The Hydrography of Barnstable Harbor, Massachusetts[1]

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ABSTRACT

Barnstable Harbor, on the north shore of Cape Cod, Massachusetts, originated from the growth of an offshore barrier bar across an indentation of the coastline. In common with many other East Coast tidal embayments of similar origin it has: 1) low runoff, carried by a few small streams, which together with direct rainfall and groundwater seepage provides a total freshwater acquisition that is small compared to the tidal prism volume; 2) essentially marine internal aquatic environments; and 3) extensive salt marshes drained by tidal creek systems. The hydrography of the harbor is largely determined by the internal arrangement of its shoals and channels. The shoals and channels act as dams and weirs, distorting the tides until they approximate those found in typical river estuaries. The tidal distortion results in a time asymmetry of the maximum currents which in turn produces a net up-harbor transport of sediments, despite the fact that the ebb currents are of the greater velocity. The hydrography of the harbor in spring, summer, and fall is described. Parameters discussed include salinity, temperature, transparency, water masses, tidal currents, sediment analyses, the salinity relations of intertidal flats, and some aspects of the annual temperature regime.

INTRODUCTION

Barnstable Harbor is located on the north shore of Cape Cod in Massachusetts. The harbor consists of an indentation of the original post-glacial coastline which has been nearly cut off by an offshore barrier bar. This type of origin is common to many of the tidal embayments of the East Coast. Their similarity in origin has endowed these embayments with certain "family" characteristics, and knowledge of one becomes (in varying degree) knowledge of all.

Among the "family" characteristics of this type of tidal embayment may be listed: low runoff which is carried by a few small streams and which, with direct rainfall and ground-water seepage, provides a total freshwater acquisition that is small compared to the quantity of tidal salt water entering and leaving the embayment; internal aquatic environments are essentially marine in character; and salt marshes drained by tidal creek systems border the open water. Barnstable Harbor exhibits these family characteristics.

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PHYSIOGRAPHY

The harbor lies in an area of glacial till on the north side of the Sandwich Moraine left by the Wisconsin glaciation. The soil of the upland is primarily sand and sandy loam with scattered glacial boulders. The glacial till varies in depth from five to more than thirty feet and overlies disturbed glaciofluvial sand and gravel. In the region of the harbor the sandy till is separated from the disturbed sand and gravel by a layer of hard-packed grey till locally called "hardpan." Johnson (1925) and Mather *et al.* (1942) review the geology of the area.

The harbor is bordered on the southwest,

[1] Contribution No. 995 from the Woods Hole Oceanographic Institution.

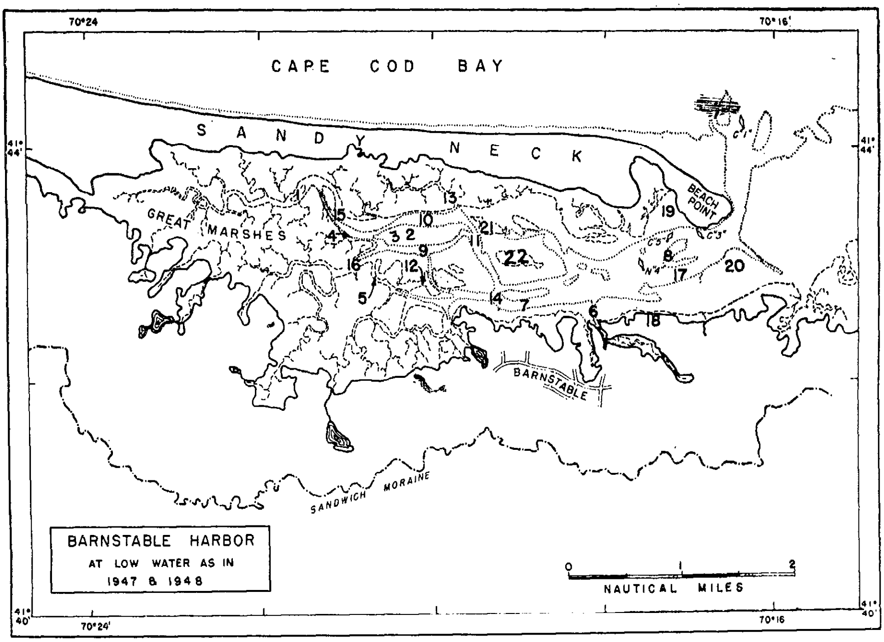


FIG. 1. Barnstable Harbor at low water as in 1947 and 1948. Dotted lines represent the junction of intertidal flats with open water; dashed lines represent the seaward edges of the salt-marsh; and a bold line indicates the meeting of salt-marsh and upland. The numbers refer to features named in Table 4.

west, and northwest by a salt marsh of considerably greater area than the harbor itself. Five major tidal creeks drain the marsh. Each tidal creek branches elaborately, and the main channels extend to the outer edge of the marsh where they receive small freshwater streams. Thirteen streams in total descend from the Sandwich Moraine and contribute to the harbor during each ebb tide about 0.3 million cubic feet of freshwater from a 22.8 square-mile watershed (Ayers 1956, p. 33).

On the north the harbor is bordered by a range of sand dunes which constitutes the barrier bar and is called Sandy Neck; this terminates in a broad sand spit at Beach Point (Fig. 1). Most of the dunes in this range are shifting, except in scattered areas where pitch pine, scrub oak, and dune grass have stabilized the sand. A continuous ocean beach lies along the north side of Sandy Neck.

Most of the harbor's inlet is occupied by intertidal sand flats. A channel cuts through these flats, but it widens and shoals offshore and terminates in a typical harbor bar at a depth of about five feet at mean low water.

At low water, shoals inside the inlet are exposed and reduce the navigable area to narrow channels. Early in the flood tide these shoals become submerged and allow water to enter through a much larger cross-section. The shoals produce a distortion of the tide which is discussed later as the "weir effect."

Numerous bars and shoals, extensive intertidal flats, and salt-grass covered islands standing two to five feet above the flats are the primary physiographic features within the harbor. In the inner parts of the harbor the intertidal flats rise about a foot above low water level. Flats rising two feet or more above the average level (three feet above low water) support the salt-grass *Spartina alterniflora* and are low (new) grassy islands.

The well-established marsh at the head of the harbor often presents cliff-like edges rising several feet above the level of the flats. Older portions of the marsh, farther back from the open water, appear to be about six inches higher than those adjacent to the harbor.

About 60 per cent of the total harbor

TABLE 1. *Mechanical analyses of surface soils from various parts of the harbor and marsh* Organic content determined as loss on ignition. Data of Harry J. Turner, Woods Hole Oceanographic Institution.

Location	% of sample passing through sieves of				Median diameter of particles, mm	Organic content, %
	20 mesh	48 mesh	100 mesh	200 mesh		
Channel-bar east of Wicks Is. (S)	98.3	80.3	18.5	0.6	0.20	3.2
WHOI flat (south side) (SM)	99.4	99.4	82.8	22.4	0.10	1.2
WHOI flat (center) (MS)	98.9	97.5	88.1	14.9	0.10	0.85
Howes' old flat (S)	99.8	97.8	77.8	6.3	0.12	0.60
Bung-hole flat (SM)	97.7	96.6	88.0	24.3	0.09	1.05
Gull Creek flat (SM)	98.7	94.1	69.4	20.0	0.12	1.3
Wicks Island (SS)	97.8	94.1	82.2	46.8	0.07	4.6
Marsh opposite Wicks Is. (SS)	98.2	96.5	85.2	35.1	0.09	3.0

20 mesh = 0.833 mm; 48 mesh = 0.295 mm; 100 mesh = 0.147 mm; 200 mesh = 0.074 mm; MS = muddy sand; SM = sandy mud; SS = sandy silt; S = sand.

bottom is exposed at low water. The western end of the harbor becomes almost completely exposed, the remaining water being confined to narrow channels which are extensions of the main tidal creeks.

The bottom is primarily fine muddy sand, though clean coarse sand occurs in the harbor mouth, and mud or sandy mud is dominant in the tidal creeks. Bottom samples from various parts of the harbor show a considerable variation in their contents of fine sediments (Table 1, column 5; see Table 4 and Fig. 1 for sampling locations). The greatest proportions of fines occur in the stabilized surface soils of the marshes and grassy islands. Moderate proportions are present in the surfaces of the somewhat less stable intertidal flats. Shifting flats of clean sand near the harbor mouth may be expected to contain the smallest proportions of fine sediments.

The harbor is shallow in all its parts above the mouth of Maraspin Creek (Table 4 and Fig. 1), and winds produce strong wave action. Local, usually temporary, silting-up and scouring occur in all parts of the harbor. Changes in the shallow inner end of the harbor consist chiefly of meanderings of the channels back and forth across the intertidal flats. There are indications (described below) that the head of the harbor, at least, is gradually filling in.

HYDROGRAPHY

The harbor ranges in depth from 8 to 30 feet at high water. The shallowness and the large tide range result in extreme volume changes during each tidal cycle The harbor volume changes from about 1000 $\times$ 10^6 cubic feet at high water to about 71 $\times$ 10^6 cubic feet at low water, the intertidal volume or tidal prism being about 93 per cent of the high-water volume. The large tidal exchange rather quickly carries to sea the small freshwater acquisition. About five tidal cycles are required to remove from the harbor a volume of freshwater equal to the quantity of freshwater accumulated in the harbor at a given high tide (Ayers 1956, pp. 32–33).

The Tides

The mean tide range at Beach Point is 9.5 feet; the range at spring tides is 11.0 feet (U. S. Coast & Geodetic Survey Tide Tables). Because shoals inside the harbor hamper the ebb current and produce an elevated low-water level, there is a reduction in tide range between the inlet and the head of the harbor. Neap tides do not inundate the salt marsh, while spring tides cover it to depths up to 1.5 feet.

As is common in small harbors along this coast, high and low waters occur at nearly the same time in all parts of the harbor, and maximum tidal currents occur near mid-tide. Preliminary tide-guage observations indicate, as first approximations, that the interval between high waters at Beach Point and the head of the harbor is about 0.5 hour, and that the interval between low waters at these points is about 0.9 hour.

TABLE 2. *Durations of ebb and flood tides in various parts of the harbor*
Head of the harbor begins with innermost weir.

Position	Date	Duration of flood, Hrs.–Min.	Duration of ebb, Hrs.–Min.	Remarks
Can 1	17–VI–48	6–15	6–15	Normal tidal cycle
				Major weirs at this level, 6 in. rise needed to stop ebb
Nun 4	27–X–47	5–45	5–45	
Main Channel at mouth of Maraspin Cr.	21–X–47	6–25	6–15	
	17–VI–48	5–45	7–0	
Yacht Club Channel	2–VI–48	5–45	6–35	Minor weir, 3 in. needed to stop ebb
	22–X–47	5–50	6–50	
			6–30	
	28–VIII–52	5–30	7–18	
Jct. North Channel with Phillis Is. Channel	8–VI–48	6–10	7–0	Minor weir, ca 3 in. needed to stop ebb (estimated)
	17–VI–48	5–20	7–10	
Midway, S of WHOI flat	22–X–47	5–45	7–0	
	20–X–47	5–5	6–40	
	17–IX–47	4–45	7–30	
		5–5		
	21–X–47	5–25	7–0	
			6–50	
Mouth of Scorton Cr.	2–VI–48	5–35	7–10	Net elevation of low water level: ca 1 foot
	17–VI–48	5–40	7–25	

Head of harbor average: Flood 5.5 hrs.; ebb 7.1 hrs.

The durations of flood and ebb in the upper harbor are about 5.5 and 7.1 hours, respectively (Table 2).

The weir effect

Shortening of flood and prolongation of ebb is typical of the tidal wave in shoal water (Doodson and Warburg 1941), but in Barnstable this effect is exaggerated by the shoals in the harbor.

At low water Horseshoe Shoal and the flats along shore beside it act as a dam with two weirs. The two weirs are narrow channels through which the tidal currents must pass during the hours when the shoal and adjacent flats are exposed. The pronounced reduction in cross-section at this point hinders and prolongs the outflow of the ebb tide and allows a head of water to develop above the weirs. The weirs retain this head until the waters outside the harbor have passed through their low water stage and begun their flood-tide rise.

The time used in overcoming the head of water above the weirs is the period during which the weakest flood current would flow into a harbor of more usual physiography. When the head is exceeded and the flood current begins to flow through the weirs, it soon reaches a velocity close to its maximum (Fig. 2).

Temporary tide staffs have shown that the tide outside the harbor rises about six inches before the ebb current ceases to flow out through the weirs at Horseshoe Shoal. This rise is sufficient to submerge a major part of Horseshoe Shoal and adjacent flats. The shoal and flats become completely submerged soon after the flood current begins to run in through the weirs.

Lesser weirs exist at Yacht Club Channel, where tide staffs have shown that the water rises about three inches before the ebb current stops. At the points where Midway and North Channel enter Phillis Island Channel, visual estimates suggest a further three-inch rise before the ebb ceases. The weirs result not only in distortion of the flood and ebb durations but also in an elevation of low water level along the length of the harbor (Table 2).

Figure 2 shows the surface current velocities observed during a tidal cycle in Yacht Club Channel and over the crest of an inter-

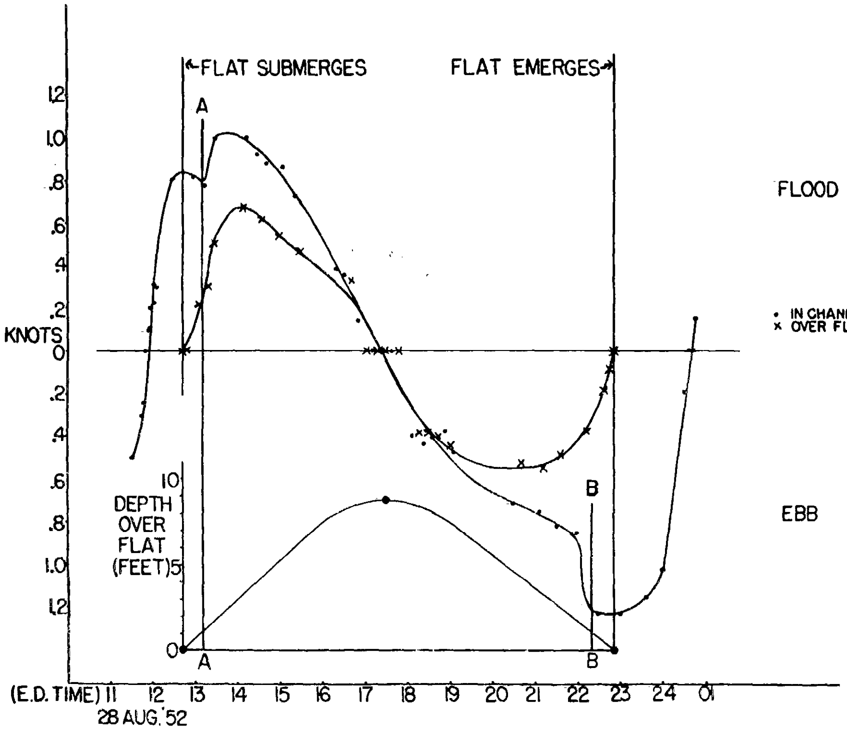


FIG. 2. Tidal current velocities in Yacht Club Channel and over the intertidal flat immediately north of that channel. 28 August 1952.

tidal flat immediately north of that channel. The very rapid increase of current velocity in the channel during early flood was interrupted by a plateau in velocity, beginning just before the adjacent flats became submerged and ending when the flats were about a foot under water (line AA). After the flats were overflowed the flood velocity in the channel quickly rose to its maximum of 1.03 knots, at the end of the second hour of flood, then declined steadily until the end of flood 3.5 hours later. The flood current over the flat attained its maximum velocity of 0.67 knot at the same time as did that in the channel and also went to zero at 5.5 hours of the flood tide, 4.7 hours after the flat's submergence.

During the first hour of ebb no velocity difference between the currents in the channel and over the flat was discernible. After 1.25 hours of ebb the current velocity over the flat became less than that in the channel. Ebb current over the flat attained its maximum velocity of 0.53 knot at the end of the third hour of ebb, after which it decreased steadily until the flat emerged after 5.5 hours of ebb. The current in the channel increased steadily to about 0.9 knot at 4.6 hours of the ebb when the water over the flat was about one foot deep (line BB); between that time and 5.1 hours of ebb (when there was about six inches of water over the flat) the channel current increased to 1.23 knots. It attained its maximum of 1.25 knots at 5.5 hours of the ebb when the flat emerged, then decreased to 1.03 knots at 6.6 hours, and went to zero at 7.3 hours of the ebb.

The data indicate that the ebb current experiences effective confinement to channels at a time when there is still about a foot of water over the flats. Prior to this time the freer drainage in the open channel tends to lower its water level and water from over the flat, retarded by friction with the flat, flows obliquely into the channel. The friction-slowed water entering the channel requires acceleration from the channel current and causes a temporary decrease in the acceleration of the channel current (see Fig. 2 between 19 and 22 hours). By the time only a foot of water remains over the flat the quantity of friction-slowed water leaving the flat has become insignificant, and its retarding effect on the velocity of the channel current disappears (Fig. 2 between 22 and 23 hours).

A condition at least superficially similar to the above occurs during submergence of the flat on the flood tide. From just before the flat submerges until it is covered by about a foot of water the velocity of flood remains nearly constant. In this case the retarding effect of friction-slowed water that crosses the flat and the increasing cross-sectional area available as the flat becomes submerged both act to reduce current velocity in the channel. The flood velocity at this period is increasing, and the two retardant effects produce only a velocity plateau. The plateau disappears when the harbor's full cross-section becomes available for flow and when the quantity of water slowed by friction of the flat becomes insignificant in the total volume flowing (Fig. 2 between 12 and 14 hours).

Effects of tidal currents on bottom physiography

Maximum velocity of the flood current occurs near mid-flood when the intertidal flats are submerged and the cross-sectional area of the harbor is large. The flood current attains maximum surface velocities of 50 to 80 cm/sec. These correspond to average velocities of 37.5 to 60 cm/sec. (Sverdrup *et al.* 1942, p. 568) through the harbor's cross-section. These average velocities are ample (Sverdrup *et al.* 1942, Fig. 251) to erode sands of particle sizes 0.06 to 3.0 mm and to transport silt particles of 0.005 to 0.01 mm toward the head of the harbor. The flood current thus is capable of moving sediments up-harbor. Plankton nets towed at the times of maximum current capture large quantities of sediment.

Sediments carried up-harbor by the flood tide settle out at slack high water. Those settling into the channels are swept seaward during the ebb. Those sinking onto the flats are subjected, during the ebb, to currents less than those that brought them there (Fig. 2). The fact that the ebb currents over the flats are nearly zero when the ebb reaches its maximum in the channels indicates that some of the sediments dropped on the flats at slack high water are able to remain on the flats. That such is taking place is indicated by the formation of new (low) *Spartina*-covered islands on the intertidal flats, by local tradition that the upper harbor (at least) is shoaling, and by the fact that the flats contain more fine sediments than do the channels (compare row 1 with rows 2–6, Table 1). Once salt-grasses are established, mechanical trapping and plant decomposition products further increase the proportion of fines in the island and marsh soils.

Maximum ebb velocity in the harbor occurs after the intertidal flats are bared sufficiently to confine the current to the channels (Fig. 2). The maximum erosive effect of the ebb current is thus limited to the channels, which it keeps open. Apparently for this reason submerged bars protruding into the channels become recurved toward the harbor mouth. Also, this is probably the reason that the intertidal flats have their long axes lengthwise of the harbor. Horseshoe Shoal just inside the inlet apparently has a central portion that does not shift, though its arms point seaward as do the other flats of the harbor.

The effect of the asymmetry of the maximum currents on sediment transport is augmented by flotation. On calm days the flood tide overflowing the flats floats off many dry particles of sediment on the water's surface film. These particles are carried up-harbor until turbulence breaks the surface film and allows them to sink.

By these means the currents achieve a net movement of sediments toward the head of the harbor, even though the ebb current is stronger than the flood.

Water types

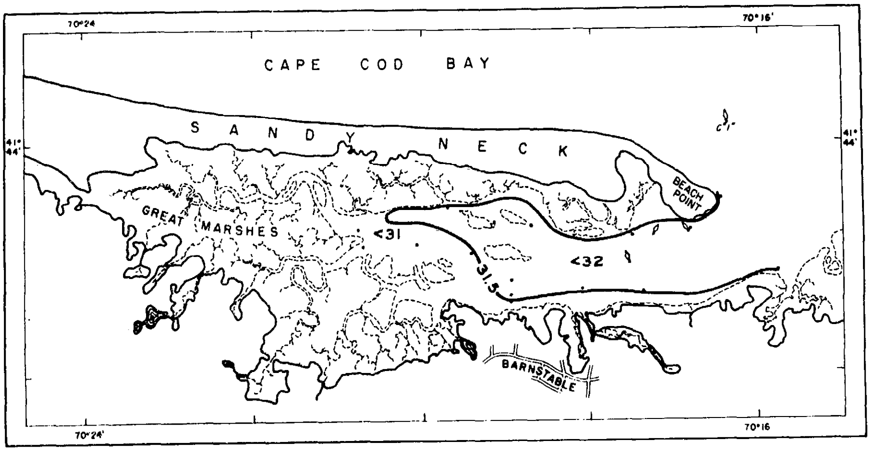
Two parent water types, and a mixture of the two, are present in the harbor and the creeks tributary to it. They are: Cape Cod Bay Water, found at the mouth of the harbor; freshwater, entering at the periphery of the marsh; and Mixed Water, in the creeks and head of the harbor. Each type migrates back and forth under the influence of the tide.

At all stages of the tide, except in spring freshet conditions, Cape Cod Bay Water can be found along Beach Point below the weirs at Horseshoe Shoal. It is clear, greenish in color, and of salinity 31.50 to 32.50‰. The freshwater entering the creeks is typical swamp water. It is brown in color but free of silt. Its salinity near the limit of tidal influence ranges from 1.00 to 1.18‰.

The upper harbor and major portions of the tidal creeks are occupied at all stages of the tide by Mixed Water with characteristics between those of the main two types. This water is greenish-brown in color, is definitely turbid, and its salinity ranges from about 1.00‰ near the heads of the creeks to about 31.50‰ in the head of the harbor.

Tidal movements of water types

On the flood tide Cape Cod Bay Water moves into the harbor and by high water is found up-harbor to points beyond Sand



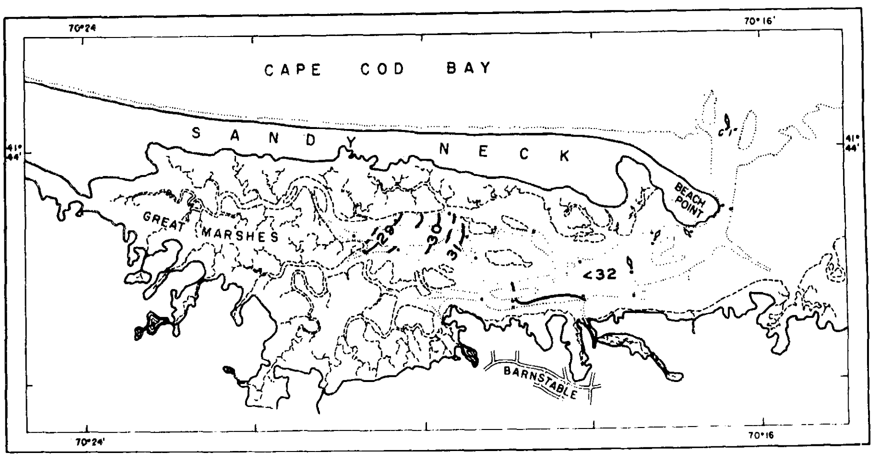


FIG. 3. Distribution of surface salinity (‰) in summer. 25 and 29 August 1947. *Above*: at high water. *Below*: at low water.

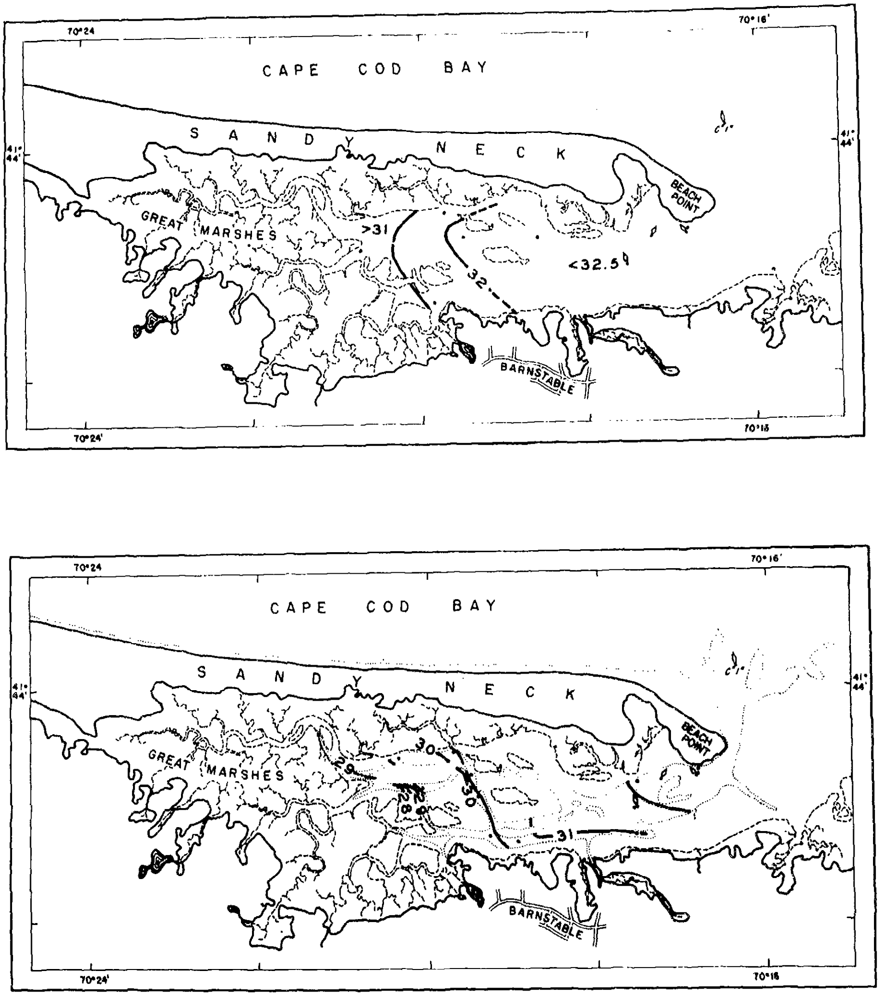


FIG. 4. Distribution of surface salinity (‰) in fall. 17 November 1947. *Above*: at high water. *Below*: at low water.

Island and Wells Creek. The advance and retreat of the tide cause extensive horizontal migration of the water and result in horizontal mixing. At full high water only a small amount of the Mixed Water remains in the upper harbor near the mouths of the creeks, while the tidal creeks are filled by it. By late ebb the column of high salinity water has retreated down the harbor, and the Mixed Water has followed it. At low tide, Cape Cod Bay Water is present only between the inlet and Horseshoe Shoal. During freshets it is forced out of the harbor. The horizontal distributions of salinity in summer and fall are shown in Figures 3 and 4. Figure 5 is the salinity distribution during spring freshet.

Above the mouth of Maraspin Creek very small vertical salinity gradients are occasionally found at high water and at low water. At other times no salinity gradient is present.

The salinity relations of intertidal flats

During the advance and retreat of the tide, water moving along the shores of the harbor is outrun by that in the middle of the channels. As a result, intertidal flats along the shores are subjected to less salinity

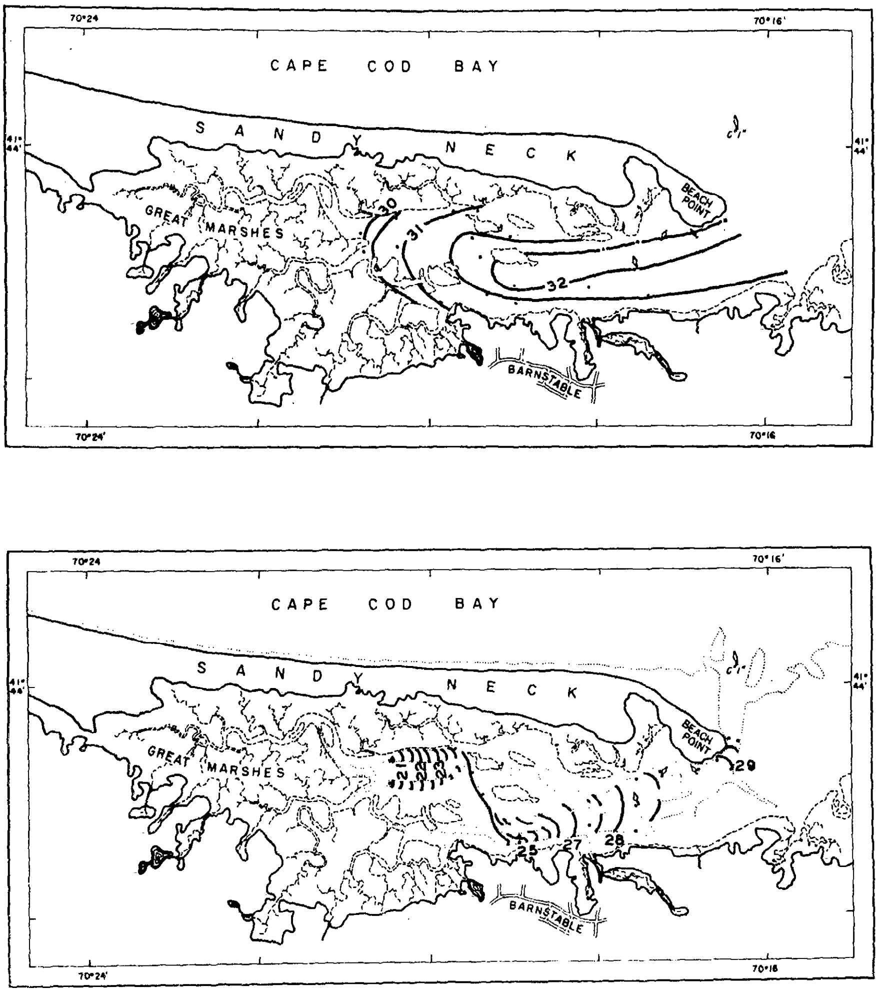


FIG. 5. Distribution of surface salinity (‰) during spring freshet. 12 and 16 April 1948. *Above*: at high water. *Below*: at low water.

TABLE 3. *Salinity ranges in various parts of Barnstable Harbor*
Spring freshet conditions are starred.

Location	Salinity range, ‰	Position in harbor
Beside WHOI flat	20.46*-31.40	Head of harbor
Off Sand Island	29.63 -31.73	Near head of harbor
Phillis Island Channel	24.51*-31.89	Near middle of harbor
Off Maraspin Creek mouth	27.38*-31.71	Below middle of harbor
Off Cobb's Village	28.49*-31.62	South shore near inlet
The Cove	28.62*-31.67	North shore near inlet
Beside Yarmouthport flat	31.38 -32.14	South shore, at inlet

TABLE 4. *Orientation table*
The numbers in Figure 1, and the station letters in the B and D parts of Figures 7 through 10, indicate the following locations.

1. Wicks Island
2. Experimental area of Woods Hole Oceanographic Institution
3. Howes' flat
4. Bung-hole flat
5. Gull Island flat
6. Maraspin Creek
7. Yacht Club Channel
8. Horseshoe Shoal
9. Midway Channel
10. North Channel
11. Phillis Island Channel
12. Sand Island
13. Wells Creek
14. Scudders Lane Landing
15. Scorton Creek
16. Spring Creek
17. Fisherman's Gut
18. Cobb's Village
19. The Cove
20. Yarmouthport flats
21. Big Thatcher Island
22. Phillis Island

A. Buoy "C 1"
B. Buoy "C 3"
C. Buoy "C 5"
D. Buoy "N 4"
E. Main channel, off Maraspin Creek
F. "14" in Figure 1
G. Main channel, west of Phillis Island
H. North Channel, off mouth of Wells Creek
I. "15" of Figure 1
J. Buoy "C 3"
K. "7" of Figure 1
L. Midway, south of the W. H. O. I. flat
M. "16" of Figure 1
N. North edge of Beach Point, west side of channel
O. "9" in Figure 1
P. North edge of Beach Point, east side of channel
Q. "11" in Figure 1
R. North Channel, north of W. H. O. I. flat
S. "17" in Figure 1

variation during a tidal cycle than are flats in the center of the harbor. Similar conditions have been observed in the Tees (Alexander *et al.* 1935) and in the Tamar (Milne 1938).

Although flats along the axis of the harbor are subject to more salinity variation than those along the shore, they are not subject to the whole salinity range of that part of the harbor. At low tide the least saline water encircles them, but does not cover them. It is pushed up-harbor before the flats are overflowed by the flood tide, and the flats have emerged before this water returns again during the late ebb. In the same fashion, tidal pools on the higher grassy islands are of greater salinity than those on lower islands. Increased evaporation during their longer periods out of water may also contribute to their increased salinity.

The distance of a flat from the mouth of the harbor determines which water types bathe it. Most of the flats are submerged only during the more saline two-thirds of the normal salinity range obtaining in that part of the harbor.

Table 3 gives the salinity ranges of the water in various parts of the harbor. All of the salinities observed have been used; they include conditions of drouth, of spring freshet, and of all stages of the tide. In those parts of Table 3 which include freshet values, the normal variation in salinity is approximately the most saline one-quarter of the range indicated.

Temperature distribution

Water temperatures in the harbor do not reflect the origin or composition of the water, for they depend upon the previous association of the water with the harbor. Water which has ascended furthest into the harbor is the warmest or coolest depending upon the season. In spring and summer, water passing up the harbor is warmed; in fall and winter it is cooled. The temperature of the water in any part of the harbor at low tide reflects (by its degree of heating or cooling relative to the Cape Cod Bay Water at Beach Point) the previous high-tide position of that water in the harbor.

Water remaining in the harbor at low tide is essentially isothermal from surface to bottom. The tortuous nature of the channels, irregularities on the channel bottoms, and the high velocity of the late ebb current produce thorough mixing.

During early flood the channels overflow; in spring and summer the overflowing water absorbs heat which the flats have

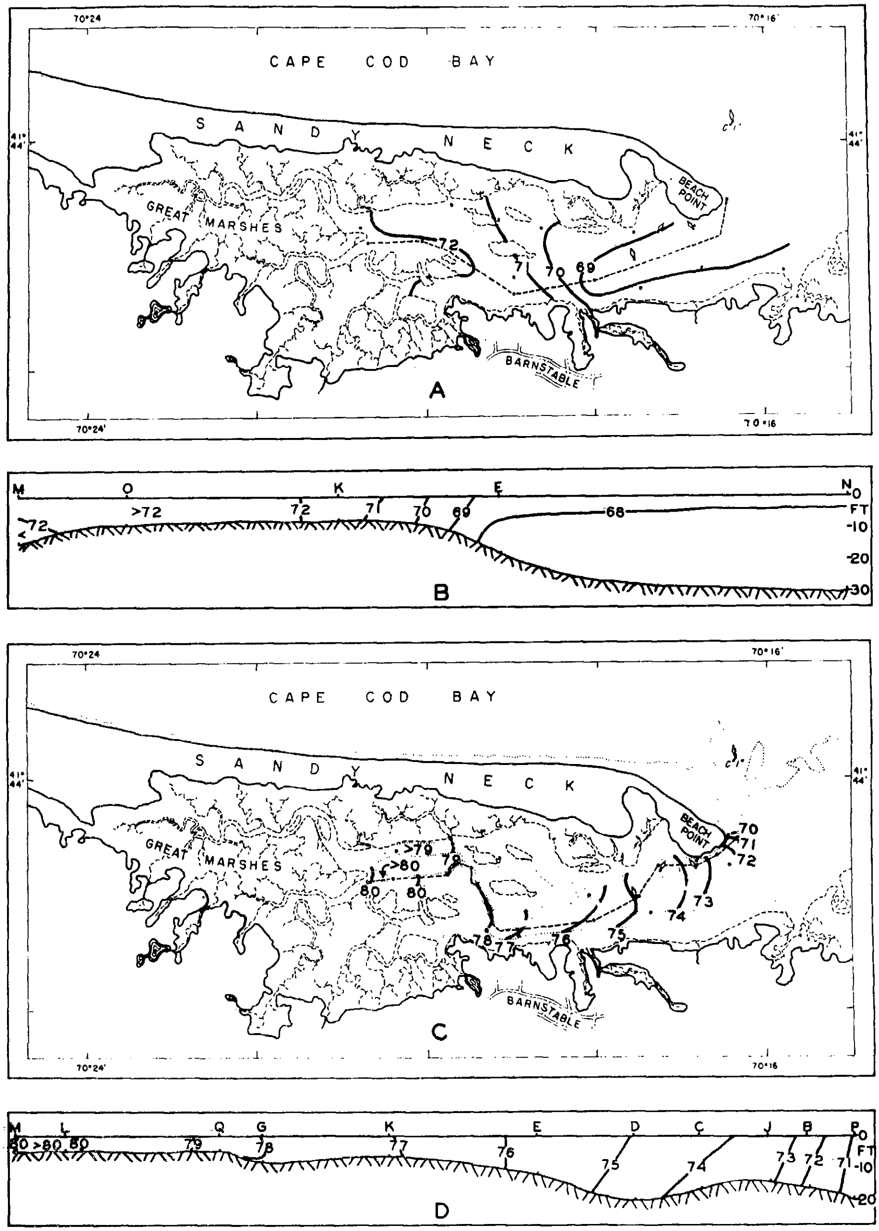


FIG. 6. Horizontal and vertical distributions of temperature (°F) in summer. 25 and 29 August 1947. Heavy dashed lines in A and C show the positions of vertical sections B and D. Station letters in B and D are as listed in Table 4. A and B at high water; C and D at low water.

acquired during their exposure to the sun and air. After the flats become submerged, the water is still shallow enough for sunlight to reach bottom throughout most of the flood tide period. During this time continued warming of the bottom by the sun and continued transfer of heat from bottom to water are both probable.

A similar warming occurs during ebb when water over the flats becomes shallow and

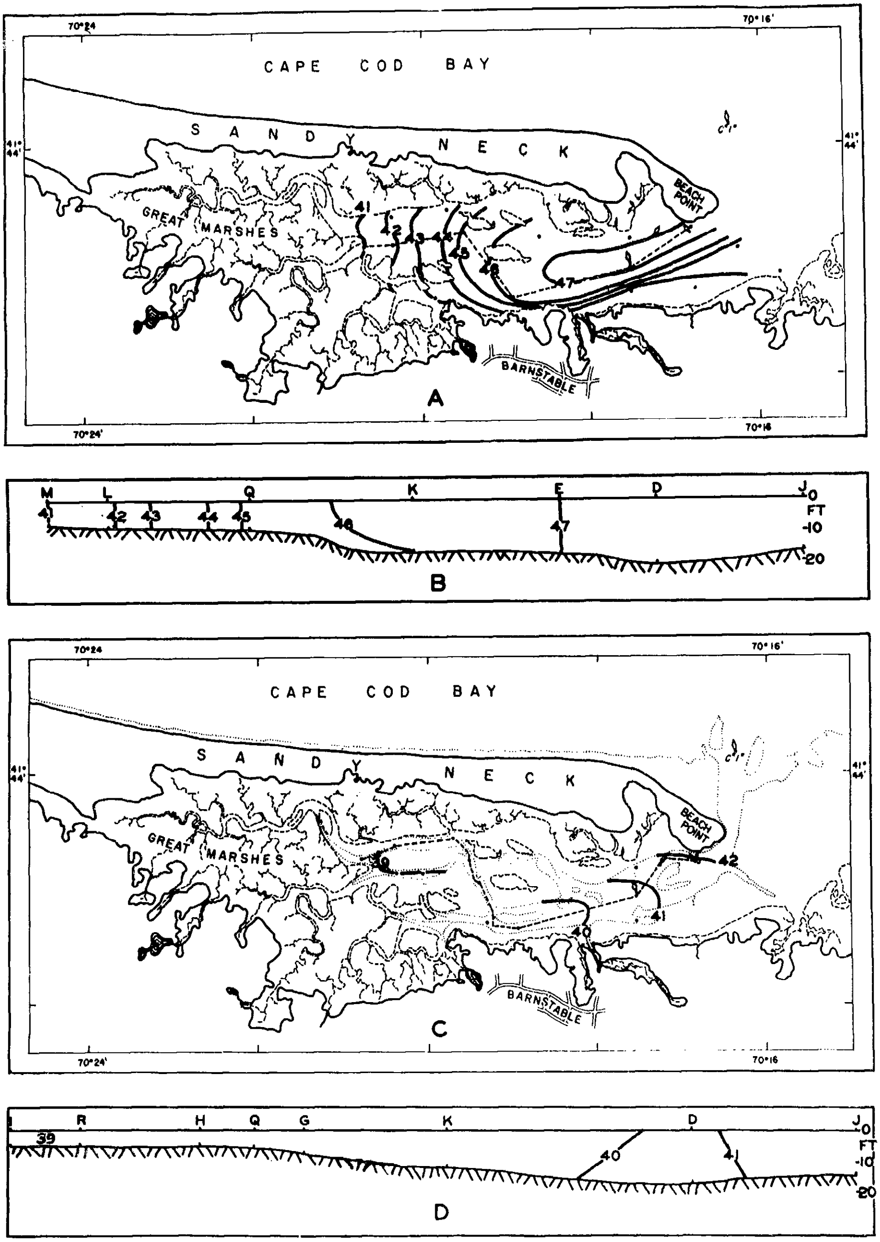


Fig. 7. Horizontal and vertical distributions of temperature (°F) in fall. 17 November 1947. Heavy dashed lines in A and C indicate the positions of vertical sections B and D. Station letters in B and D are listed in Table 4. A and B at high water; C and D at low water.

recedes from the flats. The warming taking place during the ebb tide is more readily noted than that during the flood, for by low tide the warmed waters have accumulated in the channels.

In surveys made at high water during the spring and summer the subsurface water is occasionally observed to be warmer than the surface. This water appears to be unstable and the condition temporary. In

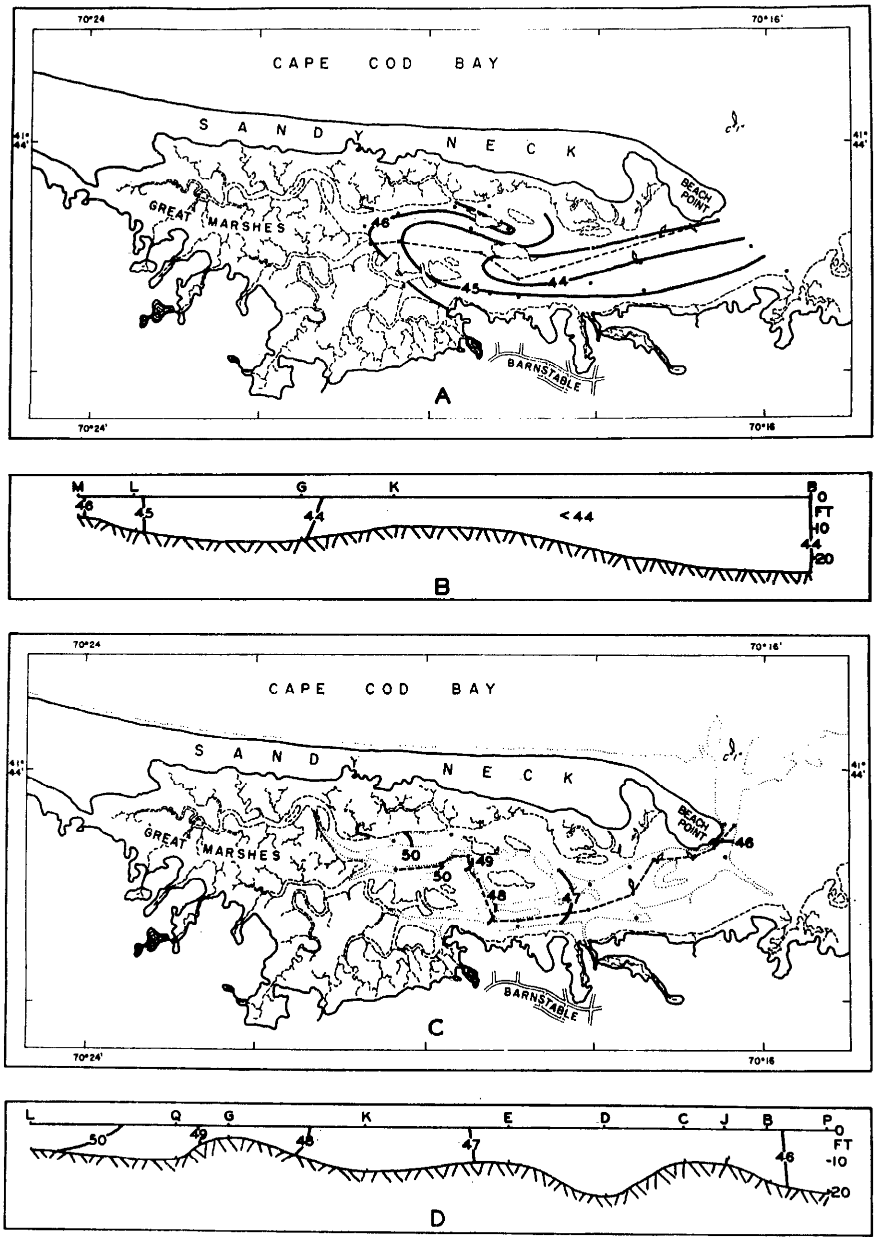


FIG. 8. Horizontal and vertical distributions of temperature (°F) during spring freshet. 12 and 16 April 1948. Heavy dashed lines in A and C indicate the positions of the vertical sections B and D. Station letters in B and D are listed in Table 4. A and B at high water; C and D at low water.

practically all cases this occurs in water shallow enough for sunlight to penetrate to bottom.

Figures 6, 7, and 8 show temperature distributions in summer, fall, and spring.

The transition periods

Twice a year the harbor goes through a transition period when its temperature approaches that of Cape Cod Bay. One of these periods occurs in late March or early

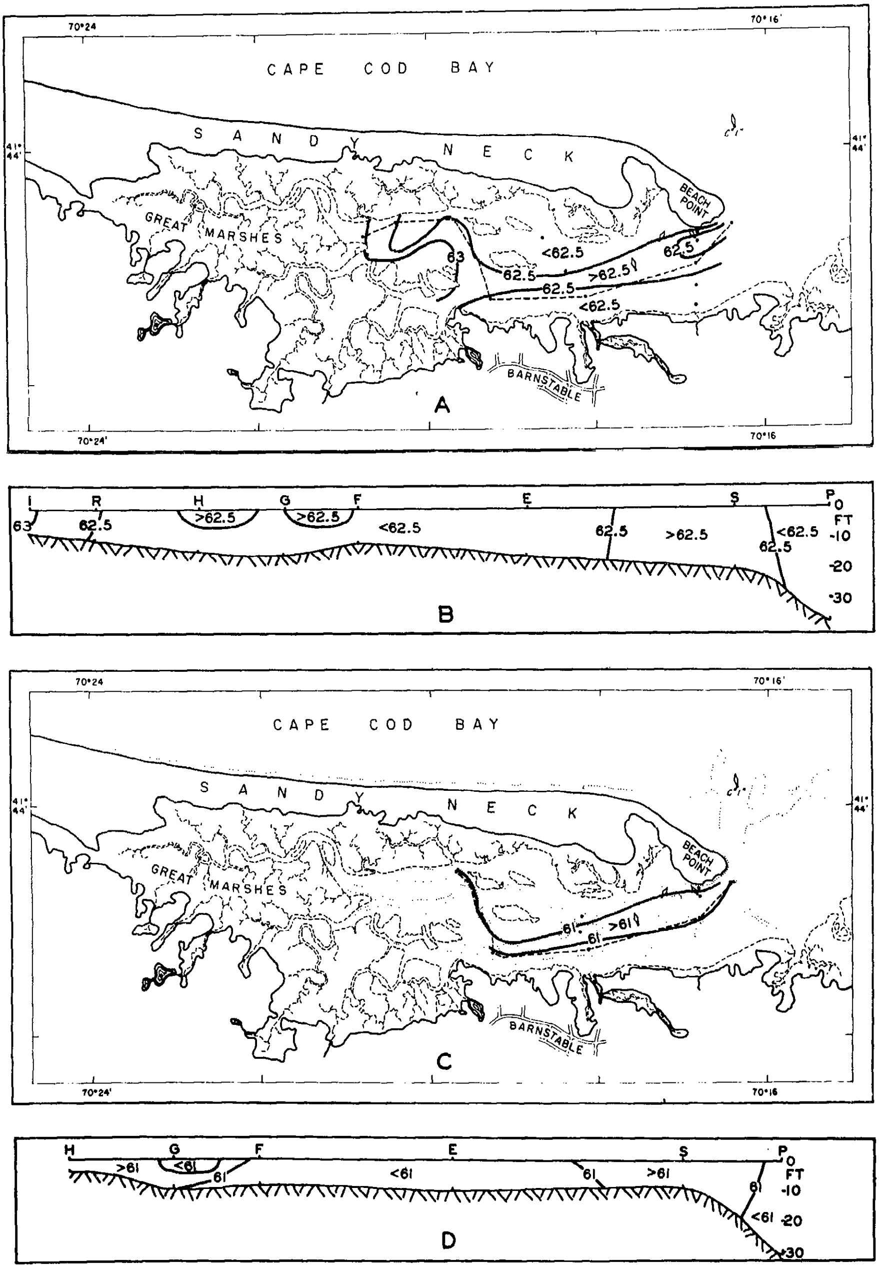


Fig. 9. Horizontal and vertical distributions of temperature (°F) during the fall transition period. 23 September 1948. Heavy dashed lines in A and C show the positions of the vertical sections. Station letters in B and D are listed in Table 4. A and B at high water; C and D at low water.

April when the harbor's rather rapid spring warming overtakes the slower warming of Cape Cod Bay. The other occurs when the harbor's rather rapid autumn cooling overtakes the slower cooling of Cape Cod Bay. At these times high-water and low-water temperatures become very nearly alike. In 1948 the fall transition took place during the latter part of September; Figure 9 presents surveys made on September 23rd.

Transparency

In summer, light penetrates to different depths in various parts of the harbor. Transparencies by white Secchi disc range from 6.5 feet in the Mixed Water at the head of the harbor to more than 13 feet in the Cape Cod Bay Water at Beach Point.

The decrease in transparency toward the head of the harbor is a reflection of the increasing amounts of plankton and suspended sediments which occur there.

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