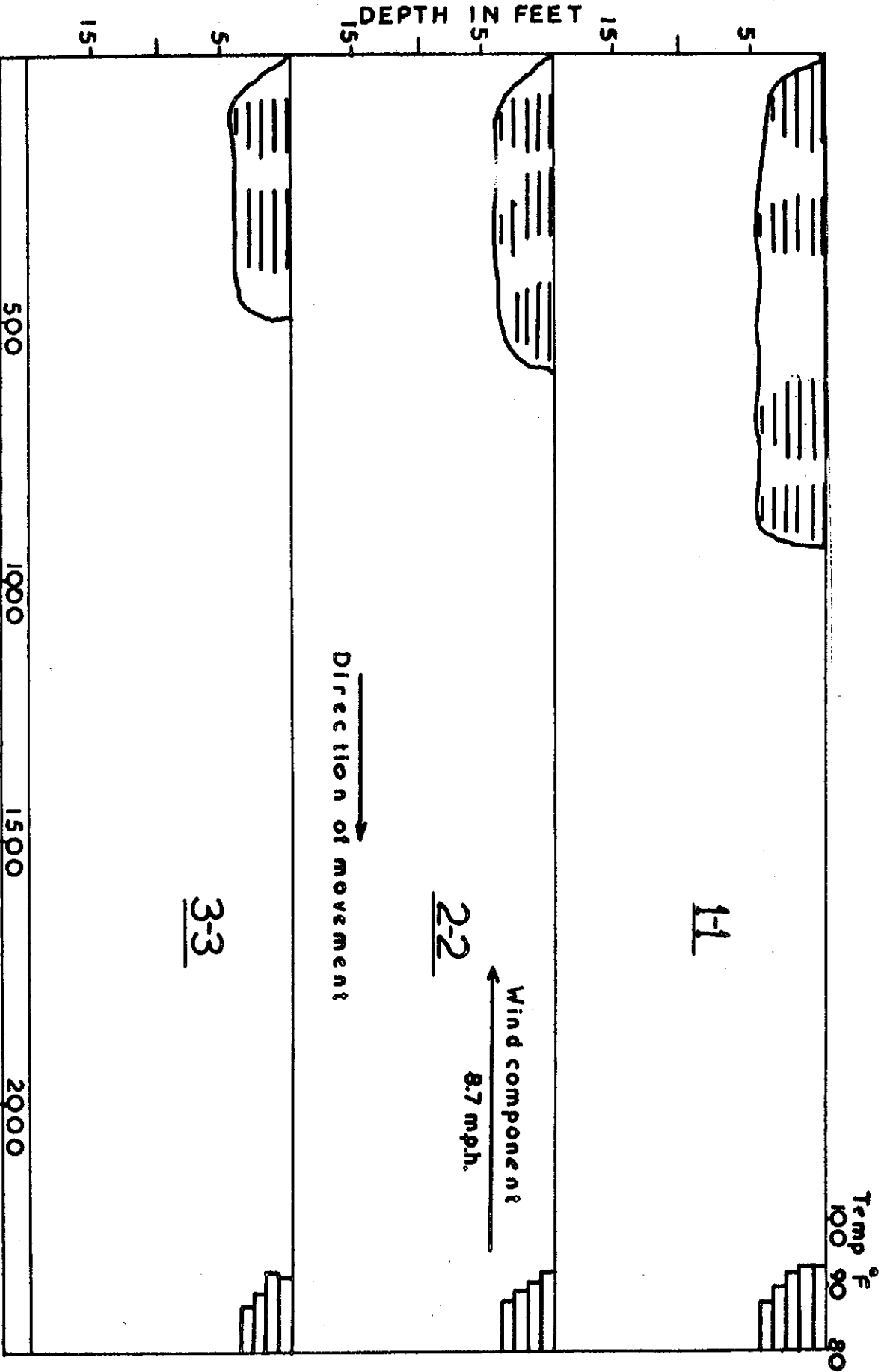
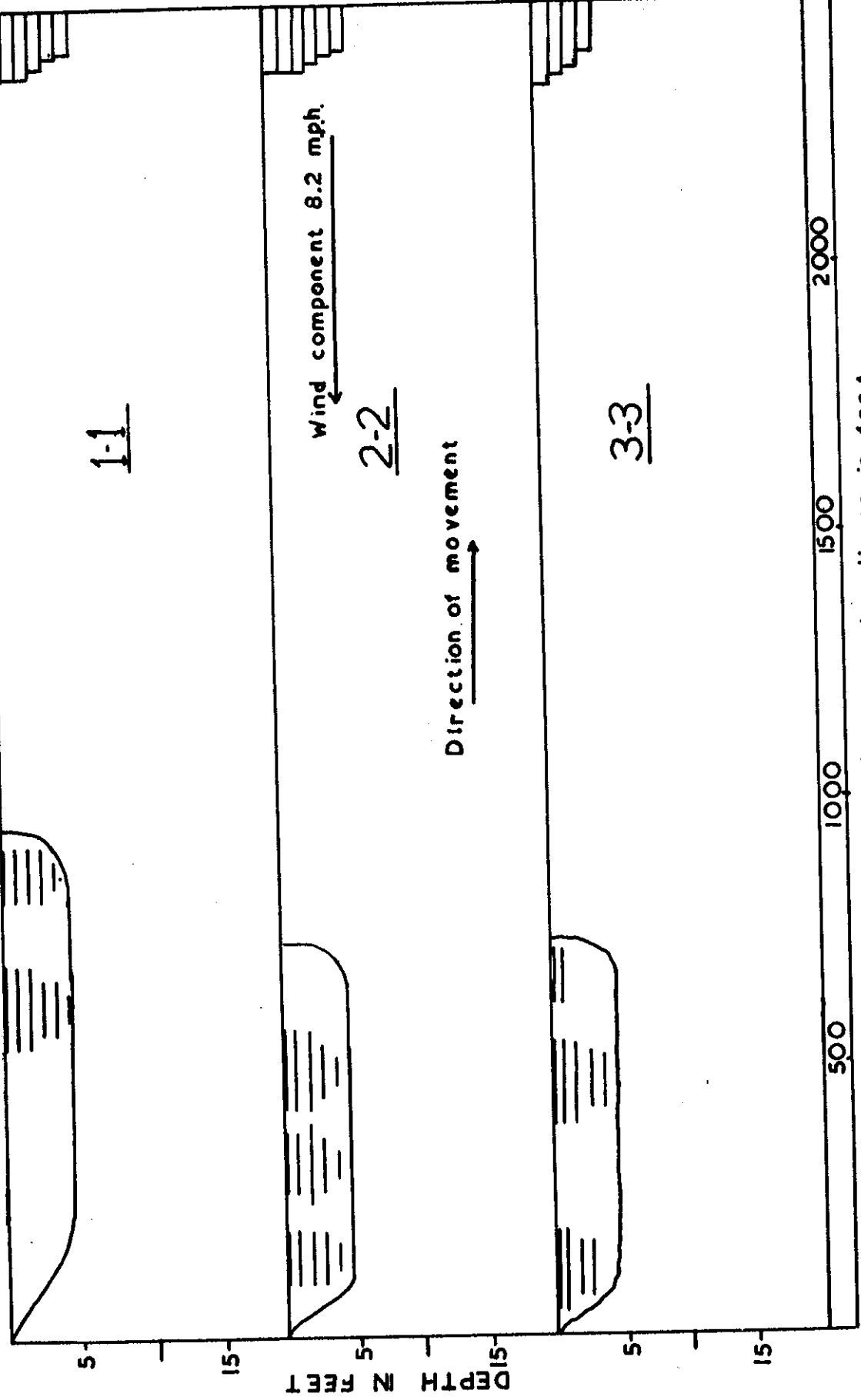


FIGURE 12. DEPTH DISTRIBUTION OF TRACER - FIRST DAY, 8.00 TO 8.30 a.m.

Temp. °F  
100 90 80



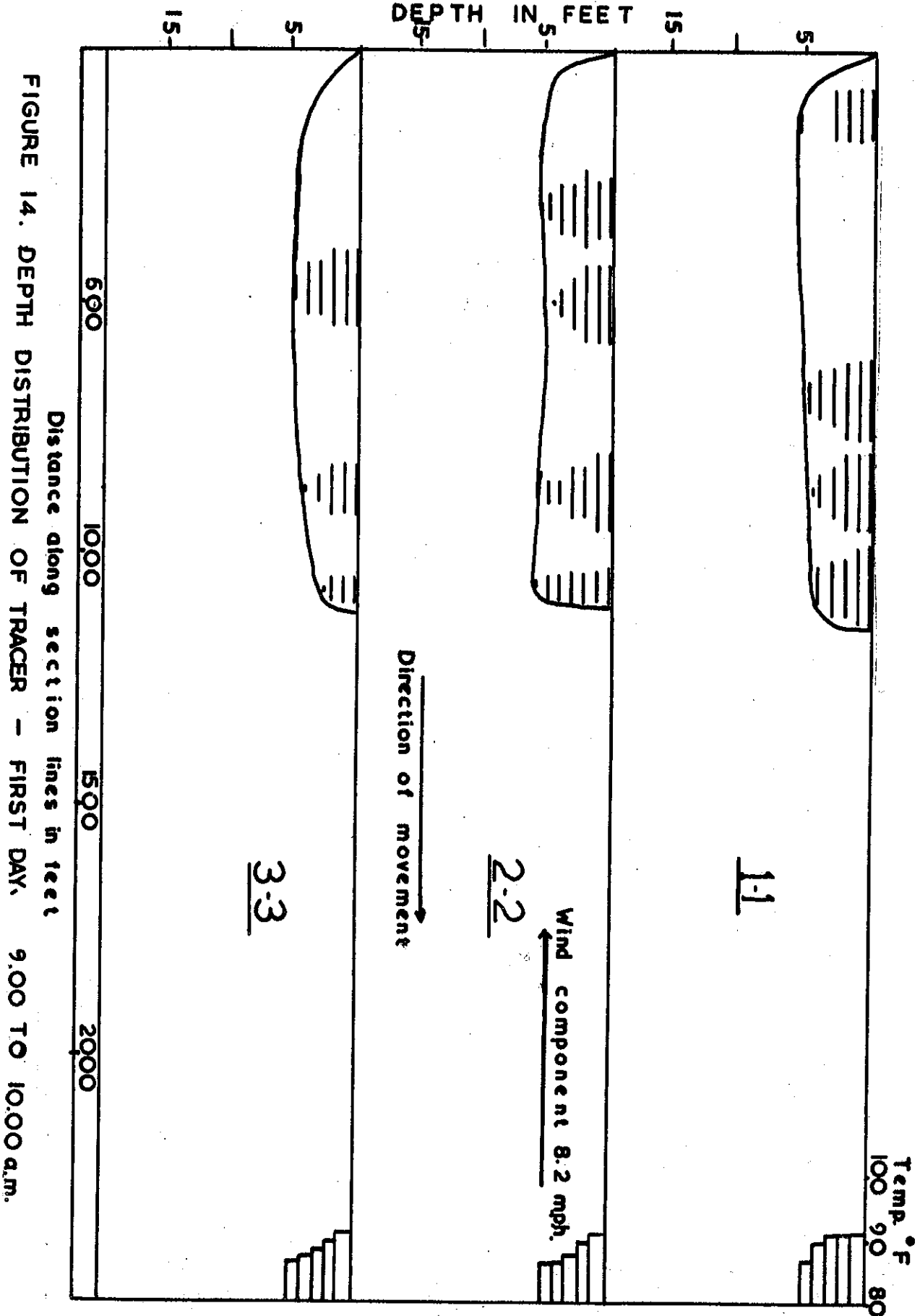
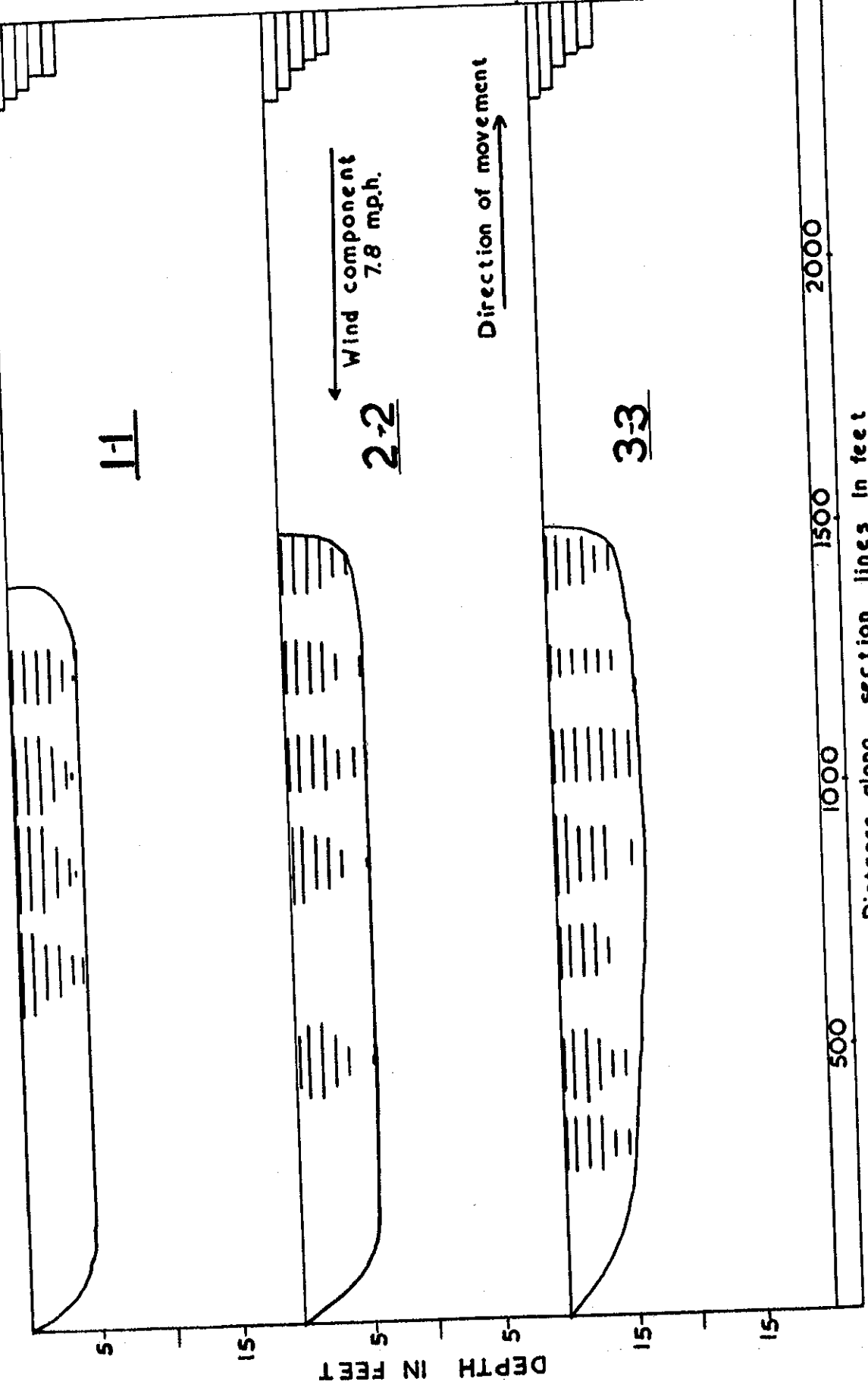


FIGURE 14. DEPTH DISTRIBUTION OF TRACER - FIRST DAY, 9.00 TO 10.00 a.m.

Temp. °F  
100 90 80



1000 TO 1100 A.M.  
FIRST DAY

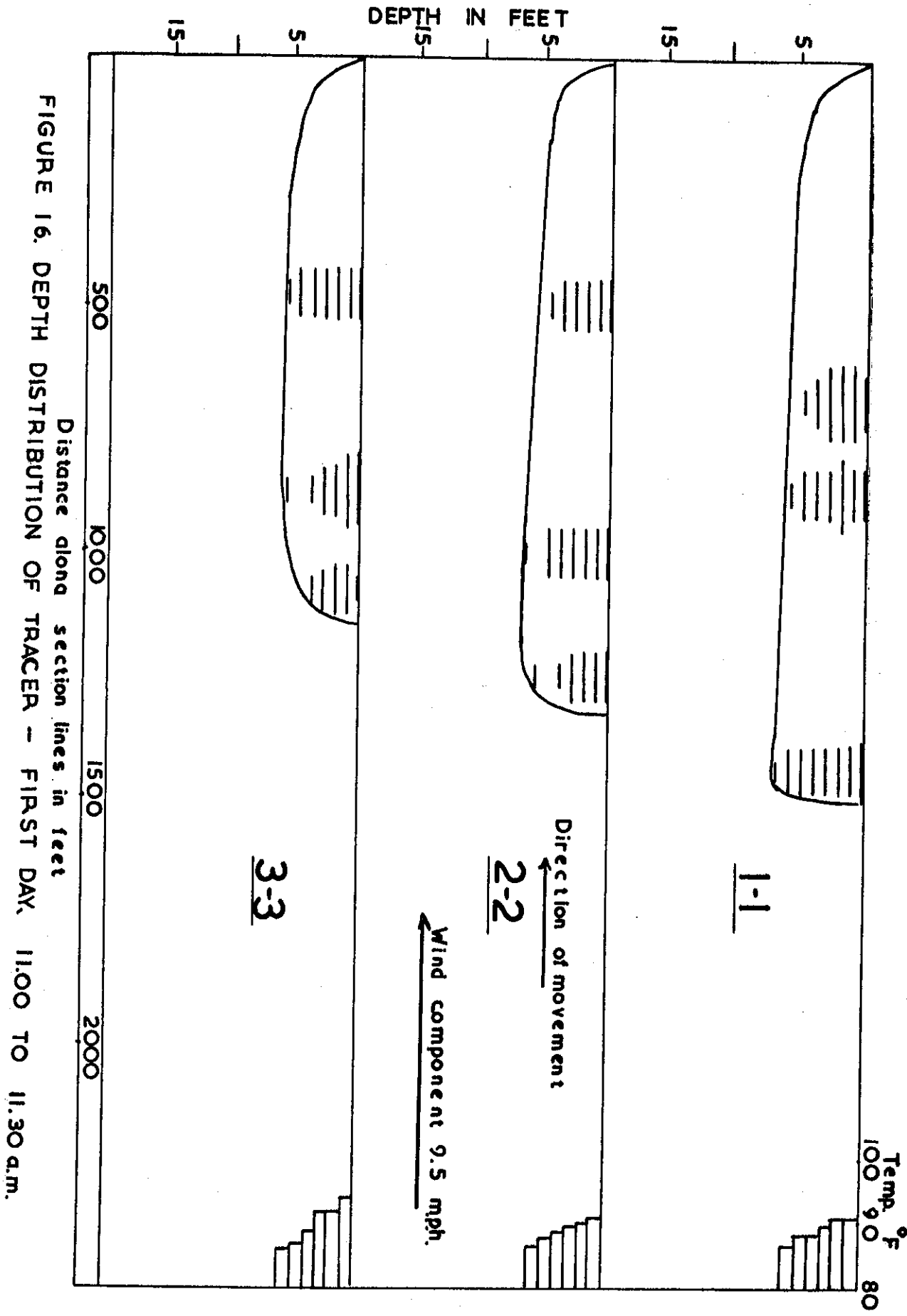
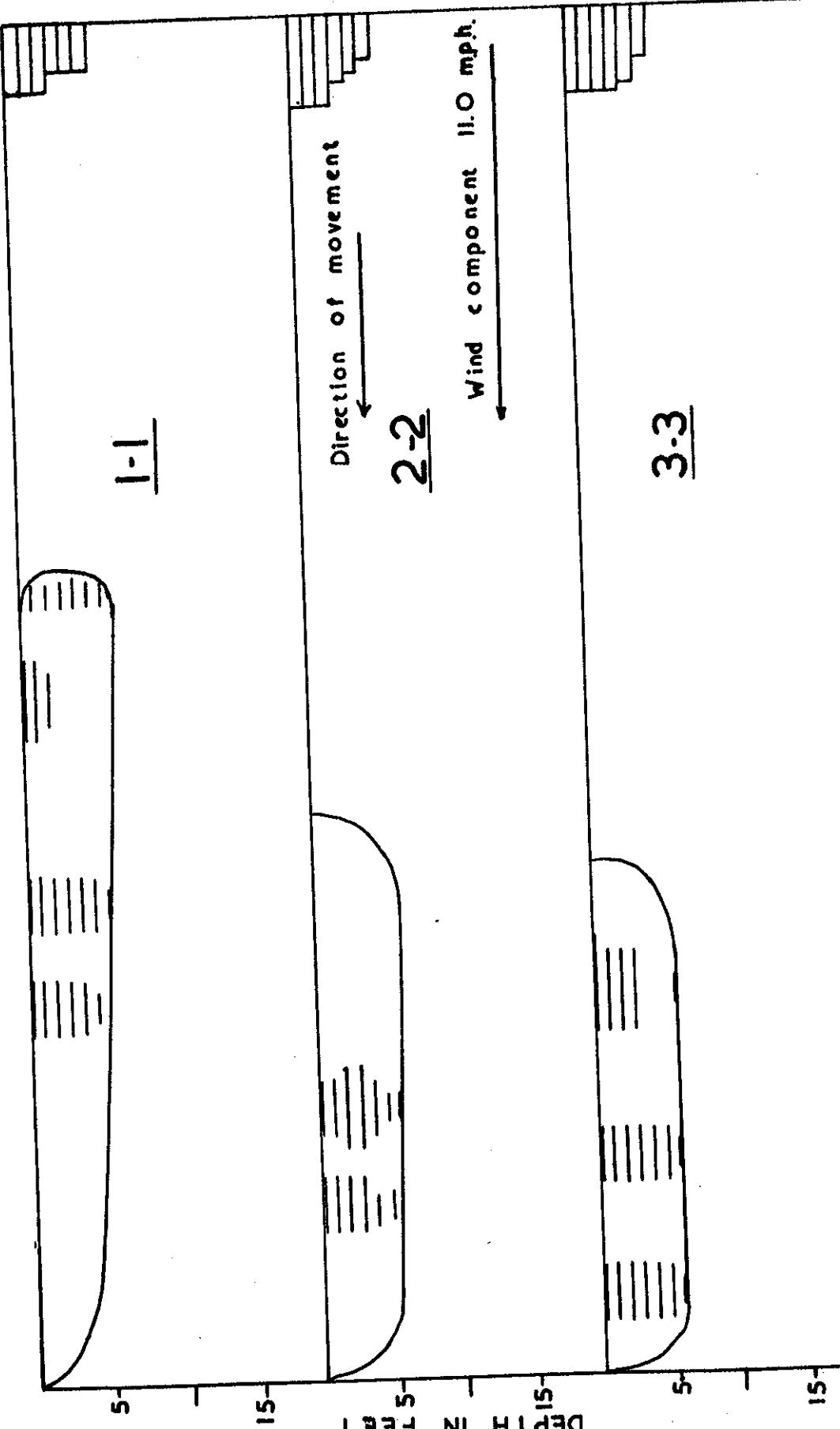


FIGURE 16. DEPTH DISTRIBUTION OF TRACER -- FIRST DAY, 11.00 TO 11.30 a.m.

Temp °F  
100 90 80



1-1

Direction of movement  
←

2-2

Wind component 11.0 mph.  
←

3-3

5

15

25

15

5

5

15

500

1000

1500

2000

Section lines in feet

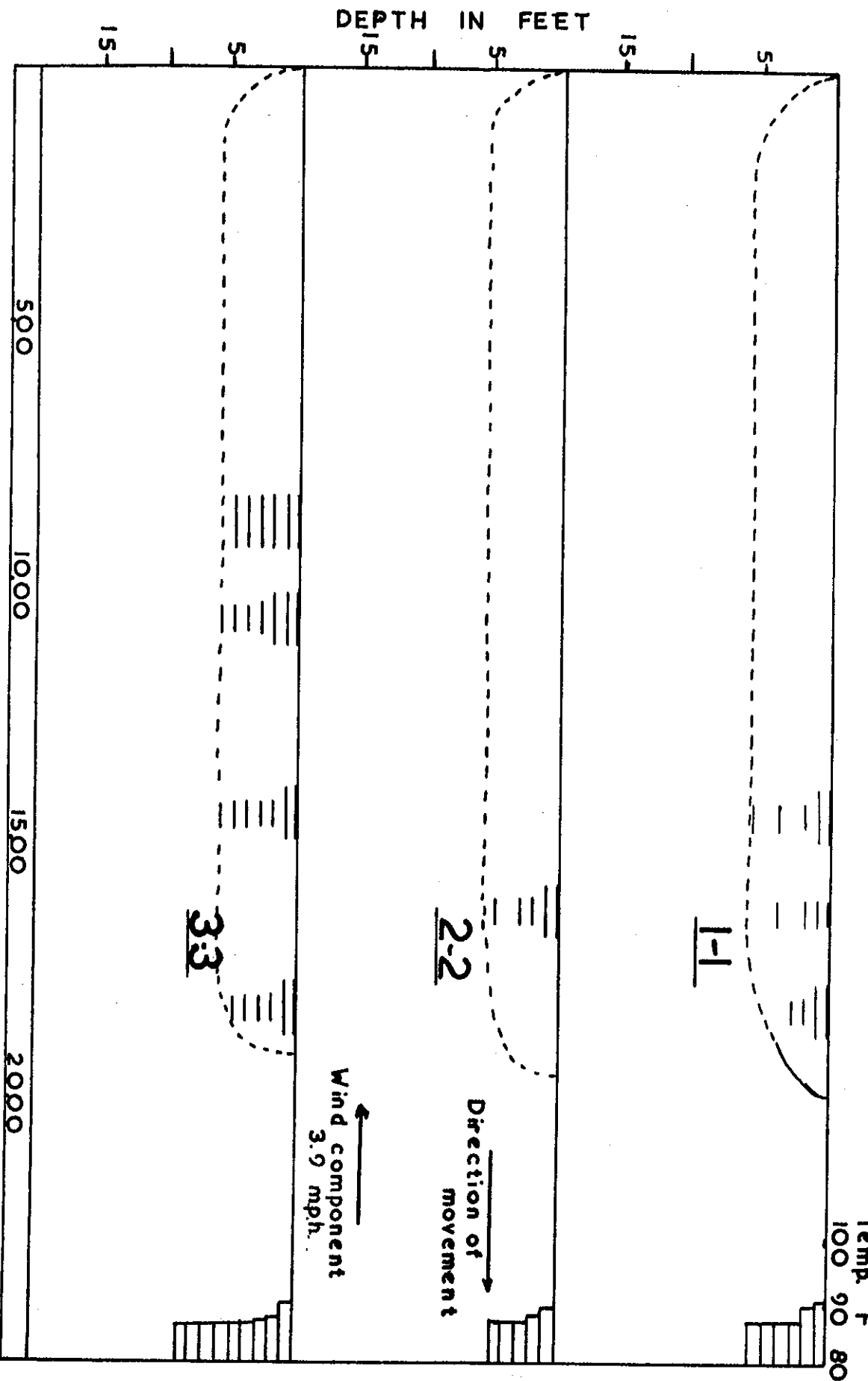


FIGURE 18. DEPTH DISTRIBUTION OF TRACER — FIRST DAY, 1.15 TO 2.00 p. m.

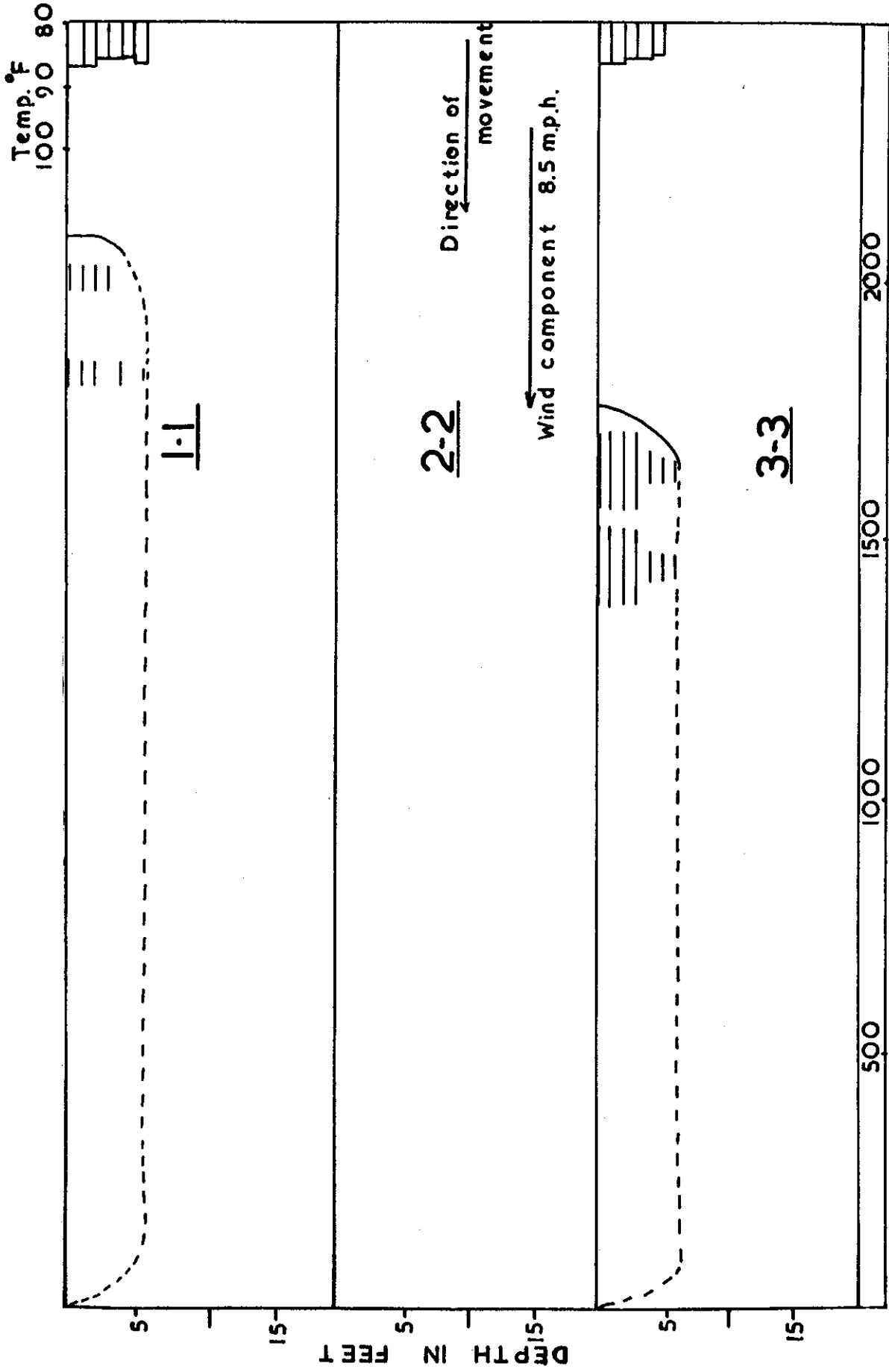


FIGURE 19 DEPTH DISTRIBUTION OF TRACER - FIRST DAY. 2 00 TO 2 45 P.M.

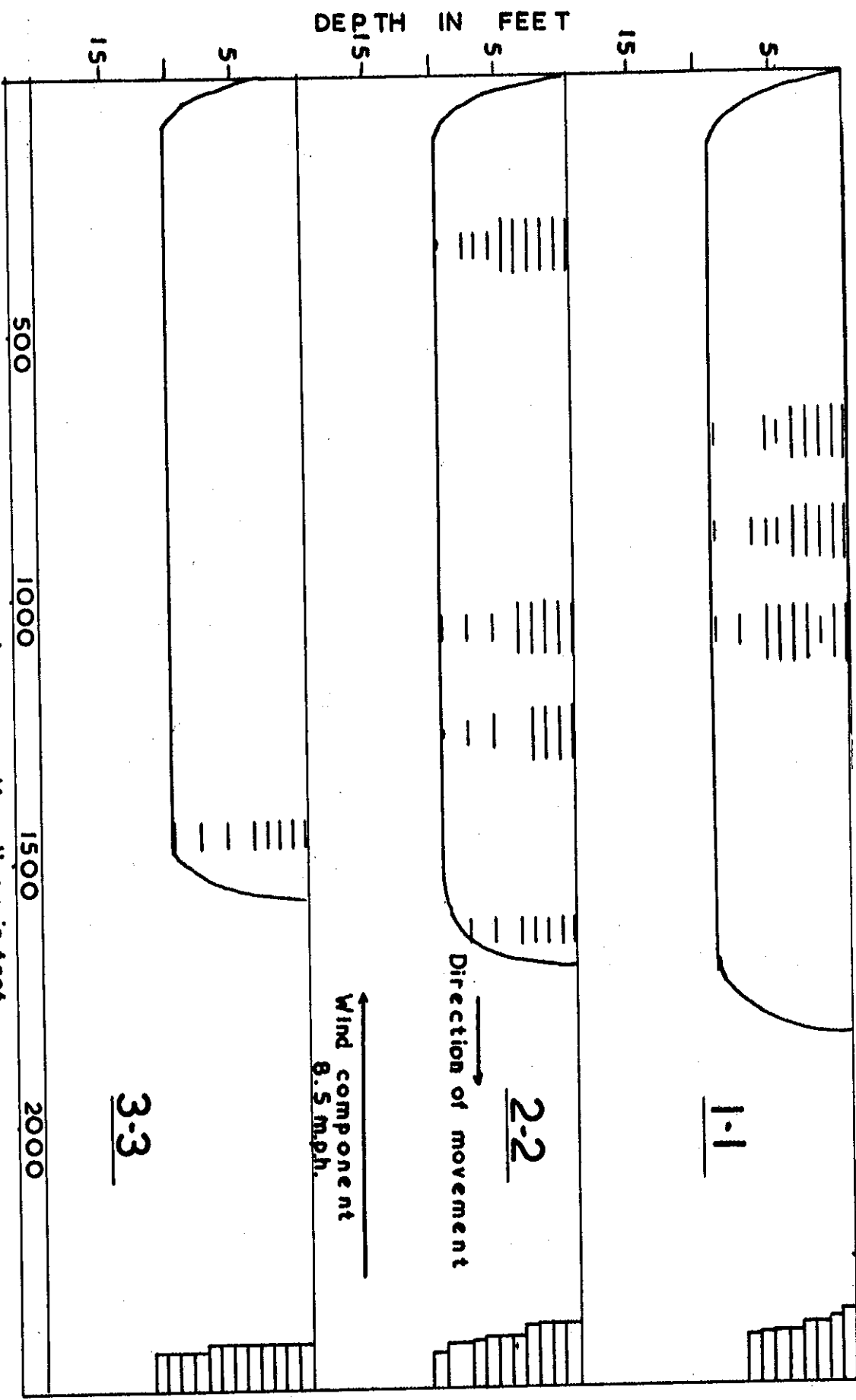
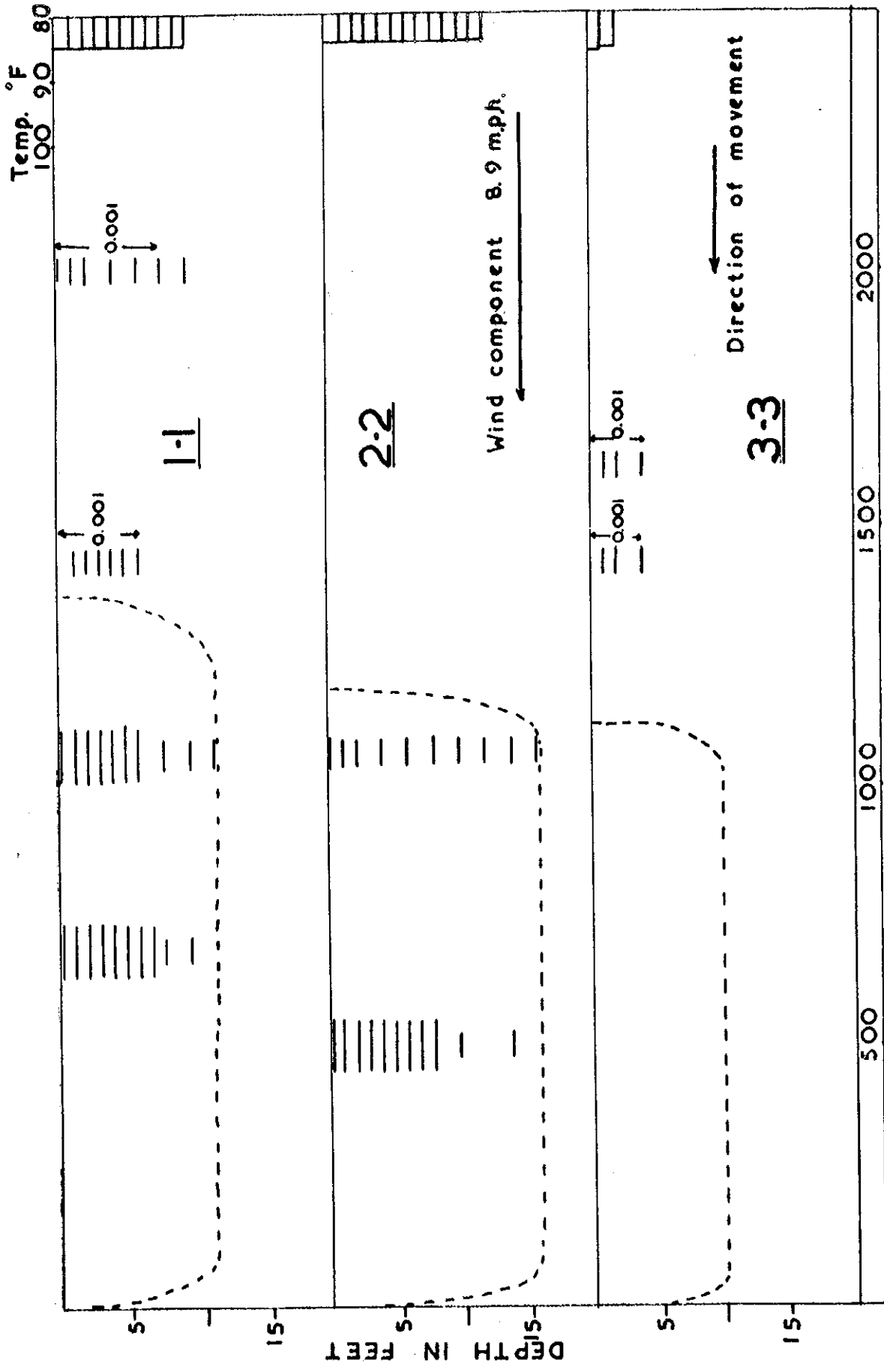


FIGURE 20. DEPTH DISTRIBUTION OF TRACER—FIRST DAY, 2.45 TO 3.30 P.M.



SECTION DISTANCE FROM 0 TO 2000 FEET DAY 120 TO 130000

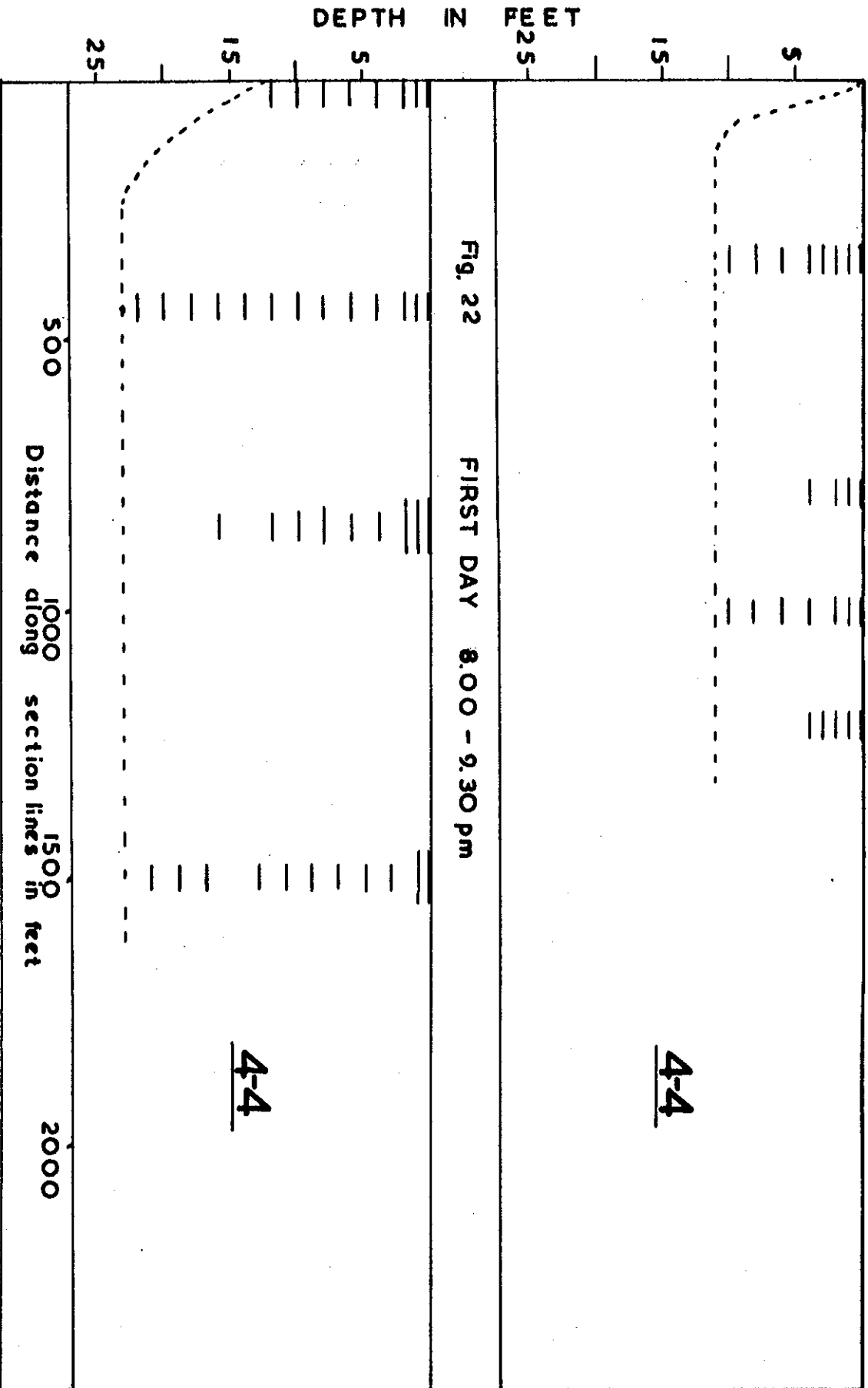


FIGURE 22. DEPTH DISTRIBUTION OF TRACER—FIRST DAY, 4.30 TO 5.30 p.m.

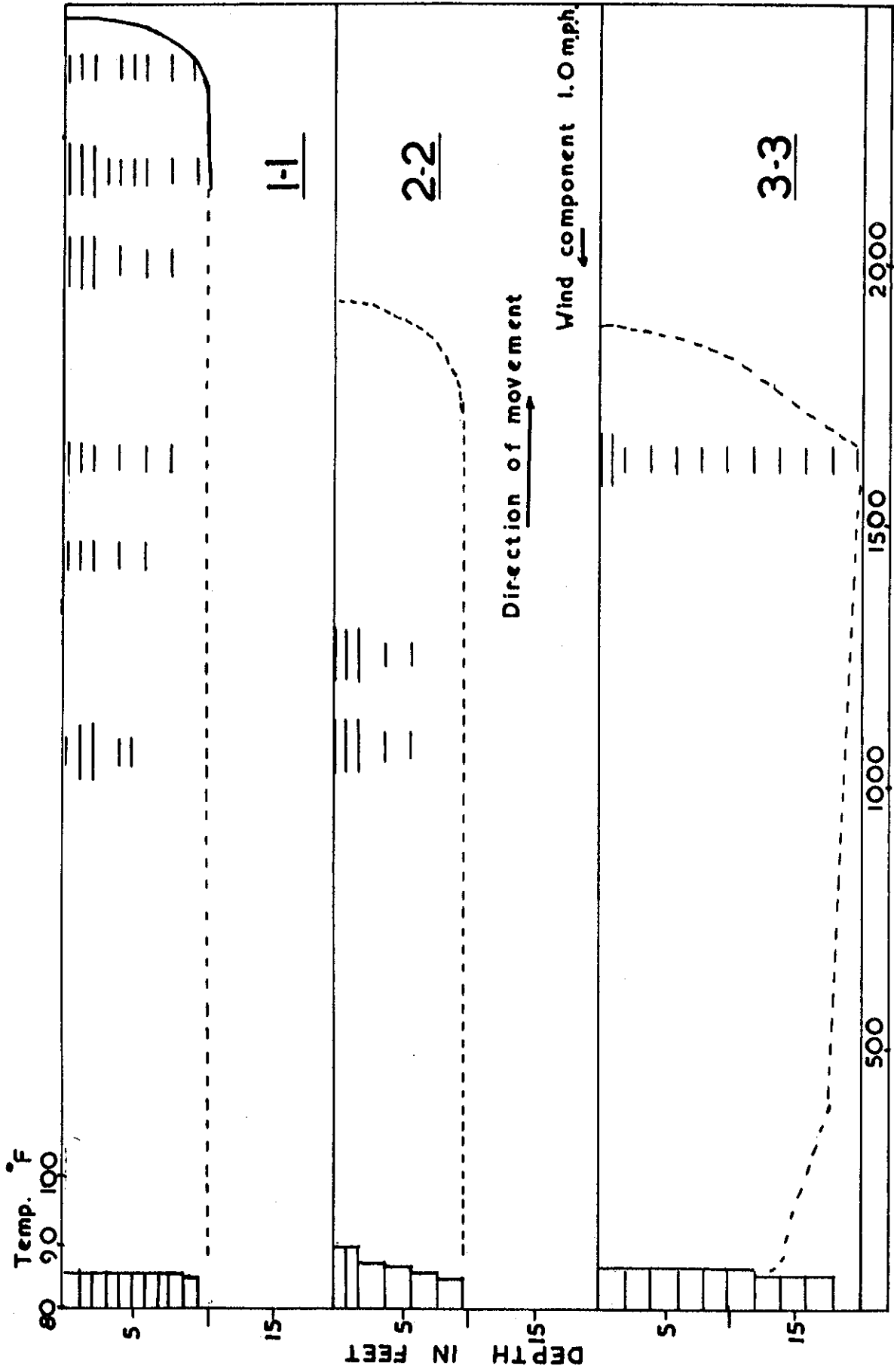


FIGURE 23. DEPTH DISTRIBUTION OF TRACER-FIRST DAY, 800 TO 930 A.M.

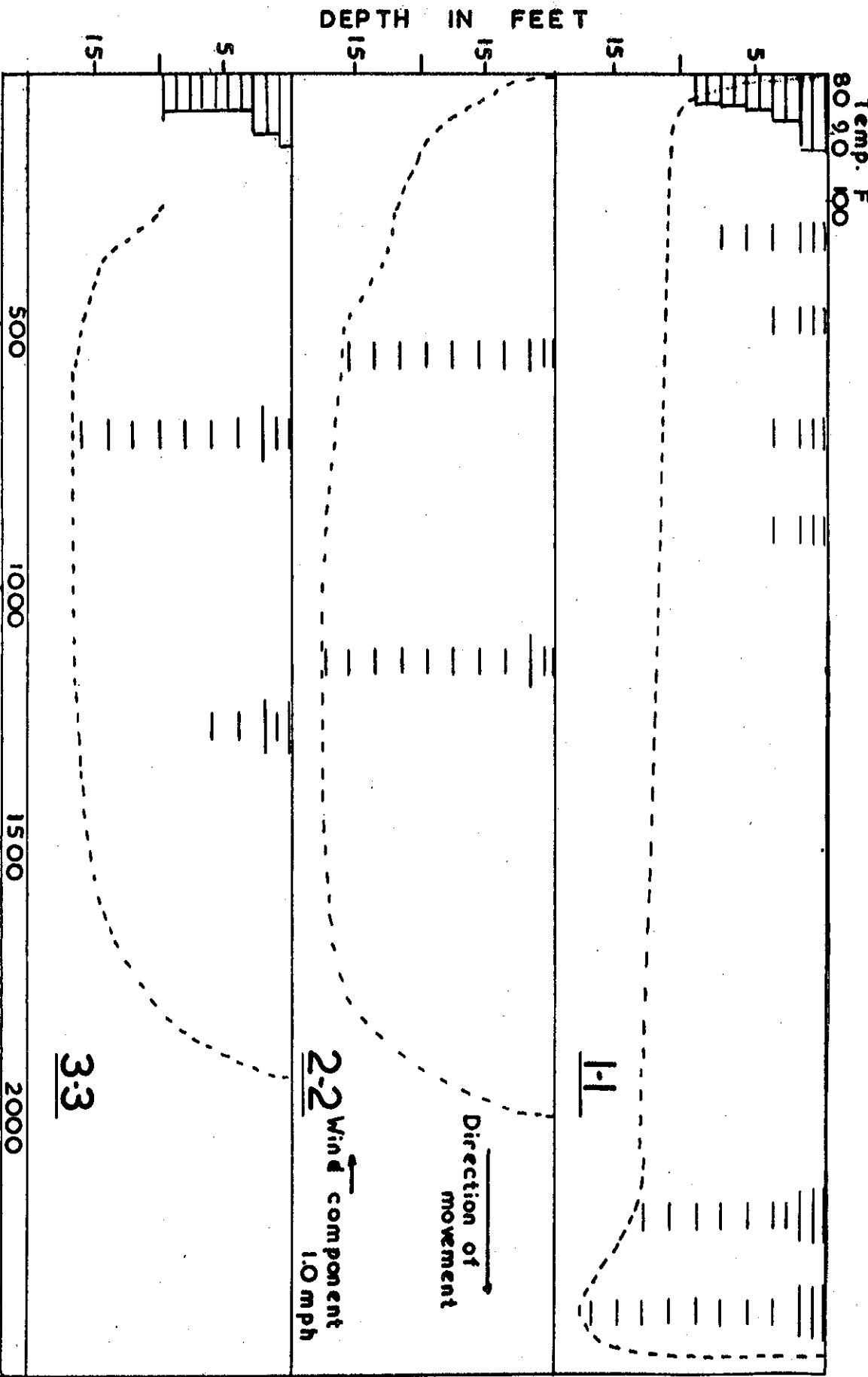
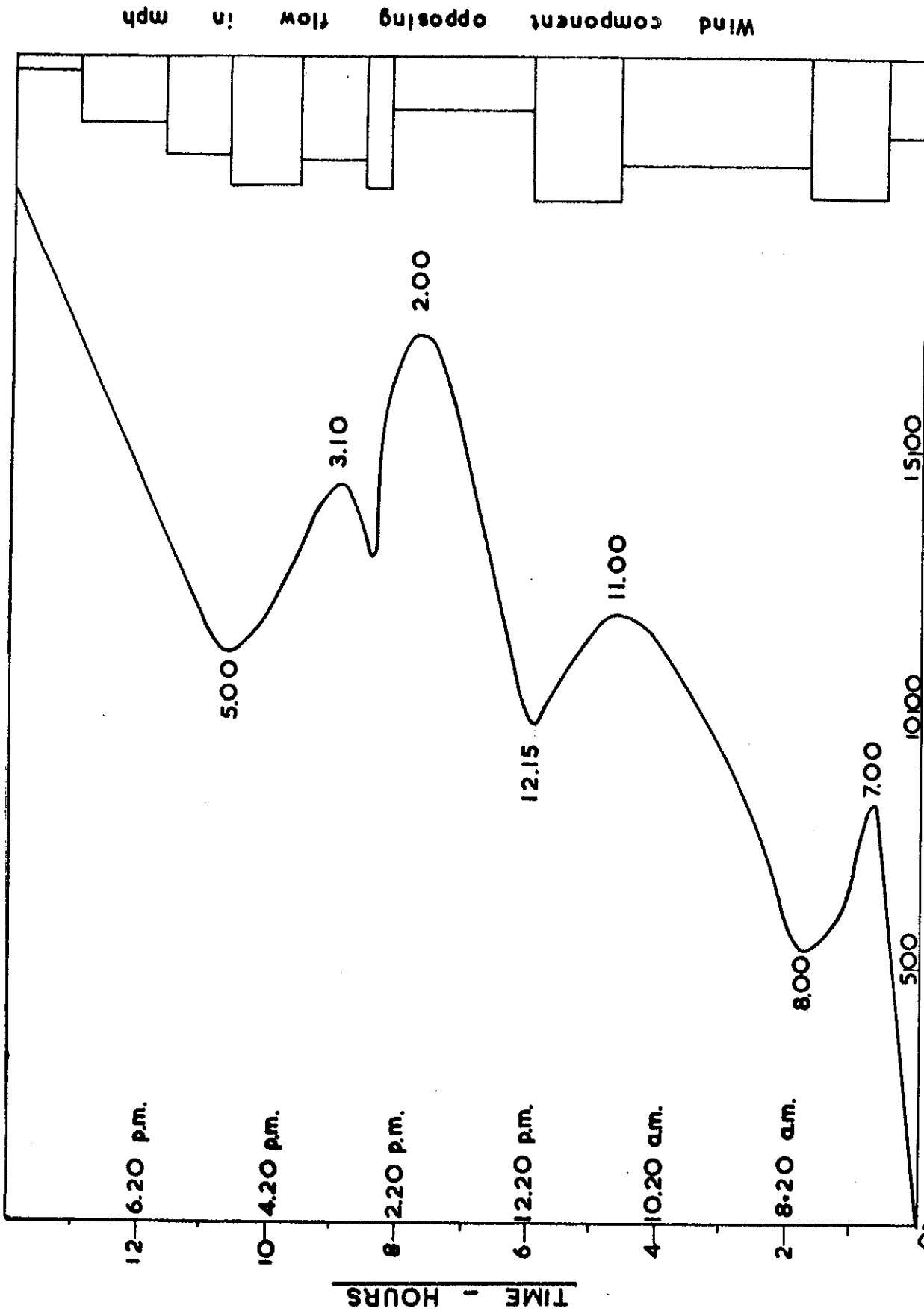


FIGURE 24. DEPTH DISTRIBUTION OF TRACER-LINES IN FEET  
 Distance along section lines in feet  
 9.30 TO 11.00 P.M.



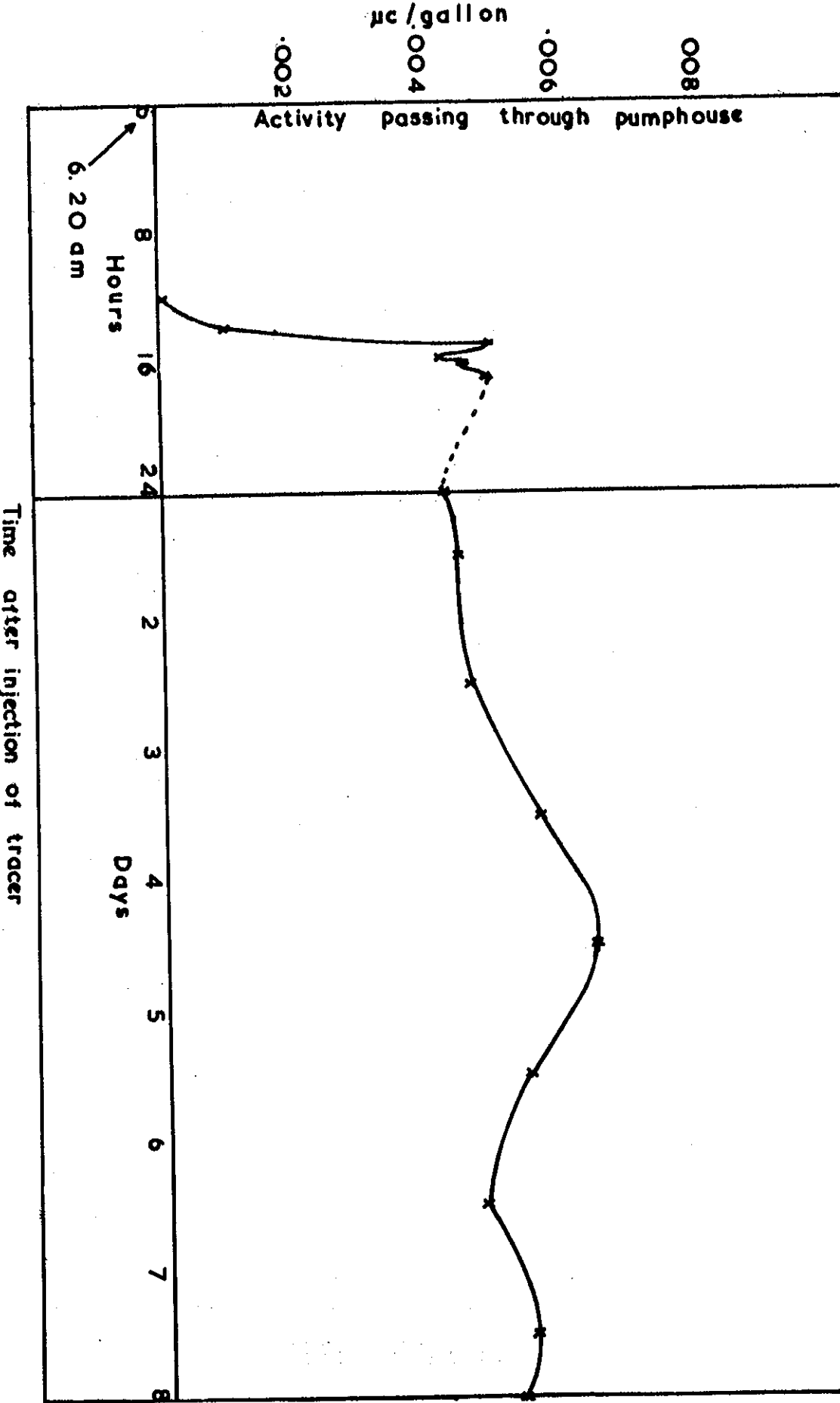


FIGURE 26. ACTIVITY PASSING THROUGH PUMPHOUSE.

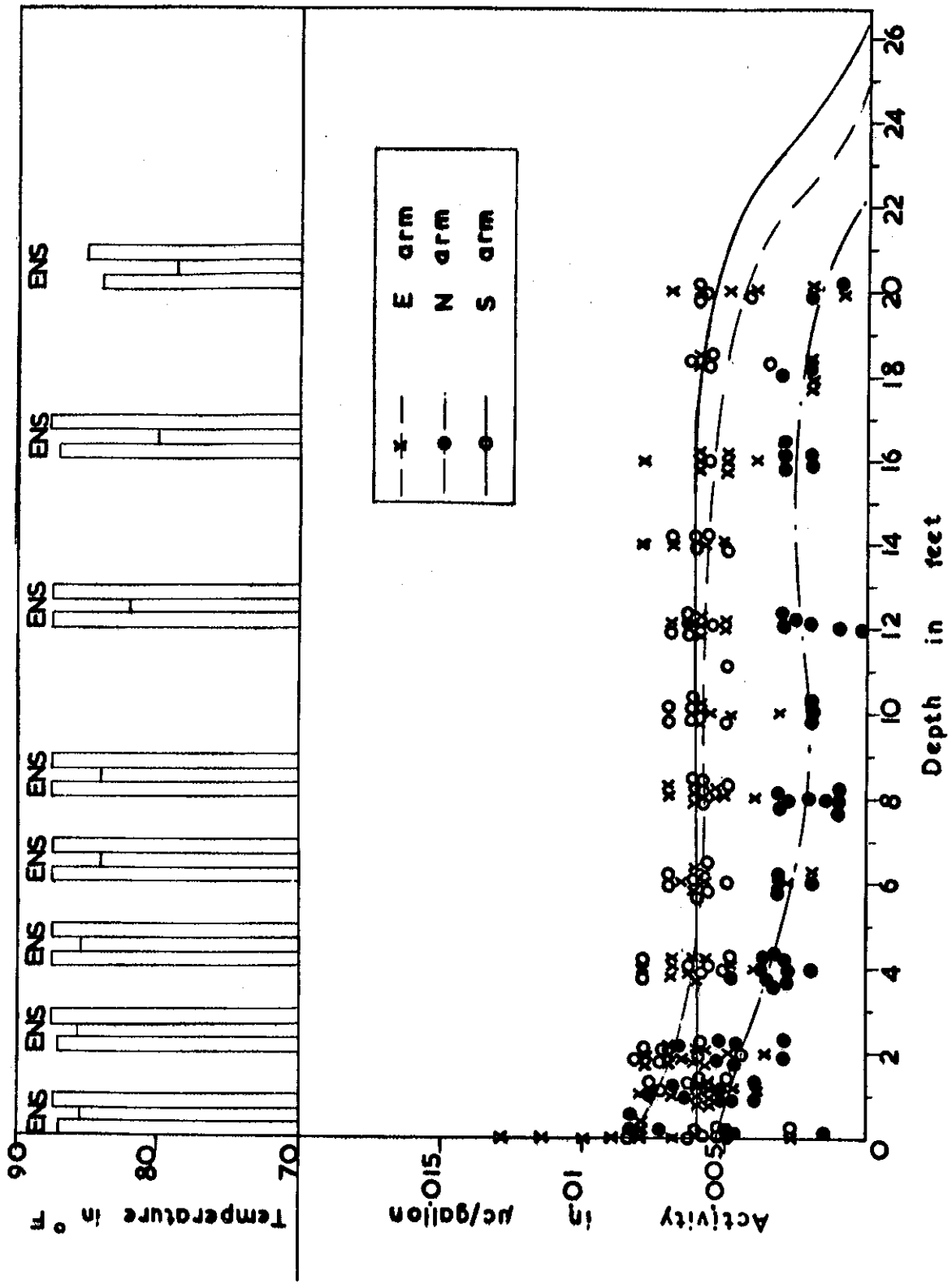


FIGURE 27. AVERAGE TEMPERATURE & ACTIVITY DISTRIBUTION WITH DEPTH

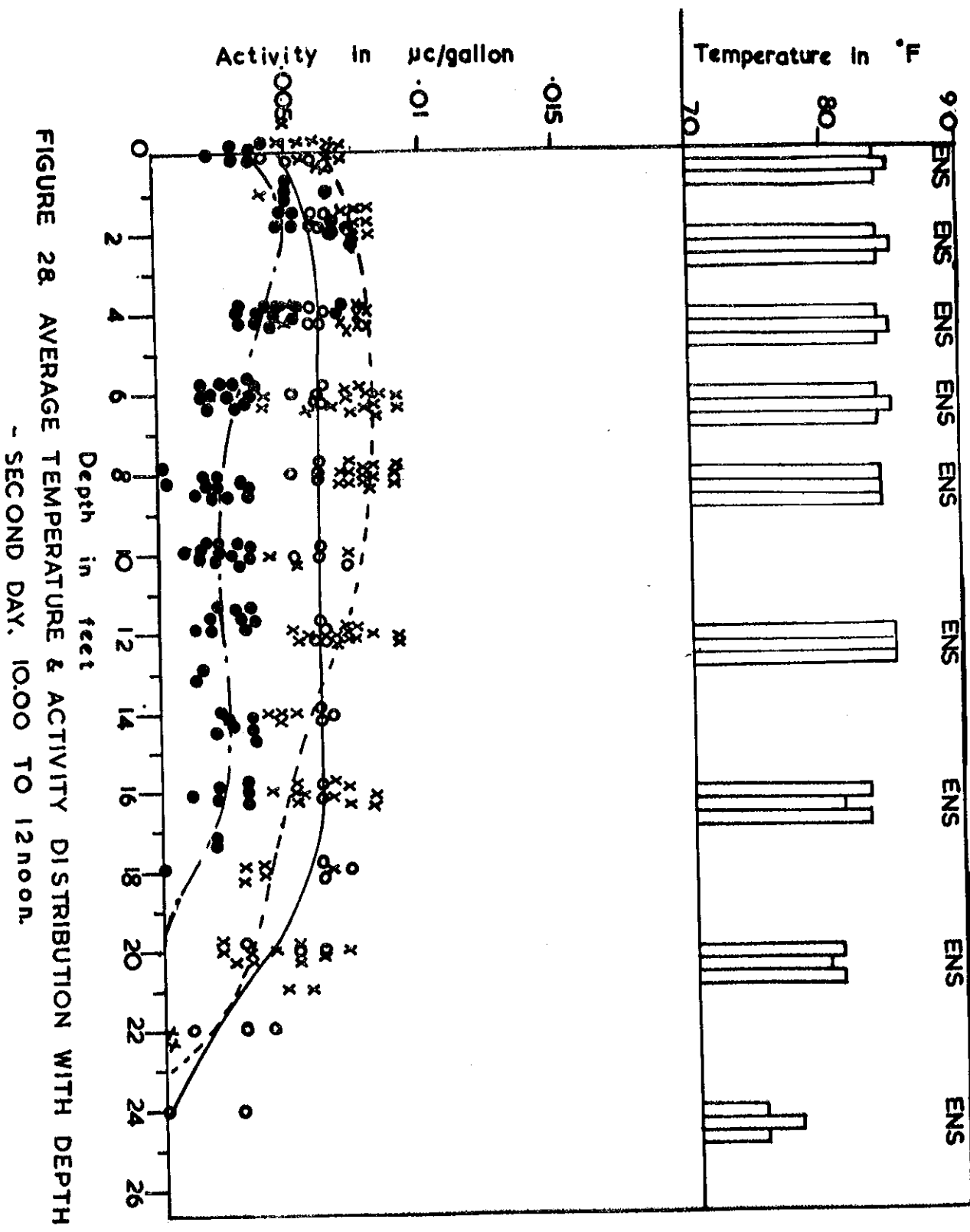
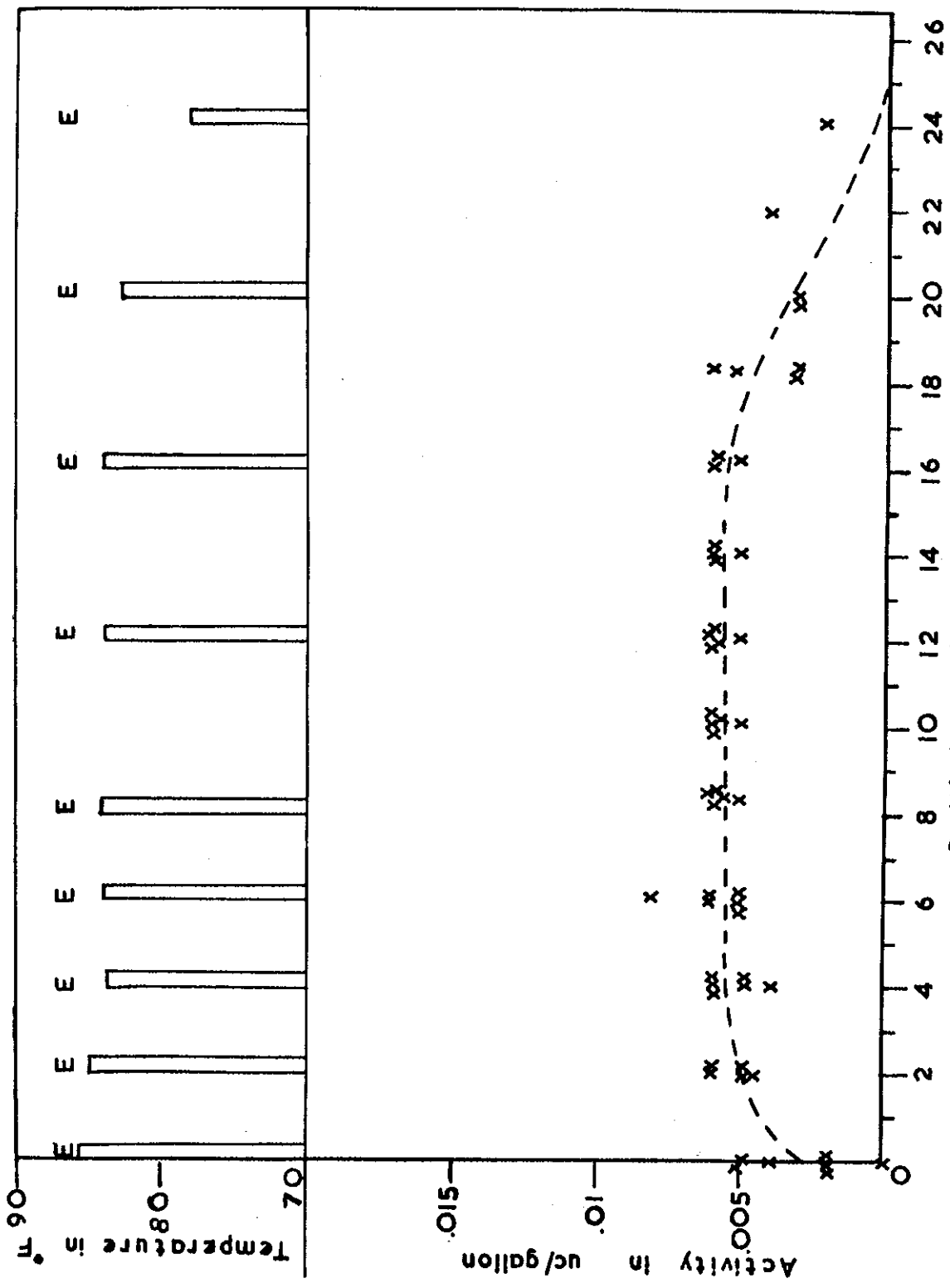


FIGURE 28. AVERAGE TEMPERATURE & ACTIVITY DISTRIBUTION WITH DEPTH  
 - SECOND DAY, 10.00 TO 12noon.



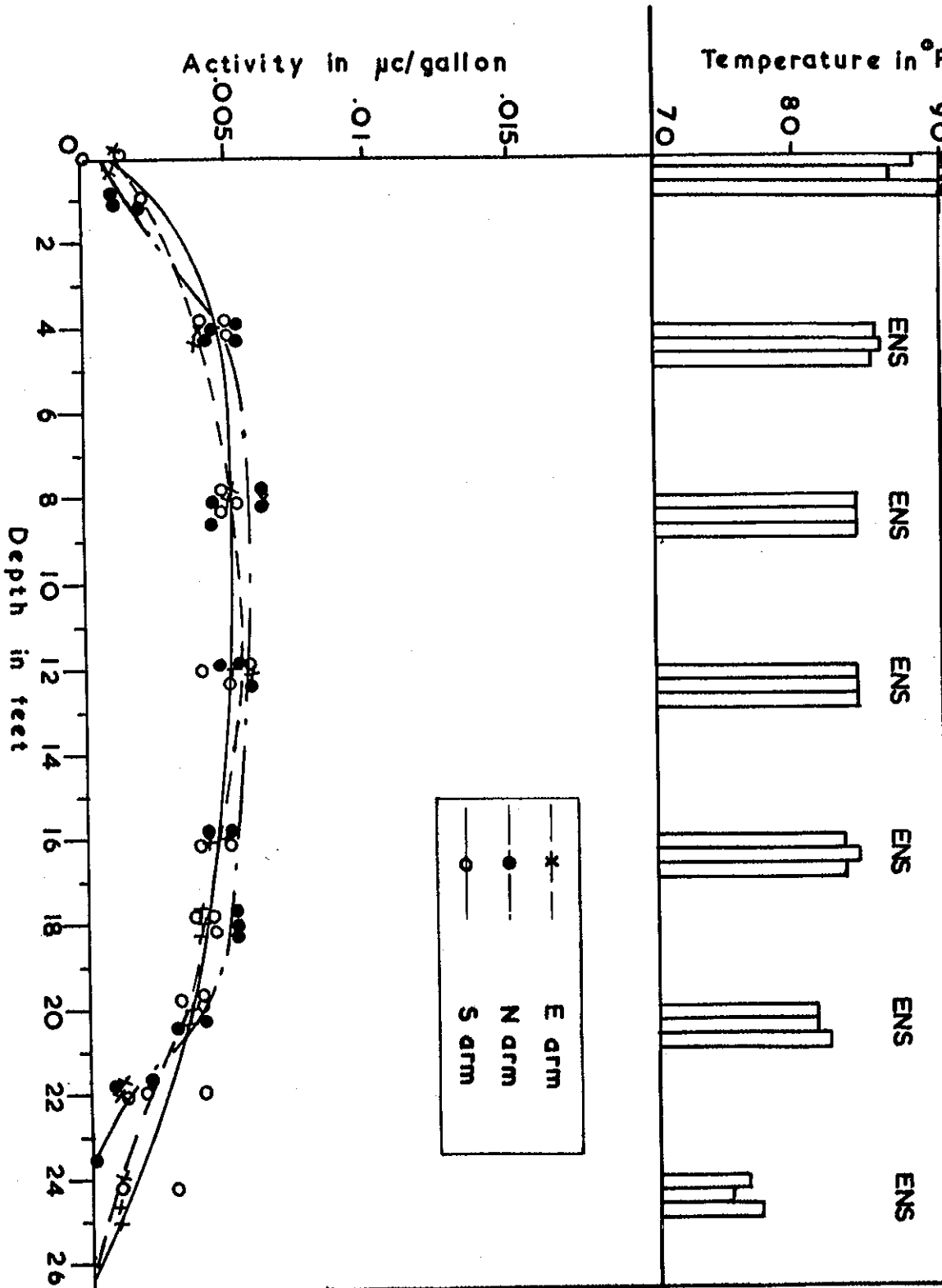


FIGURE 30. AVERAGE TEMPERATURE & ACTIVITY DISTRIBUTION

- THIRD DAY 9.45 TO 10.30 P.M.