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ABSTRACT

A study of hydrography and sediment transport adjacent to Tybee Island, Georgia illustrated the role of tidal currents and residual currents in producing sediment transport patterns. Adjacent to Tybee Island, onshore currents associated with the flooding tide appear to be important mechanisms of sediment transport toward the Savannah River entrance.

In most cases the residual flow of water determines the net flow of sand, however, some inconsistencies were present adjacent to Tybee Island. At two stations, there was a net flow of water in one direction and a potential net transport of sediment in the opposite direction.

INTRODUCTION

This report is the second in a series of reports relating to the sediment budget of the beach and shoreface of Tybee Island. Tybee Island is located just south of the Savannah River entrance, and approximately twenty miles east of the city of Savannah, Georgia. Described herein, are the patterns of water flow and sediment dispersion associated with an eroding barrier island. Water flow data was obtained with recording current meters. Ten current meters were emplaced one meter above the sea bed where they simultaneously recorded current speed and direction (fig. 1) for thirteen hours. Data were recorded on film at six minute intervals. Upon recovering the meters, the film was processed and data points were recorded and organized. Graphs of speed and direction versus time were plotted for the stations and periods sampled (fig. 2-11). Scrutiny of these graphs illustrated the residual flows of water for the tidal cycles sampled. Comparisons of vectors of residual flow also permitted an approximation of the areal distribution of water flow for a thirteen hour period.

PATTERNS OF WATER FLOW (HYDROGRAPHY)

Sample stations for water flow data were located as described on figure 1. Ten stations were made that permitted the recovery of approximately 2600 data points. Five stations were made simultaneously during a relatively calm day in October 1972 (calm to 2 foot swell) and five more in November 1972 (1 to 2 foot swell). Stations were adjacent to the Savannah River entrance and

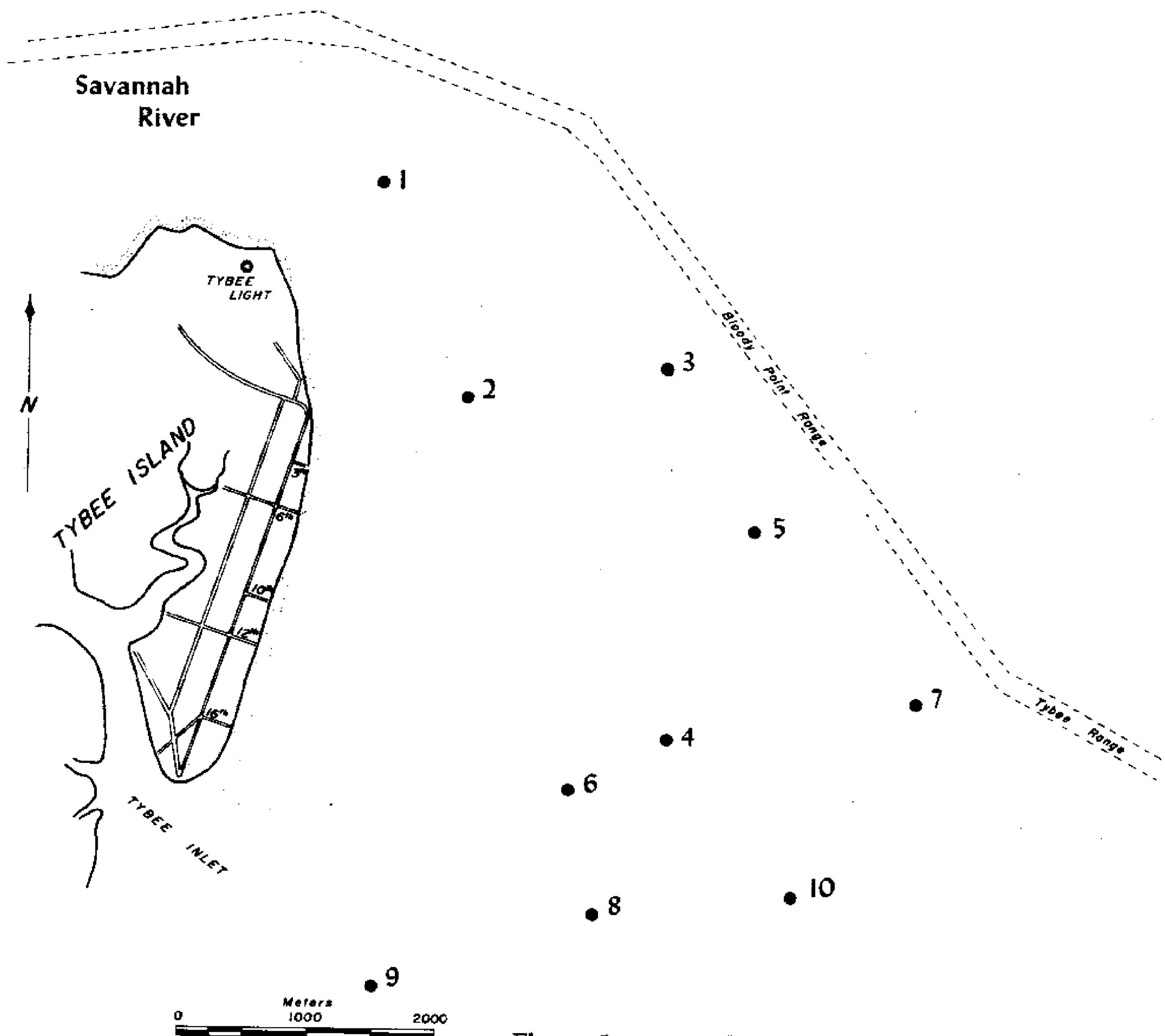


Figure 1. Location map of study area illustrating the location of current meter stations.

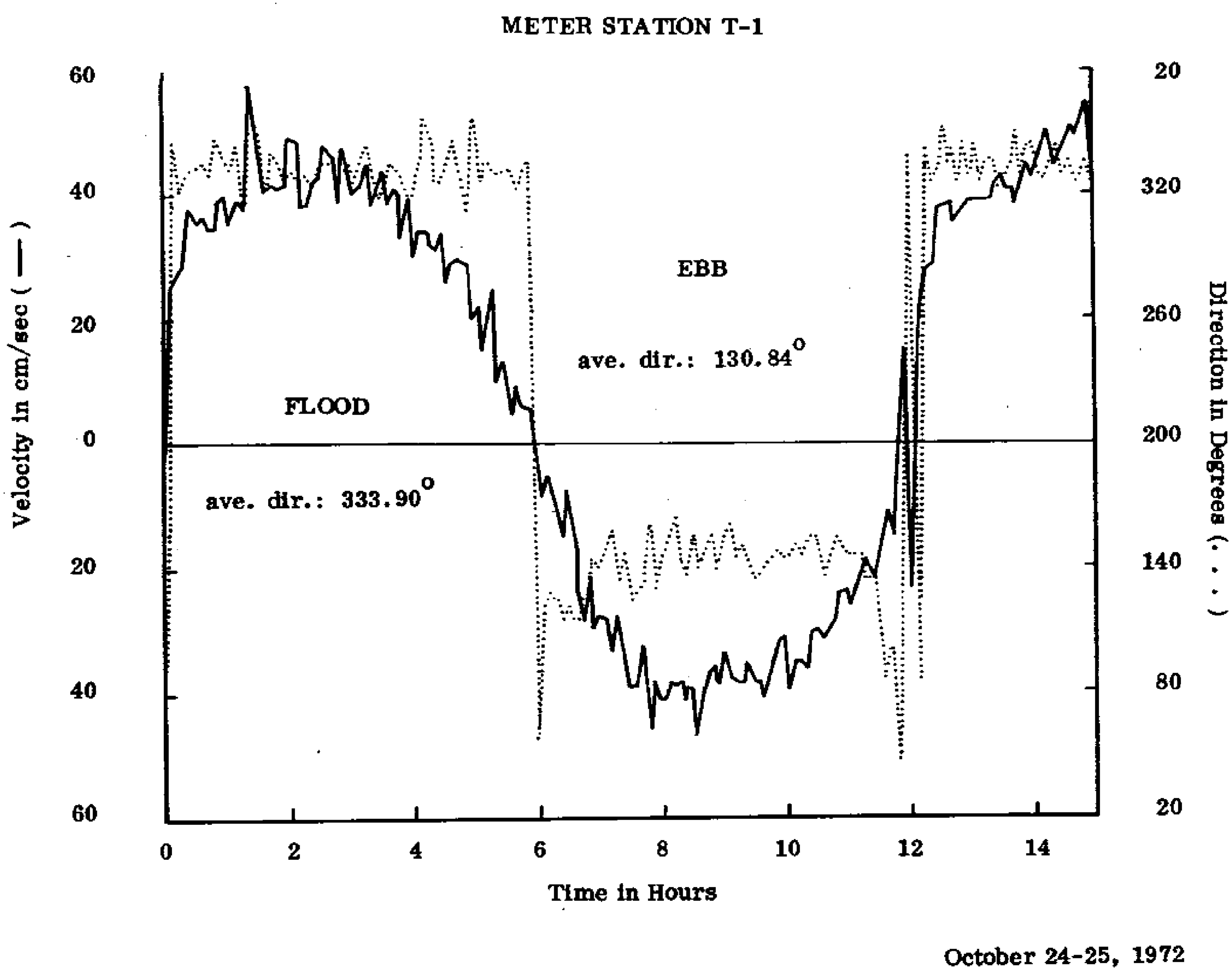


Figure 2. Water flow (speed and direction) at station T-1 (data recorded in six-minute intervals).

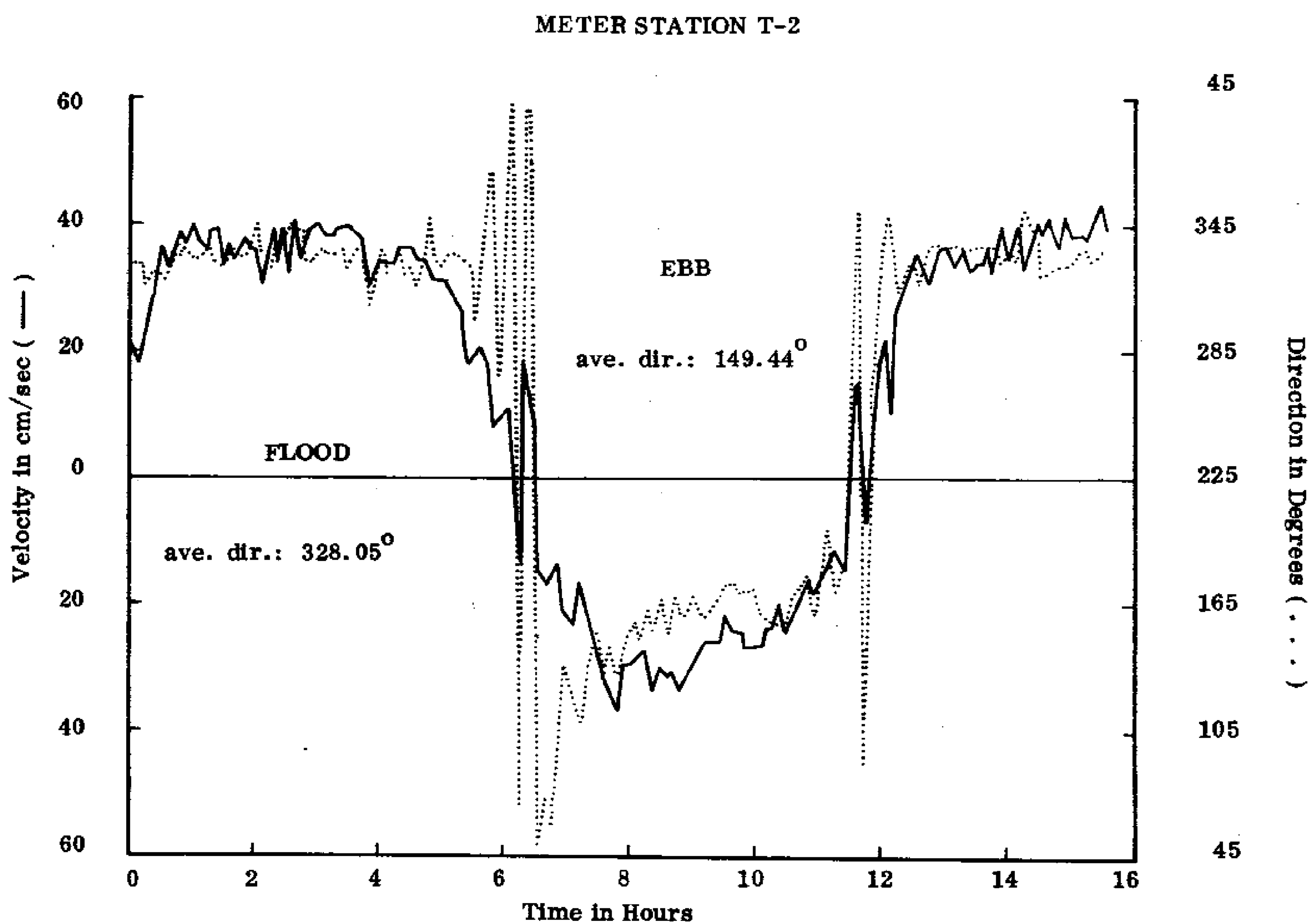


Figure 3. Water flow (speed and direction) at station T-2 (data recorded in six-minute intervals). October 24, 1972

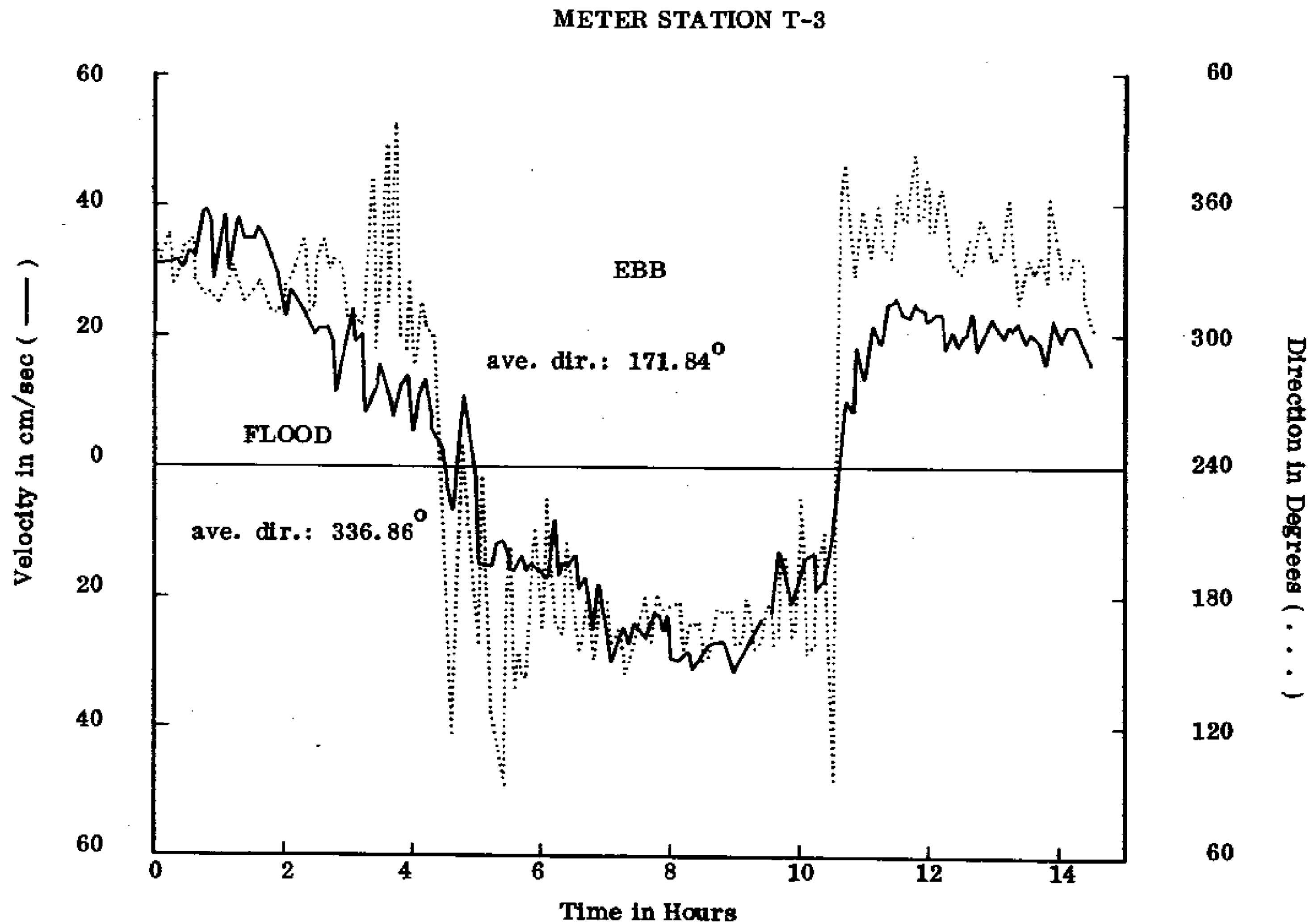


Figure 4. Water flow (speed and direction) at station T-3 (data recorded in six-minute intervals). November 10, 1972

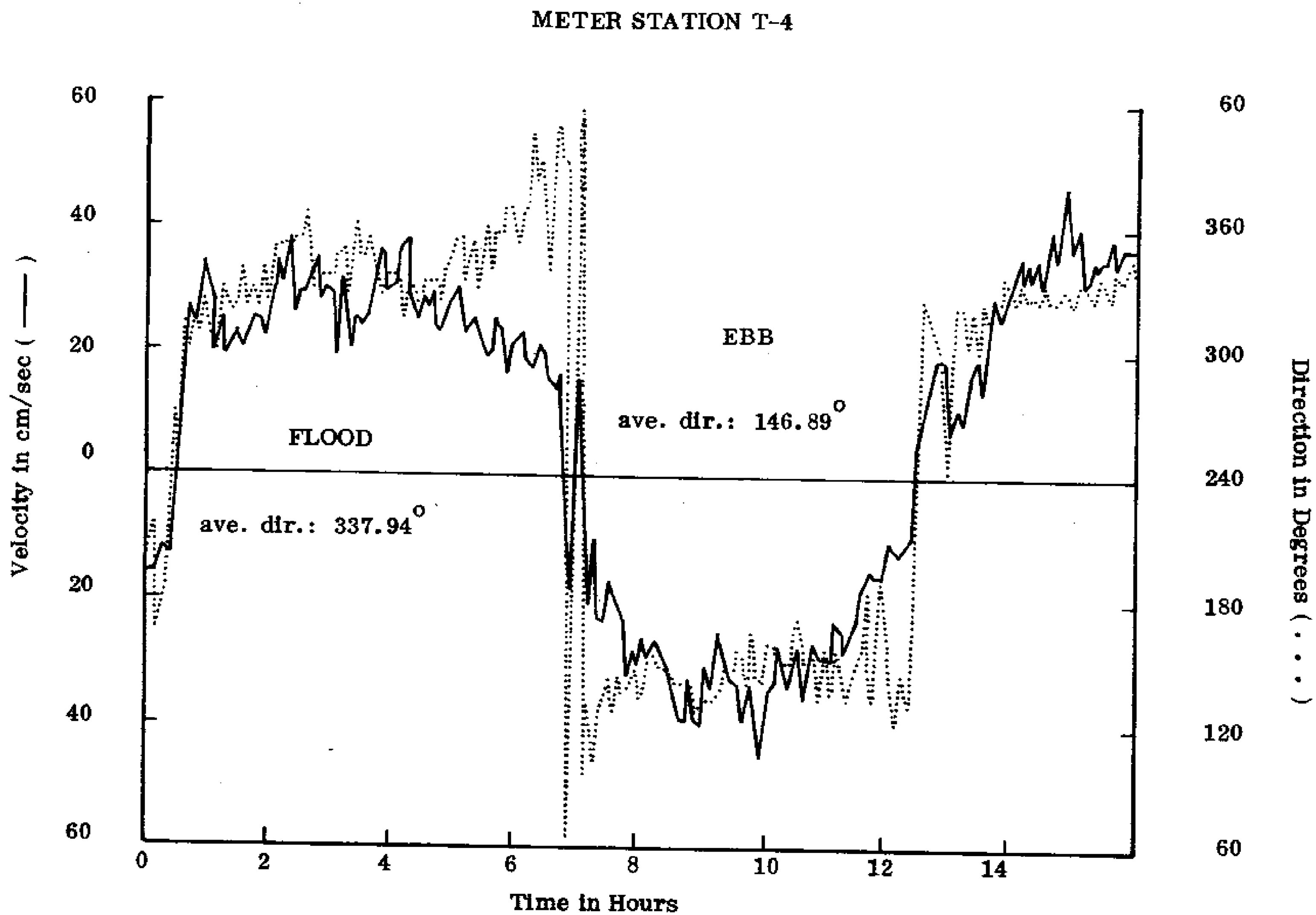
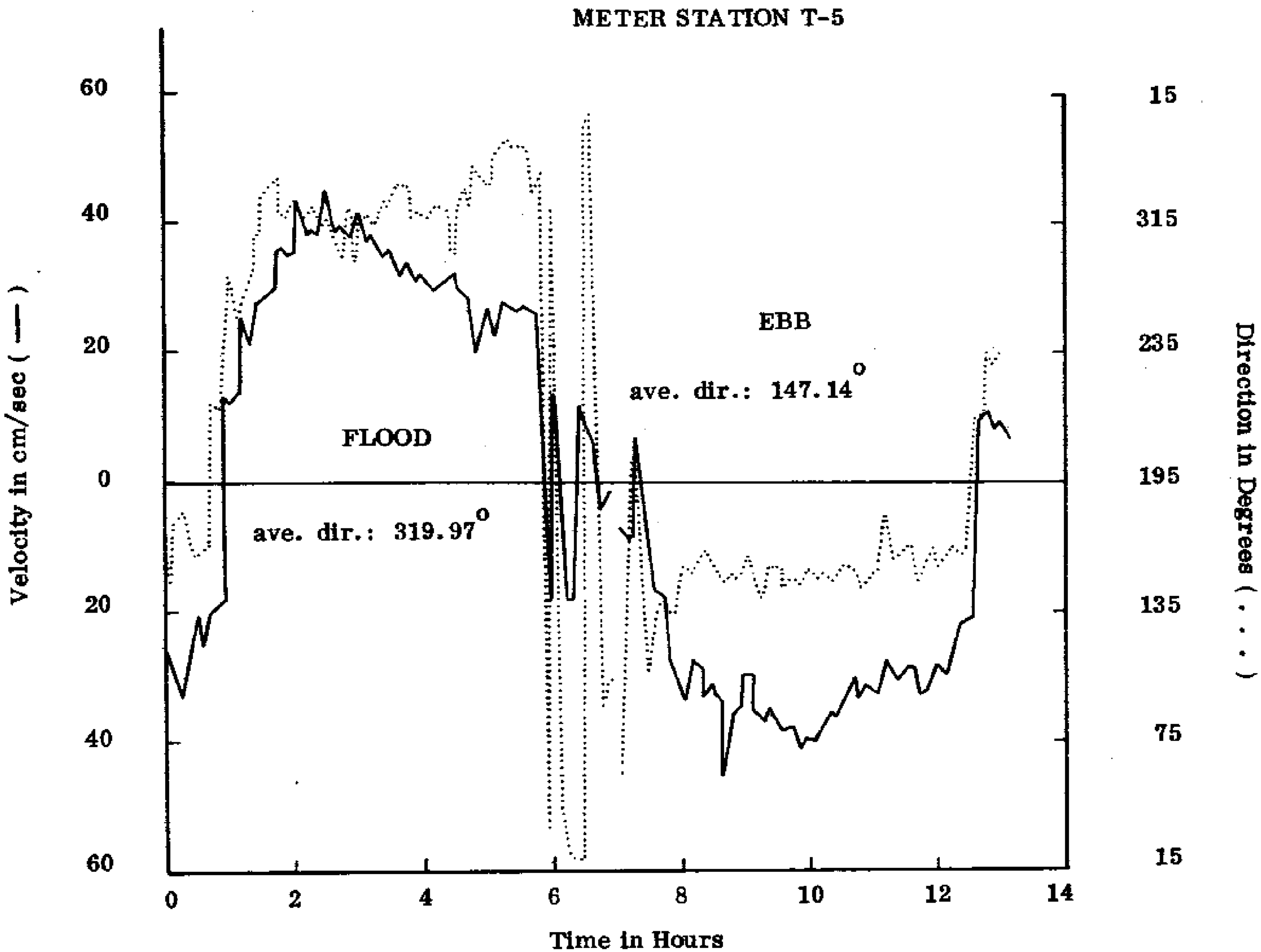


Figure 5. Water flow (speed and direction) at station T-4 (data recorded October 24-25, 1972 in six-minute intervals).



October 24, 1972

Figure 6. Water flow (speed and direction) at station T-5 (data recorded in six-minute intervals).

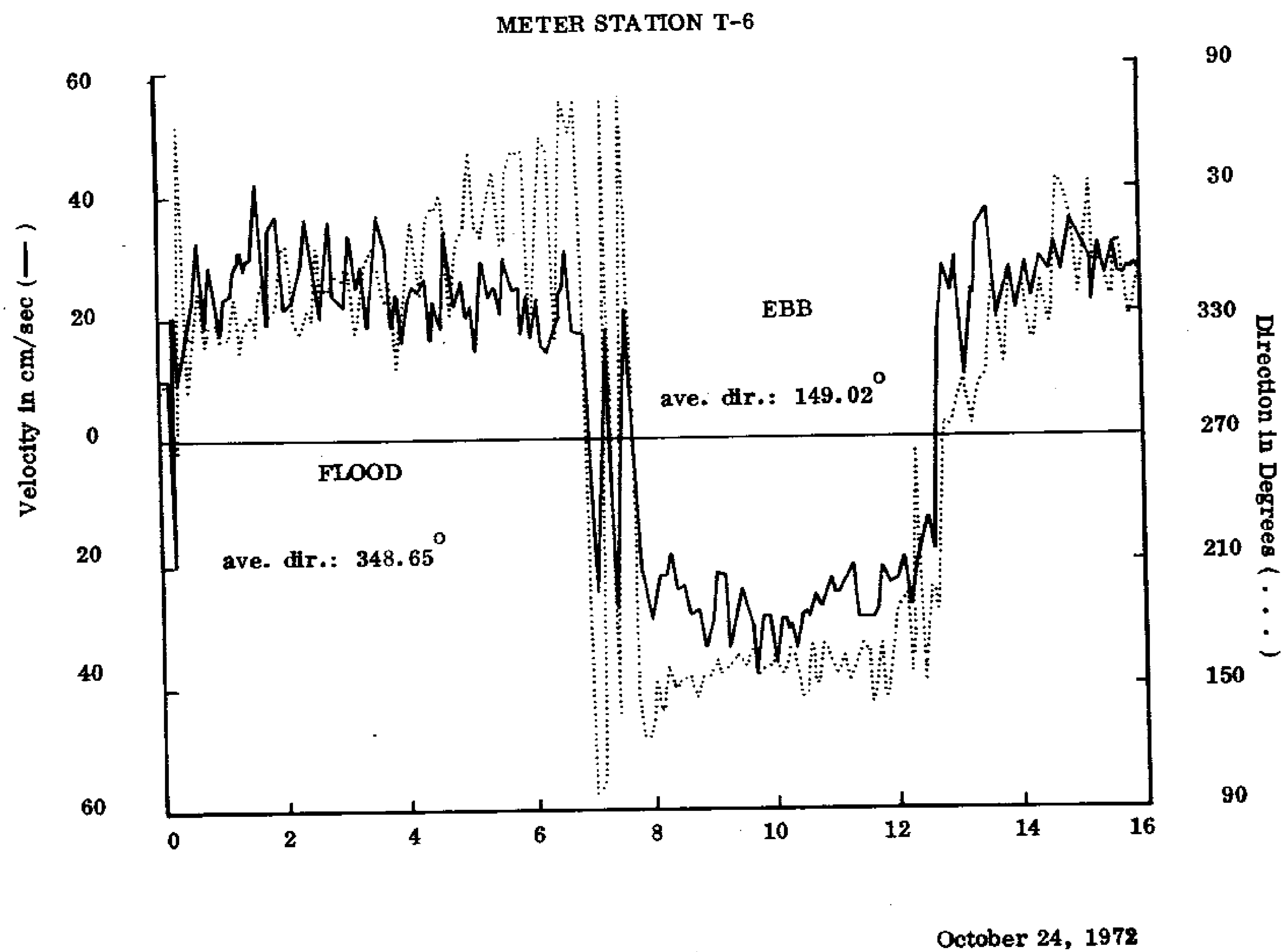


Figure 7. Water flow (speed and direction) at station T-6 (data recorded in six-minute intervals).

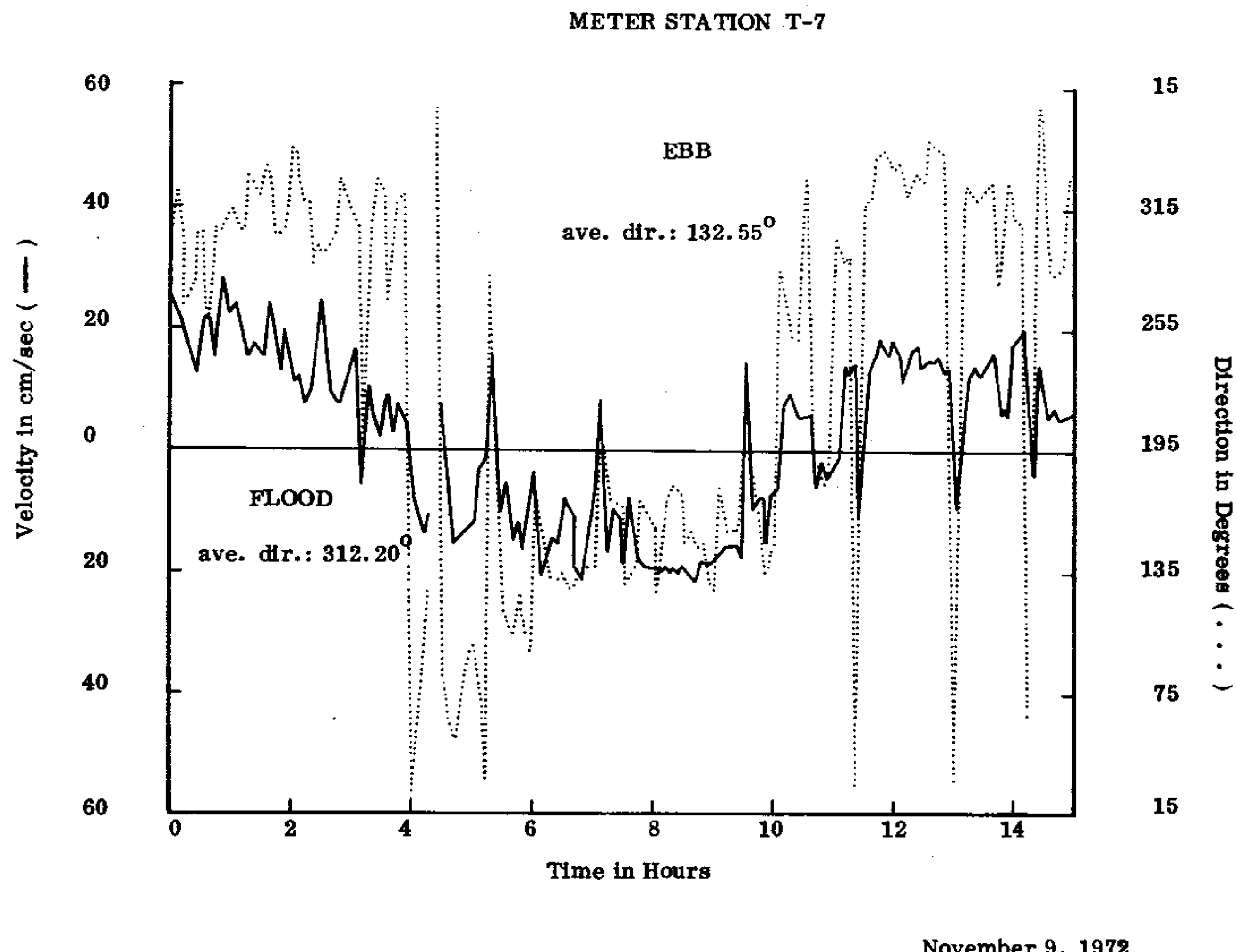
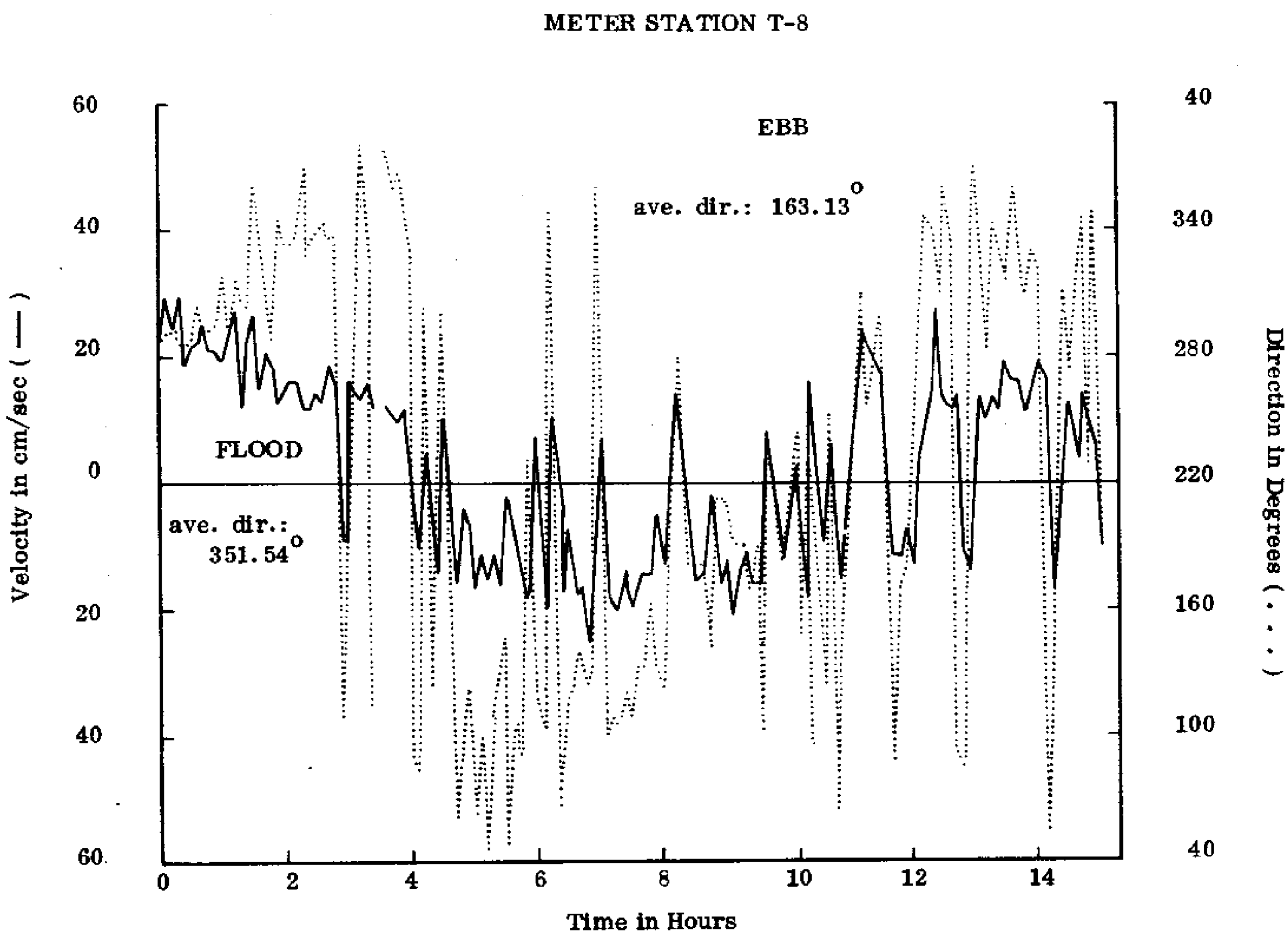


Figure 8. Water flow (speed and direction) at station T-7 (data recorded in six-minute intervals).



November 7, 1972

Figure 9. Water flow (speed and direction) at station T-8 (data recorded in six-minute intervals).

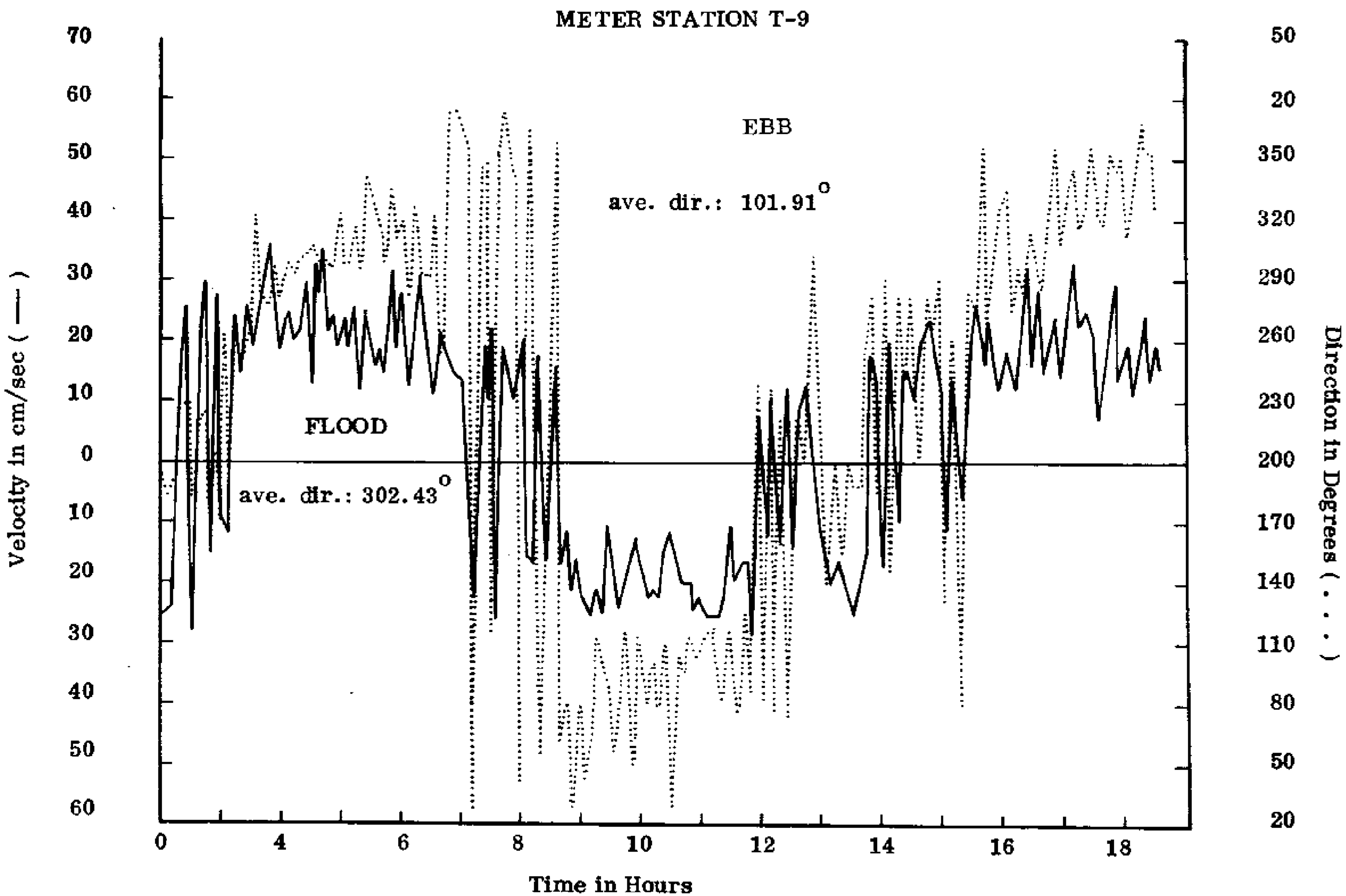


Figure 10. Water flow (speed and direction) at station T-9 (data recorded November 9, 1972 in six-minute intervals).

METER STATION T-10

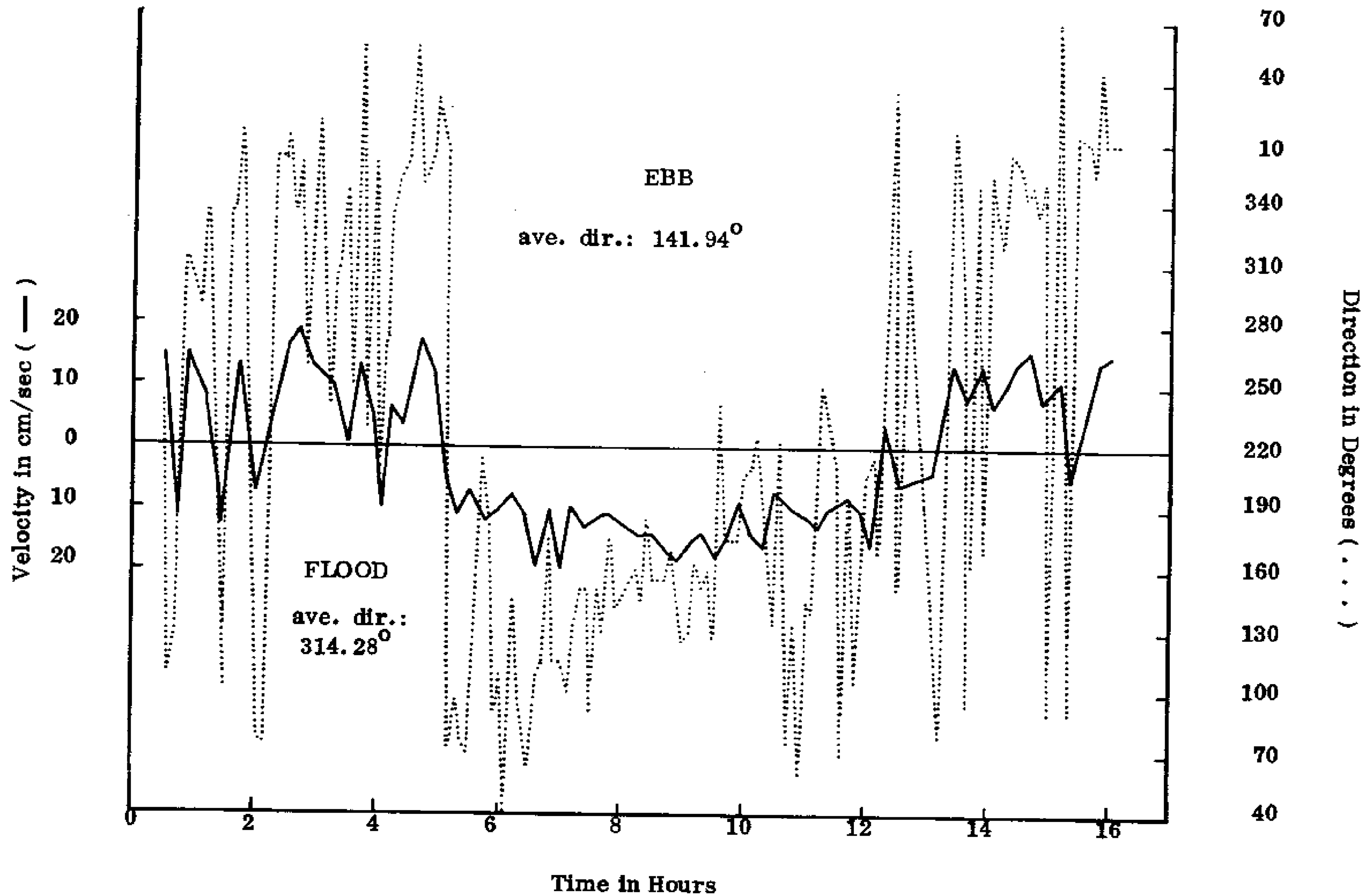


Figure 11. Water flow (speed and direction) at station T-10 (data recorded November 8-9, 1972 in six-minute intervals).

ranged from approximately 1000 meters offshore to 5500 meters offshore. Plots of data recorded at each station illustrated reverses in flow that approximately corresponded to the ebb and flood reverses of the tide. The average directions of the ebbing currents generally illustrated a spreading away from the Savannah River entrance in a centrifugally distributed pattern, whereas flooding currents were generally issued toward the inlet in a centripetally distributed pattern. Although reverses in tidal flow were illustrated at each of the ten stations, the duration of average velocities for the ebb and flood portions of the tide were often assymetrical (Table 1). Flow assymetry was not areally consistent and zones of ebb or flood predominance were apparent. At each station, the total flow for a tidal cycle was approximated by multiplying the average flood velocity by the flood duration and then subtracting this product from the product of the average ebb velocity multiplied by the ebb duration, the resultant dimension is in meters (Table 2). Vectorial presentation of these dimensions illustrate the patterns of water flow for the velocity field of an entire tidal cycle (fig. 12). The term velocity field in this report is defined as being all of the velocities in a tidal cycle ranging from the lowest to the highest velocities in the field. The areas adjacent to the shoreline of Tybee Island and adjacent to the Savannah River channel were flood dominated areas. Seaward of this area, the residual flow is in an offshore and southeast direction. This bidirectional pattern of mutually evasive flow is reminiscent of inlet gyres described by Kaye, 1961, Bajorunas and Duane, 1967, Oertel, 1973a. Whereas the velocity

CURRENT METER DATA

Meter Number	Date	Total Flood hrs	Total Ebb hrs	Residual (hrs) Ebb or Flood	Duration > 22 cm/sec Ebb	Duration > 22 cm/sec Flood	Residual (hrs) Ebb or Flood	Duration > 30 cm/sec Flood	Duration > 30 cm/sec Ebb	Residual (hrs) Ebb or Flood
T1	Oct 24-25, 1972	6:00	5:58	0:02 Flood	4:51	4:33	0:18 Flood	4:09	2:56	1:13 Flood
T2	Oct 24-25, 1972	6:18	5:12	1:06 Flood	5:06	3:02	2:04 Flood	4:39	1:02	3:37 Flood
T3	Nov 9-10, 1972	6:24	5:36	0:48 Flood	3:34	2:42	0:52 Flood	1:48	0:18	1:30 Flood
T4	Oct 24-25, 1972	6:27	5:24	1:03 Flood	3:57	3:51	0:06 Flood	1:12	2:00	0:48 Ebb
T5	Oct 24-25, 1972	5:24	5:57	0:33 Ebb	4:30	4:30	Equal	2:48	3:12	0:24 Ebb
T6	Oct 24-25, 1972	7:03	5:06	1:57 Flood	4:12	3:42	0:30 Flood	1:12	0:54	0:18 Flood
T7	Nov 9-10, 1972	4:48	6:06	1:18 Ebb	0:42	0:00	0:42 Flood	0:00	0:00	-
T8	Nov 9-10, 1972	5:12	5:36	0:24 Ebb	0:54	0:06	0:48 Flood	0:00	0:00	-
T9	Nov 9-10, 1972	5:42	5:12	0:30 Flood	2:00	1:18	0:42 Flood	0:24	0:00	0:24 Flood
T10	Nov 9-10, 1972	4:48	7:12	2:24 Ebb	0:00	0:00	-	0:00	0:00	-

Table 1. Durations of flood and ebb flow, and residual flow for stations T-1 through T-10. Data tabulated for entire velocity field, for velocities greater than 22 cm/s and velocities greater than 30 cm/s.

Table 2. Residual flow of various portions of the velocity field for current meters 1 - 10. (F) indicates flood flow direction (E) indicates ebb flow direction.

	Residual Flow (meters)		
Stations	Total Velocity Field	Velocities > 22 cm/sec	Velocities > 30 cm/sec
1	1110.0 F	237.6 F	1314.0 F
2	2904.0 F	1686.8 F	3906.0 F
3	630.0 F	686.4 F	1620.0 F
4	698.0 F	79.2 F	864.0 E
5	320.2 E	Equal	432.0 E
6	1788.4 F	396.0 F	324.0 E
7	666.0 E	554.4 F	-
8	59.2 E	633.6 F	-
9	1030.8 F	554.4 F	432.0 F
10	1255.8 E	-	-

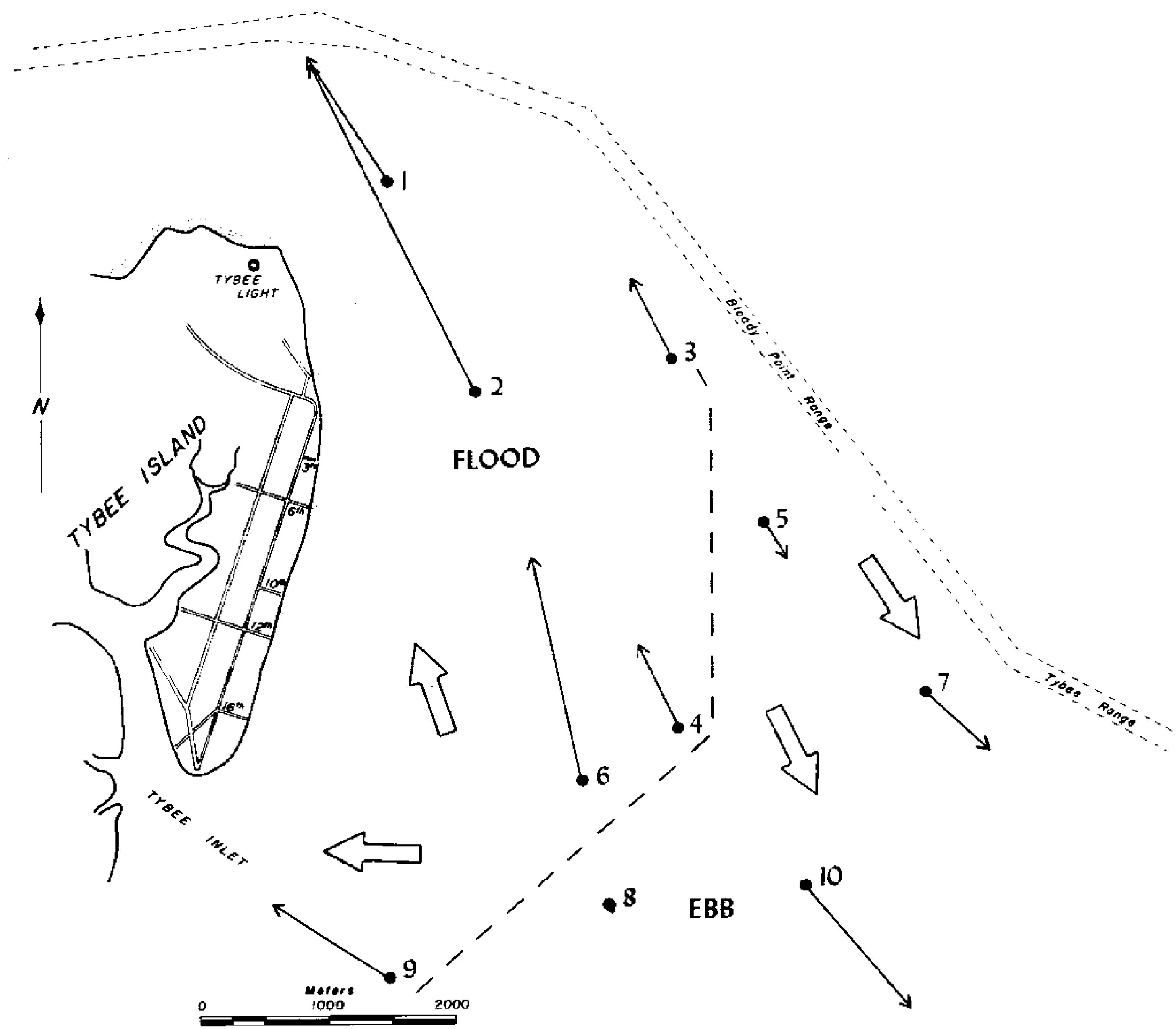


Figure 12. Residual flow of water considering all of the current speeds recorded in the velocity field. Vectors (meters) are the product of speed (m/s) times duration (s).

field observed for the entire tidal cycle is necessary for calculating flushing patterns and dispersion patterns of suspended sediments, only a portion of this velocity field has an effect on the tracted sediments. The velocity necessary to produce movement of a grain resting on the sediment bed is termed the "critical" or "threshold" velocity. Since it is very difficult to accurately measure velocity at the sea bed, threshold velocities must be related to velocities that can be measured at some distance above the sea bed. Sundborg, 1956, made some approximations of threshold velocities based upon velocities recorded at various intervals above the sea bed. The threshold velocity for fine sand resting on a horizontal sea bed was approximately 33 cm/sec, and on the inclined surfaces of a rippled sea bed this could be lowered to as much as 22 cm/sec. Thus, portions of the velocity field greater than 22 cm/sec and greater than 33 cm/sec are extremely important in determining patterns of tracted transport of fine sand. The duration of ebb and flood flow for velocities greater than 22 cm/sec and greater than 30 cm/sec was determined for each of the ten stations in the study area (Table 1). The residual flow for these portions of the velocity field was also approximated by multiplying the duration of residual flow in the ebb or flood direction by 22 cm/sec and 30 cm/sec (fig. 13 and 14). Vectorial plots of these products produced flow fields that may be useful approximations for dispersion patterns of tracted sediments over rippled and horizontal sea beds, respectively.

In terms of sediment transport, it is very important to realize the differences between the residual flow for the total velocity field and various portions of the velocity field. For the most part, the direction of residual flow for the total velocity field was the same as the directions of residual

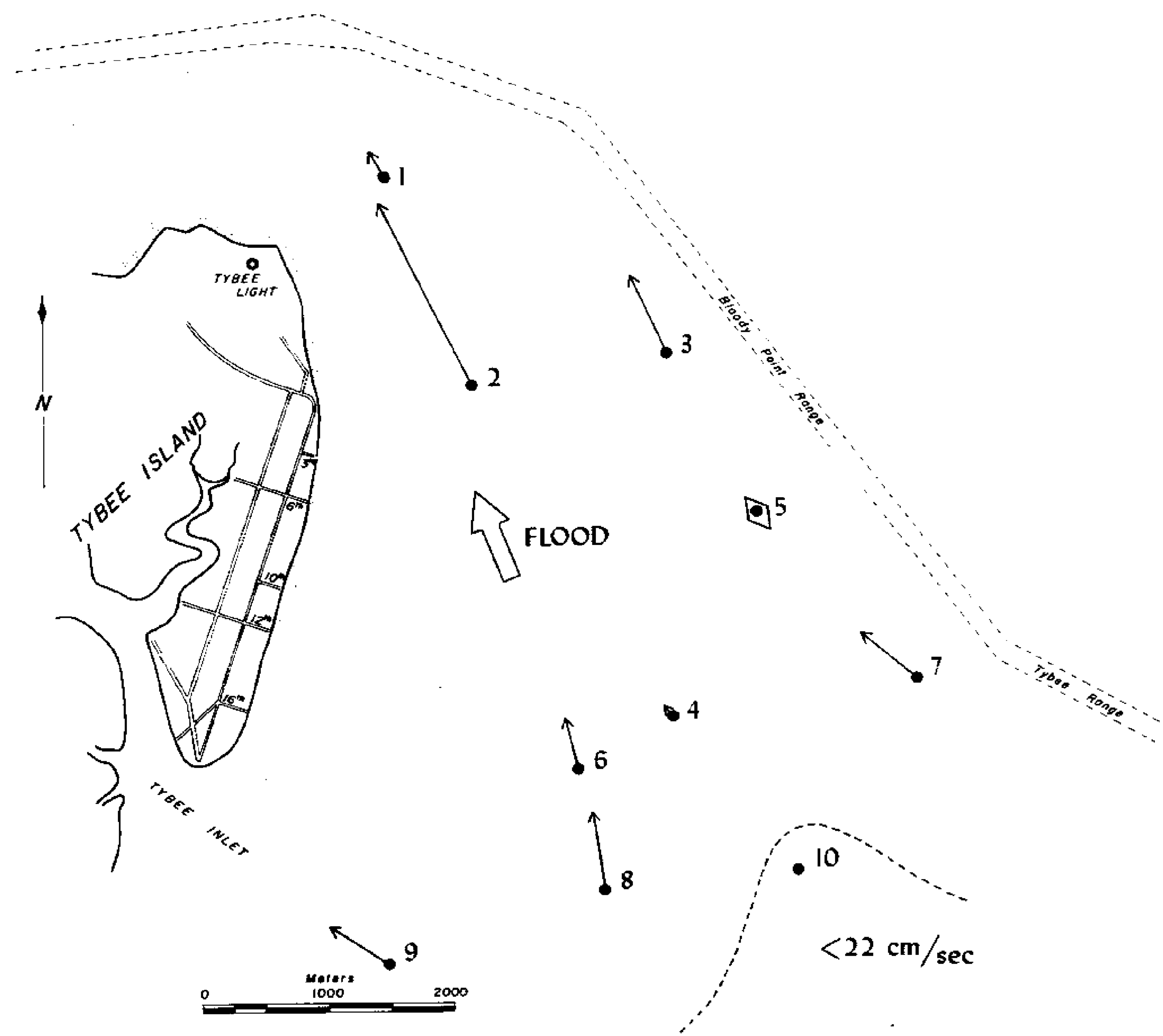


Figure 13. Residual flow of water considering only the current speeds greater than 22 cm/sec. Vectors (meters) are the product of speed (m/s) times duration (s).

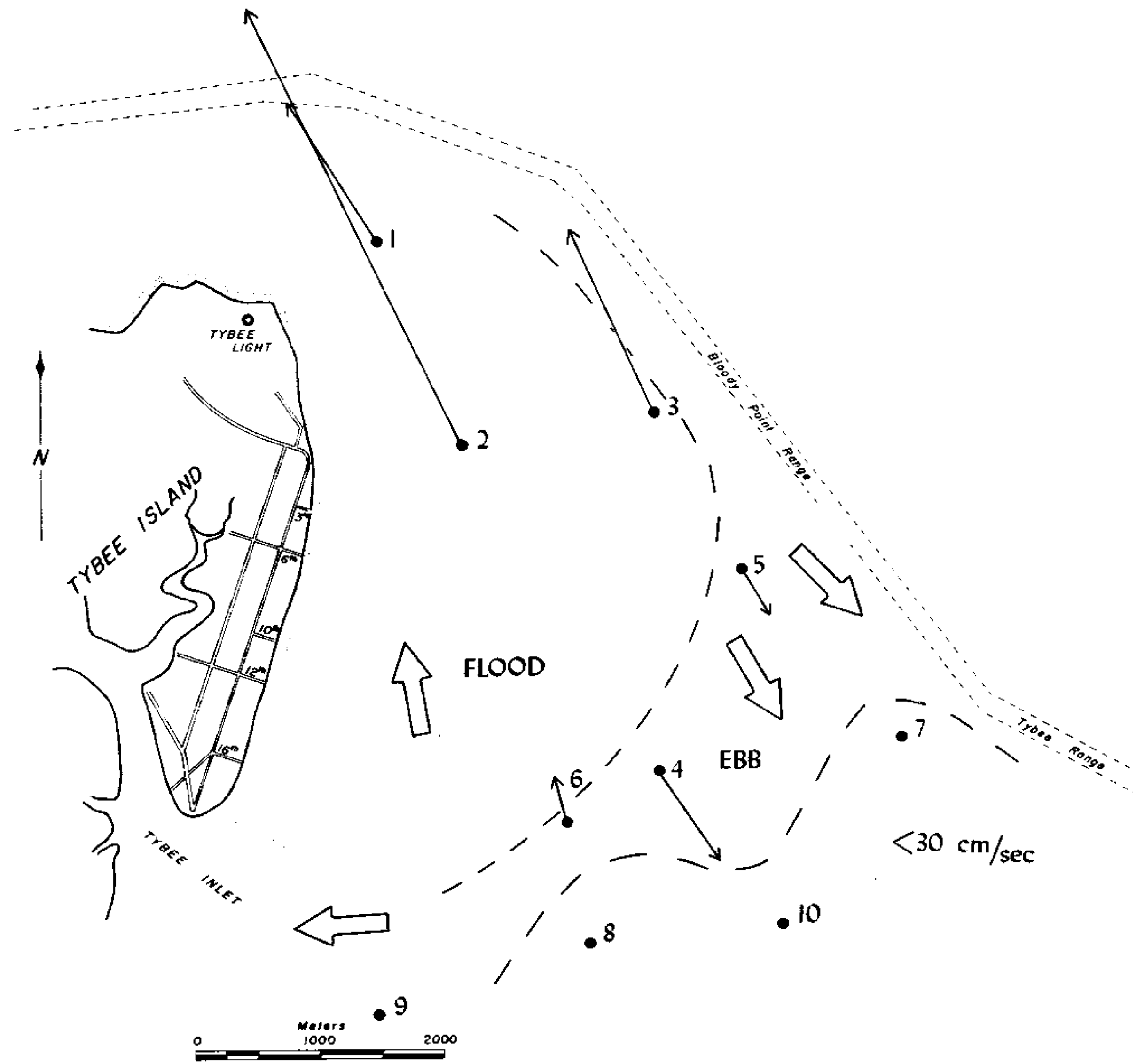


Figure 14. Residual flow of water considering only the current speeds greater than 30 cm/sec. Vectors (meters) are the product of speed (m/s) times duration (s).

flow for the higher velocities in the total field (Table 2). At stations 4 and 6 a very important inconsistency exists. The total velocity fields for stations 4 and 6 had residual flows in the flood direction, however, the residual flow for velocities greater than 30 cm/sec (at these stations) had a residual flow in the ebb direction. With respect to sediment transport, this could mean that sands and tracted sediments at the sea bed have a residual offshore movement, whereas, suspended sediments in the water column have a residual onshore movement. Thus although the sampling of multiple data points, during a tide cycle, is far superior to spot, random samples, it must be remembered that the directions of water flow are not necessarily indicators of sediment transport. At station 6, a relatively large (1788.4 m) residual flood flow of water is present for the total velocity; however, the portion of the velocity field capable of entraining sand illustrates a moderate ebb flow (Table 2).

In considering the duration of velocities greater than 22 cm/sec, the entire study area was apparently a flood dominated area. According to Sundborg's (1956) curves, find sand resting on 20^{o} slopes would move in onshore directions at distances proportional to the respective vectors (fig. 13), however, these vectors are not quantitative measures of sediment transport. It is interesting to note that although the total velocity field was distributed in ebb and flood dominated zones, the duration of flow that was greater than 22 cm/sec illustrated an onshore dominated field throughout the study area.

In considering the portion of the velocity field greater than 30 cm/sec, several zones became apparent (fig. 14). The inner portion of the study area is a flood dominated zone with resultant vectors directed toward the Savannah River entrance. An ebb-dominated area was located in the central portion of the study area with vectors oriented in a southeast direction. During the sampling period, velocities in the seaward portion of this study area were always less than 30 cm/sec.

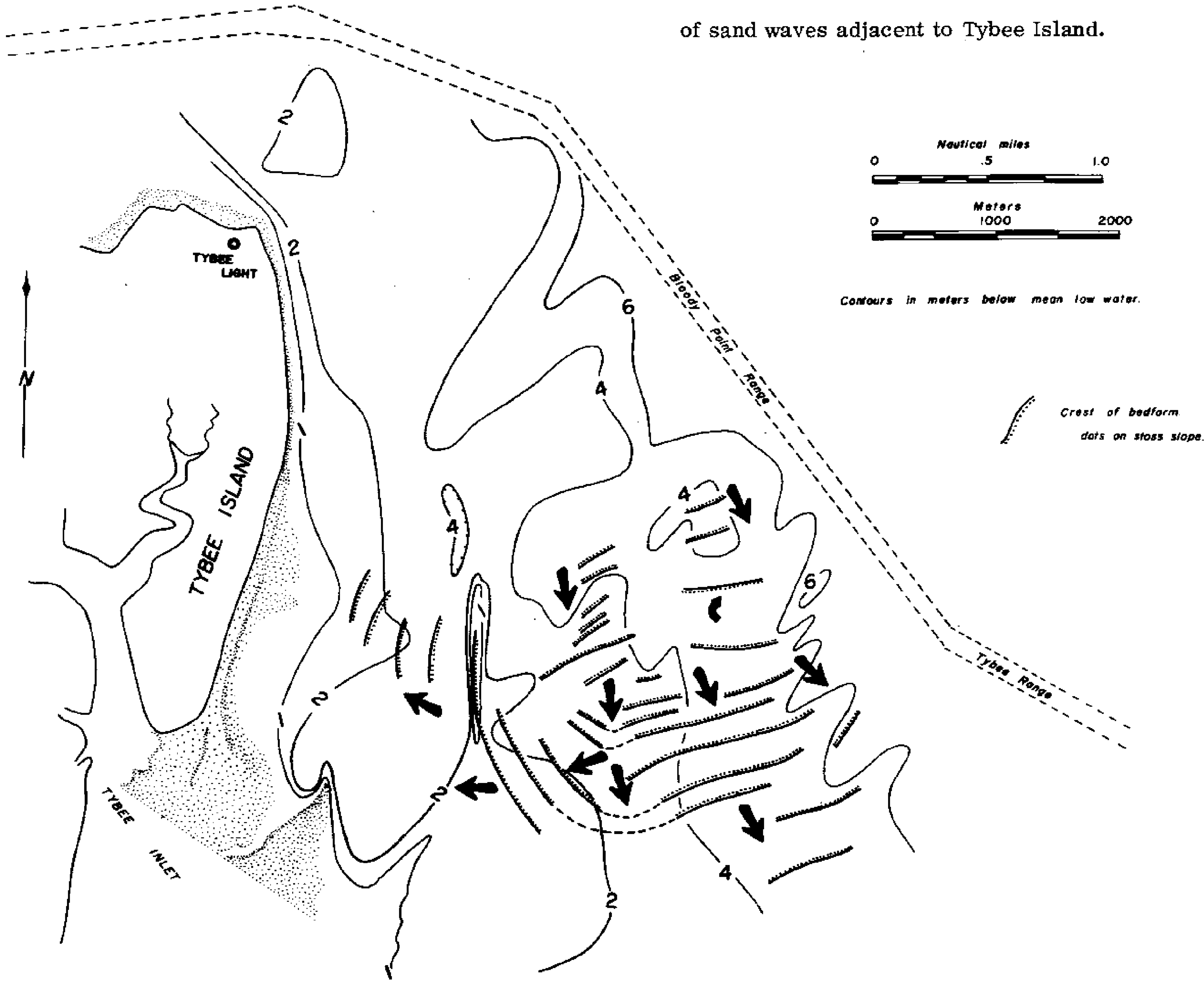
In terms of sediment transport, this portion of the velocity field is very significant. At velocities approaching 33 cm/sec, the threshold velocity of fine sand is achieved at all portions of the sea bed, thus residual-current vectors may be called indicators of fine grained sediment transport. Adjacent to the beach, fine sand would have a net transport toward the Savannah River entrance. In the central portion of the study area, fine sand would have a net transport toward the southeast. In the offshore portion of the study area, this portion of the velocity field does not play a role in influencing patterns of sediment dispersion.

The upper portion of the velocity field (>30 cm/sec) may also affect some of the patterns of medium and coarse grained sand transport. In areas where medium and coarse sand grains are resting on inclined portions of the sea bed threshold velocities are interpreted to be in the mid thirties (cm/sec) (Sundborg, 1956), and the residual flow in this portion of the velocity field may also determine the migration patterns of bedforms that are composed of medium and coarse sand. Currents in this portion of the velocity field may also produce a sorting of the coarser grained sediments into the bedforms while finer material is winnowed out. These processes would not affect the inner portion of the study area since medium and coarse sand is generally not present in that area. However, the central portion of the study area has a good deal of medium and coarse sand and echo surveys have illustrated that this area has numerous, large, assymetrical sand waves (Oertel, 1973b). The orientations of the sand waves also illustrate a southeast movement of the bedforms that is similar to the residual flow of velocities greater than 30 cm/sec. This is in agreement with the suggestion that sand wave migration is a response to only the higher velocities of the velocity field (fig. 15).

In that the velocity field for tidal currents is in a constant state of flux between neap and spring tides, the areal distributions of the various portions for the velocity field is also variable. During spring tides, a much larger portion of the study area may experience high velocity (>33 cm/sec) currents for a longer duration of time. During neap tides, a much smaller portion of the study area may experience these high velocity currents. Much more data are needed to determine the extent to which the boundaries of these zones may vary; however, the available data is a good approximation for conditions at mean tides.

During the study period, coastal currents generally did not alter the centrifugal flow of ebbing currents or the centripetal flow of flooding currents. However, storms have the effect of compressing the radially distributed flow patterns into a narrow zone against the shoreline. Southeast storms restricted the offshore limit of inlet tidal currents and compressed these reversing currents to a narrow zone adjacent to the shoreline on the north

Figure 15. Map illustrating bottom topography and the distribution of sand waves adjacent to Tybee Island.



side of the entrance. Northeast storms also compress the tidal flow into a narrow zone adjacent to the shoreline on the south side of the inlet. The intensity of these storms will determine the degree of diversion and the patterns of sediment dispersion. The coastal currents associated with storms are not the only factors affecting patterns of sedimentation. Storms also produce large waves that "touch" bottom considerable distances offshore. The orbital motion of water in these waves has been suggested to produce longitudinal ripples in very deep areas of the continental shelf and slope. At the sea bed, this orbital motion often "kicks" sand grains into temporary suspension with the passage of wave crests. When wave-orbit currents are compounded with low velocity tidal currents (10 cm/sec to 22 cm/sec), then grain-transport distances may be increased. For example, a 10 cm/sec is generally not capable of transporting fine sand; however, if a grain of fine sand is elevated 10 cm above the sea bed (by orbital motion) then a 10 cm/sec current will transport the grain approximately 0.5 meters before it comes to rest on the sea bed. In light of this possibility, the areas that generally experience currents too weak to transport sand may become zones of active sediment during periods of high wave energy. In these areas the residual flow of low velocity tidal currents must be considered.

Waves also play a very important role within the breaker zones. As waves dissipate their energy along the shoreline, the resultant longshore current transports large quantities of sand in a down current direction. The direction in which wave currents (longshore currents) flow is highly dependent upon wave approach and wave refraction as determined by shoreline orientation and offshore topography. Tybee Island has a pronounced bend at its ocean shoreline approximately at Sixth Street. When waves approach the island from due east, they refract around this point (Sixth Street) and produce a longshore current that flows to the northwest, north of the Sixth Street and a longshore current that flows to the southwest, south of Sixth Street. Seasonal trends generally determine the direction of wave approach and these trends will be described with regard to beach responses in a forthcoming report.

PATTERNS OF SEDIMENT TRANSPORT

Although the bedform surveys and the various portions of the velocity field illustrated apparent patterns of sedimentation, ground proof was desirable to verify suggested patterns. Part of the present study was to trace the movement of "tagged" sand grains away from a depositional site. Experiments were conducted utilizing methods similar to those used by Jolliffe, 1963, Ingle, 1966, and Oertel, 1971, 1973c. Relatively large quantities of sand were taken from each test-run site, labeled, and returned to the laboratory for processing. At the laboratory the grains were dried and coated with a commercial, fluorescent acrylic paint. Four different hues were used to color code the different test-run sites indicated on figure 16.

Initially tagged sand was deposited at two predesignated points in sample grid F indicated by dashed-lines on figure 16. Insufficient recovery illustrated that sample stations on this grid were too far apart and recovery

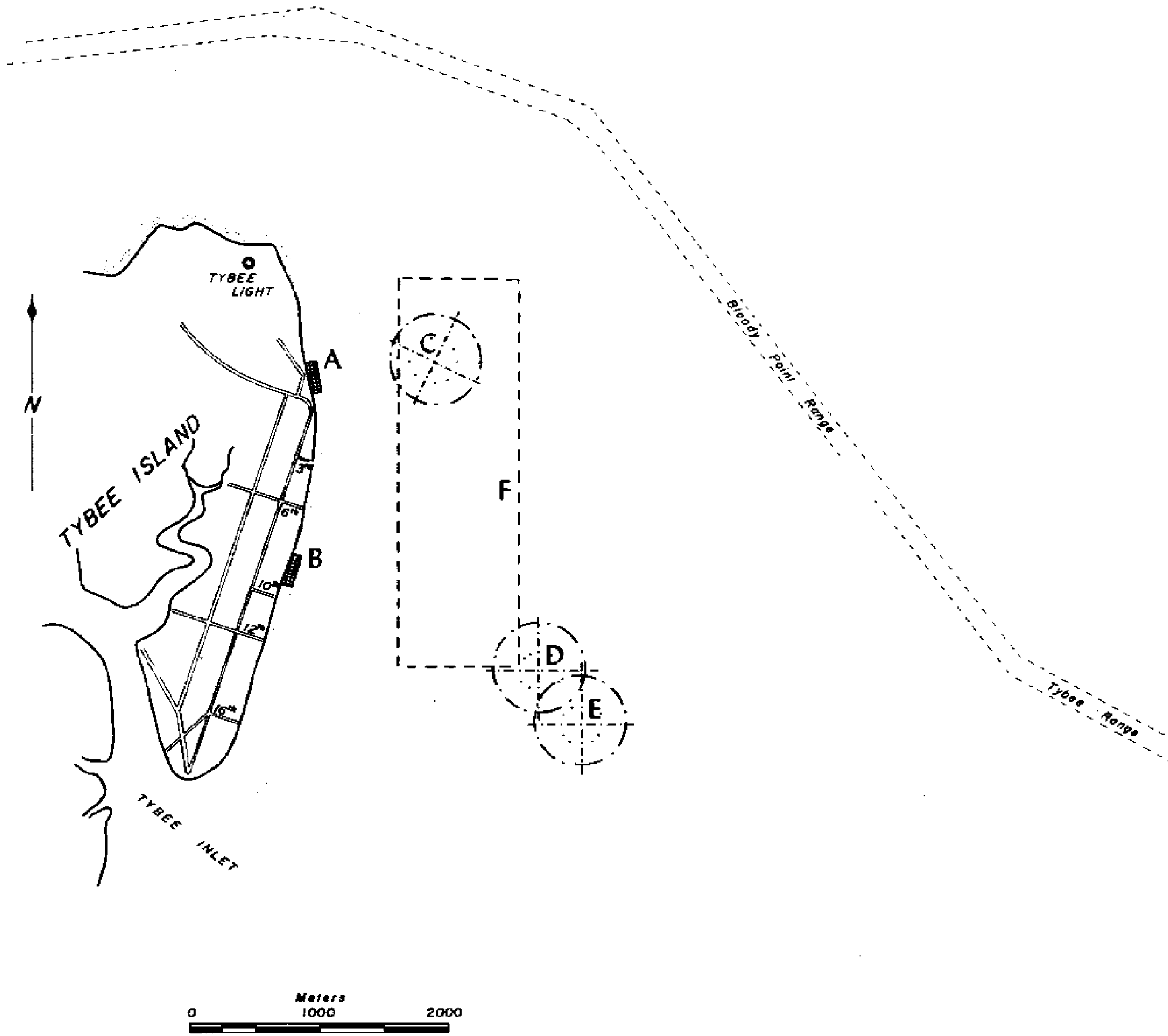


Figure 16. Index map of sample grids for fluorescent tracer experiments.

was too sparse. Smaller, circular sample grids were finally used. At these sites, the tagged grains were released on the bottom and allowed to experience bottom currents associated with multiple tidal cycles before sea bed samples were taken within the circular grids. Samples were returned to the laboratory where they were processed under a black light microscope. The number of fluorescent grains observed on each sample card (100 sq. cm) was recorded and plotted on a base map of the sample grid. Isopleths of fluorescent grain recovery illustrated the sediment dispersion patterns for the experimental period.

On December 11, 1972, fine sand weighing approximately 150 pounds was coated with a red fluorescent acrylic and was released on the sea bed in the center of sample grid C. A sampling of the grid was made after two complete tidal cycles. Sample stations were made on the periphery of circles 1/8 and 1/4 miles from the release point. Sparse recovery was made over this relatively large sample grid. However, recovery trends showed no inconsistencies and appear to be reliable. Several transport trends were illustrated by the dispersion pattern shown on figure 17. The most pronounced concentration was along a 330° bearing or directly toward the entrance of the Savannah River. This trend is very similar to the orientations illustrated for the residual tidal currents, and it illustrates that the dispersion of the tagged fluorescent sand may be produced by the residual flow of tidal currents. Two secondary trends also were apparent from the December 11th study. A weak longshore trend of tagged-grain depletion was illustrated by an isopleth which bulged out along a 210° bearing. A transport trend toward the margin

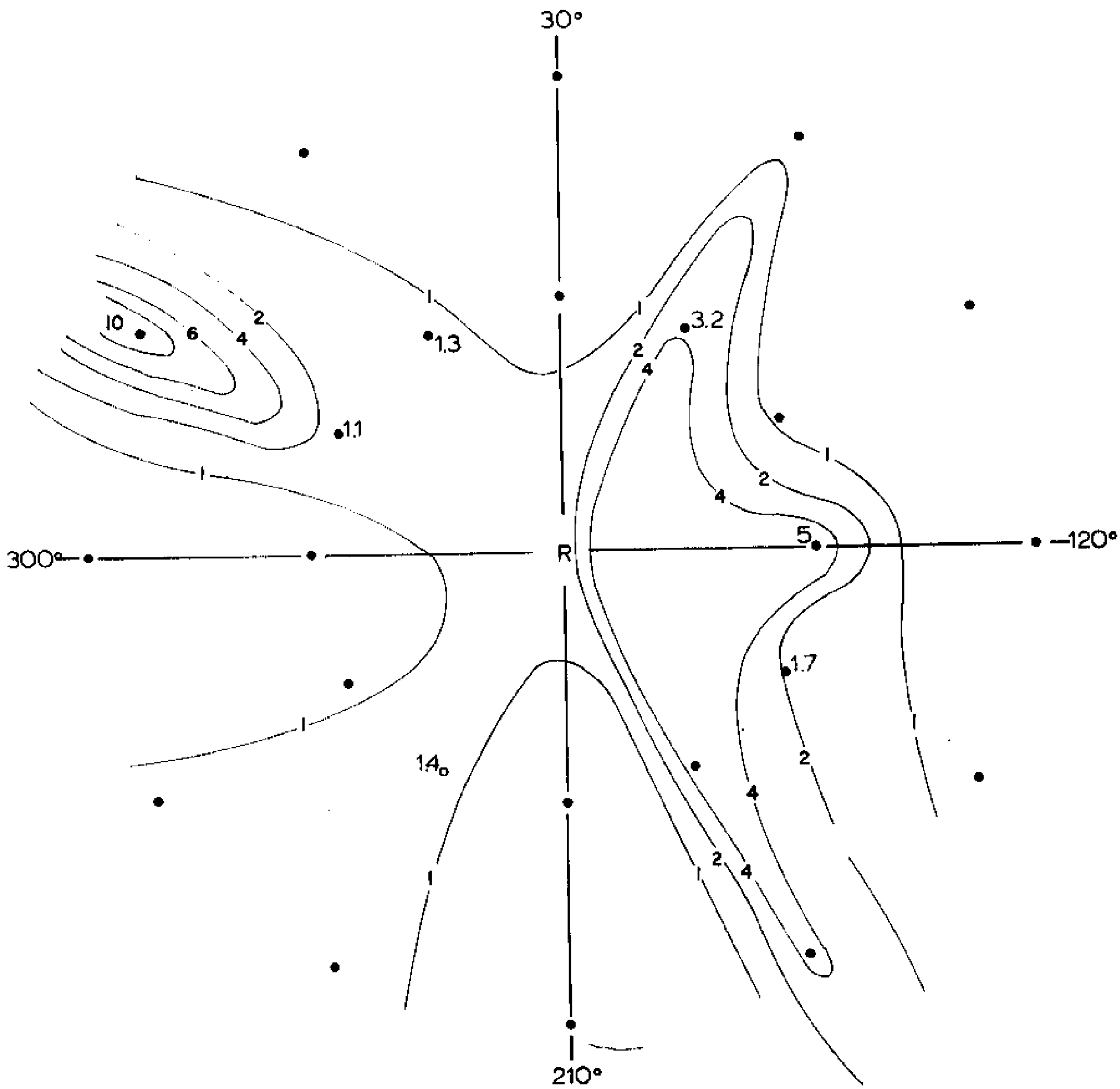


Figure 17. Map of fluorescent-grain dispersion at sample-grid C (December 11, 1972). Approximately 150 lbs of sand coated with red-fluorescent acrylic were released on the sea bed at point R. Sampling was made after two complete tidal cycles (approximately 25 hours). Isopleth are in units of grains per 100 square centimeters.

of the Savannah River channel was also indicated by a bulge in an isopleth that extended along a 90° bearing (fig. 16). This particular tracer experiment qualitatively illustrated a major transport trend toward the Savannah River entrance adjacent to the north end of Tybee Island. Secondary patterns of sediment transport are southward along the shoreline and eastward toward the margin of the navigation channel.

On January 25, 1973 fluorescent tagged sand weighing approximately 150 pounds was deposited in the center of sample grid C. This material was again allowed to interact with the bottom currents for two complete tidal cycles. Although dispersion patterns were not exactly the same as trends exhibited by the December 11th experiments, several similarities were apparent (fig. 18). Once again, three transport trends immerged from the reduced data. The greatest recovery of fluorescent tagged sand was sampled 1/4 mile northwest of the release point. The suggested path of sand transport is toward the entrance of the Savannah River. This conforms closely with the major trend illustrated by the December 11th experiment. Once again there were some secondary trends that illustrated several directions of offshore sediment dispersion. One of the secondary trends was oriented directly south, while two other trends illustrated transport directions toward the margin of the Savannah River navigation channel.

On January 25, 1973, another experiment utilizing fluorescent sand was conducted in the middle of the undulating topography at sample grid D. The quantity of fluorescent sand and the dimensions of the sample grid were equivalent to that used at sample grid C. The character of the sediment

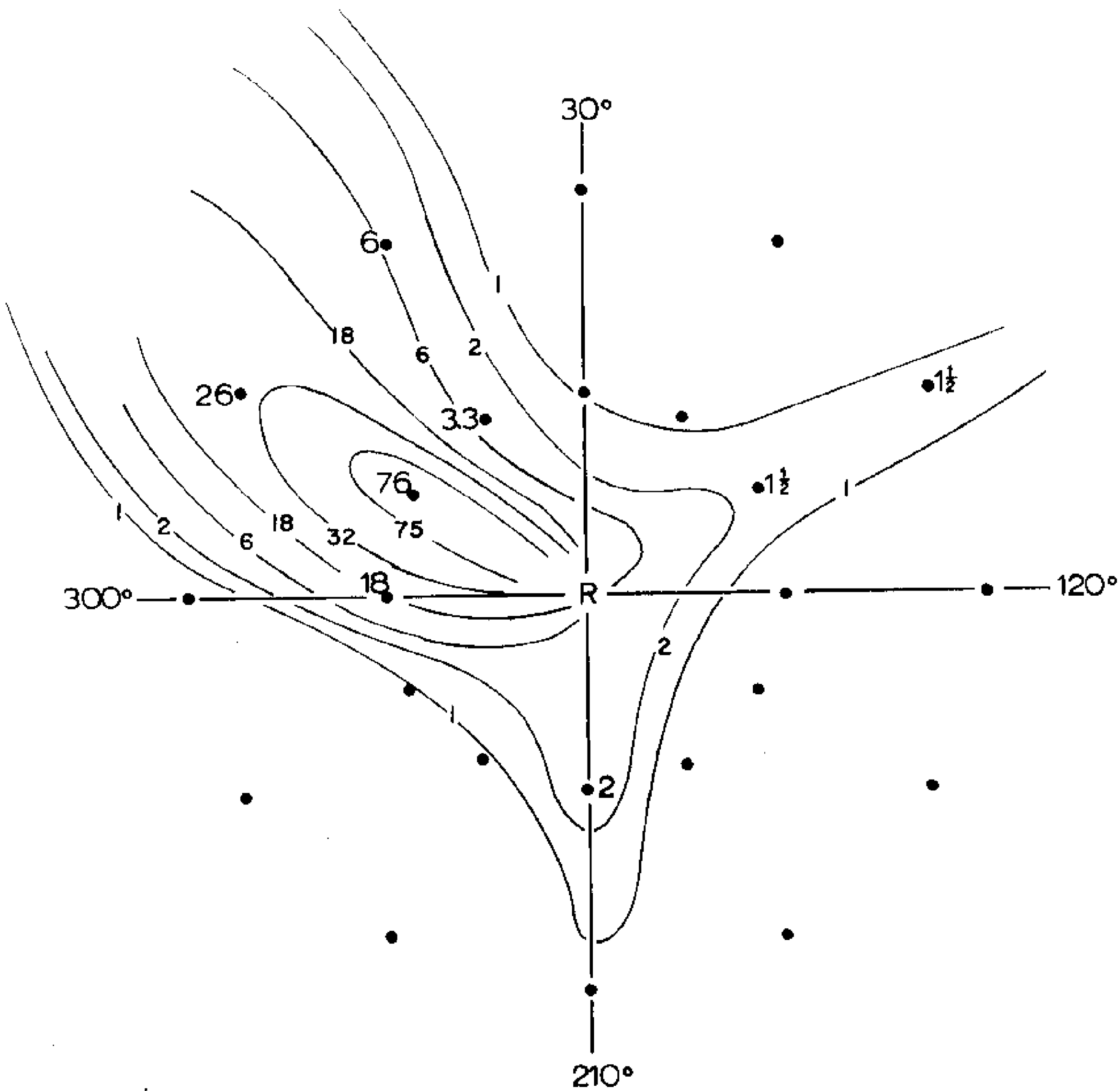


Figure 18. Map of fluorescent-grain dispersion at sample-grid C (January 25, 1973). Approximately 150 lbs of sand coated with a green-fluorescent acrylic were released on the sea bed at point R. Sampling was made after two complete tidal cycles (approximately 25 hours). Isopleth are in units of grains per 100 square centimeters.

at sample grid D was considerably coarser (medium to granular sand with shell fragments) than the material on the sea bed at sample grid C. This may be a reason for the relatively poor recovery illustrated on figure 19. As indicated by the water flow data described above, the velocities were generally too low to dislodge coarse sand from the bed for a significant period of time. The recovery in this sample grid was limited to fine sand that was apparently winnowed out of a coarse-grained, sand wave. Coarse sand is generally left on the bed forms as lag deposits that are reworked as the entire dune slowly migrates. The direction of transport illustrated by the modest recovery was directly south of the release point. Apparently, the coarse material of the sand waves is relatively stable under non-storm conditions.

On April 9, 1973, approximately 300 pounds of tagged sand were released at sample sites C and E; however, moderate seas and a "thrown" shaft on the R/V Golden Isles caused the cancellation of the experiment.

ACKNOWLEDGMENTS

This report is the second in a series of reports that describes the results of a project of the Georgia Sea Grant Program, entitled, "Patterns of Sedimentation" affecting the sediment budget of Savannah Beach (Project No. R/EE-4). The Georgia Program is part of the National Sea Grant Program of the National Oceanic and Atmospheric Administration. Captain Paul Glenn and the crew of the research vessel Golden Isles assisted in collecting samples as did Dr. J.L. Harding and Mr. Tor Hanson. The R/V Golden Isles is supported by a ship grant from the National Science Foundation.

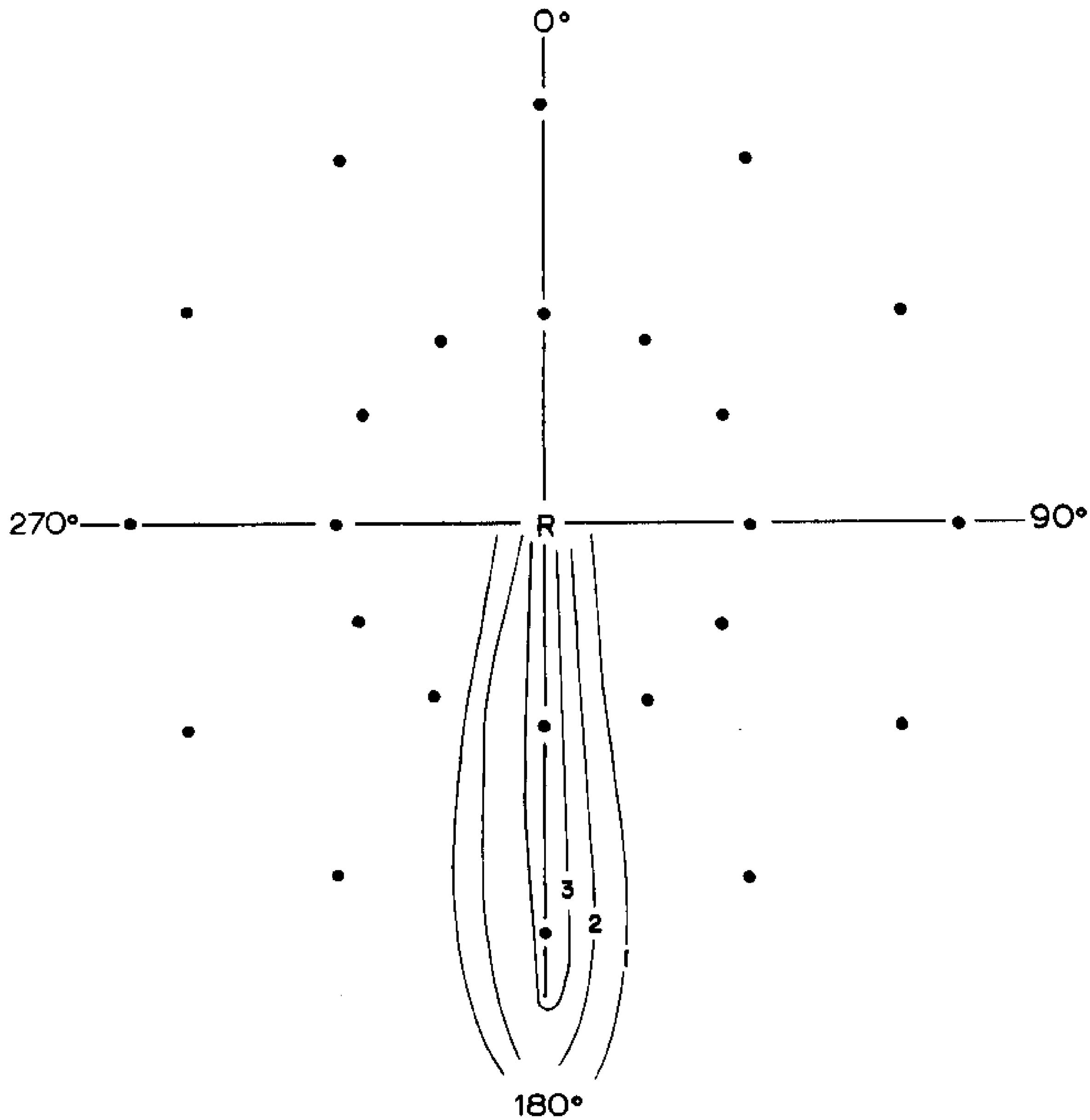


Figure 19. Map of fluorescent-grain dispersion at sample-grid D (January 25, 1973). Approximately 150 lbs of sand coated with a green-fluorescent acrylic were released on the sea bed at point R. Sampling was made after two complete tidal cycles (approximately 25 hours). Isopleth are in units of grains per 100 square centimeters.

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