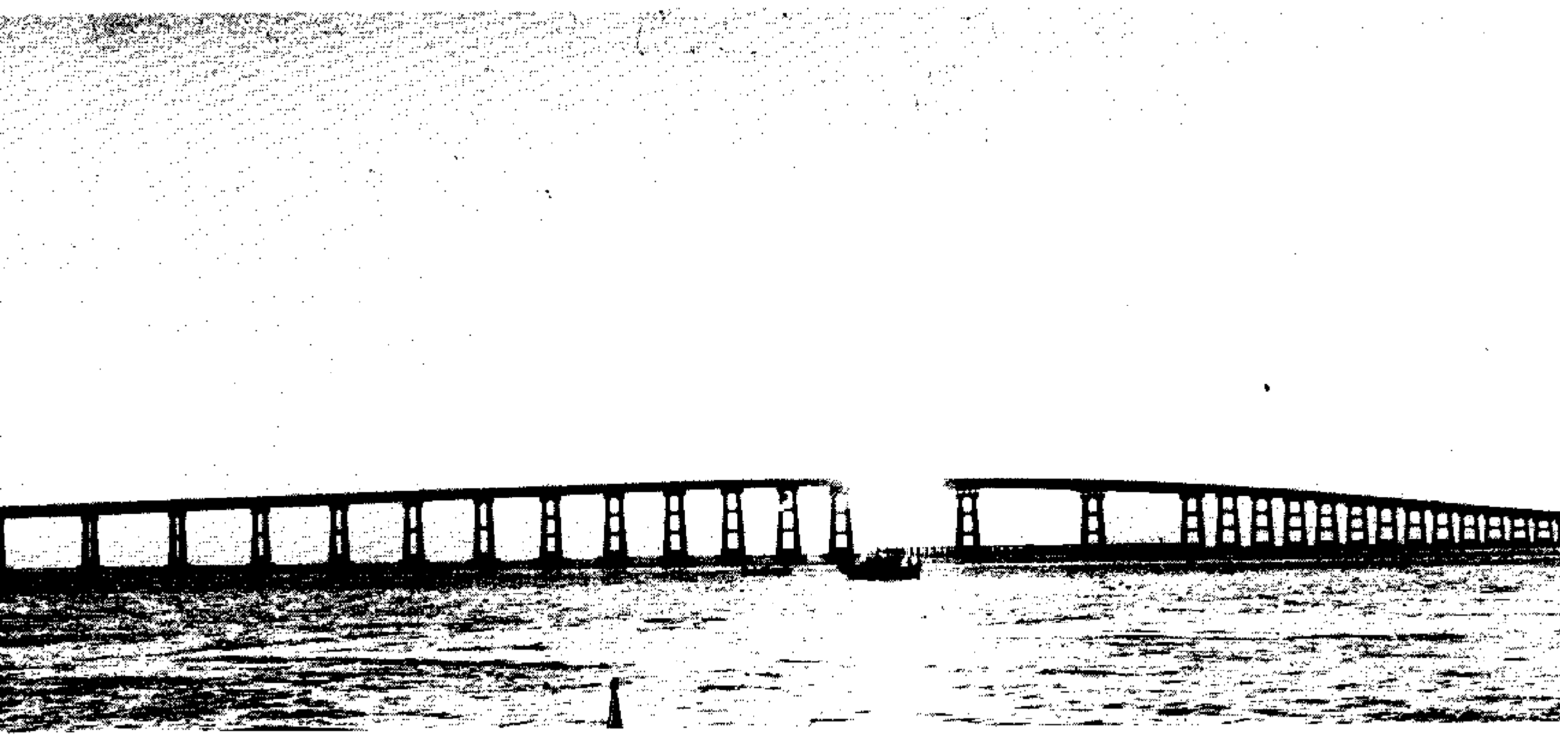
HYDROLOGY AND CIRCULATION PATTERNS IN THE VICINITY OF OREGON INLET AND ROANOKE ISLAND, NORTH CAROLINA



The Bonner Bridge spanning Oregon Inlet

J. J. Singer
C. E. Knowles

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HYDROLOGY AND CIRCULATION PATTERNS IN THE VICINITY OF OREGON INLET AND ROANOKE ISLAND, NORTH CAROLINA

by

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ABSTRACT

SINGER, JAMES JAY. Hydrology and Circulation Patterns in the Vicinity of Oregon Inlet and Roanoke Island, North Carolina. (Under the direction of CHARLES E. KNOWLES).

The hydrology and circulation data compiled in the study encompassed three major areas of interest. These included flow in Roanoke and Croatan Sounds, the influences of wind on ebb and flood at Oregon Inlet, and thermographic data collected at Oregon Inlet.

The flow of bottom waters in Croatan Sound and in mid-Roanoke Sound was observed to be essentially a direct response to the prevailing winds, except where the winds had prevailed for in excess of 24 to 36 hours causing pileup and subsequent flow reversal. In north Roanoke Sound, the flow of bottom waters south during northerly winds was observed to be essentially non-existent. In south Roanoke Sound, the flow was observed to be influenced by both the winds and flood tides at the inlet. In conjunction with this interaction in south Roanoke Sound, a mechanism was proposed for the northerly penetration of high salinity waters northward through Roanoke Sound towards Albemarle Sound. It is thought that a similar mechanism may be applicable to Croatan Sound.

Both extended ebbs (missed floods) and extended floods (missed ebbs) were recorded at Oregon Inlet. The initiation of these events was observed to be not nearly so dependent on long durations of high wind speeds as previously thought. In fact, rapid wind reversals (within 24 to 36 hours) were noted as apparently enhancing the likelihood of such events.

Thermographic records collected at three near bottom stations in or near Oregon Inlet revealed unexpected results. These suggest a rather unique documentation of oceanic upwelling off the North Carolina coast.

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INTRODUCTION

Purpose of Study

The purpose of this study was to examine the general hydrology of Oregon Inlet and the circulation in the vicinity of Roanoke Island along the North Carolina "Outer Banks." Besides these matters being of general interest in themselves, it was thought that in carrying out such a study one could better understand how this inlet influences the salinity of both Pamlico Sound and Albemarle Sound to the north. It had been reported earlier by the Corps of Engineers in House Document 155 (1935, p. 27) that:

> In general terms it seems probable that Oregon Inlet may affect the salinity of the sounds about as far north as the "Narrows" in Currituck Sound, and at least as far west as the mouth of North River in Albemarle Sound.

Description of Study Area

General Location

The study area is located in Dare County along the North Carolina coast. It is a region in which the coastline has essentially a NNW to SSE orientation. See Figure 1. In this figure particularly note the location of Oregon Inlet. It is the sole northerly source of oceanic water (excluding occasional washovers) to the extensive North Carolina estuary system. It is situated between the south end of Bodie Island (which is not an island at this time) and the north end of Pea Island in the barrier island system known as the "Outer Banks." Pea Island is continuous with Hatteras Island as a result of the closing of New Inlet. Hatteras

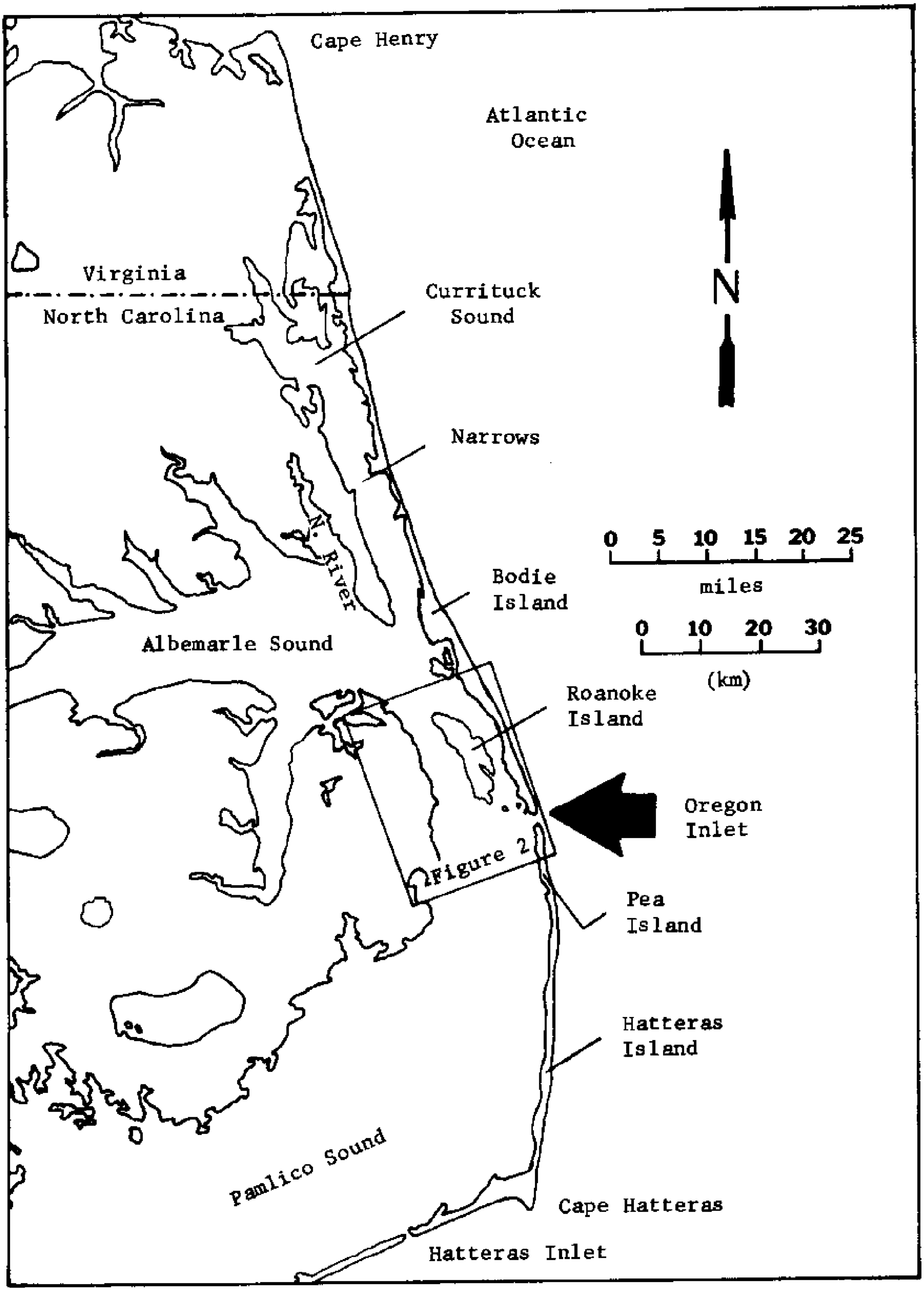


Figure 1. General location of study area along the North Carolina coast

Island is the southerly stretch of this same section of barrier beach and borders on Hatteras Inlet, the next nearest inlet to the south. Oregon Inlet is approximately 58 miles (93 km) SSE of the Virginia state line and 44 miles (71 km) NNE of Hatteras Inlet. Its position is 35° 47' N. latitude and 75° 32' W. longitude. The sound side opening of the inlet is approximately 3.6 miles (5.8 km) south of Roanoke Island.

The barrier islands in this region range in width from approximately 0.5 miles (0.8 km) to 2 miles (3.2 km). They are predominately sandy beaches backed by dunes with beach grass to the sound side. The natural processes here have been augmented by the addition of sand fences to encourage dune building and dune stability. Along Bodie Island the dunes range in height from 15 feet (4.6 m) to 20 feet (6.1 m) and along Pea Island they are about 15 feet (4.6 m) high (Langfelder et al., 1968).

Roanoke Island stretches roughly parallel to and behind the barrier beach at Bodie Island. It is approximately 11 miles (17.7 km) long and generally less than 3 miles (4.8 km) wide. It is surrounded by four sounds. To the north is the southeastern section of Albemarle Sound and to the south is the northern section of Pamlico Sound. To the east and west there are respectively Roanoke and Croatan Sounds (see Figure 2). Table 1 relates the area and volume of the four sounds as reported by Roelofs and Bumpus (1953).

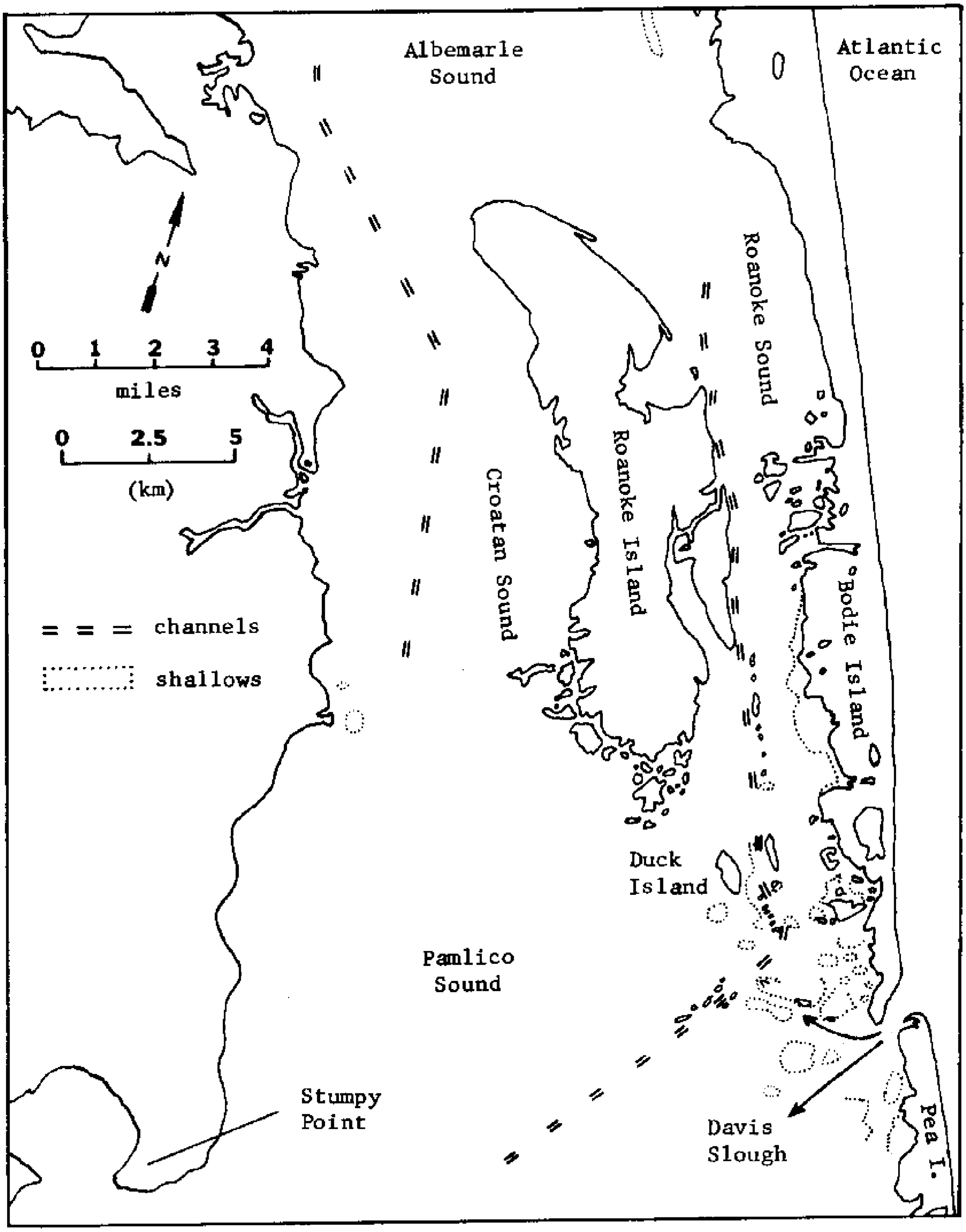


Figure 2. Study area

Table 1. Area and volume of the sounds (after Roelofs and Bumpus, 1953)

Sound	Area $\times 10^8$ m^2	Volume $\times 10^8$ m^3
Albemarle	18.2	65.4
Pamlico	43.5	166.0
Roanoke	0.96	1.5
Croatan	1.2	3.4

Basic Hydrography of the Sounds

The general depth in the southeastern section of Albemarle Sound pertinent to this study is 8 feet (2.4 m) to 9 feet (2.7 m). In contrast, depths for the northern section of Pamlico Sound are quite variable, ranging in depth from 1 foot (0.3 m) to 12 feet (3.7 m) with the shallower areas lying to the east. The dredged channels present in the region just opposite Oregon Inlet are 10 feet (3.0 m) to 12 feet (3.7 m) deep and 100 feet (30.5 m) wide. These channels are susceptible to extensive shoaling and must be redredged periodically (U. S. Army Engineer District Wilmington, 1973).

Roanoke Sound varies in width from approximately 0.7 miles (1.1 km) to 3 miles (4.8 km). It has a maximum length of 12 miles (19.3 km) and a maximum depth of 12 feet (3.7 m). Its average depth is 5.2 feet (1.6 m) (Magnuson, 1967), though the major part of the sound ranges in depth from 1 foot (0.3 m) to 3 feet (0.9 m). In addition, there is a dredged channel 6 feet (1.8 m) to 12 feet (3.7 m) deep and 100 feet (30.5 m) wide extending the length of the sound from Albemarle Sound to Pamlico Sound. This channel hugs the eastern shore of Roanoke Island and is susceptible to extensive shoaling at its most southerly extents (U. S. Army Engineer District Wilmington, 1973).

Croatan Sound varies in width from approximately 2.6 miles (4.2 km) to 5 miles (8.0 km). It has a maximum length of 12 miles (19.3 km) and a maximum depth of 23 feet (7 m). Its average depth is 9.4 feet (2.9 m) (Magnuson, 1967). A dredged channel ranging from 10 feet (3.0 m) to 12 feet (3.7 m) in depth and 100 feet (30.5 m) to 200 feet (61 m) in width extends the length of the sound. This channel is centrally located in the sound in a region in which erosion is taking place (Riggs and O'Connor, 1974). Consequently, it is not as susceptible to shoaling as those channels closer to the inlet.

Hydrology and Hydrography of Oregon Inlet

The mean tidal range at Oregon Inlet is 2.0 feet (0.61 m) and the spring tidal range is 2.4 feet (0.73 m) (U. S. Department of Commerce, 1973b). In addition, "tidal currents in the inlet are reported to be as much as 5 knots" (U. S. Department of Commerce, 1973c, p. 75).

There are two channels linking the inlet to the sound. One is a dredged channel that runs westward and joins the dredged channel network running along the east side of Roanoke Island and thence into Pamlico Sound. This channel is maintained for a depth of 12 feet (3.7 m) and a width of 100 feet (30.5 m) (U. S. Army Engineer District

Wilmington, 1973). The other is a natural channel that runs to the southwest and is known as the Davis Slough. It may range in depth from 9 feet (2.7 m) to 13 feet (4.0 m) and is subject to continual change (U. S. Coast and Geodetic Survey, 1973).

The inlet gorge itself has generally ranged in depth from 20 feet (6.1 m) to 33 feet (10.1 m) and its present width is nearly 1/2 mile (0.8 km) (U. S. Army Engineer District Wilmington, 1968, and a composite photograph for September 21, 1973, also from the Wilmington District Corps of Engineers).

HISTORY

Oregon Inlet

History: 1585 to Present

The history of Oregon Inlet is well documented in map records compiled by Cumming (1966) and in a table compiled by Col. S. T. Abert in 1876. This latter table appears in Drane (1923), House Documents (1935, 1948), and Marshall (1951). Cumming's compilation of maps is listed in Appendix A.

Records such as these indicate the existence of Oregon Inlet at least as early as 1585 and suggest that the inlet closed sometime between 1795 and 1808. It reopened again September 8, 1846, during a severe storm. The reopening was documented (Carney and Hardy, 1967, p. 9) and is reported below.

> A hurricane moving up from the south had apparently approached slowly, and the long northeasterly fetch had piled an unusual amount of water into the sounds. Then, on September 7 at 11 a.m., the winds shifted and came from the southwest, piling the waters onto the Banks and sweeping them back over into the ocean. Thus were created the present Hatteras and Oregon Inlets, the former on the night of September 7 and the latter on September 8.

During the span of time from 1585 to 1846 the inlet's name changed four times. It was known as Hatorask in 1590, Gun in 1733, Gunt in 1770, and as Gant in 1775 according to maps by White-De Bry, Moseley, Collet, and Mouzon respectively. Col. Abert reported that the inlet was called New Inlet in 1838, however, having examined a map by MacRae-Brazier for the year 1833, it would seem that this is in error. MacRae and Brazier's map indicates that there was no inlet at this location but that another inlet further south known as New Inlet did exist. After the storm in 1846 the reopened inlet became known as Oregon Inlet. It was renamed for one of the first boats to pass through it, the steamer "Oregon" (Dolan and Glassen, 1973).

In the years between 1585 and 1846 there were as many as six and as few as one inlet open simultaneously between Cape Hatteras to the south and Cape Henry to the north. According to maps by White-De Bry and Mercator-Hondius for 1590 and 1606 respectively, there were three unnamed inlets along Currituck Sound, a fourth inlet a few miles north of the southern end of Roanoke Island and a fifth inlet known as Hatorask (Oregon Inlet). Ogilby in 1672 shows one less inlet along Currituck Sound and two additional inlets south of Oregon Inlet but north of Cape Hatteras for a total six. In 1833, according to MacRae-Brazier, the only inlet north of Cape Hatteras was New Inlet.

After the reopening of Oregon Inlet in 1846 there was apparently a brief period during which there was one other inlet open to the north. It was known as South Inlet and was located along Currituck Sound. It appears on maps by both Colton and Bachman for 1861 and is neither present on a map by the U. S. Coast Survey for 1865 nor on subsequent maps. On maps from 1861 to 1896 two inlets between Oregon Inlet and Cape Hatteras are reported. They were known as New and Loggerhead Inlets. According to House Documents (1935, 1948) Loggerhead Inlet was closed by 1934 and New Inlet closed in January of 1922. It was artificially reopened in 1924, but closed again almost immediately. New Inlet was again reopened by a storm March 6, 1932, and was reported closed by 1947. Therefore, at least since 1947 Oregon Inlet has been the only opening in the barrier island north of Cape Hatteras, and it has been the northern-most inlet along the "Outer Banks" at least since 1865.

Inlet Migration: 1849 to Present

In the 60 years from 1849 to 1909 the inlet apparently experienced a major change of location. It migrated nearly 1 mile (1.6 km) southward and increased its width by some 900 feet (274 m) to 2,500 feet (762 m). In the following 57 year span from 1909 to 1966 the north and south shoulders migrated southward at an average annual rate of 3 feet (0.9 m) and 48 feet (14.6 m) respectively. Over this same span the width of the inlet throat increased to a maximum of 7,770 feet (2368 m) by April of 1962 and then began narrowing down to 5,040 feet (1536 m) by August of 1966. In the course of this narrowing process, the north shoulder migrated southward some 2,180 feet (664 m) and the south shoulder migrated northward some 550 feet (168 m). This narrowing process has continued in recent years to the extent that the inlet throat is now approximately 2300 feet (701 m) wide (U. S. Army Engineer District Wilmington, 1968, and composite photograph for September 21, 1973, also from the Wilmington District Corps of Engineers).

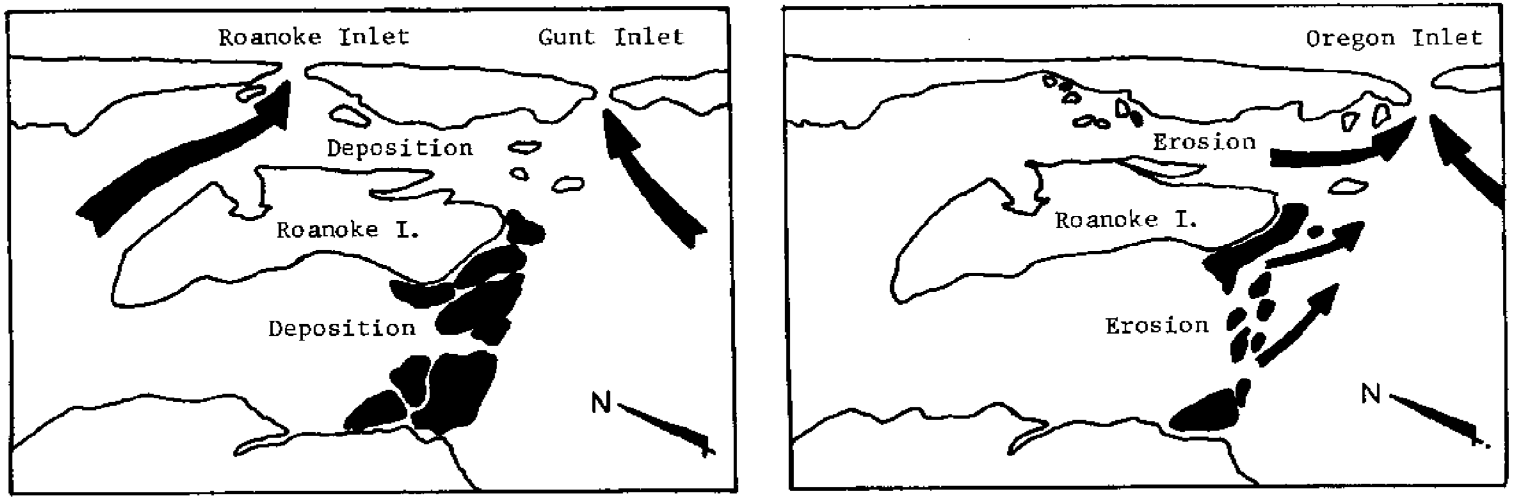
In 1964, the Herbert C. Bonner Bridge was completed over the inlet. Its presence serves as a good reference from which to view the southerly migration of the northern shoulder. See Figure 3. This photograph was taken in 1973 and is looking from the south to

Figure 3. A 1973 photograph of Oregon Inlet (Note the buildup of the north shoulder. The dotted line corresponds to a rough estimate of the north shoulder in 1964.) (Photo taken by Lee U. Howe of the U. S. Army Corps of Engineers, Wilmington, N. C.)

the north. The dotted line on the northern shoulder corresponds to a rough estimate of the north shoulder as revealed in a photograph of the inlet (from the Gastonia Gazette, June 7, 1964) just after the opening of the bridge.

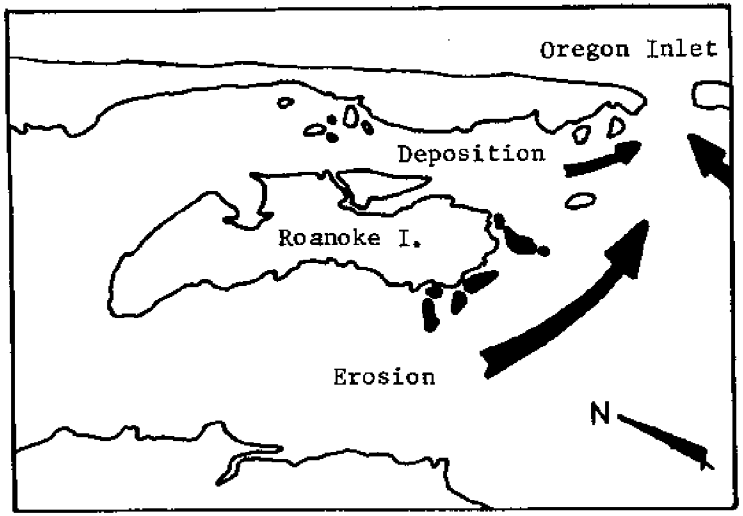
Roanoke and Croatan Sounds

Riggs and O'Connor (1974) summarize the sequence of events leading to Roanoke and Croatan Sounds as we know them today. Between 1585 and 1817 water flowing out of Albemarle Sound flowed past the northern end of Roanoke Island and out Roanoke Inlet (see Figure 4). This resulted in deposition of sediment in the region between Roanoke Inlet and Oregon Inlet. During the same time span there was heavy deposition at the southern end of Croatan Sound. In the next period, from post 1817 to the mid-1800's when Roanoke Inlet was closed, there was erosion at the southern ends of both Roanoke and Croatan Sounds. Finally, from the mid-1800's to the present there has been deposition in Roanoke Sound and continued erosion in the southern section of Croatan Sound.



1585 - 1817

POST 1817 - MID 1800's



MID 1800's - PRESENT

Figure 4. Historical development of the Roanoke Island estuarine system (The size of each arrow represents the relative volume and direction of the fresh water discharge (from Riggs and O'Connor, 1974))

REVIEW OF LITERATURE

Oregon Inlet

Velocity, Flow and Discharge Data from Earlier Studies

Four studies have been made involving the collection of hydrologic data at Oregon Inlet. Two of these are reported in House Documents (1935, 1948), a third in a paper by Roelofs and Bumpus (1953) and a fourth in a review report compiled by the U. S. Army Engineer District Wilmington (1968). This latter publication summarizes velocity, flow and discharge data collected at the inlet during these studies. This data is presented in Table 2.

From such data as this and observations made at the time, the following conclusions were drawn:

(1) ". . . that the volume of tidal prism varies with the wind conditions" (House Document, 1935, p. 21).

(2) ". . . that the tidal flows for any inlet vary considerably" (House Document, 1948, p. 13).

(3) that such variations in flow

> . . . are due to differences in the tidal range, differences in water levels in the sounds, . . . and differences in the conditions of the inlet, as evidenced by the differences in cross-sectional area"

(House Document, 1948, p. 13).

(4) that

> strong southwest winds occasionally move enough water northward to raise the sound water level above that of Oregon Inlet at high tide (such that) . . . there is a continuous ebb current through the inlet (and that this ebb current may prevail) . . . for two or three days . . .

(Roelofs and Bumpus, 1953, p. 185).

Table 2. Tabulation of velocity, flow and discharge data from earlier studies (after U. S. Army Engineer District Wilmington, 1968)

Documentation	Date	Cross-sectional area[a] (m^2)	Winds[b] Direction	Winds[b] Average Speed (knots)	Predicted Tidal Range ft(m) Flood	Predicted Tidal Range ft(m) Ebb	Maximum Velocities (knots) Flood	Maximum Velocities (knots) Ebb	Maximum Rates of Discharge (m^3/sec.) Inflow	Maximum Rates of Discharge (m^3/sec.) Outflow	Observed Total Flow ($x10^6$ m^3) Inflow	Observed Total Flow ($x10^6$ m^3) Outflow	Percent Difference, Inflow and Outflow	Computed Total Flow (x 10^6 m^3) Inflow	Computed Total Flow (x 10^6 m^3) Outflow	Percent Deviation Inflow	Percent Deviation Outflow
H. D. 155 (1935)	9 Sept. 1931	3623	NE	5.4	2.0 (.61)	1.5 (.46)	1.5	1.4	3796	2524	58.92	46.13	21.7	54.07	35.96	-9.0	-28.3
H. D. 155 (1935)	31 Aug. 1932	----	W	9.9	2.2 (.67)	1.8 (.55)	1.4	1.6	3656	2908	52.70	49.40	6.3	52.07	41.42	-1.2	-19.3
H. D. 155 (1935)	11 Oct. 1932	----	SW	10.3	1.7 (.52)	1.8 (.55)	1.4	1.9	3582	3605	43.01	70.56	64.0	51.02	51.35	15.7	-37.3
H. D. 763 (1948)	24 Aug. 1937	4125	S	6.0	2.2 (.67)	2.1 (.64)	2.2	2.0	5097	4021	78.33	68.95	12.0	72.60	57.27	-7.9	-20.4
H. D. 763 (1948)	14 Aug. 1939	5203	SW	9.1	2.5 (.76)	2.2 (.67)	1.7	2.3	4304	3993	46.63	88.19	89.1	61.31	56.87	24.0	-55.1
Roelofs and Bumpus (1953)	23 April 1950	2601	SSW	17.8	---	---	---	1.9[d]	----	2549	-----	47.12[e]	----	-----	36.30	----	-29.8
Wilmington Dist. Corps of Engineers (1968)	27 Sept. 1965	6185[c]	NE	7.5	2.8 (.85)	2.5 (.76)	1.9	1.3	8269	4129	121.13	66.85	44.8	117.77	58.81	-2.9	-13.7

[a] Cross-sectional area along line of current measurements at mean low water.

[b] Data obtained from Cape Hatteras weather station (sensor height 47 feet from 1902 to 1946, 54 feet from 1946 to 1957 and 32 feet from 1957 to present according to data provided by James Owenby of the National Climactic Center, Asheville, N. C., October, 1974).

[c] Magnuson (1967) reports this value as 6205 m^2.

[d] Maximum velocity reported in text of work was 2.7 knots.

[e] This is the observed total flow over a period of 6 hours 45 minutes during which Roelofs and Bumpus (1953) were present and taking data. The ebb reportedly continued longer than this.

(5) that computed values of flow using the integral equation:

$$Q = \int_{0}^{T/2} q \, dt \tag{1}$$

where Q = total volume of flow,

q = instantaneous discharge at time t,

$= q_{max} \sin 2\pi/T$,

and T = tidal-wave period (44,712 seconds)

yielding

$$Q = q_{max} \frac{T}{\pi} \tag{2}$$

often deviate from the observed flow and that this deviation is in part attributable to the winds (U. S. Army Engineer District Wilmington, 1968).

(6) that a more refined equation derived by Keulegan and Hall (1950), introducing a third harmonic term into the basic equation for q, would also deviate from observed flow due to the strong effects of winds on past measured flows at the inlet. This equation is stated as follows:

$$Q = q_{max} \frac{T}{0.86\pi} \tag{3}$$

(U. S. Army Engineer District Wilmington, 1968).

More recently, Jarrett (1966) made calculations of the velocity of water passing through Ocracoke Inlet, N. C., on both flood and ebb. He found that by using Bernoulli's equation for steady flow between two points in the inlet in conjunction with Manning's equation (see Appendix B), he could come up with velocities in close agreement with those predicted in the "Tidal Current Tables." Such a method, he emphasized, could be particularly valuable in ". . . estimating the velocities and flows for abnormal tidal fluctuations that are a result of winds" (p. 107). This would tend to suggest that this equation could be particularly applicable to Oregon Inlet. However, perhaps because of the tremendous wind influence, average tidal current velocities are not given for Oregon Inlet in the "Tidal Current Tables." This in turn complicates the assignment of a value for n, the Manning coefficient of roughness, for Oregon Inlet which is necessary in order to solve the equation. Furthermore, this lack of velocities reported in the tables further prevents a comparison of computed values with predicted values.

Temperature and Salinity at Oregon Inlet

Temperatures reported at the inlet have ranged from a minimum of 3.98°C in January to a maximum of 20.80°C in August (Williams *et al.*, 1973). Roelofs and Bumpus (1953) report that the water flowing into the sounds through the inlets is isothermal. However, due to the difference in temperature of the sound waters, temperature gradients may be found in the vicinity of the inlet within the area of tidal influence.

Salinities at the inlet have ranged from 8.51 to 32.14 ppt (Williams *et al.*, 1973). A seasonal trend here is less obvious in that both extremes may be approached in the same month. However, influences such as river runoff interacting with wind speed, direction and duration (which are general seasonal trends in themselves) should be considered as influential along with the state of the tidal cycle.

The Sounds

Flow from Albemarle Sound to Pamlico Sound

Jarrett (1966) computed the average daily contribution of fresh water flow from Albemarle Sound to Pamlico Sound. He estimated this value to be $48.11 \times 10^6 \ m^3$ per day. Such an estimate implies current velocities on the order of 1.98 cm per second (0.04 knots). However, to avoid confusion, it is pointed out here that such a value has no practical application to observed currents in the sounds. They are more inclined to be influenced by the winds than the fresh water input.

Jarrett (1966) also assumed that 85 percent of the flow from Albemarle Sound to Pamlico Sound passed through Croatan Sound. This assumption was based on the fact that Croatan Sound constitutes 85 percent of the volume of the two sounds linking Albemarle Sound to Pamlico Sound. As it turns out, this does not appear to be a bad assumption when compared with the actual flow data reported in House Document (1935). Here, during a period of northerly flow in the two sounds, Croatan Sound accounted for better than 76 percent of the flow.

Currents in the Sounds

Seabed drifters from a study of coastal waters off Chesapeake Bay by Norcross and Stanley (1967) reportedly passed through Oregon Inlet and into the sounds. The inferred paths of these drifters into the study area are related in Figure 5. It should be emphasized that these are inferred paths. That is, the lines of travel of the drifters are drawn in a pretty much direct manner from the point of origin to the point of recovery. It is not really known how they got there, but only that they got there in a certain amount of time. In consequence, though it may be a point of interest, such data does not really reveal the current or circulation patterns in the sounds.

Earliest reports of currents in the sounds date back to Winslow (1887). He noted that currents experience a generally southerly set from Albemarle Sound to Pamlico Sound. This he said is occasionally ". . . interrupted by the backing up of waters in Pamlico Sound after strong easterly and southerly winds" (p. 21). In addition, he noted that for the northern section of Pamlico Sound ". . . both the direction and velocity of the currents are directly dependent upon the winds . . ." (p. 25). Finally, he made the following remarks with respect to Croatan and Roanoke Sounds:

> The currents in both Croatan and Roanoke Sounds are quite strong, being on an average one half knot per hour, and in certain localities and under certain circumstances much stronger. About the Roanoke marshes and at the southern end of Roanoke Sound, near Duck Island, the ebb and flow is very strong, and with or after favoring winds exceeds at times a knot an hour (p. 21).

In contrast, House Document (1935) relates that the ". . . flow in Roanoke Sound follow(s) the direction of the wind" (p. 23). It is independent of the ebb and flood at the inlet. Consequently, it is hoped that the present study should determine to what extent ebb and flood at the inlet actually affect Roanoke Sound.

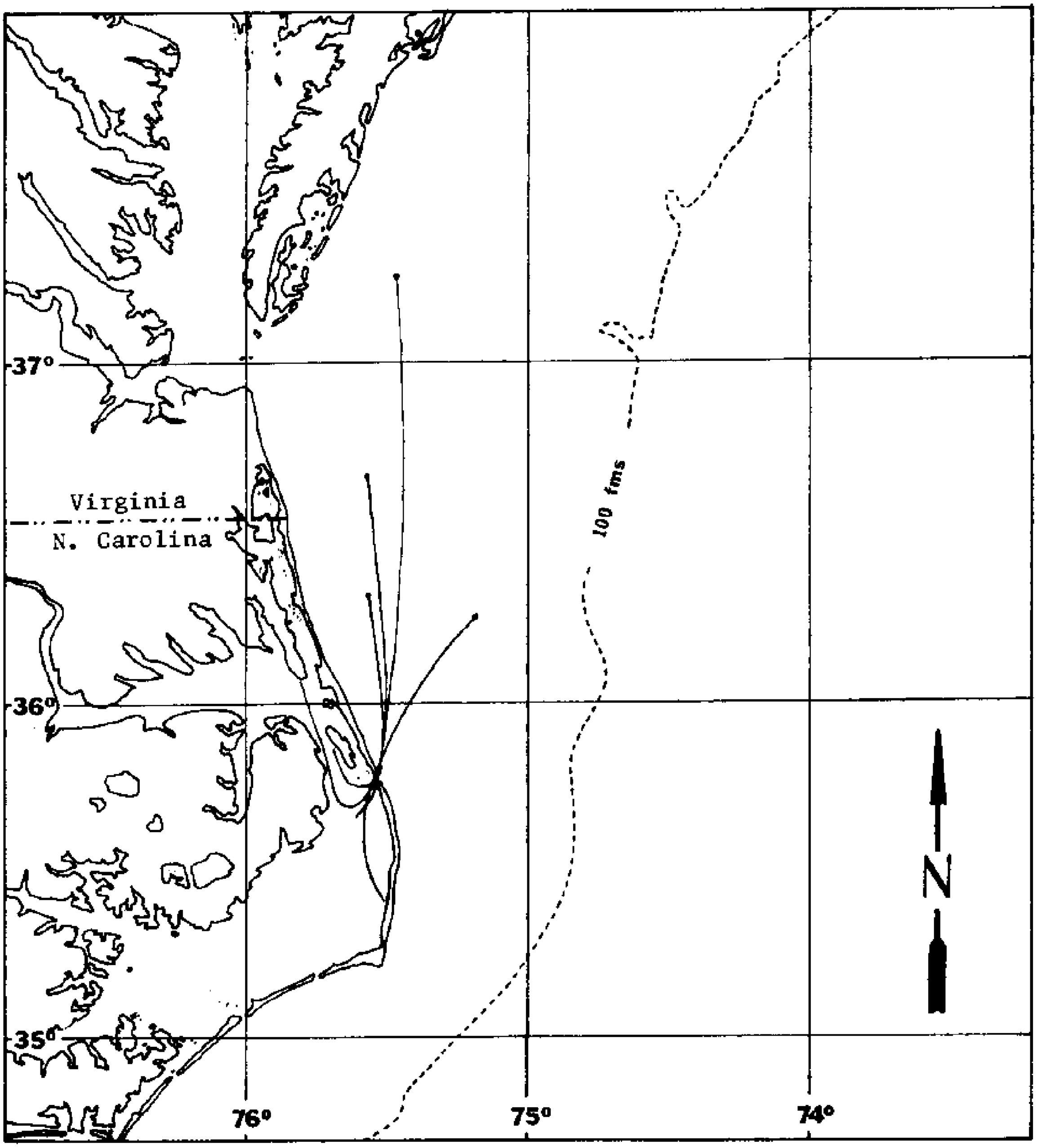


Figure 5. Inferred path of seabed drifters into the study area (after Norcross and Stanley, 1967)

Tidal Action in the Sounds

According to Winslow (1887) no regular tidal action has ever been observed in the northern section of Pamlico Sound. Others, including Marshall (1951), Posner (1959) and Riggs and O'Connor (1974), have indicated much the same for the sounds in general. However, on occasion, some slight tidal variation has been detected as much as 15 miles (24 km) from the inlet near the northern end of Roanoke Island (House Document, 1935). When this has occurred, the effect has been observed to lag 3 to 6 hours more or less behind a gauge just inside the inlet. Gauges further north of Roanoke Island in Currituck Sound show no effect.

U. S. Coast and Geodetic Survey charts carry the following notation: "In Pamlico Sound except near the inlets the periodic tide has a mean range less than one-half foot." In addition, Roelofs and Bumpus (1953) have predicted a tidal range of about 5 cm, but as Magnuson (1967) states: "No firm data are available on the present tid(al) range in the sounds" (p. 137).

With this general absence of lunar tides, wind induced tides dominate in the sounds. In the western part of Albemarle Sound, waters have been recorded as having risen as much as 5 feet (1.5 m) above mean sound level (House Document, 1935). However, for the open sounds, Marshall (1951) relates a 2 foot (0.6 m) range above or below normal, and Riggs and O'Connor (1974) bluntly state that wind tides can be as high as 10 feet (3.0 m).

In conjunction with wind induced tides, Roelofs and Bumpus (1953) estimated the height of the head of the water in the northern section of Pamlico Sound near Oregon Inlet for different southerly wind speeds using Keulegan's (1951) equation for setup. It may be stated as follows:

$$\frac{S}{L} = 3.3 \times 10^{-6}(1 + 63(H/L)^{1/2}) \frac{V^2}{gH} \tag{4}$$

where S = setup, $h_2 - h_1$, the difference in the displacement of the windward and leeward water levels,

L = length of bay,

V = velocity of wind,

H = mean depth,

and g = acceleration of gravity (cgs units).

Since this equation was actually designed for rectangular bodies of water of constant depth, Roelofs and Bumpus broke Pamlico Sound up into three sections for the computation of S. S_1 designated the windward 46 miles (73.6 km) of the sound having a mean depth of 5.2 meters, S_2 the next 8 miles (12.8 km) having a mean depth of 4.0 meters and S_3 the leeward 6 miles (9.6 km) with a mean depth of 1.0 meter. This latter section of the sound corresponds to the vicinity of Oregon Inlet. The following table was compiled based on these computations (Table 3). However, as pointed out by Roelofs and and Bumpus, these values do not consider the funneling effect of the sound. Consequently, higher setups should be expected than are predicted by the equation.

Table 3. Computation of setup corresponding to various wind speeds (from Roelofs and Bumpus, 1953)

Wind Speed (kts)	5	10	20	40
S_1 (cm)	6	18	73	292
S_2 (cm)	2	6	23	92
S_3 (cm)	4	13	53	212
S (cm)	12	37	149	596
Rise in Level (cm) h_1	6	18	75	298
Rise in Level (ft) h_1	0.2	0.6	2.5	9.8

Temperature in Roanoke and Croatan Sounds

According to Marshall (1951), Posner (1959) and Woods (1967) the temperature of the open sounds follows the air temperature rather closely with the sounds exhibiting a slightly lower temperature. In addition, there is generally little vertical variation with depth. Roelofs and Bumpus (1953) report that such variations never exceed 2°C. Finally, horizontal variation of surface temperature reportedly does not exceed 3 or 4°C over the entire sound and river complex except ". . . in June and November when the temperature of water in shallow areas of the sound is changing more rapidly than oceanic water coming through the inlets" (Woods, 1967, p. 105). For the present study area, temperatures as low as 5°C have been reported for January (Williams _et al._, 1973) and as high as 28 to 29°C for July (Schwartz and Chestnut, 1973).

Salinity in the Sounds

Before really discussing salinities it should be interjected at this point that salinities in the study area as a whole are quite variable. According to Winslow (1889) lower salinities in the four sounds generally correspond to northerly winds blowing fresher water from Albemarle Sound down through Croatan and Roanoke Sounds into Pamlico Sound and that higher salinities generally correspond to the reverse process. This, he points out, however, is not always the case. For example, had southerly winds prevailed for some time, thereby moving more saline Pamlico Sound waters north, one could expect to observe higher than normal salinities coming from Albemarle Sound upon the initiation of northerly winds. See Winslow's comments on the effects of winds on salinity in the sounds in Appendix C.

Salinities in the southeastern section of Albemarle Sound just north of Croatan Sound have been observed to range from 0.0 to 19.52 ppt (Schwartz and Chestnut, 1973, and Williams *et al.*, 1973). In addition, bottom salinities have been observed to increase from 3.5 to 20.5 ppt in less than two hours in a region designated by Posner (1959) as "the eastern section of Albemarle Sound."

In Pamlico Sound, mid-sound salinities just opposite Oregon Inlet have been observed to range from 7.1 to 31.8 ppt (Schwartz and Chestnut, 1973).

Sufficient data have not been documented to relate the extremes of salinity characteristic of Roanoke Sound. However, some map records by H. R. Seiwell for January and July 1927 reproduced in

Marshall (1951) indicate salinities as low as 5 ppt to the north and as high as 18 ppt to the south. This sound, however, has generally been considered to be more under the influence of oceanic waters passing through Oregon Inlet than is Croatan Sound. The early observations by Winslow (1887) of oyster cultures and those of Posner (1959) related above tend to strengthen this view.

In Croatan Sound, mid-sound salinities obtained in 1972 just north of the sound's widest point were found to range from 0.0 to 12.0 ppt (Schwartz and Chestnut, 1973). However, based on data from Williams _et_ _al_. (1973), an interpolated higher value would range between 19.52 and 27.79 ppt.

PRESENT INVESTIGATION

Instrumentation and Equipment Used

The instruments used in this study were predominantly of the film recording type manufactured by General Oceanics, Inc. These included film recording tide gauges, current meters and thermographs. In addition, a Martek Water Quality Monitoring System and a Bendix Q-15 current meter were used for vertical profiles of current, temperature and conductivity. The conductivity data were converted to salinities numerically using a program and algorithm (Knowles, 1973) that are based upon normal sea water conductance data (Reeburgh, 1965) and the UNESCO salinity-conductivity tables (Cox et al., 1967). A Raytheon DE 719 precision fathometer was used for depth profiles, and wind data were collected from a portable Science Associates field station and from the Oregon Inlet Coast Guard Station. The general specifications on these instruments are given in Appendix D.

Two boats were used in the course of this study. One was a 19 foot "Winner" motor boat provided by the N. C. State University Center for Marine and Coastal Studies. The other was a 19 foot "Glaspar" motor boat belonging to the N. C. State University Department of Zoology.

Study Periods and Instrument Locations

Data were collected on two occasions: a 13 day period from 20 June to 2 July, 1973, and again for 36 days from 27 January to 3 March, 1974. This latter visit was made with the hope of answering questions derived from the initial visit, ascertaining the effects of strong northeast winds generally characteristic of the winter months, and to find out if there was any significant influence on the circulation due to the high spring tide predicted for 6 February, 1974.

During the initial study (20 June to 2 July, 1973), 14 film recording instruments were set to collect data at 5 minute intervals. These units were bottom mounted for the duration of the study. (For details of bottom mounting see Appendix E.) Of these, there were 7 current meters, 5 thermographs and 2 tide gauges. Instruments of this type were not placed at intermediate depths due to the general shallowness of the sounds and because of the limited number of instruments available for use. However, to compensate for this, vertical profiles of current and temperature were planned at most stations during at least some part of the study period.

Figure 6 relates the types of film recording instruments installed and the general location of the units from which data were obtained during this initial study. A tabulation of the actual location of these and all other stations occupied during the course of this research (according to U. S. C. and G. S. Chart 1229 for 1973) is included in Appendix F. This tabulation also gives the approximate depths corresponding to these stations.

The fact that instruments were at stations for the entire length of the study periods does not necessarily imply that data were collected at the stations continuously. This is because at times and for a variety of reasons, certain instruments ceased

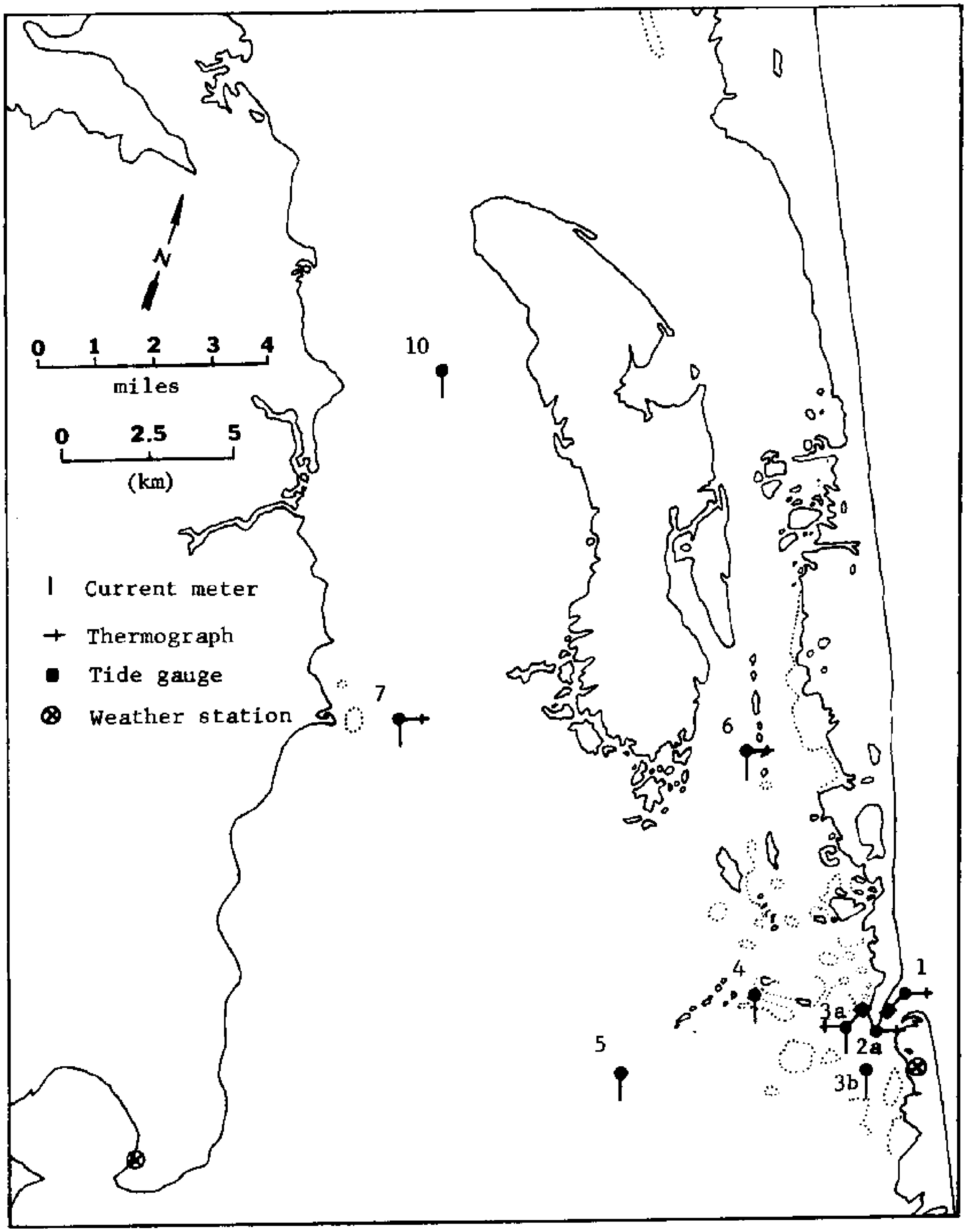


Figure 6. Bottom mounted film recording instrument and weather station locations during the initial study (20 June - 2 July, 1973)

operation. In addition, some stations are not even mentioned due to the total lack of data from them. For example, on two occasions tide gauges were placed in Croatan Sound and once in Roanoke Sound and the instruments failed to collect any data at all. Consequently such instrumentations are ignored in the discussions to follow.

The locations from which wind and temperature data were collected are also shown in Figure 6. These include the Coast Guard Station at Oregon Inlet and a temporary field station at Stumpy Point. Sensors at these weather stations were at heights of 72 feet (22 meters) and 10 feet (3 meters) respectively. Data were reported at 3 hour intervals by the Coast Guard Station and continuous records were maintained at the field station by a strip chart recorder.

In general, there was good agreement with regard to wind direction at these two stations, but the velocities recorded at Stumpy Point were generally lower than those recorded at Oregon Inlet. This was probably due to the difference in the heights of the sensors, the trend being that the lower the sensors the greater the influence of the surface roughness on them. This would particularly apply to the Stumpy Point station where there were tall beach grasses and a wood structure within 100 feet of the station. Consequently, for the purpose of this study, data from the Stumpy Point station serve essentially as a backup to confirm wind direction at the inlet.

A comparison is made of data collected at these two stations during the first two weeks of the second study period and is included in Figure 7. The Stumpy Point data here are plotted for the same three hour intervals and the trends seen are typical of both study periods. In addition, data from the Weather Bureau station at Cape Hatteras (38 miles south of Oregon Inlet) are also included for comparison over this same time span. It may be recalled that earlier in the review of literature the wind data furnished in conjunction with flow and discharge at Oregon Inlet were from the Cape Hatteras station. The wind sensors at this station are currently at a height of 32 feet (10 meters).

Once again, there is generally good agreement with regards to wind direction. However, the fact that the station is 38 miles to the south would tend to suggest that it would be more appropriate to use the data from the Oregon Inlet Coast Guard Station even though the sensors here are somewhat higher than usual. Perhaps as a consequence of this difference in height, or differences in surface roughness for various directions of approach to the sensors, or because of differences in the meteorological conditions at these locations, or a combination of these factors, there are some differences in the recorded wind velocities. Particularly note the difference in north to northwest wind speeds. At Oregon Inlet these wind speeds are generally 5 knots higher than at Cape Hatteras. (It is estimated that differences in height and roughness alone could account for nearly 5 knots difference in recorded velocities, with surface roughness having the greater influence.) In turn, during southwesterly winds neither station appears to show preference over the other. At times the velocities reported are almost identical

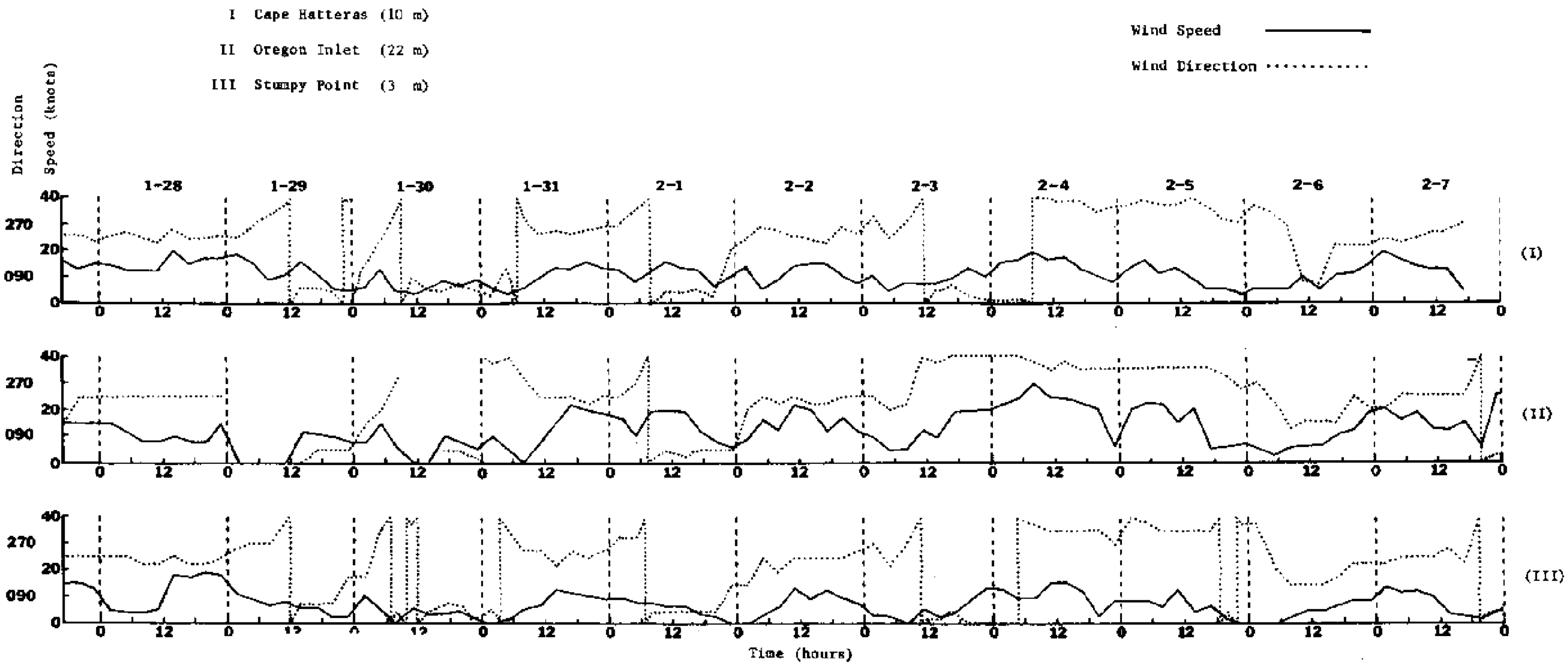


Figure 7. Comparison of wind speed and direction data from stations at: (I) Cape Hatteras, (II) Oregon Inlet and (III) Stumpy Point during second study from 1700 on 27 January through 7 February, 1974

and at other times one or the other station may exhibit slightly higher wind speeds. Wind speeds and directions reported for the Oregon Inlet Coast Guard Station will be used in the present study.

Vertical profiles of current velocity, temperature, and salinity were made at numerous stations using a Bendix Q-15 current meter and a Martek Water Quality unit. These stations are shown in Figure 8. The profiles made in Croatan Sound did not include measurement of current velocity with the Q-15, but as related earlier two stations in the sound (stations 7 and 10) were instrumented with bottom mounted film recording current meters.

Unfortunately, in that only one water quality monitoring system was working and only one boat was available for much of the in-residence study period, this part of the investigation (involving vertical profiles) had to be broken up into two sampling sections. These sections were investigated on different days. One such section in the vicinity of the inlet included stations 1 through 6. The other section was in Croatan Sound and consisted of stations 7 through 12.

Because of its distance from the other stations and the effects of both northeasterly and southwesterly winds, it was also found difficult to include station 6 in the study with any regularity. Northeasterly winds caused a loss of time in getting to the station because of the wave setup coming from the northeast. In turn, southwesterly winds caused a loss of time in returning from the station to the inlet because of the wave setup coming from the southwest.

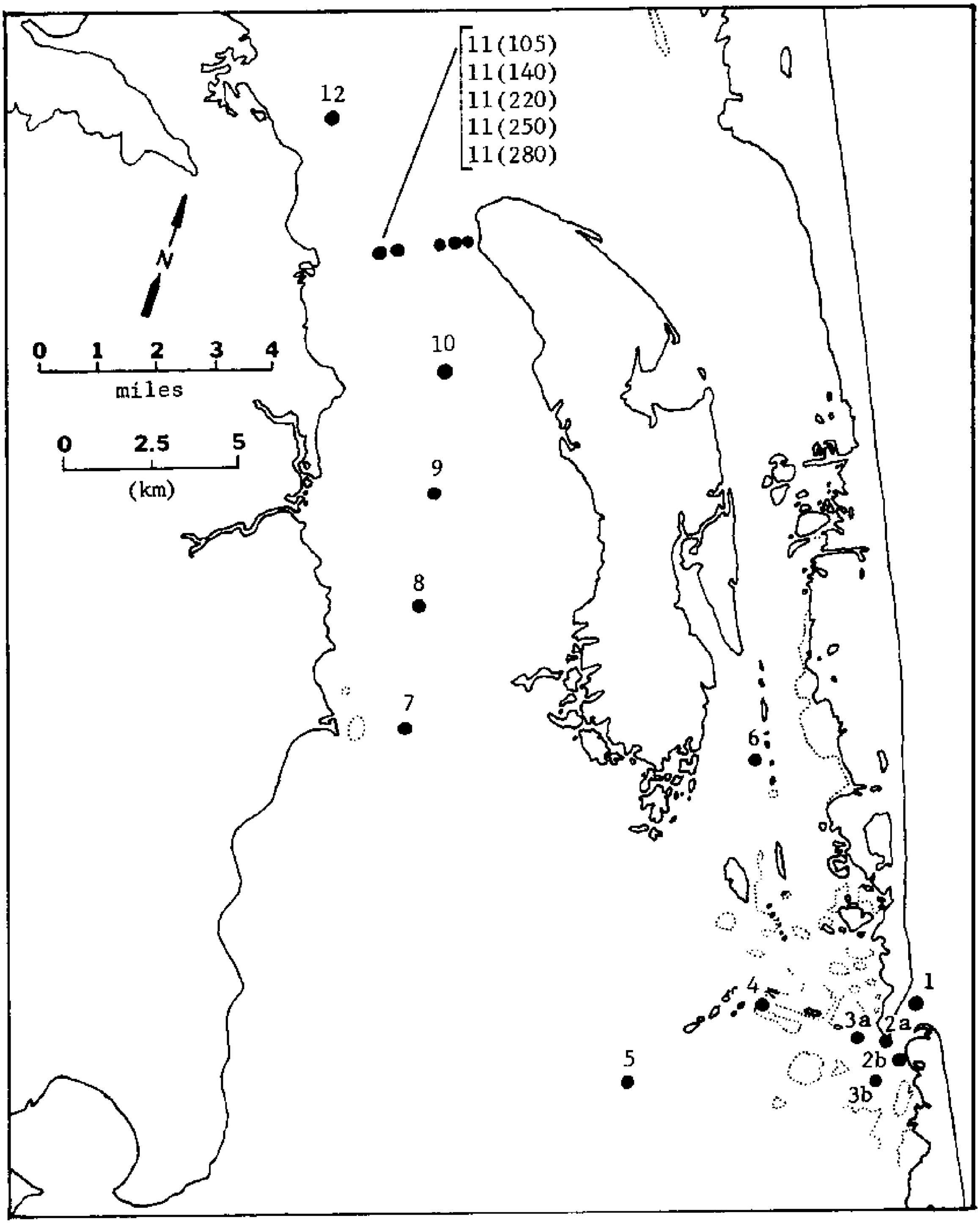


Figure 8. Stations of vertical profiles of current velocity, temperature and salinity for the initial study (20 June-2 July, 1973) (Those stations labeled 11(105), 11(140), etc. correspond to bents 105 and 140 along the Croatan Sound bridge; additional stations along the inlet bridge and the Croatan Sound bridge, not shown here, are included in Appendix F. Note: Vertical profiles of current velocity were not collected for Croatan Sound.)

Consequently, station 6 was generally ignored except for two sets of data collected on 29 June.

During the second study (27 January to 3 March, 1974), 14 film recording instruments set for 15 minute intervals were bottom mounted. Of these, there were 10 current meters, 2 thermographs and 2 tide gauges. The general locations of these instruments are related in Figure 9. As noted earlier, a listing of the actual locations and depths corresponding to these stations is included in Appendix F. Wind data were obtained from the same wind stations as the initial study. No vertical profiles of temperature, salinity or current velocity were made.

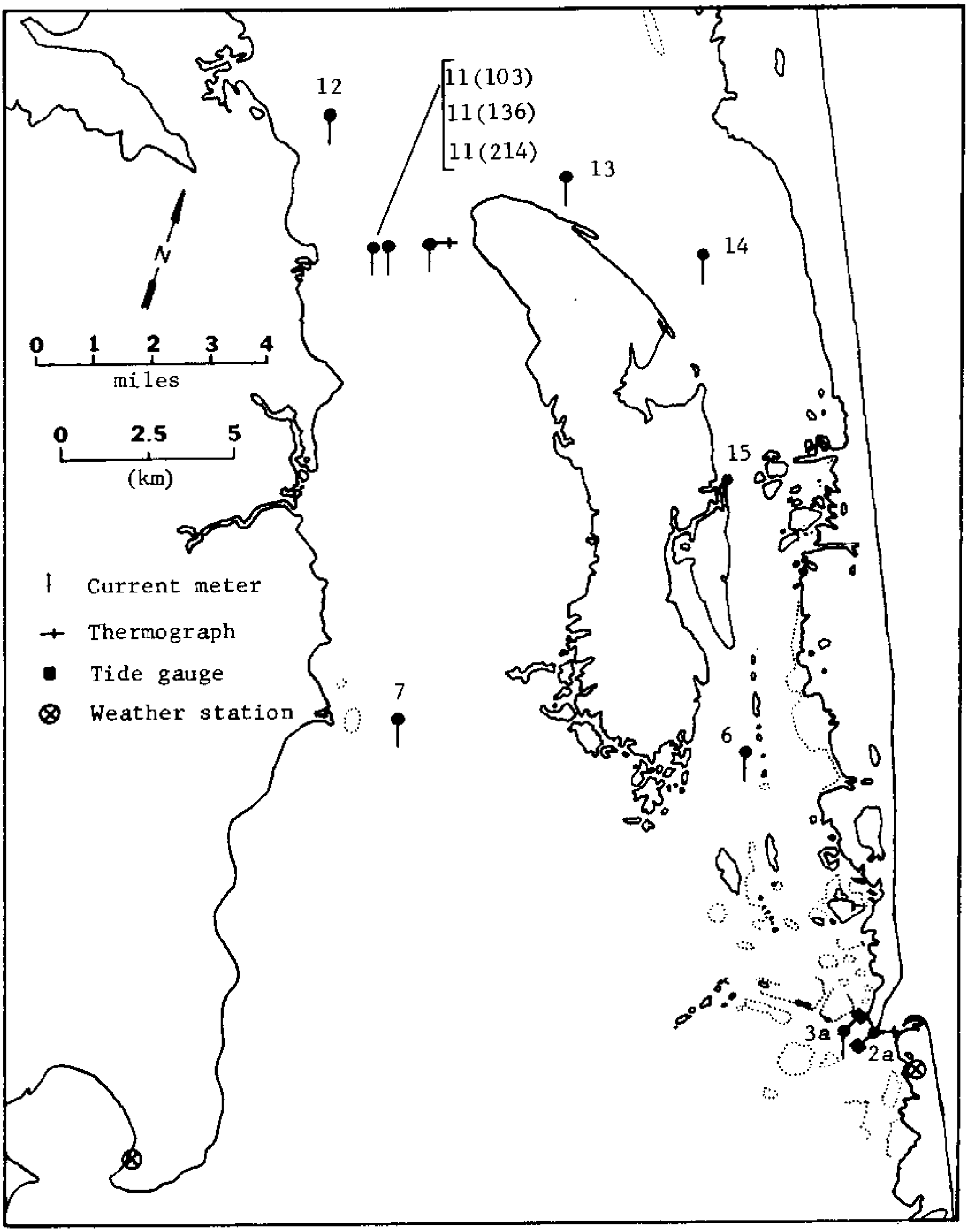


Figure 9. Bottom mounted film recording instrument and weather station locations during the second study (27 January - 3 March, 1974)

RESULTS AND DISCUSSION

Ebb and Flood at Oregon Inlet

Calculation of Flow from Verticals across the Length of the Inlet Bridge

A depth profile was taken along the length of, and approximately 15 yards (13.7 m) to the sound side of the bridge at the inlet on 3 July, 1973, using a Raytheon DE 719 precision fathometer. This profile followed the curvature of the bridge (see Figure 10). From this, the cross sectional area along the bridge was found to be 6390 m^2 at MLW.

Vertical profiles of current velocities were measured along this length for both ebb and flood on 28 June. On this day the winds were southwest at 4 to 8 knots. Each of the two profiles took one hour to complete and included stops at some eight to nine stations along the bridge. During the course of one of these surveys, maximum flood conditions were nearly attained. However, maximum ebb conditions were missed by nearly two hours, the survey being that much early. Computations of the mean maximum rate of discharge corresponding to the average of the velocities of the eight or nine columns of water included in the surveys were made and are given in Table 4. These values compare favorably with discharge data compiled earlier by the Corps of Engineers and others for the inlet gorge.

As far as preferred channels of flow are concerned the following observations were made.

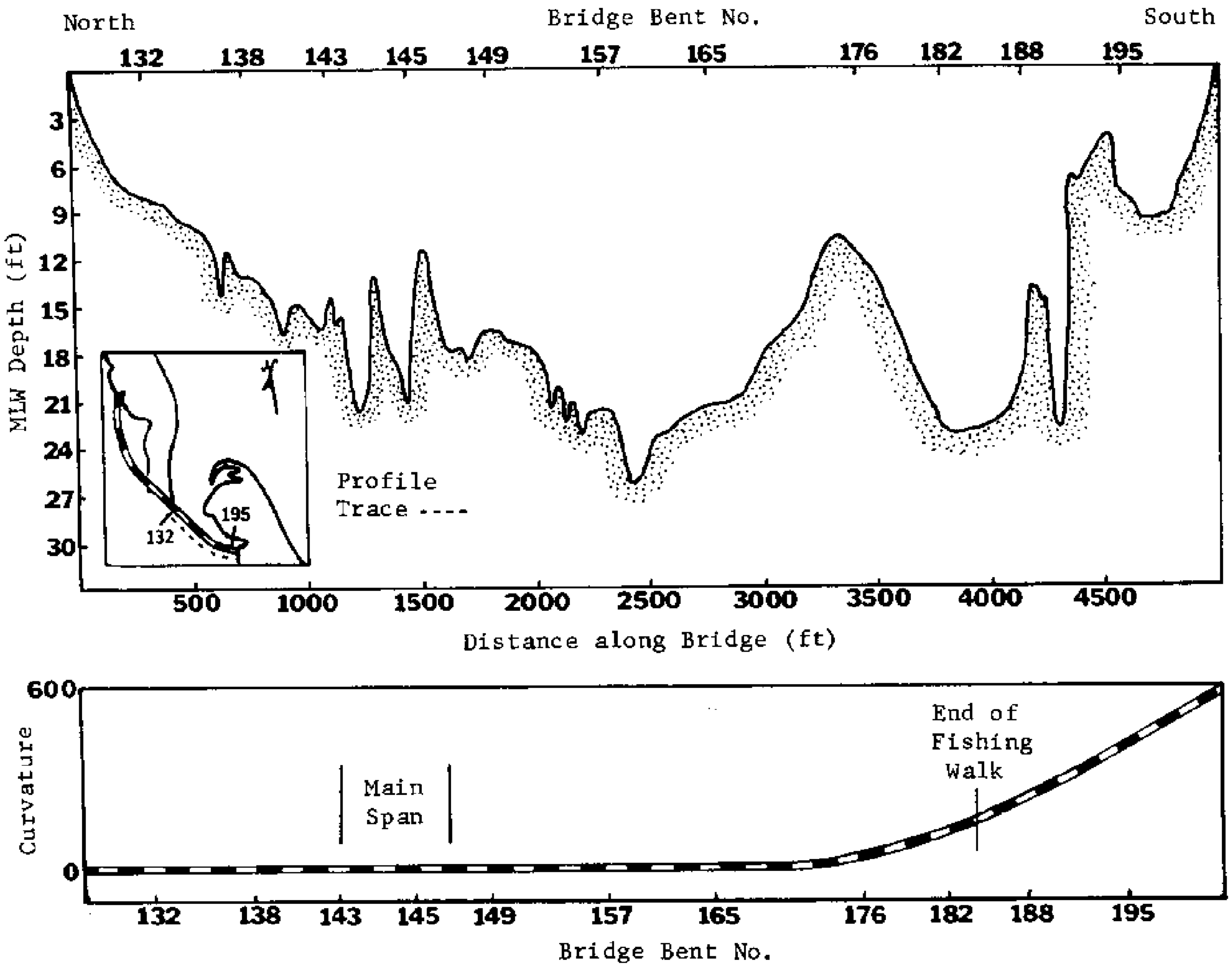


Figure 10. Depth profile taken approximately 15 yards (13.7 m) to the southwest of the Oregon Inlet bridge along its curvature on 3 July, 1973 (Bridge bents are labeled according to the "General Drawing for Bridge over Oregon Inlet (Nov., 1961).")

Table 4. Maximum rate of discharge through Oregon Inlet for one hour study periods on 28 June, 1973

Tide Cycle	Time	Avg. Vel. (knots)	Max. Rate of Discharge (m/s)	Wind
Ebb	0900-1000	1.20	4135	SE 4-8
Flood	1700-1800	1.37	4869	SE 4-8

(1) There is a distinctive flood channel corresponding to the main span of the bridge which was found to possess the highest velocities measured in this study. In addition, much of the flow during a flood passes through an even wider and deeper central channel just south of the main span and extending down to where the bridge begins curving to meet the southern shoulder of the inlet. From this point south, though there is a rather deep channel available for flow, the actual flow during flood is strikingly limited in comparison to that of the other channels to the north (see Figure 11). Figure 11 provides a clear cross-sectional view of flood waters entering the sound as viewed from the sound side; to facilitate discussion, the inlet is divided into three channels. For the purpose of this figure, it is assumed that all data were collected at the same time. Of course, such an assumption does not necessarily provide an accurate picture of coincidental velocities with time from one side of the inlet to the other, but it does provide a means of comparison of the limited flow passing through the southern channel (leading to the Davis Slough) with that at the main span, for instance. It should be noted, too, that data collected in the

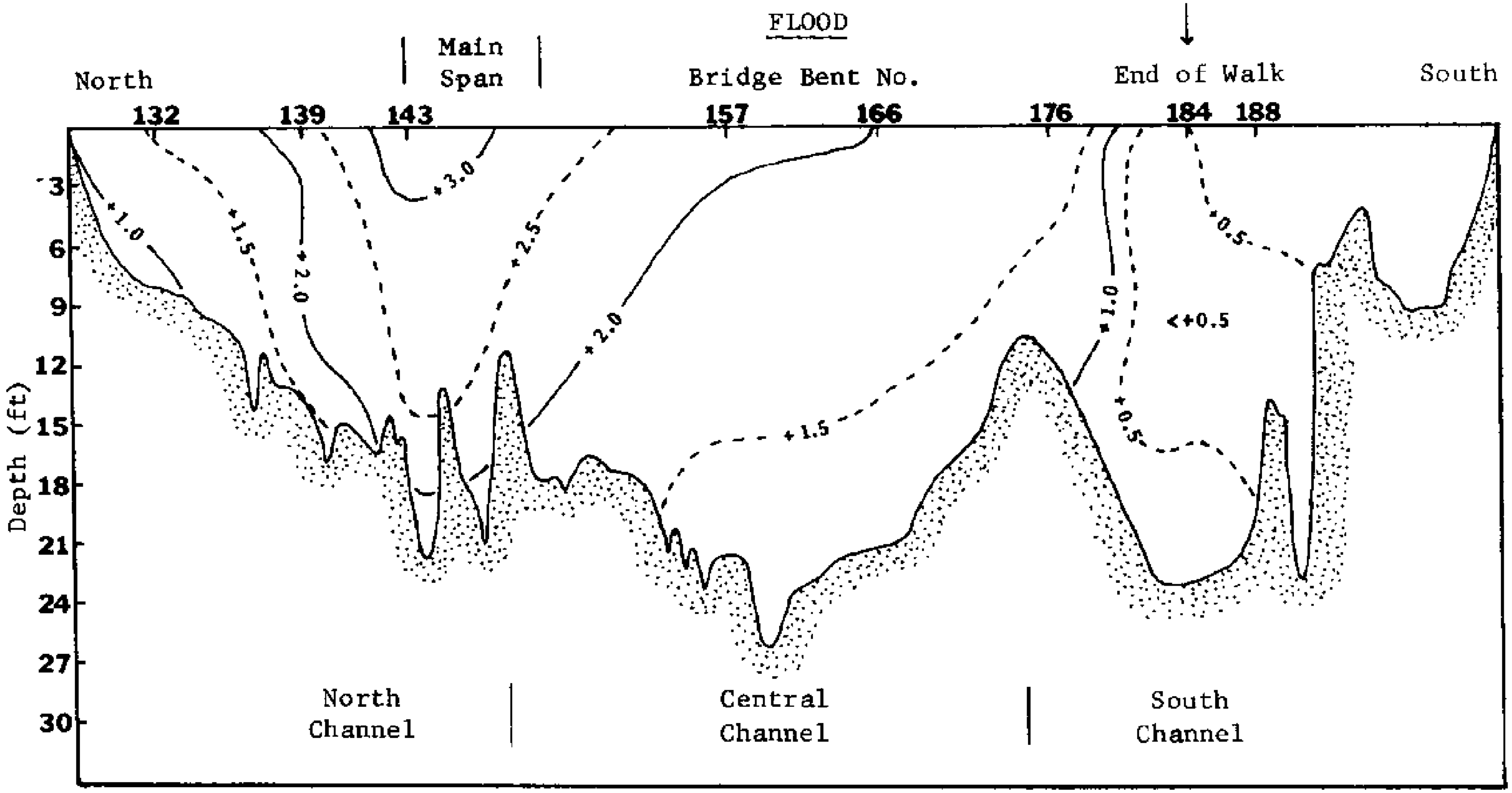


Figure 11. Cross section of velocity profiles during flood between 1700 and 1800 on 28 June, 1973 (Profile run made from south to north; velocities are in knots.) (As viewed from the sound side)

south channel were collected 1 hour and 30 minutes into flood and within 1 hour of maximum flood (as judged from bottom mounted current meters located at stations 3a and 3b related earlier in Figure 6). It should also be pointed out that though flow was reduced considerably in this most southerly channel, a large portion of the flow through the center channel still proceeded down to and through the Davis Slough.

Figure 12 perhaps best provides an understanding of this fact. In this photograph one can see where flood waters entering through the throat of the inlet suddenly come upon a widening of the southern shoulder. In response to this, some of the flooding waters flow down this side channel. However, the direct influence of the tidal head is apparently reduced and current velocities are consequently reduced as well. In this same figure one can see where the wide central channel along the bridge feeds into the Davis Slough.

(2) During ebb, both the southern and northern channels exhibited heavy flows of water with the highest velocities being observed in the southern channel. The wider and deeper central channel exhibited somewhat uniform velocities top to bottom, but these velocities were generally less than those found for the northern and southern channels by as much as a knot (see Figure 13). In the course of the hour that it actually took to make the composite set of profiles, it is possible that the maximum velocities observed for the northern channel could actually have increased to or exceeded those of the southern channel. Generally throughout the study period, however, it was observed that back to back measurements for these two channels

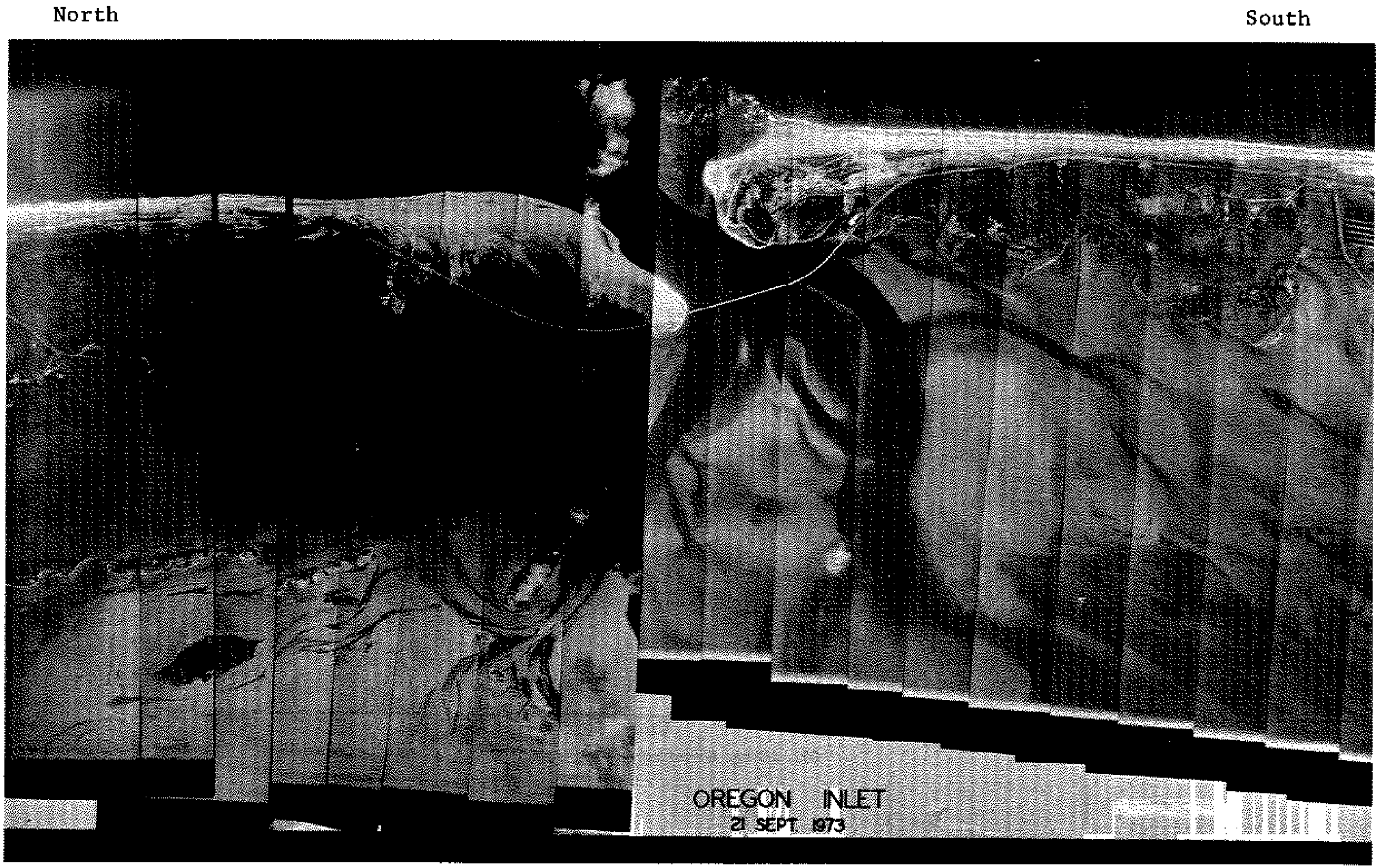


Figure 12. Composite photograph of Oregon Inlet for September 21, 1973 (by Lee U. Howe of the U. S. Army Corps of Engineers, Wilmington, N. C.)

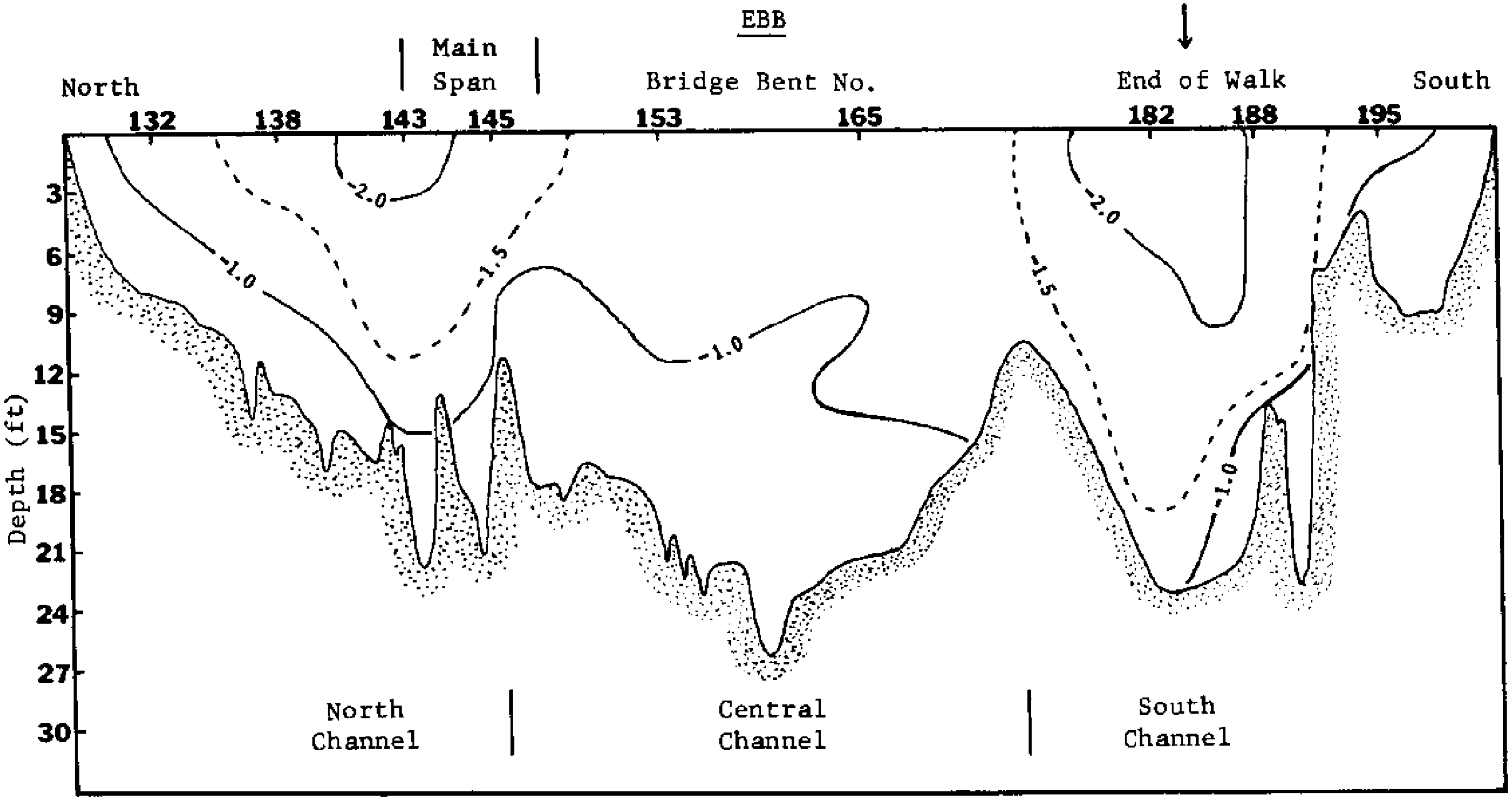


Figure 13. Cross section of velocity profiles during ebb between 0900 and 1000 on 28 June, 1973 (Profile run made from north to south; velocities are in knots) (As viewed from the sound side)

showed higher velocities in the southern channel up to maximum ebb and generally higher velocities in the northern channel thereafter. Throughout the entire flood period, by comparison, higher velocities were always in the northern channel.

Wind Influences on Ebb and Flood at Oregon Inlet

As noted earlier, winds have a rather profound influence upon ebb and flood at Oregon Inlet. It is the intent of this section to relate such influences for various wind speeds, directions and durations based on bottom mounted film recording current meter data collected at station 3a during both study periods. This station is used because of its close proximity to the inlet though an instrument in the inlet gorge would be even more appropriate. Difficulties in relocating and recovering such an instrument in addition to the fact that such an instrument would certainly experience velocities in excess of its range and conceivably freeze up, however, discouraged placement in this area.

Also included with this data will be tidal data collected at stations 1 and 3a for the initial study period and at stations 2a and 3a during the second study period.

Before presenting the actual data for these stations several matters concerning the presentation of the data should be considered. First, both sets of current meter data to be presented in this section will include broken line segments. These correspond to estimated velocities in excess of those which the instrument was able to record. Such estimation was necessary in that during the initial study the data logger in the current meter at station 3a was upside down resulting in instrument shutdown (because of a mercury cut-off switch) for velocities generally in excess of 0.59 knots. Likewise, during the second study current velocities in excess of 1.62 knots, the units upper limit, could not be recorded. Consequently, these too were estimated. In addition to this problem, the inclinometer sphere for this same unit froze up on five occasions during the second study period. These instances will be designated by small arrows and will be noted as rather abrupt flattening of the data curves. Also, it will be seen from the tidal records that the actual depth of instrument placement during the second study at station 3a was shallower than during the initial study by some 2 to 3 feet. This may, along with the differences in wind, partially account for differences in the maximum velocities observed at station 3a during the two studies.

Finally, during the second study, the response of the tide gauge at station 3a is considerably flattened compared to that for the earlier period. The explanation for this is not clear though it is thought that the unit was not performing properly.

With these conditions in mind, it is now feasible to examine the data. During the initial study period, winds were generally light, seldom exceeding 12 knots. Furthermore, SW winds prevailed for 21 percent of the time whereas NE and SE winds dominated and accounted for nearly 68 percent of all prevailing winds (see Figure 14). Of these, southerly winds prevailed for the first part of the initial study period from approximately 1530 on 20 June through 0930 on 24 June. During this time there were seven floods and six ebbs

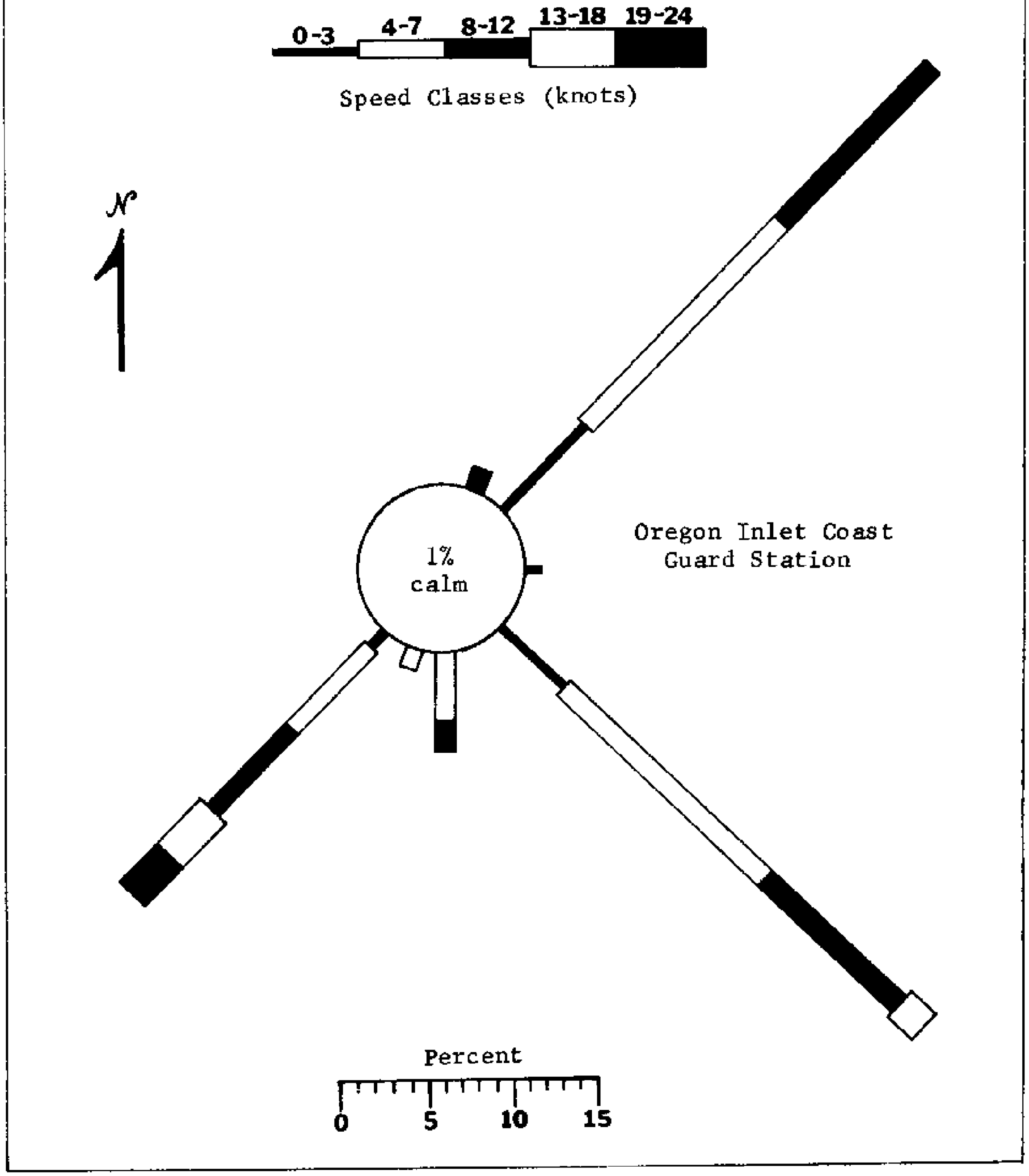
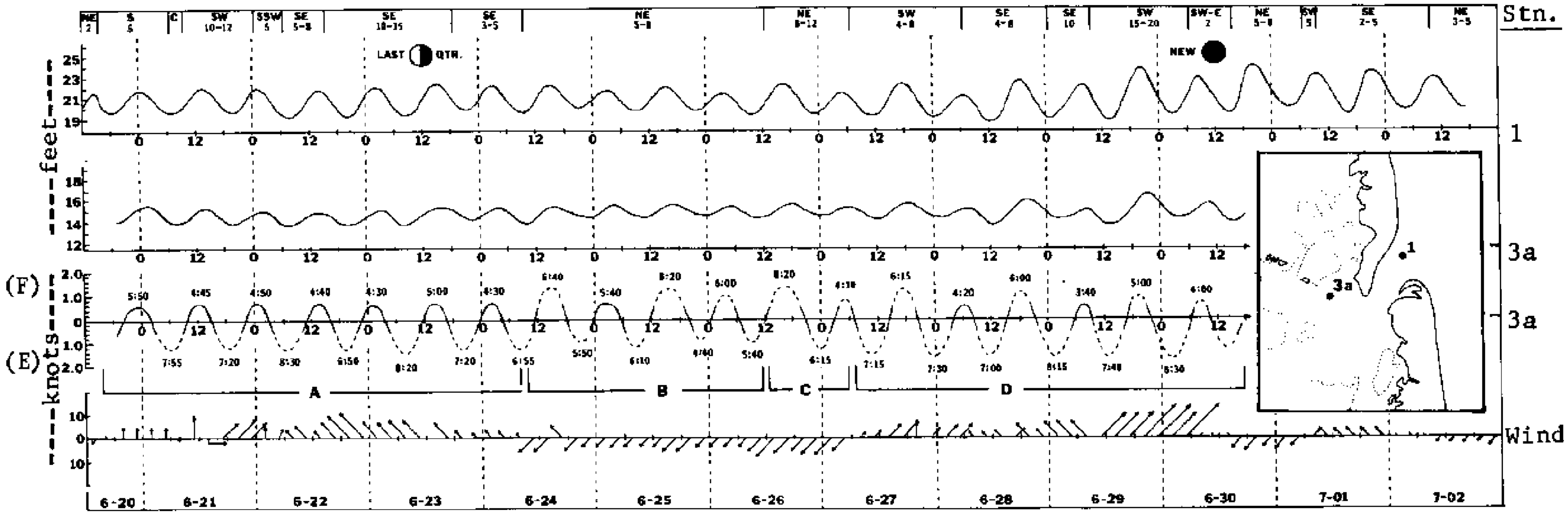


Figure 14. Wind rose relating prevailing wind conditions during initial study period (20 June through 2 July, 1973) (Bias not removed)

(see time sector A of Figure 15). The first of these seven floods, during which the wind was southerly at 5 knots, lasted nearly 6 hours. The remaining six floods were abbreviated and lasted between 4 hours and 30 minutes and 5 hours, averaging 4 hours and 43 minutes. Over this same time span, the six ebbs were lengthened somewhat ranging from 6 hours and 50 minutes to 8 hours and 30 minutes and averaged 7 hours and 44 minutes. The longest ebb came during the period in which the winds were SSW 5 to SE 5-8 knots. This followed a period during which the winds were SW 10-12 knots. The second longest ebb, 8 hours and 20 minutes, came during a period of SE winds at 10 to 15 knots.

As the winds shifted to the NE around 0930 on 24 June floods became longer and ebbs shorter. For example, during a period of rather steady NE winds at 5 to 8 knots four consecutive floods were observed (see time sector B of Figure 15). They were 6 hours and 40 minutes, 5 hours and 40 minutes, 8 hours and 20 minutes, and 6 hours for an average of 6 hours and 40 minutes in length. The longer flood occurred during a period when the winds rose from a steady 5 knots to 8 knots. The corresponding ebbs ranged between 4 hours and 40 minutes and 6 hours and 10 minutes for an average of 5 hours and 35 minutes. A second longer flood of 8 hours and 20 minutes occurred on 26 June (time sector C of Figure 15) when NE winds rose to as high as 12 knots.

From approximately 0630 on 27 June through 1530 on 30 June (time sector D of Figure 15) winds were southerly once again. This period of time was generally characterized by longer ebbs and shorter floods, as was the case for the earlier period of southerly winds.



Legend: (F) = Flood (E) = Ebb

Figure 15. Tidal data for stations 1 and 3a and bottom mounted current meter data for station 3a during the initial study (20 June - 2 July, 1973)

From such data the following conclusions were drawn:

(1) Southerly winds in general, whether they be SW, S or SE tend to shorten flood and lengthen ebb at the inlet.

(2) Northeasterly winds lengthen flood and shorten ebb at the inlet.

(3) During a period of relatively constant NE winds in the 5 to 8 knot range there may still be great variability in the length of floods and perhaps to a lesser extent the length of ebbs at the inlet (time sector B of Figure 15).

(4) During extended periods of fluctuating southerly winds successive floods may tend to be of comparable length (time sector A of Figure 15) or they may tend to vary considerably (time sector D of Figure 15). Corresponding successive ebbs may follow similar trends.

(5) Floods and ebbs lasting but 6 hours in length at Oregon Inlet are uncommon and unlikely as long as there are prevailing winds.

(6) Higher current velocities are associated with the longer ebbs and floods and vice versa.

During the second study period much higher wind speeds were observed. In addition, the predominate wind directions proved to be SW and SSW as opposed to NE (see Figure 16). Based on climatological data for this season, NE winds had been expected to dominate.

In conjunction with these southerly winds six examples of extended ebbs (missed floods) were documented. Such phenomenon,

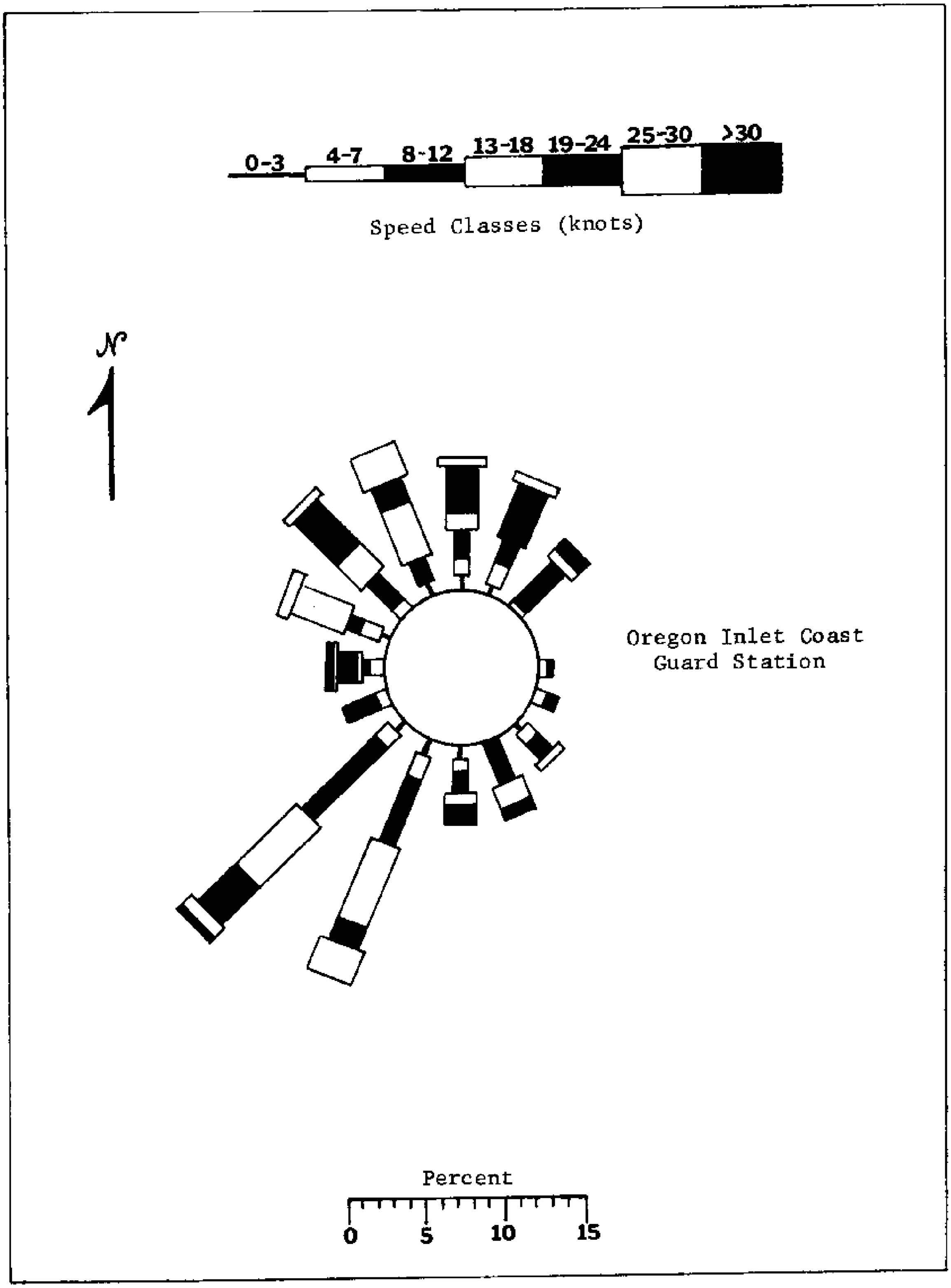
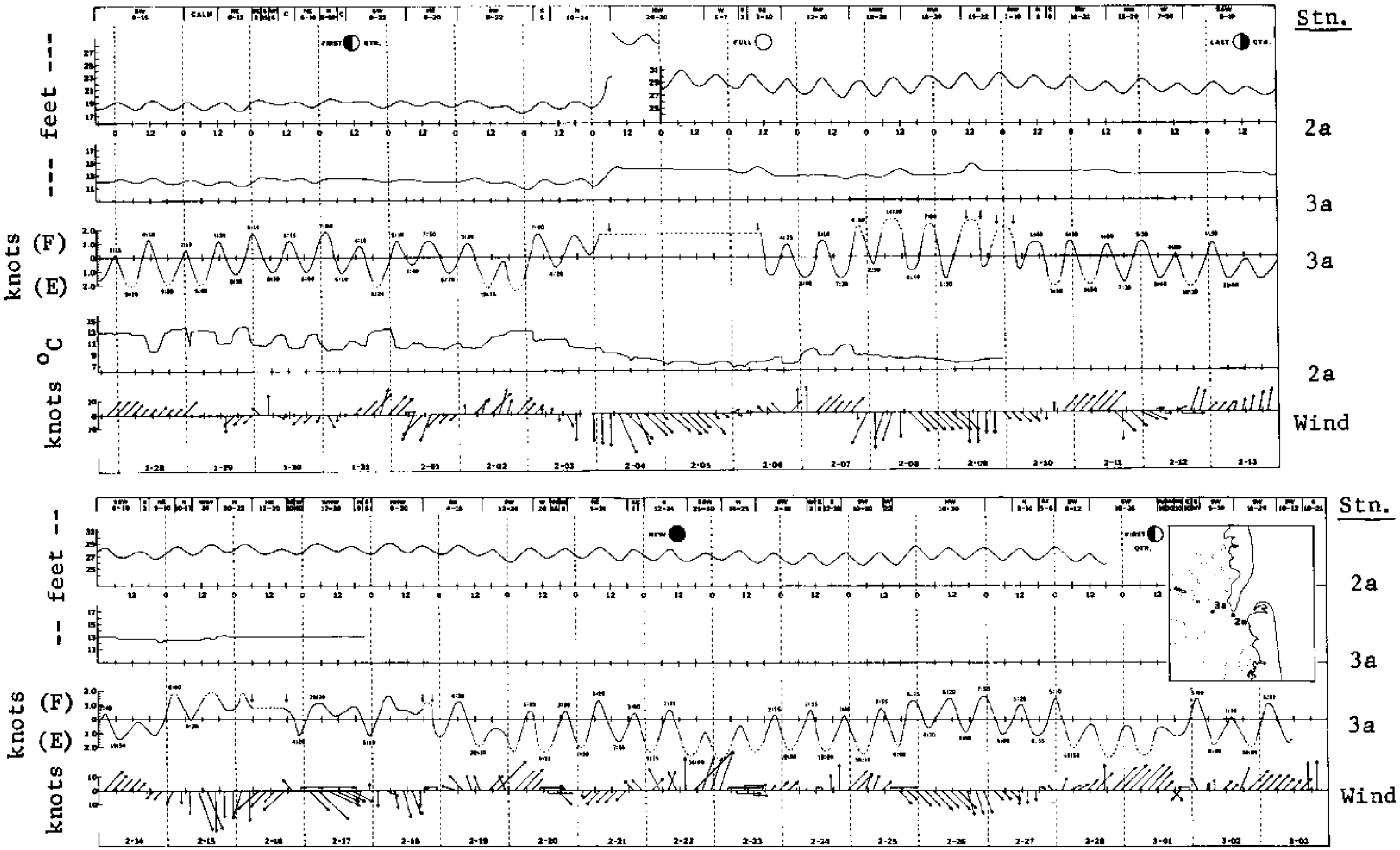


Figure 16. Wind rose relating prevailing wind conditions during the second study period (27 January through 2 March, 1974) with bias removed and calms distributed

according to Roelofs and Bumpus (1953), has been reported by fishermen to have occurred in the past during periods of strong SW winds. During the present study, all six such events occurred with SW or W winds ranging in speed from 8 to 40 knots. These events occurred during the month of February on the 2nd, 13th, 14th, 19th, 22nd and 28th (see Figure 17). The latter two events were the longest, extending over two and three floods respectively. The event beginning on the 22nd lasted 34 hours and that beginning on the 28th lasted nearly 45 hours. This latter event was still some 24 hours short of the three day ebbs reported to Roelofs and Bumpus. However, it would appear that had SW winds of comparable wind speed prevailed for another 24 hours this ebb could conceivably have extended over three days.

In addition to these extended ebbs, a phenomenon not previously reported in the literature was also observed. That is the extended flood (missed ebb). Four examples of this were recorded during the study period. They occurred in conjunction with N to NW winds generally in excess of 20 knots.

The first of these events occurred on February 3rd, less than 24 hours after an extended ebb (to which it might be related, in that the southern part of Pamlico Sound was probably partially emptied by SW winds and water piled up at the northern end, so that with wind reversal, the pressure head release could make the extended flood more likely), and on the 15th, 17th and 18th of the same month. Unfortunately, during three of these extended floods (those on the 3rd, 15th and 18th of February) the current meters malfunctioned



Legend: (F) = Flood (E) = Ebb

Figure 17. Tidal data for stations 2a and 3a, bottom mounted current meter data for station 3a and near bottom temperature data for station 2a during the second study (27 January - 3 March, 1974)

(the inclinometer froze in one position) and the actual length of these floods is not known. A fourth flood, however, beginning on the 17th was recorded to have persisted for 19 hours and 30 minutes.

It is particularly unfortunate that the current meter malfunctioned during the extended flood which began on 3 February, because on the following day (during what should have been a flood following an ebb under calm wind conditions) both tide gauges in the vicinity of the inlet (stations 2a and 3a) recorded rather marked increases in the water level (see Figure 17). This could not be attributed to a pileup of water due to strong southerly winds but was apparently due to a massive surge of water passing through the inlet and into the sound in conjunction with N to NW winds in the 20 knot range. Furthermore, the flow passing through the inlet apparently transported so much sand that the tide gauge and thermograph at station 2a beneath the bridge were buried under several feet of sand. Such was found to be the case when retrieval was initially attempted at the conclusion of the study period. The sudden increase in the tide gauge reading at station 2a around 0700 on 4 February suggests that these instruments may have been buried at this time. Thermograph data from station 2a shows a rather marked decrease in the water temperature as being coincident with the increase in water level and freeze up of the current meter on 4 February (see Figure 17). This it would seem further supports the view of a massive influx of oceanic water as having occurred. Finally, extensive flow in both Croatan and Roanoke Sounds was noted for this time. This flow will be discussed in the section on circulation. As a final point, it is noted that this event occurred some three days in advance of the predicted high spring tide for 6 February. Had northerly winds prevailed at that time (which they did not) a comparable or perhaps even more intense surge may have been observed.

Returning to the discussion of extended ebbs, it is noted that they were found to occur for various periods of prevailing southerly winds. For example, those occurring on 2, 13, 19, 22 and 28 February followed southerly winds having a duration of 16 to 33 hours and a range in speed from 4 to 40 knots. In particular, the extended ebb on 28 February occurred after a period of 16 hours of southerly winds that ranged in speed from 5 to 12 knots. In contrast to this, however, no such similar phenomenon was observed during the initial study period when on two occasions the duration of southerly winds was in excess of 72 hours with speeds ranging from 5 to 15 knots and 4 to 20 knots (refer to Figure 15, page 47). All of this tends to suggest that there is (at least for these study periods) more involved with the initiation of an extended ebb than simply long periods of high southerly winds.

Similar implications can also be made for the extended floods. For example, it was noted that on 3 February the initial extended flood came during a period of northerly winds which had prevailed for 12 hours and ranged in speed from 6 to 20 knots. The same phenomenon nearly re-occurred on 15 February when northerly winds in the 9 to 17 knot range prevailed for 15 hours. In contrast to this, however, are two examples of northerly winds with a much longer duration which did not induce extended floods. These were from 8 through 9 February when northerly winds persisted in the 15 to 26 knot range for over 48 hours and once again on 26 through 27 February when northerly winds persisted in the 8 to 20 knot range also for in excess of 48 hours.

Data to be presented later in the section on circulation in the sounds reveal that the waters in the sounds generally flow in the direction that the winds blow. This is the case except for when the winds are steady and have perhaps prevailed for in excess of 24 to 36 hours. At such times the waters tend to turn around and flow against the prevailing winds as a result of the pressure gradient head established. Such phenomenon, when associated with rather frequent wind reversals as were observed during the second study period, could result in enhanced flow in either direction. This could be likened to a seiche effect or fundamental mode of oscillation in the sounds. Under such circumstances, as implied once earlier, southerly winds could pile water up in the north and with a rapid reversal of wind, there could be an enhanced southerly flow and an extended flood at Oregon Inlet. This flood could persist for some time if the northerly winds continued to intensify sufficiently enough to delay return flow to the north. Conversely, northerly winds could pile water up in the south and with a rapid reversal of wind, there could be an enhanced northerly flow causing an extended ebb at the inlet. Obviously, one such phenomenon could lead right into the other. Furthermore, if such is the case (as it appears to be), such brief periods (24-36 hours) of northerly or southerly winds, as reported above, could induce extended floods or extended ebbs respectively. In turn, longer periods (> 36 hours) of prevailing winds could tend to dampen the effect (as a pressure head-wind force equilibrium seems to be reached after about 36 hours and the water flow reverses its direction to opposite that of the wind). As an example, note that the two periods of northerly winds that lasted nearly 48 hours were preceded by nearly 48 hours of southerly winds. During these southerly winds, considerable southerly flow of waters was observed to precede the northerly wind reversal by 12 hours. This may have reduced the potential head as compared to what it might have been had the flow reversal been more coincident with the wind reversal, thereby conceivably reducing the likelihood of an extended flood.

Estimate of Response Times of Bottom Mounted Film Recording Current Meters to Current Reversal at Various Distances from the Inlet

The response times to current reversal at three stations (3b, 4 and 5) were compared to reversal at the inlet (station 3a). A similar comparison was attempted for station 6 at the southern end of Roanoke Sound, but the response time was so irregular that it was thought other factors than ebb and flood should be considered. This will be taken up later. Similarly, no direct regular relationship to ebb or flood at the inlet (station 3a) could be correlated to the data collected by the instruments at stations 7 and 10 in Croatan Sound. See Figure 18 for these instrument locations.

For the three stations considered, it was noted that there was an apparent difference in the response times for ebb and flood. Consequently, a value of average response time is given for ebb and

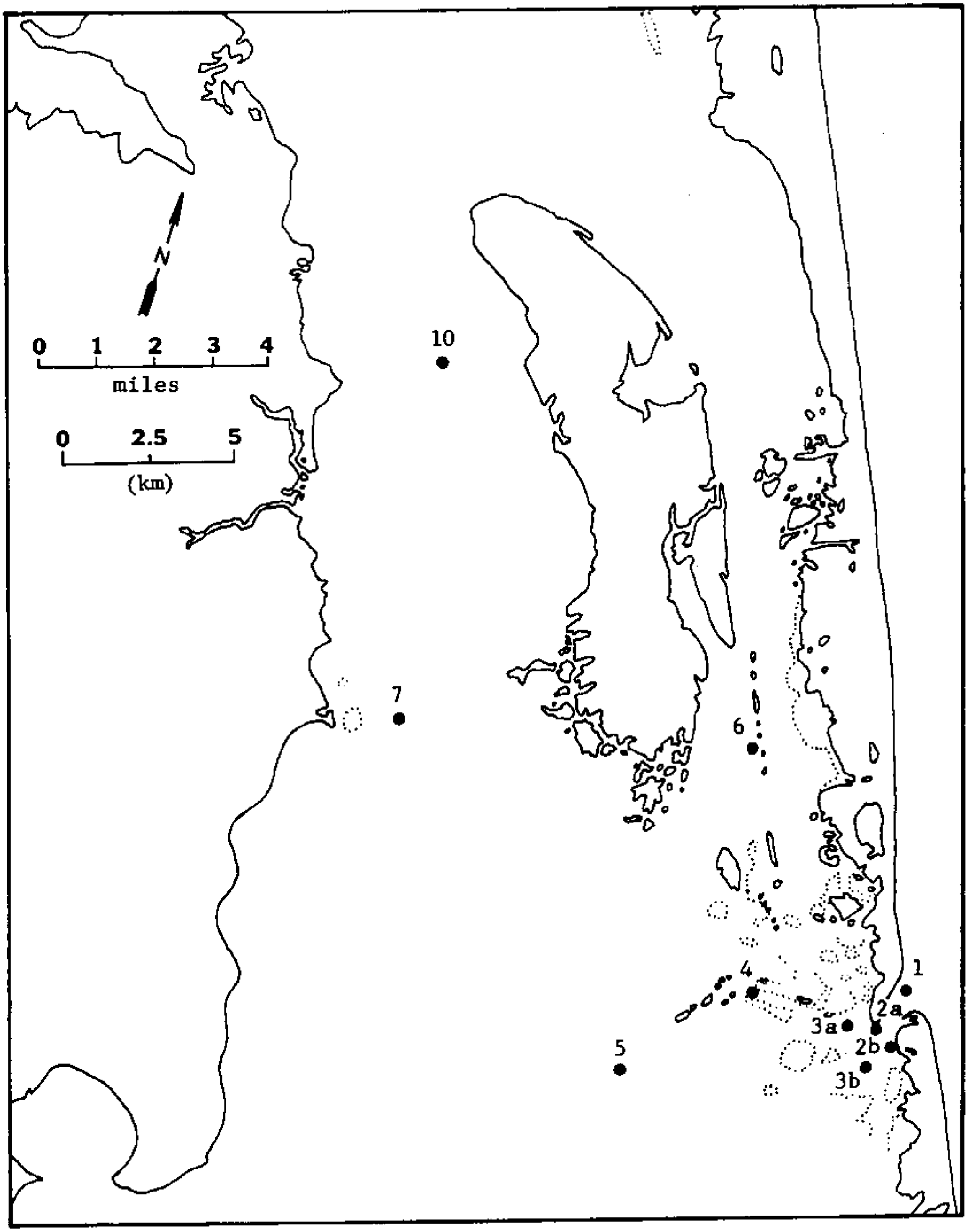


Figure 18. Location of stations for ebb and flood response time analysis (Only data for stations 3a, 3b, 4 and 5 are related in the text; the other stations are cited for convenience and future reference)

flood at each station. In addition, an attempt was made initially to further subdivide this data according to wind direction but no detectable wind effect was found for these three stations during this period. Table 5 summarizes this information. The actual response data are included in Appendix G.

Table 5. Summarization of response times of bottom mounted film recording current meters as related to ebb and flood at Oregon Inlet (station 3a) ((+) implies an earlier time and (-) implies a later time than the response at station 3a; values are good to within ± 5 minutes)

Station	Avg. Ebb Response (min.)	Avg. Flood Response (min.)	Range of Responses Ebb (min.)	Range of Responses Flood (min.)
3b	+15	+04	+70 to - 03	+30 to -15
4	-05	-20	+43 to - 28	+06 to -40
5	-82	-39	-10 to -193	-10 to -64

Data from Table 5 reveals that, on the average, waters begin ebbing 15 minutes earlier at station 3b than station 3a and that on a flood, waters at 3b turn around 4 minutes earlier than at station 3a. At station 4, ebb follows reversal at station 3a by 5 minutes and flood by 20 minutes. Finally, at station 5, some 4 miles into the sound from station 3a along the dredged channel, the average time for a flood response follows that at 3a by 39 minutes. Delayed responses as brief as 10 minutes and as long as 1 hour and 4 minutes have been observed. In turn, the average time for an ebb response follows that at 3a by 1 hour and 22 minutes. During ebb, delayed responses as short as 10 minutes and as long as 3 hours and 13 minutes have been observed.

Longer ebb responses were observed at station 5 for three consecutive late evening ebbs beginning at station 3a at 2040 on 27 June, 2127 on 28 June and 2200 on 29 June. The two intermediate ebbs during this time span followed ebb at 3a by 1 hour and 3 minutes and 20 minutes respectively. It is not clear why such variation occurred. In fact, there seems to be nothing unusual regarding wind speed or direction, the length of ebbs or floods, or the direction of flow in Roanoke and Croatan Sounds, etc. to set such times apart from other times during this study. However, extensive vector map records for the entire period (not included here) suggest that this may be the result of enhanced southerly flow coming from the region between stations 4 and 6, briefly bypassing the channel running from station 4 to the inlet, and continuing in a SW flow towards station 5 in Pamlico Sound before turning around and flowing back up the channel and towards the inlet.

Maximum Observed Velocities and Directions of Flow at Stations near Oregon Inlet

The purpose of this section is to relate some general characteristics of directional flow at the stations near Oregon Inlet and to report the maximum velocities recorded during this study. Data are presented for both near surface and near bottom maximum velocities recorded by the two types of current meters used in the study.

At stations 1 and 2a, near surface velocities as high as 3.20 knots were observed. These values are 0.5 knots higher than the highs previously reported by Roelofs and Bumpus (1953) for Oregon Inlet, but not nearly as high as the 5.0 knots reported for Oregon Inlet in the "U. S. Coast Pilot." In addition, the values recorded during the present study are only the maximums observed for the few vertical profiles taken at the various stations on 26 through 29 June, 1973. Consequently, higher velocities may have occurred but were not recorded. With this in mind, Table 6 is presented for stations 1, 2a, 2b, 3a, 3b, 4, and 5 (see Figure 18 of the preceding section for these instrument locations). It provides directional flow data for these stations near the inlet in addition to maximum velocity information as stipulated above. These measurements were made at a depth of 3 feet using a Bendix Q-15 current meter.

Table 6. Maximum near surface velocities and directions of flow recorded with a Bendix Q-15 current meter during the June study for: stations near Oregon Inlet

Station No.	Flood		Ebb	
	Dir.[a]	Max. Vel. (kts)	Dir.[a]	Max. Vel. (kts)
1	220	2.00	050	3.20
2a	210	3.20	080	2.20
2b	190	1.40	030	2.50
3a	290	2.40	100	2.40
3b	195	0.40	040	1.44
4	300	1.56	125	1.50
5	240	1.00	065	1.00

[a] For true directions subtract 7° 35' from those listed.

Current direction and maximum velocity data for the bottom mounted film recording current meters at some of these same stations are given in Table 7 and are a composite of data from both study periods. For the site of repeated instrumentation (station 3a) the maximum velocities shown are the highest ones observed for the two periods. Current directions are reported with 20 to 30 degree ranges for both ebb and flood. Such ranges were selected based on the relative recurrence of directions in these sectors for data collected at 5 to 15 minute intervals over a period of 1 to 4 weeks.

Table 7. Current direction and maximum velocities recorded by bottom mounted film recording current meters during both study periods for: stations near Oregon Inlet

	Flood		Ebb	
Station No.	Dir.[a]	Max. Vel. (knots)	Dir.	Max. Vel. (knots)
3a	270-290	> 1.62[b]	090-110	> 1.62[b]
3b	200-220	> 0.93[c]	020-040	> 1.00[c]
4	290-310	1.45	120-140	> 1.62[b]
5	220-240	0.84	040-060	0.67

[a] For true directions subtract 7° 35' from those listed.

[b] Velocities > 1.62 knots are off scale and cannot be reported.

[c] Unit cut off for velocities in excess of 0.93 knots during flood and for those in excess of 1.00 knot during ebb.

As expected, the highest velocities were recorded at the station nearest the inlet. In fact, at station 3a the velocities were higher than the instrument was capable of recording. Also, note that for station 3b the unit cut off for velocities in excess of 0.93 knots on flood and in excess of 1.00 knot on ebb.

Evidence of Lunar Tides in Pamlico Sound

There is some indication of at least occasional regular tidal action in Pamlico Sound. This is related in a power spectrum analysis of data collected from June 20 through June 30, 1973, by tide gauges at station 1 at Oregon Inlet and two other stations at Stumpy Point and Engelhard along the western shoreline of Pamlico Sound (data from these latter two stations are courtesy of the U. S. Army Corps of Engineers, Wilmington, N. C.). Engelhard is approximately 20 miles (32 km) southwest of Stumpy Point. From this analysis, it appears that while there is some spectral noise, there is an indication of some tidal energy at 12.8 hours at both Stumpy Point and further southwest at Engelhard, approximately 33 miles (52.8 km) west southwest of Oregon Inlet and 26 miles (41.6 km) northwest of Hatteras Inlet. The energy peak at Engelhard is more broad than at Stumpy Point, a result which would be consistent with its greater distance from Oregon Inlet (see Figure 19).

Data such as this do not relate tidal heights, but do in fact confirm a periodic tidal influence in Pamlico Sound at least at these two stations. It will be recalled from the review of literature that Roelofs and Bumpus (1953) estimated a tidal range in the sounds of about 5 cm.

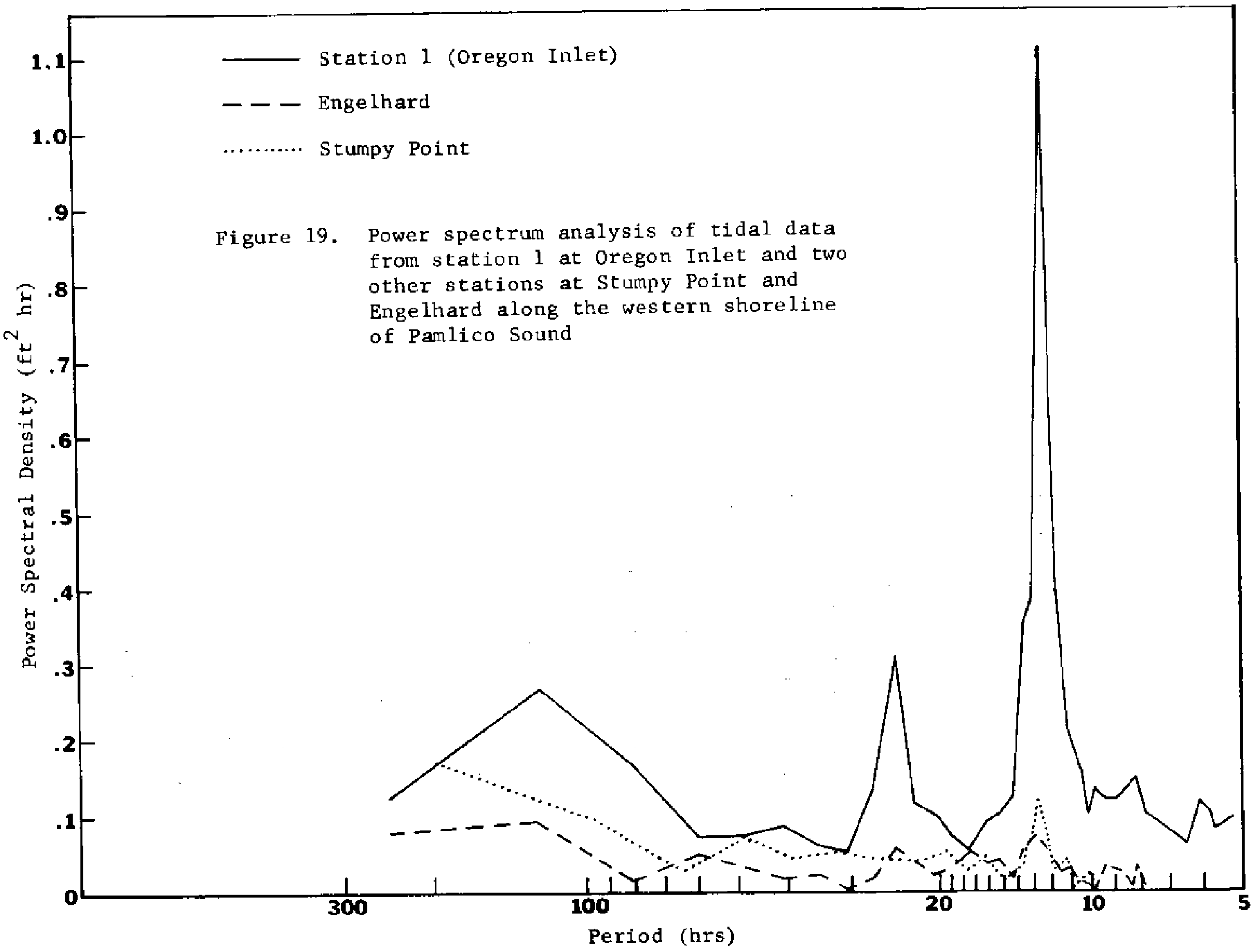


Figure 19. Power spectrum analysis of tidal data from station 1 at Oregon Inlet and two other stations at Stumpy Point and Engelhard along the western shoreline of Pamlico Sound

Flow in Roanoke and Croatan Sounds

Maximum Velocities and Directions of Flow at Stations in Roanoke and Croatan Sounds

The purpose of this section is to relate some general characteristics of directional flow for stations in Roanoke and Croatan Sounds. Here, data are presented for those stations in the two sounds occupied by bottom mounted film recording current meters during the two study periods. See Figure 20 for these instrument locations. Current directions are reported with 20 to 30 degree ranges (with one exception) for generally northerly or southerly flow at stations in Roanoke and Croatan Sounds (see Table 8).

The data presented for stations in these sounds show that near bottom velocities in excess of 0.5 knots were observed for all stations during both northerly and southerly flow except for station 7. Stations 8 and 9 were not instrumented with this type of current meter. Furthermore, maximum velocities of 1.62 knots, the instrument's upper limit, were observed in north Croatan Sound at stations 11(103), 11(136) and 11(214). It should be emphasized that these values are near bottom velocities and that surface velocities were probably higher.

For comparison, Winslow (1887, 1889) reported that current velocities in these sounds averaged one half knot and at times rose to as much as two knots. In addition, he specifically noted velocities in excess of one knot with favoring winds for a station (near Duck Island) 1 1/2 to 2 miles (2.4 to 3.2 km) south of the present study's station 6.

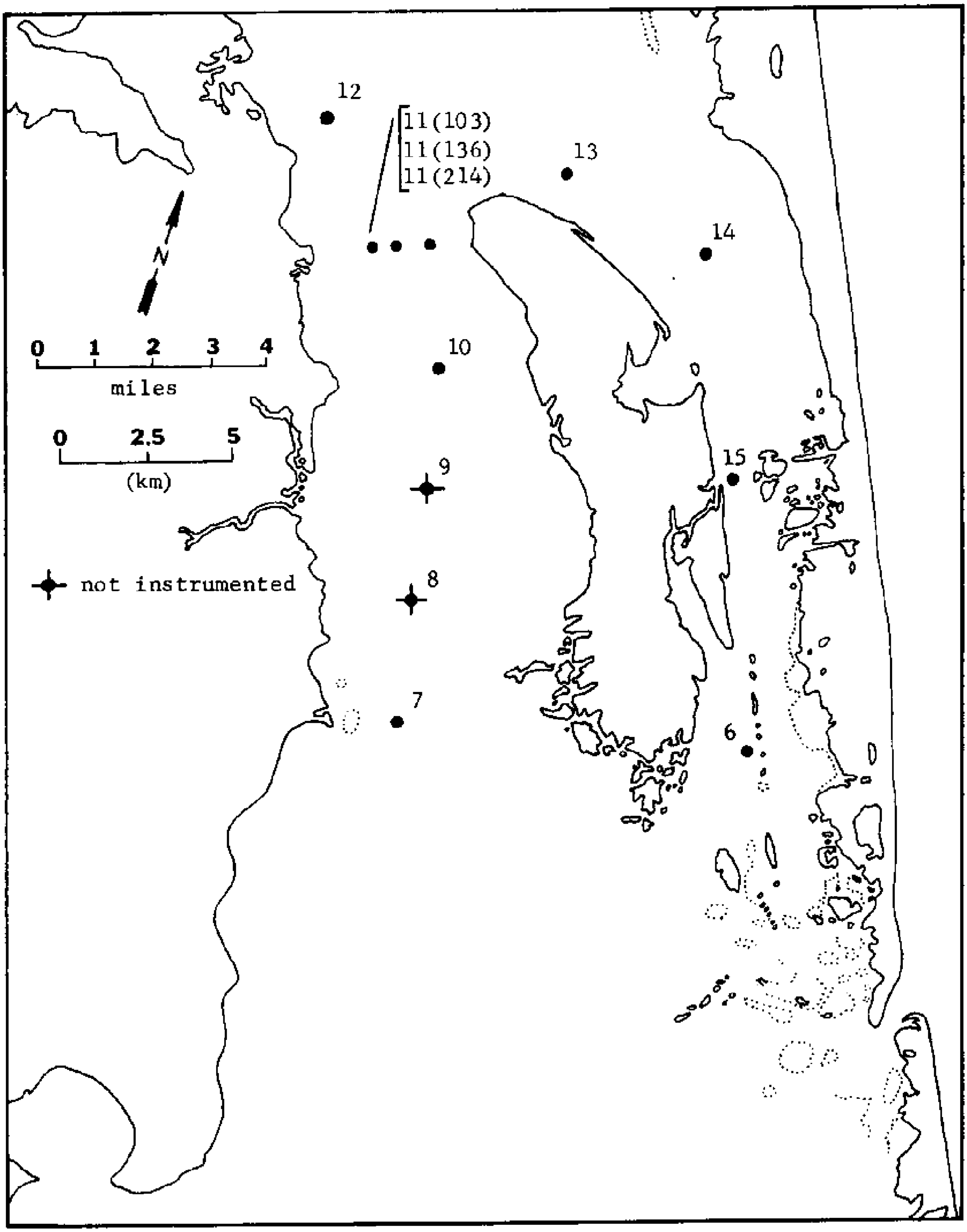


Figure 20. Location of all bottom mounted current meter stations in Roanoke and Croatan Sounds during the two study periods (stations 8 and 9 were not instrumented)

Table 8. Current directions and maximum velocities recorded by bottom mounted film recording current meters during both study periods for: stations in Croatan and Roanoke Sounds

Station No.	Northerly Flow Dir.[a]	Northerly Flow Max. Vel. (knots)	Southerly Flow Dir.[a]	Southerly Flow Max. Vel. (knots)
6	320-350	0.82	150-180	1.31
7	320-350	0.37	150-210	0.78
8	N.D.	N.D.	N.D.	N.D.
9	N.D.	N.D.	N.D.	N.D.
10	340-360	0.58	140-160	0.56
11(103)	330-350	0.76	160-180	1.62
11(136)	310-340	1.62	140-170	1.37
11(214)	330-350	0.96	160-190	1.62
12	320-340	0.94	140-160	1.27
13	variable	0.59	variable	0.59
14	variable	0.53	variable	0.53
15	310-330	1.02	140-160	0.80

[a] For true directions subtract 7° 35' from those listed. N.D. = No Data (not instrumented).

For the south end of Croatan Sound at station 7 a much wider directional range is noted for southerly flow than for the other stations. It ranges from 150° to 210°. The lower limit is generally approached during periods of low flow (< 0.20 knots = 74 percent of all velocities for this direction) and the higher limit is generally approached during periods of higher flow (> 0.29 knots = 60 percent of all velocities for this direction). It should be emphasized that these are general trends and exceptions are not unusual. The southerly directions with the highest frequency of occurrence were 180° and 190°.

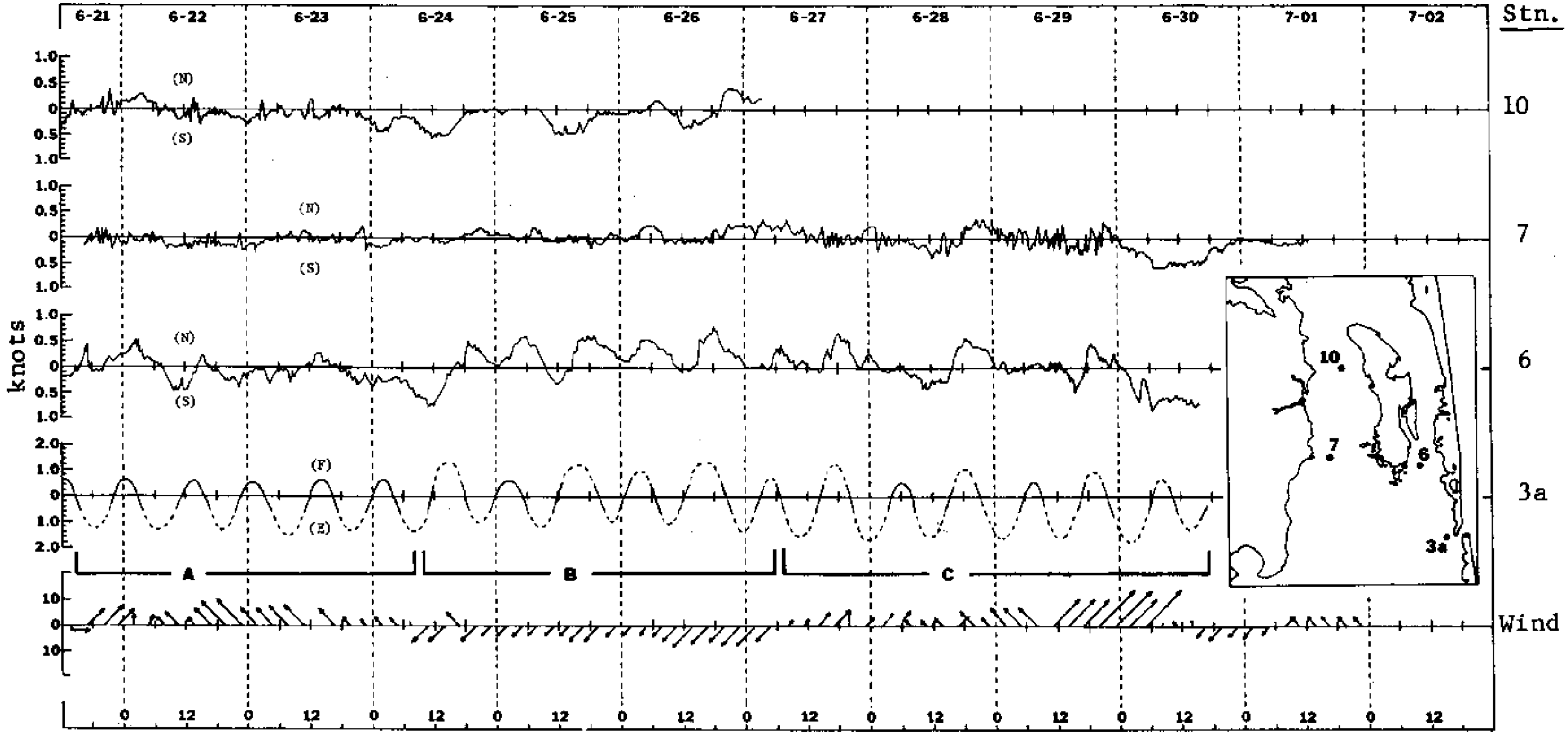
The velocities listed for station 10 appear low when compared to those for stations 11(103) and others along the Croatan Sound bridge. This is probably due to the fact that no data were collected at station 10 during the second study when generally higher velocities were observed. Finally, directional information is not given for stations 13 and 14 in north Roanoke Sound. This is because of the extreme variability of directional data for these stations. Here, no general trends of flow were observed as the current frequently shifted 180° in direction suggesting possibly that there was little sustained horizontal circulation. This particular observation will be discussed later.

Circulation in Roanoke and Croatan Sounds as Induced by the Winds and Floods at Oregon Inlet

In the discussions which follow, data will be plotted according to velocity and direction of flow (ebb or flood, or northerly or southerly flow). This means that say for a period of northerly flow at station 6 (though it is not specifically related in the plot) one can return to Table 8 of the preceding section and find that northerly flow is generally characterized by a direction in the 320°-350° range. Furthermore, it should also be pointed out that the maximum velocities reported in Tables 7 and 8 will not necessarily be included in the plots for the stations in this section. This is because the plots were made in general by taking every other available data point (time interval of roughly 30 minutes) and the tables were constructed from data taken at 15 minute intervals.

During the initial study southerly winds were observed from 1800 on 20 June up to 0930 on 24 June. During this time span, the general set of flow in both Croatan and Roanoke Sounds, as recorded by bottom mounted instruments, at stations 6, 7 and 10, was southerly. Significant northerly flow was observed only for 22 June in Croatan Sound and for both 22 and 23 June in south Roanoke Sound (see time sector A of Figure 21). Northerly flow on 22 June followed a period of SW wind in the 10 to 12 knot range for the preceding 12 hours. Northerly flow on 23 June in south Roanoke Sound was during a period of SE winds in the 10 to 15 knot range which had prevailed for some 20 hours.

At this latter station, during southerly winds, there is the suggestion of at least occasional coherence of flood at the inlet with northerly flow into Roanoke Sound. Note the apparent response to flood for 0100 and 1400 on 22 June and 1430 on 23 June. Note, however, that there is no indication of northerly flow corresponding to floods during which the winds were SE 10-15 at 0130 on 23 June and then SE 3-5 nearly 24 hours later at 0200 on 24 June. It is thought that heavy rains recorded on 23 June for the Manteo and Bodie Island area (2.49 inches and 4.40 inches respectively) may be of significance as a possible explanation for the absence of northerly flow on these two occasions (U. S. Department of Commerce, June 1973a). Manteo is a town in the northern section of Roanoke Island.



Legend: (N) = Northerly Flow (F) = Flood
(S) = Southerly Flow (E) = Ebb

Figure 21. Flow in the sounds as recorded by bottom mounted current meters at stations 10, 7, 6 and 3a during the initial study (20 June - 2 July, 1973)

The initial response to NE winds in both Roanoke and Croatan Sounds was an increase in the southerly flow of waters. This is in agreement with Winslow's (1889) observation that "the strongest currents will be found immediately after a shift of wind" (p. 123). The response can be seen in time sector B of Figure 21 on 24 June for station 10 in Croatan Sound and station 6 in south Roanoke Sound. The response is less obvious at station 7 in south Croatan Sound perhaps due to its position west of the direct path linking Croatan Sound to Oregon Inlet.

This wind change and the subsequent flow response occurred during ebb at the inlet. On the following flood, which lasted some 2 hours longer than the one preceding it, a northerly flow was begun in south Roanoke Sound which apparently fluctuated in response to ebb and flood (see time sector B of Figure 21 for 1500 on 24 June). In addition, in northern Croatan Sound, though northerly flow was not actually detected until 26 June, nearly 48 hours after NE winds had begun and were still persisting, there was a definite response to these NE winds which paralleled the response at station 6 and thus the inlet. This response was characterized by a marked slowing or cessation of the southerly flow of bottom waters at station 10 in Croatan Sound until northerly flow was observed on 26 June. At station 7 some northerly flow was observed within 2 hours of the initial northerly response at station 6 on 24 June. In general, during this period of NE winds and longer floods, northerly flow in south Roanoke Sound was greatly enhanced.

The NE winds ceased early on 27 June. On this same date the film ran out on the instrument at station 10, leaving only stations 6 and 7 for data comparison. Following the cessation of NE winds, the wind shifted to the SW at 4-8 knots. This apparently shortened the existing flood. However, the next flood was not significantly reduced in duration, lasting some 6 hours. At any rate, a northerly flow at station 6 similar to those recorded during NE winds was still observed during these two floods and on alternate floods through 29 June (see time sector C of Figure 21). (It is not clear why the second flood was lengthened but one notes this alternation of long and short floods persisted throughout the remainder of the study period in conjunction with southerly winds.)

It is noted with respect to the initial study that during the periods of ebb at the inlet associated with NE winds, very limited southerly flow was observed for bottom waters in south Roanoke Sound. This suggests that there may be an additive effect to the northerly penetration of waters into Roanoke Sound during northerly winds. That is, each subsequent flood probably pushes waters from the preceding flood further north. Obviously, if this is actually what occurred, then one can see where such high salinity waters could eventually reach Albemarle Sound by way of Roanoke Sound if the conditions persisted long enough. How such waters return is not clear but may in fact be by way of Croatan Sound which accounts for anywhere from 76 percent to 85 percent of the flow from Albemarle Sound to Pamlico Sound.

This proposed mechanism for northerly penetration into Albemarle Sound through Roanoke Sound may explain the observations of Posner (1959) for 22 through 23 January, 1956. At that time, Posner noted that for the "eastern section of Albemarle Sound . . . surface salinity varied little while the bottom salinity increased from 3.5 to 20.5 ppt in two hours" (p. 704). This phenomenon he "believed" was derived from high salinity waters from Roanoke Sound. Examination of the actual wind data from the Cape Hatteras Weather Bureau Station for this period of time in 1956 reveals that northerly winds did in fact prevail at the time of Posner's observations. These northerly winds began late on 20 January after some 30 hours of southerly to westerly winds and continued through 28 January. On 22 and 23 January when Posner's observations were made the general set of the winds was NW averaging 6 knots over a range of 3 to 10 knots and N averaging 13 knots over a range of 5 to 26 knots respectively. From noon on through the end of the day on 23 January the winds ranged in speed from 16 to 26 knots (U. S. Department of Commerce, 1956).

Clearly, the fact that northerly winds may have prevailed for as much as 30 to 40 hours preceding and then during Posner's observations is compatible with the proposed mechanism. Certainly, there would have been enough time for the waters to reach this region, and furthermore, the fact that northerly winds continued for five days beyond the date of Posner's observation would tend to suggest that there may have been quite a bit of this high salinity water moving into the region north of Roanoke Island. Personal communication with Posner[1] (May, 1974), however, reveals that no additional data are available for this region during his January 1956 study.

Unfortunately, though the initial study could relate somewhat to the extent of flow in north Croatan Sound, it could not relate with actual data to what extent high salinity waters penetrated north of south Roanoke Sound during either wind state. Consequently, a second study was undertaken.

During the second study period, a combination of wind and tidal response was once again noted for station 6 in south Roanoke Sound (see Figure 22). Also, data collected at station 15, some 4 miles (6.4 km) north of station 6, and in mid-Roanoke Sound, appear to respond entirely to wind direction up through 3 February when the instrument ceased to function.

The one exception to this trend occurs on 28 January when southerly winds were coincident with southerly flow of waters. In that southerly winds prevailed in the 10-20 knot range for the entirety of 27 January, it is thought that the observed southerly flow on the 28th was a current reversal in response to a pileup ot waters to the north and generally lighter southerly winds on this date. At any rate, excluding this exception, this allows a comparison of wind effects at station 15 with a combination of wind and tidal effects at station 6. Note in Figure 22 that from the beginning of the second study up to around 0000 on 30 January both

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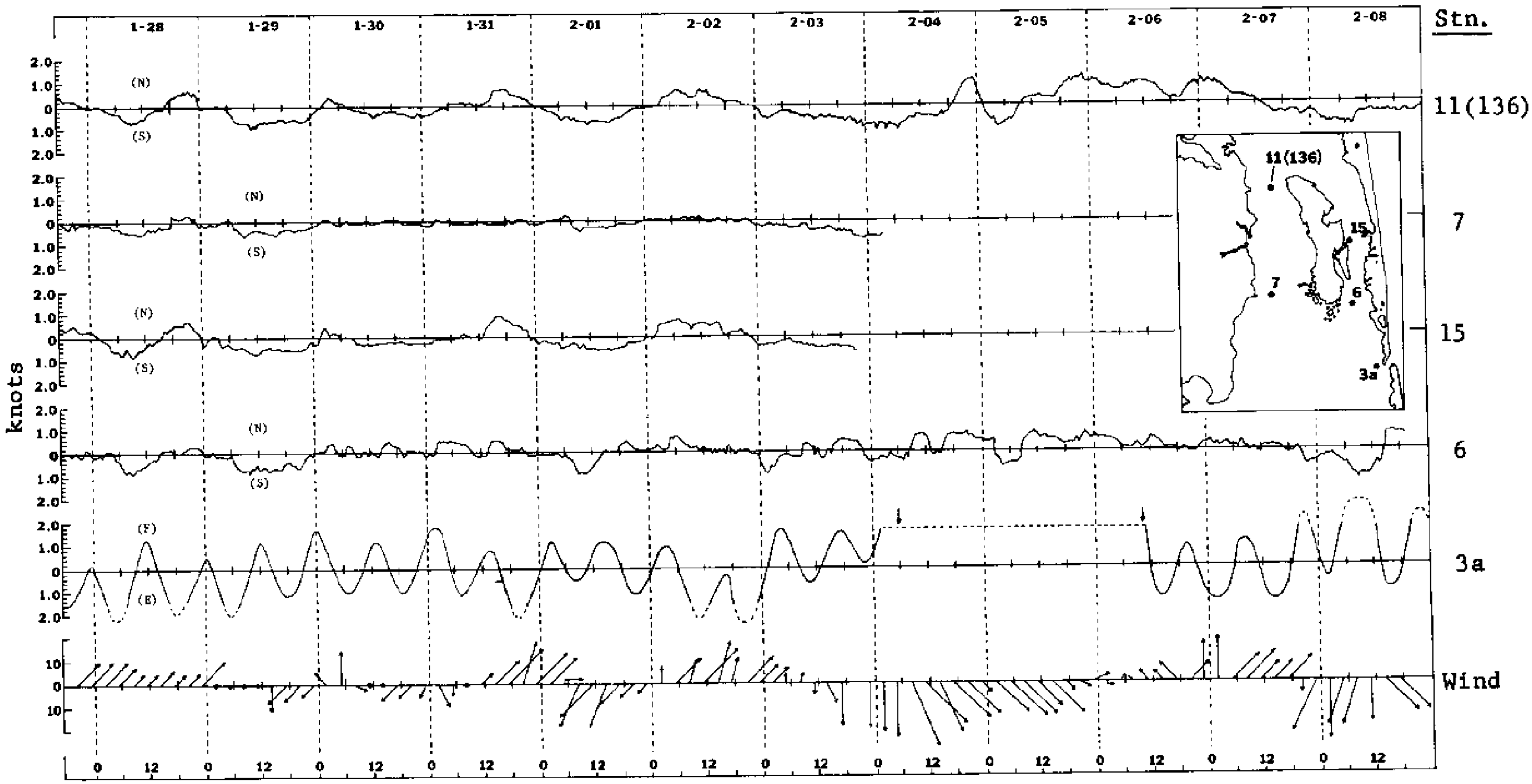
[1] Dept. of Oceanography, City College, New York, New York.



Legend: (N) = Northerly Flow (F) = Flood
(S) = Southerly Flow (E) = Ebb

Figure 22. Flow in the sounds as recorded by bottom mounted current meters at stations 11(136), 7, 15, 6 and 3a during the first twelve days of the second study period (27 January 8 February, 1974)

stations 6 and 15 record the same phenomena. Up to this time, in conjunction with southerly winds, floods at the inlet had not exceeded 4 hours and 30 minutes. However, from this point on through 2130 on 3 February the agreement was lost as the winds frequently shifted to northerly causing generally longer floods. During this span, maximum northerly velocities at station 6 generally approached 30 cm/sec (0.59 knots). Similar northerly velocities had been observed during the initial study.

Extensive northerly flow at station 6 was recorded during a period of northerly winds in the 20 knot range from 1530 on 3 February through 1530 on 5 February. This is the same period during which the current meter at station 3a froze up, a tide gauge at station 2a was buried under sand, and during which there was a considerable increase in the water level recorded at stations 2a and 3a, as was discussed earlier in the section on wind influences on ebb and flood at Oregon Inlet.

Unfortunately, since station 15 ceased operation on 3 February, the northerly flow implied at station 6 for 4 and 5 February could not be directly related to station 15. Yet, it is thought that a second comparison may in part alleviate this absence of data.

Preceding instrument shut-down at station 15, it is noted that whatever was happening in mid-Roanoke Sound seemed also to be occurring at stations 11(103), 11(136), 11(214) and 12 in north Croatan Sound. See Figure 22 for a comparison of data from station 11(136) and station 15. Only data from station 11(136) is included in this figure in that it is typical of the four stations cited for north Croatan Sound. The other three data sets are included in Appendix H.

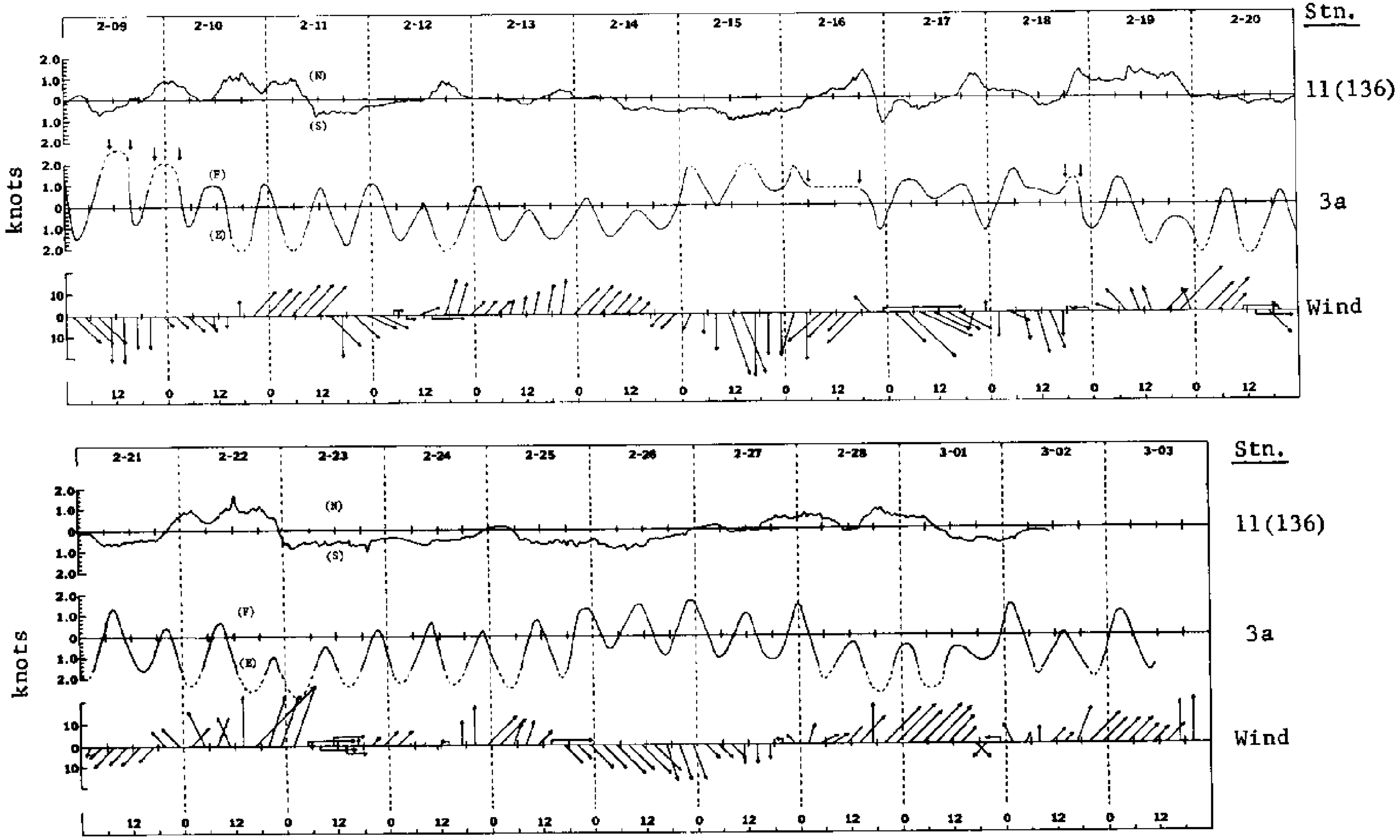
The events at station 11(136) occurred with the same relative magnitude and direction of flow but lagged in response by 1 to 2 hours the events at station 15. If this trend is consistent, then what occurred in mid-Roanoke Sound after 3 February could perhaps in part be learned by examining the stations in north Croatan Sound.

As noted earlier, the responses at station 15 and consequently 11(136) appear attributable essentially to wind direction or water pileup to the north and reversal of flow due to weakening southerly winds. Such reversal was observed for southerly winds which had prevailed for in excess of 24 hours leading up to 28 January. However, for either northerly or southerly winds prevailing for less than 24 hours it is noted that the direction of flow at these stations coincides with the direction of flow of the winds. That is, northerly winds induce southerly flow and southerly winds induce northerly flow. This is the case at least up to 3 February when data were last obtained from station 15.

On 4 February, at 1900 at station 11(136) rather significant northerly flow of bottom waters was begun which persisted for some 6 hours (see Figure 22). This phenomenon was in conjunction with a brief reduction in NW winds from around 20 knots to 7 knots and then increasing back to 20 knots over nearly the same 6 hour span of time. NW winds had prevailed in excess of 30 hours preceding this event and continued for some 18 hours following it. However, as these winds later subsided, subsequent to wind reversal to a more southerly set, the northerly flow of waters was once again resumed. This occurred on 5 February. This phenomenon was repeated on 9 and 10 February and also on 16 and 17 February (see Figure 23). In most cases northerly current velocities in excess of 1 knot were recorded.

In summary, it is thought that these events observed for Croatan Sound are applicable at least to mid-Roanoke Sound as well. This implies that a large northerly flow of water probably commenced around 1600 to 1700 on 4 February and lasted for some 6 hours in Roanoke Sound. This flow appears to be due to water pileup to the south and reversal just opposite to that noted for southerly winds on 28 January. Furthermore, it would seem that waters carried as far as station 15 by action at the inlet could be carried even further north in response to such an apparent seiche affect. Certainly, this would add to the mechanism proposed earlier in that it would further enhance the likelihood of the flow of more oceanic-like waters to the north.

Unlike the apparently regular wind/flow observations in north Croatan Sound and by similarity, mid-Roanoke Sound, there is some puzzlement attributable to data obtained from stations 13 and 14 in north Roanoke Sound. Here, both instruments responded in what appears to be a random manner for much of the study period. That is, upon initial observation, there appears to be no regular directional flow response either to wind or tidal action at the inlet. This is particularly the case for station 13. Data from these stations are shown in Figure 24. Note that the higher



Legend: (N) = Northerly Flow (F) = Flood
(S) = Southerly Flow (E) = Ebb

Figure 23. Flow at stations 11(136) and 3a as recorded by bottom mounted current meters during the last three weeks of the second study period (9 February - 3 March, 1974)

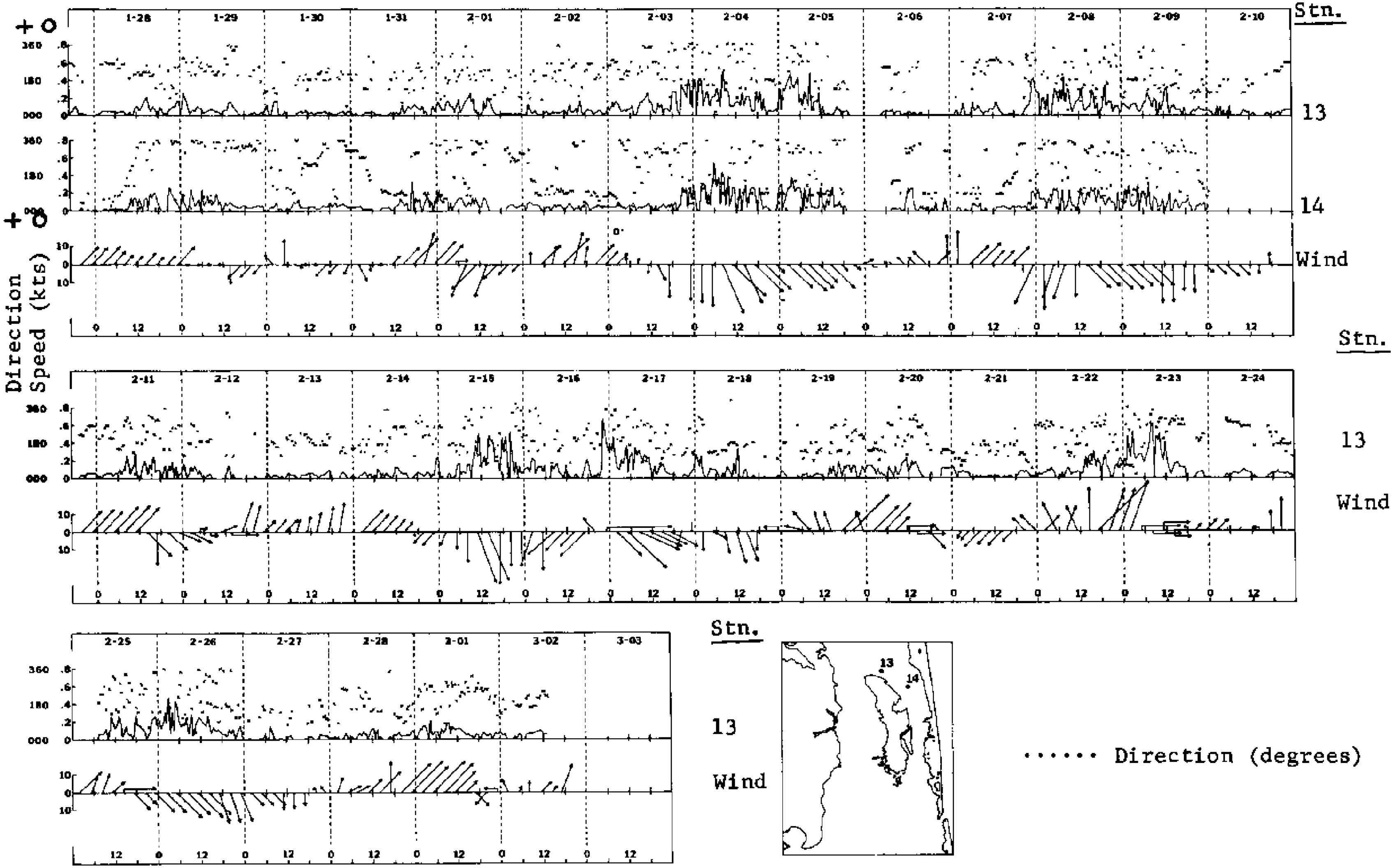


Figure 24. Flow at stations 13 and 14 in north Roanoke Sound as recorded by bottom mounted current meters during the second study (27 January - 3 March, 1974)

velocities tend to correspond to the periods of greatest fluctuation in directional flow in northern Roanoke Sound. In direct contrast to this, however, are data collected at station 14 in May 1973 as a preliminary instrument checkout to the June study. These data show a more uniform directional flow as a westerly to northwesterly flow response to SW winds and a more easterly to southeasterly response to wind reversal or apparent pileup from SW winds (see Figure 25).

In comparing these two sets of data, it is noted that the wind velocities were comparable during the two periods, but that during the preliminary instrumentation (Figure 25) the winds were almost always southerly. With this in mind, closer examination of data from Figure 24 for station 14 shows that the few periods of relatively steady directional flow were generally coincident with southerly winds. This clearly suggests that it is the northerly winds which are in fact unable to enhance a steady horizontal circulation of the near bottom waters of north Roanoke Sound. The explanation for this lack of sustained horizontal flow north of Roanoke Island may be due to the fact that most of the waters in the vicinity of stations 13 and 14 cannot be funneled through the narrow channel hugging the eastern shore of Roanoke Island when northerly winds prevail. Consequently, the waters pile up. However, during southerly winds there is no such constraint as the winds blow waters up the narrow channel and into Albemarle Sound and north Croatan Sound. In light of this, it should be pointed out too that the high current velocities in mid-Roanoke Sound may be

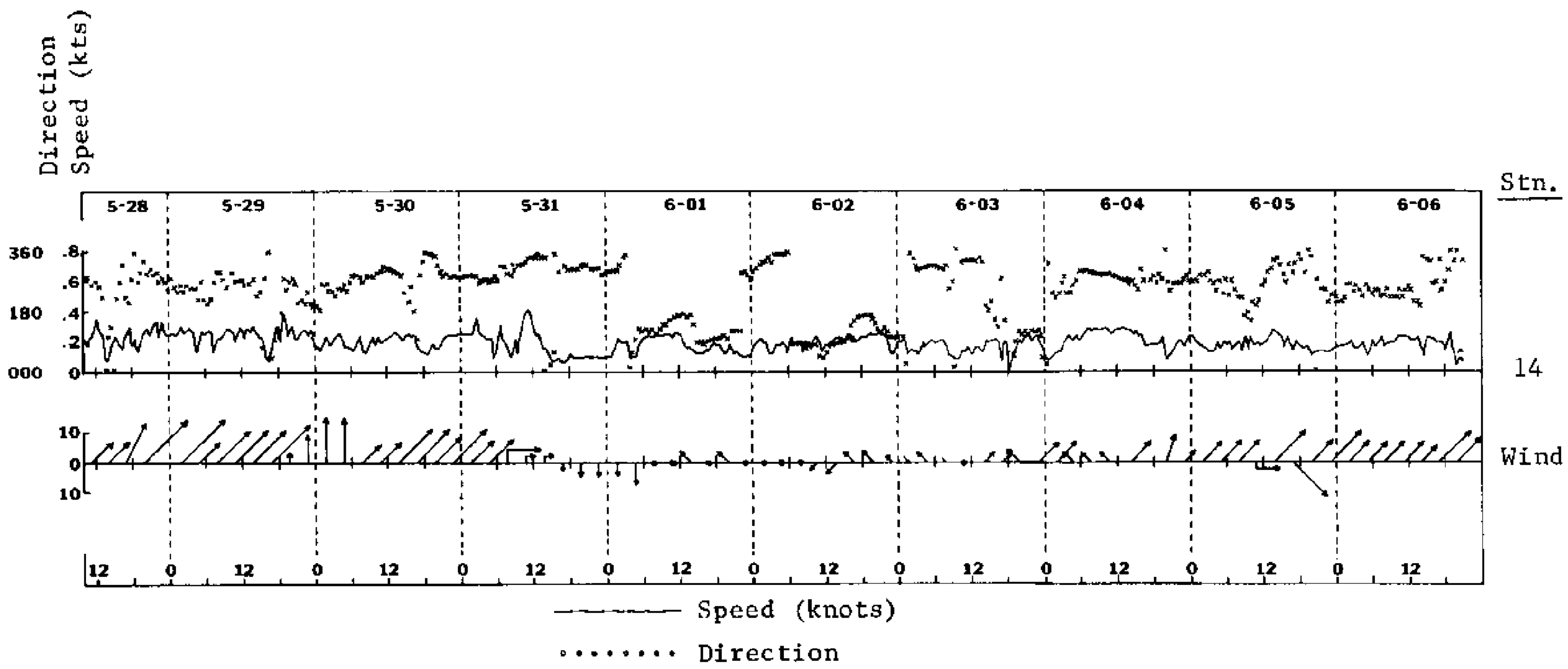


Figure 25. Flow at station 14 in north Roanoke Sound as recorded by a bottom mounted current meter during a preliminary instrument checkout to the initial study (25 May - 6 June, 1973)

due to the funnelling effect of the dredged channels (the bottom-mounted current meter at station 15 was placed in the dredged channel) and are not really a measure of the volume of water moved through the sound. At any rate, it is thought that such circulation as related here for north Roanoke Sound could, with time, still be subject to the influx of northerly flowing bottom waters generally associated with longer floods and the seiche effect in the sounds. A general summary of this section on circulation in the sounds is included in Appendix I.

Salinity and Temperature Data

Temperature and Salinity Data from Oregon Inlet (Possible Evidence of Oceanic Upwelling)

During the June study temperature data was collected at five near bottom stations by film recording thermographs. Three of these units were mounted at stations in or near Oregon Inlet (stations 1, 2a and 3a) and the other two at the southern ends of Roanoke and Croatan Sounds (stations 6 and 7 respectively). See Figure 26 for these instrument locations and Figure 27 for the subsequent data. In this latter figure air temperature and wind data from the Oregon Inlet Coast Guard Station, tidal data from station 1 and flood-ebb current meter data from station 3a are also included for reference.

Note the fluctuation in the temperature of the waters at the three inlet stations up to mid-day on 25 June and from mid-day on 27 June through 1 July, 1973. Such trends are as expected with the higher temperatures corresponding to the flow of warm sound waters into the ocean on an ebb, and the lower temperatures corresponding

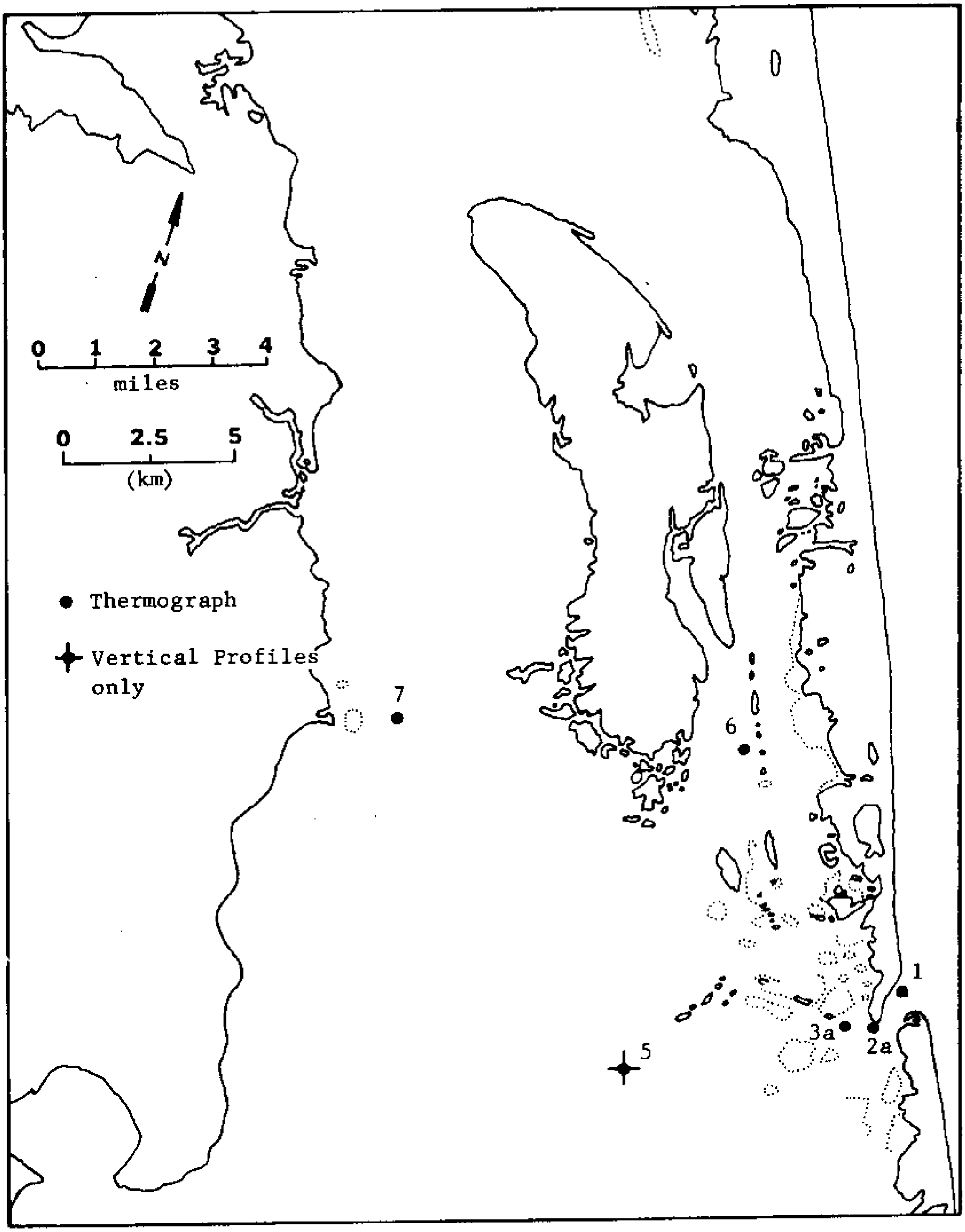


Figure 26. Location of five bottom mounted thermographs (stations 1, 2a, 3a, 6 and 7) during the initial study (20 June - 2 July, 1973) (Station 5 in Pamlico Sound is also included for future reference; it is a vertical profile station only)

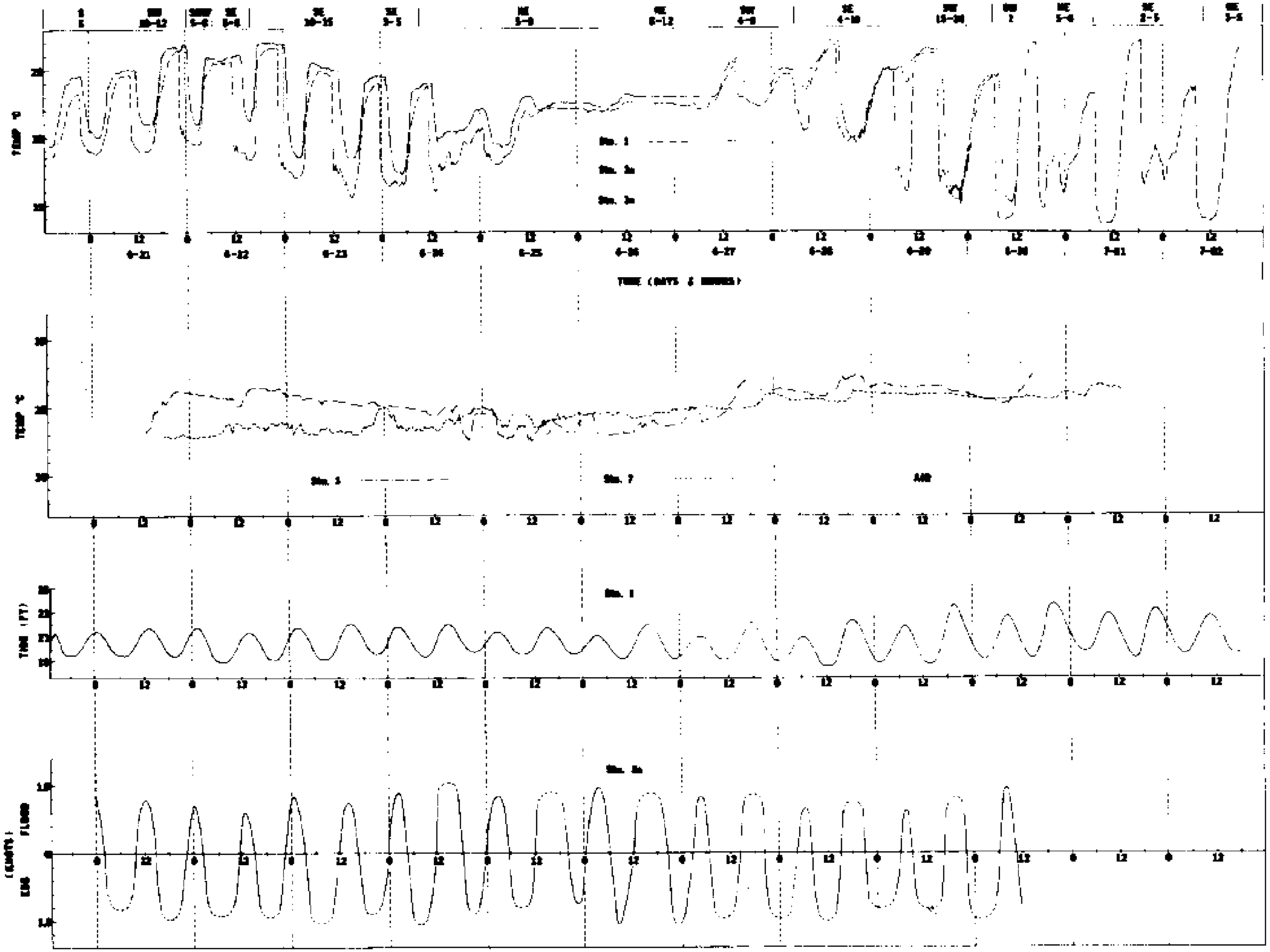


Figure 27. Near bottom temperatures reported for stations 1, 2a, 3a, 6 and 7, air temperature data, tidal data for station 1 and the near bottom current meter record compiled for station 3a during the initial study (20 June - 2 July, 1973)

to the flow of cooler (though perhaps not quite so cool) oceanic waters into the sound on a flood.

Beginning at mid-day on 24 June there is an apparent interruption in this periodicity in temperature. It coincides with the reversal of winds from a southerly set to a northeasterly one. As these winds persist, a relatively constant water temperature is attained at the inlet stations by mid-day on 25 June. This condition persists up to mid-day on 27 June. Temperatures at station 1 level off to 22.0 to 22.5^{o}C and temperatures at stations 2a and 3a are generally less than 0.5^{o}C higher. This is in sharp contrast to temperatures which had ranged from a low of 15.6^{o}C to a high of 27^{o}C in the days preceding the wind shift to northeasterly and from 13.7^{o}C to 27.5^{o}C following a return of southerly winds. At station 6 there is a general decrease in the sound temperature at the beginning of the phenomenon and an increase in the sound temperature at its conclusion.

Over the constant temperature span, normal tidal responses were observed at the inlet. There were no extended ebbs (missed floods) or extended floods (missed ebbs). However, somewhat longer floods were observed during this period than either preceding or following it. See the current meter (inclinometer) record for station 3a included in Figure 27. Also, note the tidal record for station 1. It should also be pointed out that air temperatures fluctuated during this span commensurate with those days both preceding and following the constant water temperature period. The decrease in air temperature on 23 January was in conjunction with a period of heavy rains.

All of these data tend to suggest that a large body of homogeneous water was moving back and forth through the inlet over several tidal cycles. However, it does not clarify as to whether this body of water was oceanic or estuarine in origin. Fortunately, however, vertical profiles of temperature and salinity were made at stations in and near Oregon Inlet (stations 1, 2a, 2b, 3a, 3b, 4 and 5) beginning on 26 June and running through 29 June. Consequently, data were collected at these stations during the constant temperature period and continued as its effects subsided. The data from these stations and others are included in tabular form in Appendix J. The salinities were corrected by adding 2.66 ppt. This was necessary in that the Martek unit when tested against Standard Copenhagen Water was found to be reading low by that much.

Temperature and salinity data from station 1, the ocean station, and station 5, the sound station furthest from the inlet, are included graphically in Figures 28 and 29. Of these, only station 1 corresponds to the site of a bottom mounted thermograph. Its temperature records agree to within 1°C of the vertical profile temperature readings. The accuracy of these two units is ± 0.5°C and ± 0.55°C respectively.

Note that in Figure 28 an isothermal temperature of 21.4°C is obtained for station 1 throughout the day for 26 June. The temperature is independent of tidal phase and, aside from being slightly lower in temperature than the bottom mounted instrument's readings, agrees in trend with them. Note too that the salinity of this water remains fairly constant ranging from 28.80 to 29.60 ppt throughout the

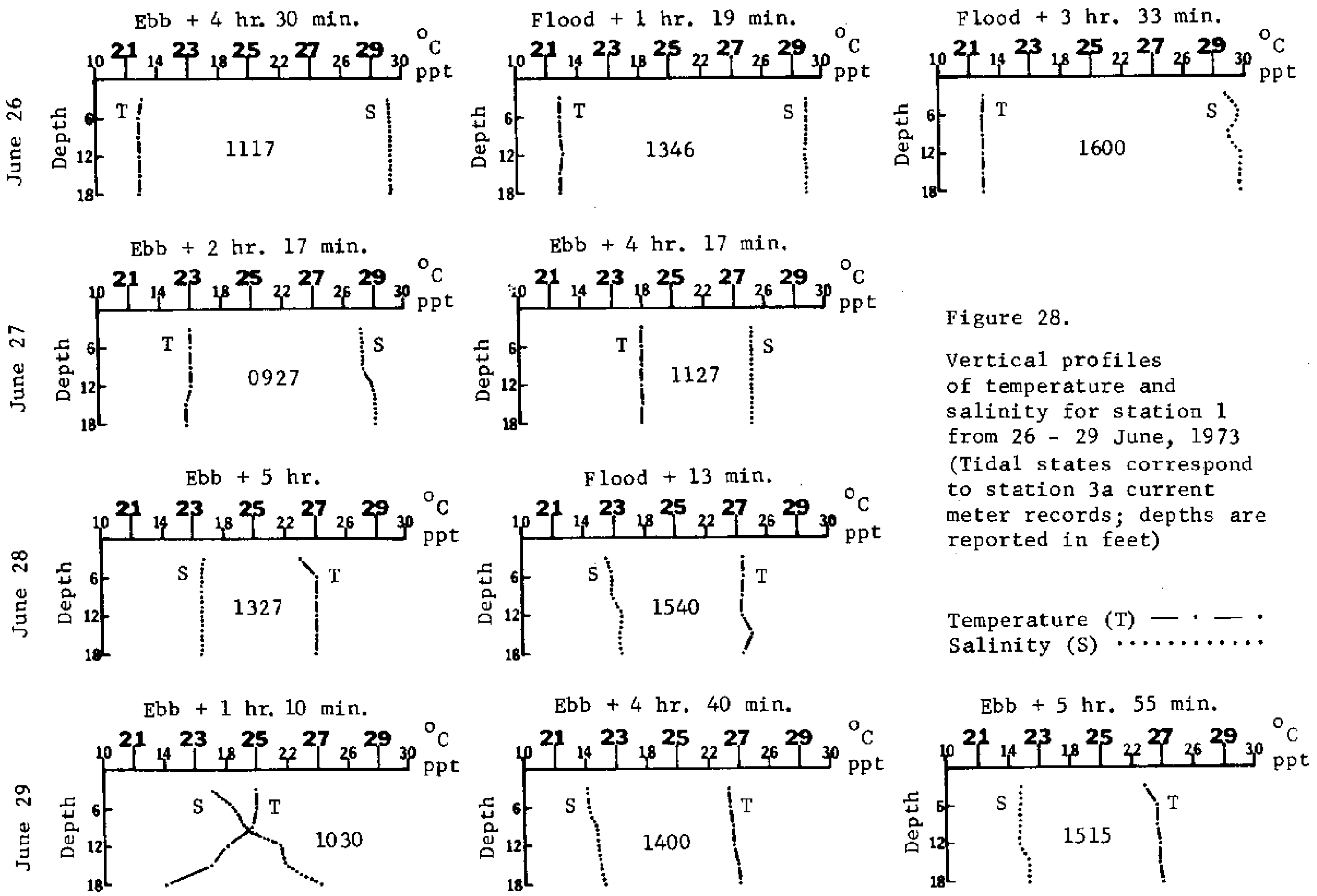
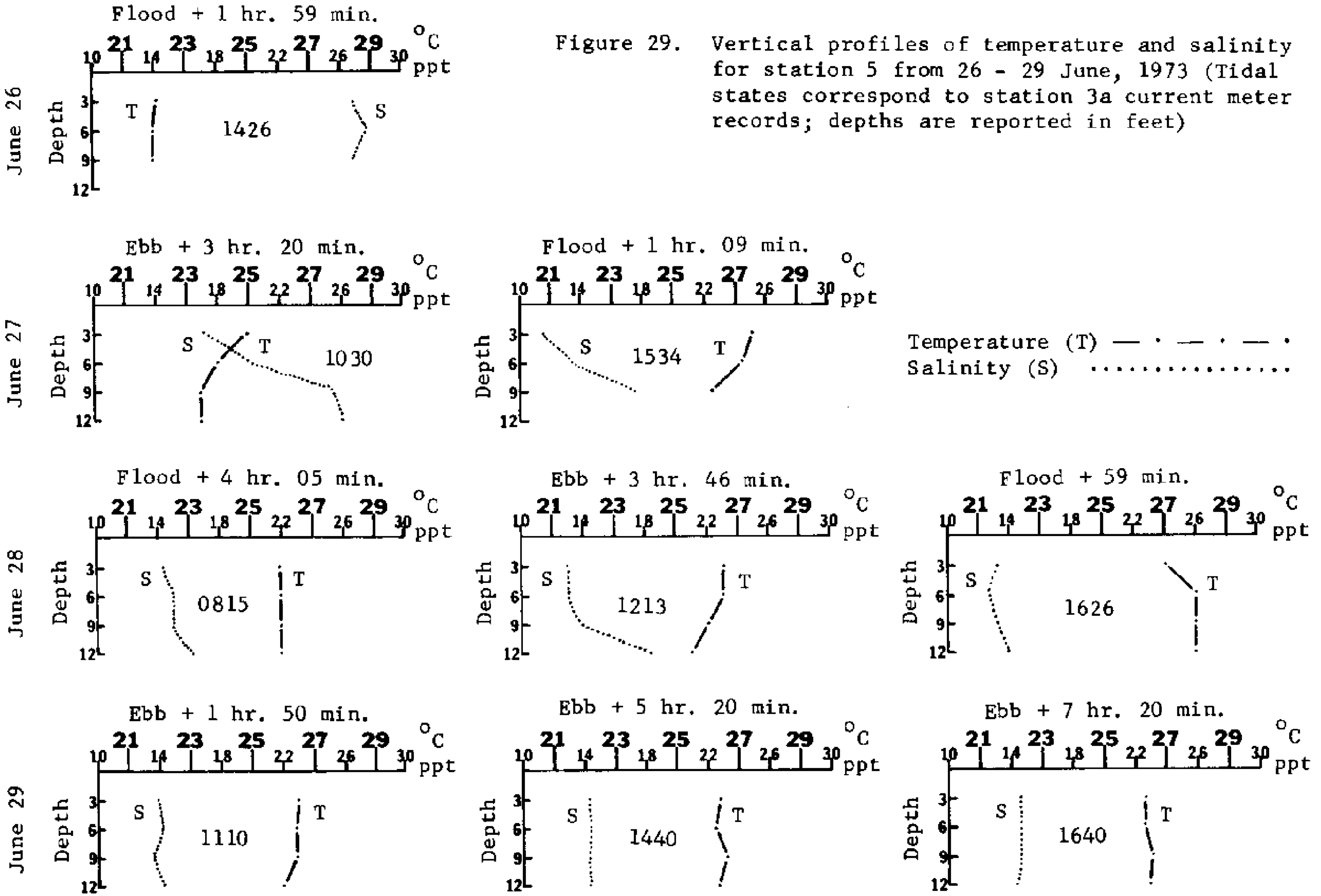


Figure 28.

Vertical profiles of temperature and salinity for station 1 from 26 - 29 June, 1973 (Tidal states correspond to station 3a current meter records; depths are reported in feet)

Temperature (T) — · — ·
Salinity (S) ············

Figure 29. Vertical profiles of temperature and salinity for station 5 from 26 - 29 June, 1973 (Tidal states correspond to station 3a current meter records; depths are reported in feet)



day and is essentially independent of ebb or flood. Such salinities are much too high to have originated in Pamlico Sound where Jarrett (1966) has estimated the average salinity to be 20.00 ppt. Likewise, the temperatures during ebb are much too low for this time of year thereby further suggesting that this warm water was induced from the ocean outside the inlet. During the next three days and subsequent to wind reversal, the salinities at station 1 during ebb dropped down ot 14 to 15 ppt and temperatures during ebb rose to 27°C. Unfortunately, data were collected only during ebb or very early in flood on these days. However, data collected during flood from stations along the inlet bridge (stations 2a, 2b, etc.) suggest that during subsequent floods salinities rose to 29 to 30 ppt and temperatures fell to 20 to 23°C. In other words, values of temperature and salinity comparable to those observed during the constant temperature period continued to be observed after the event had passed but only during floods.

Trends similar to those for station 1 are noted for station 5 (see Figure 29). Here, based on the data collected, salinities dropped from a high of 27.70 ppt on 26 June to range between 13.20 and 14.90 ppt on 28 and 29 June. Over this same time span, temperatures rose from 22°C to range between 26 and 28°C. These latter values compare favorably with data collected by Schwartz and Chestnut (1973) for this area of Pamlico Sound during the month of June 1972. At that time, they found salinities to range from 12.1 to 15.9 ppt and temperatures to range from 25 to 27°C. In view of the present findings it would seem that Schwartz and Chestnut's observations were made during a period of southerly winds.

As far as the large homogeneous body of water is concerned, it is noted that it is not unusual for there to be surface waters in the 21-23°C range for this time of year sitting just off this section of the North Carolina coast (Parr, 1933; Fuglister, 1947; Stefansson, Atkinson and Bumpus, 1971; and Boicourt, 1973). In addition, an A. R. T. (Airborne Radiation Thermometer) Isotherm Chart for 24 and 25 June, 1973, compiled by the U. S. Coast Guard Oceanographic Unit, reveals that such surface temperatures did in fact prevail during the present study period (see Figure 30). Boicourt's data for July 1971 indicates also that salinities in the 28 to 30 ppt range are not uncommon in conjunction with these coastal waters. It also suggests that the thickness of the surface water layer is variable and may extend to the bottom in near shore regions. Clearly, such observations well define the homogeneous waters which passed through Oregon Inlet on 25-27 June, 1973, and surely these waters must have been deep.

Boicourt[2] has seen in his data clear evidence of upwelling along the North Carolina coast. This he attributes to southerly winds and the subsequent Ekman transport of surface waters away from the coast and replacement by colder more saline bottom waters. In view of this it appears that the thermographic data reported for the three inlet stations provide a rather unique documentation of upwelling along the North Carolina coast.

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[2] Personal communication. March 1975. Johns Hopkins University, Chesapeake Bay Institute, Baltimore, Maryland.

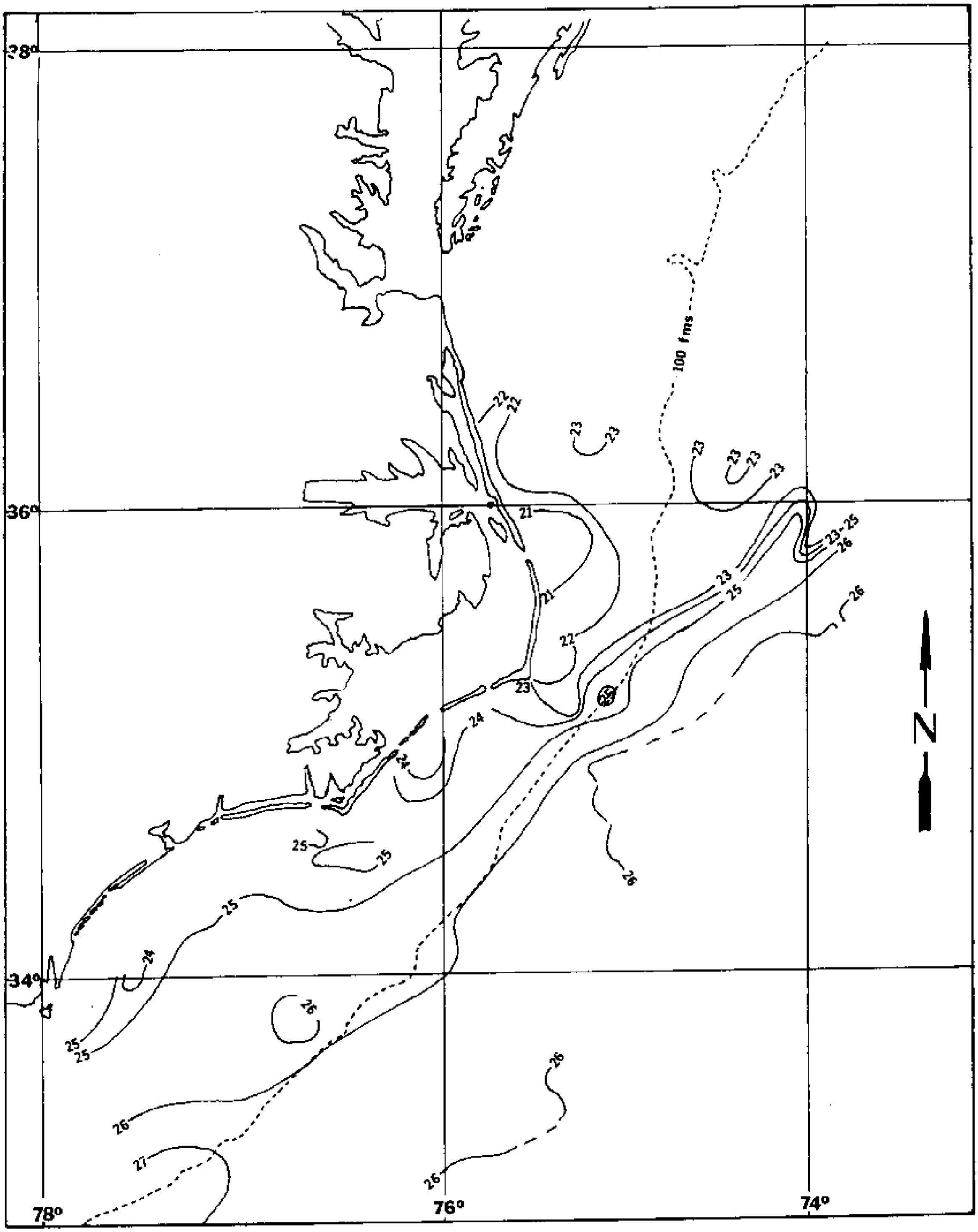

Figure 30. A. R. T. (Airborne Radiation Thermometer) Isotherm chart for 24 and 25 June, 1973, showing surface temperatures in °C of the ocean waters off the North Carolina coast

During southerly winds colder oceanic waters were observed to pass through the inlet on a flood, at least up to mid-day on 24 June. At this time, almost immediately and coincidental with the initiation of northeasterly winds, the periodicity of the temperature record was interrupted. The force function for upwelling ceased and by mid-day on 25 June the warmer oceanic surface waters had been moved into position opposite the inlet. The periodicity in temperature associated with flood and ebb previously was completely eliminated. This is probably due to the fact that NE winds tend to move sound water away from the inlet in advance of the oceanic waters passing through the inlet on a flood. Furthermore, generally longer floods and shorter ebbs are associated with NE winds. Consequently, the same oceanic water moved back and forth through the inlet in response to the tides during this time span and very little mixing of the ocean water with the warmer sound waters was achieved. When the winds returned to a southerly set once again around mid-day on 27 June these warmer oceanic surface waters were again transported away from the shore and upwelling was once again induced. This wind reversal also allowed for the warmer and less saline sound waters to return to the vicinity of the inlet and the extensive mixing of sound and oceanic waters was again possible. As a final point, the lowest flood temperatures recorded during southerly winds both preceding and following the constant temperature period (on 23 June and 1 July) followed the longest periods of high southerly winds observed during the two time spans. This is as would be expected if upwelling were occurring as does seem to be the case. It is noted too that data for the constant temperature period further suggest that there was very little heating of the oceanic water entering the sound on a flood tide; temperature changes which occurred prior to and after this event were more likely due to mixing with sound water.

As an additional factor, it is noted that this apparent upwelling phenomenon could be further enhanced by the influence of the Gulf Stream in this region. That is, given the narrowness of the shelf off this stretch of the Carolina coast, and the close proximity of the Gulf Stream, it is quite possible that the southerly winds could relieve the regime of surface coastal waters and subsequently allow sub-surface Gulf Stream waters to converge and penetrate on to the shelf. The isopycnals, which tilt upward to the left in the direction of flow of the Gulf Stream, could penetrate a considerable distance on to the shelf effecting geostrophic upwelling (see Hsueh and O'Brien (1971), Pietrafesa and Rattray (1975)[3], and O'Brien.[4]

Temperatures and Salinities in Croatan Sound

During the initial study, tempeature and salinity data were collected on 30 June in Croatan Sound for stations 7 through 12

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[3] Pietrafesa, L. J. and M. Rattray, Jr. 1975. Steady baroclinic circulation on a continental shelf under upwelling conditions. Submitted to the Journal of Physical Oceanography. (Geosciences Department, North Carolina State University at Raleigh.)

[4] O'Brien, J. J. 1975. Models of coastal upwelling: Proceedings of NAS Symposium on Numerical Models in Ocean Circulation, Durham, New Hampshire. (In press.)

(see Figure 31). On this date winds were light (2-5 knots) and were shifting from the SW to the NE. The flow in Croatan Sound during this span was southerly. Air temperature fluctuated from a low in the morning of 24.4°C to a high in the afternoon of 31.7°C. Such fluctuation in temperature was also typical of the preceding days.

Two sets of data were collected on this date for each of five stations along the Croatan Sound bridge. These were at station 11(105), 11(140), 11(220), 11(250) and 11(280). This data is given in Figure 32 and also in tabular form in Appendix K. Note that as the first survey beginning at 1249 moves from west to east (station 11(105)-11(280)) there is an increase in salinity from a low of 3.89 ppt at station 11(105) to a high of 8.02 ppt at station 11(280). During the second survey (some 3 to 5 hours later depending on the station) a similar trend is noted. Here, salinity ranges from a low of 3.91 ppt at station 11(105) to a high of 6.83 ppt at station 11(280). The apparent overall decrease in salinity during this latter survey is not surprising in view of the southerly flow which prevailed throughout the day.

Three stations to the west of station 11(105) were occupied during the initial survey on this date but not during the second one. These were stations 11(060), 11(075) and 11(090). Here, isohaline values of 4.71, 4.43 and 4.43 ppt respectively were observed. Such salinities were slightly higher than those observed at station 11(105) but not nearly as high as those observed for station 11(280). The cause of the temperature inversions at station 11(140)

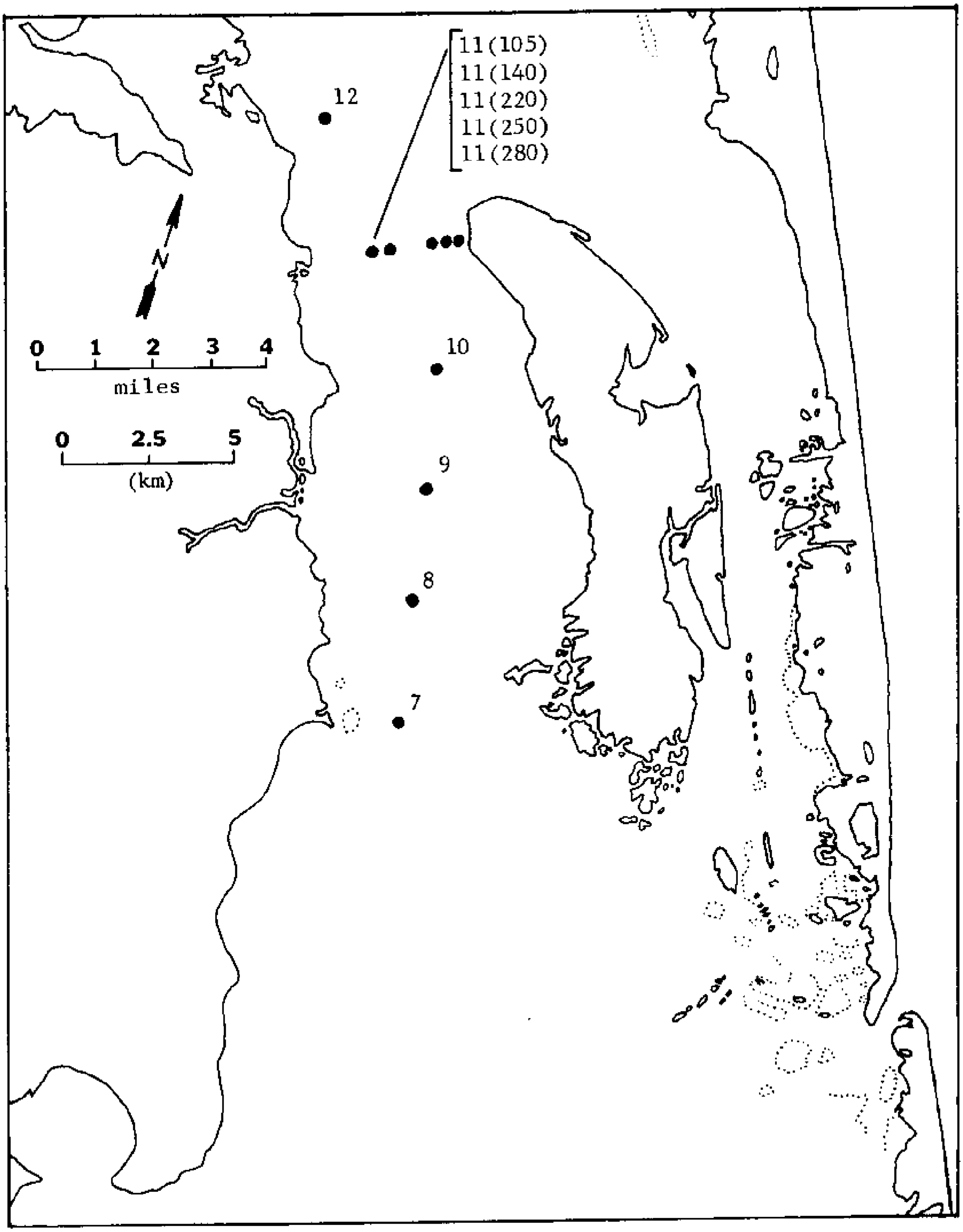

Figure 31. Stations in Croatan Sound at which temperature and salinity data were collected on 30 June, 1973

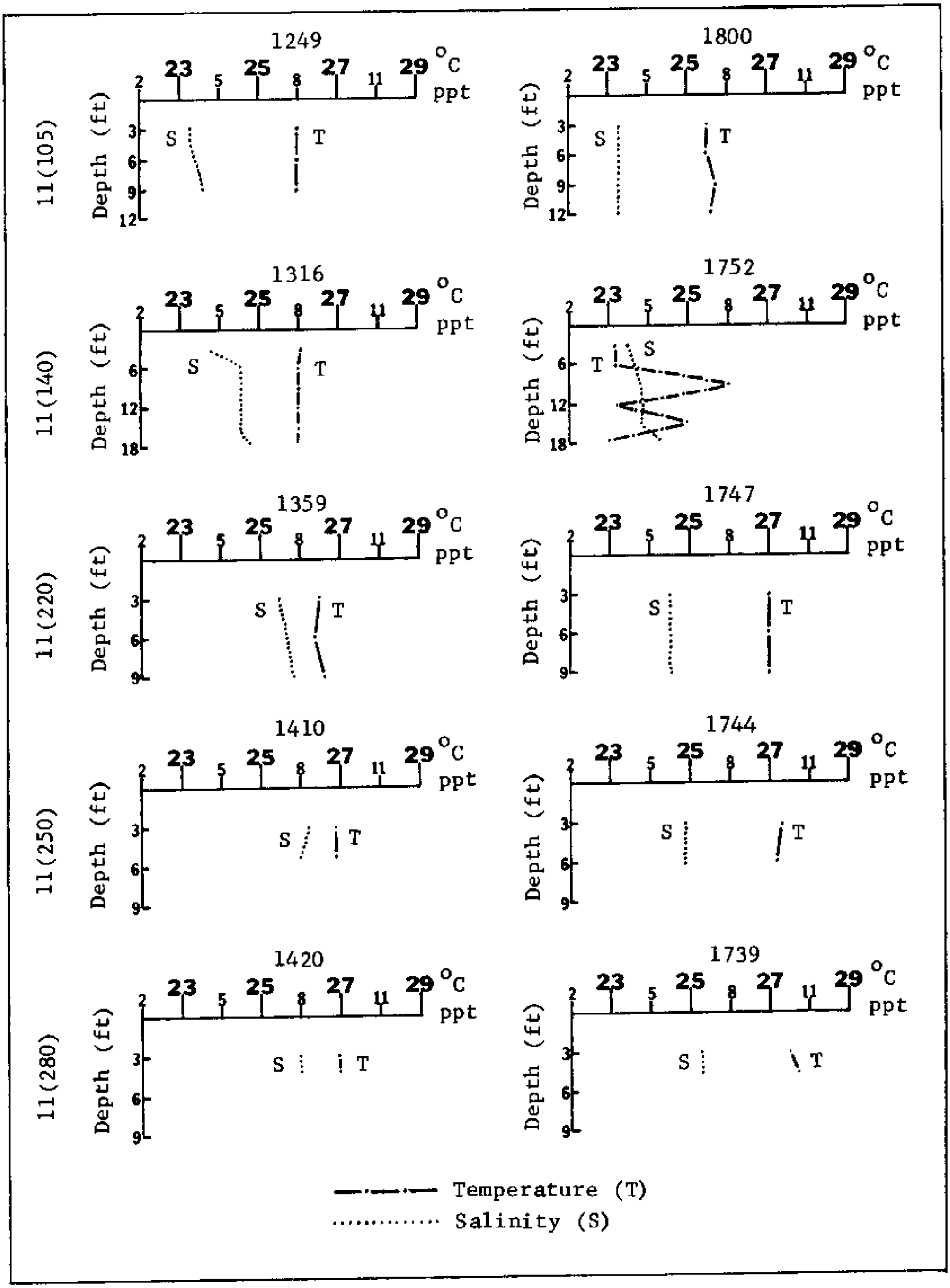

Figure 32. Temperature and salinity profiles for 30 June, 1973, for stations 11(105), 11(140), 11(220), 11(250) and 11(280) along the Croatan Sound bridge

at 1752 is not clear, but that it is a real phenomenon is certain; two sets of measurements were taken in rapid sequence, and each showed the same trends. The data for all stations mentioned here and others along the Croatan Sound bridge are included in tabular form in Appendix K.

In summary, this information suggests that during this study for southerly flow, the more saline waters tended to hug the western shore of Roanoke Island in northern Croatan Sound. This general salinity observation is consistent with records compiled by H. R. Seiwell for July 1927 and reported in Marshall (1951). He surveyed the entire area and found this trend to persist for the entire length of the sound. It may just be that this observation is a natural result of the fact that the higher salinity waters come from the south and east and the fresher waters come from the north and west hugging the respective shorelines.

Two sets of data were also collected for the length of Croatan Sound on this date. They included stations 12, 10, 9, 8 and 7. Data from these stations are included in Figure 33. In general, looking at surface salinities during the initial survey, there is an increase in salinity from a low of 3.10 ppt at station 12 to the north to a high of 9.33 ppt at station 7 to the south. During the second survey the range is from 2.62 ppt at station 12 to 8.73 ppt at station 7, again reflecting the fact that the flow was southerly throughout the day.

At stations 9 and 10 in central Croatan Sound there was fairly isohaline water during both surveys. However, to the south at

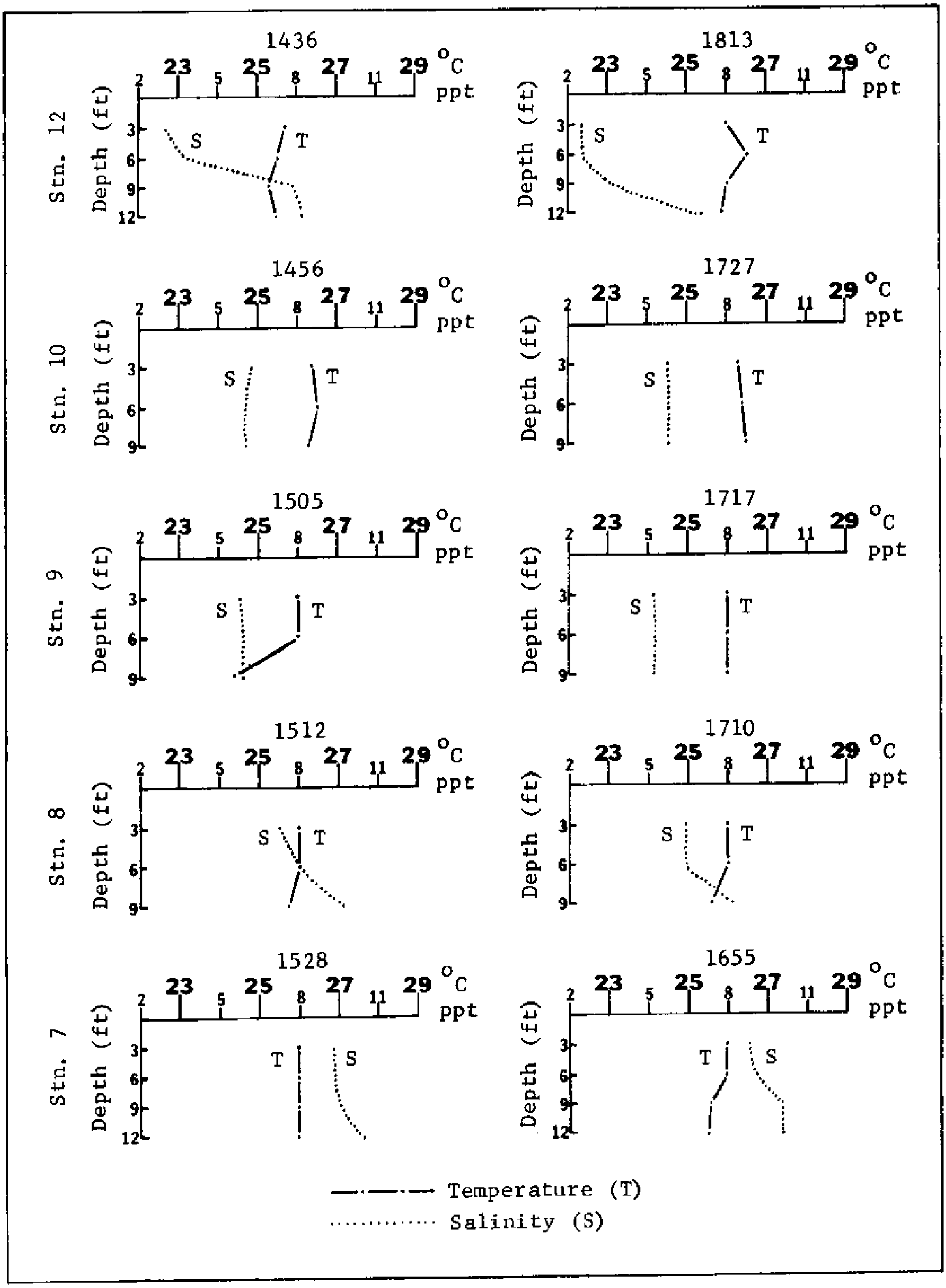

Figure 33. Temperature and salinity profiles for 30 June, 1973, for stations 12, 10, 9, 8 and 7 from north to south along the length of Croatan Sound

stations 7 and 8 there was an increase in salinity with depth probably due to the close proximity of Pamlico Sound and Oregon Inlet. Here salinities increased by not more than 2.5 ppt from top to bottom. In contrast to this, however, is the presence of a considerable gradient in the salinity profile at station 12 to the north. This is evidenced in both samplings with salinity ranges from 3.10 to 8.19 ppt and 2.62 to 6.98 ppt respectively. This more saline water is apparently a remnant of previous northerly intrusions from Pamlico Sound and Oregon Inlet. These were elaborated on earlier.

The salinities observed fit well within the ranges related for this area by earlier investigators as cited in the review of literature. Likewise, the observed temperatures are typical for this time of the year. Schwartz and Chestnut (1973) report temperatures in the neighborhood of 25 to 27°C for June.

During the February study salinity data were not collected in this area. However, one bottom mounted film recording thermograph at station 11(214) operational from 28 January through 3 February recorded temperatures ranging from 11.5 to 13.5°C. Such values are 3 to 4°C higher than those related by Schwartz and Chestnut (1973) and Williams *et al.* (1973) for this time of year. This was perhaps due to the relatively mild winter of 1973-74. Air temperatures from 28 January through 3 February fluctuated from 8.5 to 19.5°C and were generally higher in temperature than the water. This is in general agreement with the observations of Marshall (1951), Posner (1959) and Woods (1967) that the temperature of the open sounds follows the air temperature rather closely with that of the sounds being slightly lower.

SUMMARY AND CONCLUSIONS

General

As a result of this research, the following knowledge with regards to the flow in Croatan and Roanoke Sounds was obtained:

(1) The flow in south Roanoke Sound responds to those floods at the inlet which are generally in the neighborhood of six hours or more in length. (This is generally the case for northerly winds.) Under such circumstances, it is not unusual to detect continued northerly flow of bottom waters for some time after ebb has begun at the inlet and in direct opposition to southerly flowing bottom waters in mid-Roanoke Sound to the north. In that southerly flow may be brief or entirely non-existent during such periods, this suggests an additive mechanism to the northerly penetration of high salinity bottom waters into Roanoke Sound. That is, each subsequent flood, during northerly winds, apparently pushes waters from the preceding flood further north. For periods of generally shorter floods ($<$ 6 hours) generally in conjunction with southerly winds, however, the response here is essentially to the winds and not to the floods at the inlet.

(2) The flow in mid-Roanoke Sound generally parallels that in north Croatan Sound in both direction and intensity. This flow appears to be essentially a direct response to the prevailing winds. The waters will generally flow with the winds for at least 24 to 36 hours but will tend to reverse their direction and flow in the opposite direction if the winds continue to prevail from the same direction for much longer (for northerly or southerly winds).

This is apparently the result of water pileup in the southern end of Pamlico Sound during northerly winds or in northern Pamlico, Croatan, Roanoke and Albemarle Sounds during southerly winds. This parallelism is perhaps interrupted in mid-Roanoke Sound on occasion by northerly flowing bottom waters during long periods (several days) of northerly winds, causing northerly flow in Roanoke Sound by the mechanism proposed above. However, the word perhaps is emphasized in that data indicate that by the time northerly winds have prevailed long enough to induce this additive flow effect, observed for south Roanoke Sound, but in mid-Roanoke Sound, the northerly flow of bottom waters would already have begun as a result of water pileup and reversal. This, in turn, suggests an additional aspect to the proposed mechanism. Once high salinity bottom waters have begun flowing north in Roanoke Sound by the additive mechanism, they may be transported further north by the return flow effect of these same northerly winds on Pamlico Sound.

From data such as this, it is concluded that oceanic waters passing through Oregon Inlet can be projected as reaching at least as far north as the region just north of Roanoke Island. This additive penetration mechanism linked with the seiche effect of the sound may explain the observations of an increase in bottom salinity from 3.5 to 20.5 ppt in two hours for a region designated as ". . . the eastern section of Albemarle Sound" by Posner (1959, p. 704). There is the suggestion of a similarly induced trend in south Croatan Sound but without more data it is not possible to verify at this time.

(3) In north Roanoke Sound the flow data collected are somewhat erratic. There is no regular directional flow response to northerly winds but only to southerly winds and relatively calm periods subsequent to extended periods of southerly winds which had apparently piled water to the north. This is probably due to the funneling effect of Roanoke Sound. That is, northerly winds cannot move the massive body of water of north Roanoke Sound through the shallower regions to which it is linked by a narrow channel. Consequently, the bottom waters move back and forth perhaps in response to wave activity with no set direction of flow. Such tendencies further suggest that once high salinity waters reach this region they may be trapped here for some time or flow around the northern end of Roanoke Island and into Croatan Sound. This could conceivably account for the higher salinities observed on the western shore of Roanoke Island and the strong salinity gradients observed in north Croatan Sound.

(4) In south Croatan Sound, the general set of southerly flow was observed to be in the 180°-190° range. However, during periods of heavy southerly flow in Croatan Sound the data suggested a tendency towards hugging the western shoreline of the sound as it enters Pamlico Sound. This trend perhaps physically explains surface salinity data compiled by H. R. Seiwell for January 1927, presented in Marshall (1951), and by Williams et al. (1973) depicting the intrusion of less saline waters from Albemarle Sound down through Croatan Sound and along the western shore of Pamlico Sound at least to Long Shoal Point, some 10 miles (16 km) SSW of Stumpy Point.

In addition to this knowledge with respect to flow in the sounds, the following knowledge with regard to the effect of various wind conditions on ebb and flood at Oregon Inlet were documented.

(1) Southerly winds in general, whether they be SW, S, or SE tend to shorten flood and lengthen ebb at the inlet. In addition, a similar trend may be noted for northerly winds with respect to floods at the inlet. That is, NW, N, or NE winds tend to shorten ebb and lengthen flood.

(2) Even the lightest NE winds (5-8 knots) tend to shorten ebb and lengthen flood.

(3) During a period of relatively constant NE winds in the 5-8 knot range there may still be a great variability in the length of floods and to a lesser extent the length of ebbs at the inlet.

(4) During extended periods of fluctuating southerly winds successive floods may tend to be of comparable length or they may tend to vary considerably. Corresponding successive ebbs may follow similar trends.

(5) Floods and ebbs lasting but 6 hours in length are uncommon and unlikely as long as there are prevailing winds.

(6) Higher current velocities at the inlet are associated with the longer ebbs and floods and vice versa.

(7) Extended ebbs (missed floods) may be initiated not necessarily as the result of long periods of rather high or increasing southerly wind speeds but apparently as the result of water flow from reversal from the south to the north after 24 to 36 hours of

northerly winds. If this reversal is essentially coincidental with wind reversal from a northerly to a southerly set, then it may significantly enhance northerly flow in the sound so as to increase the water level and lengthen ebb. Once this has occurred, continued increasing southerly winds may prolong this phenomenon. By similar rationale, extended floods (missed ebbs) may be initiated at the inlet. As an example, if southerly winds pile water to the north and then begin return flow to the south, coincidental with wind reversal from a southerly to a northerly set, this too could result in enhanced flow and conceivably an extended flood (missed ebb). Continued increasing northerly winds would apparently prolong this phenomenon.

(8) Extended ebbs (missed floods) apparently increase the likelihood of extended floods (missed ebbs) and vice versa.

In conjunction with this study numerous other matters were investigated and discussed within the text. These included an apparent flood surge at the inlet on 4 February, 1974, the computation of maximum rates of discharge at the inlet for one hour surveys during a flood and ebb cycle, a discussion of ebb and flood channels at the inlet, the response times to ebb and flood for bottom mounted current meters placed at various distances from the inlet, the maximum velocities observed at stations near Oregon Inlet and in Roanoke and Croatan Sounds, salinity trends in Croatan Sound during a period of sustained southerly flow, and an indication that tidal energy may be felt as far into Pamlico Sound as Engelhard.

Finally, and perhaps of even more significance than all of the other findings combined, is the thermographic record recorded by three sensors in or near Oregon Inlet during the initial study period. It indicates inlet water temperatures much higher than 20.80°C, the maximum previously reported by Williams *et al.* (1973) for the month of August, the fact that NE winds cause the movement of sound waters away from the inlet and the subsequent domination of oceanic waters moving back and forth through the inlet with apparently very little mixing in north Pamlico Sound (substantially increasing the quantity of high salinity water available to be carried north by seiche activity), and also serves as a rather unique documentation of the occurrence of oceanic upwelling off the North Carolina coast.

Recommendations for Future Research

In view of the findings of the present research, there are several matters which demand further investigation. One of these is to collect an actual salinity record documenting the flow of high salinity water up Roanoke Sound. This would serve to either verify or disprove the projected mechanism. It would also be interesting to determine what happens to these high salinity waters when they reach the region just north of Roanoke Island. Do they in fact collect in the large abandoned channel area which at one time led to the now closed Roanoke Inlet (see Figure 34)? Do they mix significantly, or do they just remain near the bottom and slowly leak off down Roanoke Sound or to the west and into Croatan Sound and thence north into Albemarle Sound or south into Pamlico

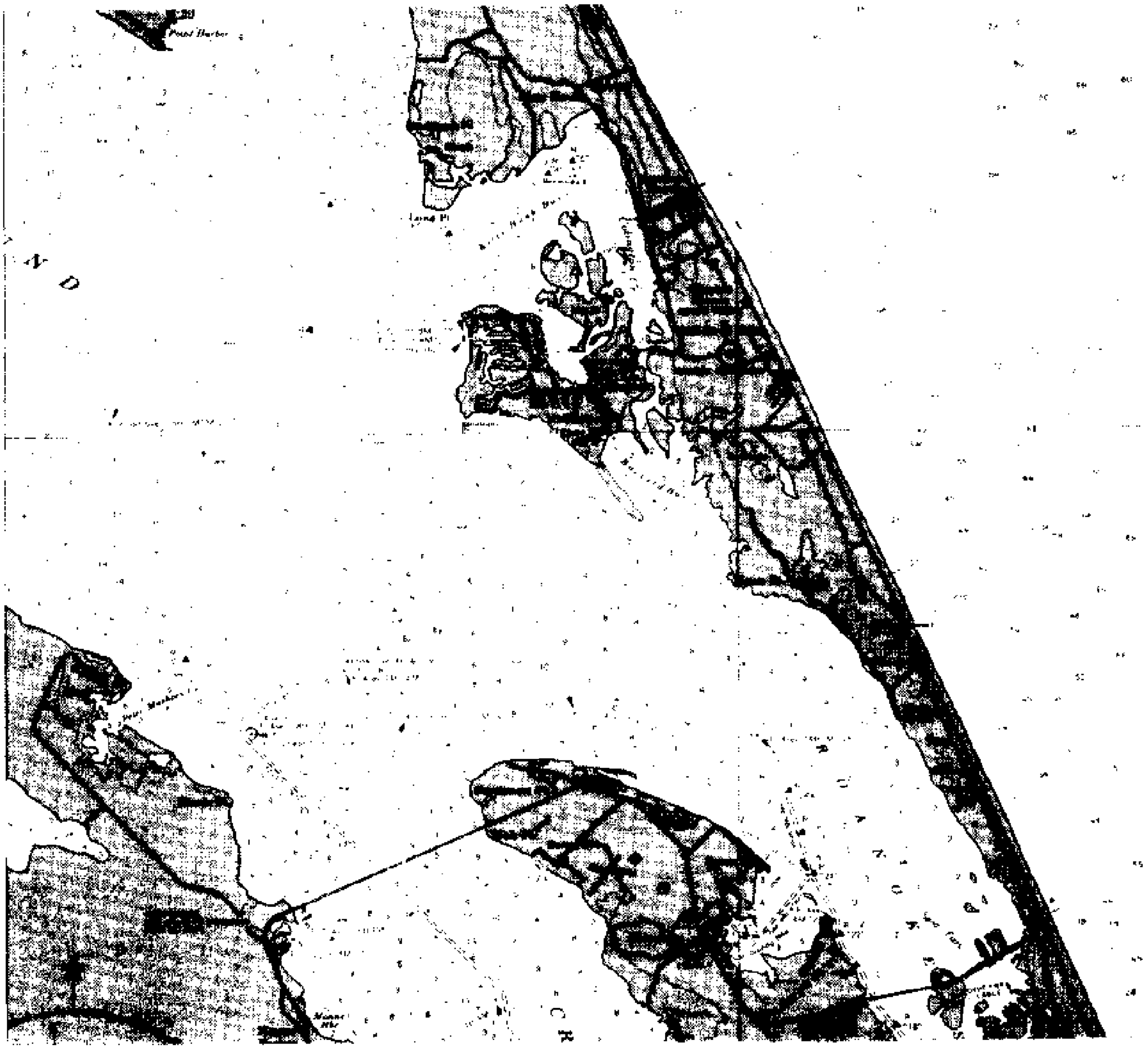

Figure 34. Map of the region north of Roanoke Island showing abandoned channel area which at one time led to the now closed Roanoke Inlet (from U. S. C. and G. S. Chart 1229, 1974)

Sound? How much high salinity water actually reaches this region? Questions such as these could be answered by further research in this area.

Another study which might be linked with this one would be to attempt to detect significant northerly flow in Croatan Sound as a result of floods at the inlet by placing another current meter in south Croatan Sound but closer to Roanoke Island than during the present study.

Other studies might center around placing tide gauges at the north and south ends of Pamlico Sound in conjunction with current meters at Oregon Inlet to re-examine the extended flood (missed ebb) and extended ebb (missed flood) phenomenon in more detail, instrumenting the region south of Croatan Sound to trace southerly flow into Pamlico Sound, and reinstrumenting Roanoke and Croatan Sounds but with both near surface and near bottom current meters to capture velocity shear data coincident with extended periods of high winds.

Finally, a reinstrumentation of Oregon Inlet with thermographs during a period of temperature and salinity collection just off the North Carolina coast could conceivably serve as a useful tool in the study of upwelling. Such a study may answer the following questions:

(1) Does the inlet always detect upwelling, and if not, what factors influence it?

(2) How frequently does upwelling occur at Oregon Inlet?

(3) How does the inlet upwelling record correlate to the oceanic one?

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APPENDICES

Appendix A

A Listing of Cumming's (1966) Compilation of Maps

White	1585
White-De Bry	1590
Mercator-Hondius	1606
Comberford	1657
Ogilby-Moxon	1672
Moseley	1733
Collet	1770
Mouzon	1775
Price-Strother	1808
MacRae-Brazier	1833
Colton	1861
Bachmann	1861
United States Coast Survey	1865
Kerr-Cain	1882
Post Route	1896

Appendix B

Manning Equation

The Manning equation may be stated as:

$$V = \frac{1.486}{n} r^{1/6} \sqrt{rs} \qquad (B1)$$

where V = velocity,

s = slope,

h = elevation of energy head, and

n = Kutter roughness factor.

Solving for s we have:

$$s = V^2\left(\frac{n}{1.486r^{2/3}}\right)^2 = \frac{V^2n^2}{2.2082r^{4/3}} \quad . \qquad (B2)$$

In turn, Bernoulli's equations may be stated as:

$$h_1 = y_1 + v_1{}^2/2g \qquad (B3)$$

$$h_2 = y_2 + v_2{}^2/2g \qquad (B4)$$

where h_1 = elevation of energy surface at point 1,

h_2 = elevation of energy surface at point 2,

y_1 = elevation of water surface at point 1,

y_2 = elevation of water surface at point 2,

v_1 = velocity at point 1, and

v_2 = velocity at point 2.

By dividing the difference in h_1-h_2 by the distance between the two we have:

$$\frac{h_1-h_2}{x_1-x_2} = S_o - \frac{n^2\bar{V}^2}{2.2082(\bar{R})^{4/3}} \qquad \text{(B5)}$$

where S_o = slope of channel bottom,

$\bar{V}$ = average velocity between points 1 and 2,

$\bar{R}$ = average hydraulic radius between points 1 and 2, and

n = Manning's coefficient of roughness.

From this, the elevation of the water levels y_1-y_2 are used as a first approximation of h_1-h_2 and an iterative approach to solution is used to find $\bar{V}$.

Appendix C

Winslow's (1889) Comments on the Effects of Winds on Salinity in the Sounds

It must be remembered that the condition of the water is not dependent upon the wind prevailing at any particular time, but upon the wind that has prevailed; while, except in the neighborhood of the inlets, the exact opposite is the case with the currents. For instance, in the upper part of Pamlico Sound, the specimens taken during a strong northwesterly wind, and with a strong southerly current, may show a high specific gravity. But by consulting the weather record of the previous days or weeks it will be found that strong easterly and southeasterly gales have prevailed. The water of the ocean was thus driven into the Sound and then up it; the natural flow from the Albemarle was stopped, and the heavier, denser waters of the lower part of the Sound banked up against it. As the wind changed to the southward and westward, the pressure at the inlets was relieved and the water there began to flow out; but the direction of the wind would prevent any great change of conditions in the main body of the Sound, as its major axis extends nearly northeast and southwest. Upon the change of the wind to the northward, however, an immediate and comparatively violent movement of the water will take place in the direction of the inlets where the level has already been reduced, and though this movement is rapid, amounting sometimes to two knots per hour, yet considerable time is necessary to displace the salt water by the fresh, and consequently high densities may easily be found with northwesterly winds and southerly currents, and vice versa, low densities with easterly and southerly winds and northerly currents. In the southerly part of the Sound the rule will be modified somewhat owing to the trend of the land and lay of the shoals, the greater densities being found, as before, after easterly winds, but a southerly wind immediately effecting a diminuation of gravity.

From a careful inspection of the determinations of specific gravity and observations of winds and currents, the following are deduced:

> Easterly winds will cause high water and high densities.
>
> Westerly winds will cause low water and low densities.
>
> Southerly winds will cause low water and low densities in the southern part of Pamlico Sound and high densities in the northern part.
>
> Northerly winds will have an exactly opposite effect in each locality.
>
> The greatest density and the highest water will be coincident.
>
> The greatest density and the highest water will be found, after continued easterly weather--
>
> In the northern part of the Sound immediately before the shift of wind to the N.W.;
>
> In the southern part of the Sound immediately before the shift of the wind to the S.W. (Winslow, 1889, pp. 122-123).

Appendix D

Instrument Specifications

Martek Mark II, Model A, Water Quality Monitoring System

Conductivity Sensor:

50 millimhos/cm range

Readout accuracy	± 0.5 millimhos/cm
Cell accuracy	± 0.5 millimhos/cm
Combined accuracy	± 1.0 millimhos/cm

Depth Sensor:

Depth accuracy	(0-30 ft. range)	± 1.2 ft.

Temperature Sensor:

Recorder output accuracy	± 0.5°C

Bendix Model Q-15 Current Meter

Speed range	0.04-5.00 knots
Speed accuracy	± 3%
Directional accuracy	± 12°

General Oceanics, Inc.

Film Recording Current Meter (Model 2010)

Speed range	0.05-1.62 knots
Inclinometer accuracy	± 1°
Speed accuracy	± 0.05 knots
Directional accuracy	± 5° for inclination over 10° or 0.25 knots
Watch accuracy	± 30 sec./24 hrs.

General Oceanics, Inc. (continued)

Film Recording Thermograph (Model 3070)

Sensor accuracy	± 0.55°C
Watch accuracy	± 30 sec./24 hrs.

Film Recording Tide Gauge (Model 3040)

Sensor accuracy (15 psi unit)	± 0.075 psi (0.168 ft.) sea water
Sensor accuracy (30 psi unit)	± 0.150 psi (0.336 ft.) sea water
Watch accuracy	± 30 sec./24 hrs.

Raytheon Model DE 719 Precision Fathometer

Depth accuracy	0.5% ± 1 inch of indicated depth

Appendix E

Details of Bottom Mounting of Film Recording Instruments

The film recording instruments were secured by two methods. The current meters were attached to 90 pound dome or bowl shaped anchors as illustrated in Figure E1. Such mounting permitted the units to measure current velocities in the neighborhood of 1 to 3 1/2 feet above the bottom. Full scale measurements would correspond to the former and lower velocities to the latter. The tide gauges and thermographs were mounted on a specially designed tripod with hooked arms to cradle the instruments. (Both instruments are cylindrical in shape.) They were secured by rubber straps. See Figure E2. Mounting of this nature placed the sensors to these units some 2 to 2 1/2 feet above the bottom. Note that in this latter figure a flow meter is also secured through the center of the tripod. It is the T-shaped instrument.

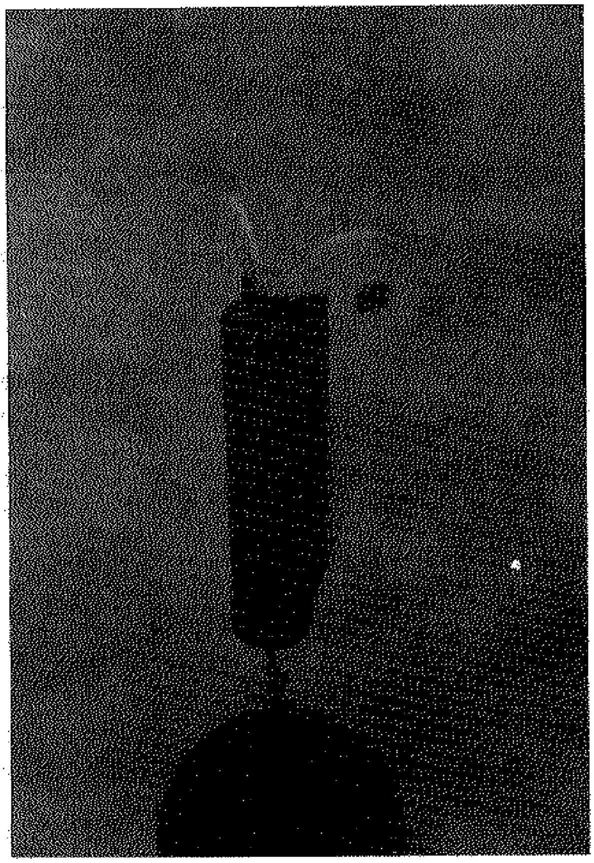


Figure E1. Mounting of current meters (inclinometers)

Figure E2. Mounting of tide gauges and thermographs (The T-shaped instrument is a flow meter)

Appendix F

Locations and Approximate Depths Corresponding to Stations Occupied during This Study According to U. S. C. and G. S. Chart 1229 (1973)

Station Number	Location on Geodetic Survey Chart	Coordinates	Approx. Depth (ft.)
1	Ocean side of inlet throat	35°47'06" N 75°31'54" W	21
2a	Under bridge at inlet between bent 143 and 144	35°46'22" N 75°32'16" W	18
2b	Under bridge at end of fishing walk at bent 184	35°46'03" N 75°31'54" W	22
3a	Channel marker #8 near Oregon Inlet	35°46'17" N 75°32'48" W	13
3b	320° from channel marker #8; 010° from center span and 070° from south end of bridge	35°45'47" N 75°32'13" W	7
4	Channel marker #16 near Oregon Inlet	35°46'22" N 75°34'04" W	10
5	Channel marker #14 near Oregon Inlet	35°44'42" N 75°36'21" W	12
6	Channel marker #7 in south Roanoke Sound	35°49'41" N 75°35'59" W	9
7	Bell in south Croatan Sound	35°48'39" N 75°42'04" W	13
8	Channel marker #6 in Croatan Sound	35°49'40" N 75°42'34" W	9
9	Channel marker #4 in Croatan Sound	35°52'00" N 75°42'54" W	10
10	Channel marker #2 in Croatan Sound	35°53'41" N 75°43'18" W	9

Station Number	Location on Geodetic Survey Chart	Coordinates	Approx. Depth (ft.)
11(103)	Bent 103 under Croatan Sound bridge	35°55'00" N 75°45'19" W	15
11(136)	Bent 136 under Croatan Sound bridge	35°55'08" N 75°44'54" W	20
11(214)	Bent 214 under Croatan Sound bridge	35°55'24" N 75°44'11" W	14
12	Bell north of Croatan Sound	35°56'42" N 75°46'40" W	12
13	Channel marker #29 in north Roanoke Sound	35°56'52" N 75°42'15" W	10
14	Channel marker #28 in north Roanoke Sound	35°56'30" N 75°39'30" W	8
15	Channel marker #18 in mid-Roanoke Sound	35°53'24" N 75°37'48" W	10

Other stations not listed above correspond to bridge bents along the Oregon Inlet and Croatan Sound bridges. These are designated by 2 or 11 respectively, followed by the bridge bent number. Depth, temperature, salinity, and velocity data are included in Appendices J and K for these stations. They are (along the inlet bridge):

2(132)

2(136)
2(138)
2(139)
2(140)
2(145)
2(149)
2(153)
2(157)
2(165)
2(166)
2(167)
2(176)
2(182)
2(188)
2(189)
2(195)

and (along the Croatan Sound bridge)

11(060)

11(075)
11(090)
11(105)
11(120)
11(135)
11(140)
11(150)
11(160)
11(175)
11(190)
11(205)
11(220)
11(235)
11(250)
11(265)
11(280)

Appendix G

Response Times (to Ebb and Flood) for Stations 3b, 4 and 5 near Oregon Inlet for 21-30 June, 1973

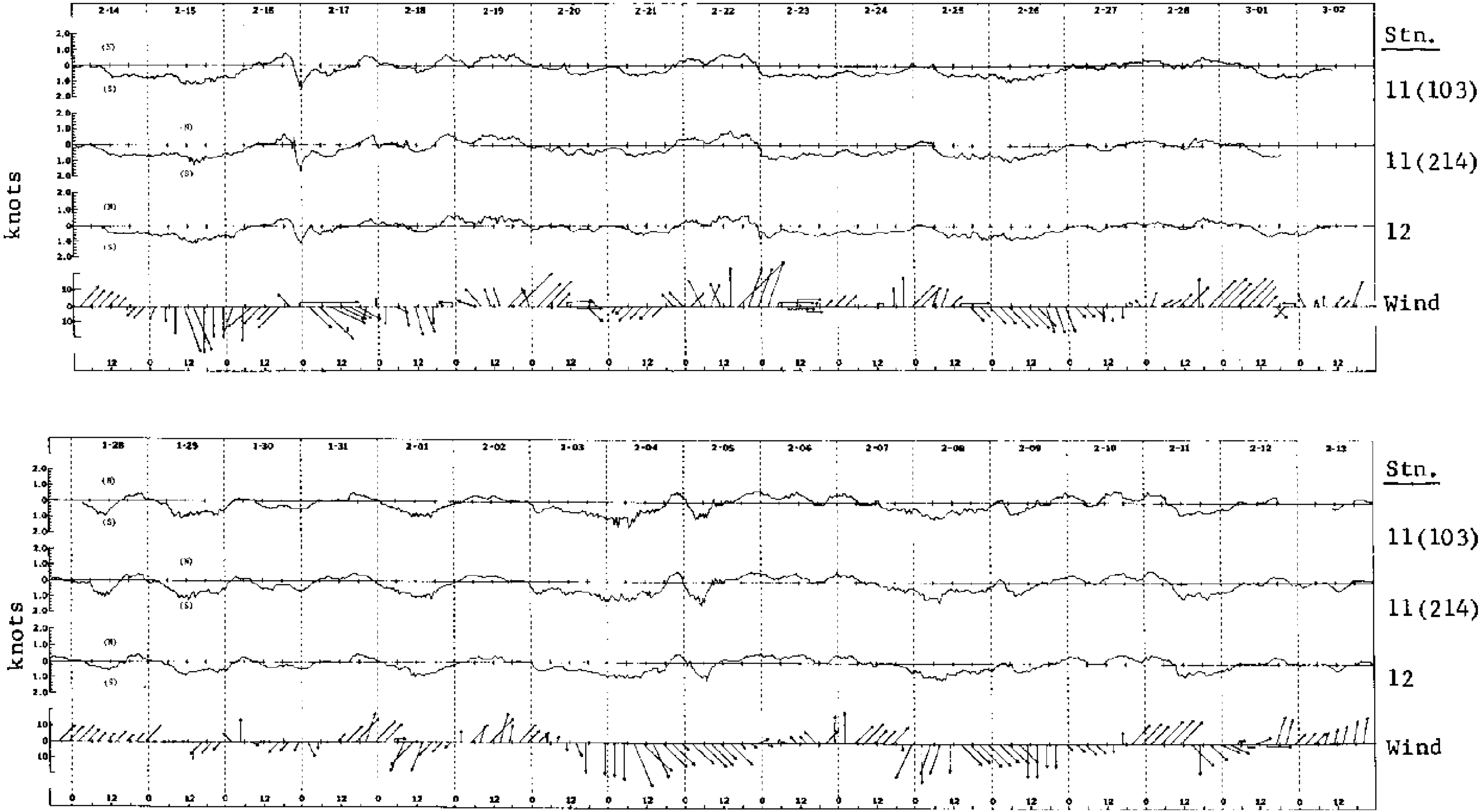
Values in parentheses indicate minutes difference from station 3a.

All times are accurate to within ± 5 minutes.

Date	3a	3b	4	5
6/21	1450 (E)	1430 (-20)	1505 (+15)	1540 (+50)
6/21	2210 (F)	2210 (0)	2250 (+40)	2300 (+50)
6/22	0300 (E)	0230 (-30)	0247 (-13)	0345 (+45)
6/22	1130 (F)	1145 (+15)	1200 (+30)	1200 (+30)
6/22	1610 (E)	1500 (-70)	1527 (-43)	1620 (+10)
6/22	2300 (F)	2245 (-15)	2320 (+20)	2340 (+40)
6/23	0330 (E)	0330 (0)	0350 (+20)	0445 (+75)
6/23	1150 (F)	1150 (0)	1210 (+20)	1240 (+50)
6/23	1650 (E)	1650 (0)	1655 (+05)	1740 (+50)
6/24	0007 (F)	2350 (-13)	0010 (+03)	0030 (+23)
6/24	0434 (E)	0430 (-04)	0450 (+16)	0520 (+46)
6/24	1130 (F)	1127 (-03)	1140 (+10)	1230 (+60)
6/24	1810 (E)	1820 (-10)	1830 (+20)	2030 (+140)
6/25	0000 (F)	2354 (-06)	0034 (+34)	0030 (+30)
6/25	0540 (E)	0530 (-10)	0550 (+10)	0620 (+40)
6/25	1150 (F)	1150 (0)	1214 (+24)	1254 (+64)
6/25	2010 (E)	1950 (-20)	2010 (0)	2130 (+80)
6/26	0050 (F)	0050 (0)	0110 (+20)	0130 (+40)
6/26	0647 (E)	0650 (+03)	0715 (+28)	0750 (+63)
6/26	1227 (F)	1210 (-17)	1240 (+13)	1250 (+23)
6/26	2045 (E)	2040 (-05)	2047 (+02)	2100 (+15)
6/27	0300 (F)	0300 (0)	0254 (-06)	0310 (+10)
6/27	0710 (E)	0650 (-20)	0710 (0)	0930 (+140)
6/27	1425 (F)	1420 (-05)	1447 (+22)	1450 (+25)
6/27	2040 (E)	2040 (0)	2034 (-06)	2350 (+190)
6/28	0410 (F)	0420 (+10)	0434 (+24)	0430 (+20)
6/28	0827 (E)	0820 (-07)	0820 (-07)	0930 (+63)
6/28	1527 (F)	1520 (-07)	1540 (+13)	1625 (+58)
6/28	2127 (E)	2120 (-07)	2135 (+08)	0040 (+193)
6/29	0540 (F)	0550 (+10)	0620 (+40)	0630 (+50)
6/29	0920 (E)	0840 (-40)	0900 (-20)	0940 (+20)
6/29	1700 (F)	1630 (-30)	1655 (-05)	1730 (+30)
6/29	2200 (E)	2200 (0)	2227 (+27)	0100 (+180)
6/30	0630 (F)	0620 (-10)	0640 (+10)	0710 (+30)
6/30	1030 (E)	1010 (-20)	1040 (+10)	1140 (+70)

Appendix H

Flow in North Croatan Sound



Legend: (N) = Northerly Flow (S) = Southerly Flow

Figure H1. Flow in response to the winds in north Croatan Sound as recorded by bottom mounted current meters at stations 11(103), 11(214) and 12 during the second study period (27 January - 3 March, 1974)

Appendix I

Circulation in the Sounds

Data have been selected to illustrate the general observations of circulation in Roanoke and Croatan Sounds which were discussed in the text. A natural time sequence of events is followed beginning with Map (B) of Figure 11 showing northerly flow in Croatan Sound during a period of SW winds at 8 knots. Map (C) shows these same stations some 5 hours later when the winds were calm and all northerly flow had essentially ceased. In Map (D), still during this period of calm winds, it is noted that the waters which had been backed up to the north during SW winds were now flowing south with considerable velocity. This flow continued for some 16 hours and 30 minutes for a total of nearly 24 hours of sustained southerly flow. Map (E) shows the final transition state for the commencement of northerly flow again as SE winds begin to dominate.

Maps (D) and (F) illustrate some general trends that were observed in the data for station 7 at the south end of Croatan Sound. To begin with, during periods of high southerly flow in Croatan Sound, the data suggest that at least some of the flow hugged the western shore of Pamlico Sound instead of being directed towards the inlet. This can be seen in Map (D). This trend perhaps physically explains surface salinity data compiled by H. R. Seiwell for January, 1927, and presented in Marshall (1951), and by Williams *et al.* (1973) depicting the intrusion of less saline waters from Albemarle Sound down through Croatan Sound and along the western shore of Pamlico Sound at least to Long Shoal Point some 10 miles

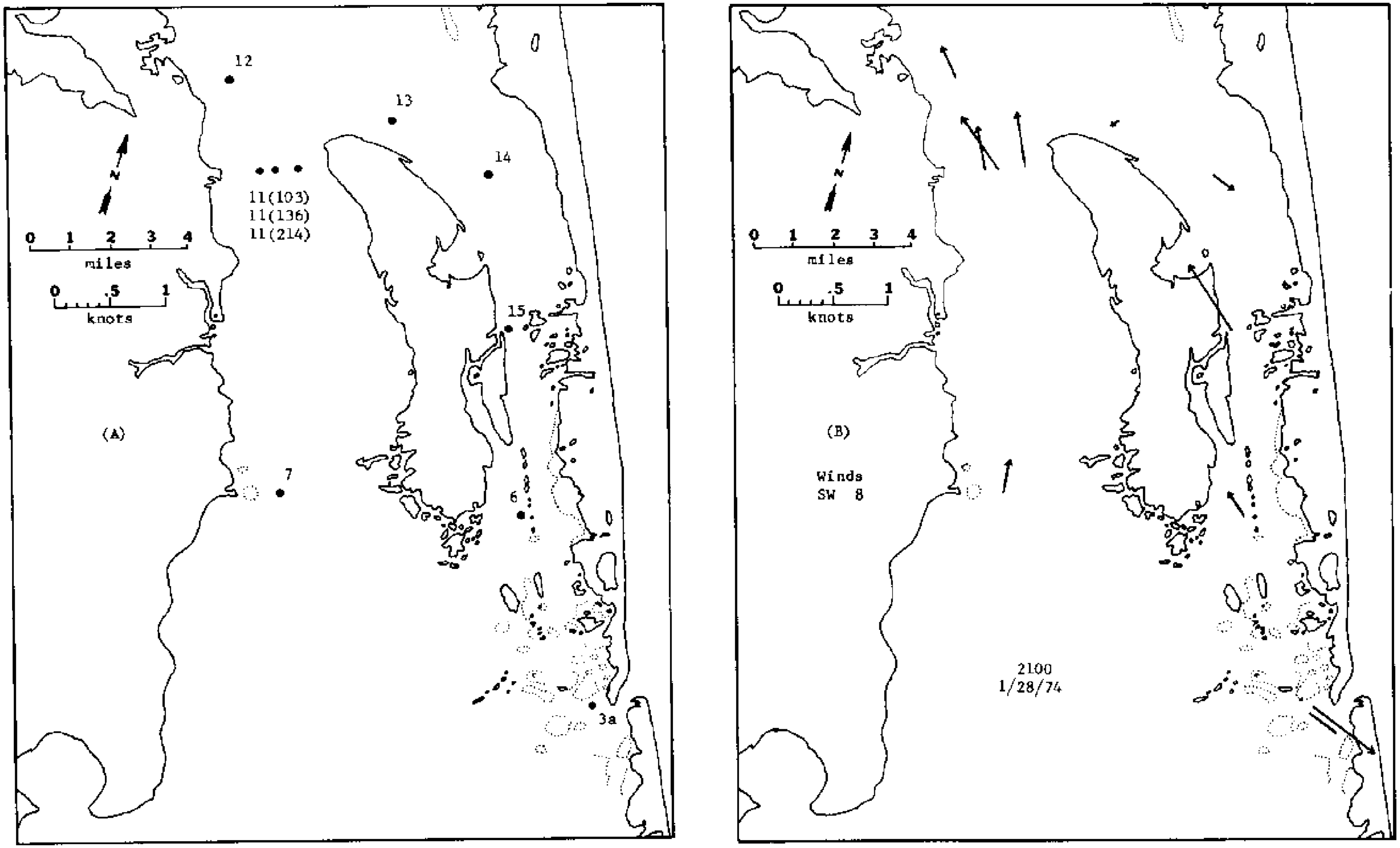


Figure 11. Maps showing stations and the various flow conditions observed in the sounds during the second study period

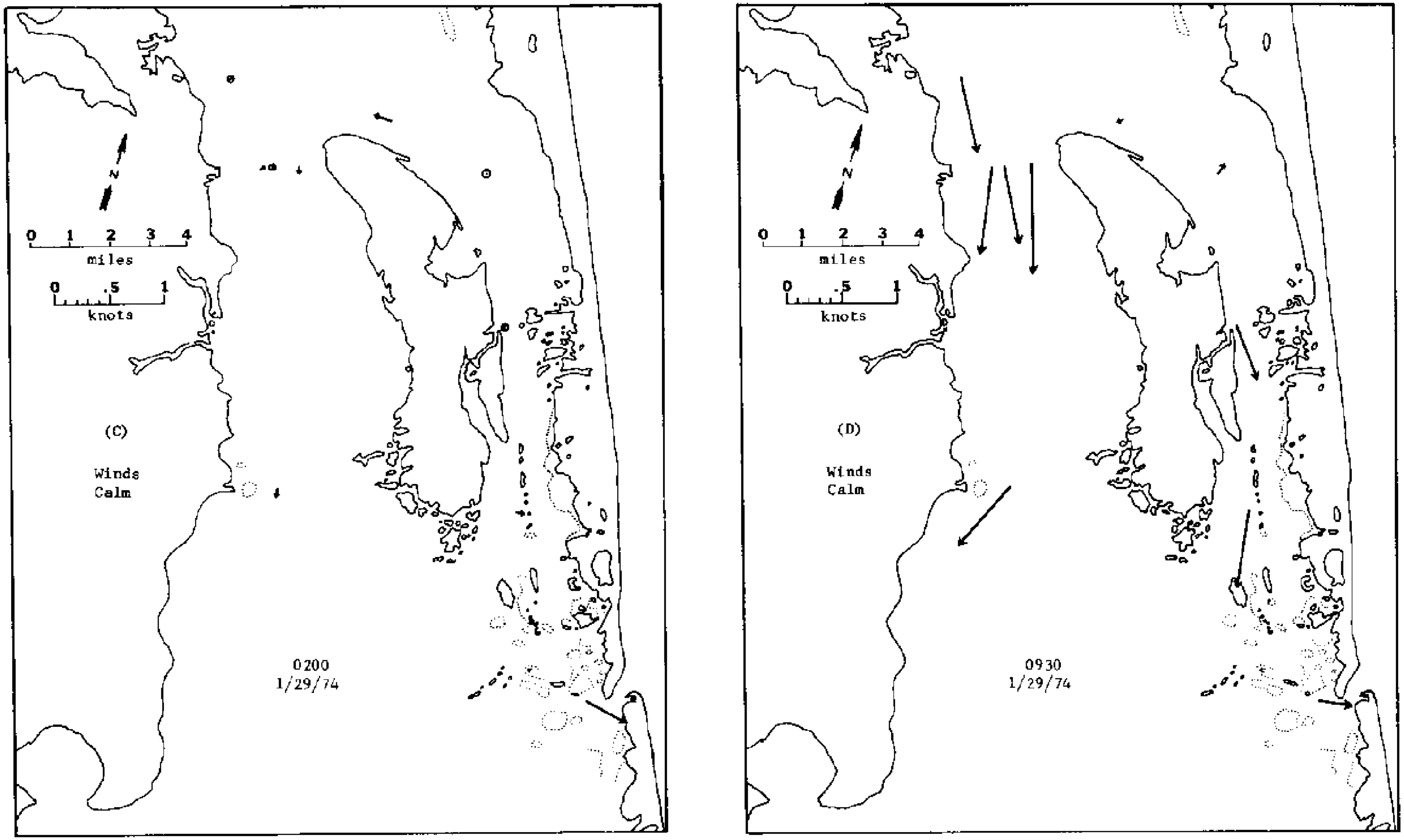


Figure I1 (continued)

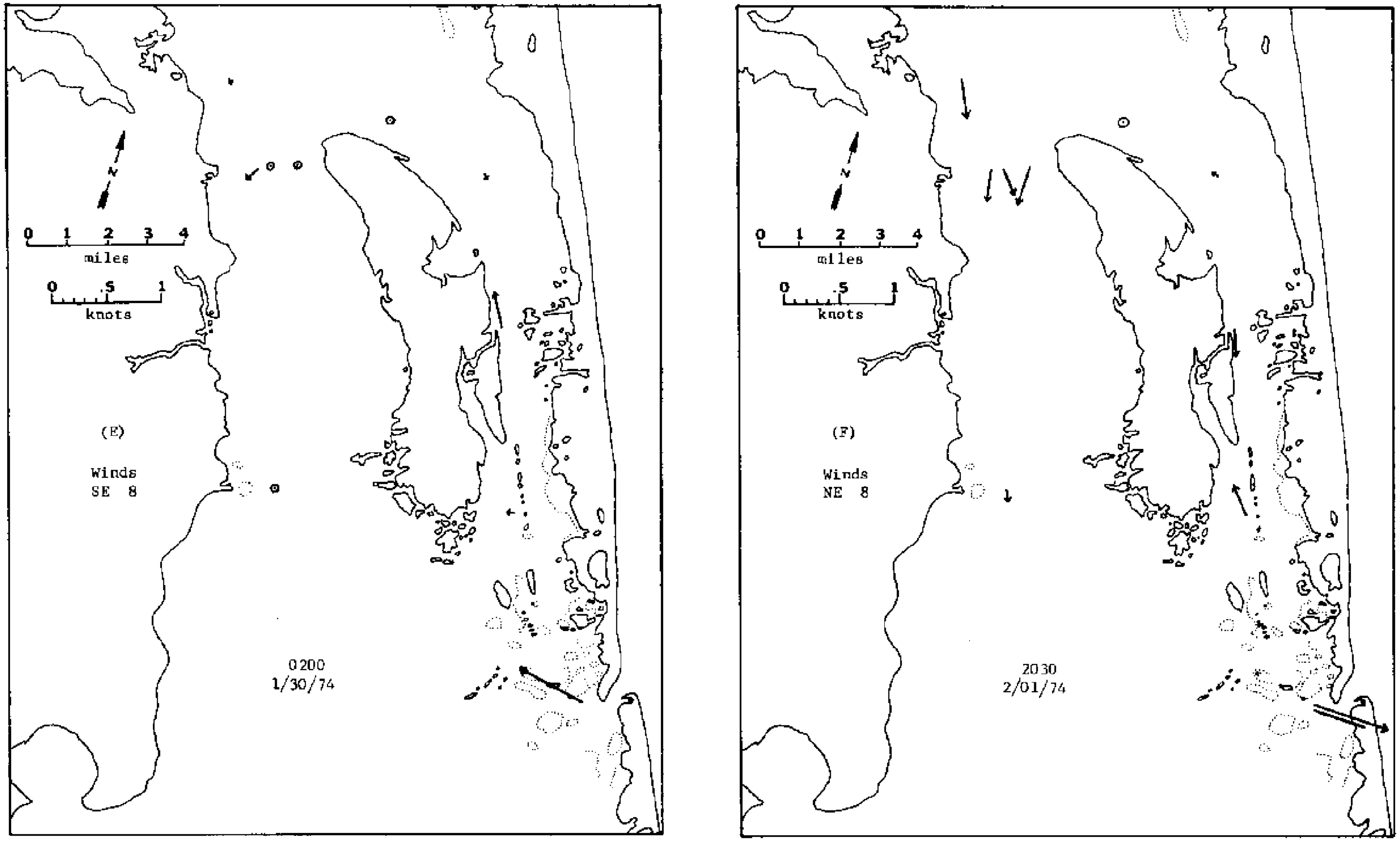


Figure I1 (continued)

(16 km) SSW of Stumpy Point. During periods of lesser flow in Croatan Sound, it was not unusual to observe currents similar in both speed and direction shown in Map (F).

For north Roanoke Sound (stations 13 and 14) it has been reported in the text that generally the flow here is quite random and of low velocity as compared to other stations (*i.e.* in north Croatan Sound). It was noted that the greatest directional fluctuation generally came as the velocities increased in conjunction with northerly winds. Maps (B), (D), and (F) depict this same randomness for three different wind conditions (*i.e.*, SW, calm and NE).

In mid-Roanoke Sound (station 15) it was reported that the events here generally paralleled those in north Croatan Sound in both direction and magnitude. This is illustrated in all of the figures except for Map (E). Here, during the transition stage, station 15 recorded significant northerly flow about 1 hour earlier than did those stations in north Croatan Sound.

Finally, flow at station 6 in south Roanoke Sound is depicted as agreeing in trend with flow in Croatan Sound during both southerly and calm wind conditions (see Maps (B), (C), (D) and (E)). However, Map (F) relates northerly flowing waters at station 6 during NE winds. This is also in conjunction with southerly flow in mid-Roanoke Sound and ebb at the inlet. All three factors, it would seem, would tend to work against such a likelihood. However, as reported in the text, it has been found that northerly winds in lengthening floods at the inlet also enhance northerly flow in south Roanoke Sound. Consequently, what is seen in Map (F) is the continued influence (momentum head) of the preceding flood still inducing northerly flow in opposition to the southerly flowing waters to the north. These more dense waters apparently flow under the less dense surface waters flowing towards the inlet.

The influence of northerly winds on flow in south Roanoke Sound is perhaps further illustrated by the knowledge that the preceding flood lasted some 7 hours and 50 minutes. In addition, the ebb in Map (F) began in excess of two hours earlier.

Appendix J

Vertical Profile Data for Stations 1 through 6

from 26 June through 29 June, 1973

In the data which follows, all salinities have been corrected by adding 2.66 ppt. Times are in EDT. Current directions are magnetic readings. Tidal states correspond to those recorded by the in situ bottom mounted current meter at station 3a. The values in parentheses adjacent to the tidal states correspond to the number of minutes which must be added to or subtracted from the tidal state at station 3a to get the tidal state at station 3b. These two units are the closest ones to the inlet from which tidal states could be determined and are given simply as reference.

Station # 1 (26 June)

Time Down 1117 Time Up 1126
1117 = Ebb + 4 hr. 30 min. (-3)
Fathometer Depth 22.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.5	29.51	1.10	030
6.0	21.4	29.57	1.10	025
9.0	21.4	29.57	0.96	020
12.0	21.4	29.57	0.90	025
15.0	21.4	29.57	0.80	025
18.0	21.4	29.57	0.74	025

Time Down 1346 Time Up 1355
1346 = Flood + 1 hr. 19 min. (+17)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.4	28.81	1.80	220
6.0	21.4	28.81	1.70	220
9.0	21.4	28.81	1.80	230
12.0	21.5	28.74	1.74	220
15.0	21.4	28.81	1.60	220
18.0	21.4	28.81	1.60	225

Time Down 1600   Time Up 1604
1600 = Flood + 3 hr. 33 min.   (+17)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kt)	C. Dir. (deg)
3.0	21.5	28.74	2.00	220
6.0	21.4	29.57	1.80	220
9.0	21.4	28.81	1.90	220
12.0	21.4	29.57	1.94	220
15.0	21.4	29.57	1.90	220
18.0	21.4	29.57	1.80	220

Station # 1 (27 June)

Time Down 0927   Time Up 0934
0927 = Ebb + 2 hr. 17 min.   (+20)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	27.13	2.40	030
6.0	23.0	27.13	2.80	030
9.0	23.0	27.13	2.20	030
12.0	23.0	27.86	2.20	035
15.0	22.8	27.98	2.00	040
18.0	22.8	27.98	2.40	035
21.0	22.8	27.98	1.80	035

Time Down 1127   Time Up 1134
1127 = Ebb + 4 hr. 17 min.   (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	25.16	2.40	030
6.0	24.0	25.16	2.60	030
9.0	24.0	25.16	2.40	030
12.0	24.0	25.16	2.00	030
15.0	24.0	25.16	2.00	030
18.0	24.0	25.16	1.40	030
21.0	24.0	25.16	1.40	030

Station # 1 (28 June)

Time Down 1327 Time Up 1333
1327 = Ebb + 5 hr. (+7)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	16.70	1.74	030
6.0	27.0	16.55	1.80	030
9.0	27.0	16.55	1.70	035
12.0	27.0	16.55	1.76	040
15.0	27.0	16.55	1.84	030
18.0	27.0	16.55	1.60	025

Time Down 1540 Time Up 1546
1540 = Flood + 13 min. (+7)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.2	15.55	0.12	270
6.0	27.2	15.86	0.06	265
9.0	27.2	15.86	0.10	260
12.0	27.2	16.49	0.12	250
15.0	27.5	16.41	0.20	215
18.0	27.2	16.49	0.16	215

Station # 1 (29 June)

Time Down 1030 Time Up 1037
1030 = Ebb + 1 hr. 10 min. (+40)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	17.17	3.20	050
6.0	25.0	18.51	2.80	040
9.0	24.8	19.25	3.00	040
12.0	24.0	21.63	2.80	040
15.0	23.5	21.84	2.40	040
18.0	22.0	24.34	2.40	045

Time Down 1400 Time Up 1405
1400 = Ebb + 4 hr. 40 min. (+40)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.7	14.11	2.20	030
6.0	26.7	14.23	2.50	030
9.0	26.8	14.71	2.30	035
12.0	26.8	14.84	2.40	035
15.0	26.9	15.00	2.60	030
18.0	26.9	15.25	2.30	040
21.0	27.0	15.29	2.40	030

Time Down 1515 Time Up 1523
1515 = Ebb + 5 hr. 55 min. (+40)
Fathometer Depth 22.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.4	14.81	2.40	055
6.0	26.8	14.71	2.00	030
9.0	26.7	14.74	1.80	035
12.0	26.8	14.71	1.80	030
15.0	26.8	15.22	1.70	040
18.0	26.9	15.25	1.64	030
21.0	26.9	15.25	1.50	035

Station # 2a (26 June)

Time Down 1100 Time Up 1108
1100 = Ebb + 4 hr. 13 min. (-3)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	27.50	1.00	090
6.0	23.0	27.13	1.00	090
9.0	23.0	27.13	0.80	095
12.0	23.0	27.13	0.70	080
15.0	23.0	27.13	0.80	080

Time Down 1254 Time Up 1304
1254 = Flood + 27 min. (+17)
Fathometer Depth 18.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	27.86	1.06	255
6.0	23.0	28.68	0.80	260
9.0	23.0	28.68	0.72	260
12.0	23.0	28.68	0.80	260
15.0	22.9	28.73	0.76	260
18.0	23.0	28.60	0.60	260

Time Down 1324 Time Up 1333
1324 = Flood + 57 min. (+17)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	28.01	1.46	270
6.0	23.0	28.01	1.50	265
9.0	23.0	28.01	1.50	265
12.0	23.0	27.94	1.40	270
15.0	23.0	28.01	1.40	270

Time Down 1403 Time Up 1408
1403 = Flood + 1 hr. 36 min. (+17)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.5	28.74	2.20	260
6.0	21.5	28.74	2.20	260
9.0	21.5	29.51	2.20	260
12.0	21.5	29.51	2.00	270
15.0	21.5	29.51	2.00	270

Time Down 1504 Time Up 1509
1504 = Flood + 2 hr. 37 min. (+17)
Fathometer Depth 17.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.5	28.74	3.00	255
6.0	21.5	28.74	2.60	260
9.0	21.5	29.51	2.60	265
12.0	21.5	28.74	2.10	270
15.0	21.4	28.81	2.20	275

Time Down 1612 Time Up 1615
1612 = Flood + 3 hr. 45 min. (+17)
Fathometer Depth 15.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.3	28.87	3.00	255
6.0	21.3	28.87	2.60	265
9.0	21.3	28.87	2.80	270
12.0	21.3	28.87	2.60	265

Station # 2a (27 June)

Time Down 0910 Time Up 0922
0910 = Ebb + 2 hr. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	26.40	2.10	065
6.0	23.0	26.40	1.90	070
9.0	23.0	26.40	1.80	070
12.0	22.8	27.24	1.64	060
15.0	22.8	26.50	1.64	065
18.0	22.8	27.24	1.30	065
21.0	22.8	27.24	1.60	070

Time Down 1007 Time Up 1013
1007 = Ebb + 2 hr. 57 min. (+20)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.1	26.34	2.00	070
6.0	23.1	26.34	1.90	080
9.0	23.1	26.34	2.00	090
12.0	23.0	26.40	1.56	080
15.0	23.1	26.34	1.60	080
18.0	23.1	27.07	1.50	080
21.0	23.1	24.89	1.32	070

Time Down 1115 Time Up 1120
1115 = Ebb + 4 hr. 5 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	25.16	2.20	070
6.0	24.0	25.16	1.80	090
9.0	24.0	25.16	1.90	080
12.0	24.0	25.16	1.64	080
15.0	24.0	25.16	1.70	080
18.0	24.0	25.16	1.50	080
21.0	24.0	25.16	1.26	060

Time Down 1209 Time Up 1214
1209 = Ebb + 4 hr. 59 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.9	24.01	2.20	080
6.0	25.0	23.97	1.60	080
9.0	25.0	23.97	1.60	080
12.0	25.0	23.97	1.60	075
15.0	25.0	23.97	1.40	075
18.0	25.0	23.97	1.20	080
21.0	25.0	23.97	0.80	070

Time Down 1258 Time Up 1301
1258 = Ebb + 5 hr. 48 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.2	21.81	1.64	075
6.0	25.2	21.81	1.60	080
9.0	25.2	21.81	1.50	085
12.0	25.1	21.86	1.30	080
15.0	25.2	22.50	1.20	080
18.0	25.2	22.50	1.08	080
21.0	25.2	22.50	1.00	080

Time Down 1335 Time Up 1339
1335 = Ebb + 6 hr. 25 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.5	21.01	1.16	080
6.0	25.5	21.01	1.16	080
9.0	25.7	21.61	0.94	085
12.0	25.6	20.97	1.00	080
15.0	25.6	20.97	0.70	075
18.0	25.8	21.56	0.80	075
21.0	25.8	20.89	0.60	070

Time Down 1408 Time Up 1414
1408 = Ebb + 6 hr. 58 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	20.81	0.64	065
6.0	26.0	20.81	0.50	080
9.0	26.0	20.81	0.40	085
12.0	26.0	20.81	0.36	080
15.0	26.0	20.81	0.36	070
18.0	26.0	20.81	0.40	060
21.0	26.0	20.81	0.36	065

Time Down 1430 Time Up 1434
1430 = Flood + 5 min. (+5)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	20.81	0.04	130
6.0	26.1	20.77	0.04	145
9.0	26.0	20.81	0.10	140
12.0	26.0	20.81	0.10	140
15.0	26.0	20.81	0.06	120
18.0	26.0	20.81	0.08	100

Time Down 1435 Time Up 1440
1435 = Flood + 10 min. (+5)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	20.81	0.30	280
6.0	26.2	20.73	0.26	245
9.0	26.0	20.81	0.30	215
12.0	26.0	20.81	0.36	205
15.0	26.0	20.81	0.24	225
18.0	26.0	20.81	0.32	195

Time Down 1440 Time Up 1445
1440 = Flood + 15 min. (+5)
Fathometer Depth 20.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.1	20.77	0.36	250
6.0	26.1	20.77	0.44	240
9.0	26.1	20.77	0.40	240
12.0	26.1	20.77	0.36	250
15.0	26.0	20.81	0.40	260
18.0	26.0	20.81	0.40	260

Time Down 1450 Time Up 1455
1450 = Flood + 25 min. (+5)
Fathometer Depth 19.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	20.15	0.44	270
6.0	26.0	20.81	0.40	270
9.0	26.0	20.81	0.42	280
12.0	26.0	20.15	0.44	270
15.0	26.0	20.81	0.30	255
18.0	26.1	21.44	0.28	240

Station # 2a (28 June)

Time Down 0639 Time Up 0644
0639 = Flood + 2 hr. 29 min. (-10)
Fathometer Depth 18.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.5	22.81	1.00	235
6.0	24.0	24.44	1.10	240
9.0	23.9	24.49	0.94	270
12.0	23.7	25.31	0.86	275
15.0	23.5	25.41	0.80	280

Time Down 0907 Time Up 0912
0907 = Ebb + 40 min. (+7)
Fathometer Depth 16.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.3	22.20	2.06	100
6.0	24.0	23.74	1.80	105
9.0	24.0	23.74	1.70	090
12.0	24.0	23.74	1.50	075
15.0	24.0	24.44	1.30	080

Time Down 1342 Time Up 1345
1342 = Ebb + 5 hr. 15 min. (+7)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.0	15.29	1.50	080
6.0	27.0	15.29	1.34	075
9.0	27.0	15.29	1.40	070
12.0	27.0	15.29	1.30	080
15.0	27.0	15.29	1.10	080

Time Down 1745 Time Up 1748
1745 = Flood + 2 hr. 18 min. (+7)
Fathometer Depth 16.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	20.6	30.08	3.20	210
6.0	20.5	30.14	2.80	240
9.0	20.7	30.01	2.80	250
12.0	20.5	30.14	2.60	260
15.0	20.5	30.14	2.60	255

Station # 2a (29 June)

Time Down 1013 Time Up 1021
1013 = Ebb + 53 min. (+40)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.5	15.70	1.64	090
6.0	25.6	15.67	1.94	090
9.0	25.8	15.62	1.90	090
12.0	25.8	15.62	1.44	080
15.0	25.9	15.65	1.28	080
18.0	25.9	15.65	0.98	080

Time Down 1345 Time Up 1350
1345 = Ebb + 4 hr. 25 min. (+40)
Fathometer Depth 17.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.8	14.08	2.20	080
6.0	26.8	14.08	2.40	085
9.0	27.0	14.03	2.00	085
12.0	27.0	14.03	1.60	080
15.0	27.0	14.03	1.48	085

Time Down 1530 Time Up 1535
1530 = Ebb + 6 hr. 10 min. (+40)
Fathometer Depth 17.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.7	14.11	1.50	080
6.0	26.8	14.08	1.60	090
9.0	26.9	14.06	1.30	090
12.0	27.0	14.03	1.00	080
15.0	27.0	14.03	1.24	080

Station # 2b (26 June)

Time Down 1525 Time Up 1534
1525 = Flood + 2 hr. 58 min. (+17)
Fathometer Depth 24.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.8	28.72	1.40	190
6.0	22.8	28.72	1.70	195
9.0	22.8	28.72	1.60	190
12.0	22.8	28.72	1.80	195
15.0	22.8	28.72	1.70	190
18.0	22.8	28.72	1.70	195
21.0	22.8	28.72	1.70	190

Station # 2b (27 June)

Time Down 0945 Time Up 0951
0945 = Ebb + 2 hr. 35 min. (+20)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	27.86	2.40	360
6.0	23.0	27.86	1.84	360
9.0	23.0	27.86	1.90	340
12.0	23.0	27.86	1.80	020
15.0	23.0	27.86	1.60	350
18.0	23.0	27.86	1.50	020

Time Down 1230 Time Up 1235
1230 = Ebb + 5 hr. 20 min. (+20)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.2	21.13	1.24	350
6.0	25.0	21.21	1.24	300
9.0	25.2	21.13	1.52	350
12.0	25.2	21.13	1.38	360
15.0	25.2	21.13	1.40	360
18.0	25.2	21.13	1.26	360
21.0	25.2	21.13	1.10	360

Station # 2b (28 June)

Time Down 0755 Time Up 0800
0755 = Flood + 3 hr. 45 min. (-10)
Fathometer Depth 22.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	21.21	0.10	030
6.0	24.0	25.51	0.14	025
9.0	23.5	26.13	0.16	025
12.0	23.2	27.75	0.20	035
15.0	23.0	27.86	0.20	050
18.0	22.3	28.27	0.20	090
21.0	22.2	28.33	0.06	150

Time Down 1314 Time Up 1320
1314 = Ebb + 4 hr. 47 min. (+7)
Fathometer Depth 19.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	17.35	1.10	020
6.0	26.5	17.35	0.90	010
9.0	27.0	17.83	0.80	010
12.0	27.0	17.83	0.90	015
15.0	27.0	17.83	1.00	350
18.0	27.0	17.83	0.46	310

Time Down 1522   Time Up 1530
1522 = Ebb + 6 hr. 55 min.   (+7)
Fathometer Depth 20.0

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.5	16.41	0.02	360
6.0	27.5	16.41	0.02	310
9.0	27.5	16.41	0.06	300
12.0	27.6	16.39	0.04	295
15.0	27.8	16.32	0.06	300
18.0	28.0	17.51	0.00	***

Time Down 1701   Time Up 1715
1701 = Flood + 1 hr. 34 min.   (+7)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.5	24.91	0.20	190
6.0	23.1	27.07	0.10	210
9.0	23.0	27.13	0.10	210
12.0	22.5	28.90	0.10	210
15.0	22.2	29.08	0.30	210
18.0	22.1	29.54	0.66	190

Station # 2b (29 June)

Time Down 1000   Time Up 1008
1000 = Ebb + 40 min.   (+40)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	17.17	2.40	025
6.0	25.0	17.84	2.20	015
9.0	24.5	18.68	1.60	285
12.0	24.7	19.97	1.36	300
15.0	24.0	21.28	1.12	300
18.0	22.1	24.66	0.58	305
21.0	21.0	27.28	0.38	040

Time Down 1334 Time Up 1340
1334 = Ebb + 4 hr. 14 min. (+40)
Fathometer Depth 19.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	16.86	2.50	030
6.0	26.0	16.86	2.00	090
9.0	26.5	16.70	1.20	360
12.0	26.7	16.64	1.60	360
15.0	27.0	16.55	2.00	040
18.0	27.0	16.55	1.00	360

Station # 2(132) (28 June)

Time Down 0614 Time Up 0619
0614 = Flood + 2 hr. 4 min. (-10)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.9	22.63	0.80	270
6.0	24.9	22.63	0.60	270

Time Down 0854 Time Up 0856
0854 = Ebb + 27 min. (+7)
Fathometer Depth 6.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	23.03	1.10	080
6.0	23.6	24.64	0.60	070

Time Down 1757 Time Up 1800
1757 = Flood + 2 hr. 30 min. (+7)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.0	29.82	1.30	210
6.0	21.0	29.82	1.04	240

Station # 2(136) (28 June)

Time Down 0624 Time Up 0629
0624 = Flood + 2 hr. 14 min. (-10)
Fathometer Depth 10.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.8	22.67	0.70	265
6.0	24.7	22.99	0.70	270
9.0	24.5	24.20	0.70	280

(28 June)
Stations # 2(140), 2(138), and 2(139) Respectively

Time Down 0630 Time Up 0635
0630 = Flood + 2 hr. 20 min. (-10)
Fathometer Depth 15.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.5	23.50	0.80	250
6.0	24.5	24.20	0.80	265
9.0	24.3	24.30	1.00	270
12.0	24.0	24.80	0.90	270

Time Down 0900 Time Up 0903
0900 = Ebb + 33 min. (+7)
Fathometer Depth 11.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	24.44	1.70	080
6.0	23.5	24.69	1.40	085
9.0	23.5	25.05	1.00	080

Time Down 1750 Time Up 1754
1750 = Flood + 2 hr. 23 min. (+7)
Fathometer Depth 13.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	20.0	29.68	2.00	190
6.0	20.0	29.68	2.00	230
9.0	20.0	29.68	2.00	250
12.0	20.0	29.68	2.00	250

Station # 2(145) (28 June)

Time Down 0646 Time Up 0648
0646 = Flood + 2 hr. 36 min. (-10)
Fathometer Depth 14.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	23.74	0.60	255
6.0	23.8	24.54	0.80	250
9.0	24.0	25.87	0.80	250
12.0	24.0	25.87	0.80	250

Time Down 0915 Time Up 0920
0915 = Ebb + 48 min. (+7)
Fathometer Depth 12.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.5	22.81	1.64	080
6.0	24.5	22.81	1.52	085
9.0	24.5	22.81	1.00	080
12.0	24.5	22.81	1.00	080

Station # 2(149) (28 June)

Time Down 0653 Time Up 0658
0653 = Flood + 2 hr. 43 min. (-10)
Fathometer Depth 16.0 ft.

D(ft)	T(^{o}C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	25.16	0.80	265
6.0	23.0	26.40	0.50	240
9.0	22.6	27.35	0.50	240
12.0	22.5	28.00	0.46	240
15.0	22.2	28.33	0.50	245

Station # 2(153) (28 June)

Time Down 0705 Time Up 0715
0705 = Flood + 2 hr. 55 min. (-10)
Fathometer Depth 24.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.8	25.97	0.70	260
6.0	23.7	26.02	0.74	240
9.0	23.1	27.07	0.76	230
12.0	23.0	27.86	0.64	225
15.0	22.4	28.21	0.60	210
18.0	22.2	28.33	0.46	210
21.0	22.2	28.33	0.40	225
24.0	22.1	28.39	0.40	220

Time Down 0923 Time Up 0931
0923 = Ebb + 56 min. (+7)
Fathometer Depth 28.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	21.21	1.10	035
6.0	25.0	21.90	1.04	035
9.0	25.0	21.21	1.04	035
12.0	25.0	21.90	1.00	030
15.0	24.7	22.72	0.96	035
18.0	24.5	22.81	0.96	035
21.0	24.5	23.50	0.66	015
24.0	24.5	22.81	0.40	015
27.0	24.3	23.60	0.10	020

Station # 2(157) (28 June)

Time Down 0718 Time Up 0726
0718 = Flood + 3 hr. 8 min. (-10)
Fathometer Depth 27.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.5	26.13	0.40	220
6.0	23.5	26.13	0.50	220
9.0	23.3	26.60	0.42	210
12.0	23.1	27.81	0.36	210
15.0	23.0	27.86	0.48	200
18.0	22.6	28.09	0.50	210
21.0	22.2	28.33	0.48	205
24.0	22.0	28.45	0.52	190

Time Down 1732 Time Up 1730
1732 = Flood + 2 hr. 5 min. (+7)
Fathometer Depth 25.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.0	29.96	2.00	210
6.0	22.0	29.96	1.84	210
9.0	21.5	30.28	1.70	210
12.0	21.5	30.28	1.60	210
15.0	21.5	30.28	1.70	225
18.0	21.5	30.28	1.30	225
21.0	21.5	30.28	1.40	210
24.0	21.5	30.28	1.30	220

(28 June)
Stations # 2(167), 2(165), and 2(166) Respectively

Time Down 0729 Time Up 0731
0729 = Flood + 3 hr. 19 min. (-10)
Fathometer Depth 21.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.1	26.34	0.46	210
6.0	23.0	26.40	0.40	215
9.0	22.5	28.15	0.32	215
12.0	22.2	28.33	0.20	215
15.0	22.1	27.64	0.14	215
18.0	22.0	28.45	0.12	200

Time Down 0936 Time Up 0940
0936 = Ebb + 1 hr. 9 min. (+7)
Fathometer Depth 19.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.8	22.67	1.10	020
6.0	24.8	22.67	1.24	015
9.0	24.8	23.02	1.00	310
12.0	24.8	23.02	1.20	020
15.0	24.6	22.76	1.00	020
18.0	24.5	23.50	0.90	020

Time Down 1724 Time Up 1730
1724 = Flood + 1 hr. 57 min. (+7)
Fathometer Depth 18.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.5	29.65	1.90	200
6.0	22.5	28.90	1.80	200
9.0	22.0	29.96	1.70	200
12.0	22.0	29.96	1.60	190
15.0	22.0	30.72	1.50	190

Station # 2(176) (28 June)

Time Down 1720 Time Up 1723
1720 = Flood + 1 hr. 53 min. (+7)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.5	28.90	1.60	140
6.0	22.5	29.65	1.48	200

Station # 2(182) (28 June)

Time Down 0945 Time Up 0950
0945 = Ebb + 1 hr. 18 min. (+7)
Fathometer Depth 20.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	21.21	2.40	030
6.0	25.0	21.21	2.00	030
9.0	25.0	21.90	1.74	360
12.0	25.0	21.21	1.80	360
15.0	25.0	21.21	1.70	300
18.0	25.0	21.90	1.60	310

Stations # 2(188) and 2(189) Respectively (28 June)

Time Down 1003   Time Up 1008
1003 = Ebb + 1 hr. 36 min. (+7)
Fathometer Depth 15.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.5	20.34	1.90	010
6.0	25.5	20.34	1.90	020
9.0	25.5	20.34	1.90	010
12.0	25.5	20.34	1.70	010
15.0	25.7	20.26	0.96	360

Time Down 1654   Time Up 1700
1654 = Flood + 1 hr. 27 min. (+7)
Fathometer Depth 17.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	22.58	0.80	170
6.0	25.0	23.27	0.54	180
9.0	25.0	23.97	0.30	190
12.0	24.0	25.16	0.04	180
15.0	24.0	25.16	0.06	170

Station # 2(195) (28 June)

Time Down 0957   Time Up 1000
0957 = Ebb + 1 hr. 30 min. (+7)
Fathometer Depth 5.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.5	21.69	0.96	010
5.0	25.5	21.01	0.20	300

Station # 3a (26 June)

Time Down 1036   Time Up 1055
1036 = Ebb + 3 hr. 49 min. (-3)
Fathometer Depth 13.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.0	26.40	1.40	115
6.0	23.0	27.13	1.40	120
9.0	23.0	27.13	1.50	115
12.0	23.0	27.13	1.10	100

Time Down 1633 Time Up 1637
1633 = Flood + 4 hr. 6 min. (+17)
Fathometer Depth 15.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.5	28.74	2.40	290
6.0	21.5	28.74	2.20	290
9.0	21.5	28.74	2.20	295
12.0	21.5	28.74	2.20	300
15.0	21.5	28.74	2.00	300

Station # 3a (27 June)

Time Down 1105 Time Up 1108
1105 = Ebb + 3 hr. 55 min. (+20)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	25.16	2.40	100
6.0	24.0	25.87	2.40	110
9.0	24.0	25.87	2.00	115

Time Down 1245 Time Up 1253
1245 = Ebb + 5 hr. 35 min. (+20)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.2	21.13	1.40	090
6.0	25.2	21.81	1.50	110
9.0	25.2	21.81	1.56	110
12.0	25.2	21.81	1.24	110

Time Down 1500 Time Up 1505
1500 = Flood + 35 min. (+5)
Fathometer Depth 16.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.1	20.11	0.80	290
6.0	26.1	20.77	0.78	290
9.0	26.0	21.48	0.80	295
12.0	26.0	21.48	0.78	295
15.0	26.0	21.48	0.72	295

Station # 3a (28 June)

Time Down 0842 Time Up 0847
0842 = Ebb + 15 min. (+7)
Fathometer Depth 14.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	21.21	1.14	100
6.0	24.1	24.40	1.06	100
9.0	24.0	24.44	0.80	110
12.0	23.7	24.73	0.54	100

Time Down 1254 Time Up 1257
1254 = Ebb + 4 hr. 27 min. (+7)
Fathometer Depth 11.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	15.56	1.90	090
6.0	26.0	15.56	1.80	110
9.0	26.0	15.56	1.70	110

Time Down 1556 Time Up 1601
1556 = Flood + 29 min. (+7)
Fathometer Depth 17.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.5	14.53	0.26	270
6.0	27.5	14.53	0.20	265
9.0	27.6	14.51	0.16	270
12.0	27.6	14.51	0.14	270
15.0	27.8	14.46	0.20	270

Station # 3a (29 June)

Time Down 1045 Time Up 1048
1045 = Ebb + 1 hr. 25 min. (+40)
Fathometer Depth 13.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	15.50	2.40	090
6.0	26.0	15.50	2.20	105
9.0	26.0	15.50	1.90	107
12.0	26.0	15.50	1.74	110

Time Down 1411   Time Up 1415
1411 = Ebb + 4 hr. 51 min.   (+40)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.0	13.91	2.40	130
6.0	27.0	14.03	2.40	140
9.0	26.9	14.06	2.20	130
12.0	27.0	14.03	2.40	140

Time Down 1540   Time Up 1543
1540 = Ebb + 6 hr. 20 min.   (+40)
Fathometer Depth 13.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.8	14.08	1.50	110
6.0	26.9	14.06	1.36	110
9.0	26.9	14.06	1.40	110
12.0	26.9	14.06	1.36	120

Station # 3b (26 June)

Time Down 1137   Time Up 1144
1137 = Ebb + 4 hr. 50 min.   (-3)
Fathometer Depth 7.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.1	28.69	0.50	070
6.0	23.1	28.69	0.42	070

Time Down 1542   Time Up 1550
1542 = Flood + 3 hr. 15 min.   (+17)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.8	27.98	2.20	240
6.0	22.9	27.92	1.90	245

Station # 3b (27 June)

Time Down 1000   Time Up 1002
1000 = Ebb + 2 hr. 50 min.   (+20)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.5	24.69	1.20	060
6.0	23.5	24.69	1.50	055

Time Down 1221   Time Up 1223
1221 = Ebb + 5 hr. 11 min.   (+20)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.5	19.00	1.36	050
6.0	25.5	19.00	0.80	045

Station # 3b (28 June)

Time Down 0737   Time Up 0741
0737 = Flood + 3 hr. 27 min.   (-10)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.0	24.30	0.40	195
6.0	23.7	26.02	0.30	205

Time Down 1305   Time Up 1307
1305 = Ebb + 4 hr. 38 min.   (+7)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	16.70	1.00	045
6.0	27.0	16.55	1.04	045

Time Down 1507   Time Up 1513
1507 = Ebb + 6 hr. 40 min.   (+7)
Fathometer Depth 6.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.6	15.13	0.06	040
6.0	27.8	15.07	0.04	045

Station # 3b (29 June)

Time Down 0928   Time Up 0931
0928 = Ebb + 8 min. (+40)
Fathometer Depth 8.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.0	16.86	1.30	060
6.0	26.0	16.86	1.20	050

Time Down 1312   Time Up 1321
1312 = Ebb + 3 hr. 52 min. (+40)
Fathometer Depth 6.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.7	14.11	1.44	040
6.0	27.0	14.03	1.20	035

Time Down 1505   Time Up 1509
1505 = Ebb + 5 hr. 45 min. (+40)
Fathometer Depth 7.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	14.16	1.22	045
6.0	26.5	14.16	1.10	045

Station # 4 (26 June)

Time Down 1445   Time Up 1455
1445 = Flood + 2 hr. 18 min. (+17)
Fathometer Depth 8.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	23.1	29.28	1.00	320
6.0	23.0	29.34	1.10	315

Time Down 1645   Time Up 1647
1645 = Flood + 4 hr. 18 min. (+17)
Fathometer Depth 10.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	21.5	28.74	1.56	300
6.0	21.5	28.74	1.36	310
9.0	21.5	28.74	1.20	320

Station # 4 (27 June)

Time Down 1051 Time Up 1100
1051 = Ebb + 3 hr. 41 min. (+20)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	24.5	22.81	1.30	120
6.0	24.5	22.81	1.00	150

Time Down 1514 Time Up 1517
1514 = Flood + 49 min. (+5)
Fathometer Depth 5.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.8	18.54	0.86	325
5.0	27.0	19.77	0.40	320

Time Down 1545 Time Up 1550
1545 = Flood + 1 hr. 20 min. (+5)
Fathometer Depth 5.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	19.30	0.96	310
5.0	26.5	19.96	0.80	315

Station # 4 (28 June)

Time Down 0832 Time Up 0837
0832 = Ebb + 5 min. (+7)
Fathometer Depth 7.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	19.18	0.34	120
6.0	25.0	19.18	0.20	125

Time Down 1241 Time Up 1245
1241 = Ebb + 4 hr. 14 min. (+7)
Fathometer Depth 5.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.0	14.66	0.84	130
5.0	27.0	14.97	0.40	130

Time Down 1610 Time Up 1614
1610 = Flood + 43 min. (+7)
Fathometer Depth 6.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.7	13.87	0.10	270
6.0	27.8	13.84	0.02	280

Station # 4 (29 June)

Time Down 1100 Time Up 1102
1100 = Ebb + 1 hr. 40 min. (+40)
Fathometer Depth 6.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	14.16	1.50	125
6.0	26.3	14.21	1.30	125

Time Down 1423 Time Up 1427
1423 = Ebb + 5 hr. 3 min. (+40)
Fathometer Depth 11.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.7	14.11	1.20	110
6.0	27.0	14.03	1.20	115
9.0	26.8	14.08	1.00	120

Time Down 1550 Time Up 1553
1550 = Ebb + 6 hr. 30 min. (+40)
Fathometer Depth 11.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	14.16	1.10	150
6.0	26.5	14.03	0.90	150
9.0	26.5	14.03	1.10	150

Time Down 1655 Time Up 1700
1655 = Ebb + 7 hr. 35 min. (Flood + 25)
Fathometer Depth 6.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.2	14.23	0.40	345
6.0	26.0	13.96	0.36	305

Station # 5 (26 June)

Time Down 1426 Time Up 1430
1426 = Flood + 1 hr. 59 min. (+17)
Fathometer Depth 11.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	22.1	26.89	1.00	240
6.0	22.0	27.69	1.04	250
9.0	22.0	26.94	0.98	245

Station # 5 (27 June)

Time Down 1030 Time Up 1038
1030 = Ebb + 3 hr. 20 min. (+20)
Fathometer Depth 13.5 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.0	17.17	0.60	090
6.0	24.0	20.24	0.30	110
9.0	23.5	25.41	0.34	080
12.0	23.5	26.13	0.34	055

Time Down 1534 Time Up 1539
1534 = Flood + 1 hr. 9 min. (+5)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.5	11.48	0.44	250
6.0	27.2	13.37	0.96	250
9.0	26.2	17.44	1.04	245

Station # 5 (28 June)

Time Down 0815 Time Up 0821
0815 = Flood + 4 hr. 5 min. (-10)
Fathometer Depth 13.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	25.9	14.31	0.20	260
6.0	26.0	14.92	0.40	225
9.0	26.0	14.92	0.44	215
12.0	26.0	16.21	0.44	220

Time Down 1213 Time Up 1225
1213 = Ebb + 3 hr. 46 min. (+7)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	12.91	0.50	045
6.0	26.5	12.91	0.20	060
9.0	26.0	13.65	0.08	070
12.0	25.5	18.33	0.02	050

Time Down 1626 Time Up 1631
1626 = Flood + 59 min. (+7)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	27.0	13.11	0.02	125
6.0	28.0	12.58	0.04	125
9.0	28.0	13.19	0.02	175
12.0	28.0	13.80	0.02	210

Station # 5 (29 June)

Time Down 1110 Time Up 1115
1110 = Ebb + 1 hr. 50 min. (+40)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.5	13.84	0.90	050
6.0	26.4	14.12	0.82	050
9.0	26.4	13.55	0.70	050
12.0	26.0	14.28	0.60	050

Time Down 1440 Time Up 1443
1440 = Ebb + 5 hr. 20 min. (+40)
Fathometer Depth 14.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.3	14.21	0.84	045
6.0	26.2	14.23	0.88	060
9.0	26.5	14.16	0.80	060
12.0	26.3	14.21	0.66	060

Time Down 1640 Time Up 1645
1640 = Ebb + 7 hr. 20 min. (Flood + 10)
Fathometer Depth 12.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.3	14.52	1.00	065
6.0	26.3	14.52	0.60	060
9.0	26.5	14.47	0.50	040
12.0	26.4	14.25	0.50	010

Station # 6 (29 June)

Time Down 1134 Time Up 1138
1134 = Ebb + 2 hr. 14 min. (+40)
Fathometer Depth 10.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.9	13.44	0.38	075
6.0	26.8	13.46	0.20	105
9.0	26.5	13.53	0.50	130

Time Down 1612 Time Up 1615
1612 = Ebb + 6 hr. 52 min. (+40)
Fathometer Depth 9.0 ft.

D(ft)	T(°C)	S(ppt)	C. Spd. (kts)	C. Dir. (deg)
3.0	26.8	13.15	0.40	160
6.0	26.8	13.15	0.40	250
9.0	26.8	13.15	0.30	220

Appendix K

Vertical Profile Data for Stations 7 through 12 for 30 June, 1973

In the data which follows, all salinities have been corrected by adding 2.66 ppt. Times are in EDT. Flow through Croatan Sound is southerly.

Station # 7 (30 June)

Time Down 1528 Time Up 1531
Fathometer Depth 12.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	9.33
6.0	26.0	9.33
9.0	26.0	9.63
12.0	26.0	10.42

Time Down 1655 Time Up 1657
Fathometer Depth 13.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	8.73
6.0	26.0	9.03
9.0	25.6	9.99
12.0	25.6	9.99
13.5	25.5	10.01

Station # 8 (30 June)

Time Down 1512 Time Up 1515
Fathometer Depth 9.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	7.26
6.0	26.0	8.14
9.0	25.8	9.66

Time Down 1710 Time Up 1712
Fathometer Depth 9.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	6.39
6.0	26.0	6.39
9.0	25.6	8.18

Station # 9 (30 June)

Time Down 1505 Time Up 1507
Fathometer Depth 10.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	5.82
6.0	26.0	5.94
9.0	24.4	5.94

Time Down 1717 Time Up 1720
Fathometer Depth 10.5 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	5.26
6.0	26.0	5.26
9.0	26.0	5.26
10.5	26.0	5.26

Station # 10 (30 June)

Time Down 1456 Time Up 1458
Fathometer Depth 9.0 ft.

Depth(ft)	Temp(°C)	Salinity(ppt)
3.0	26.4	6.36
6.0	26.5	6.07
9.0	26.3	6.09

Time Down 1727 Time Up 1729
Fathometer Depth 9.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.3	5.80
6.0	26.4	5.80
9.0	26.5	5.79

Station # 11(060) (30 June)

Time Down 1211 Time Up 1215
Fathometer Depth 7.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	4.71
6.0	26.0	4.71
7.5	26.0	4.71

Station # 11(075) (30 June)

Time Down 1225 Time Up 1227
Fathometer Depth 6.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	4.43
6.0	26.0	4.43

Station # 11(090) (30 June)

Time Down 1232 Time Up 1235
Fathometer Depth 5.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	4.43
5.5	26.0	4.43

Station # 11(105) (30 June)

Time Down 1249 Time Up 1252
Fathometer Depth 11.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	3.89
6.0	26.0	4.16
9.0	26.0	4.43

Time Down 1800 Time Up 1804
Fathometer Depth 14.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	25.5	3.91
6.0	25.5	3.91
9.0	25.7	3.90
12.0	25.6	3.90
14.0	25.5	3.91

Station # 11(120) (30 June)

Time Down 1255 Time Up 1258
Fathometer Depth 10.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	4.71
6.0	26.0	5.26
9.0	26.0	5.43

Station # 11(135) (30 June)

Time Down 1309 Time Up 1314
Fathometer Depth 15.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	4.71
6.0	26.0	5.26
9.0	26.0	5.82
12.0	26.0	5.82
15.0	25.9	6.11

Station # 11(140) (30 June)

Time Down 1316 Time Up 1320
Fathometer Depth 17.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.1	4.70
6.0	26.0	5.82
9.0	26.0	5.82
12.0	26.0	5.82
15.0	26.0	5.82
17.0	26.0	6.11

Time Down 1752 Time Up 1757
Fathometer Depth 17.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	23.2	4.26
6.0	23.2	4.55
9.0	26.0	4.71
12.0	23.2	4.84
15.0	25.0	4.75
17.5	23.0	5.44

Station # 11(150) (30 June)

Time Down 1325 Time Up 1327
Fathometer Depth 13.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	4.71
6.0	26.0	5.82
9.0	26.0	6.11
12.0	26.0	6.11

Station # 11(160) (30 June)

Time Down 1330 Time Up 1334
Fathometer Depth 11.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.5	5.23
6.0	26.0	5.82
9.0	26.0	6.11
11.0	25.8	6.41

Station # 11(175) (30 June)

Time Down 1339 Time Up 1342
Fathometer Depth 13.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.0	6.39
6.0	25.9	6.40
9.0	25.8	6.99
12.0	25.8	6.99

Station # 11(190) (30 June)

Time Down 1346 Time Up 1350
Fathometer Depth 11.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.5	5.79
6.0	26.4	6.93
9.0	26.3	6.37
11.0	26.4	6.93

Station # 11(205) (30 June)

Time Down 1354 Time Up 1356
Fathometer Depth 11.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.7	6.06
6.0	26.5	6.92
9.0	26.5	6.92
11.0	26.4	7.22

Station # 11(220) (30 June)

Time Down 1359 Time Up 1401
Fathometer Depth 9.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.5	7.21
6.0	26.4	7.51
9.0	26.6	7.77

Time Down 1747 Time Up 1750
Fathometer Depth 9.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	27.0	5.76
6.0	27.0	5.76
9.0	27.0	5.76

Station # 11(235) (30 June)

Time Down 1404 Time Up 1406
Fathometer Depth 6.5 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	27.0	6.88
6.0	26.8	7.47

Station # 11(250) (30 June)

Time Down 1410 Time Up 1412
Fathometer Depth 5.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.9	8.32
5.0	26.9	8.03

Time Down 1744 Time Up 1745
Fathometer Depth 6.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	27.3	6.29
6.0	27.2	6.30

Station # 11(265) (30 June)

Time Down 1415 Time Up 1417
Fathometer Depth 5.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	26.9	8.03
5.0	26.9	8.03

Station # 11(280) (30 June)

Time Down 1420 Time Up 1421
Fathometer Depth 4.0 ft.

Depth(ft)	Temp. (^{o}C)	Salinity(ppt)
3.0	27.0	8.02
4.0	27.0	8.02

Time Down 1739 Time Up 1740
Fathometer Depth 4.5 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	27.5	6.83
4.5	27.7	6.81

Station # 12 (30 June)

Time Down 1436 Time Up 1442
Fathometer Depth 12.0 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	25.7	3.10
6.0	25.5	3.74
9.0	25.3	7.92
12.0	25.5	8.19

Time Down 1813 Time Up 1819
Fathometer Depth 12.5 ft.

Depth(ft)	Temp. (°C)	Salinity(ppt)
3.0	26.0	2.62
6.0	26.5	2.62
9.0	26.0	3.62
12.0	25.9	6.98