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The accumulation of river water over the continental shelf between Cape Cod and Chesapeake Bay *

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Summary—The depth mean salinities for the waters of the continental shelf between Cape Cod and Chesapeake Bay show a seasonal variation in the concentration of river water. The spring and the winter accumulations are about the same, but about 25% more river water is present in the summer. The total volume of fresh water in spring and winter is equivalent to that produced by the rivers in about one and a half years. The extra accumulation in summer is equal to half a year's flow, and reflects, in part, the fact that the high spring flows of two successive years are present on the shelf at this time.

There is a decrease in the average content of river water in the direction of the flow of the coastal current, in spite of the addition of river water along its course. It is concluded that considerable transport of river water and of salt normal to the coast is necessary. The horizontal mixing coefficients normal to the coast are computed from the seasonal changes in salinity. They range from 0·58 to $4{\cdot}96 \times 10^6$ cm^2/sec, with the values for the decrease in salinity from spring to summer being smaller than those for the increase from summer to winter conditions. At both times, the values decrease with increasing depth and distance from shore.

Professor H. B. Bigelow initiated extensive studies of the distribution of temperature and salinity over the continental shelf between Cape Cod and Chesapeake Bay in 1913. In a series of papers, he and his associates have described the seasonal variations and correlated these with vernal warming, river runoff and the water circulation of the area.

The sea water of this section of the continental shelf is greatly diluted by the fresh water continuously supplied by several major rivers. Both regional and seasonal variations in salinity are great, and the area is one of complicated dynamic structure and circulation. The accumulation of river water affords a direct means of evaluating the rate of the circulation and mixing when compared to the rate of discharge of the rivers. This approach has been used extensively in estuaries in recent years. While it may be unorthodox to treat this open coastal area as an estuary, it was felt that some of the methods of study should be informative, and provide a time scale for the circulation in various parts of the region.

The area included in this study (Fig. 1) extends across the continental shelf and slope from the coastline to the 1000 fathom depth contour. It is bounded to the north-east by a section extending SSE from the western tip of Martha's Vineyard, and to the south by a section extending ESE from the mouth of Chesapeake Bay. This region has a surface area of 104×10^{10} ft^2, or 29,000 square nautical miles, and contains a volume of water equal to 732×10^{12} ft^3 or 3400 cubic nautical miles (Table I).

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The major rivers discharging into this region, their gaged drainage basin and the average rates of flow, are listed in Table II. The total drainage area is estimated to be 116,000 square statute miles, nearly 62% of which is gaged in these rivers. Assuming the ungaged area to have similar drainage characteristics, the total river flow into this region is 167,764 cubic feet per second. The volume of water contributed by the rivers annually is thus $5{\cdot}29 \times 10^{12}$ cubic feet, less than one per cent of the total

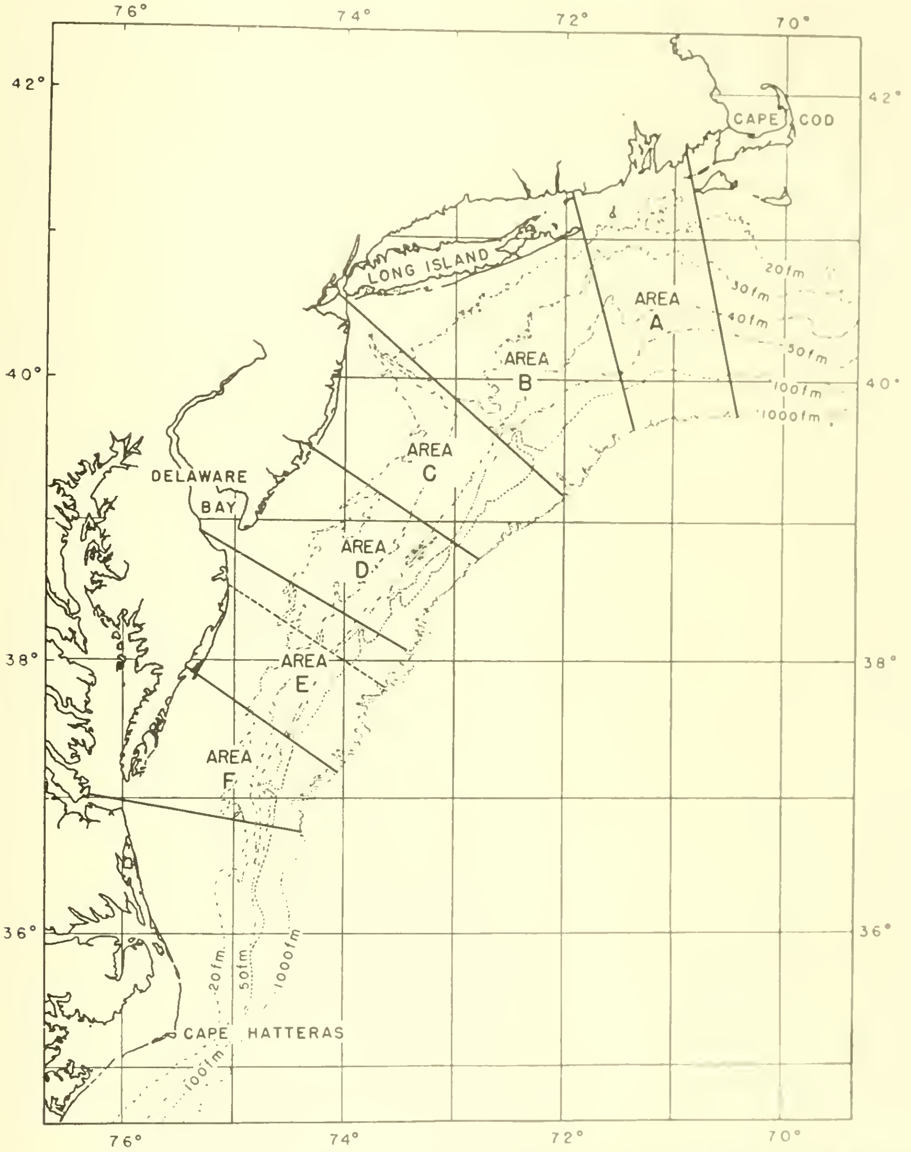

Fig. 1. The continental shelf from Cape Cod to Chesapeake Bay, showing the areas used in Table I and Fig. 2. The dashed line in Area E indicates the southern limit of Area D′ and the northern limit of Area E′ used for the summer observations.

volume of water within the region considered. The discharge of all of these rivers is already mixed with large volumes of sea water in the sounds and estuaries before reaching the continental shelf.

Table I

The total volume of water contained between depth contours for various areas of the continental shelf, Cape Cod to Chesapeake Bay

Depth range fathoms	Total volume (10^{10} ft^3) within region *A*	*B*	*C*	*D*	*E*	*F*	*Total*
0– 20	114	376	513	403	412	498	2316
20– 30	363	981	509	613	360	220	3046
30– 40	869	964	715	407	378	98	3431
40– 50	643	740	292	248	103	157	2183
50– 100	1170	954	648	423	621	205	4021
100–1000	8244	10386	8000	7151	17433	7038	58252
Total	11403	14401	10677	9245	19307	8216	73249

Table II

The major gaged rivers discharging between Cape Cod and Chesapeake Bay Data from U.S. Geological Survey Water-Supply Paper 1051

Group	*River*	*Years of record*	*Drainage area sq. miles*	*River flow* ft^3*/sec.*	ft^3*/sec/sq. mi.*
A	Thames	29	711	1210	1·70
	Connecticut	19	9661	16260	1·68
	Housatonic	19	1545	2494	1·61
	others*	—	1171	1702	1·45
C	Hudson	—	8090	16510	2·04
	Passaic	49	785	1442	1·83
	Raritan	—	779	643	1·31
D	Delaware	34	6780	11770	1·74
	Schuylkill	24	1893	2715	1·43
F	Susquehanna	16	25990	35650	1·37
	Potomac	17	11560	10830	0·94
	Rappahannock	40	1599	1648	1·03
	York	—	1072	729	0·68
	Total gaged:		71636	103603	1·45

* The Taunton, Providence, Pawtuxet and Pawcetuck Rivers gaged flow for 1946–1947.

Direct precipitation on the area would add 2·38 × 10^{12} ft^3 per year, but the loss from evaporation would be 3·42 × 10^{12} ft^3 per year. WÜST's data for 35° and 40° North Latitude of the Atlantic Ocean (SVERDRUP *et al.*, 1942, Table 30) give a mean precipitation of 2·29 feet and a mean evaporation of 3·29 feet per year. The excess of evaporation over precipitation of one foot per year gives a net loss for the exchanges across the sea surface of 1·04 × 10^{12} cubic feet per year. This is equivalent to 20% of the water supplied by river drainage. The remaining 80% must be transported through the region by advection and eddy diffusion, and mixed away in the more saline water offshore.

The Gulf Stream flows offshore, separated from the waters of the continental shelf by the slope water of intermediate characteristics (ISELIN, 1936, 1940). The upper 200 metres or so of the slope water is generally less saline than corresponding waters of the Gulf Stream, reflecting the effects of varying amounts of coastal water at different times of the year. Ultimately the river water which is not evaporated locally must be entrained, via the slope water, in the Gulf Stream system. The volume transport of the Gulf Stream varies between 76 and 93 million cubic metres per second (ISELIN, 1940). This flow is twenty thousand times greater than the rate of addition of river water to this part of the continental shelf, so that direct assimilation of all of this river water in the Gulf Stream would not make a measurable change in its salinity.

The general westerly and southerly drift of the inshore water is well known, and is indicated by the temperature and salinity sections given by BIGELOW (1933) and BIGELOW and SEARS (1935). Extensive current measurements from lightships throughout the area south of New York show non-tidal drifts largely paralleling the coast of from 1·8 to 2·8 nautical miles per day (ZESKIND and LELACHEUR, 1926; HAIGHT, 1938; MARMER, 1935). The non-tidal current observed at Ambrose Lightship flows nearly east, and little or no residual drift was observed at Nantucket Shoals Lightship except for transitory effects of the winds. *The Current Atlas of the North Atlantic Ocean* (Hydrographic Office, 1946) gives consistent westerly and southerly drifts, paralleling the coast for the inshore areas south of New York, with frequent easterly components over the mid shelf area south of Martha's Vineyard and east of both the Delaware and Chesapeake Bays.

The general character of these coastal drifts has been recently confirmed by drift bottle studies (REDFIELD and WALFORD, 1951; MILLER, 1952). Practically all of the bottles released close to shore south of New York drifted southward. Only two bottles, of several thousand released north of Cape Hatteras, were recovered south of that point, indicating an abrupt reversal of the current. Many of the bottles released to the east of New York were recovered north of the point of release, along the Long Island shore. The percentage returns of bottles released close to the coast was high, but decreased rapidly with increasing distance from the coast. Few bottles released more than 20 miles offshore were recovered on the beach, though several of these have crossed the Atlantic and have been recovered on European shores.

The question arises whether these drifts can be expected to add substantial amounts of fresh water to this area of the continental shelf. To the south, the Gulf Stream is very close inshore and the shelf is only 30 miles wide at Cape Hatteras. BIGELOW and SEARS (1935, p. 87) state: "Just south of Cape Hatteras a wedge of pure oceanic water presses in across the shelf entirely separating the shelf and slope water bands to the north from the low coastal salinities farther south". All of the evidence thus indicates that no significant increment of fresh water may be expected to enter the area from the south.

The possibility that freshened Gulf of Maine water may enter the area through the Martha's Vineyard section cannot be categorically excluded. BIGELOW (1915) concluded that northern water in this area was hardly appreciable, except perhaps in unusual years. *The Current Atlas of the North Atlantic Ocean* shows southerly or easterly drifts most of the year south of Martha's Vineyard, and, when westerly components are present, adjacent currents suggest an eddy which does not penetrate beyond the tip of Long Island. Some of the drift bottles released by BIGELOW (1927) in the Gulf of Maine were recovered on Nantucket and Martha's Vineyard, but rarely entered the area under consideration. Several bottles, however, which were released in July 1922 outside the 50 fathom contour southeast of Cape Cod, were recovered along the coast to the west. A series of drift bottles were released in October 1951 from the *Caryn* between Cape Cod and Nantucket Lightship, but none of these were returned from within the area considered here. It is concluded that, although there may be some influx of fresh water from the northeast into the area, it cannot be evaluated, and is probably small relative to the volumes supplied directly by the rivers.

The details of the salinity distribution are given by BIGELOW and SEARS (1935). The following brief review of their conclusions will be helpful in understanding the general patterns. " The basic feature in the pattern of salinity of the region, the year around, is that isohalines tend to parallel the coastal trend with values increasing continuously from the shore, seaward, along any given profile normal to the coast" (p. 6). The salinity is at a maximum during the winter months when water of salinity lower than 32°/₀₀ is found only in the mouths of Delaware and Chesapeake Bays. About 50% of the total annual discharge of river water is concentrated in March, April and May. This produces local and irregular freshening off the mouths of the rivers. The salinity off the Husdon River and Chesapeake Bay falls to 27°/₀₀ 8–10 miles from land, and all of the inshore water is freshened to 32°/₀₀ or less at this time. This vernal freshening may not culminate before late summer in exceptional years, though in all years of record the extent of water freshened to less than 32°/₀₀ was greatest during the summer. The vertical stratification was also a maximum at this time, being most pronounced off Chesapeake Bay, and least over Nantucket Shoals to the northeast, where turbulence keeps the waters nearly homogeneous throughout the summer. During the autumn the vertical gradients of salinity decrease and the surface salinities increase, so that by January the distribution has returned to the winter maximum condition.

THE ACCUMULATION OF RIVER WATER

The total volume of river water accumulated in the area has been computed from the distribution of salinity. When this is compared to the rate of river flow, the average flushing time can be determined. The calculations have been made for three periods of the year, namely (1) April, May and June; (2) July, August and September; (3) October through March inclusive.

The fraction of fresh water (f) in any sample is given by: $f = \frac{\sigma - s}{\sigma}$

in which s is the salinity of the sample considered and σ is the salinity of the undiluted sea water. For this value we have taken 35°/₀₀, since water of this salinity is found at the bottom along the continental slope, usually in a continuous band throughout this region. Data from 856 hydrographic stations were utilized. These included stations reported by BIGELOW and his associates, stations along the continental slope (ISELIN, 1936), and in the New York Bight (KETCHUM, REDFIELD and AYERS, 1951), as well as several stations occupied by the *Atlantis* and by other vessels of the Woods Hole Oceanographic Institution during recent years.

The volume of water between depth contour lines for the various areas shown in Fig. 1 are listed in Table 1. These were computed from the planimetered surface area and the average depth which was obtained from the U.S. Coast and Geodetic Survey Navigation Chart ♯1000. All volumes, and the average fraction and accumulation of fresh water, are computed for the entire depth of the water column, the contour lines being the inshore and offshore limits of the area considered.

The average fraction of fresh water was computed from the graded depth mean of the salinity values for each station. The bottom bottle of each cast was used to characterize the water from that depth to the recorded or chart depth of the station. This results in an underestimate of the deep salinities, but the volume of river water calculated for the depths below the bottom bottle rarely exceeded 10 % of the total river water, even for the summer observations when stratification was greatest and the error would be most pronounced.

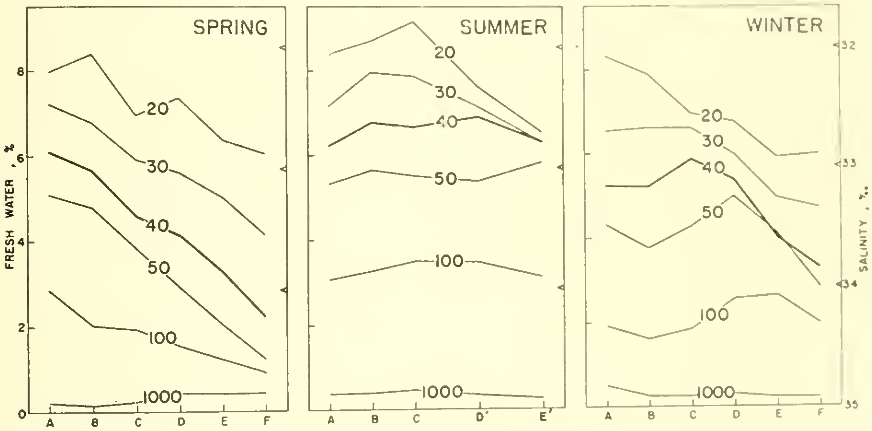

Fig. 2. The depth mean salinity and proportion of fresh water for various areas indicated in Fig. 1. The numbers on each line indicate the depth, in fathoms, of the outer boundary of the subdivision considered.

Spring: 328 stations occupied during April, May and June;
Summer: 203 stations occupied during July, August and September;
Winter: 325 stations occupied during October–March inc.

The average fraction of fresh water and the corresponding salinity for each sub-area of Fig. 1 are given in Fig. 2 for the three periods of year. The river water found in the spring period decreases from a mean value of 7·02 % for the innermost portion (shore—20 fathoms) to a mean value of 0·33 % over the continental slope (100–1000 fathoms). The values also decrease from north to south. This would not appear obviously from the salinity charts of Bigelow and Sears (1935) which show lower surface salinities to the south. However, they also show maximum vertical gradients of salinity in this area, and the average salinity over the entire water column is greater. The decreasing fresh water fraction to the south is observed for all of the depth ranges to the 100 fathom contour. Between the 100 and 1000 fathom contours the fresh water fraction decreases somewhat toward the north.

In the summer period the fresh water content is at a maximum for all fo the depth ranges, decreasing from 7·86% for the innermost band to 0·41% for the waters over the continental slope. Within the 30 fathom contour, there is an increase of fresh water content from the Martha's Vineyard section to the offing of the Hudson River, but to the southward there is a gradual decrease. Beyond the 40 fathom contour the fraction of fresh water shows little variation from north to south for the various areas.

The conditions observed in the October-March period have marked similarities to the spring distribution. The inshore band is least fresh (6·75%) at this time of year. There is, however, a considerable accumulation of fresh water from the middle of the shelf to the 100 fathom contour over the southern part of the area. All of the areas south of New York between the 30 and the 100 fathom contour contain greater proportions of fresh water than are found in these areas in the spring, though they are consistently less than the concentration found in these areas in the summer.

The decrease in the concentration of fresh water over the inner part of the shelf to the south is remarkable. As mentioned above, there is a consistent southward drift of the inshore waters, at least below New York, and there are substantial increments of fresh water from the Hudson, Delaware and Chesapeake Bay systems. Thus in each succeeding area some of the river water entering from the adjacent area, and the water locally added, must be dispersed across the shelf, and mixed locally with higher salinity water to give the observed decreases in average concentration. Although the 20 and 30 fathom contours are further off shore in the south, the volume available for dilution (Table I) is not enough greater to give the observed decrease in the concentration of fresh water. Qualitatively, such a distribution can be maintained only when the transport of fresh water normal to the coastline exceeds the transport parallel to the coast. This will be discussed further in the section on diffusion coefficients.

THE FLUSHING TIME

The ratio between the volume of river water accumulated and the rate of river flow gives the flushing time for the region. This has been calculated for the various depth ranges at three times of year with the result shown in Table III. The accumulation of river water during the spring (April–June) agrees closely with the accumulation found in the winter period (Oct.–March) and corresponds to the contribution from the rivers during a period of about one and a half years (1·61–1·65). The accumulation during the summer period (July–September) is about 25% greater than at the other times. Using the annual average river flow, this corresponds to nearly half a year of excess. This excess does not necessarily indicate a slower circulation at this time, but may reflect the excess river flow during the period of maximum discharge. The lag of 3–4 months before this excess discharge is recognizable over the shelf is not unreasonable for the time required for the exchanges through the estuaries and sounds. With a three-month lag period, this 25% excess accumulation during the summer corresponds to expectation since " fifty per cent of the total annual discharge of river water is concentrated in March, April and May " (BIGELOW and SEARS, 1935, p. 88) and since the excess spring flows of two successive years are represented by the accumulation during the summer. The surface inshore waters reflect this increased flow within a month after maximum river discharge, but on the average the maximum effect over the entire shelf is delayed, as would be expected considering the length of time required for transport of river water through the area.

Table III

Flushing times of the continental shelf between Cape Cod and Chesapeake Bay for an average river flow of $14{\cdot}5 \times 10^9$ *ft*^{3}*/day* (167,764 *ft*^{3}*/sec.*)

Depth Range Fathoms	*FLUSHING TIME, DAYS*		
	April–June	*July–Sept.*	*Oct.–March*
0– 20	112	125	108
20– 30	127	156	130
30– 40	119	157	123
40– 50	62	83	62
50– 100	52	91	56
100–1000	131	140	110
Total, days:	603	752	589

THE FLUX OF FRESH AND SALT WATER

The total transport through any complete cross-section must result in the movement seaward of a quantity of river water equivalent to the quantity contributed by the rivers in unit time if the distribution is to remain in steady-state. The cross-sections must completely surround the source of fresh water. Those we have used extend from shore at the eastern boundary of area A, to a depth contour, along the contour line to the southern boundary of area F, and back to the shore.

For any given part of the cross-section this transport is a complicated sum of the effects of horizontal and vertical advection and eddy diffusion. However, our method of averaging gives the depth mean salinity and obscures the vertical effects. Thus, it seems possible to treat the system as STOMMEL (1953) has treated estuarine circulation, as a two dimensional one in which the advection produced by river water entering the system is balanced by horizontal eddy diffusion normal to the coast.

The flux of material in the direction normal to the coast (F_x) is given by STOMMEL (1953):

$$F_x = Qc - SA\frac{dc}{dx}$$

in which c is the fraction of fresh (or salt) water, Q is the rate of river flow, S the cross-sectional area, A the horizontal mixing coefficient, and x is the distance normal to the coast. Under steady-state conditions the flux of river water through any cross-section equals the rate of river flow ($F = Q$), and the flux of salt through any cross-section is zero.

The eddy diffusion parallel to the coast has been neglected in the above equation. If the coefficient of horizontal diffusion is the same in the two directions, the transport by diffusion parallel to the coast must be proportionately very small. The gradients in this direction range from one tenth to one thirtieth the value of the gradients normal to the coast; and the cross-sectional areas at the ends are also small compared to the area along the contour line. For example, the product $S_x \; df/dx$ is

400 times as great as the product $S_v \triangle f/\triangle y$ for the winter distribution and the 30 fathom contour. This product for the direction parallel to the coast never exceeds one per cent of the value normal to the coast.

As has been shown above, there is a decrease of salinity for this area between the spring and summer conditions, and a corresponding increase between the summer and winter conditions, with little or no change between the winter and spring conditions. Since the flushing time of the area is a year and a half, and these changes occur in shorter periods, the distribution cannot be treated as a steady-state. However, it is possible to evaluate the flux of salt from the seasonal changes, and to compute average mixing coefficients from these data. The necessary data are presented in Table IV, and the coefficients are given in Table V.

Table IV

The mean salinities at three seasons of year, and the flux of salt across different depth boundaries on the continental shelf between Cape Cod and Chesapeake Bay. The contours selected average 28 kilometers apart

Depth Contour Fathoms	*Mean Salinities ‰*			*Flux of Salt $10^7 g/sec.$*	
	Spring	*Summer*	*Winter*	*Sp.–Su.*	*Su.–Wint.*
20	32·54	32·24	32·64	2·53	— 2·24
30	32·88	32·40	32·84	7·86	— 5·48
40	33·24	32·69	33·18	14·68	— 9·52
100	34·06	33·57	34·04	25·78	—16·58
1000	34·88	34·86	34·91	30·03	—23·63

Table V

The coefficients of horizontal diffusion computed from the changes in salinity at different seasons of the year

Depth Contour Fathoms	*Horizontal Diffusion Coefficients $10^6 cm^2/sec.$*	
	Sp.–Su.	*Su.–Wint.*
30	2·52	4·96
40	1·72	3·41
100	0·58	1·48

The net flux of salt is positive for the change from spring to summer, since salt is being transported offshore in the plus x direction, and negative for the change from summer to winter when the salinity increases again. The net flux of salt resulting from changes from season to season range from about 15 to 50% of the offshore advection of salt with the river water escaping from the area. The coefficients of eddy diffusion (Table V) obtained for the spring-summer change range from 0·58 to 2·52 × $10^6 cm^2/sec.$, and the values obtained for the summer-winter change vary from 1·48 to 4·96 × 10^6 $cm^2/sec.$ At both times the value decreases with increasing depth and distance from shore. Although the vertical component of turbulence has been averaged out of the data, it is worth noting that the smaller coefficients are found at the time of year when vertical stability is developing to maximum values.

The value of horizontal mixing coefficients obtained for this area are in substantial agreement with previous determinations for coastal areas. SVERDRUP and FLEMING (1941) obtained a coefficient for the California coastal region of $2 \times 10^6 cm^2/sec.$; and BOWDEN (1950) computed coefficients for the Irish Sea ranging from 0·36 to 9·0 $\times 10^6 cm^2/sec.$

It has been mentioned above that inclusion of the excess spring river flow of two successive years could account for the excess accumulation of river water during the summer. Such an increase in river flow would increase the spring-summer coefficients of eddy diffusion by only about 25%, and would not make them as great as those observed for the summer-winter change. It must be concluded, therefore, that the excess accumulation of river water in the summer is a joint effect of the increased river flow and the decreased turbulence.

DISCUSSION

The flushing times estimated from the accumulation of fresh water, and some general aspects of the circulation, are approximately confirmed by the drift bottle studies described by MILLER (1952). Practically all of the bottles were recovered south of the point of release, confirming the net drift southward parallel to the coast. The proportion of returns decreased greatly with distance from shore, however, and very few bottles released more than 15–20 miles from shore were returned. This confirms, for the surface waters at least, the active offshore transport as well as the narrow band of current parallel to the coast.

The rate of drift of the bottles released near shore varied over wide limits. Several gave velocities greater than 10 miles per day, but all of these were released either just south of Delaware Bay or off Chesapeake Bay, where the net drifts appear to occupy a very narrow coastal strip. Most of the bottles drifted at rates of 3–5 miles per day. A bottle travelling at this rate, which did not beach en route, could traverse the 350 mile stretch of coast in 70–117 days. This corresponds approximately to our flushing time within the 20 fathom contour of 108–125 days. Since very few bottles were recovered from greater distances offshore, it is impossible to check our flushing times for the deeper areas in this way.

The flushing times are based upon the assumption that no substantial volume of fresh water is added to the area except as river flow. MILLER (1952) obtained eighteen returns of bottles released on or near the 20 fathom contour in our area A. Their average drift was about 3·5 miles per day. The drift bottles, of course, do not give an evaluation of the movement of the deeper waters, but it seems probable that the surface drifts are greater than the average. Thus a maximum estimate of the advection of fresh water into the area can be made assuming that the water at all depths within the twenty fathom contour is passing from area A to area B at this velocity. The appropriate cross-section area is $3{\cdot}52 \times 10^6 ft^2$, so that the total volume transport would be $7{\cdot}5 \times 10^{10} ft^3/day$. Since the fresh water content ranges from 7·98–8·40 ‰, the corresponding transport of fresh water would be $5{\cdot}6–6{\cdot}3 \times 10^9 ft^3/day$. This includes the river water discharged directly into area A from the rivers emptying into Long Island Sound (Table 11, Group A) which accounts for about one-fifth of the total gaged drainage, or about $2{\cdot}9 \times 10^9 ft^3$ per day. Including the remainder,

$3{\cdot}4 \times 10^9$ ft^3/day, in the total river flow used in calculating the flushing times, would decrease them from about 1·6 years to 1·3 years—a change which is not significant considering the other approximations which have been made.

One tacit assumption has been made in the calculation of the horizontal mixing coefficients which has not been discussed. It is assumed that the current produced by the escaping river water is the only advective process of importance. Other currents, such as density and wind-induced currents, are also present. From the continuity of volume, the net transport of these currents must be zero, but it does not follow that the net transport of salt and fresh water must be zero. If, as seems likely, there are one or more large scale, counter clockwise eddies over the shelf, with an onshore current in the northern, low salinity, part of the region, and an offshore current in the southern higher salinity area, there will be a net offshore transport of salt. This would result in an underestimate of the coefficients of horizontal eddy diffusion. Unfortunately, our knowledge of the currents over the continental shelf, except for the narrow coastal strip, is inadequate to evaluate this effect.

A brief discussion of some of the forces which could produce the turbulence over the shelf may be of some interest. The tidal transport, the winds, the currents due to river flow and density structure, and the upwelling along the coast as a result of offshore winds, are the most obvious turbulent forces. In estuaries the mixing process has been related to the tidal volumes moving over a mixing length determined by the excursion of the tidal currents (ARONS and STOMMEL, 1951; KETCHUM, 1951). The approximate contribution of tidal flow over the continental shelf to the overall mixing process can be evaluated. For turbulent flow, the mixing effect would be proportional to the product of the velocity and the transport distance ($v_x l_x$). The coefficient of proportionality will vary, depending upon the actual degree of turbulence resulting from the flow, but the potential effect will always be less than this product. Both velocity and transport distance depend on the shape of the bottom contour and distance from shore, and the product will be greatest where the ratio of distance from shore to depth is a maximum (FLEMING, 1938). This product has been calculated for various depth contours for a semidiurnal tide with a mean amplitude of 50 cm, and has the following values, which may be compared with the coefficients of eddy diffusion listed in Table V.

30 fathoms	$0{\cdot}65 \times 10^6$ cm^2/sec.
40 fathoms	$1{\cdot}08 \times 10^6$ cm^2/sec.
100 fathoms	$0{\cdot}32 \times 10^6$ cm^2/sec.

This product increases to a maximum value at the 40 fathom contour and decreases beyond this depth, whereas the mixing coefficients decreased with increasing depth throughout this range. The tidal mixing product is always less than the coefficients of horizontal diffusion and the coefficient of proportionality is probably much less than unity. It may be concluded that the tides alone can contribute only a small fraction of the total turbulence, and that the other forces must contribute substantially at all times of year.

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