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CURRENT STUDIES
IN THE
PAMLICO RIVER AND ESTUARY

OF
NORTH CAROLINA

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Current Studies in Pamlico River and Estuary of North Carolina

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Summary

1. Three Rhodamine B dye releases were made in the Pamlico River during the summer of 1967. The movement and concentration of the dye was followed in the estuary with fluorometers equipped with flow-through cuvettes and mounted on boats. Inherent errors in the techniques used and in the choice of fluorometer filters reduced the reliability of the fluorometer readings, particularly at low concentrations.
2. Reliable estimates of the size and downstream movement of the dye patch following the last dye insertion was possible. The average net movement of the dye patch was 915 m per day downstream. Concentrations of the dye in the patch indicated that high fluorometer readings far downstream, outside of the dye patch, were caused by background fluorescence and not Rhodamine B.
3. The movement of the dye patch was compared to predicted water movements derived from a tidal prism model of estuarine flushing. Under low fresh water inflow conditions existing at the time of the dye insertion, the predicted average transport for the section of the estuary in which the dye was released was 213 m per day.
4. The tidal prism model was also applied using fresh water volume data representative of average conditions. The model permits the calculation of flushing times and exchange ratios for each segment of the estuary. These values are of considerable importance in predicting the fate of an introduced contaminant. Although the model results do not accurately predict the actual salinity structure or the net downstream movement of the dye, the estimates of exchange

ratios, flushing times and half-life values are believed to be representative for average fresh water volume inflow conditions.

Introduction

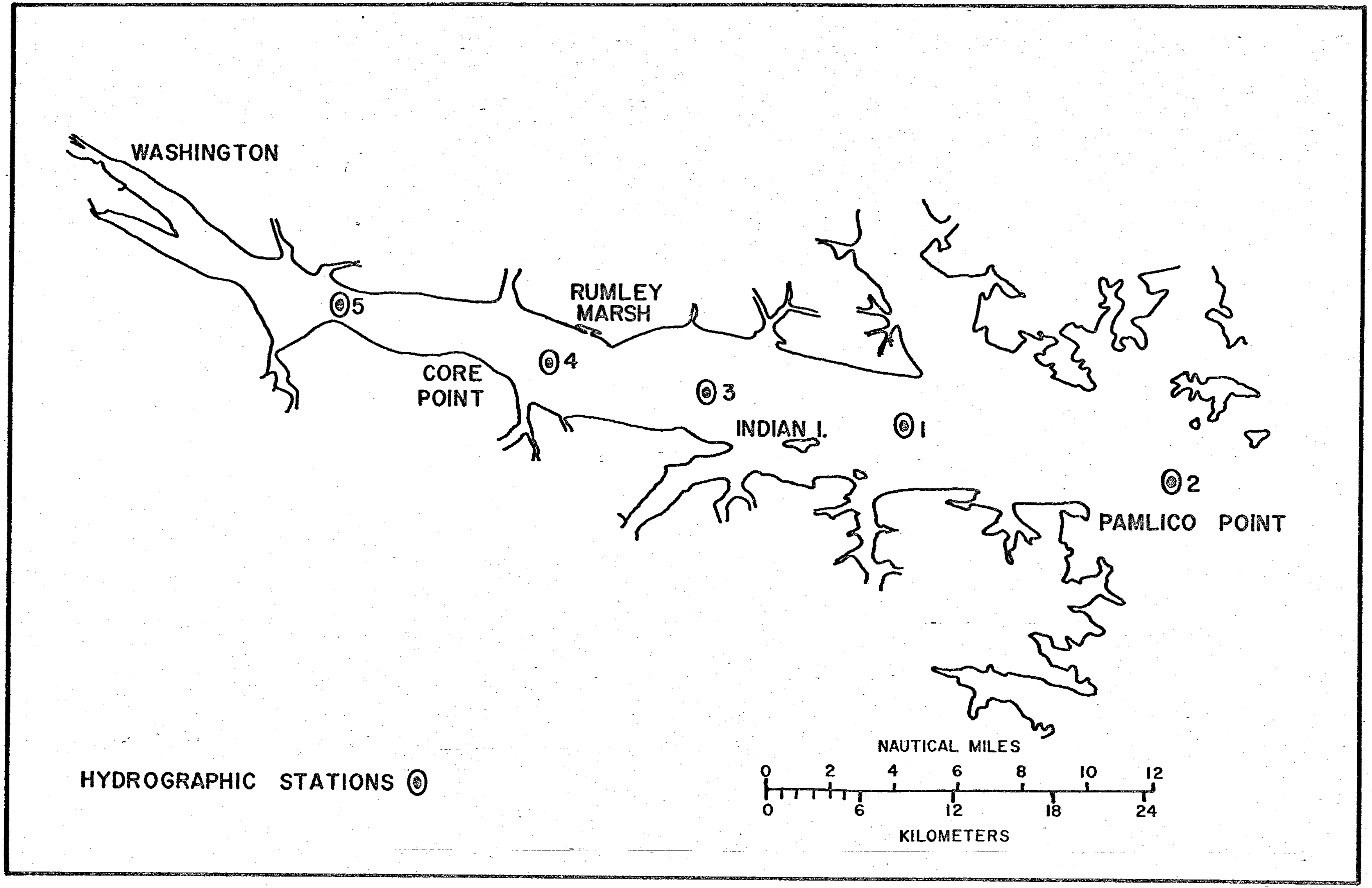
This report is intended to present a brief review of the hydrography of the Pamlico River estuary, North Carolina and to present some results of a dye tracer study conducted during the summer of 1966.

The Pamlico River estuary (Figure 1) runs in an approximate northwest-southeast direction from Washington, North Carolina to the vicinity of Pamlico Point where it enters Pamlico Sound. The estuary tapers gradually landward from a width of about 3.5 miles (5.6 km) at the mouth. Average tidal amplitude is approximately 7 to 9 inches (18 to 23 cm), presumably because of the damping affect of Pamlico Sound. However, wide fluctuations in water depth are related to changes in wind direction and velocity. The estuary is shallow, averaging 7.5 feet (2.3 m) in the upper portion, 10.5 feet (3.2 m) in the central region and 13 feet (4.0 m) in the lower region.

Dye Tracer Study

Rhodamine B has been shown by Pritchard and Carpenter (1960) to be one of the most sensitive and least expensive tags for measuring water mass movements. It is a fluorescent pigment which is relatively resistant to photochemical decay. Maximum absorbancy of Rhodamine B occurs at 550 millimicrons while maximum fluorescence occurs at 580 millimicrons. Chlorophyll and its derivatives are likely to be the principle component of the fluorescence background in tracer studies. However, this error can be eliminated by using filters with narrow absorbancy peaks. Since fluorescence decreases 2.3 percent per degree centrigrade temperature should be monitored continuously while sampling.

Figure 1. Pamlico River estuary between Washington, N. C. and Pamlico Light Station locations are shown and referred to in text.


WASHINGTON
RUMLEY MARSH
CORE POINT
INDIAN I.
PAMLICO POINT
5
4
3
1
2
HYDROGRAPHIC STATIONS ◎
NAUTICAL MILES
0 2 4 6 8 10 12
0 6 12 18 24
KILOMETERS

Two major sources of error must be considered in evaluating the Rhodamine B dye concentrations measured during this study. First dye concentrations were not corrected for changes in temperature. Second, the primary and secondary filters used were not suitable for isolating the Rhodamine B dye for fluorescence spectra. Dr. Woods measured the absorbancy spectra for the filters used and established that both the primary and secondary filters were only marginally effective. There was no transmission through the latter until 520 millimicrons and a plateau was recorded starting at 630 millimicrons. Primary filter transmission peaks were recorded at 418 millimicrons and 550 millimicrons. Rhodamine B fluoresces (maximum) at 580 millimicrons when the secondary filter was transmitting only approximately 25 percent. As has been noted, maximum chlorophyll fluorescence occurs at 650-675 millimicrons, well within the range transmitted by the filter used. Moreover, chlorophyll is excited maximally at about 440 millimicrons which is close to one of the peaks of the primary filters. It is assumed that the high backgrounds which occurred during field sampling were caused by faulty filter selection. Although the background fluorescence usually did not vary more than 4 to 6 fluorometer units ($\pm$ 0.6×10^{-5} mg/L), occasionally it did go much higher. For example, readings on one fluorometer reached 10 fluorometer units above background in Durham's Creek, a small tributary. Usually, background readings increased when proceeding from mouth to head waters of tributaries. A more suitable filter combination would probably have reduced the high background and increased the reliability at low concentrations (Dr. James H. Carpenter, personal communication).

Movement of the dye was detected in the field with a Turner Model 111 Fluorometer equipped with a flow through cuvette. One fluorometer was mounted on each of two vessels. Power requirements were met satisfactorily with a DC to AC power inverter connected to a 12 volt storage battery. Water was pumped to the cuvette through polyethylene tubing threaded through a 1-inch (2.5 cm) pipe to which was attached a small submersible pump. The pump could be lowered to the desired depth and water pumped continuously while the boat was underway at a speed of 8 to 10 knots. There was a 30 second lag between the pump and the time the water reached the cuvette. A time-lag correction was made when the dye concentrations were plotted.

Three dye insertions were made. The first was a small dye release (4.1 pounds, 1.86 kg) in South Creek, a tributary of Pamlico River. This release (May 12-16, 1966) was made to test methods, and to develop ways to fix boat position. Dry Rhodamine B powder was mixed with water from the site of insertion (2% by weight) and siphoned into the river from a 19 L carboy supported by a Coast Guard channel marker. The carboy was refilled at regular intervals and it was assumed that the rate of dye release was approximately 0.8 pounds (0.36 kg) per/24 hours for the 5 day period.

The second dye release was made at a channel marker north of Indian Island (Figure 1). This release was made over a 7 day period from June 28 through July 4, 1966. Dye was mixed with water from the site of insertion and pumped into the river from a 190 L drum fixed to the navigation marker. The pump used was an electric fuel pump powered by a 12 volt storage battery. The rate of dye insertion is assumed to have been 24 lbs. (10.9 kg)/24 hours. A total of 150 pounds (68 kg) of

Rhodamine B was released.

The third dye release was made at Station 5 (Figure 1) starting 1335 August 3, 1966 and ending 1200 August 5, 1966. The dye solution (2.7 kg pounds/170 L of water/2 hours) was pumped into the river from the deck of a vessel anchored near the Mauls Point navigation beacon. A total of 144 pounds (65.3 kg) of the dye was released at a rate of 72 pounds (32.7 kg)/24 hours.

Mechanical difficulties encountered during the first two dye insertions prevented a continuous dye insertion. This uncertainty makes impossible the assumption of even dye distribution. Because of this only data accumulated during the period of tracing of the last dye insertion will be treated.

Results

Reliable estimates of the size and location of the dye patch was possible for the first four days after insertion. Transects were run across and through the patch starting on the last day of insertion, August 5, 1965. By August 9, the concentrations measured did not exceed 5 x 10^{-5} mg/L anywhere in the river from a location 8 km upstream from the site of insertion to 27 km downstream. On August 9 there was a patch of dye at Core Point on the South shore of the estuary, 7 km below the point of insertion. Also, on August 9, 11 and 12, a large volume of water along the North shore of the river, nine to seventeen miles below the point of dye release gave a reading of up to 38 fluorometer units above background. A tracer study during a dye release one month earlier showed very high background readings in the same general area. Fluorescence increased continuously from the mouth of the Pungo River (Figure 1) toward its head.

The boundaries of the dye patch are shown in Figure 2. The average net movement of the patch was about 915 m/day (2 tidal cycles) downstream. Assuming a decay of 5 percent per day, the average concentration of the dye patch should have been about 9.6 x 10^{-5} mg/L on August 8. The patch concentrations averaged 4 x 10^{-5} mg/L. Apparently the large areas of apparent dye far downstream was in fact background fluorescence and not introduced Rhodamine B.

Tidal Prism Model

A tidal prism model was used to estimate exchange rates and predict the half-life of introduced contaminants and to compare these with salinity data and Rhodamine B dye concentrations. The model developed by Ketchum

(1951) was employed. More realistic models have been developed by Arons and Stommel (1951), Pritchard (1954) and Kent (1958) which take turbulent diffusion processes into account. Nevertheless, the simpler model was considered appropriate to make preliminary comparisons with the rather meager amount of data available.

In Ketchum's model, the estuary is divided into a number of volume segments, each defined by an effective mixing length which is equal to the mean distance covered by the flooding tide. The model assumes that mixing is complete vertically, that steady state conditions exist during the time period that the model is applied (nonvariable river flow on tidal prism) and that there are no large lateral differences in salinity. Incomplete vertical mixing can be accounted for in the model by a correction term derived from salinity stratification. When stratification does exist, the model assumes that mixing is limited to the upper layers only and the volumes are computed only to the mixed depth.

Schultz and Simmons (1957) observed that when the flow ratio of a coastal plain estuary (ratio of volume of fresh water inflow during a tidal cycle to the tidal prism) is less than 0.1, the estuary is normally a well mixed type in which vertical salinity differences may be undetectable. During the month preceding the dye insertion in Pamlico River estuary (July 1966), the fresh water inflow averaged $4.2 \times 10^{-5} m^3$/ tidal cycle (9.9 m^3/sec). Assuming an average tidal height of 17.7 cm (a four-month average), the flow ratio was approximately 0.007, and, in fact, the vertical salinity differences were relatively small. Using a stratification parameter S/S_o, where S is the top to bottom salinity difference and S_o is the sectional mean salinity, the ratio ranged from .004

to .08 throughout the length of the estuary on August 1, 1966. Therefore, during this period it was assumed that vertical mixing was complete.

Table 1 compares the salinity values predicted by the model to the observed salinities at four locations in Pamlico River (see Figure 1). The source salinity was assumed to be 18 o/oo based on data collected on August 1 by Dr. William J. Woods. The calculated salinities averaged between 12 and 26 percent higher than observed for most of the estuary which is reasonably good correspondence. The average fresh water input was approximately 42 x $10^5 m^3$/ tidal cycle (99.1 m^3/sec), a value ten times higher than the very low runoff during July 1966. Therefore, a considerable part of the salinity discrepancy between the observed and calculated results was likely due to accumulated fresh water during periods of high fresh water inflow.

The predicted flushing time, defined as the average length of time for the river water to move through all 61 volume segments of the estuary, is 587 days under these low fresh water flow conditions. Average exchange ratios and half-life values for fresh water in the volume segments in four regions of the estuary are given in Table 2. The exchange ratio is the proportion of the river water (or its continued pollution) within a volume segment, that is lost to the adjacent seaward segment on the ebbing tide. The half-life is the time where half of the river water introduced to a volume segment during a tidal cycle has been removed. The predicted flushing time for the section of the estuary in which the dye was released corresponds to an average transport of 213 m per day. The actual net dye movement was about 915 m per day. Therefore the actual flushing time

Table 1. Observed salinities in o/oo in Pamlico River estuary on August 1, 1966; and salinities calculated from the model. Fresh water inflow was 4.2×10^5 m^3/ tidal cycle (9.9 m^3/ sec).

Location	Distance from Mouth (km)	Observed Salinity	Calculated Salinity
Core Point	40.2	8.6	8.1
Rumley Marsh	32.5	9.7	11.7
Indian Island	21.1	10.7	14.6
Pamlico Point	1.6	14.3	16.3

Table 2. Average exchange ratios and half-life values estimated for volume segments within sections of the Pamlico River estuary. Fresh water inflow was 4.2×10^5 m^3/ tidal cycle (9.9 m^3/sec).

Section	Length of Section (km)	Number of Volume Segments	Average Exchange Ratio	Half-life/ Segment (tides)
Washington to Core Point	22.7	28	.099	6.4
Core Point to Hickory Point	16.1	13	.056	12.0
Hickory Point to Wades Point	9.0	8	.048	14.0
Wades Point to Pamlico Point	16.4	12	.042	16.2

during the period of time may have been considerably less than the predicted value. This seemingly large discrepancy is understandable when one considers that the fresh water inflow may have been underestimated (only an average value for the month preceding the dye insertion was used in the calculation), and vertical mixing was assumed to be complete. More importantly, most of the net seaward movement may have been at the surface in spite of the small amount of stratification observed. Hansen and Rattray (1966) point out that the advective (gravitational) component of salt flux is not necessarily proportional to salinity stratification.

The volume segment model was applied to conditions of normal river flow 42 x $10^5 m^3$/ tidal cycle, (99.1 m^3/sec). These conditions reflect the average fresh water inflow for the year, but, of course, do not imply steady state conditions. However, average river flow data for the month of June 1965 did yield this value. Salinities measured on June 28-29, 1965 are given in Table 3 for the stations indicated in Figure 1. A considerable degree of stratification exists during normal to high water inflow conditions. These values are for a particular time and are not time-mean values over a tidal cycle. A smooth line was drawn through the halocline at the five stations, and the volume segment model was applied, assuming complete mixing of the water column above the estimated halocline. The predicted salinities are given in Table 3. In this case the predicted salinities are 22 to 35 percent lower than those observed. The model does not account for two other transport mechanisms that are of considerable importance; wind and diffusion. Wind has been observed to bring about considerable change in water level in the estuary, and therefore, it must be important in salt transport and

Table 3. Observed "mixed depth" salinities in o/oo in Pamlico River estuary on July 28-29, 1965, and salinities calculated from the model. Fresh water inflow was 42 x 10^5 m^3 / tidal cycle (99.1m^3/sec).

Station Location	Distance from Mouth (km)	Observed Salinity	Calculated Salinity
2	1.6	9.29	6.40
1	17.2	6.19	4.00
3	27.4	4.71	3.04
4	37.2	2.46	1.92
5	48.4	1.42	

flushing mechanisms. There are no independent criteria as yet to assess the relative importance of wind stress.

The relative importance of diffusion in upstream salt flux has been determined for several estuaries by Hansen and Rattray (1966). These authors have classified estuaries by two independent parameters when wind stress is not important: a stratification parameter, S/S_o (defined earlier), and a circulation parameter, Us/Uf, where Us is the longitudinal time-mean velocity at the surface and Uf is the integral velocity (R ÷ cross sectional area of the estuary).

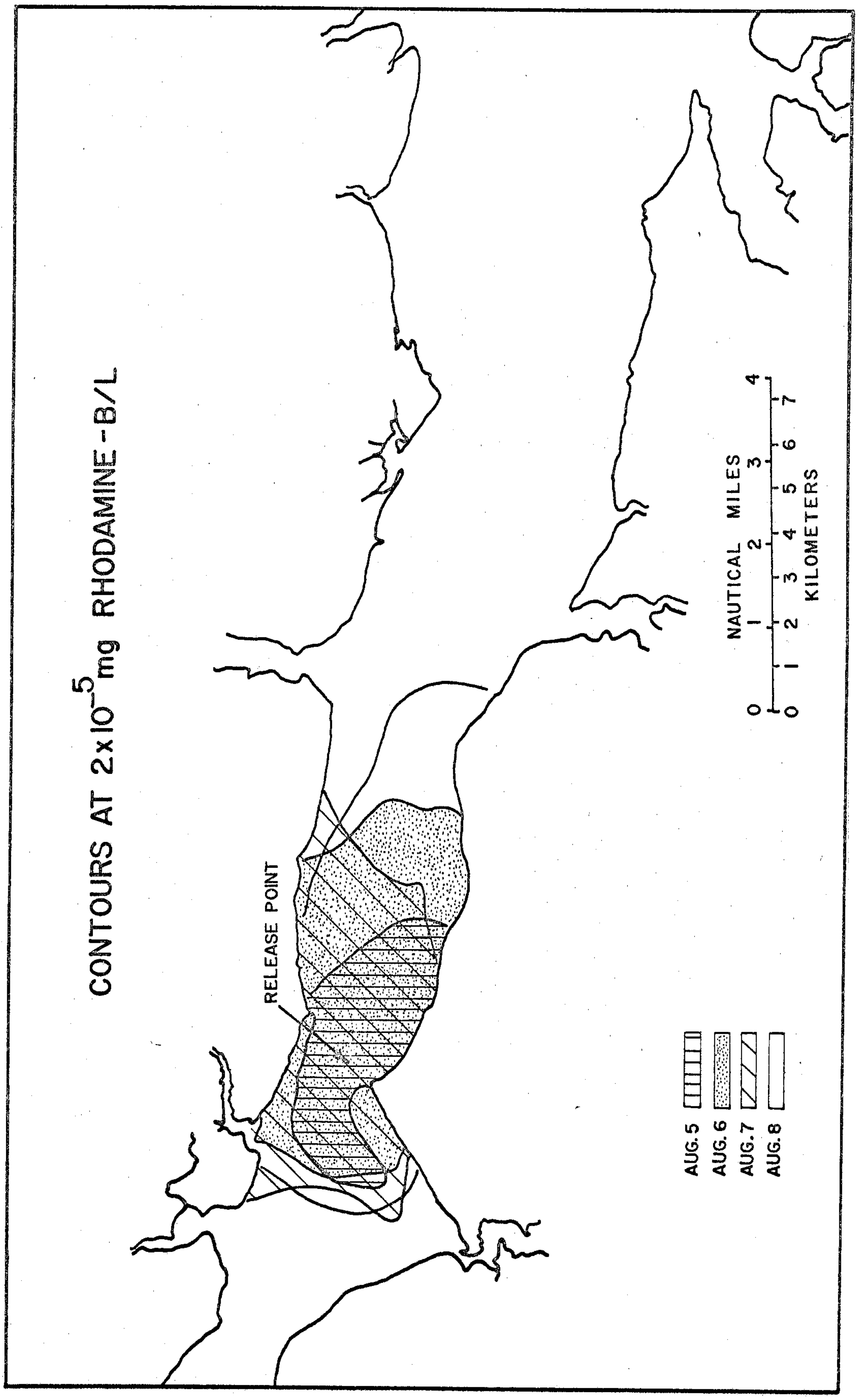
Application of these parameters to the best available information indicates that net flow reverses with depth, and both advective and diffusion contribute importantly to upstream salt flux. The data suggest that the diffusion fraction of the upstream salt transfer is between 0.1 and 0.5 for hydrographical conditions during July, 1965. Therefore, the discrepancy between the observed and calculated values in the volume segment model application may be due to the diffusive salt flux.

The exchange ratios and predicted half-life values for the higher fresh water inflow conditions are given in Table 4. Under these conditions of greater flow and vertical stratification the number of volume segments is reduced, and the flushing time is estimated to be 65 days for the entire length of the estuary. Several sets of water current measurements in the estuary taken over a tidal cycle clearly demonstrated the existence of a two layer transport system. Moreover, the mean current velocities at the bottom corresponded to the length of the volume segments predicted from the model.

Table 4. Average exchange ratios and half-life values estimated for volume segments within sections of the Pamlico River estuary. Fresh water inflow was 42 x 10^5 m^3 / tidal cycle (99.1 m^3/sec).

Section	Length of Section	Number of Volume Segments	Average Exchange Ratio	Half-life/ Segment (tides)
Washington to Bayview	28.0	3	.084	7.9
Bayview to Hickory Point	10.8	2	.082	8.0
Hickory Point to Pamlico Point	25.4	5	.073	9.1

Figure 2. Rhodamine B dye location in the Pamlico River estuary on the first four days after insertion, 1966.



CONTOURS AT 2×10^{-5} mg RHODAMINE-B/L

Conclusions

Clearly, the volume segment model of tidal flushing does not accurately fit the hydrographic characteristics of the Pamlico River estuary. Possible reasons for the discrepancies between observed and predicted values have been cited. Better correspondence was shown for model estimates and observed data during higher fresh water inflow conditions. The estimates of exchange ratios, flushing times and half-life values for the volume segments of the estuary are believed to be representative for average fresh water inflow conditions. The attempt to fit the model to the known parameters of fresh water inflow, basin topography and tidal amplitude gave insight into the relative importance of other important parameters.

Exchange ratios between volume segments of the estuary may be estimated and compared with actual tracer substances (dye, fresh water or industrial wastes). This information can be used to help predict the fate of an introduced pollutant during various fresh water inflow and tide conditions. With more complete data, the relative importance of diffusion and wind transport may be assessed and their role in the dynamics of Pamlico River estuary estimated.

Literature Cited

Aarons, A. B. and H. Stommel. 1951. A mixing length theory of tidal flushing. Trans. Amer. Geophys. Un., 32(3):419-421.

Hansen, D. V. and M. Rattray, Jr. 1966. New dimensions in estuary classification. Limnol. and Oceanog. 11(3):319-326.

Kent, R. E. 1958. Turbulent diffusion in a sectionally homogenous estuary. Tech. Rep. Chesapeake Bay Inst., 16, Ref. 58-1; 86 p.

Ketchum, B. H. 1951. The exchanges of fresh and salt waters in tidal estuaries. J. Mar. Res., 10(1):18-38.

Pritchard, D. W. 1954. A study of the salt balance of a coastal plain estuary. J. Mar. Res., 13(1):133-144.

Pritchard, D. W. and J. H. Carpenter. 1960. Measurements of turbulent diffusion in estuarine and inshore waters. Proc. XII Gen. Assembly, International Un. Geodesy and Geophys. 51(36).

Schultz, E. A. and H. B. Simmons. 1957. Fresh water-salt water density currents, a major cause of siltation in estuaries. Tech. Bull. No. 2, Comm. Tidal Hydraulics, U. S. Army, Corps of Engineers, 28 p.