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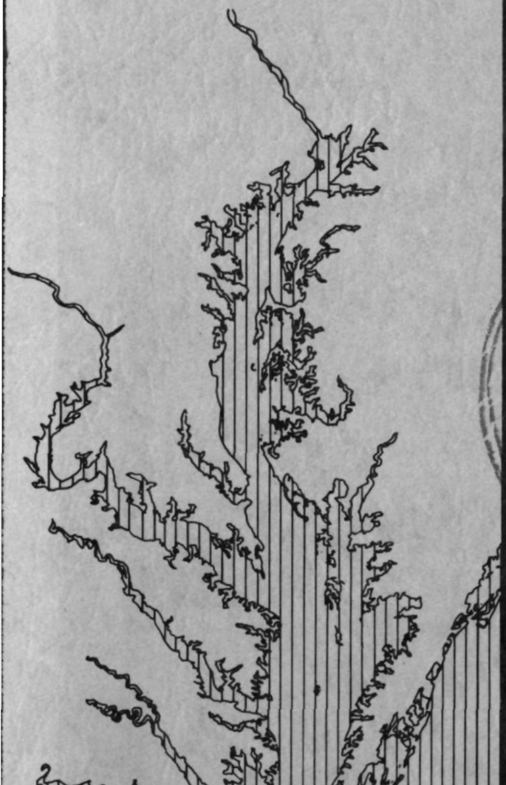

A STUDY OF THE PHYSICAL HYDROGRAPHY OF THE PATUXENT RIVER AND ITS ESTUARY

Wadsworth Owen

Technical Report 53

Reference 69-6 April 1969

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TECHNICAL REPORT 53

A STUDY OF THE PHYSICAL HYDROGRAPHY OF THE PATUXENT RIVER AND ITS ESTUARY

by

Wadsworth Owen

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Reference 69-6
April 1969

D.W. Pritchard
Director

Abstract

The Patuxent River has the largest drainage basin in the State of Maryland. The estuary of the Patuxent is tributary to the Chesapeake Bay which itself is an estuary. A distinguishing feature of the Patuxent Estuary is its intermittent transition from a two-layer flow system to a three-layer flow system, a transition which occurs most often in the month of April.

Acknowledgements

The author is deeply indebted to his faculty advisor, Dr. D.W. Pritchard, for technical guidance in the preparation of this essay. He is indebted to Dr. Kinsman for his encouragement over a period of many years and for his editorial guidance. He is also indebted to Dr. J. Schubel for his encouragement and to Mrs. Schubel who painstakenly transferred the data points from the CBI reports to the cross-sections. Mr. M. Hiller of Westinghouse and Westinghouse, itself, cooperated in the preparation of this essay. Mr. R. Cory of the U.S. Geological Survey made special field trips to the Patuxent and both Mr. Cory and Mr. S.G. Heidel also of the U.S. Geological Survey supplied data on conductivity and chemical composition. Credit for final typing of the manuscript is due Mrs. E.S. Shinn. The guidance of Mr. R.W. Linfield was invaluable in the preparation of the figures. The numerous contoured cross-sections were inked by Mrs. D.J. Loose. Credit for inking the many other illustrations is due Mr. Wayne Dorsey of New London, Connecticut.

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1.0 Introduction

The Patuxent River, located on the Western shore of the Chesapeake Bay, is one of the seven primary estuaries tributary to the Chesapeake Bay system of drowned river valleys. Figure 1 shows the location and the extent of the river and its drainage basin. The Patuxent extends 174 km along its center line, has an area of 1.41×10^8 m^2, and a volume of 7.57×10^8 m^3. Its volume-mean depth is $7.57 \times 10^8 / 1.41 \times 10^8 = 5.37$ m. A comparison of the Patuxent with the other primary estuaries of the Chesapeake is made in Table 1. It is

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Table 1. Primary tributary estuaries to the Chesapeake Bay. After Stroup and Lynn (1963).

Tributary	Volume* (10^8m^3)	Area* (10^8m^2)	Mean* Depth (m)	Rank Volume	Rank Area	Rank Depth
Potomac	72.83	12.78	5.70	1	1	1
James	23.39	6.54	3.64	2	2	7
Rappahannock	17.33	3.83	4.50	3	3	5
Choptank	10.70	2.23	4.80	4	4	4
York	7.93	1.62	4.90	5	5	3
Patuxent	7.57	1.41	5.36	6	7	2
Chester	5.56	1.44	3.86	7	6	6

* Statistics based on U.S.C. & G.S. charts Nos. 77 and 78. They are thus effectively restricted to tide water.

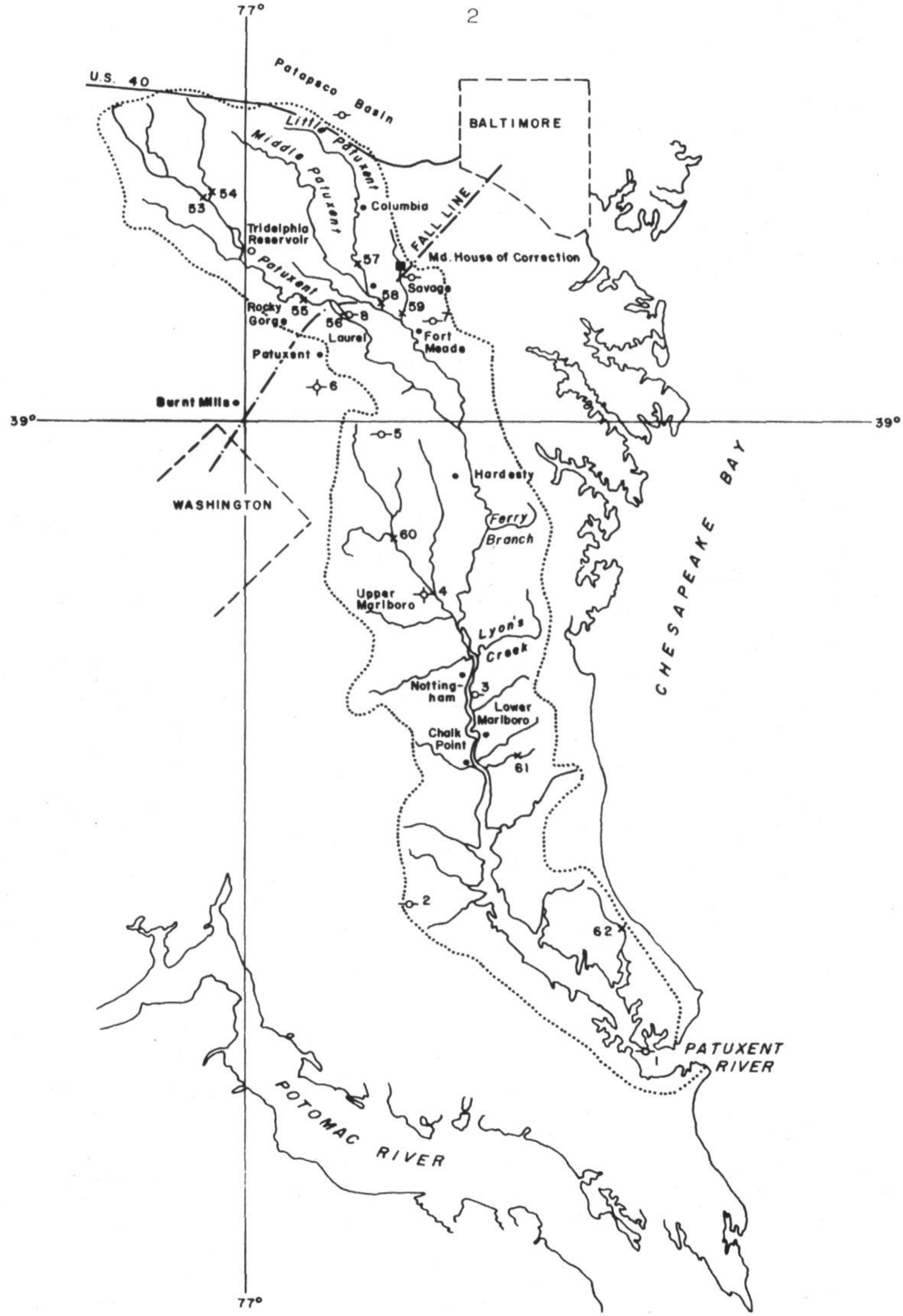

Figure 1. The Patuxent Drainage Basin.

interesting to note that although the Patuxent is not large, it ranks second in mean depth.

The Patuxent is a unidirectionally flowing fresh water river from the headwaters near the northwest extremity of Howard County to approximately Hardesty 90 km above the mouth. Between this point and the mouth, the Patuxent is subject to tidal influence. The upper limit of intrusion of measurable quantities of sea salt varies between 44 km (near Chalk Point) and 90 km (near Hardesty), the position depending on river flow. The segment of the waterway between the head of the tide and the upper limit of sea salt intrusion is called the tidal river, Pritchard (1967), and below the upper limit of sea salt intrusion is called the estuary. This essay is devoted primarily to a description of the estuarine segment of the Patuxent.

As is so often the case, the legal division between "tidal water," which is supervised by the Department of Chesapeake Bay Affairs, and "fresh water," which is the province of the Department of Inland Game and Fish, is an administrative rather than a physical distinction. The boundary has been set, arbitrarily, at the New Queen Ann's Bridge near Upper Marlboro where U.S. Route 4 crosses the Patuxent.

The maximum extension of sea salts occurs in late August and early September, when river flow is at its lowest, while in April, when maximum fresh water runoff occurs, the length of the estuary proper is at a minimum.

An estuary is characterized by a non-tidal circulation driven largely by the density distribution resulting from the mixing of sea water with fresh water. A classification of estuaries based on the salt-balance equation was proposed by Pritchard (1955). The Patuxent estuary corresponds most of the time to Pritchard's type B (partially mixed) estuary and exhibits the two-layered circulation which marks the type. However, it occasionally shows a transition toward a three-layered circulation near its mouth. This three-layered circulation has been found most frequently in April but it is known to occur sporadically in other months as well. For comparison, Baltimore Harbor is an embayment with a permanent three-layered flow (Carpenter (1960)). The Patuxent estuary is the first in which a normal two-layered flow associated with an intermittent three-layered flow has been found.

The drainage basin of the Patuxent is the largest lying entirely within Maryland--2.413×10^3 km^2, roughly 8.8% of the state. It is bounded on the north by a ridge of high ground extending west from Baltimore parallel to route U.S. 40 west. This ridge divides the basins of the Patuxent and the Patapsco. About one fourth of the Patuxent basin lies on the Piedmont plateau. Here the banks of the Patuxent and its tributaries, the Middle Patuxent and Little Patuxent, are characteristically steep. The elevation of the river bed diminishes from 240 to 84 m near the geographic fall line which runs more or less directly from Baltimore to Washington crossing the Patuxent at a point 130 km from its mouth. Seaward of the fall line, the Piedmont plateau gives way to the coastal plain where the basin begins to take on a more mature aspect with meanders between gently sloping banks and occasional marshes. The position along the Patuxent at which its bed stands at mean sea level is uncertain. However, it must be located above the extreme limit of salt intrusion at Hardesty.

The use of the Patuxent and its drainage basin is expanding. Laurel, located on the Patuxent near the geographic fall line, is the basin's largest city and is growing rapidly. The construction of the city of Columbia in the northwest section of the drainage basin near the little Patuxent will accelerate the population growth of the region. In contrast to the northern section of the drainage basin, the southern coastal plain region is largely undeveloped.

This region once supported a prosperous agriculture and fishing economy which has become less important with the decline of waterborn traffic on the Bay as a major link in the local transportation system. The extension of the road net has supplanted the agricultural and fishing economy with one based on recreation and suburban commuting which promises to grow at a rapid rate. The expansion of human use of the lower reaches of the Patuxent will probably affect the water quality and perhaps the region's importance as a wild life refuge, the Patuxent being situated on a major waterfowl flyway.

The principal users of the water of the Patuxent at the present time are listed in Table 2. The Washington Suburban Sanitary Commission regulates the flow of the Patuxent with dams at the Tridelphia and Rocky Gorge reservoirs. It diverts about 72.5% of the total yearly flow through these dams to its Patuxent and Burnt Mills water treatment plants. Ultimately, this water is discharged as effluent to the Potomac Basin, not to the Patuxent. This diverted flow amounts

Table 2. Principal Users of Patuxent Water, 1964.

Principal Patuxent Basin water treatment plants:

Plant	Location	Effluent Ultimately Returned to:
Patuxent*	near Laurel	Potomac
Burnt Mills*	Burnt Mills	Potomac
Fort Meade	Fort Meade	Little Patuxent
Maryland House of Correction	near Georgetown	Little Patuxent (by way of Dorsey Run)

Principal Patuxent Basin sewage treatment plants:

Plant	Location	Effluent Ultimately Returned to:
Fort Meade	Fort Meade	Little Patuxent
Savage	Savage	Little Patuxent
Laurel	Laurel	Patuxent
WSSC*	on Western Branch	Anacostia
Maryland House of Correction	near Georgetown	Little Patuxent (by way of Dorsey Run)

* These plants are part of the Washington Suburban Sanitary Commission.

to about 11% of the total Patuxent river flow above Lyon's Creek. Other water treatment plants served by the Patuxent drainage area are the Fort Meade and Maryland House of Correction plants. Of the sewage treatment plants which discharge effluent to the Patuxent, the Fort Meade plant is the largest.

With respect to pollution as it is ordinarily understood, the Patuxent is in resaonably good condition. On the average, there are no extensive permanently polluted areas. However, during periods of low fresh water flow, the state of the river below Savage becomes unsatisfactory (Wolman, *et al.* (1961)). As new plants are built and put into operation, the generally good condition will undoubtedly deteriorate. In addition to the ordinary types of pollution considered above, there is another type of pollution which is of importance to the Patuxent estuary. Water withdrawn at ambient temperature, used for cooling, and returned to a river, or estuary, at a higher temperature even without change in its chemical quality can be harmful to marine life either directly if the temperature change is great or indirectly by upsetting the established ecosystem. For example, biological studies have shown that some species of plankton are killed by passage through the condensers of the Potomac Electric and Power Company's Chalk Point plant. However, there is no present evidence of a detrimental effect on the estuary. On the contrary, during the winter months it appears that the heated discharge improves sport fishing. The potential effects of the heated water effluent in this region have been studied by Mihursky (1963) and Pritchard and Carter (1965).

2.0 The salinity distribution and the inferred net non-tidal circulation in the Patuxent estuary

The interaction of salt water from the sea with fresh water run off from the land causes the density gradients which drive the net non-tidal circulation in estuaries. Thus it is often possible to consider the spatial variation of salinity as representative of the spatial variation of density although in temperate latitudes the temperature decreases the vertical density gradients in winter and increases them in summer. The circulation in the Patuxent can best be understood in terms of the seasonal variation of the water available at the head and at the mouth of the estuary.

2.1 The head of the estuary

The ratios of the ionic constituents of sea water are usually taken as constant. There are measurable variations but for many problems they are negligibly small. The ratios for river water show much greater variation both with season and with location and the variations can seldom be neglected. Pritchard (1967) defines the upstream limit of an estuary as the transition region where the ratios of the major dissolved ions to one another undergo a rapid change. There is insufficient data available to document precisely the seasonal variation of this transition zone in the Patuxent Estuary. However, the ratio of total dissolved solids to chloride ion for the available data is plotted as a function of distance from the mouth of the estuary in Figure 2. The transition from the ratio characteristic of sea water to that of the Patuxent River occurs between Nottingham, 66 km from the mouth, and Hardesty, 90 km from the mouth, in late August through early October, a period of low river flow. In April the transition region occurs between Chalk Point 44 km from

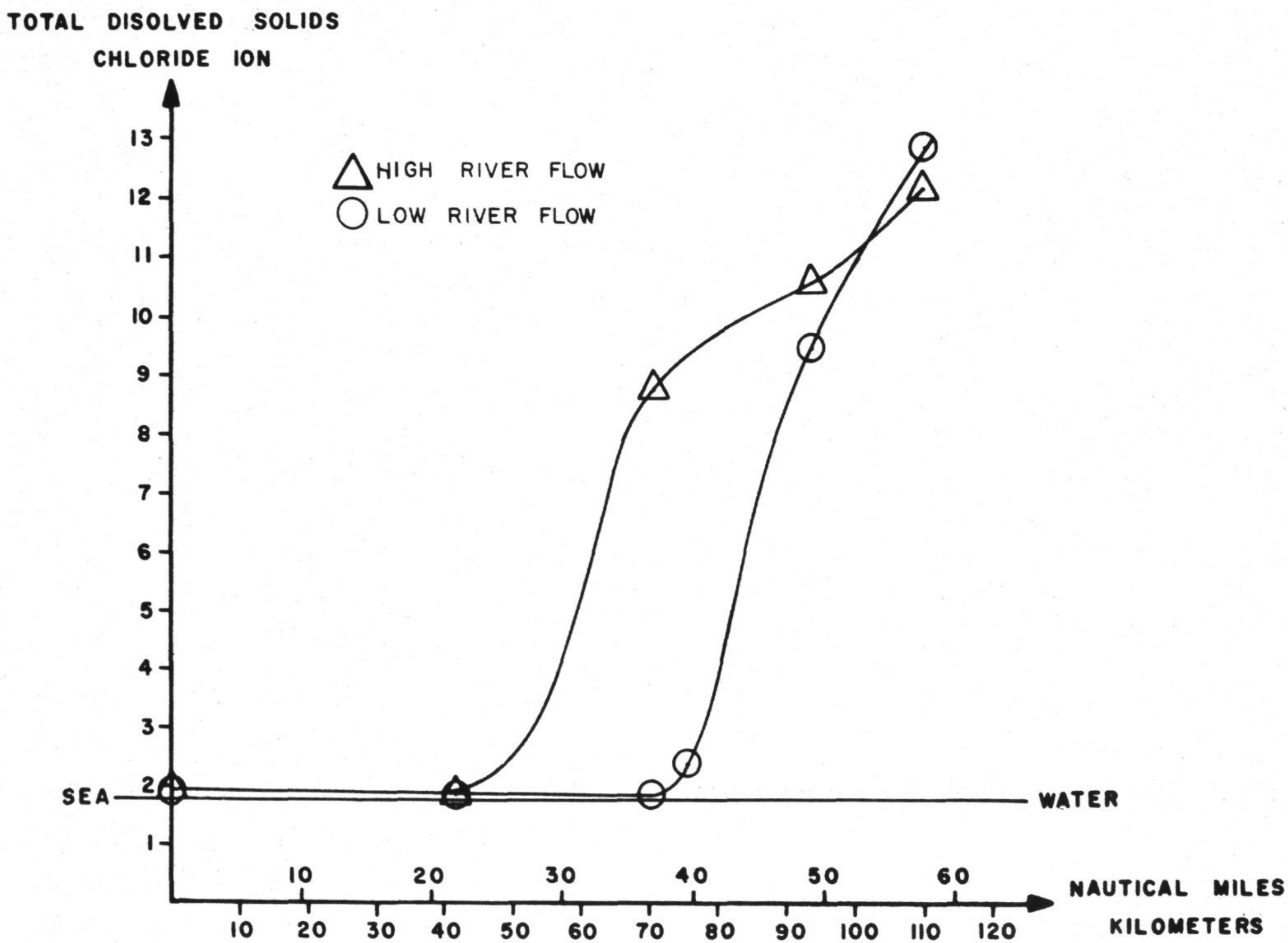

Figure 2. Ratio of total dissolved solids to chloride ion.

the mouth and Nottingham, a period of high river flow. The observations of the chemical constituents in the Patuxent were made during the calendar year 1963 by Heidel and Frenier (1965). Chemical composition data are not available from the years for which the detailed hydrographic and runoff data have been compiled. However, measurements of conductivity in the Patuxent made by the Chesapeake Bay Institute indicate a marked reduction in conductivity in this region of the Patuxent as does more recent conductivity data taken by the U.S. Geologic Survey (Cory (1964)).

The seasonal variation of the fresh water runoff in the Patuxent is a function of net precipitation less total evapotranspriation on the watershed, natural and man derived storage, and to a lesser extent, the net precipitation less evaporation from the water surface.

Stream gauge records are available for approximately 1/3 of the area of the Patuxent drainage basin. These data together with rainfall records were used to estimate the seasonal variation in fresh water runoff in the Patuxent. The estimated mean monthly runoff above Lyon's Creek, 71 km from the mouth, is shown in Figure 3. The runoff increases from January through April to a maximum. Low flow periods occur in July, October, and December. The estimated mean monthly runoff for the year 1952 is shown in Figure 4. It is much more irregular than the 10 year mean monthly runoff, but similar trends are discernable. The flow was unusually low in February 1952 and also unusually high in April. However, the April maximum and the July and October minima appear in both records. The estimated mean monthly runoff for the Patuxent River and its estuary, adjusted

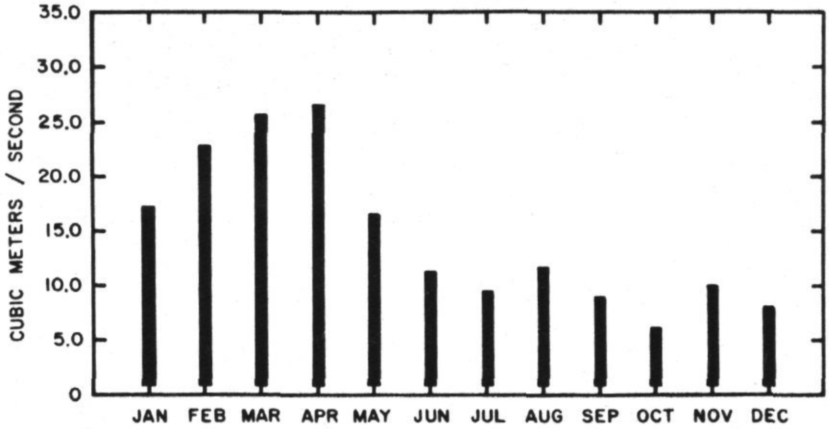

Figure 3. Mean monthly runoff for the Patuxent River above Lyons Creek. Average: 1952-1961.

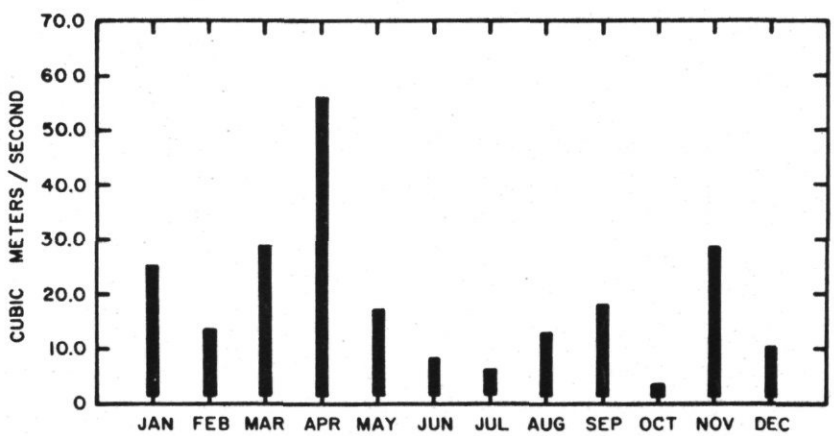

Figure 4. Mean monthly runoff for the Patuxent River above Lyons Creek. Year: 1952.

for net precipitation less evaporation from the estuary surface is shown in Figures 5 and 6. The magnitude of the flow is increased because of the added drainage area which is now included in the estimate. The character of the seasonal variation of the runoff remains unchanged with the peak flow in April and the minimum flows occurring in the same months as previously noted for both the 1952-1961 mean and for the 1952 record.

2.2 The mouth of the estuary

At the mouth of the Patuxent Estuary is the Chesapeake Bay which is a partially-mixed estuary (Pritchard (1955, 1963)). In the Chesapeake Bay off the entrance of the Patuxent Estuary the seasonal mean salinity of the surface water varies from about 15.5‰ in the fall to a low of about 10‰ in the spring and the bottom water has a similar variation from about 17‰ in the fall to a low of about 12‰ in the spring (Stroup and Lynn (1963)). For the Patuxent the Chesapeake Bay serves as a low salinity (low density) surface water source and high salinity (high density) bottom water source throughout the year.

The seasonal changes in the water of the Chesapeake Bay off the mouth of the Patuxent have a direct bearing on the interaction of the water of the Chesapeake Bay and the Patuxent Estuary. Dominating these seasonal changes in the salinity on the right-hand side of the Chesapeake Bay looking seaward is the effect of the freshwater discharge from the Susquehanna River at the head of the Bay. The Susquehanna usually has high flows in March and April with the peak flow often occurring in March, Figures 7 and 8, whereas the Patuxent,

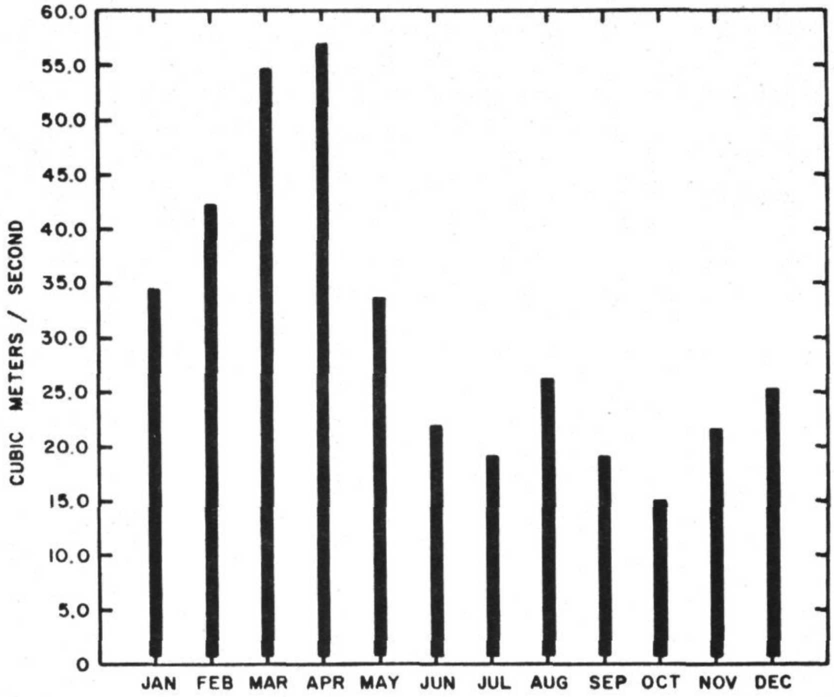

Figure 5. Mean monthly runoff for the Patuxent River and Estuary adjusted for net precipitation less evaporation from the estuary surface. Average: 1952-1961.

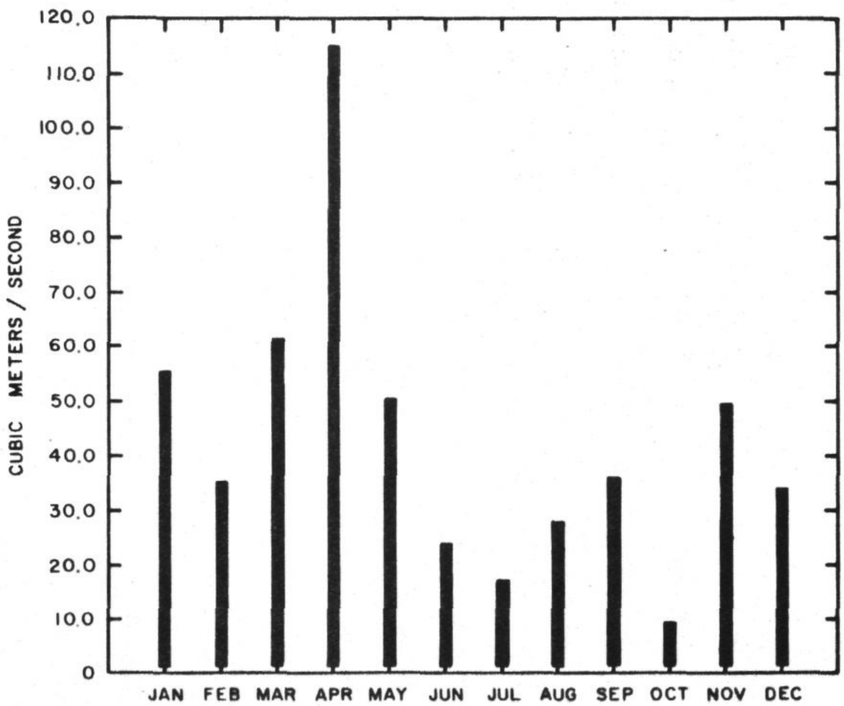

Figure 6. Mean monthly runoff for the Patuxent River and Estuary adjusted for net precipitation less evaporation from the estuary surface. Year: 1952.

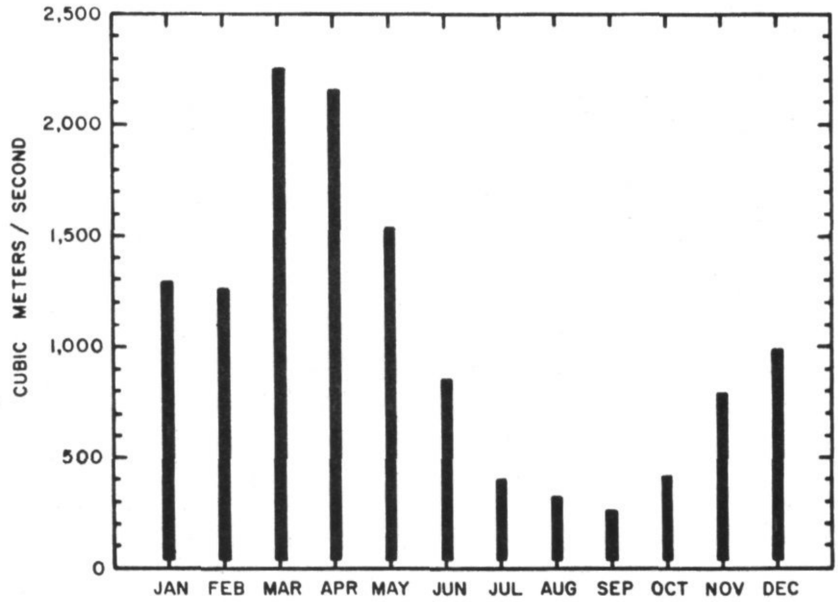

Figure 7. Mean monthly discharge rate of the Susquehanna River at Conowingo. Average: 1938-1955.

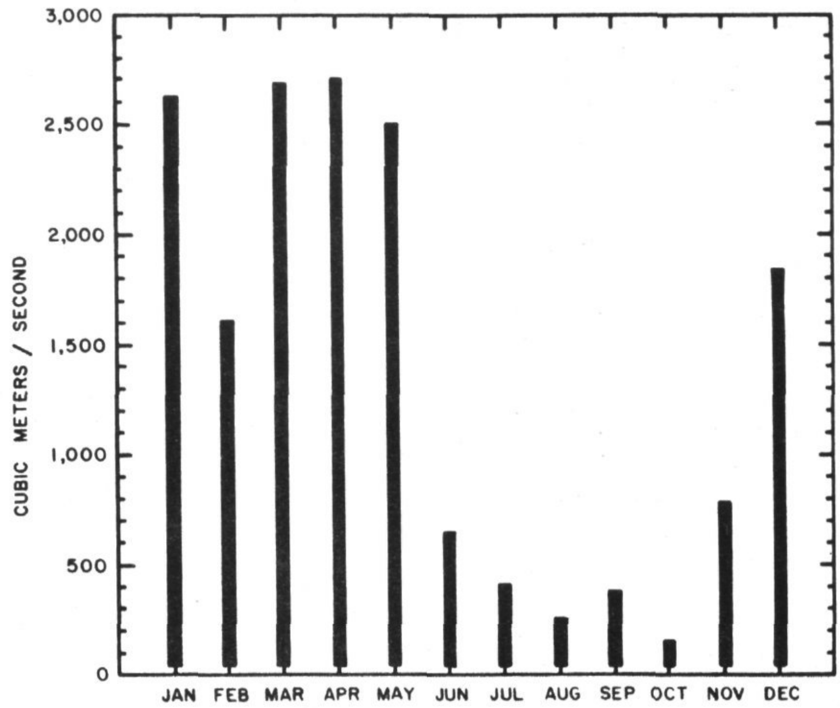

Figure 8. Mean monthly discharge rate of the Susquehanna River at Conowingo. Year: 1952.

Figure 5, has high flows in March and April with the peak flows usually occurring in April. The Patuxent River contributes very little to the spring surface-salinity reduction in the Chesapeake Bay. The upper Bay is dominated by the Susquehanna and the spring salinity decrease usually precedes the spring reduction in salinity in the lower reaches of the Patuxent. This phenomenon has been reported by Beaven (1946) and Nash (1947) and is also evident in the data taken by the Chesapeake Bay Institute in the years from 1949 to 1963.

It might be mentioned here that there is diversion and storage in the reservoirs in the Patuxent but this is only about 5.7% of the yearly runoff into the Patuxent River and estuary and its monthly variation is not large being on the order of 3.5% of the yearly average runoff. It is therefore unlikely that the diversion of flow from the Patuxent River has an important effect on the salinity distribution in the lower reaches of the estuary. Control of the Susquehanna River is so slight that it, too, has little long term effect on the Bay. The Susquehanna flow can be stored for periods of only a few days. Hence, the monthly averages may be considered to be essentially unregulated.

The seasonal envelope of salinity, indicated by crosses connected by straight lines, of C.B.I. Station 818-A on the western side of the Chesapeake Bay is shown in Figure 9. The vertical bars which cross the envelope indicate the extent of the variation of the mean monthly salinity at Solomon's near C.B.I. Station Px-4 for the years 1950 through 1957. The salinity at Bay Station 818-A is at a maximum in late October or early November following the low runoff from the

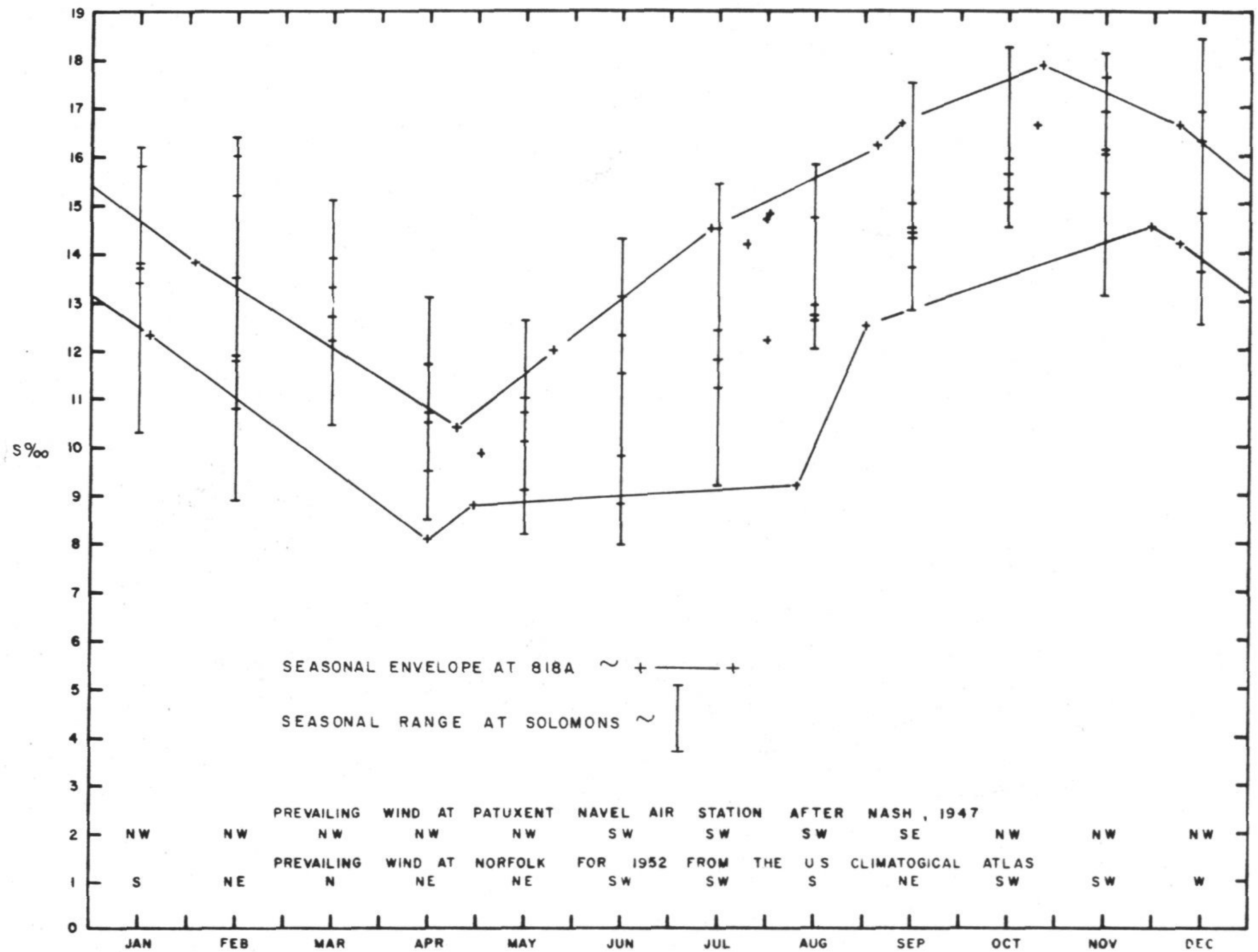

Figure 9. Seasonal envelope of salinity at C.B.I. Station 818A compared with the seasonal range of surface salinity at Solomons.

Susquehanna which occurs in late summer and fall. In November, the Susquehanna runoff begins to increase and the salinity at Station 818-A begins to decrease until late April or early May when it reaches its minimum. From this time on it increases until the peak is again reached. The mean monthly salinities at Solomon's appear to decrease less rapidly in the spring than those of C.B.I. Station 818-A. This is indicated in Figure 9 by the extent to which the vertical bars protrude above the envelope in the period of decreasing salinity. In contrast, during the period of increasing salinity they are more nearly contained within the envelope. Thus, not only does the seasonal variation of runoff in both systems affect the salinity distribution of the lower reaches of the Patuxent but it is probable that the sequence in which the runoff occurs is also important.

2.3 The salinity distribution in the Patuxent Estuary

Beginning in 1949, the Chesapeake Bay Institute has maintained salinity, temperature, oxygen, and pH stations in the Patuxent. The station locations used in this report are indicated in Figure 10. In 1952, an intensive seasonal survey was made in the Patuxent during which hourly measurements of salinity, temperature, and current velocity over a 24 hour period were made at 5-foot (about 1.5 meter) depth intervals at each of the stations. The distributions of salinity and temperature in a longitudinal-section along the axis of the estuary are depicted in Figures 11 through 18. These figures have been prepared from the 24-hour average salinity and temperature as observed at the stations shown in Figure 10 on the Patuxent

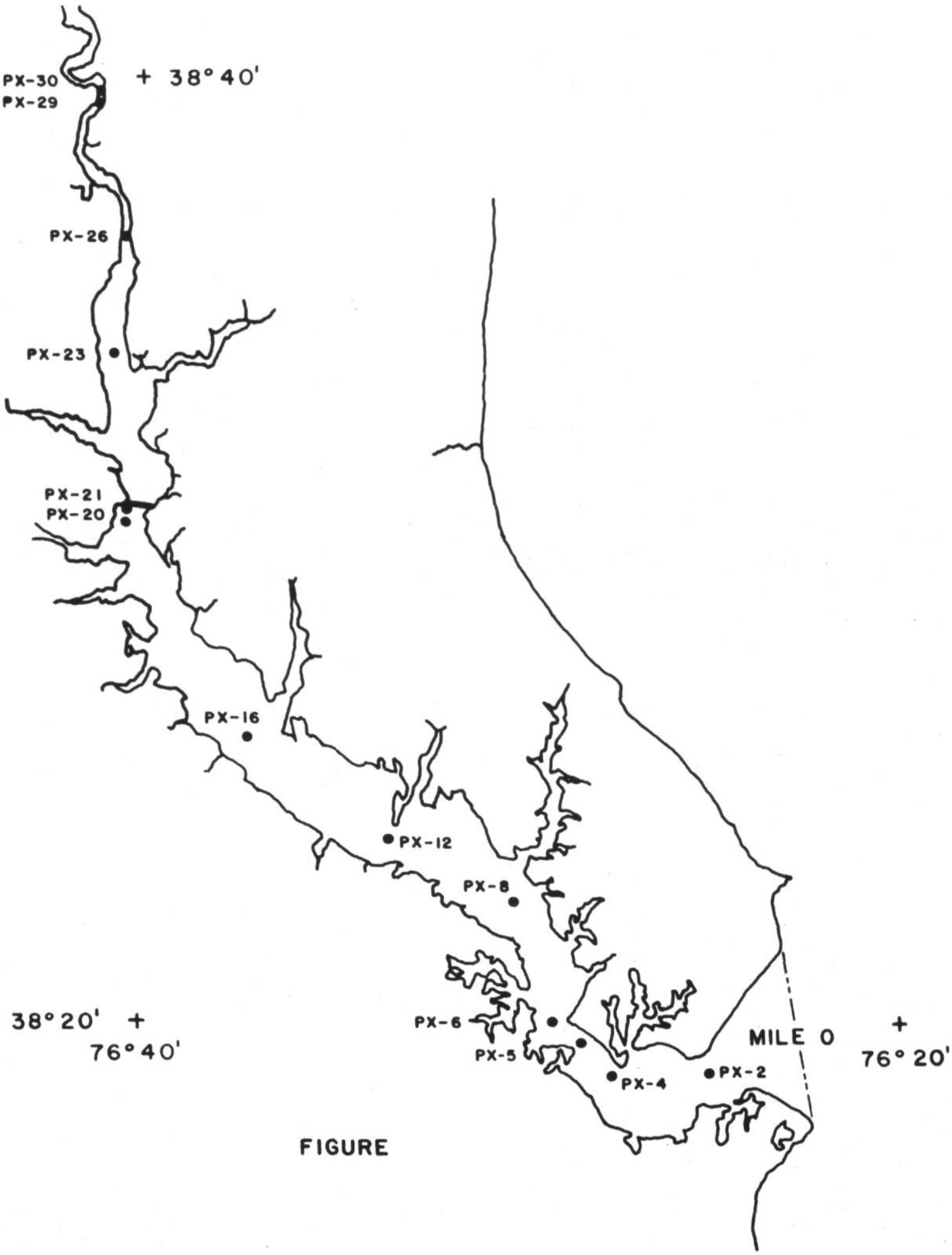

Figure 10. C.B.I. Station locations in the Patuxent.

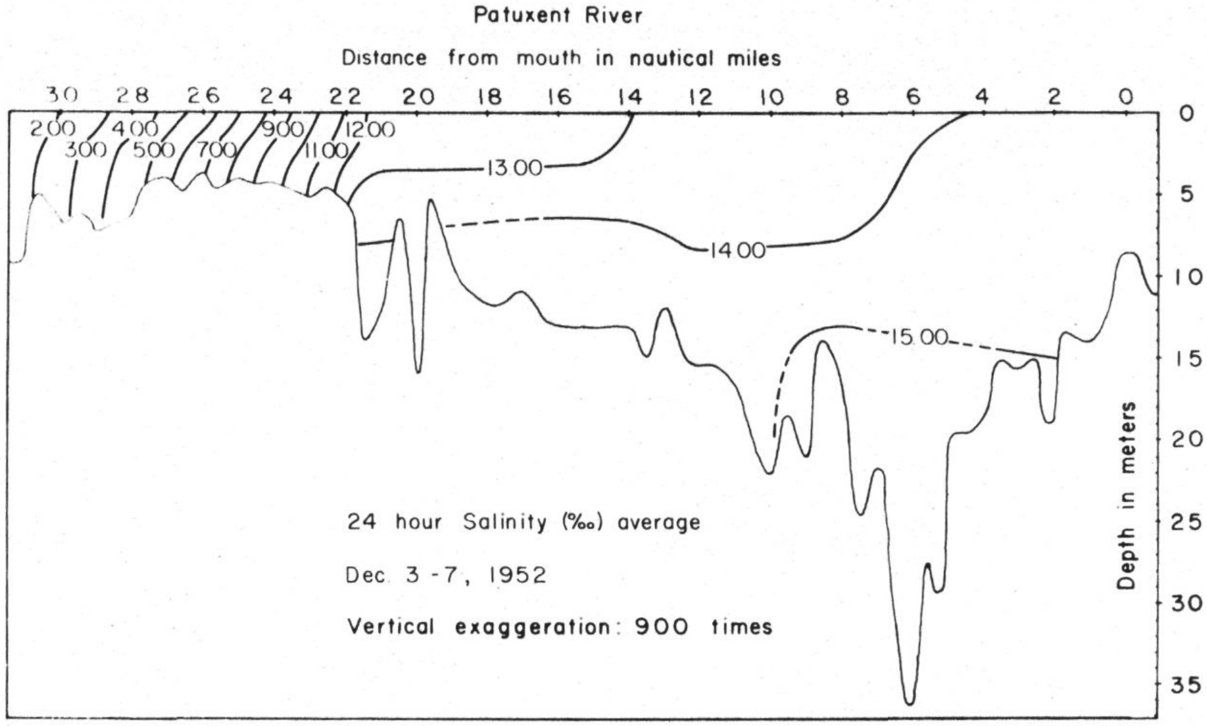

Figure 11. 24 hour salinity average, Dec. 3-7, 1952.

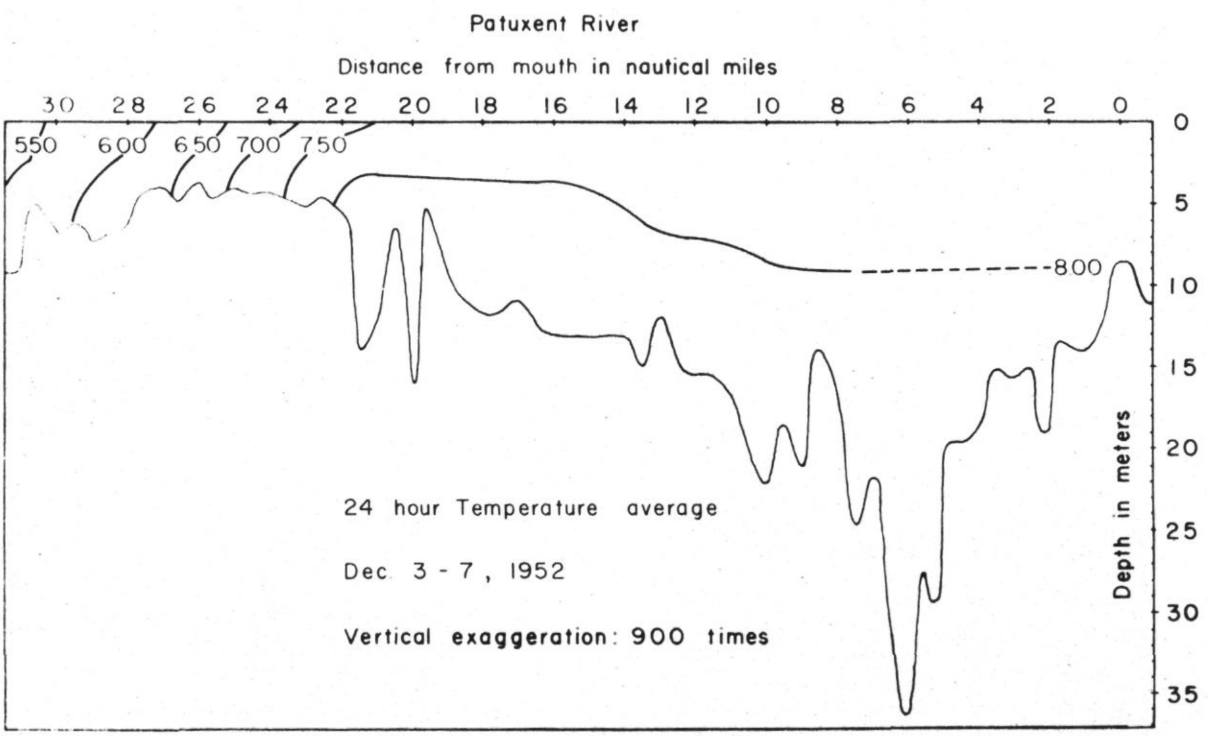

Figure 12. 24 hour temperature average, Dec. 3-7, 1952.

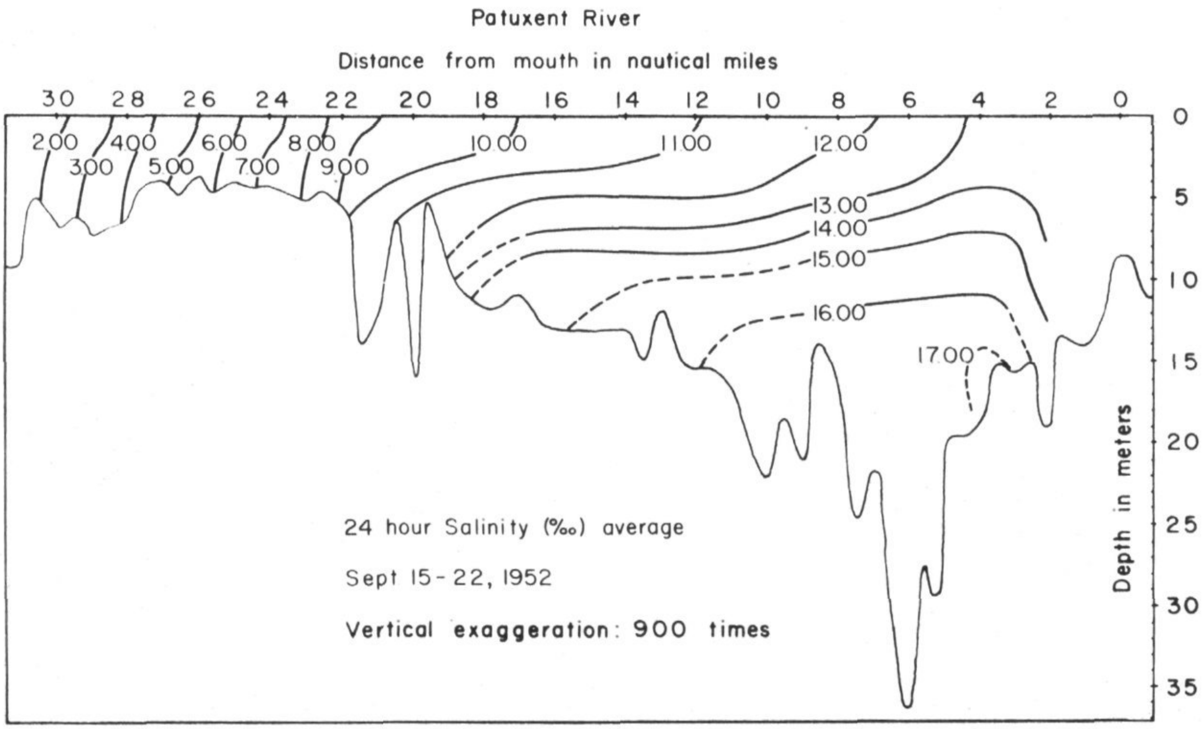

Figure 13. 24 hour salinity average, Sept. 15-22, 1952.

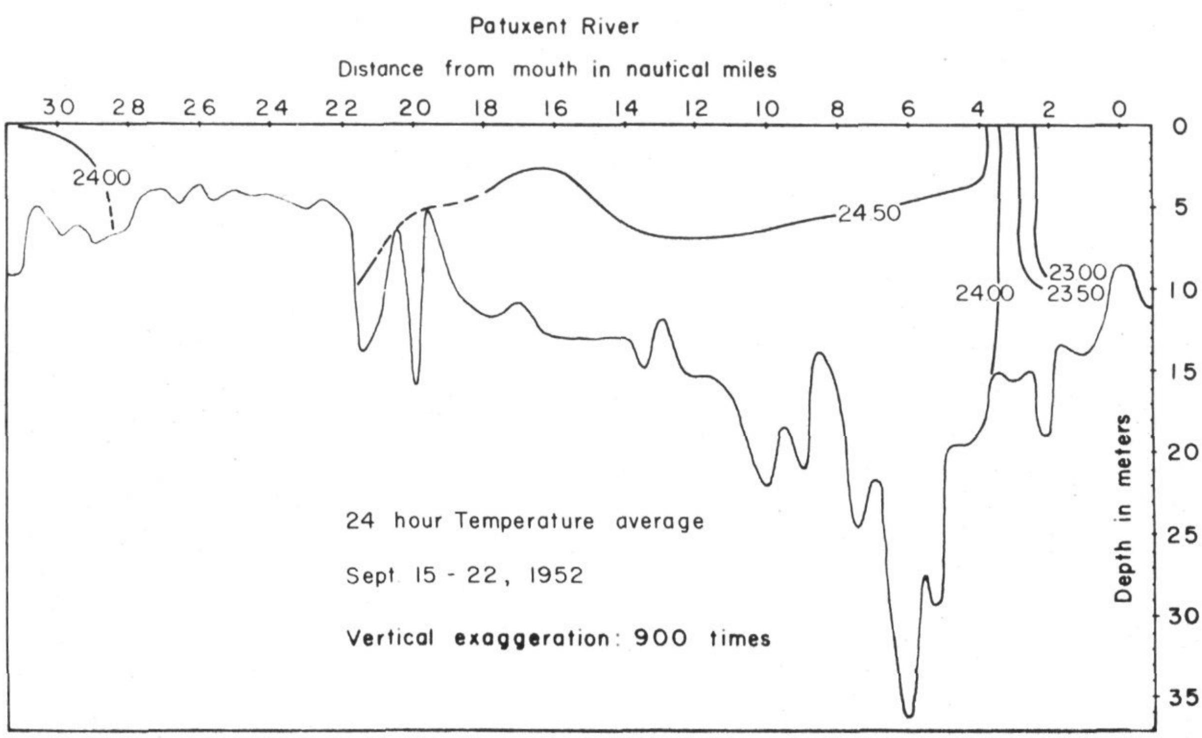

Figure 14. 24 hour temperature average, Sept. 15-22, 1952.

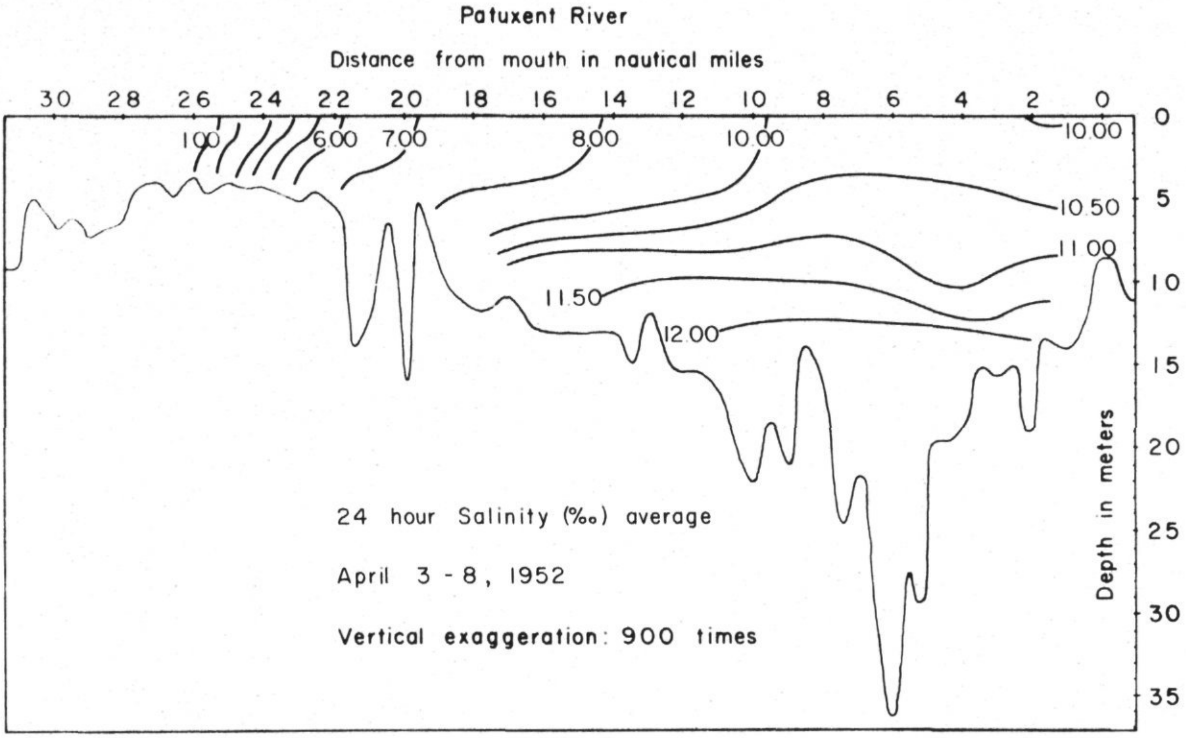

Figure 15. 24 hour salinity average, April 3-8, 1952.

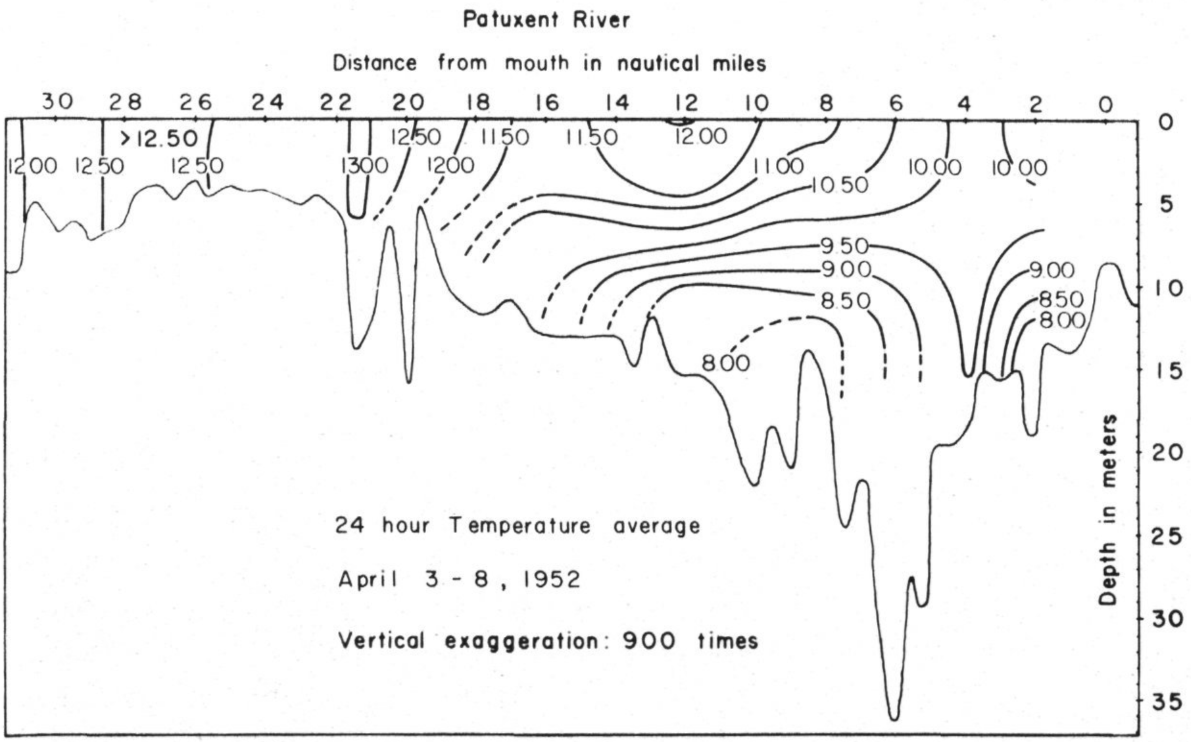

Figure 16. 24 hour temperature average, April 3-8, 1952.

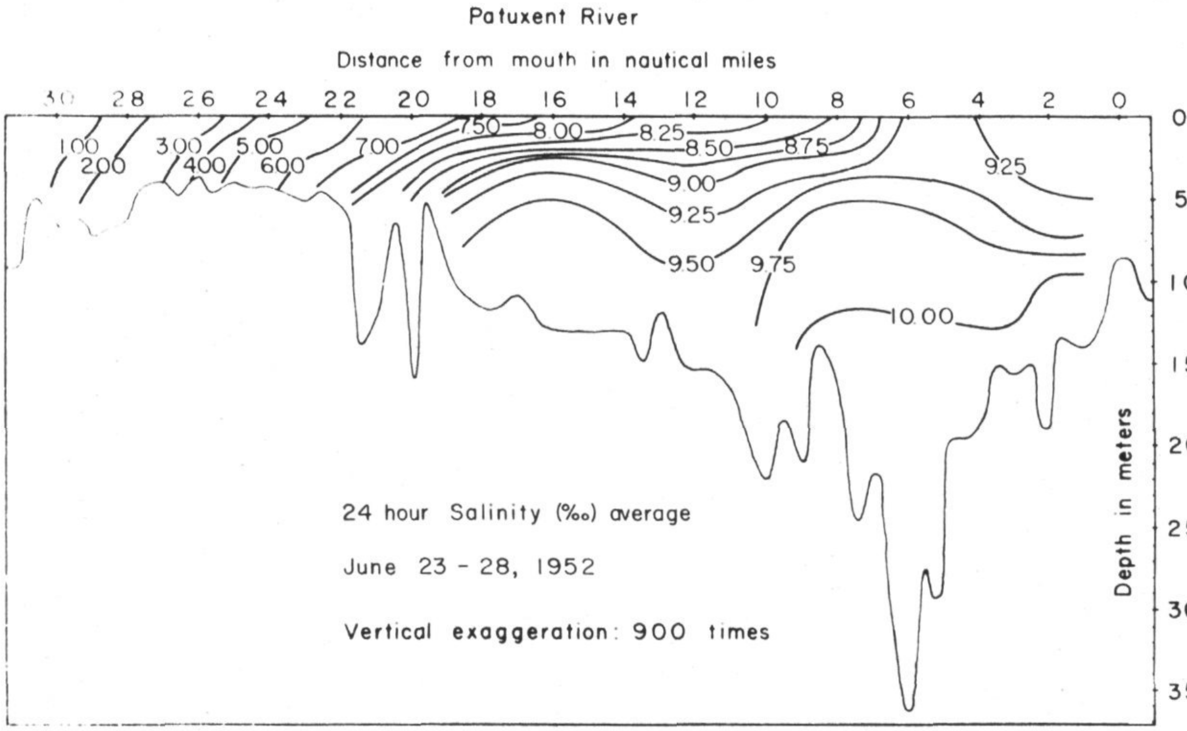

Figure 17. 24 hour salinity average, June 23-28, 1952.

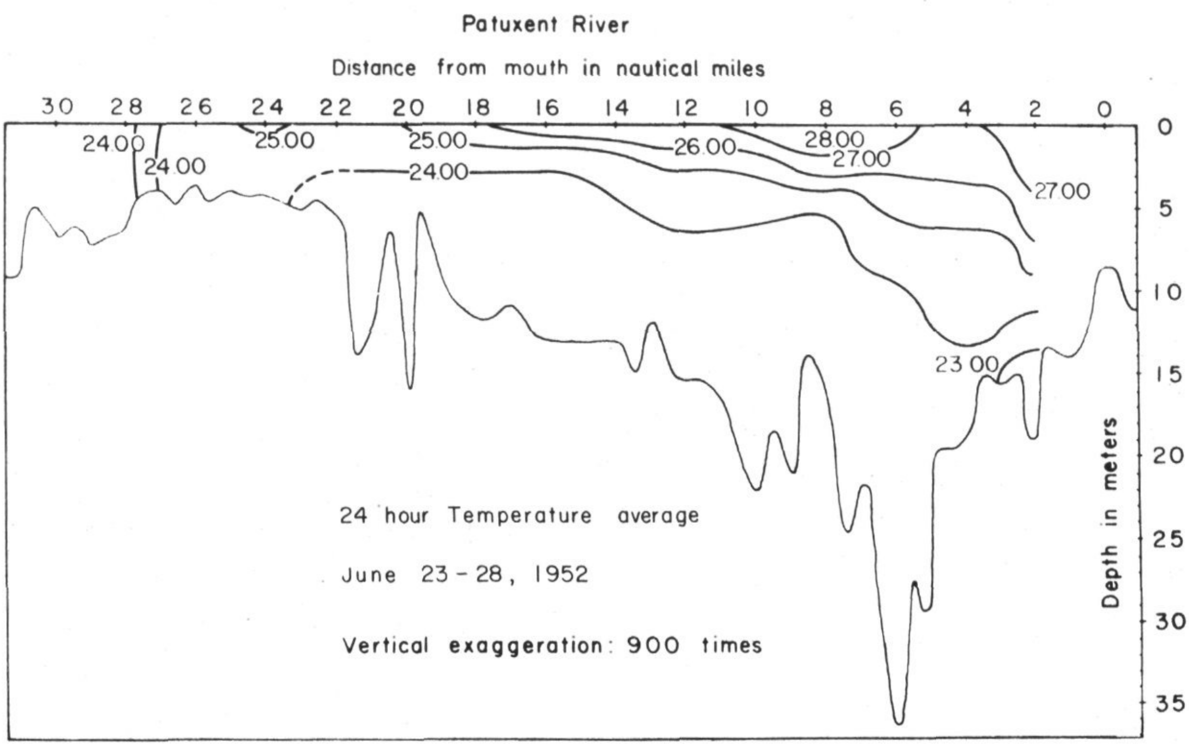

Figure 18. 24 hour temperature average, June 23-28, 1952.

Winter, Spring, Summer, and Fall cruises.

The salinity distribution found during the Winter Cruise, December 3-7, 1952, Figure 11, is representative of a partially-mixed estuary with its two-layer flow. The upper layer is less saline than the lower layer while both layers increase in salinity toward the mouth of the estuary. The temperature distribution, Figure 12, has little vertical stratification.

The salinity distribution for the Fall Cruise, September 15-22, 1952 is a similar two-layer system. However, in the Fall Cruise the vertical salinity gradient is stronger and the salinity greater than it was in the winter. Another difference appears in the isopleths of salinity which open up between miles 2 and 4. The temperature distribution has a horizontal gradient between miles 2 and 4. The wider spacing of the isopleths of salinity and the horizontal temperature gradient between miles 2 and 4 may indicate an intrusion of Bay water at all depths above the sill at the entrance to the Patuxent. With this possible exception, the Winter and Fall Cruises of 1952 have the salinity and temperature distributions to be expected in tributary coastal plain estuaries along the Eastern coast of the United States.

The salinity distributions for the Spring Cruise, April 3-8, 1952, Figures 15 and 16, and the Summer Cruise, June 23-28, 1952, Figures 17 and 18, appear to be quite different from the Fall and Winter Cruises. During the Spring Cruise there is a reduction of the vertical salinity stratification between miles 2 and 10. The 10.00‰ salinity isopleth reaches the surface near mile 2 and, again, seaward of mile 10. Thus the surface salinity increases from less than 10‰ at the mouth to a maximum value greater than 10‰ between miles 2 and 10 and, from that point on, decreases until the upper limit of the estuary is reached. If one takes the salinities averaged over 24 hours and further averages them over the depth at stations Px 2, 4, and 8, the values are remarkably uniform.

The Summer Cruise data indicate similar spreading of the spacing between the isohalines in the lower reaches of the estuary. The vertical averages of the salinities at Px 2, 4, and 8, however, are not as consistent as they were for the Spring Cruise. The surface salinity maximum appears between mile 2 and slightly above mile 6. The temperature data for both the Spring and Summer Cruises indicate a reduction of stratification in the lower reaches of the estuary.

During spring and summer near the mouth of the Patuxent low salinity water at the surface is underlain by high salinity water. The surface water of the Bay is less saline (lighter) than Patuxent surface water and the bottom water is more saline (heavier) than Patuxent bottom water. Bay water thus flows into the Patuxent at both surface and bottom. To satisfy continuity, there must be an outflow. It is postulated that this outflow occurs at mid-depths in a manner similar to that found in Baltimore Harbor (Stroup *et al.* (1961)), Cameron and Pritchard (1963)). The source of the low salinity surface water and high salinity bottom water in the lower reaches of the Patuxent is, as is the case of Baltimore Harbor, the Chesapeake Bay. As shown by the solid line in Figure 19, the salinity in

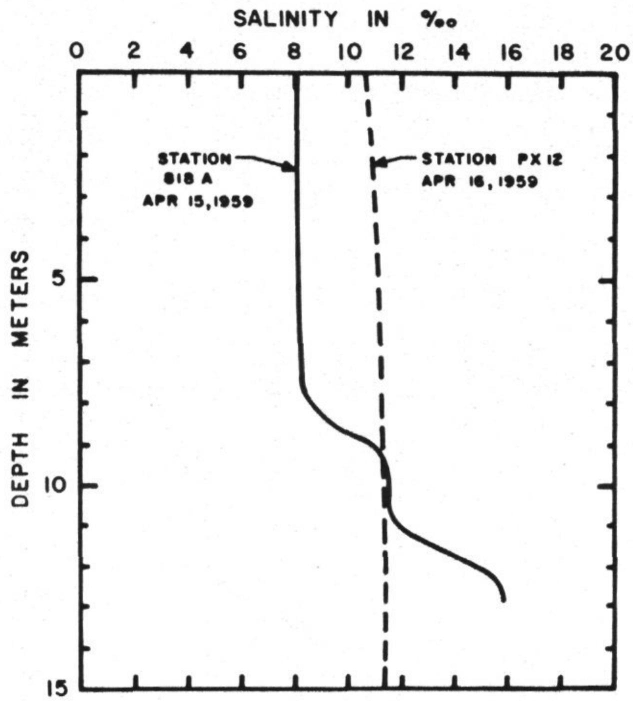

Figure 19. Salinity near the mouth of the Patuxent (Station 818-A) and in the Patuxent (Station Px 12).

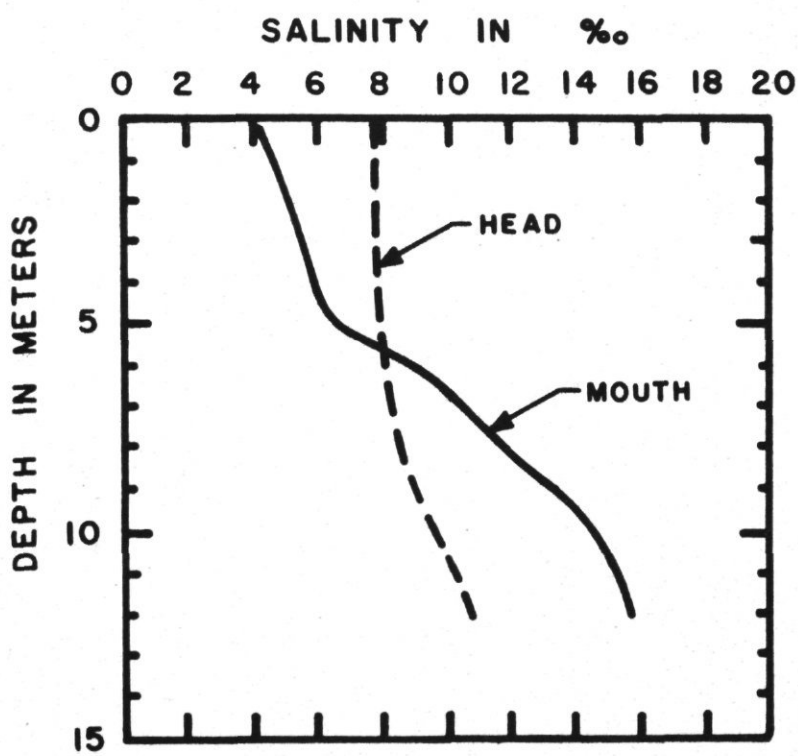

Figure 20. Salinity at the head and at the mouth of Baltimore Harbor (after Pritchard and Cameron, 1961).

Chesapeake Bay at C.B.I. Station 818-A is lower in the surface water than in the bottom water. At Station Px 12 in the Patuxent the salinity, as shown by the dotted line, has a nearly uniform vertical profile. Corresponding salinity stations at the mouth and head of Baltimore Harbor, Figure 20, are similar. In Baltimore Harbor the mechanism which supplies the water of intermediate salinity is tidal mixing in an embayment of restricted fresh water inflow. In the Patuxent the mechanism which supplies the water of intermediate salinity is not as clear. The low fresh water in-flow in the Patuxent and the tendency of this flow to reach its maximum later in the spring than does the flow in the Susquehanna provides a possible explanation. The phase difference would give rise seasonally to conditions similar to that of Baltimore Harbor, although, the mechanism is different. Evidence for this explanation is that the phenomenon occurs most often in April. An alternative is that vertical mixing occurs in the region of mile 4 in the Patuxent where the cross-sectional area of the channel is restricted. If this be the case, then both the mechanism and the three-layer flow are strictly equivalent to those of Baltimore Harbor. Evidence to support this view is that, for the available data, the region of least vertical stratification where the isolines surface occurs most often in the restricted part of the channel near mile 4. The salinity distribution of the April 16, 1959, Appendix B, Figure B23, cruise extends to mile 16, much above the region of restricted cross-sectional area. It is possible that the restricted cross-sectional area contributes to the three-layer flow. However, the available evidence seems to indicate that the low flow-seasonal lag mechanism is dominant.

In a partially mixed estuary two inter-related processes operate to prevent the intrusion of salt upstream to the point where mean sea level intersects the bottom of the river bed. One of these is the turbulent mixing between the seaward-flowing upper layer and the counter-flowing lower layer, which produces a net flux of salt from the lower layer into the upper layer, where it is carried back to the mouth of the estuary. The second process involves the longitudinal pressure gradients required to balance the turbulent stresses associated with the net seaward movement of the fresh water inflow. In order for a net seaward flow to exist, the surface of the estuary must, on the average, slope seaward. The resultant seaward pressure force decreases with depth in the estuary proper, and is in fact reversed in sign in the up-estuary flowing lower layers. In the fresh water tidal river, however, the required mean seaward directed pressure force extends to the bottom. Increased river flow requires an increased downstream slope to the water surface, and hence an increased seaward directed pressure gradient. The seaward boundary of the fresh water tidal river consequently moves further down the estuary. Within the estuary proper, the dynamic balance requires that the slope of the isobaric surfaces reverse at about mid-depth. In the upper layer, as already noted, the isobaric surfaces slope down toward the mouth of the estuary, while in the lower layer these surfaces slope down toward the head of the estuary. In an embayment such as Baltimore Harbor or the lower reaches of the Patuxent the pressure surfaces must make similar adjustments. In the reach of the estuary where the three-layered flow pattern prevails the mean water surface must slope downward toward the head of the estuary. The isobars must slope downward toward the mouth of the estuary at mid-depths in the outward flow and the isobars must slope toward the head of the estuary in the inward flowing bottom layer. It should be obvious that such a flow pattern necessitates a minimum slope to the water surface within the estuary. It has been shown that the forces in the lateral direction are in near geostrophic balance, Pritchard (1956), with the possible exception of a balance of forces in the vicinity of bends in the channel, Stewart (1957).

The best evidence for the existence of a three-layer flow in the Patuxent is the salinity distributions from which the intrusion of surface water of low salinity from the Bay may be inferred. This inferred three-layer flow is indicated in schematic form in Figure 21. Figure 22 sketches the two-layer flow which is more often found in the Patuxent.

The current measurements made during the 1952 C.B.I. seasonal cruises in the Patuxent lend further support to the three-layer flow deduced from the salinity and temperature data. The 24 hour, June 1952, salinity profiles at Patuxent Stations Px 2 and Px 4, Figure 23, are similar to those from Baltimore Harbor. The 24 hour average of the axial component of the current velocity as a function of depth, at Px 2, Figure 24, clearly shows the three-layered structure. Figure 25 which presents the same information synoptically for stations Px 2 to Px 30 shows that the three-layered flow occurs only below Px 4.

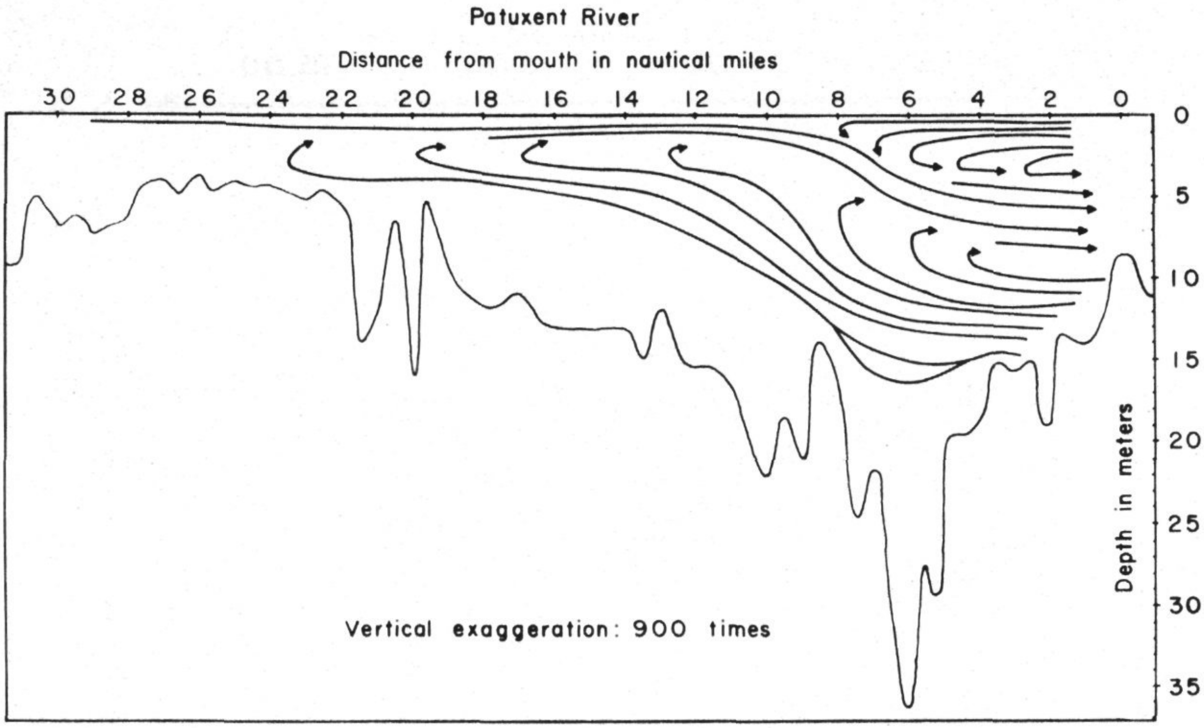

Figure 21. Schematic diagram of net non-tidal volume transport of the three-layer flow system in the Patuxent.

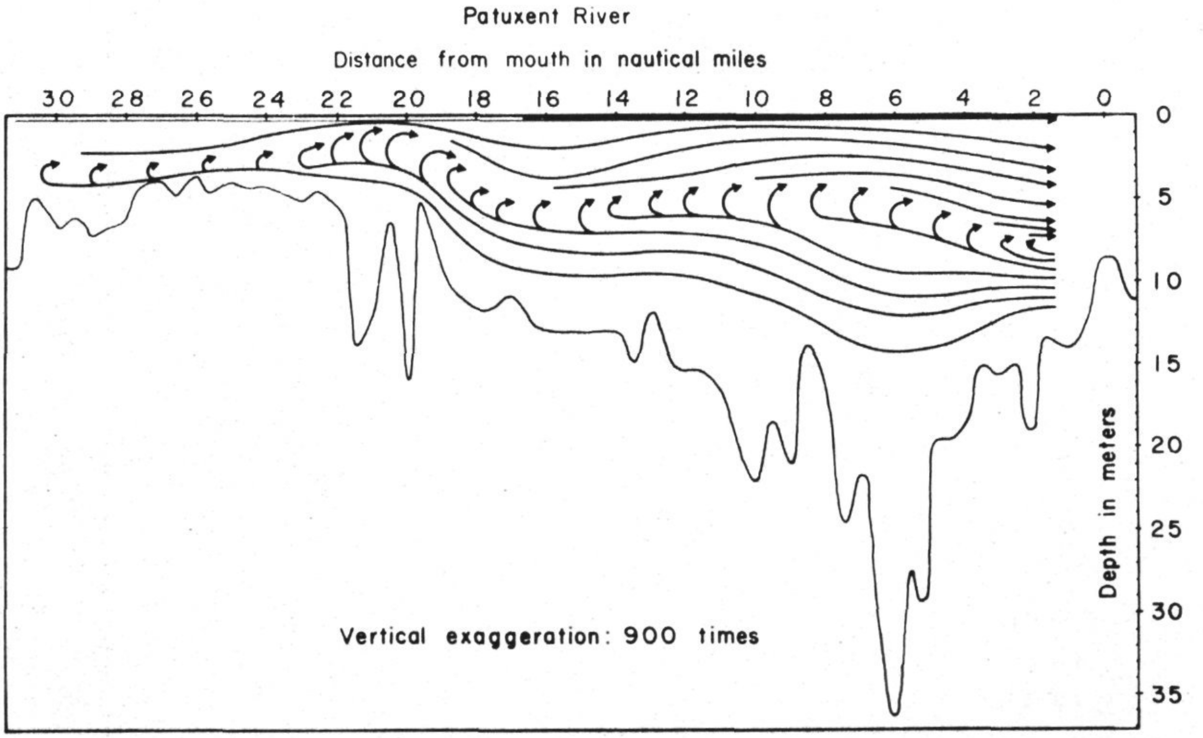

Figure 22. Schematic diagram of net non-tidal volume transport of the two-layer flow system in the Patuxent.

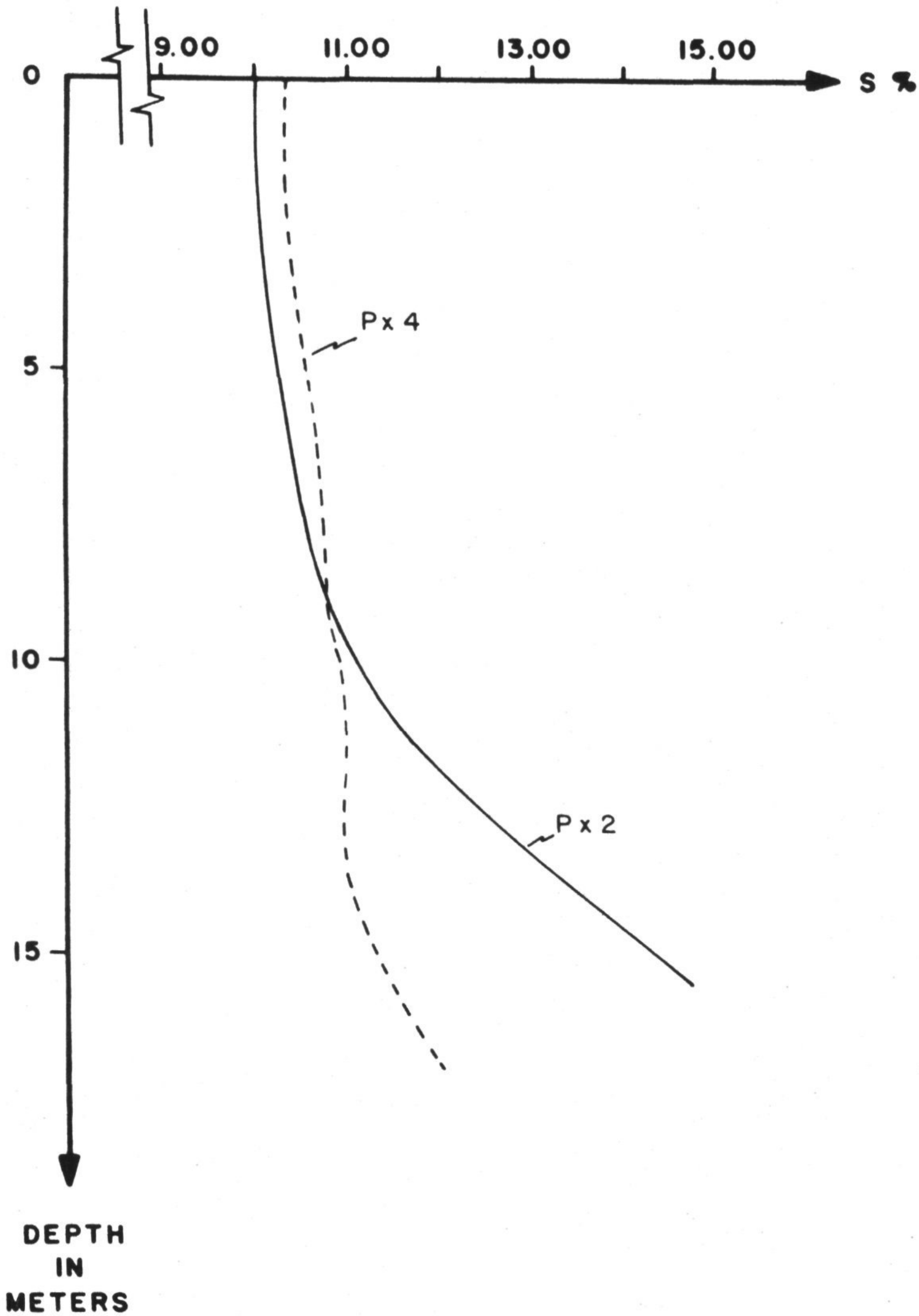

Figure 23. 24 hour average salinity at C.B.I. Stations Px 2 and Px 4, June 27-28, 1952.

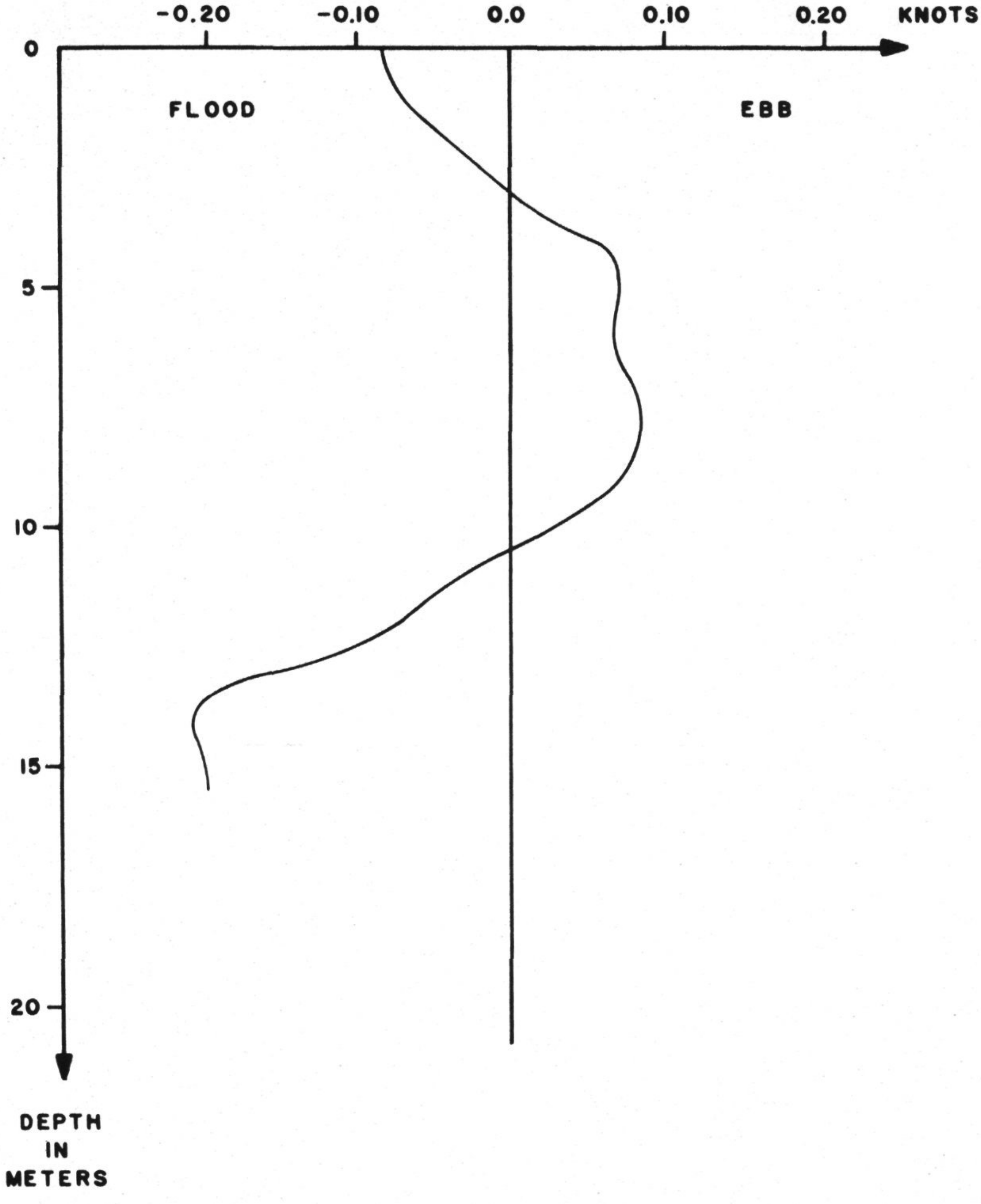

Figure 24. Net non-tidal current at C.B.I. Station Px 2, June 27-28, 1952.

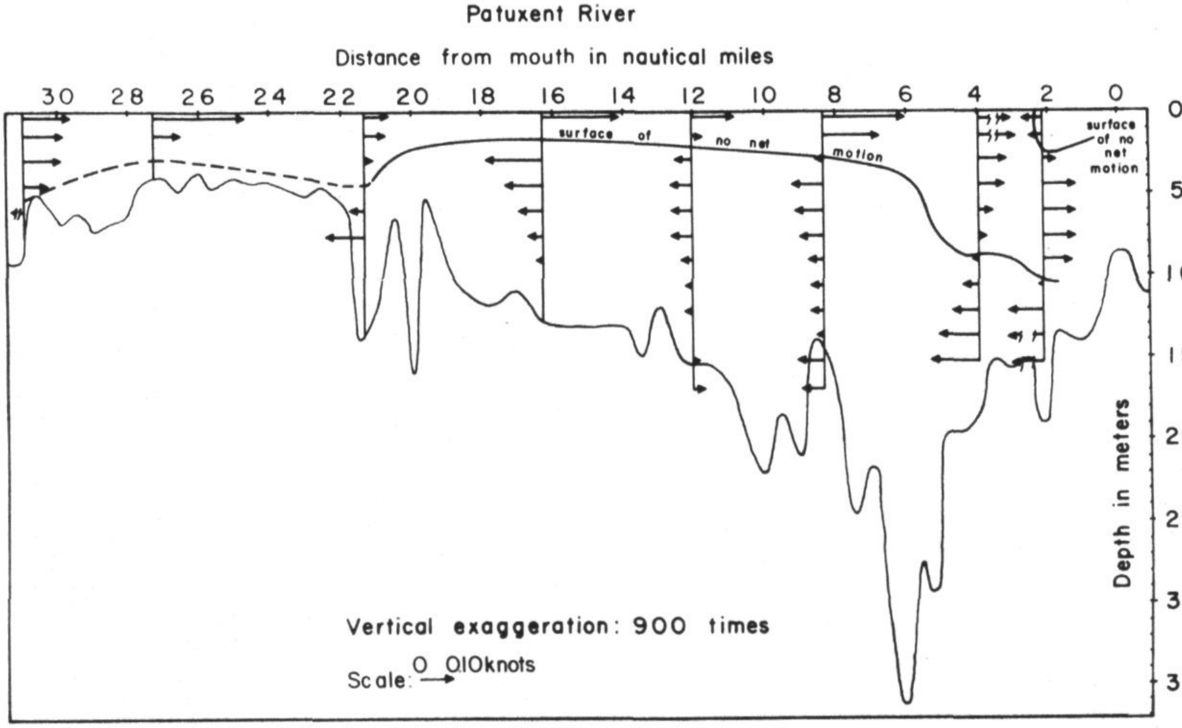

Figure 25. 24 hour longitudinal velocity component average, June 23-28, 1952.

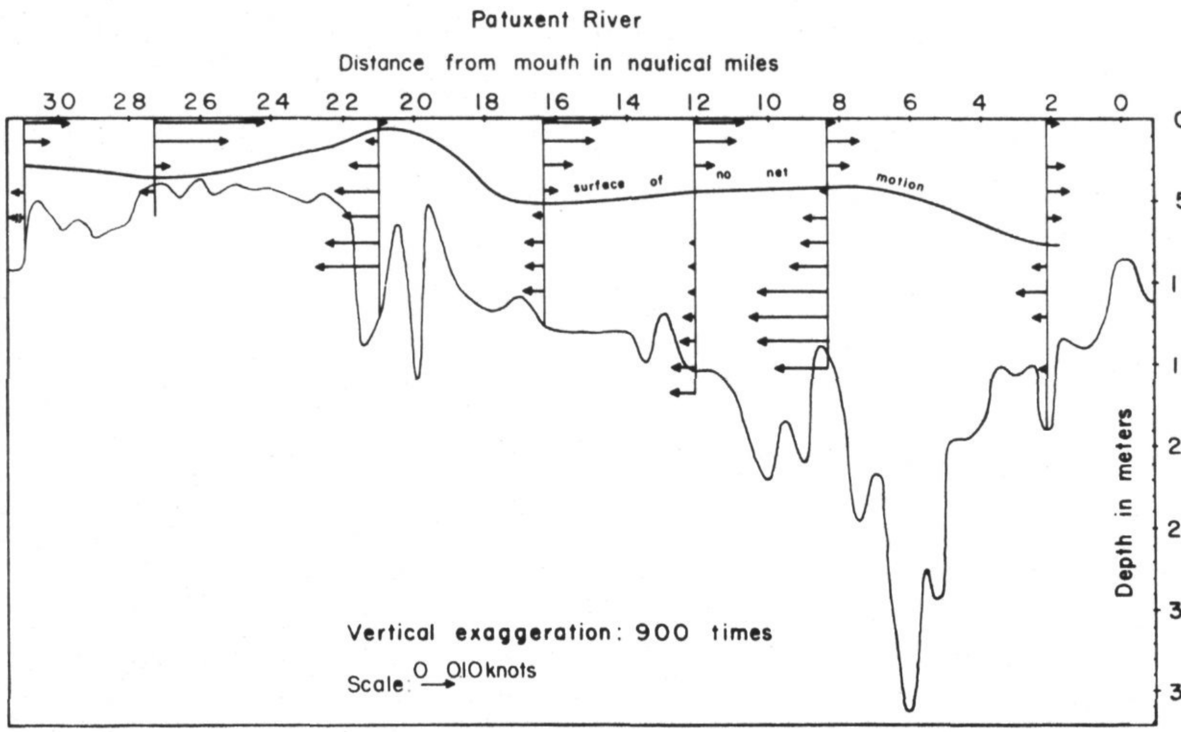

Figure 26. 24 hour longitudinal velocity component average, Dec. 3-7, 1952.

The arrows indicate the magnitude of the net-non-tidal current in the axial direction. Figure 26 shows a two-layered flow for the 24-hour axial velocity component average from the December 1952 Cruise. This is compatible with the salinity distribution for the December 1952 Cruise shown in Figure 11.

3.0 Concluding remarks

Appendix A contains a description of the methods used to estimate the run off in the Patuxent drainage basin. Appendix B is a graphical atlas of the C.B.I. salinity, temperature, dissolved oxygen, and pH data from the Patuxent Estuary for the years 1949 to 1963.

The data, for the most part, reveal the seasonal trends common to the other estuaries tributary to the Chesapeake Bay. The salinity is highest in the autumn months and lowest in the spring during the month of April. The water temperature follows the seasonal trends in the air temperature as might be expected for an estuary in a temperate climate.

The salinity distribution of April 16, 1959, Figure B23, is noteworthy because the surface salinity maximum is between miles 10 and 16. This is the furthest penetration of surface Bay water so far found. Between miles 4 and 6 the estuary is quite constricted and the water there less stratified. A demonstrable penetration of Bay water beyond the constriction is highly significant since without it it might well be argued that Bay water is unnecessary to sustain the three-layered flow. The temperature distribution of April 16, 1959, Figure B24, has no strong vertical gradients in the estuary below mile 12. Between mile 12 and mile 27 the isotherms are roughly similar to the isopleths of salinity. The oxygen distribution found on April 16, 1959, Figure B59, is consistent with the premise of an intrusion of surface water from the Bay.

The salinity (density) structure associated with a three-layer flow in the Patuxent Estuary occurs most often in April. The salinity data from 4 out of 5 April cruises made by the Chesapeake Bay Institute between 1950 and 1960 have this form of salinity distribution. The data from only two of the remaining 17 C.B.I. cruises, one in June and one in December, show similar salinity distributions. Thus, it seems reasonably certain that a three-layered flow similar to that found in Baltimore Harbor exists intermittently in the Patuxent and that its cause is a phase difference in fresh water inputs from the Susquehanna and from the Patuxent.

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Appendix A

Method of Runoff Estimation

The ratio of the runoff in gauged streams to the water measured at 8 rainfall stations was computed for each month for 5 different regions of the drainage basin. The ratios were found to vary with month and with location in the drainage basin. These ratios were used to estimate the monthly runoff for ungauged drainage areas near each of the five gauged areas. The data have been arranged by calendar years from the "water year" statistics given in the Water Supply Papers of the U.S. Geological Survey.

The evaporation from the estuary surface was estimated using the class "A" pan coefficients from the Lake Hefner report, U.S.G.S. Prof. Paper 220. The rainfall data are those of the Climatological Atlas 1952-1961, U.S. Dept. of Commerce. The drainage basin area data were compiled by Martin (1953).

Appendix B

Graphical Atlas of Salinity, Temperature, Dissolved Oxygen, and pH for the Patuxent Estuary--August 1949 to March 1963

Appendix B is a graphical summary of salinity, temperature, dissolved oxygen, and pH data taken in the Patuxent Estuary by the Chesapeake Bay Institute from 1949 to 1963. The data have been represented by contours drawn on a longitudinal section taken along the main channel of the estuary.

Vertical shaded lines denote the geographical limits of the data. Where no contours appear data exists only at the points shown.

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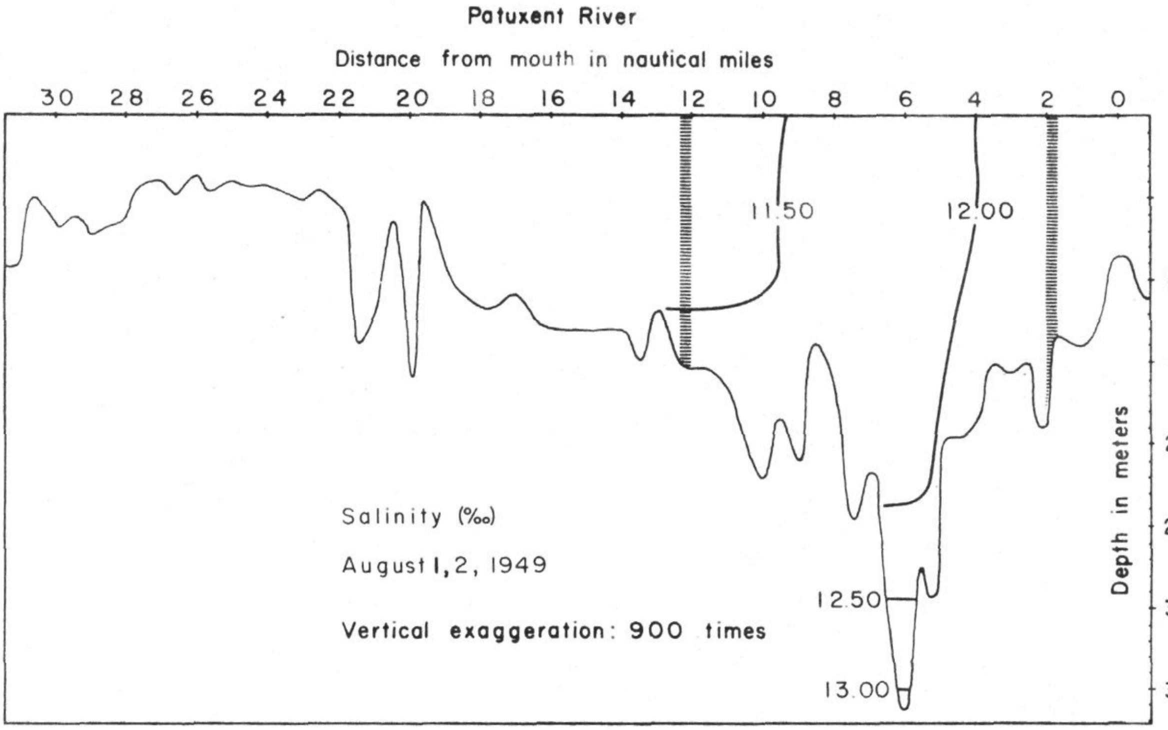


Figure B1. Patuxent River: Salinity, Aug. 1,2, 1949.

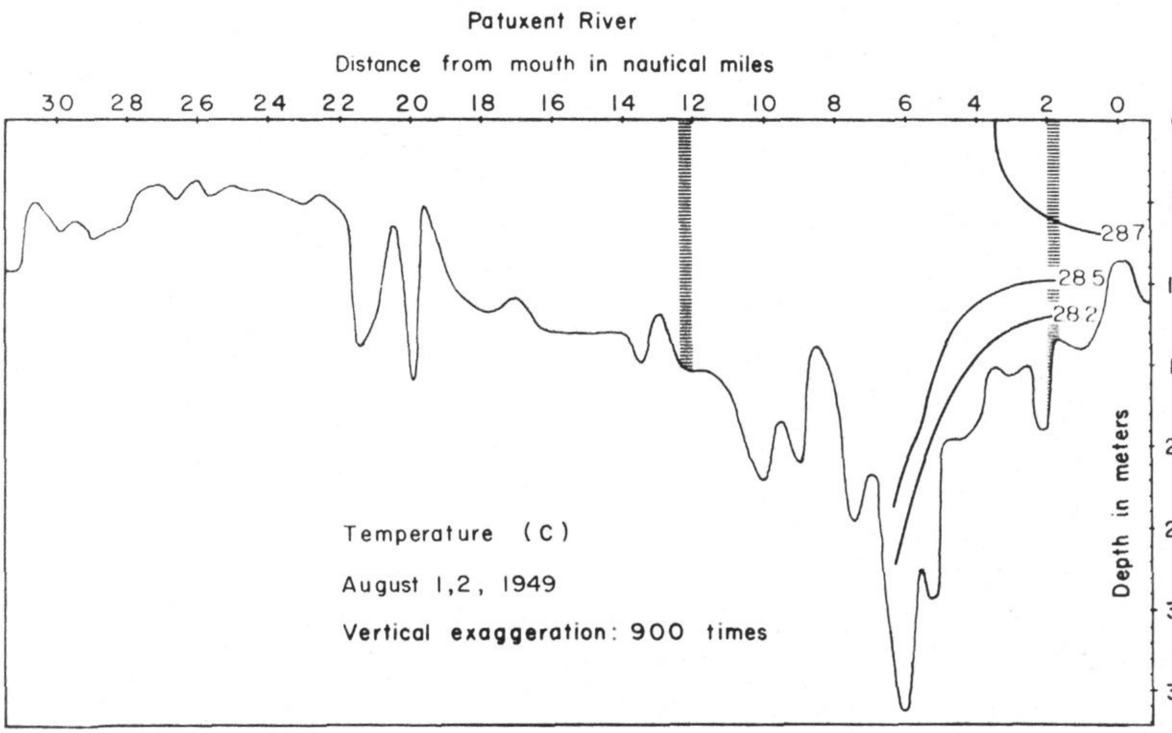


Figure B2. Patuxent River: Temperature, Aug. 1,2, 1949.

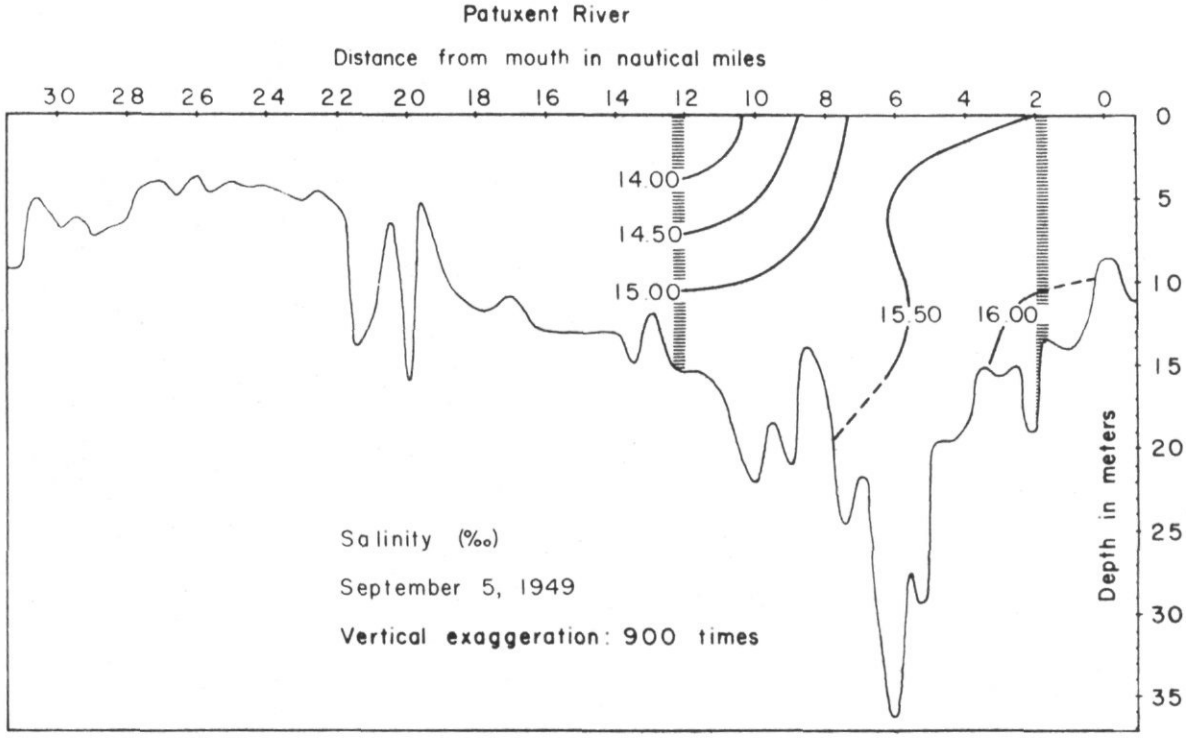


Figure B3. Patuxent River: Salinity, Sept. 5, 1949.

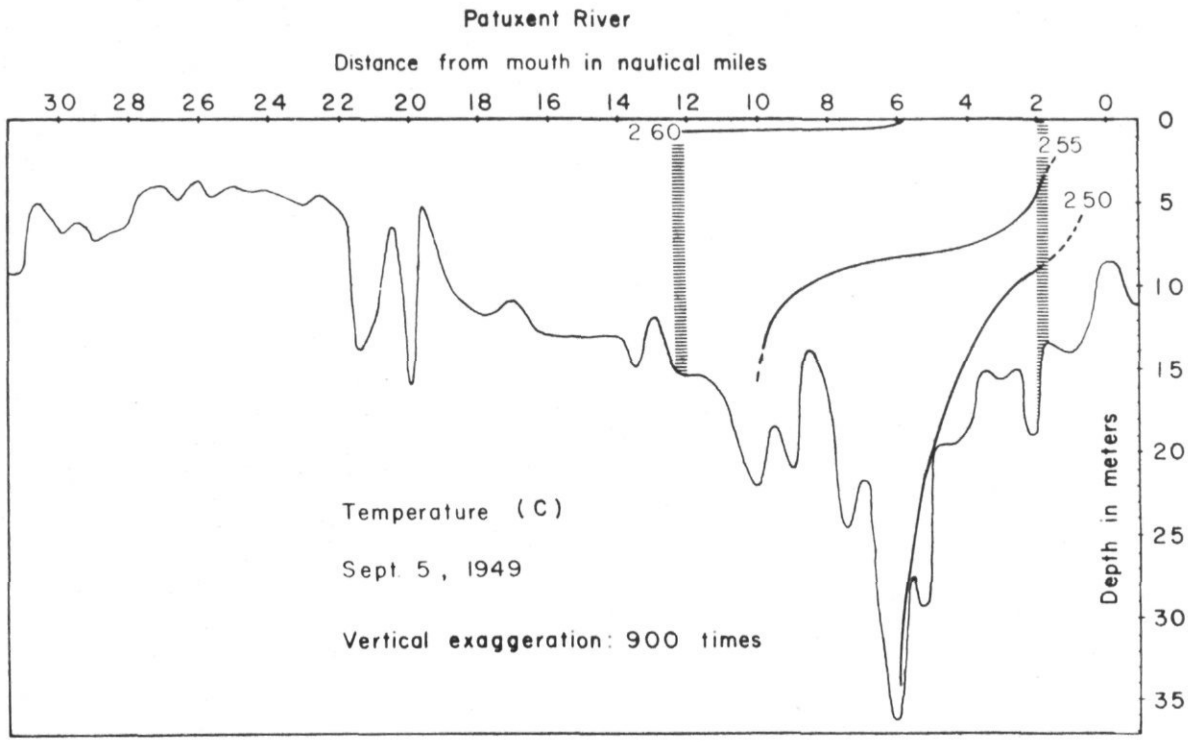


Figure B4. Patuxent River: Temperature, Sept. 5, 1949.

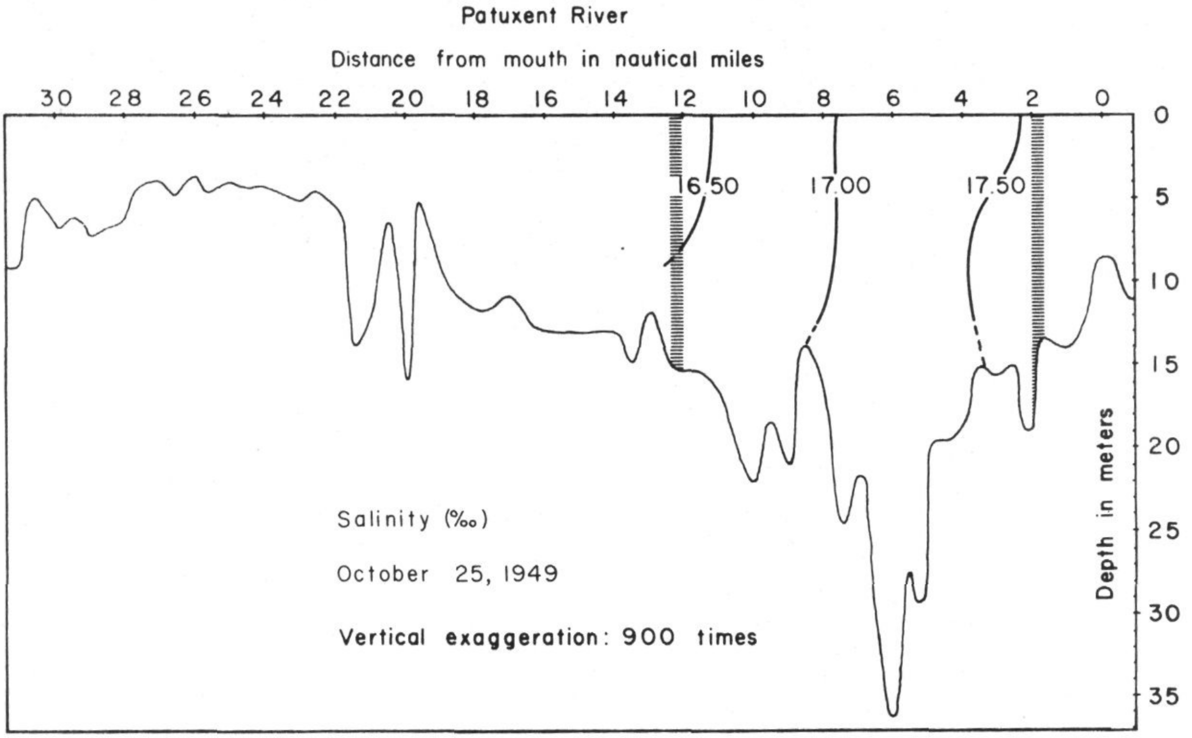


Figure B5. Patuxent River: Salinity, Oct. 25, 1949.

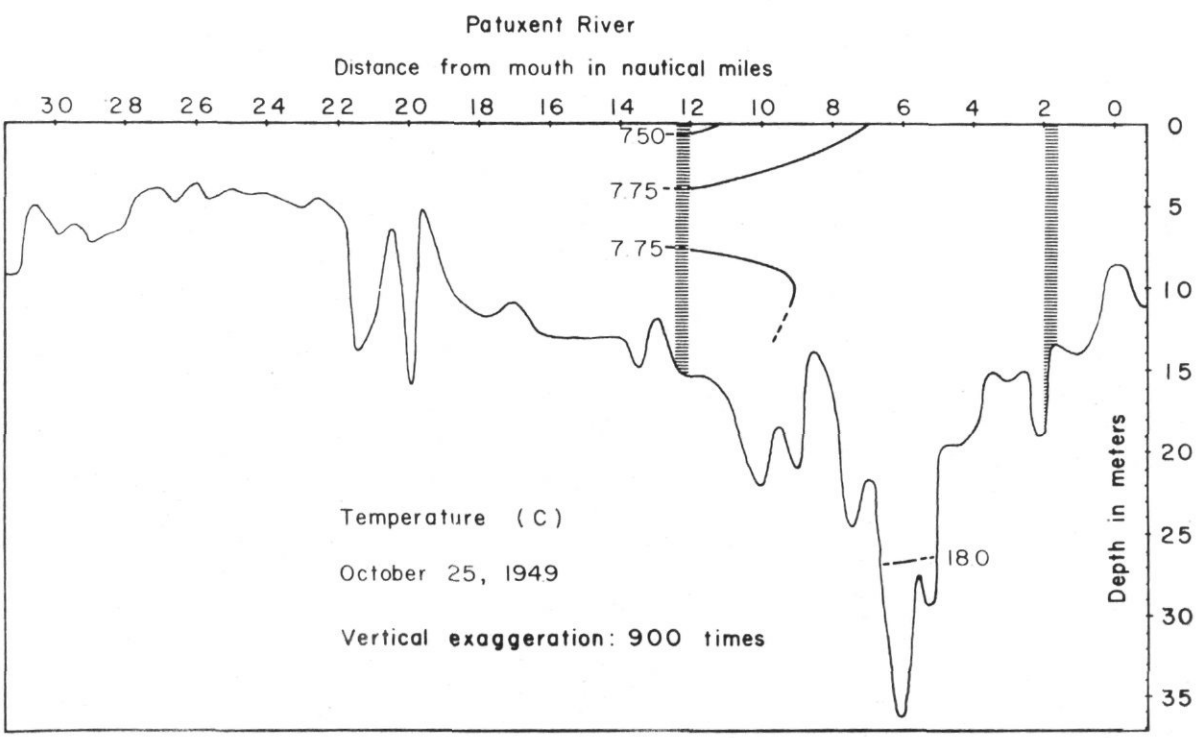


Figure B6. Patuxent River: Temperature, Oct. 25, 1949.

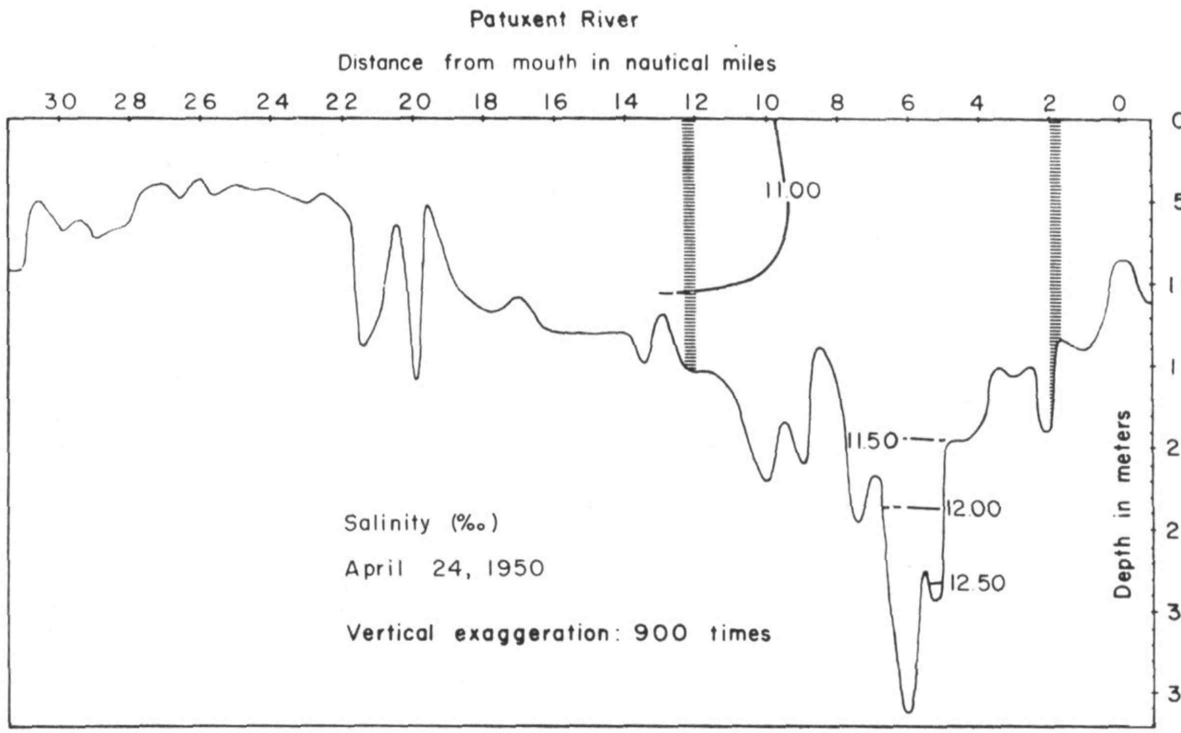


Figure B7. Patuxent River: Salinity, April 24, 1950.

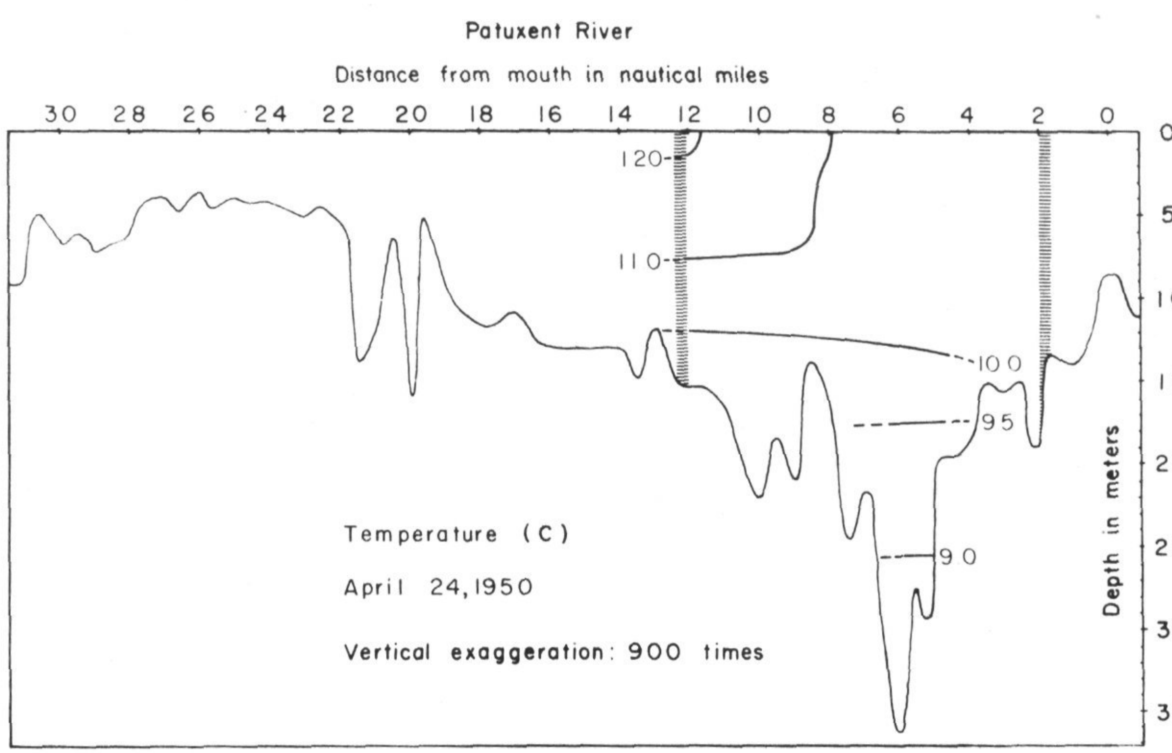


Figure B8. Patuxent River: Temperature, April 24, 1950.

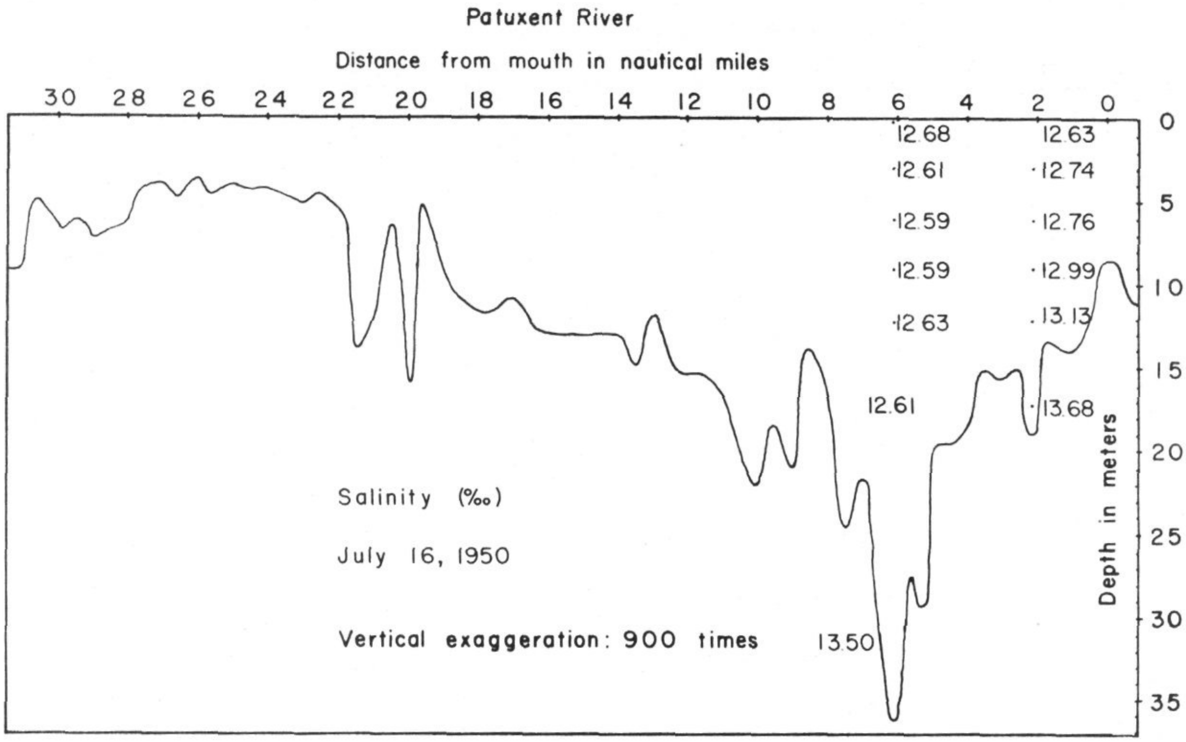


Figure B9. Patuxent River: Salinity, July 16, 1950.

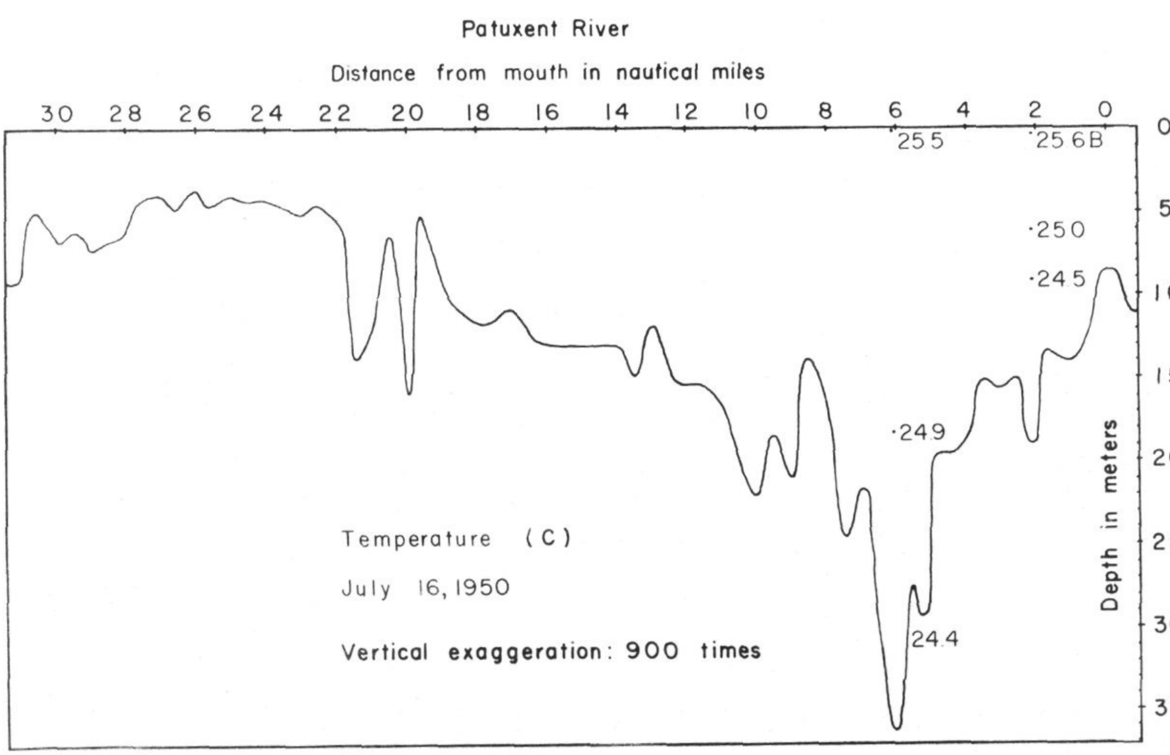


Figure B10. Patuxent River: Temperature, July 16, 1950.

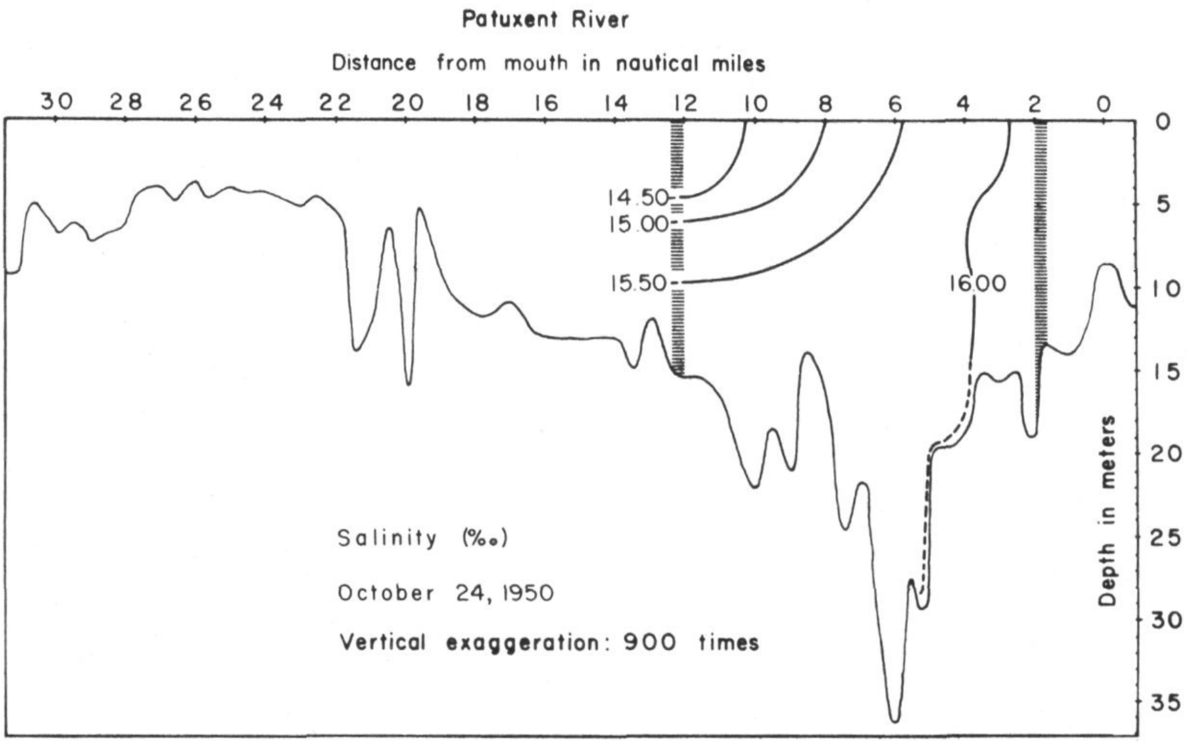


Figure B11. Patuxent River: Salinity, Oct. 24, 1950.

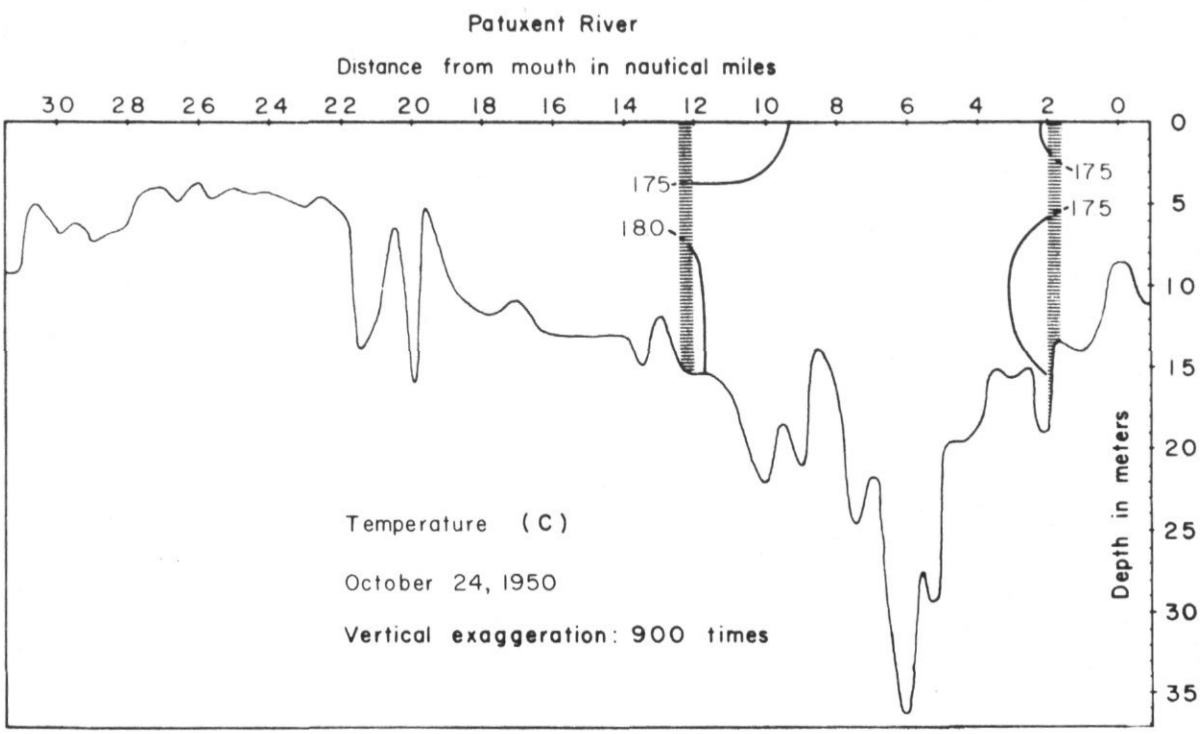


Figure B12. Patuxent River: Temperature, Oct. 24, 1950.

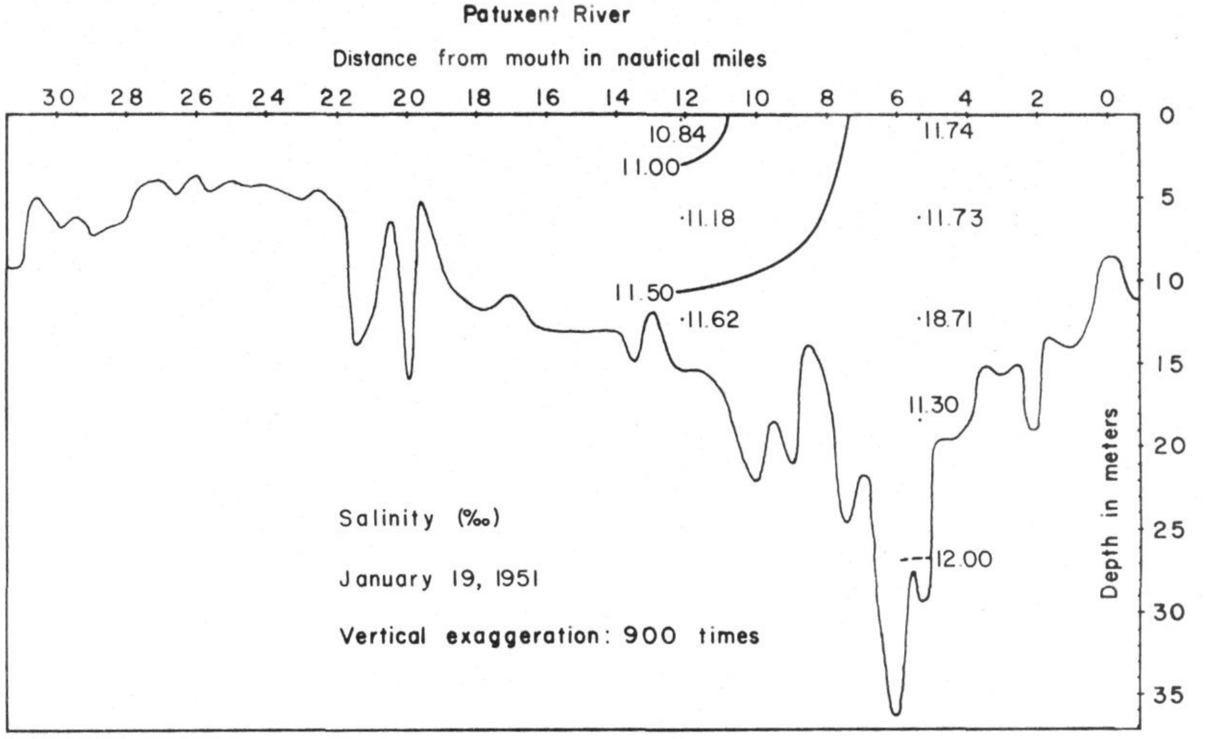


Figure B13. Patuxent River: Salinity, Jan. 19, 1951.

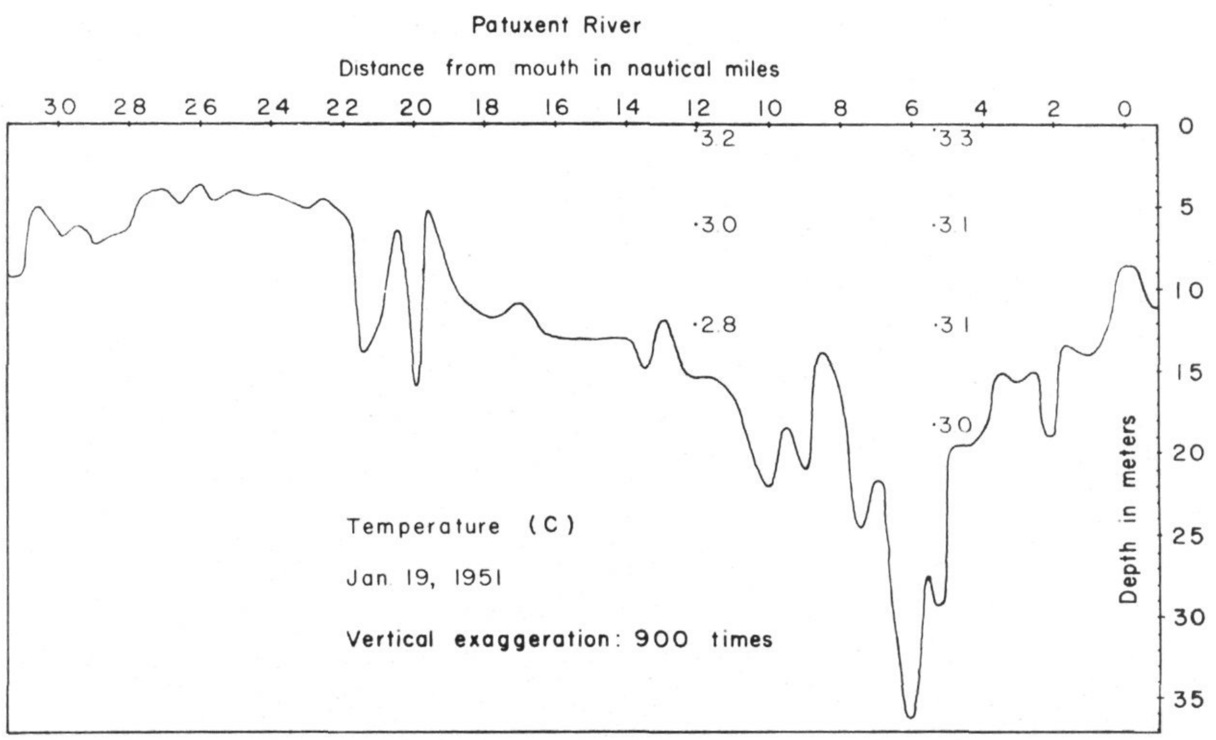


Figure B14. Patuxent River: Temperature, Jan. 19, 1951.

NO DATA

Figure B15. Patuxent River: Salinity, April 13, 1951 (no data).

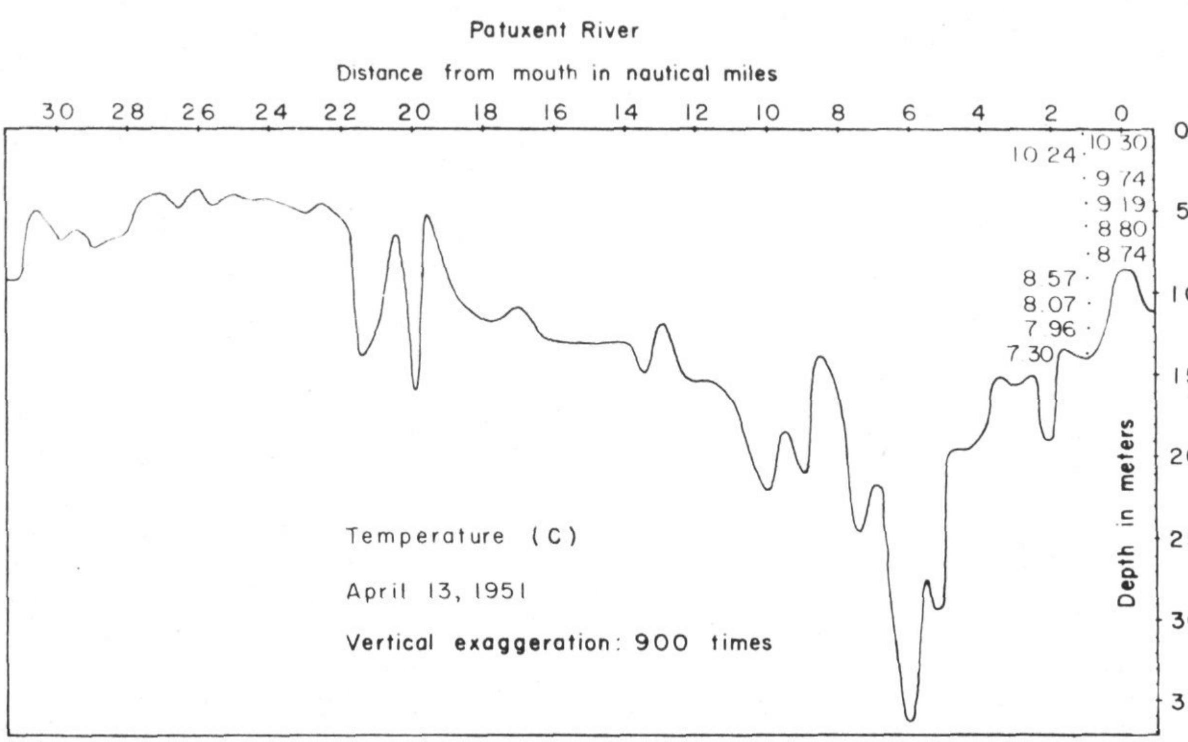


Figure B16. Patuxent River: Temperature, April 13, 1951.

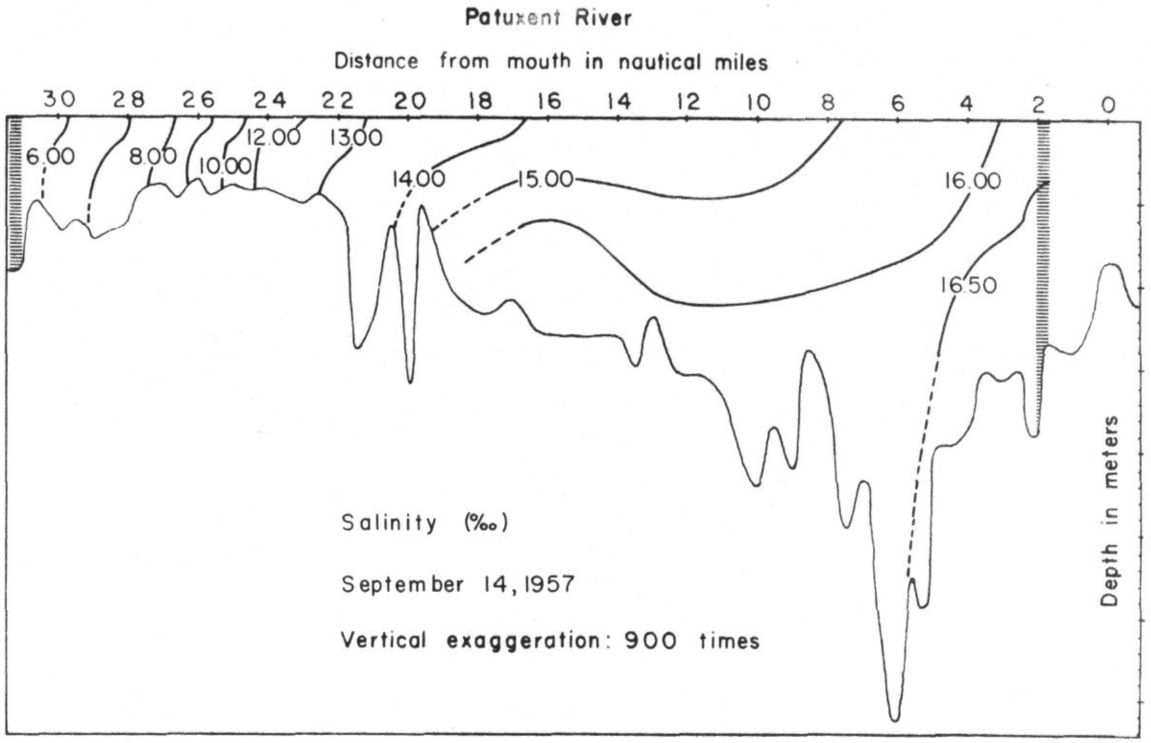
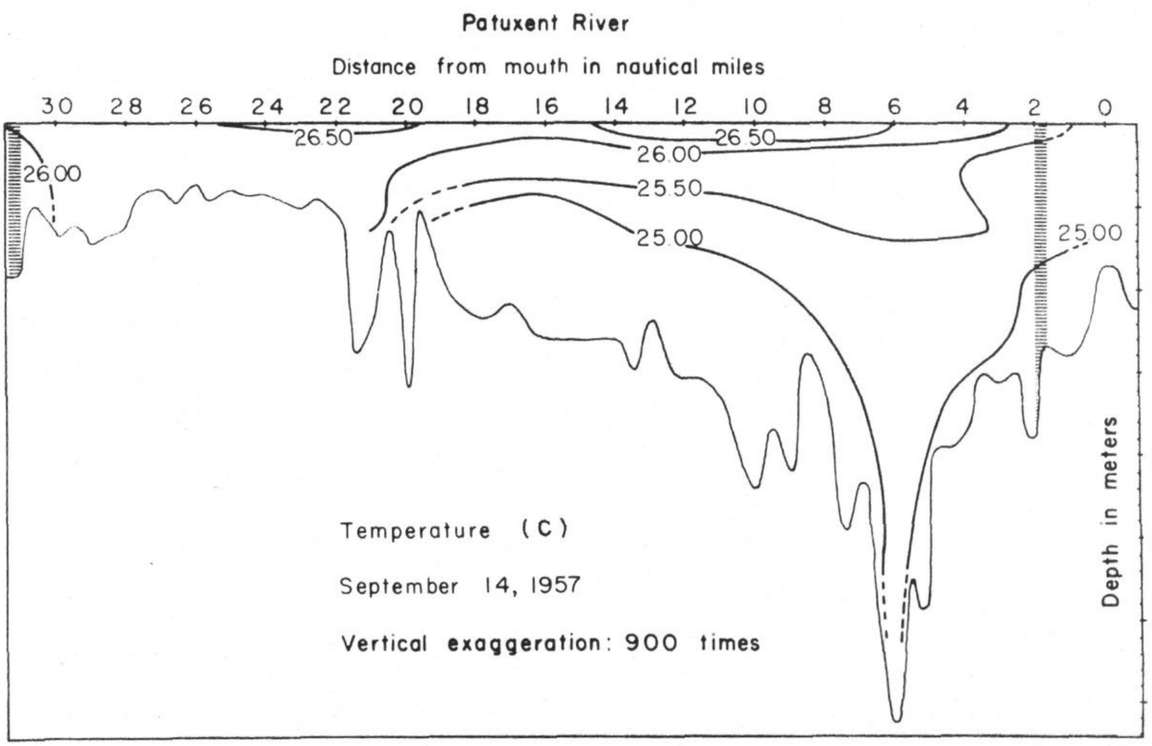


Figure B17. Patuxent River: Salinity, Sept. 14, 1957.



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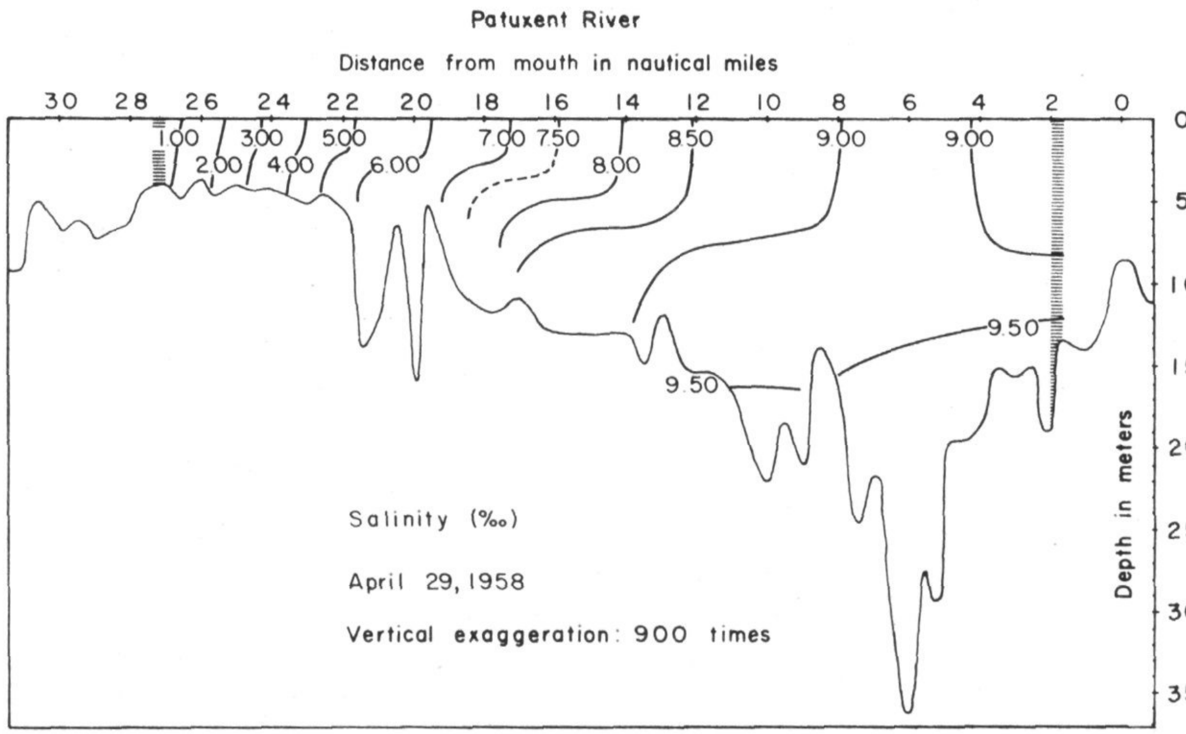


Figure B19. Patuxent River: Salinity, April 29, 1958.

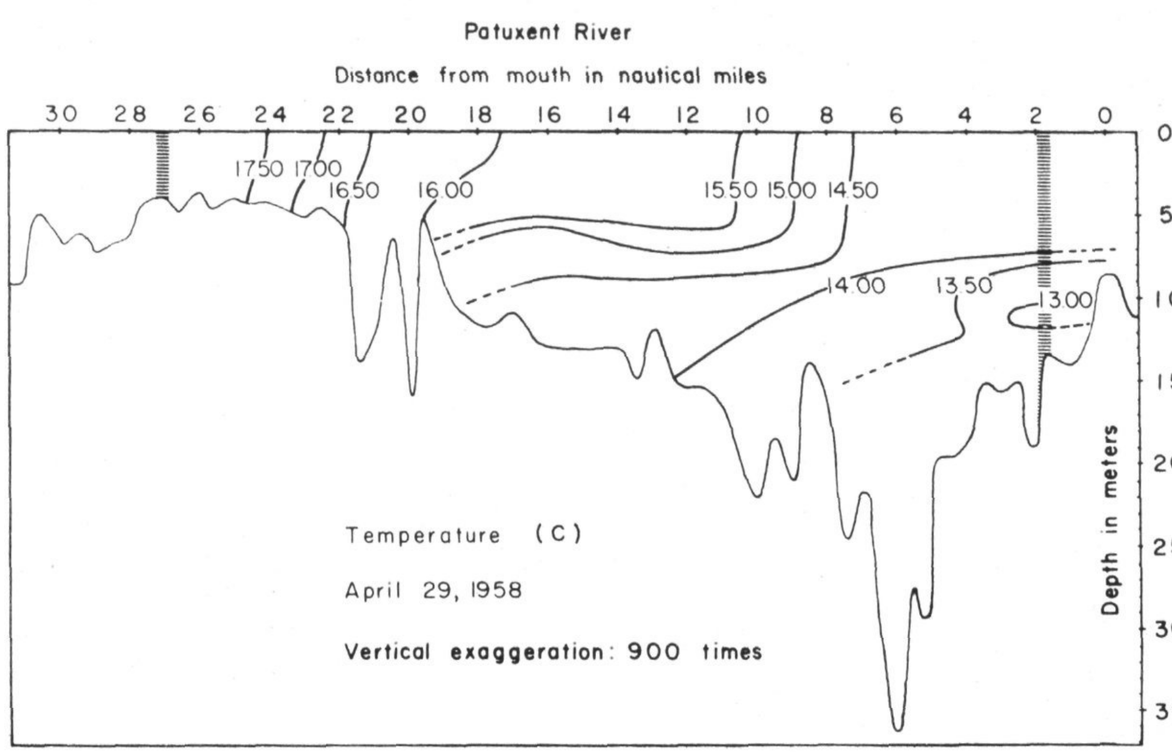


Figure B20. Patuxent River: Temperature, April 29, 1958.

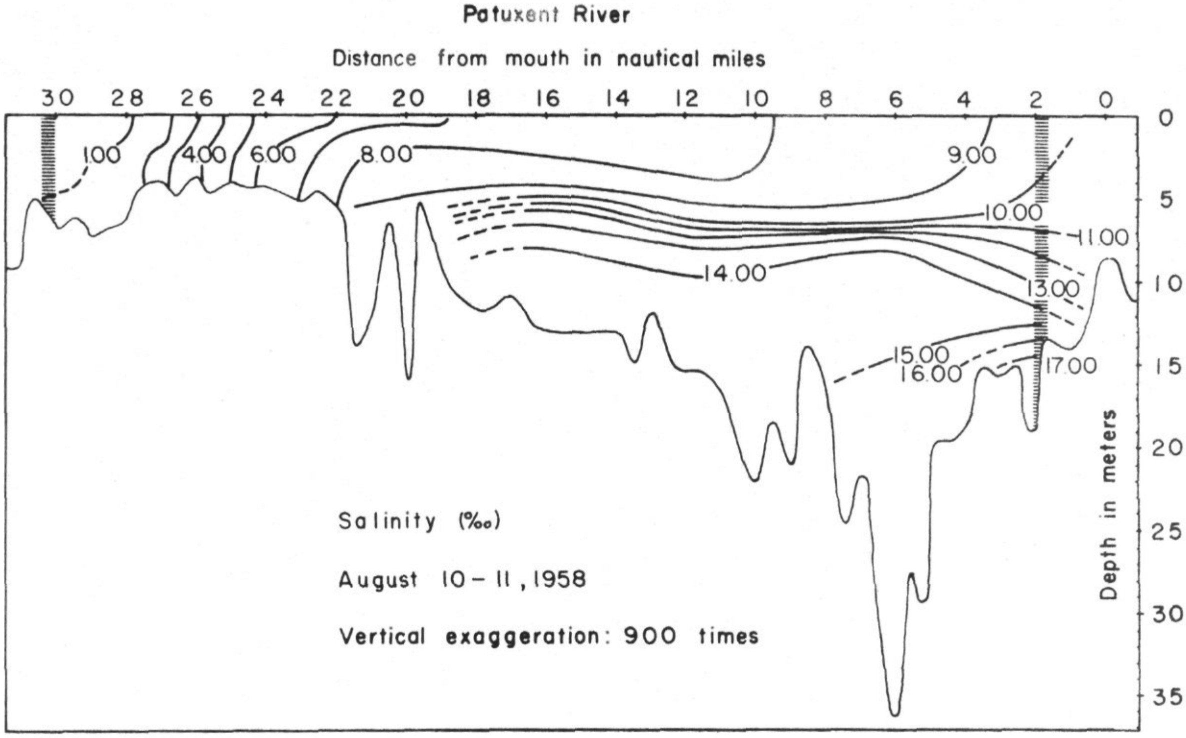


Figure B21. Patuxent River: Salinity, Aug. 10-11, 1958.

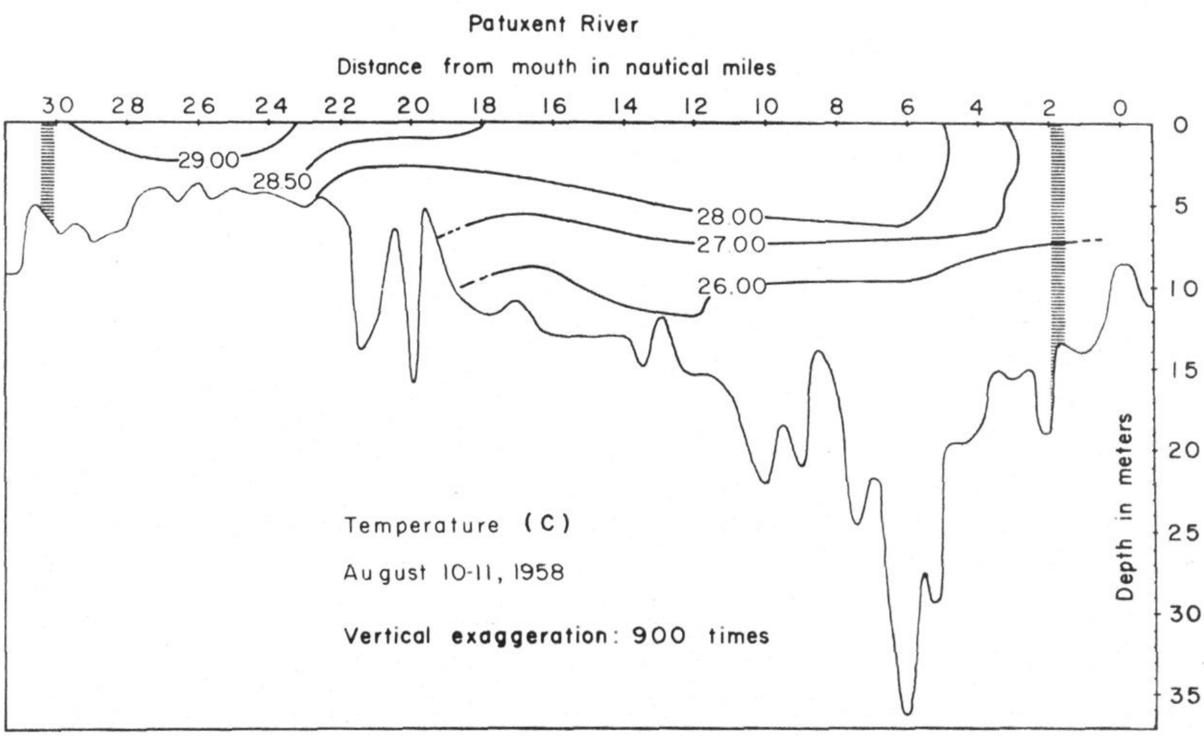


Figure B22. Patuxent River: Temperature, Aug. 10-11, 1958.

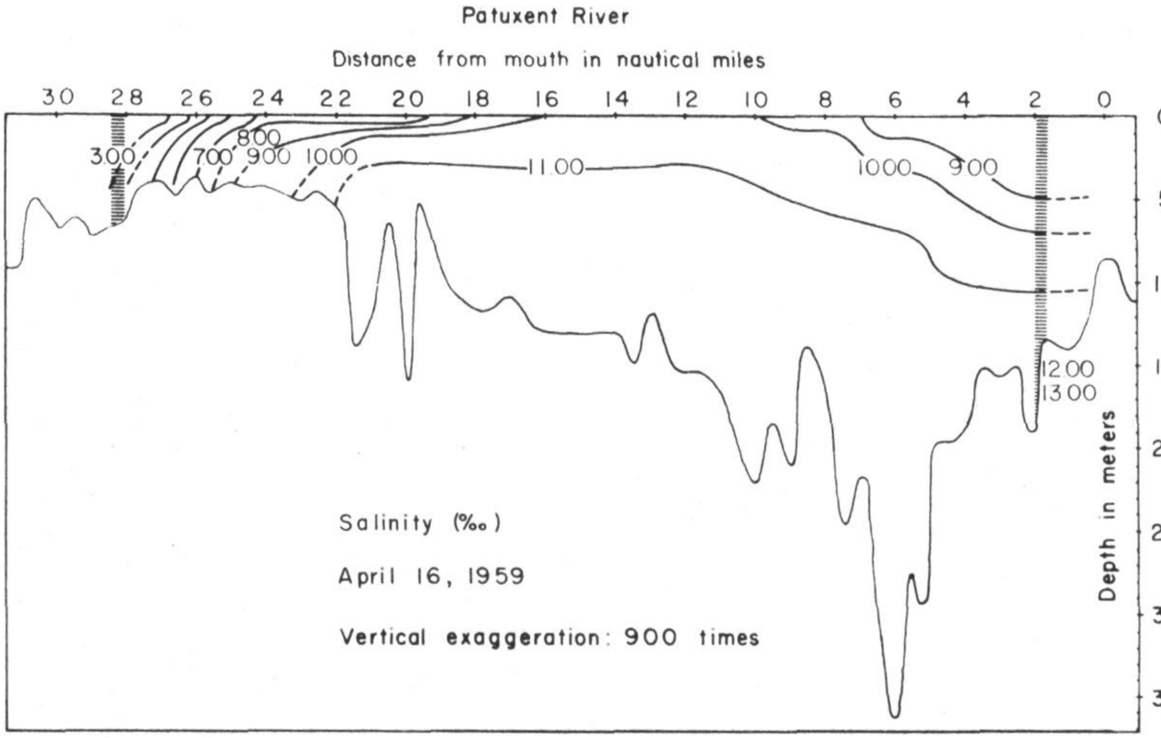


Figure B23. Patuxent River: Salinity, April 16, 1959.

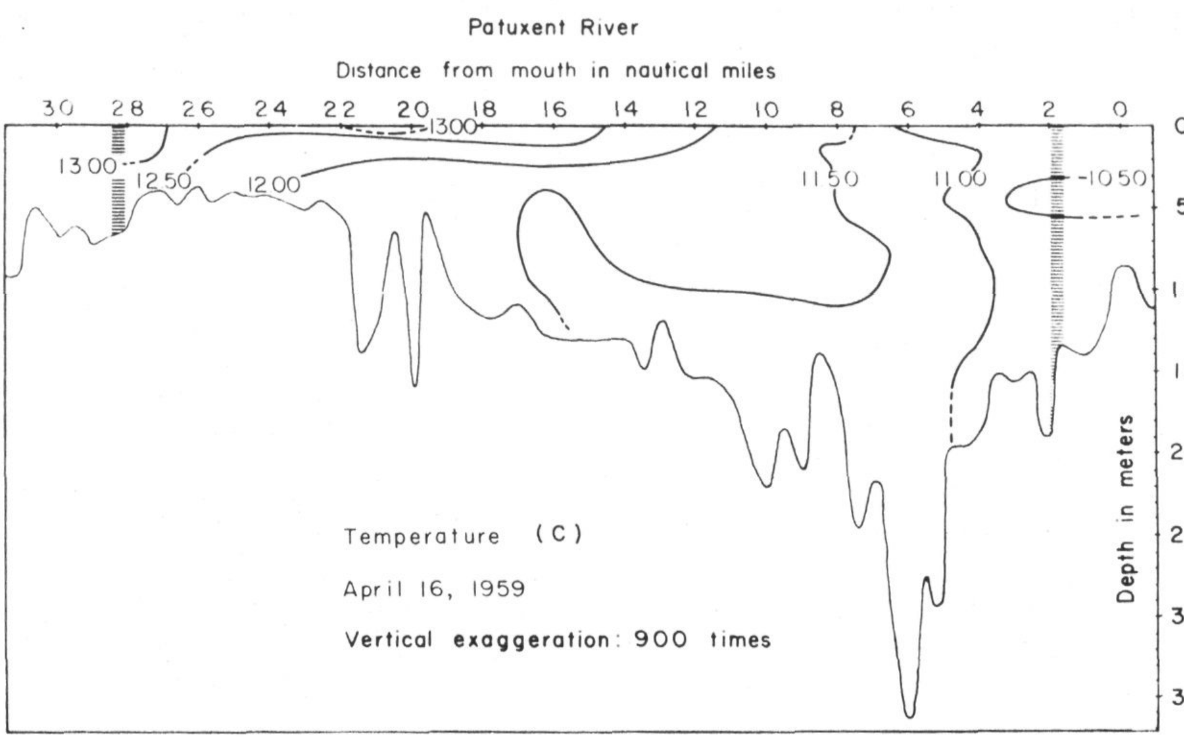


Figure B24. Patuxent River: Temperature, April 16, 1959.

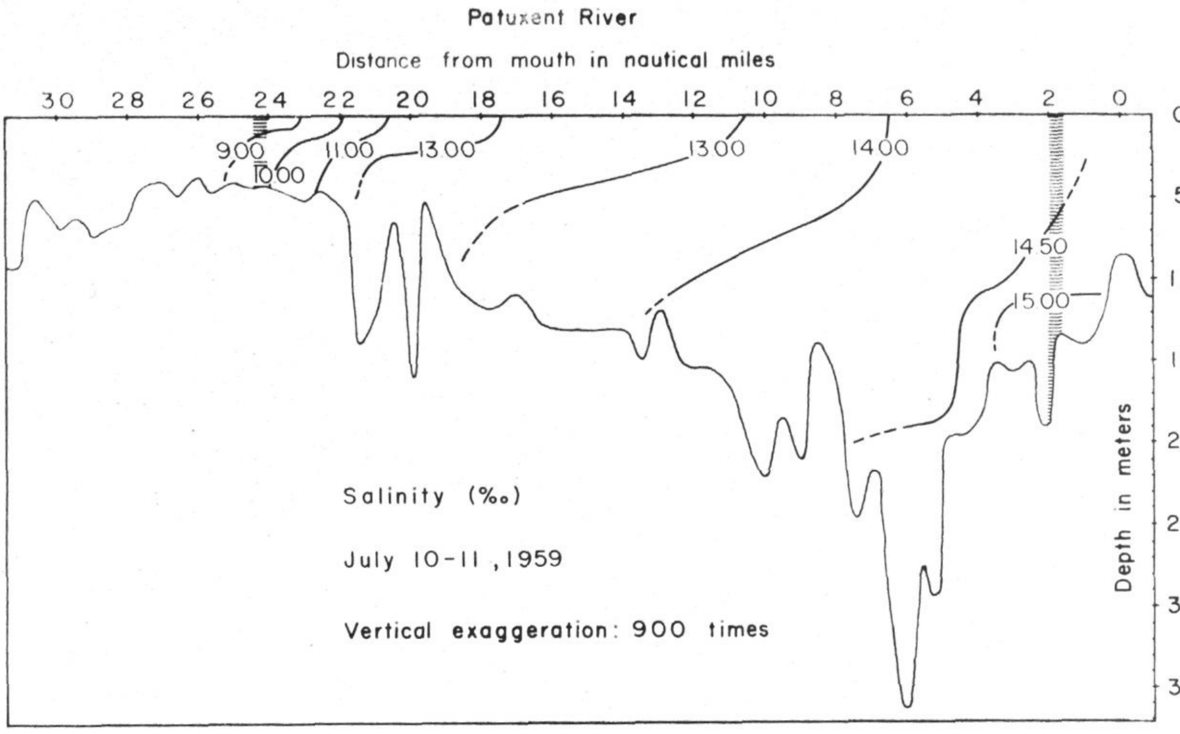


Figure B25. Patuxent River: Salinity, July 10-11, 1959.

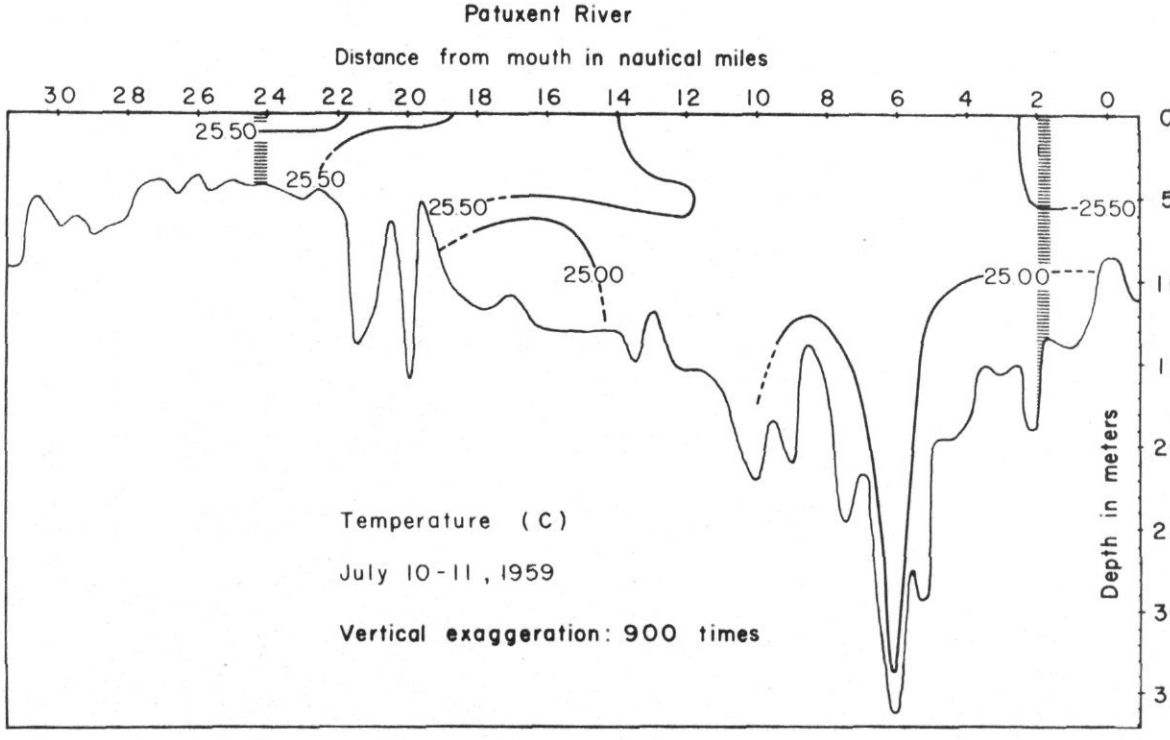


Figure B26. Patuxent River: Temperature, July 10-11, 1959.

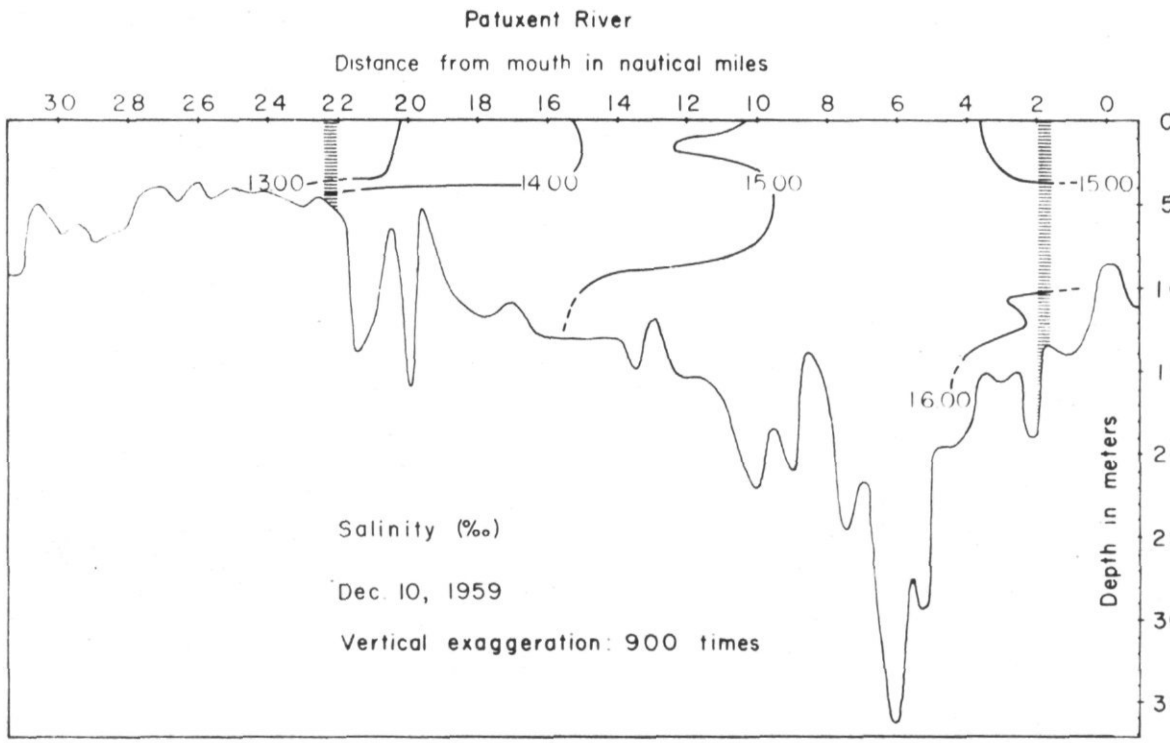


Figure B27. Patuxent River: Salinity, Dec. 10, 1959.

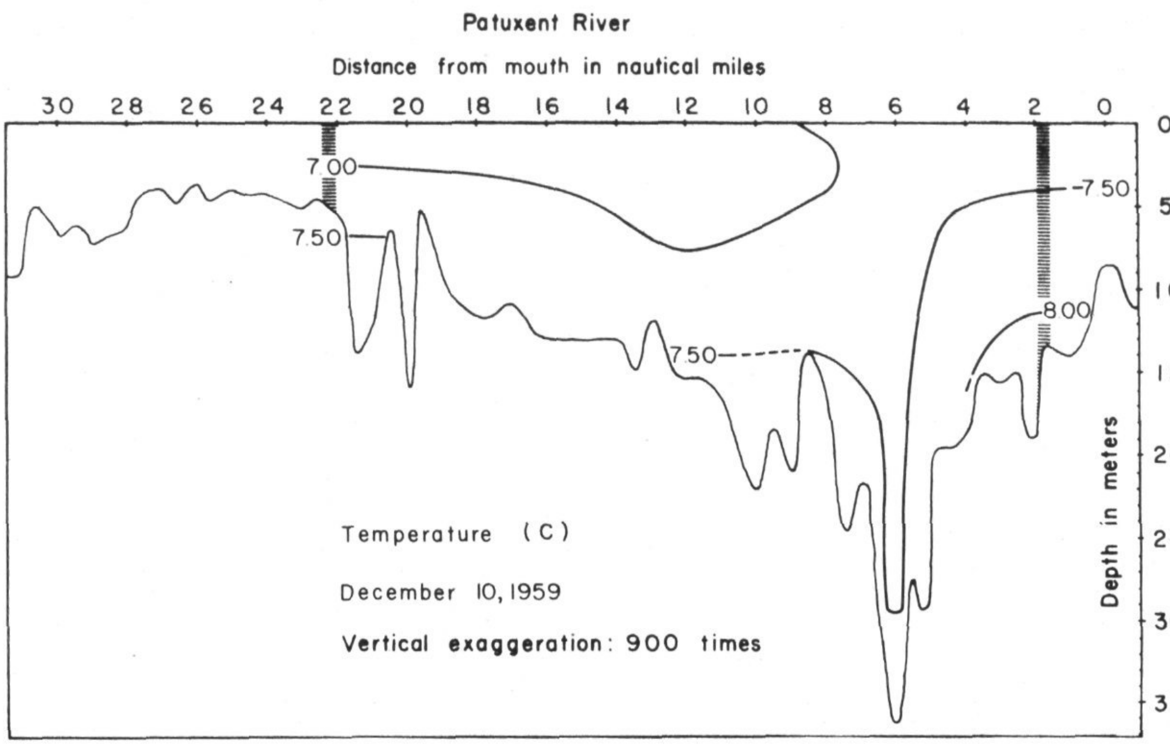


Figure B28. Patuxent River: Temperature, Dec. 10, 1959.

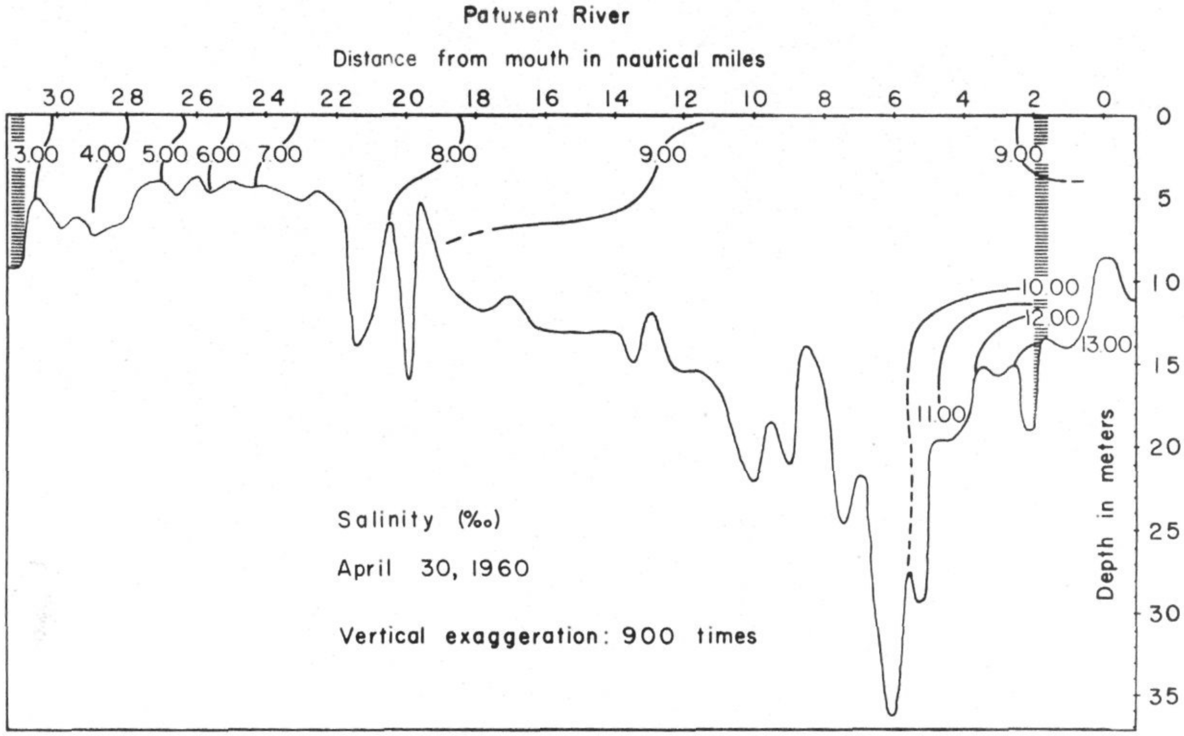


Figure B29. Patuxent River: Salinity, April 30, 1960.

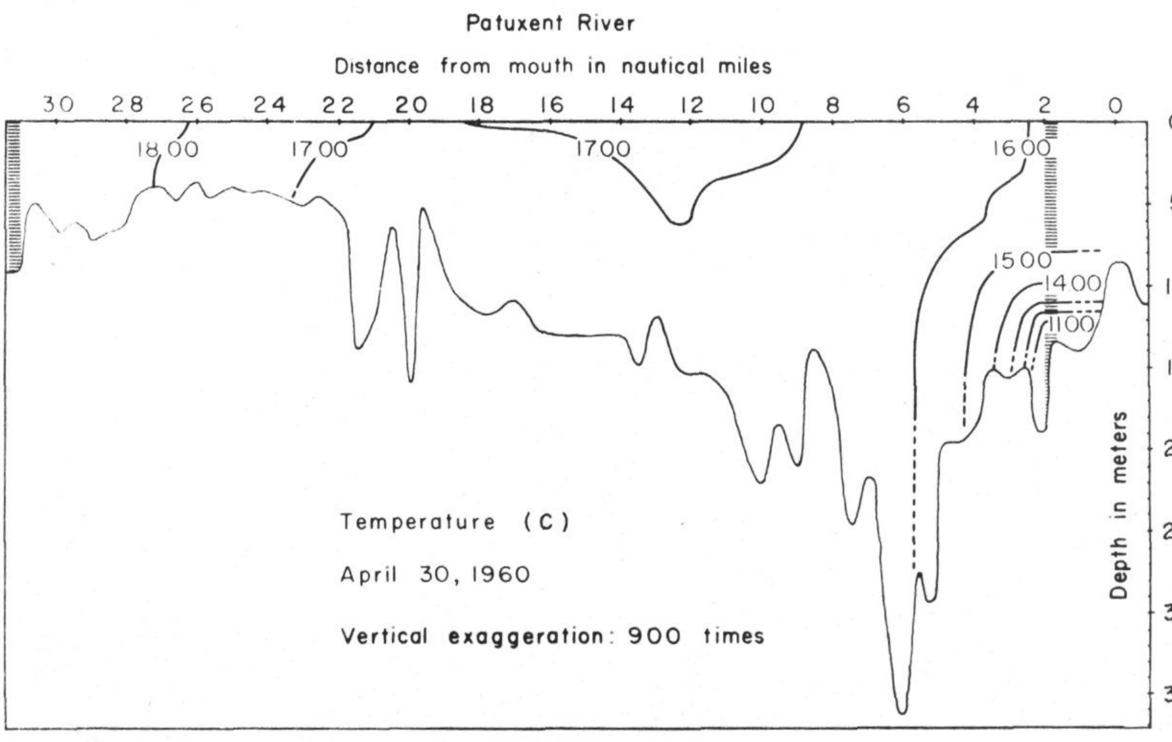


Figure B30. Patuxent River: Temperature, April 30, 1960.

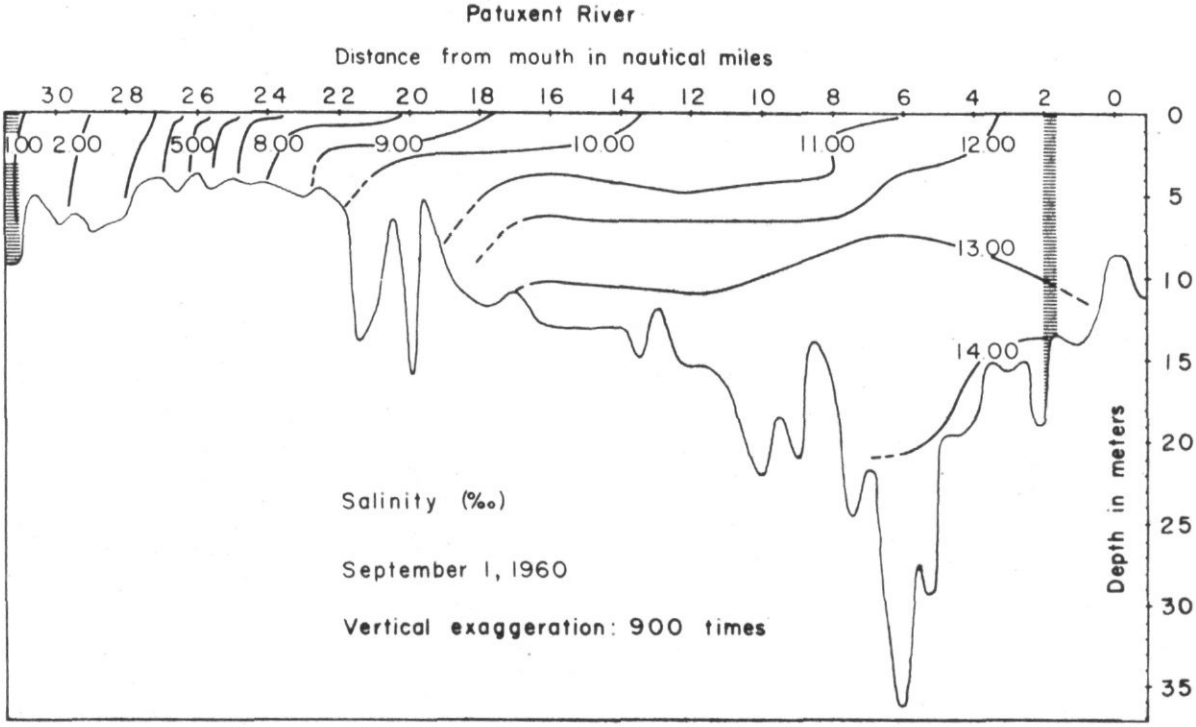
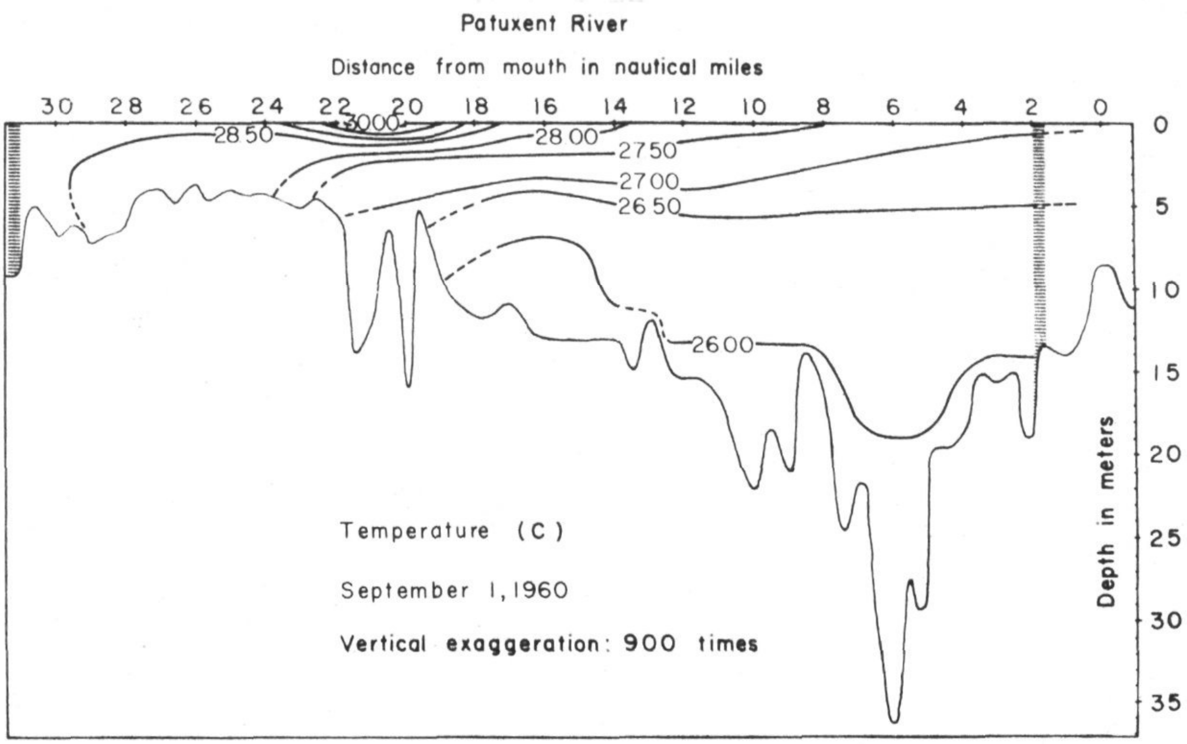


Figure B31. Patuxent River: Salinity, Sept. 1, 1960.



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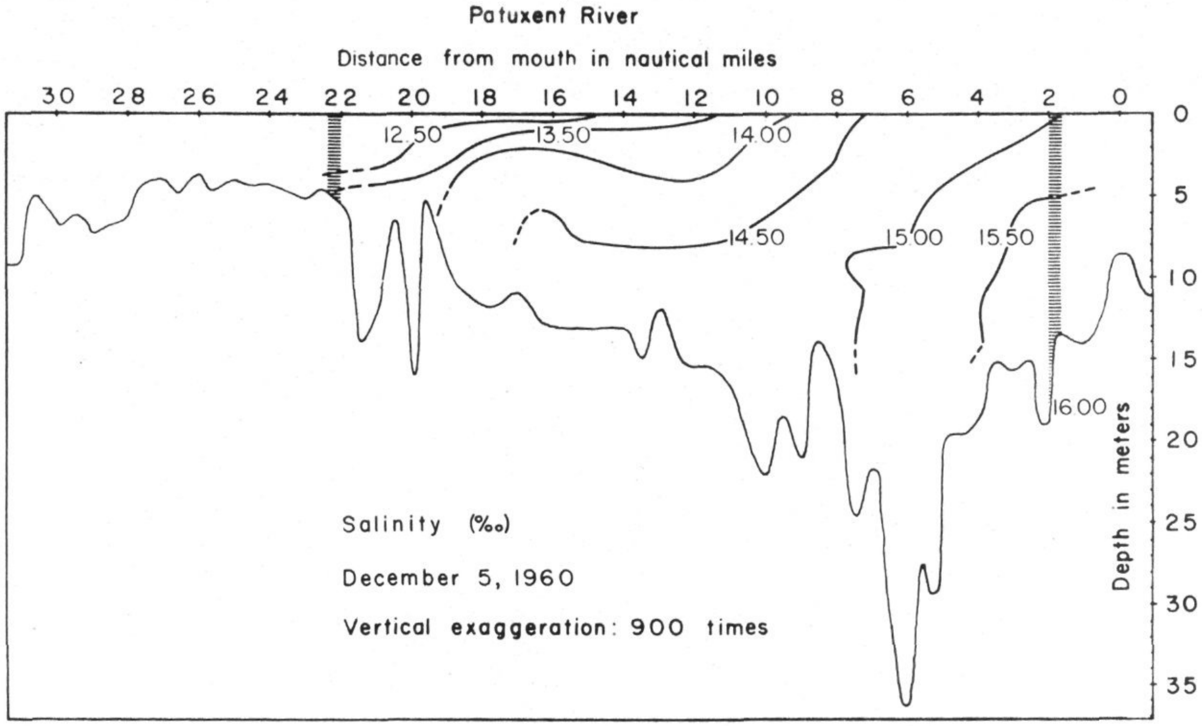

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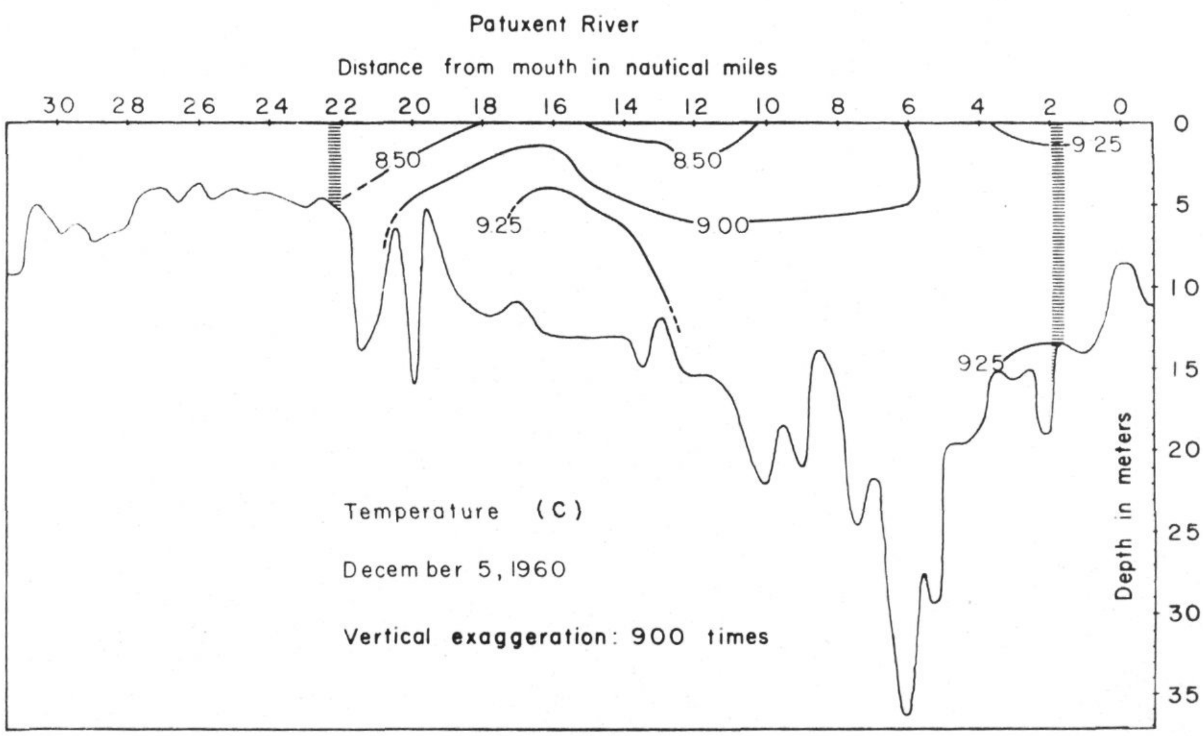

Figure B34. Patuxent River: Temperature, Dec. 5, 1960.

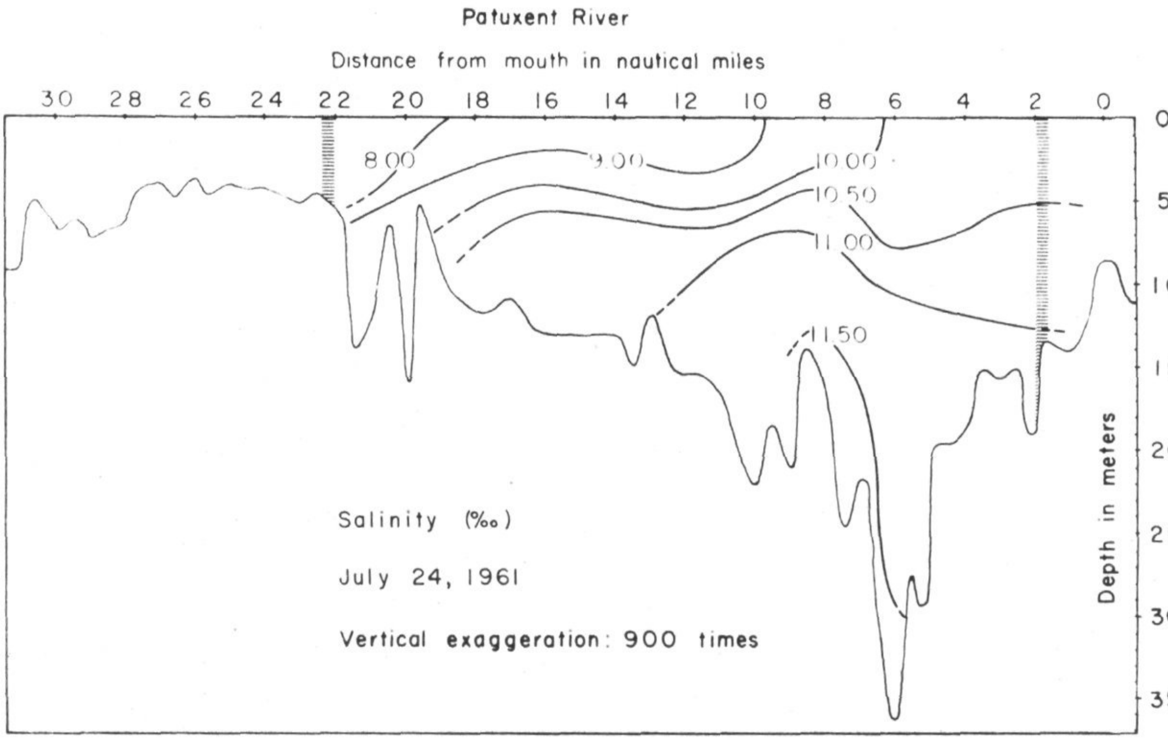

Figure B35. Patuxent River: Salinity, July 24, 1961.

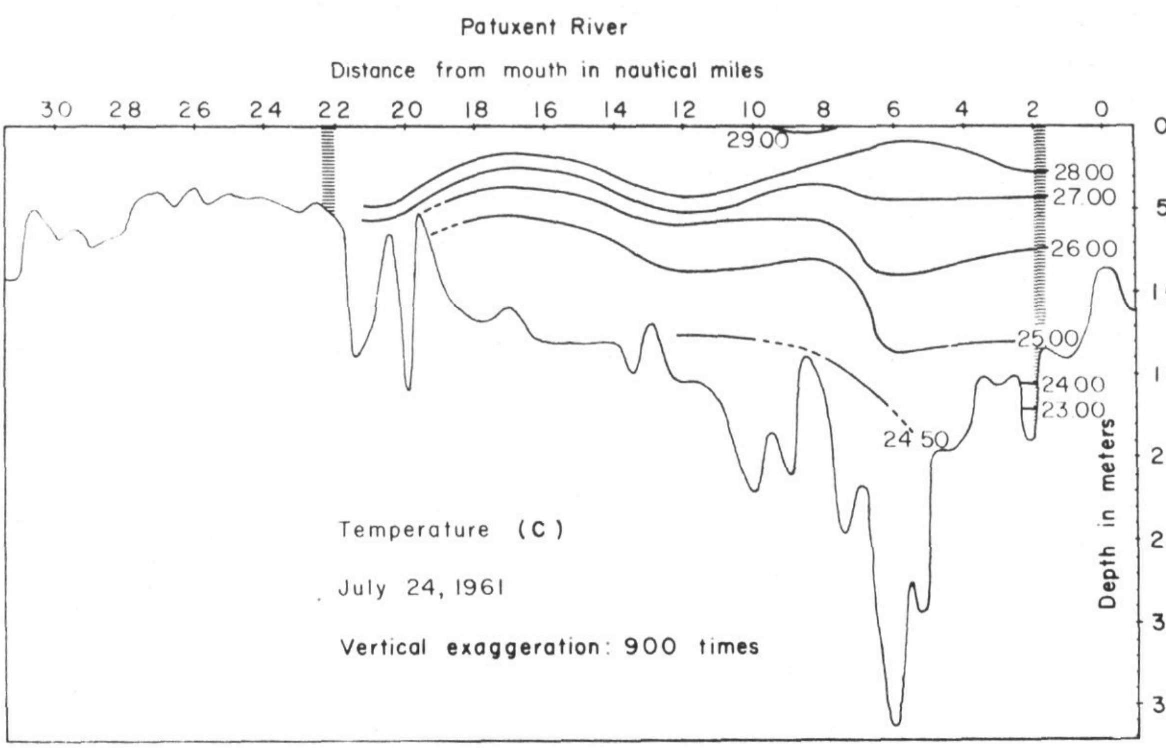

Figure B36. Patuxent River: Temperature, July 24, 1961.

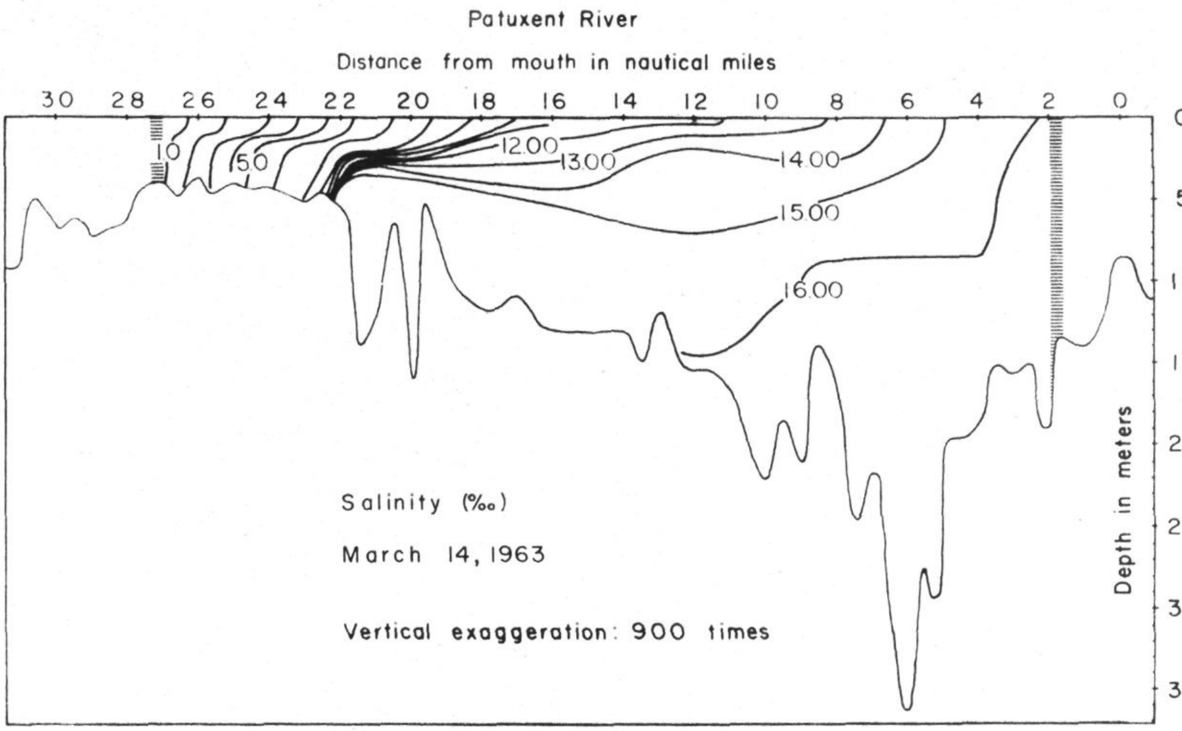

Figure B37. Patuxent River: Salinity, March 14, 1963.

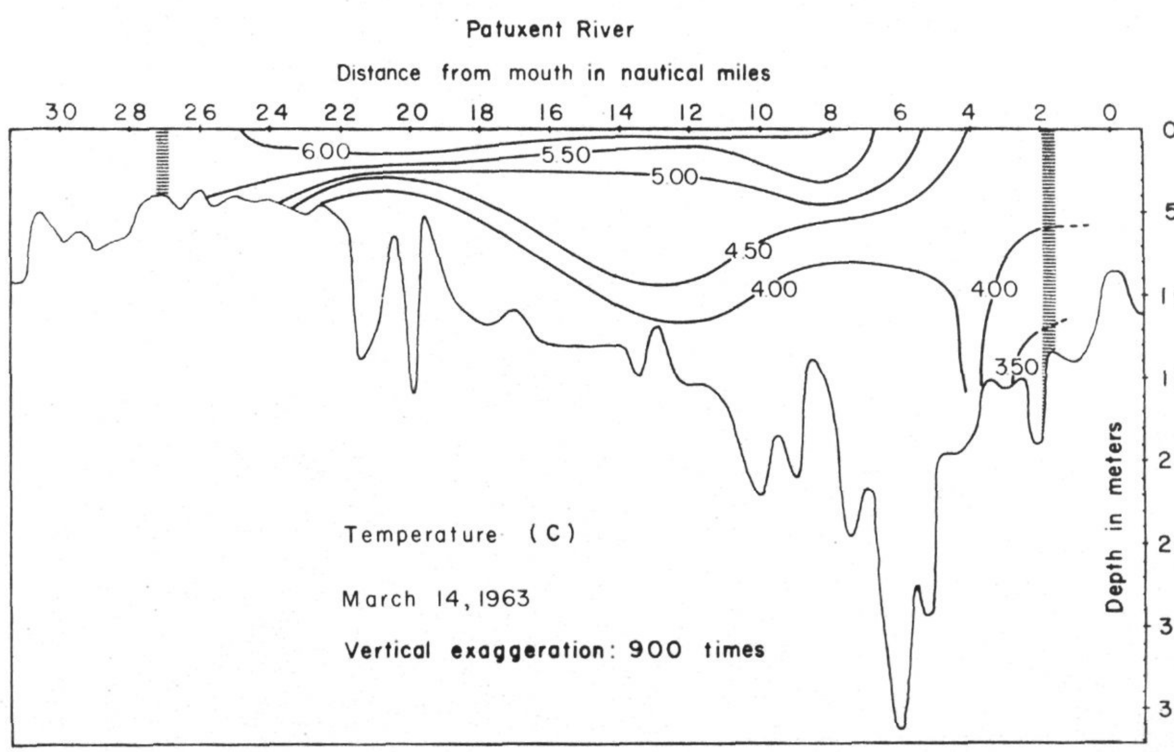

Figure B38. Patuxent River: Temperature, March 14, 1963.

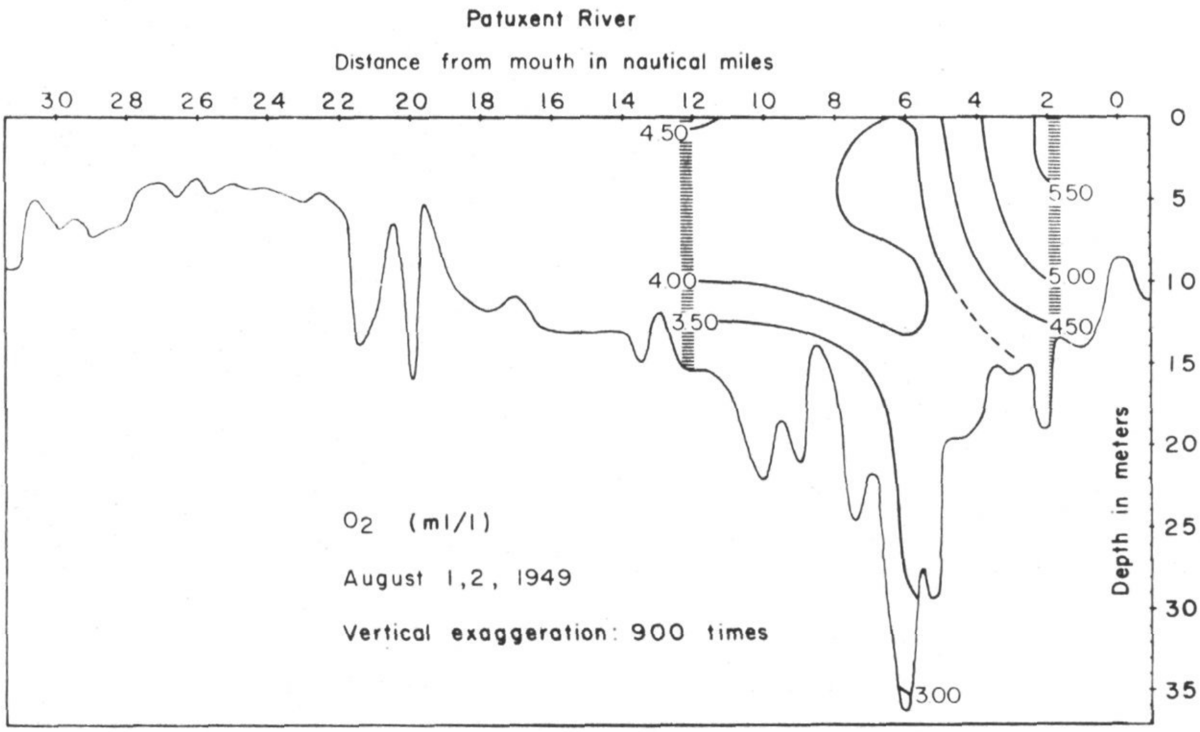

Figure B39. Patuxent River: O_2, Aug. 1,2, 1949.

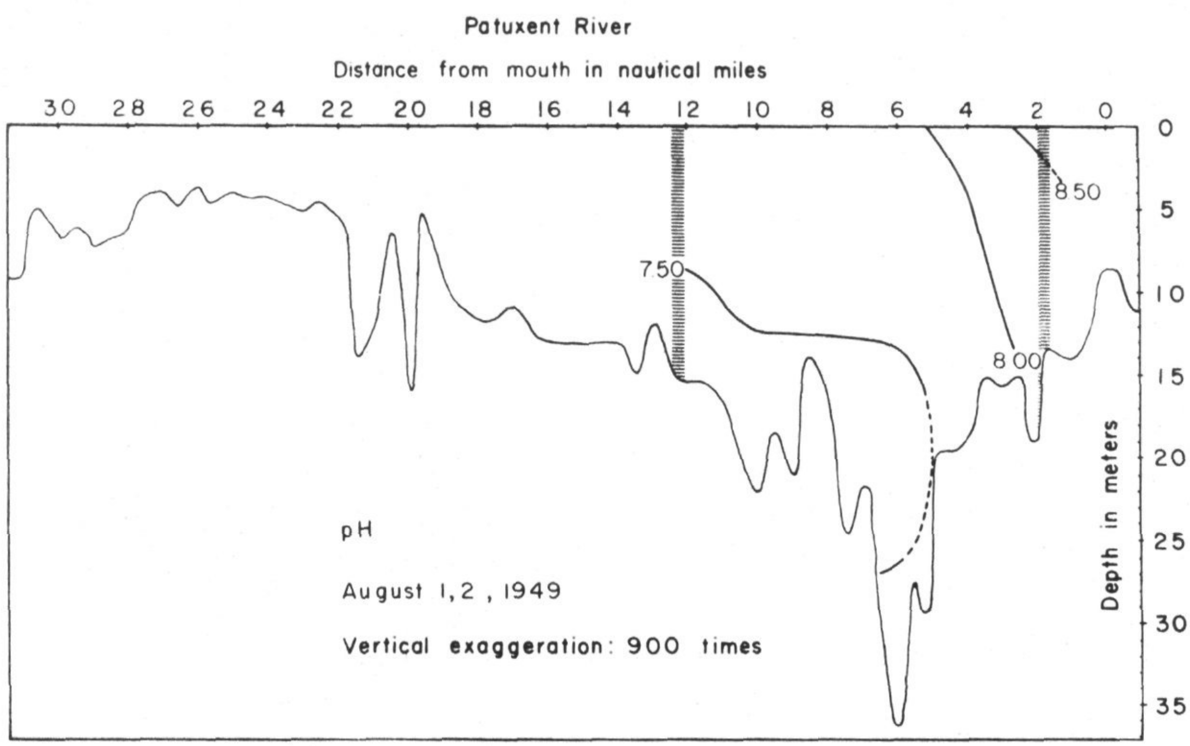

Figure B40. Patuxent River: pH, Aug. 1,2, 1949.

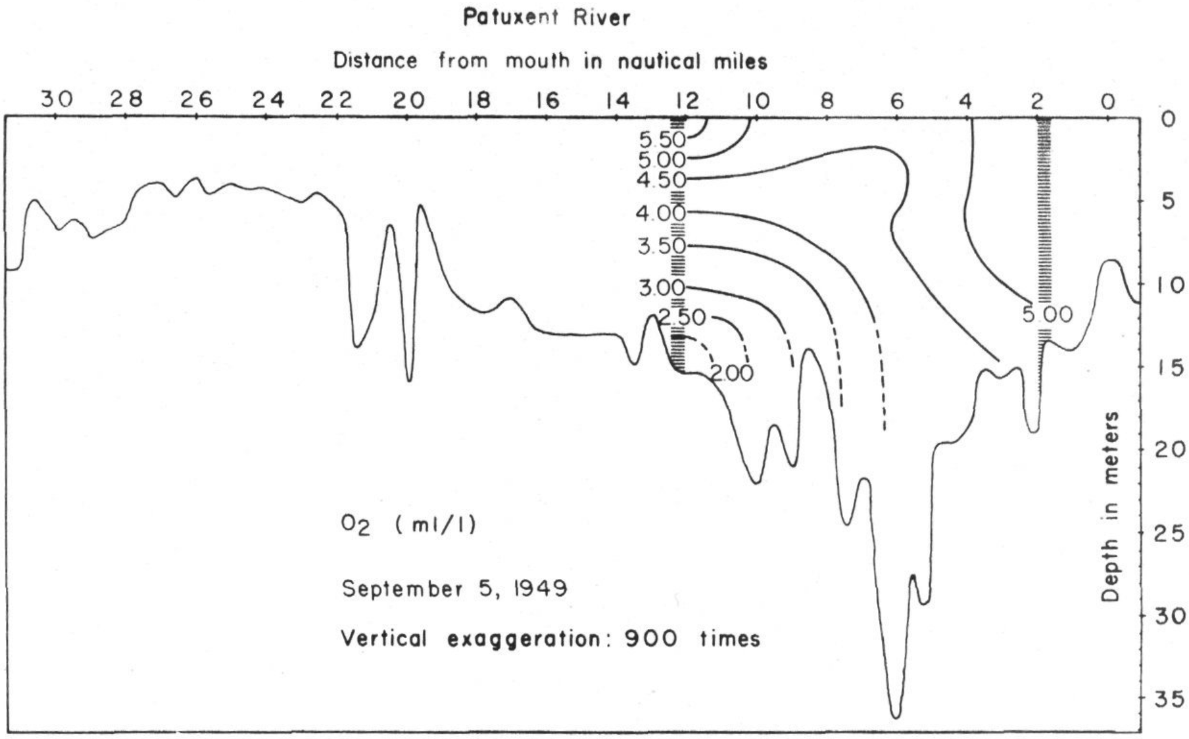

Figure B41. Patuxent River: O_2, Sept. 5, 1949.

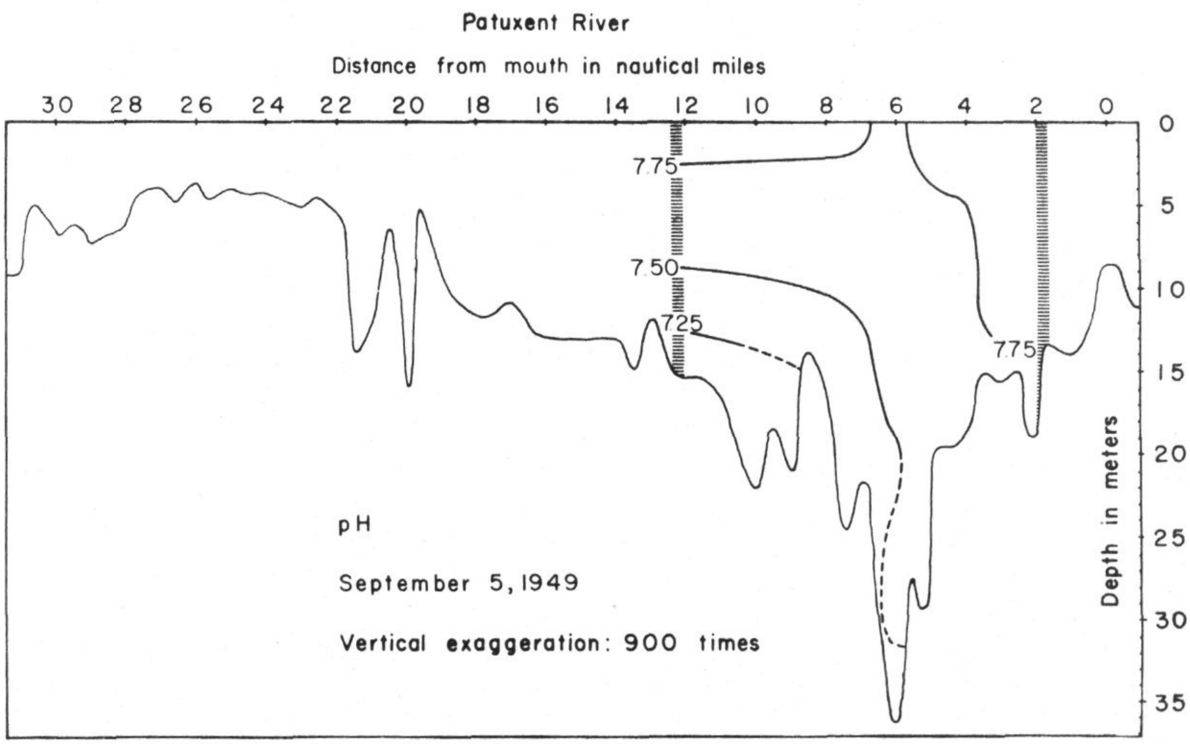

Figure B42. Patuxent River: pH, Sept. 5, 1949.

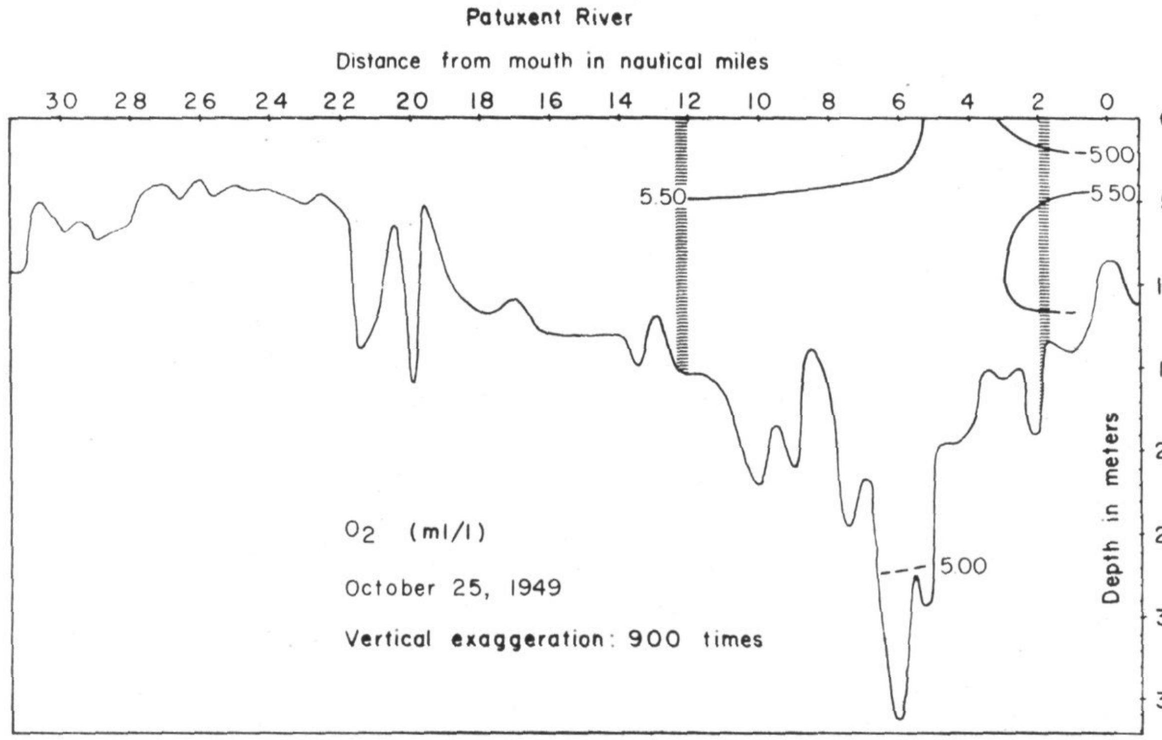

Figure B43. Patuxent River: O_2, Oct. 25, 1949.

NO DATA

Figure B44. Patuxent River: pH, Oct. 25, 1949 (no data).

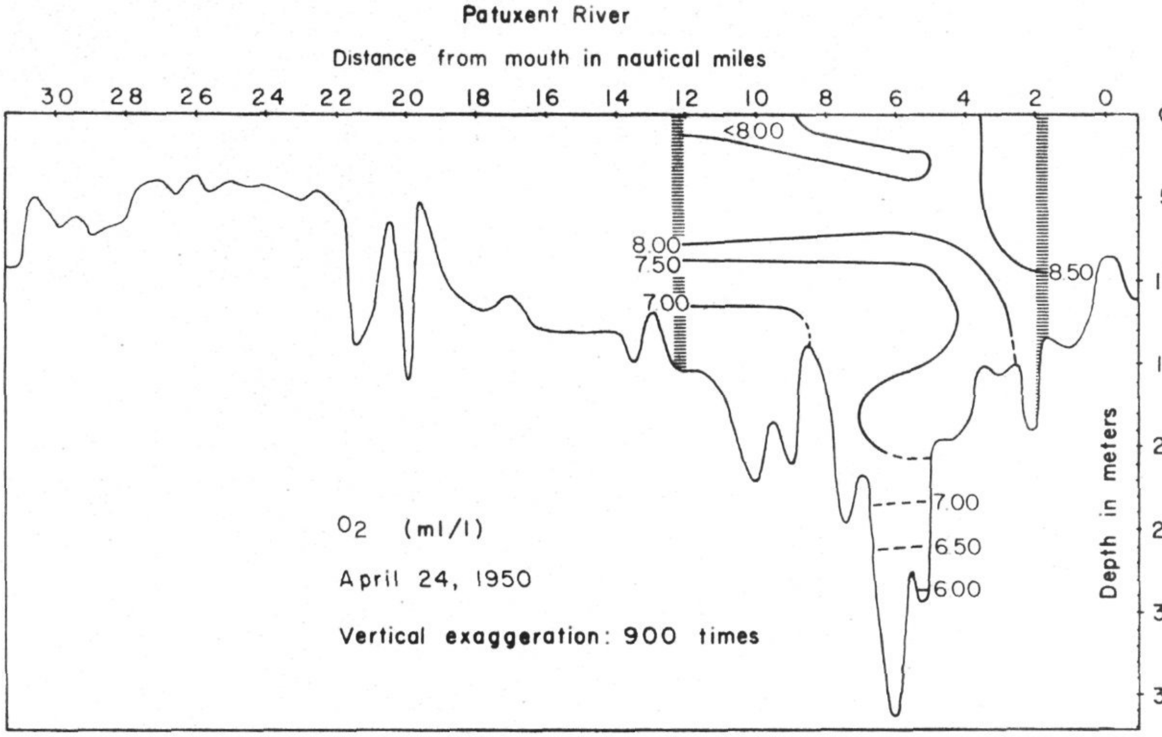

Figure B45. Patuxent River: O_2, April 24, 1950.

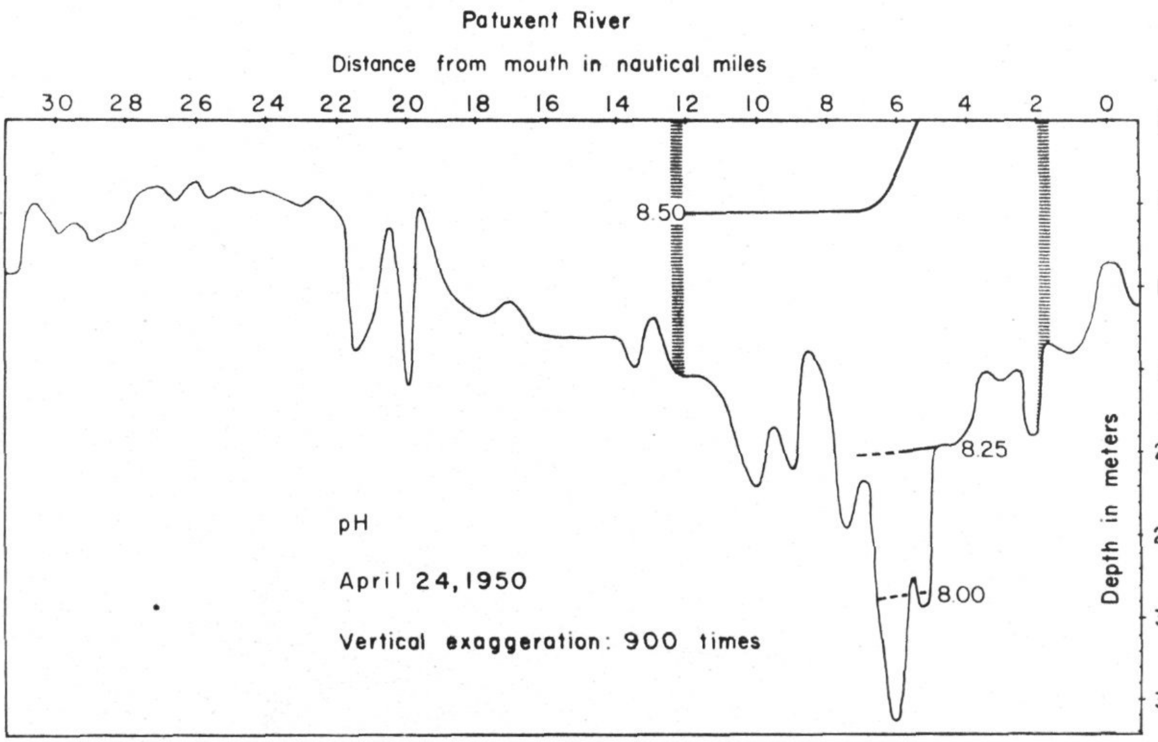

Figure B46. Patuxent River: pH, April 24, 1950.

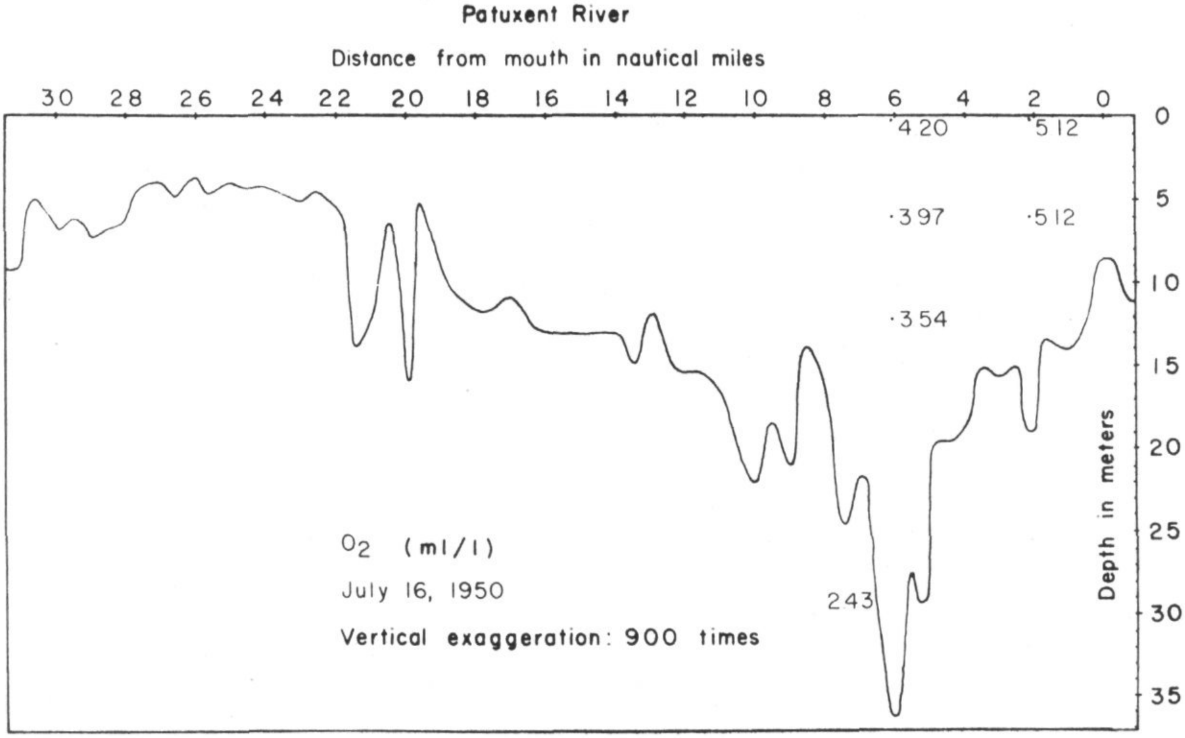

Figure B47. Patuxent River: O_2, July 16, 1950.

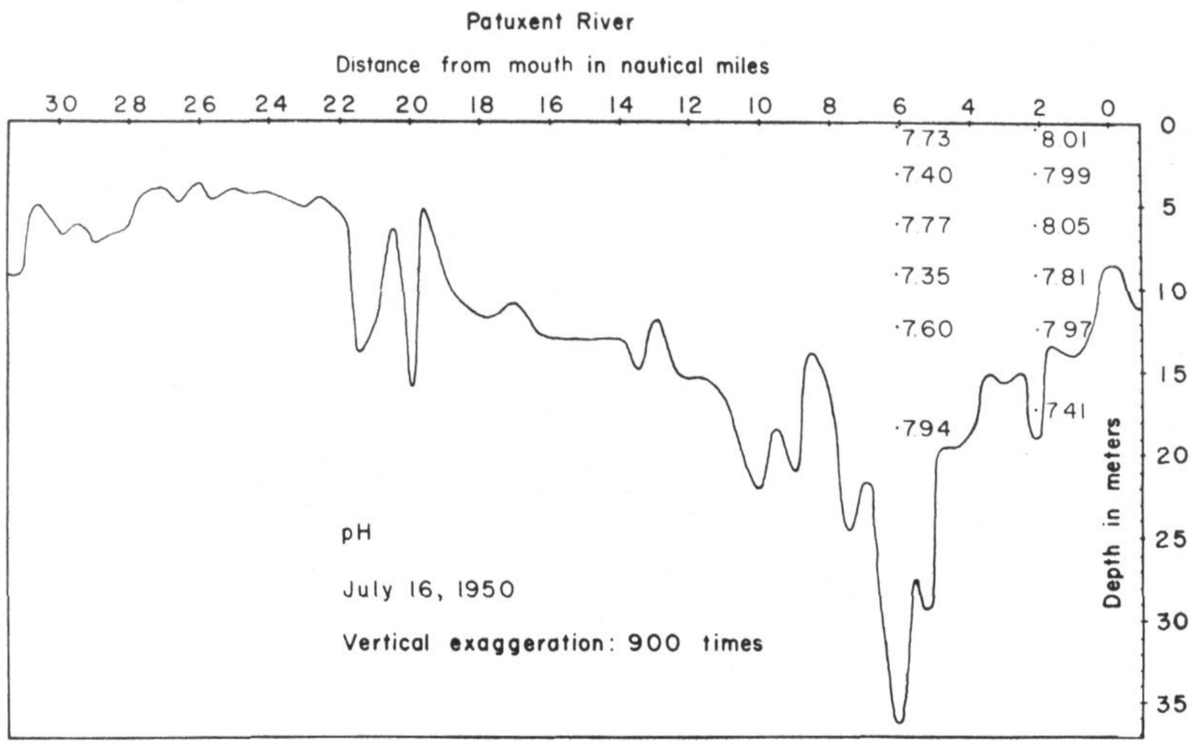

Figure B48. Patuxent River: pH, July 16, 1950.

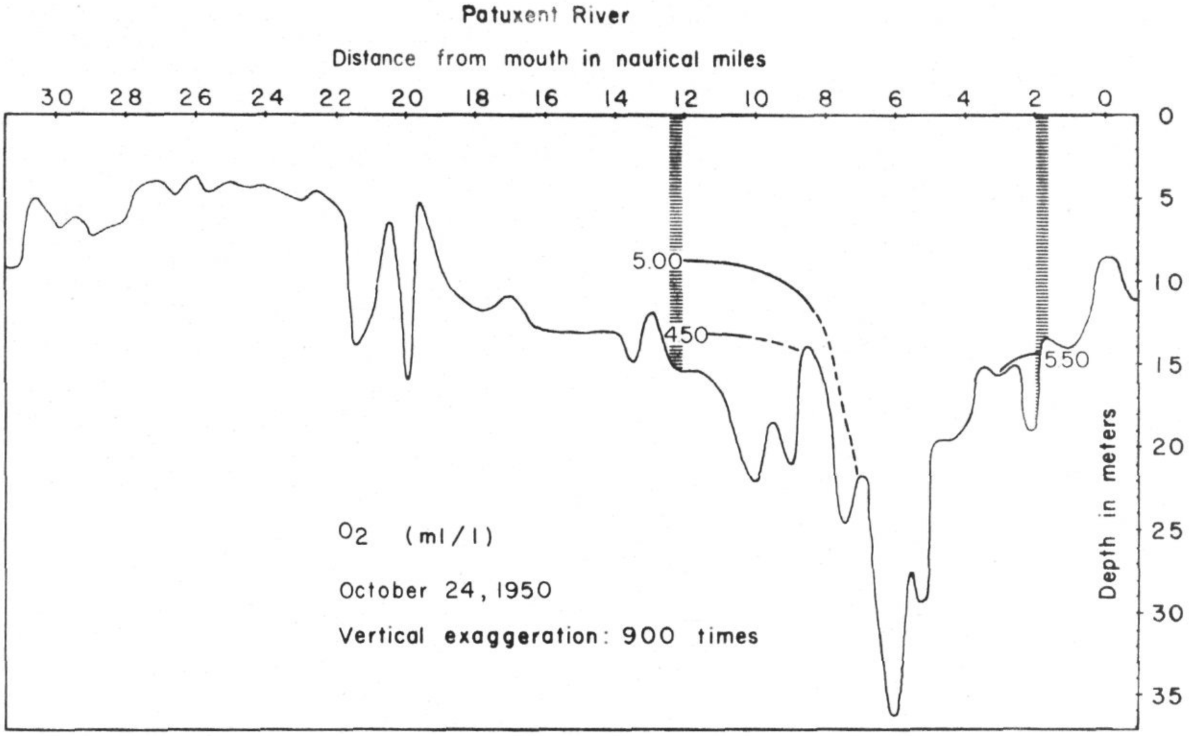

Figure B49. Patuxent River: O_2, Oct. 24, 1950.

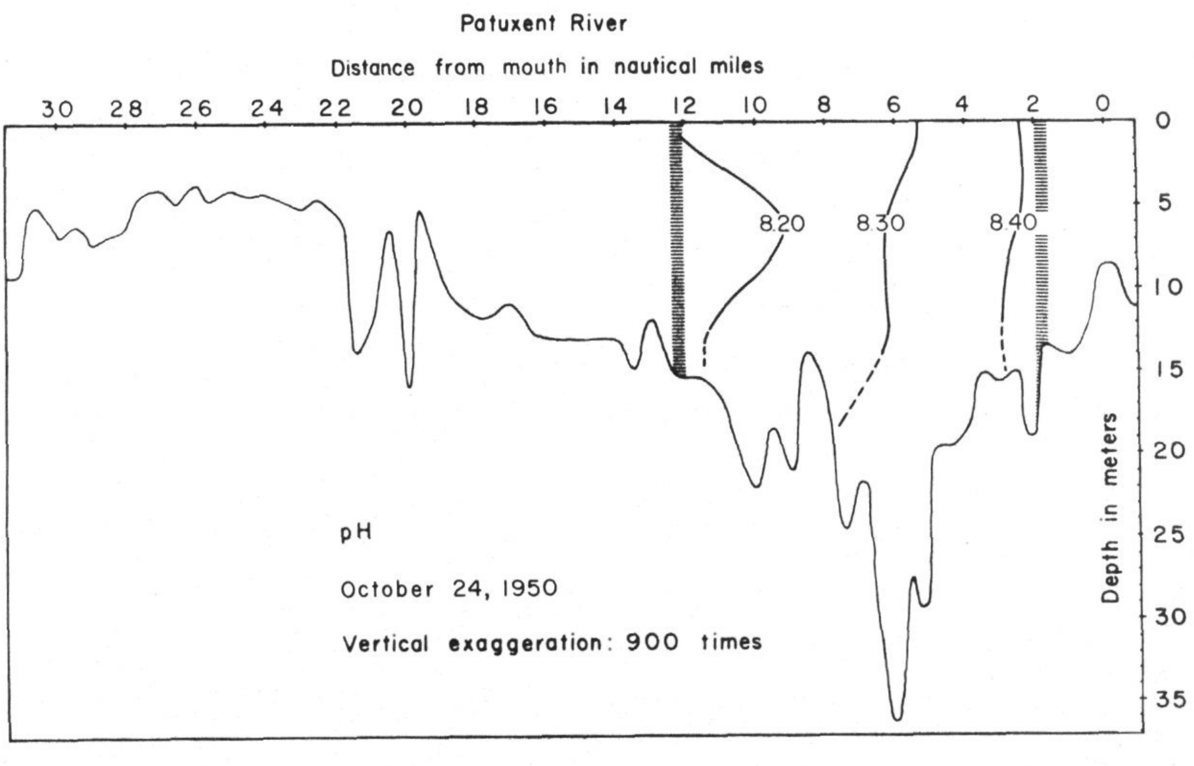

Figure B50. Patuxent River: pH, Oct. 24, 1950.

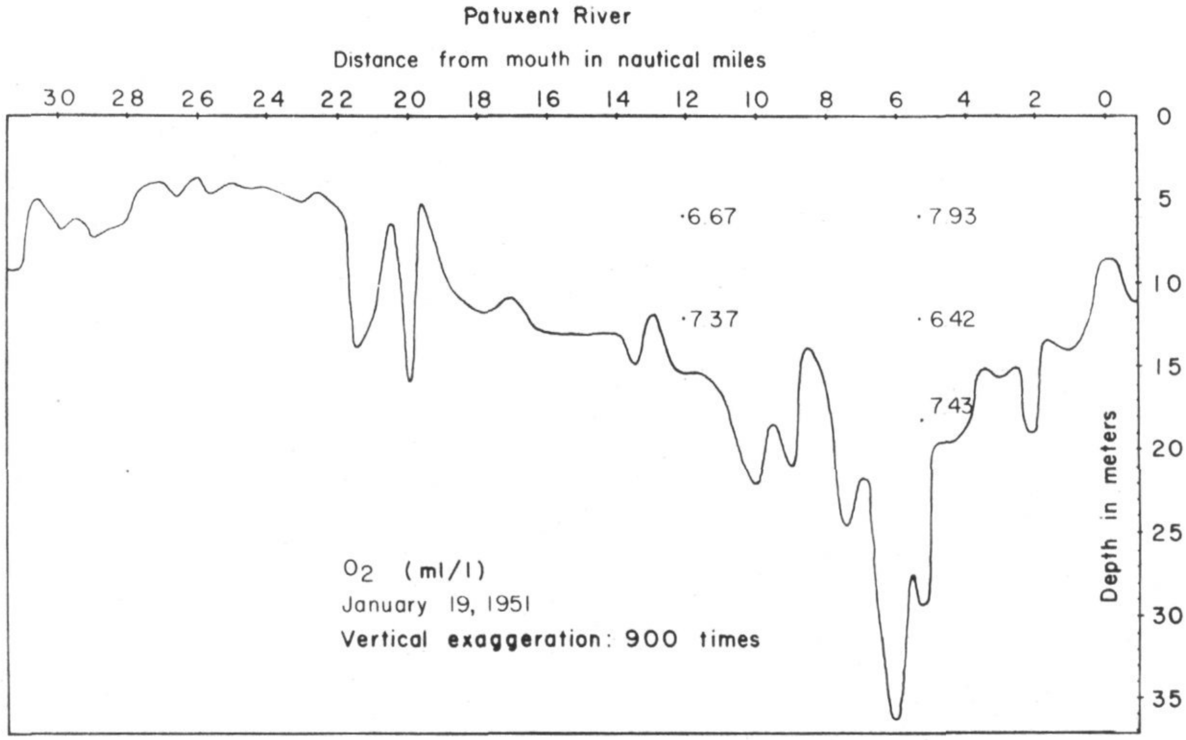

Figure B51. Patuxent River: O_2, Jan. 19, 1951.

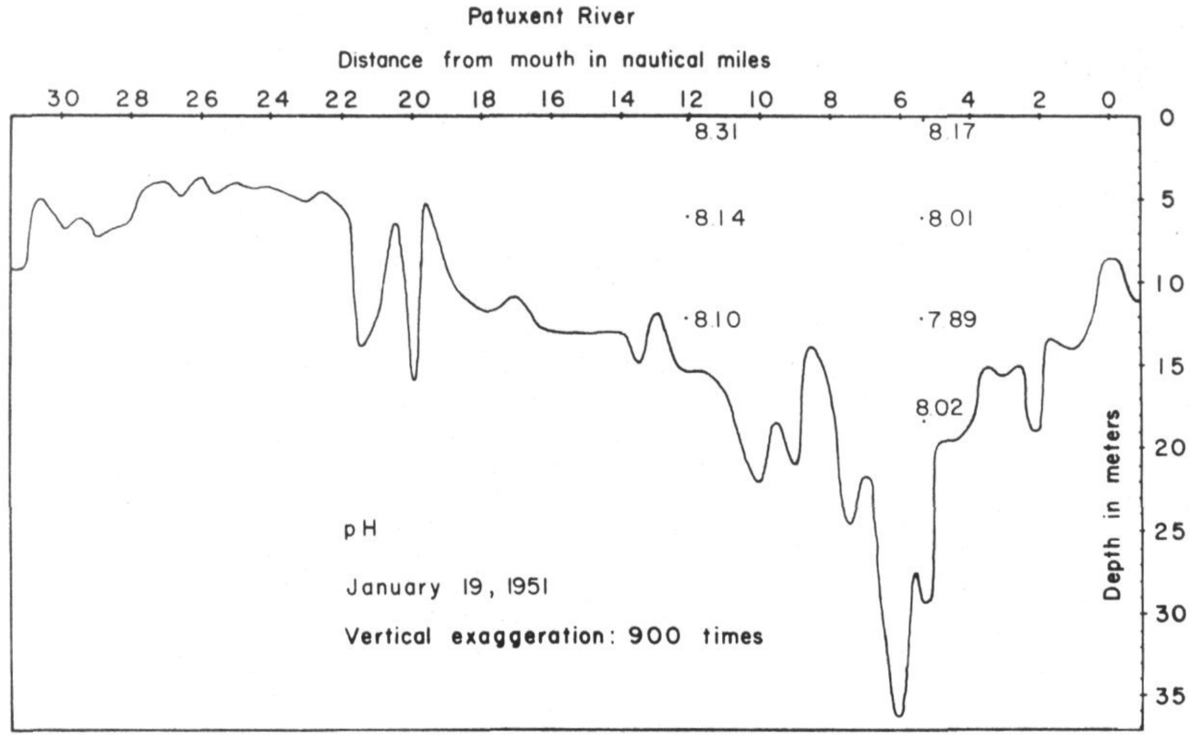

Figure B52. Patuxent River: pH, Jan. 19, 1951.

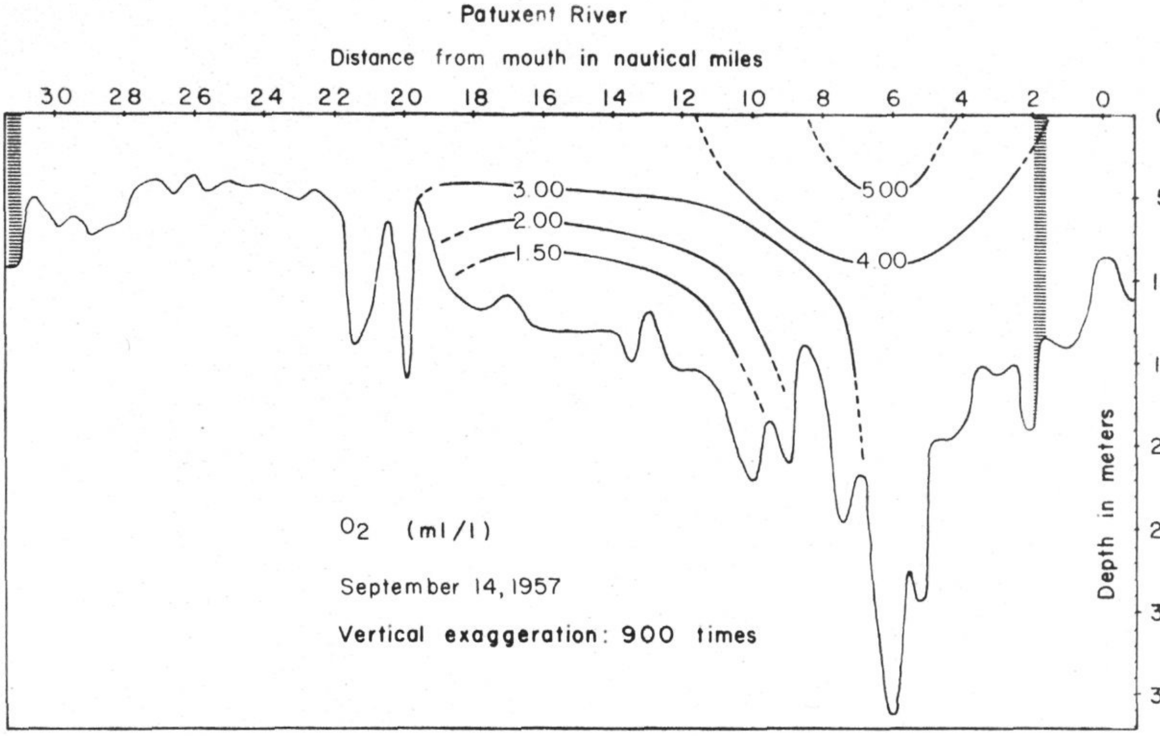

Figure B53. Patuxent River: O_2, Sept. 14, 1957.

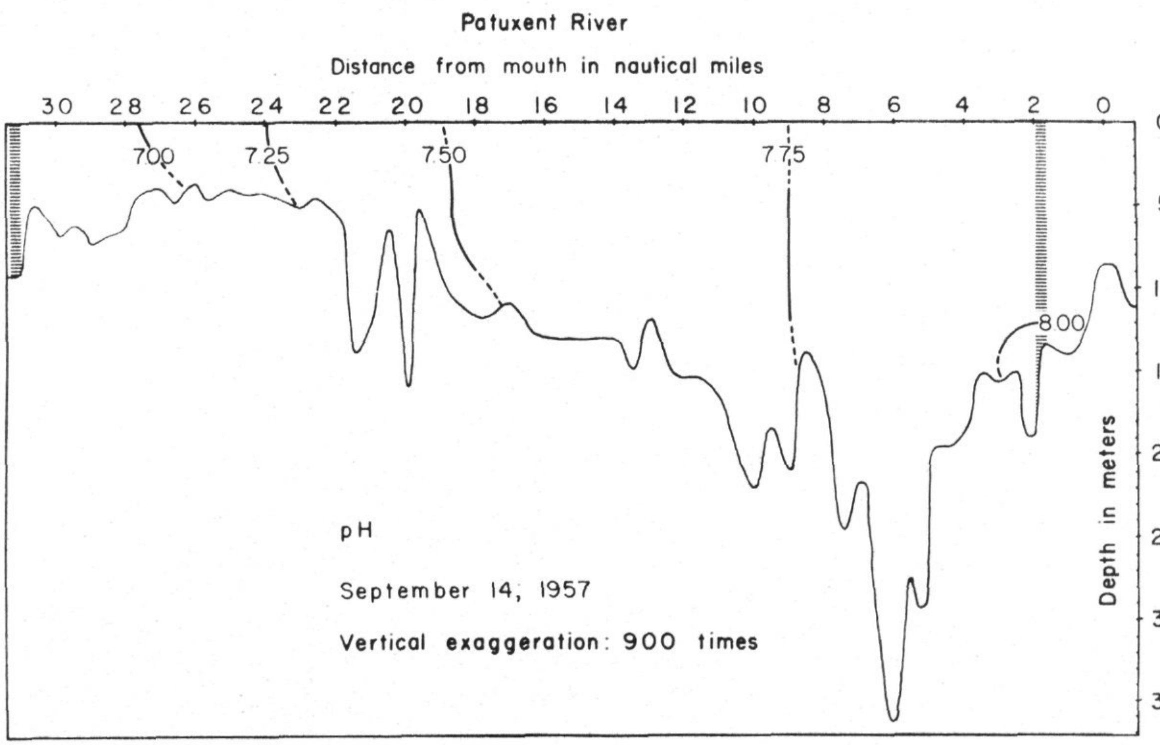

Figure B54. Patuxent River: pH, Sept. 14, 1957.

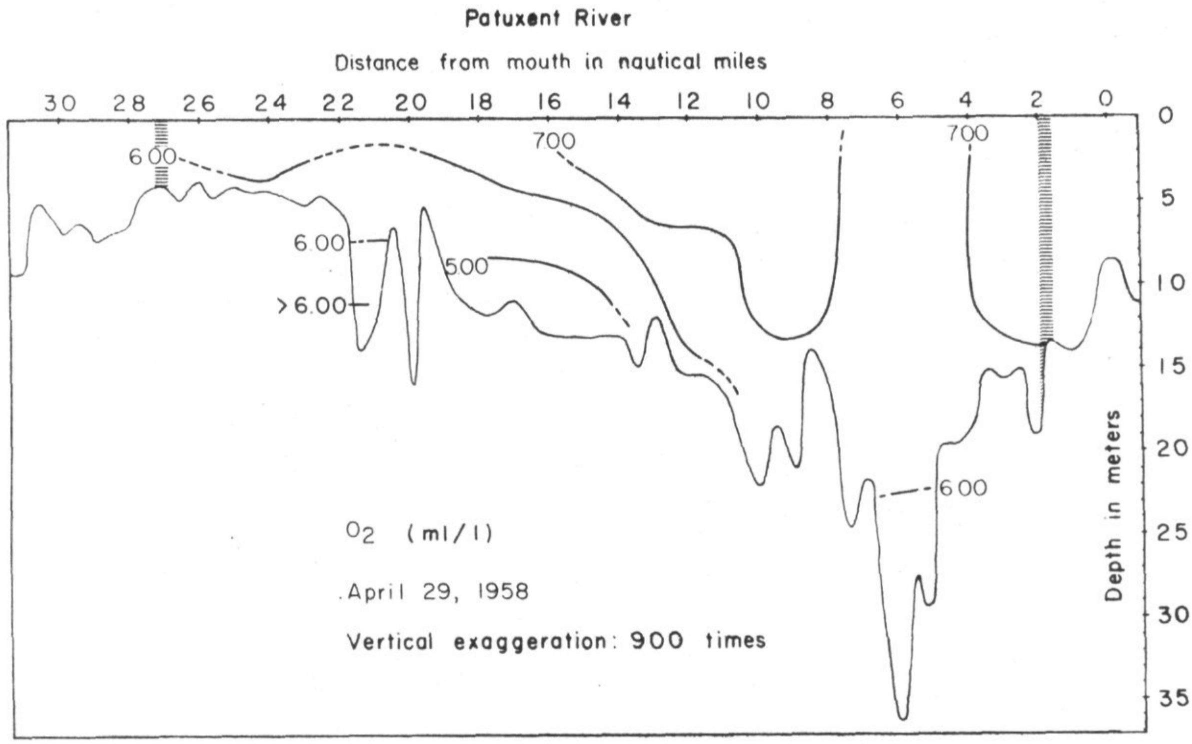

Figure B55. Patuxent River: O_2, April 29, 1958.

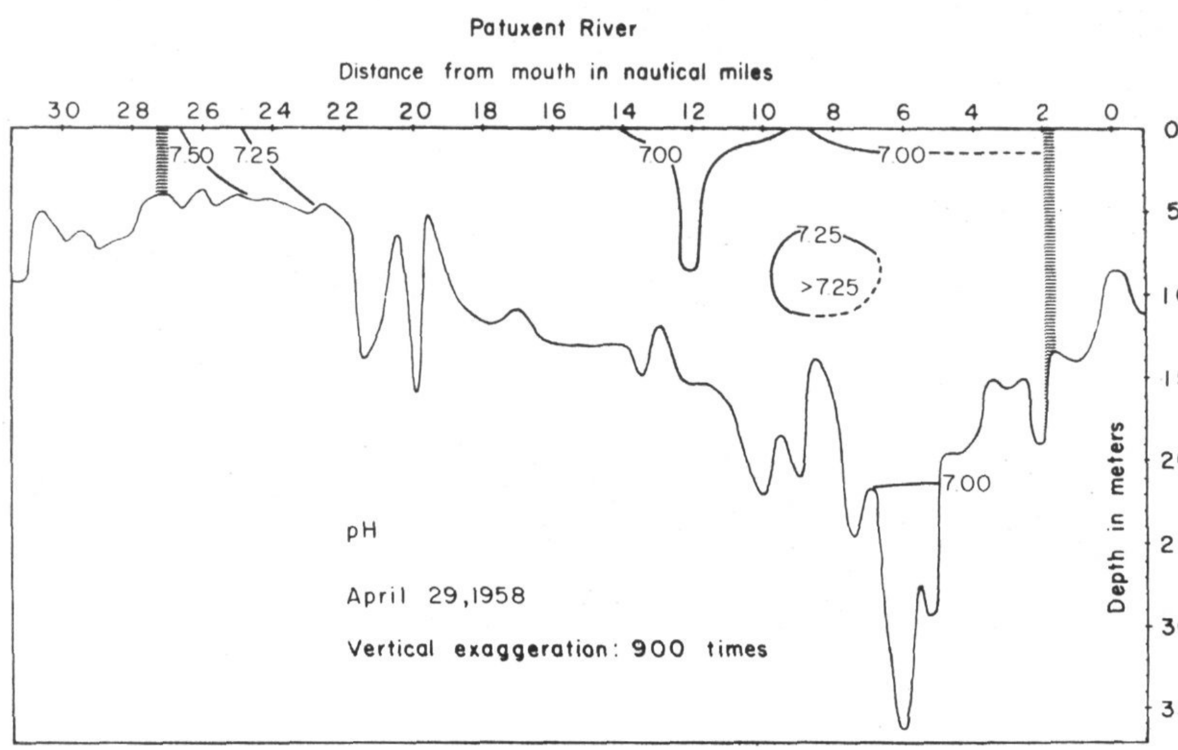

Figure B56. Patuxent River: pH, April 29, 1958.

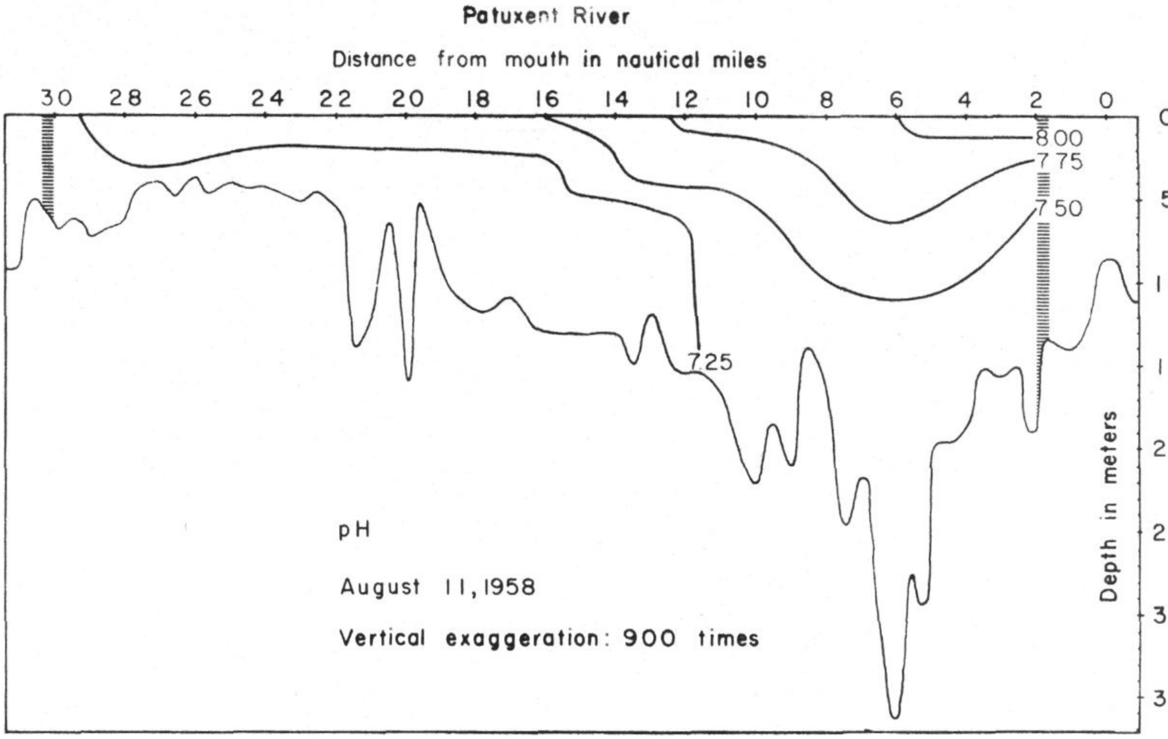

Figure B57. Patuxent River: O_2, Aug. 11, 1958.

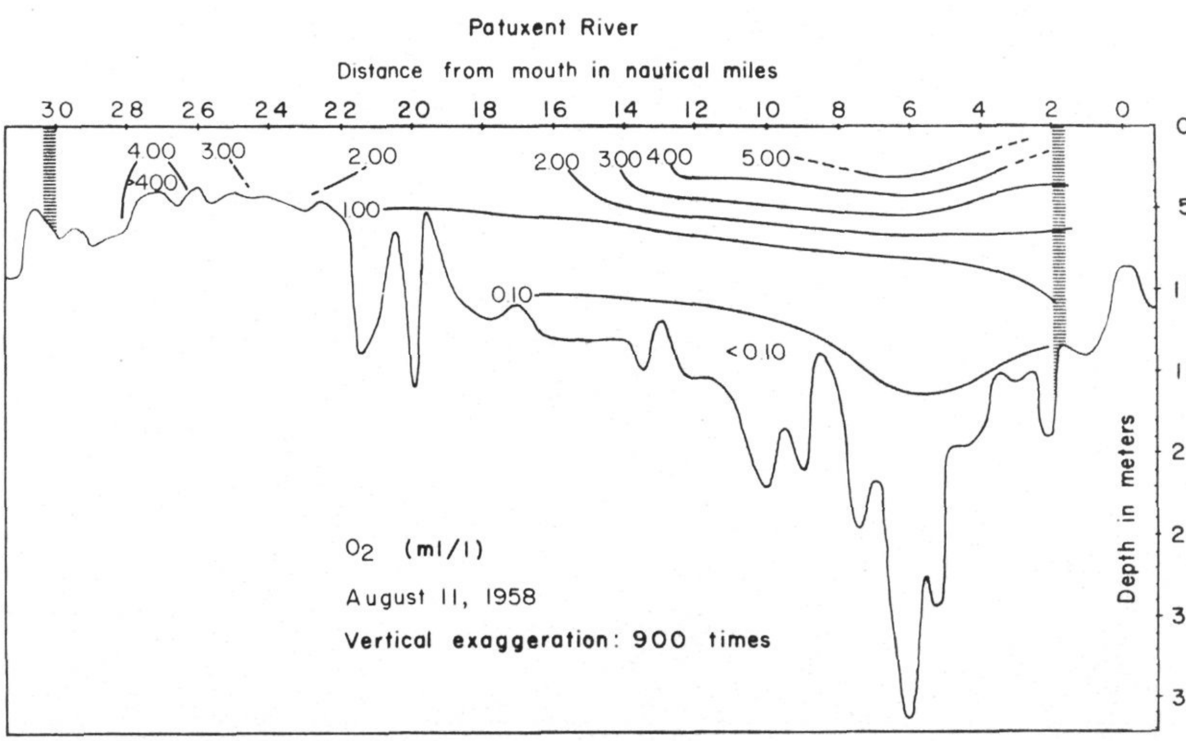

Figure B58. Patuxent River: pH, Aug. 11, 1958.

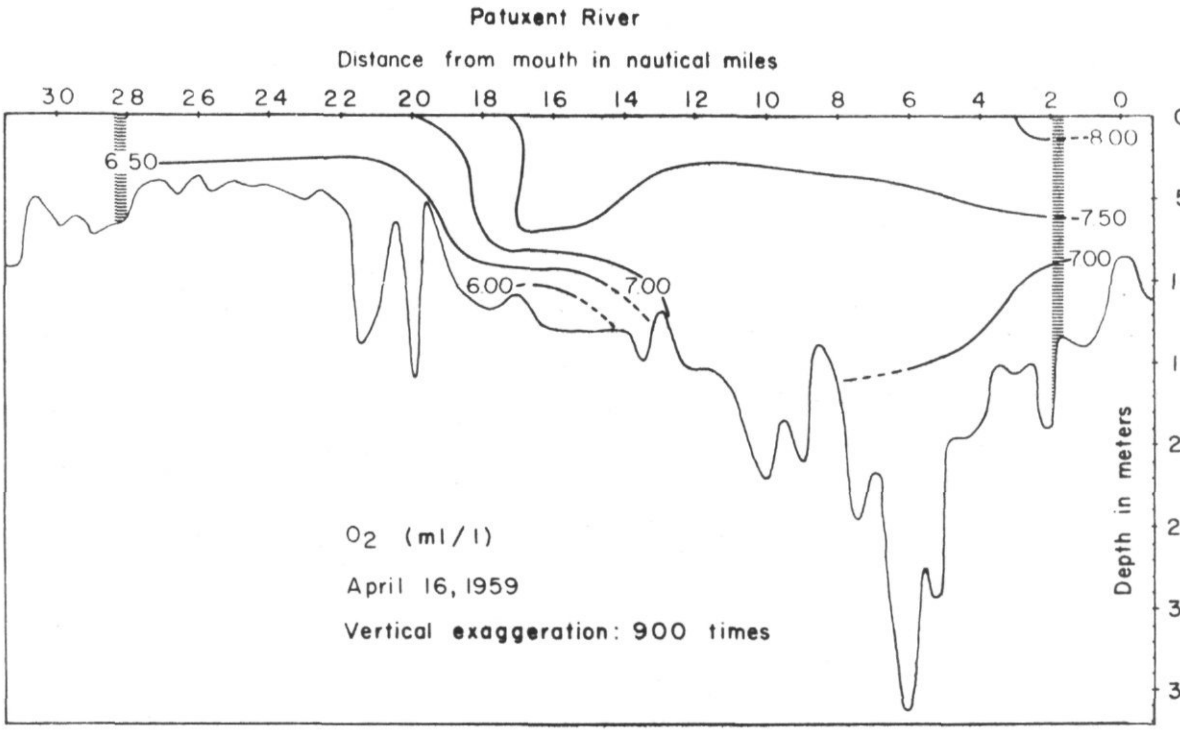

Figure B59. Patuxent River: O_2, April 16, 1959.

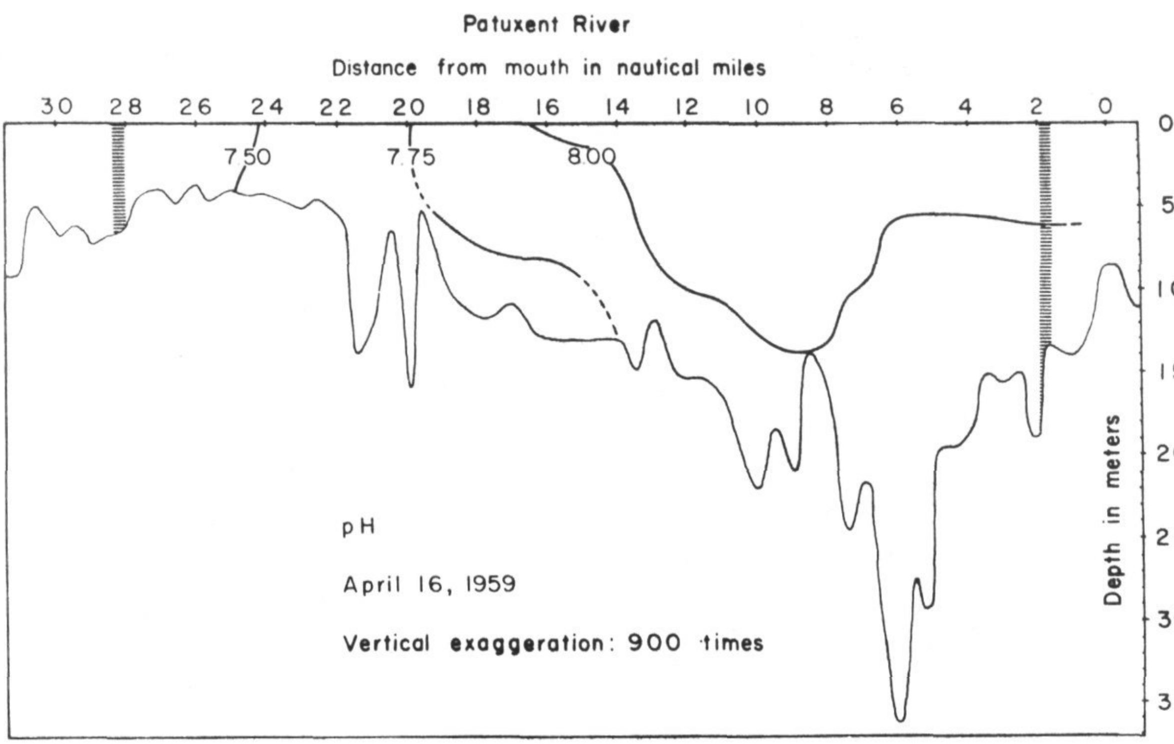

Figure B60. Patuxent River: pH, April 16, 1959.

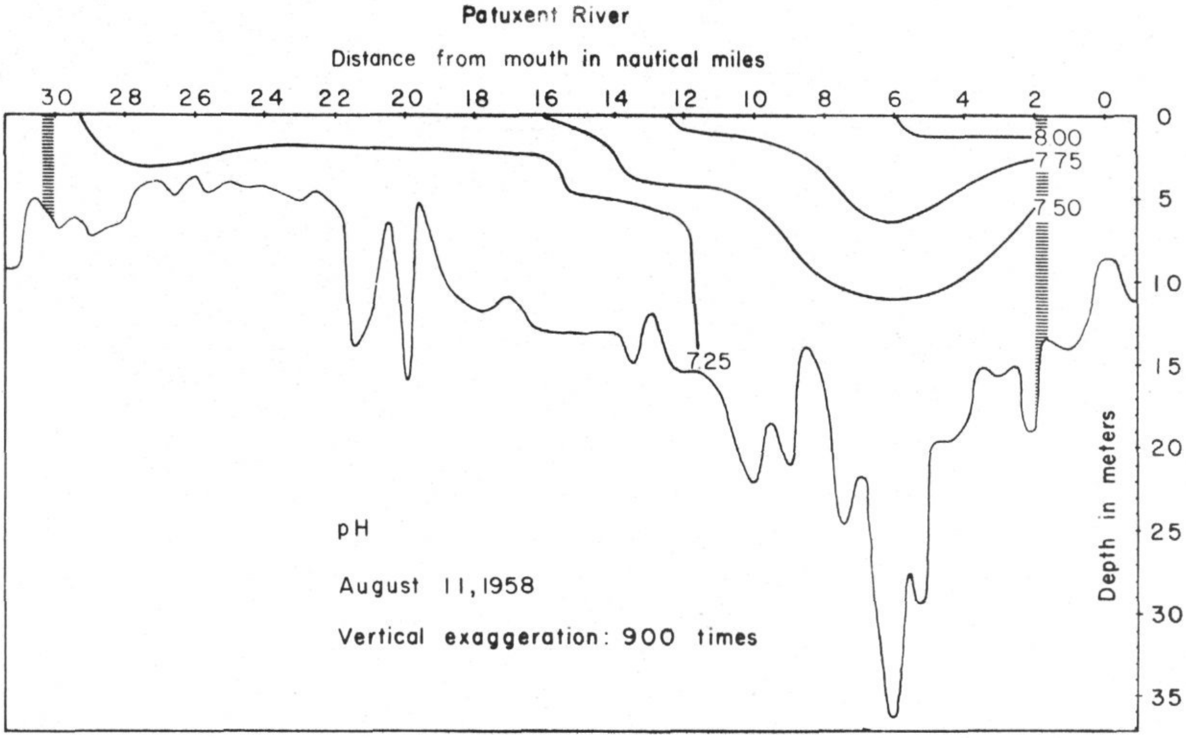

Figure B57. Patuxent River: O_2, Aug. 11, 1958.

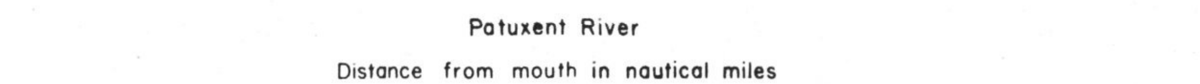

Figure B58. Patuxent River: pH, Aug. 11, 1958.

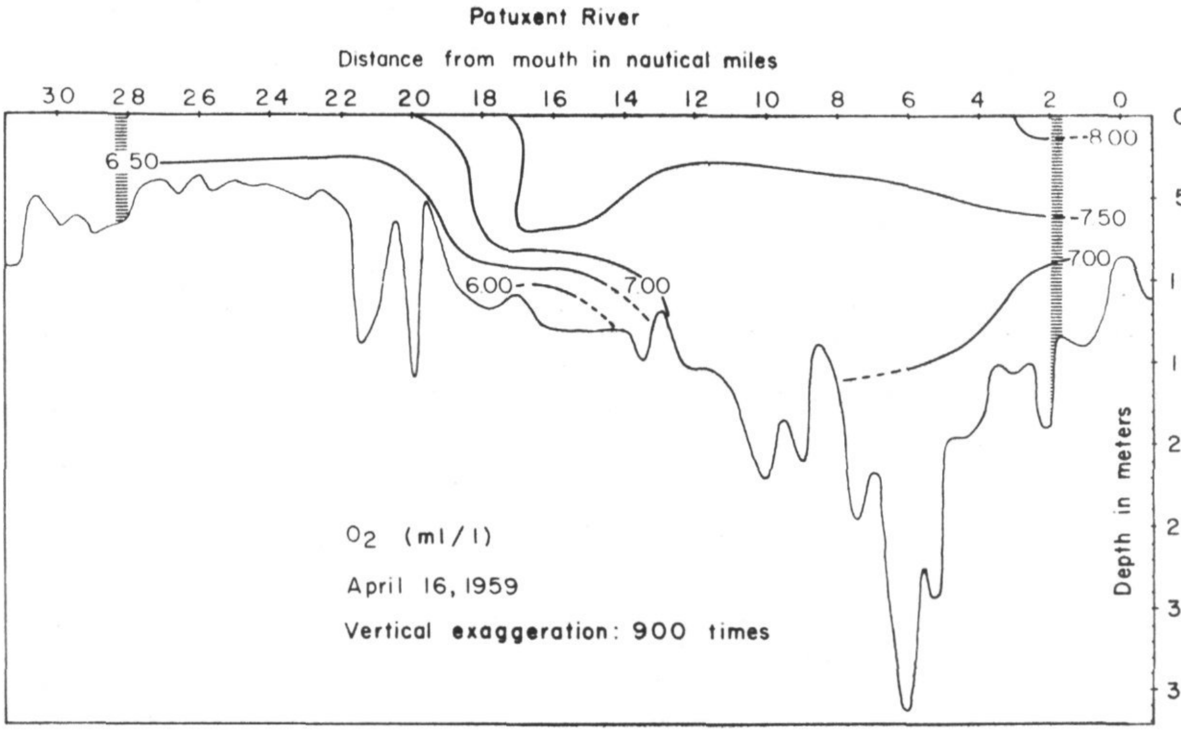

Figure B59. Patuxent River: O_2, April 16, 1959.

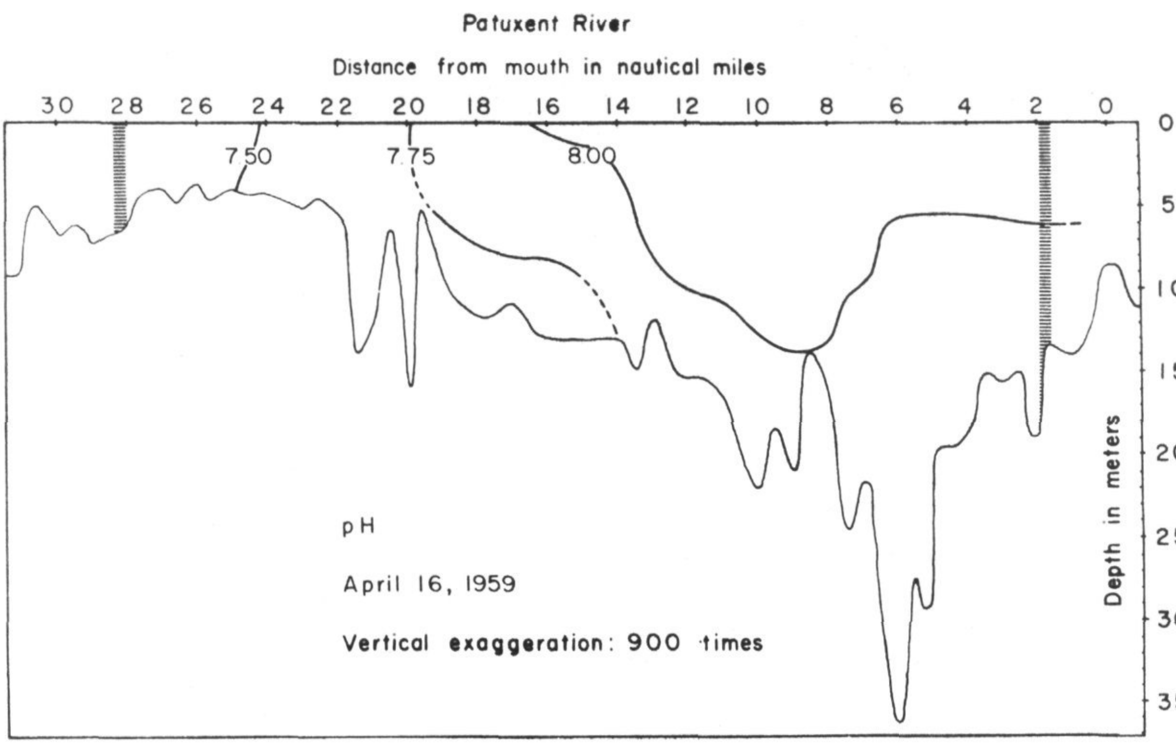

Figure B60. Patuxent River: pH, April 16, 1959.

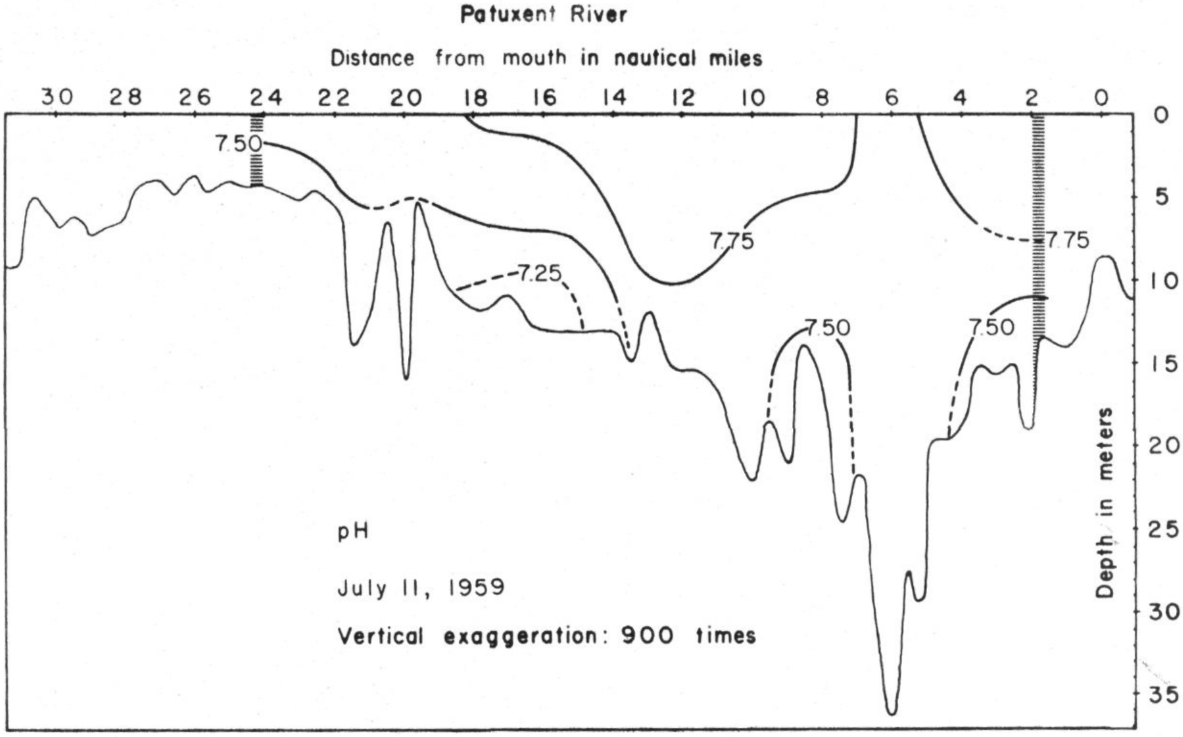

Figure B61. Patuxent River: O_2, July 11, 1959.

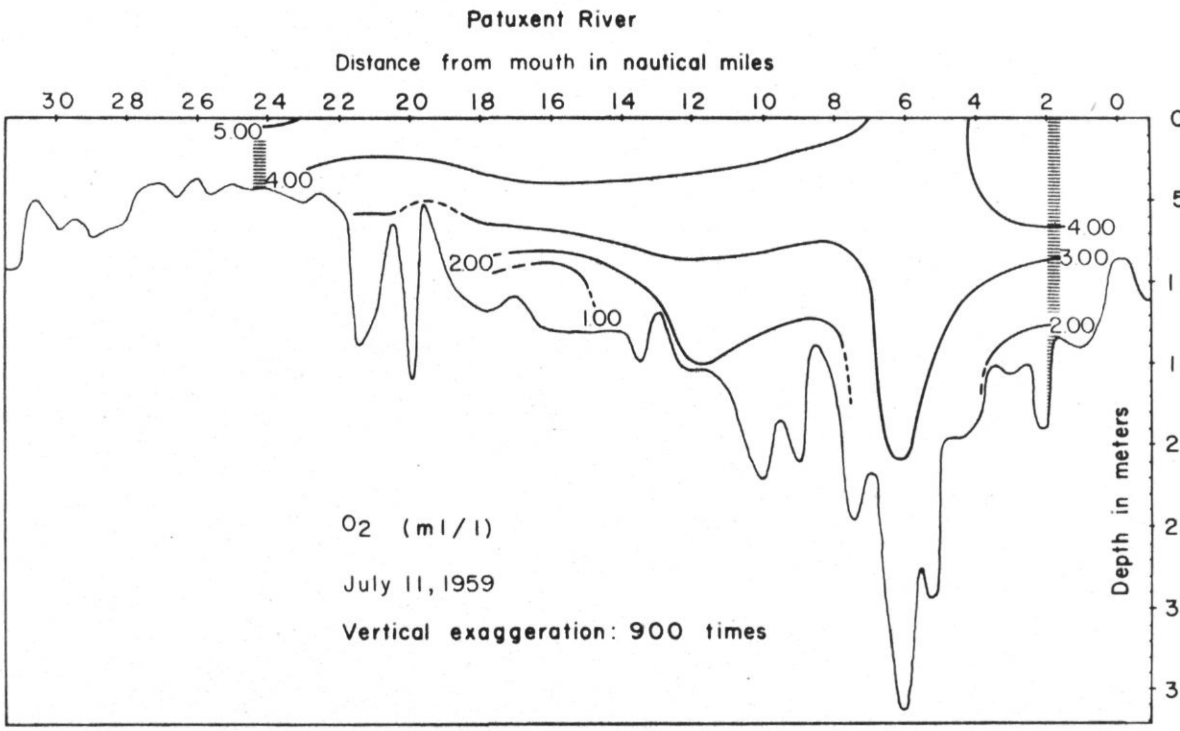

Figure B62. Patuxent River: pH, July 11, 1959.

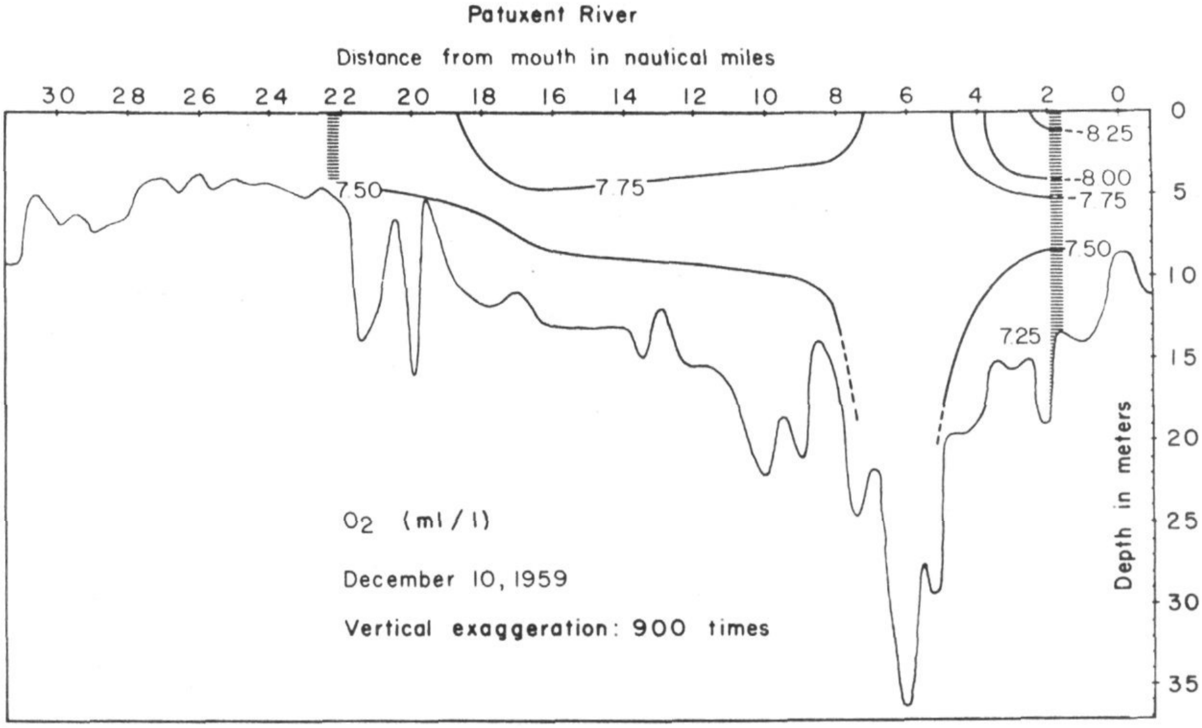

Figure B63. Patuxent River: O_2, Dec. 10, 1959.

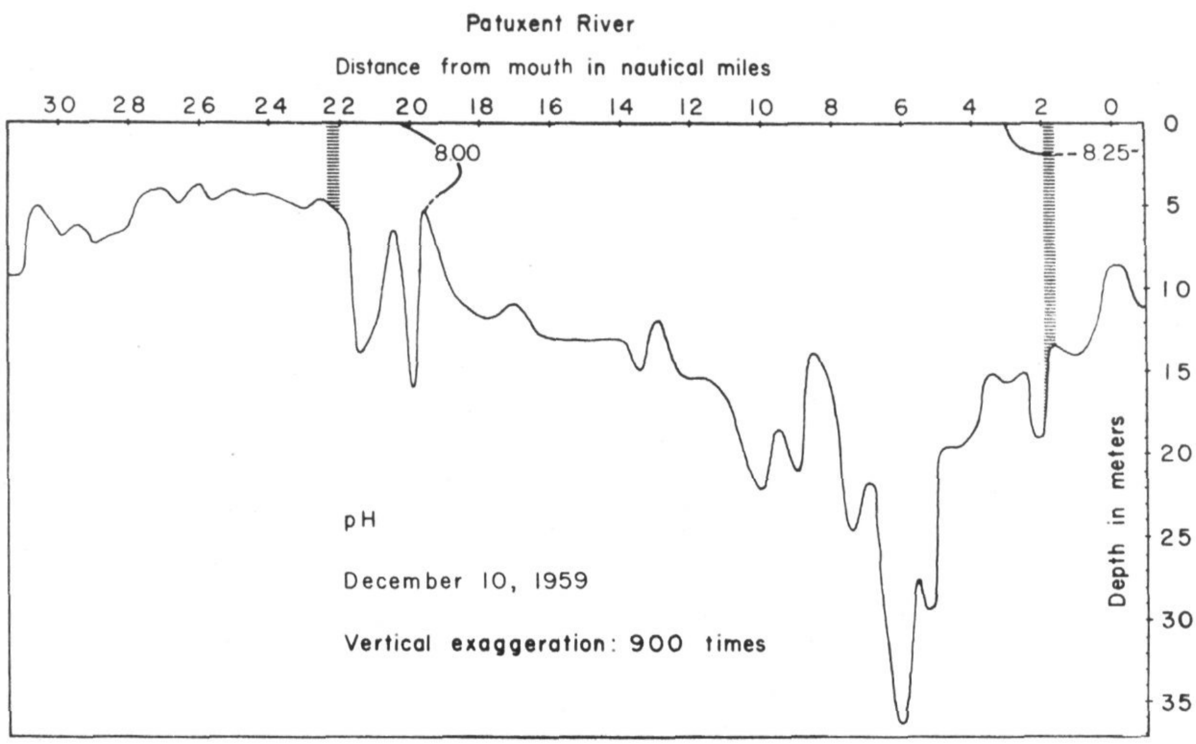

Figure B64. Patuxent River: pH, Dec. 10, 1959.

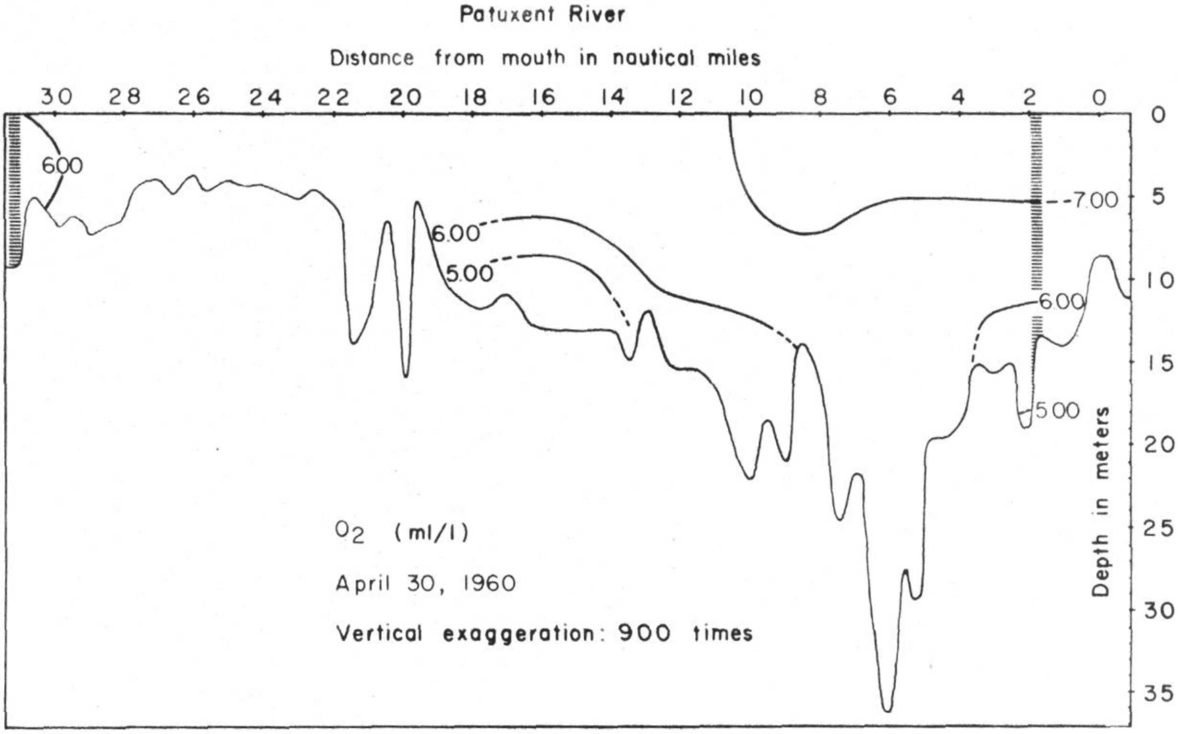

Figure B65. Patuxent River: O_2, April 30, 1960.

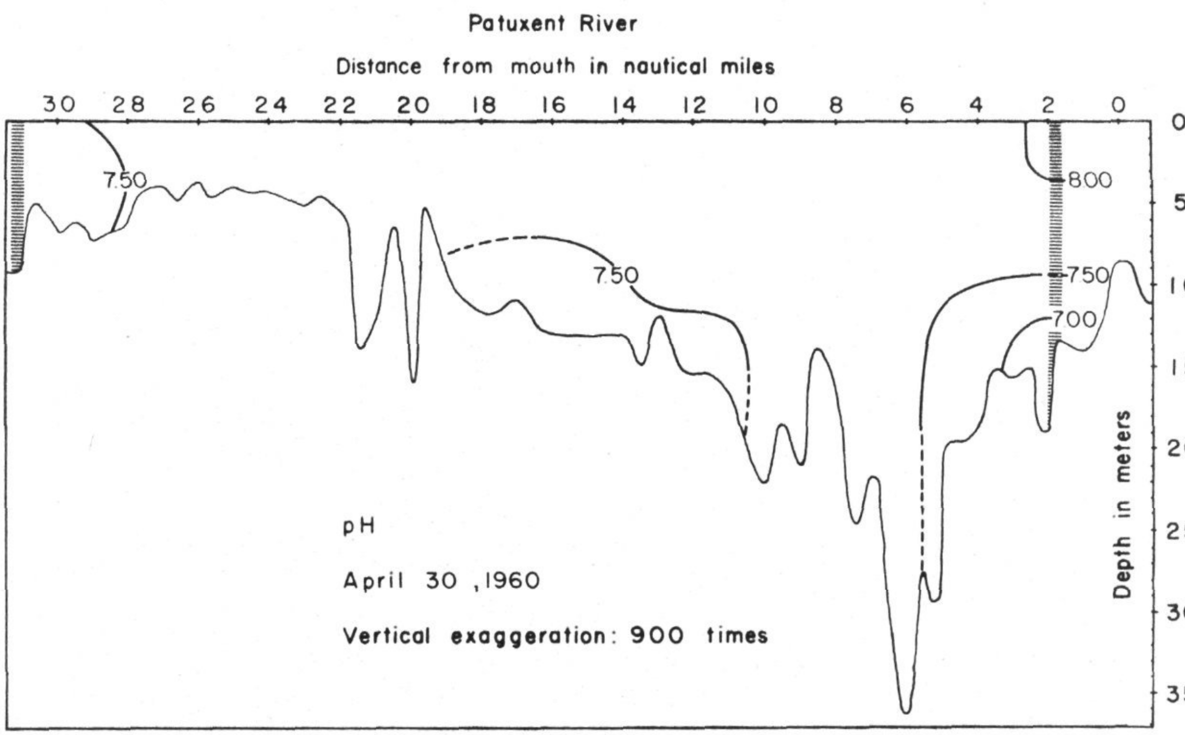

Figure B66. Patuxent River: pH, April 30, 1960.

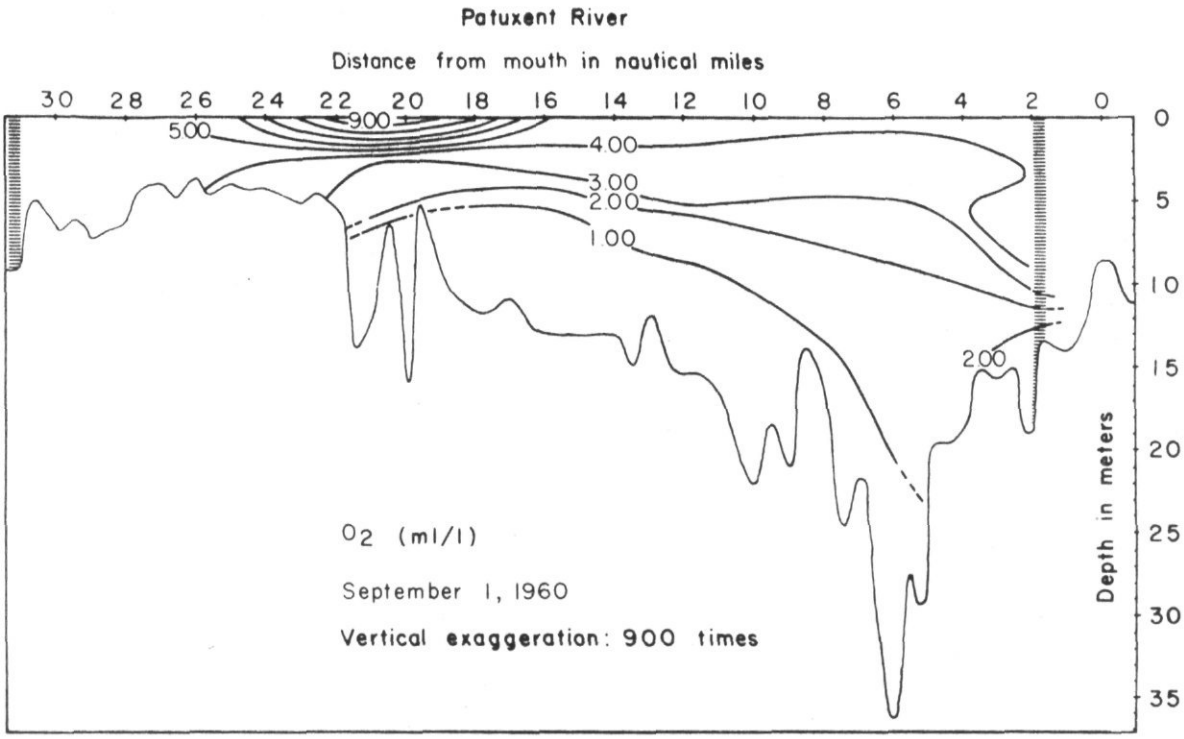

Figure B67. Patuxent River: O_2, Sept. 1, 1960.

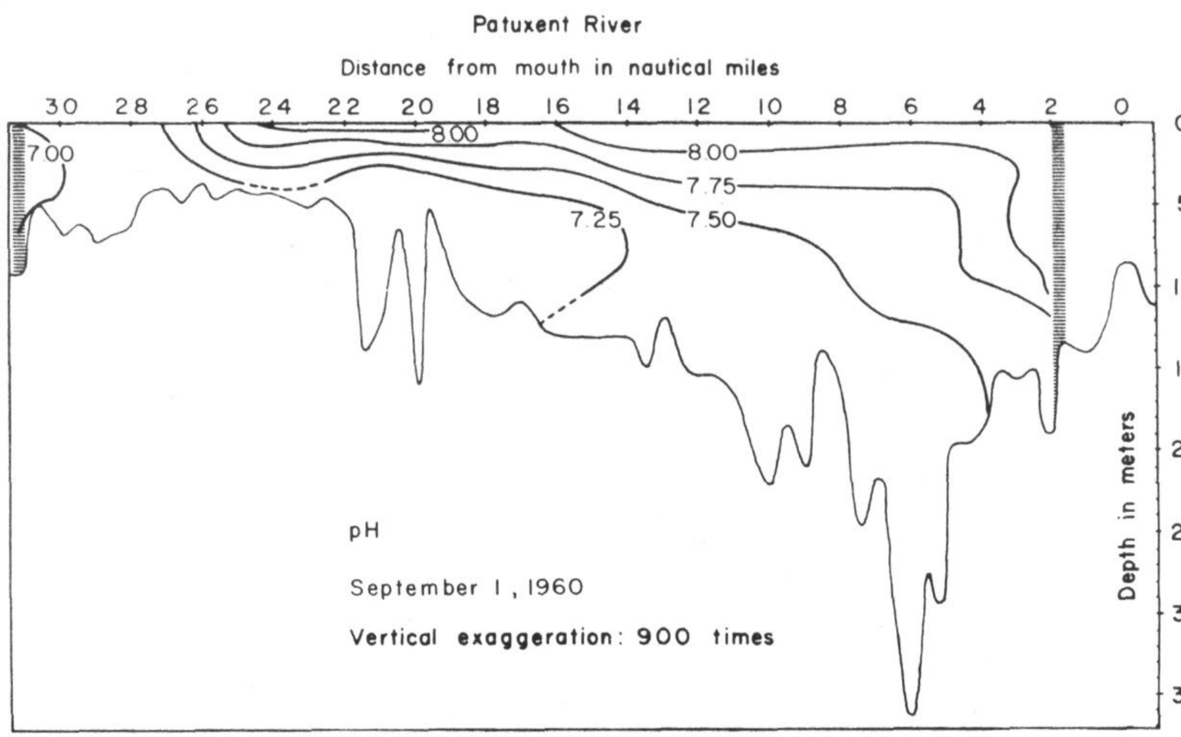

Figure B68. Patuxent River: pH, Sept. 1, 1960.

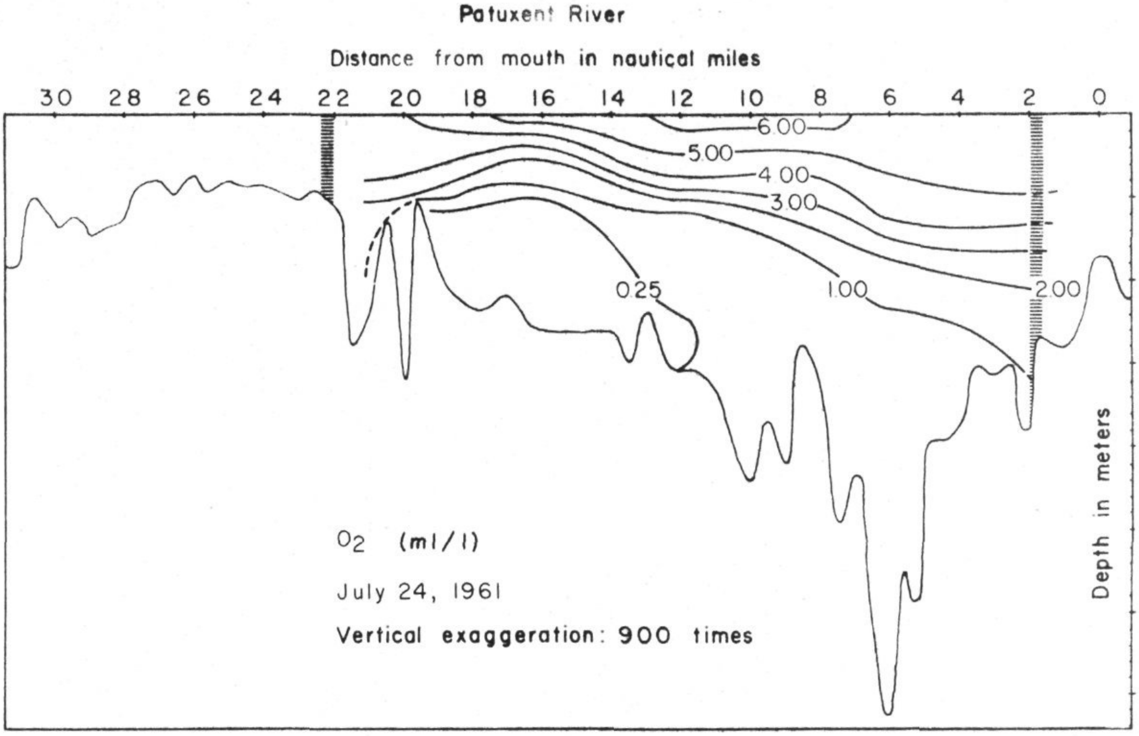

Figure B69. Patuxent River: O_2, July 24, 1961.

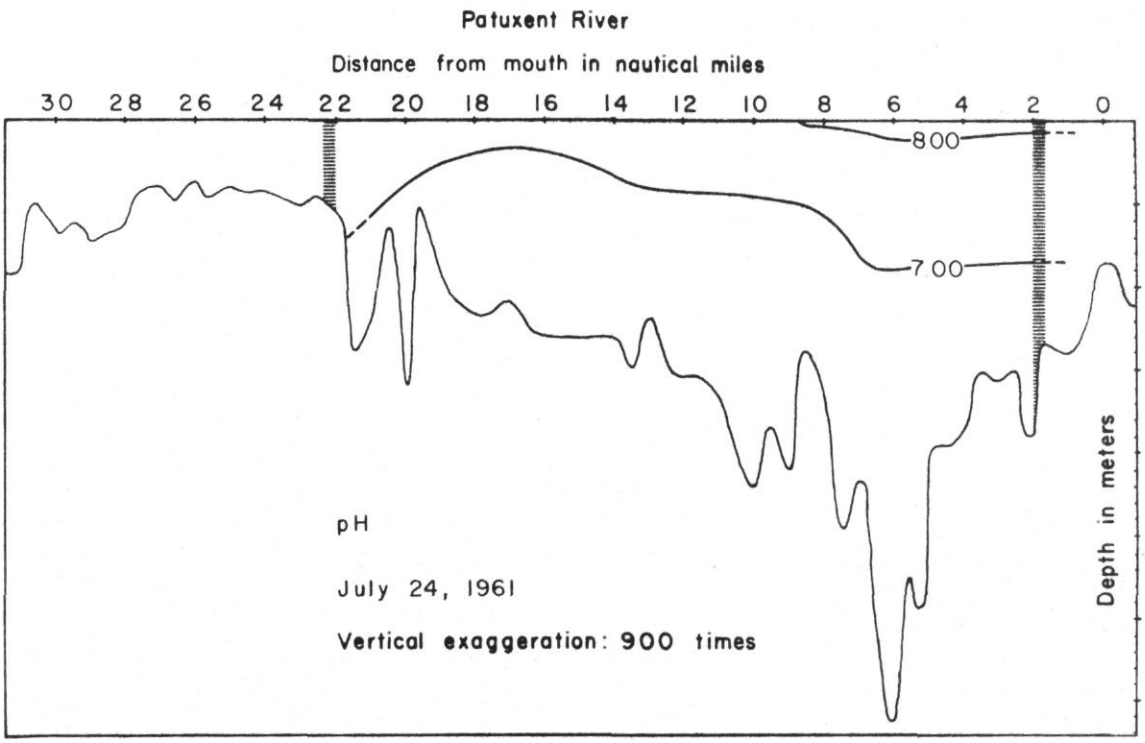

Figure B70. Patuxent River: pH, July 24, 1961.

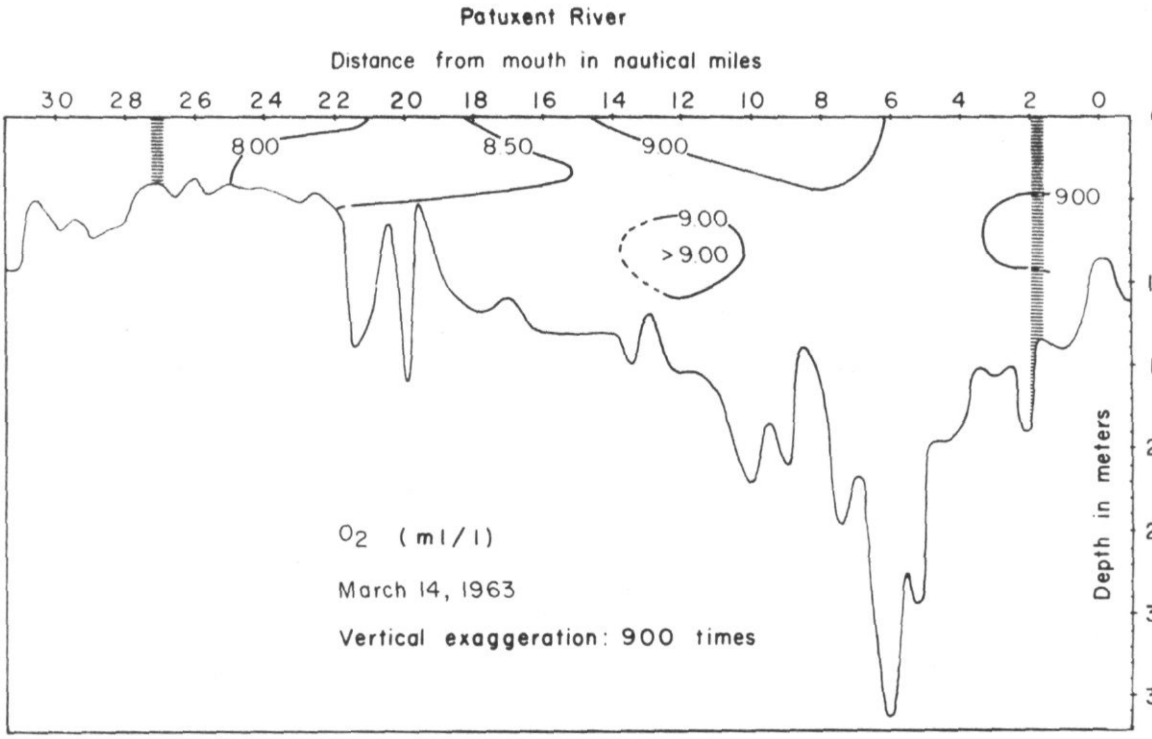

Figure B71. Patuxent River: O_2, March 14, 1963.

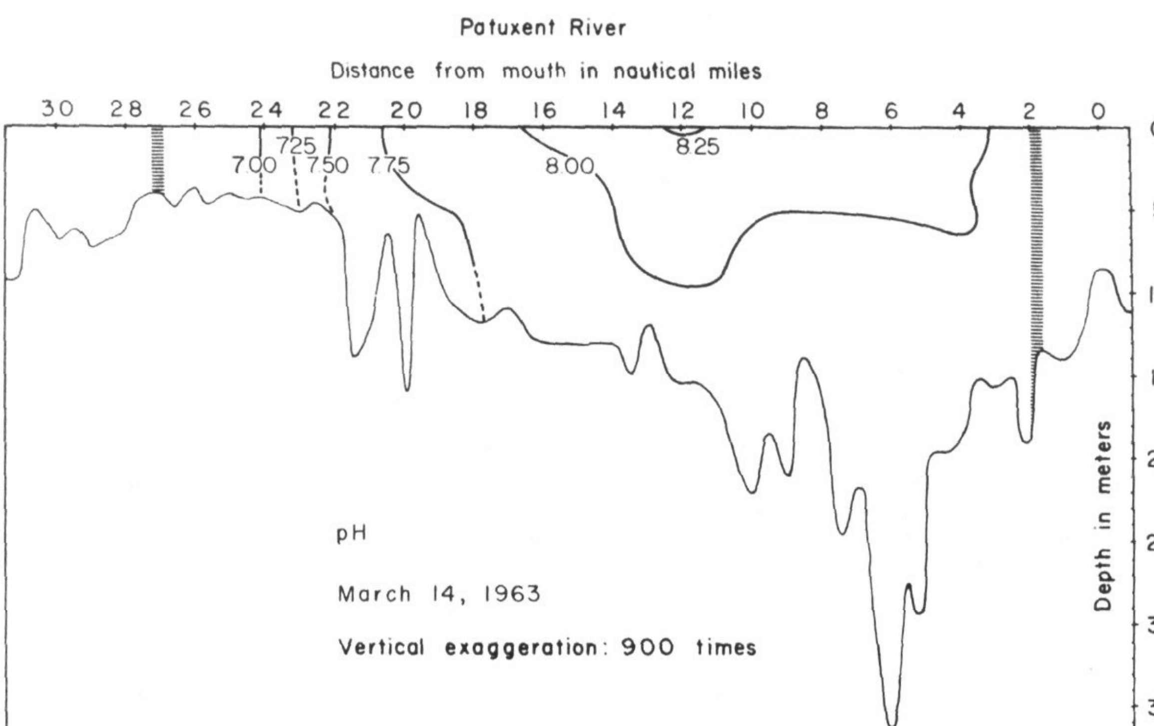

Figure B72. Patuxent River: pH, March 14, 1963.

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Chesapeake Bay Institute The Johns Hopkins University	Unclassified

A study of the physical hydrography of the Patuxent River and its estuary.

Technical Report

Wadsworth Owen

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ABSTRACT

The Patuxent River has the largest drainage basin in the State of Maryland. The estuary of the Patuxent is tributary to the Chesapeake Bay which itself is an estuary. A distinguishing feature of the Patuxent Estuary is its intermittent transition from a two-layer flow system to a three-layer flow system, a transition which occurs most often in the month of April.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
circulation						
net non-tidal circulation						
estuary						
two-layered flow						
three-layered flow						
density flow						
salinity distribution						
pH distribution						
O_2 distribution						
temperature distribution						
Patuxent						
Chesapeake Bay						
Susquehanna						
Flushing						
current measurements						

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