OBSERVATIONS ON THE SUSPENDED SEDIMENT DISTRIBUTION IN THE HUDSON RIVER ESTUARY

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by

Stacey Seplow
Polgar Fellow

Henry Bokuniewicz
Advisor
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794-5000

Abstract

There is some evidence to suggest the presence of a turbidity maximum near the limit of sea salt in the Hudson River estuary. Observations of the suspended sediment distribution also show a maximum in the turbidity where the salinity range is much higher. The suspended sediment distribution was measured in the lower Hudson River estuary over nine months. A maximum in turbidity near Manhattan was not always observed, but an annual averaged section showed turbidity levels over 40 mg/l decreasing to 15 mg/l upstream to the Tappan Zee Bridge and 5 mg/l downstream to the Narrows. This turbidity maximum was found in a region where the salinity was between 14 and 22 parts per thousand and the average vertical salinity gradient was 7 parts per thousand.

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Introduction

Levels of suspended sediment concentrations in the Hudson River estuary have been measured rarely. There is some evidence (Olsen, 1979 and Arnold, 1982) to suggest that a turbidity maximum exists near the northern limit of sea salt in the Hudson. This limit varies from 20 to 80 km above the river's mouth at the Battery depending on the river's freshwater discharge. Other observations in the lower Hudson River, that have recently been analyzed, also show a turbidity maximum along the Manhattan shoreline (Hirschberg and Bokuniewicz, 1991). We will discuss the occurrence of these features and possible causes, in this article.

Early measurements of suspended sediment concentrations were made primarily to estimate the total sediment load carried by the river. In 1909, Dole and Stabler calculated an annual average value of 17 mg/l from daily measurements 190 km above the Battery. Panuzio (1965) found an annual average value of 33 mg/l from daily samples taken 120 km above the river's mouth. An average value of 33 mg/l was also calculated by Olsen (1979) from samples at a location 30 km above the Battery.

Olsen (1979) also measured tidal and seasonal variations in the suspended sediment concentrations. Suspended sediment concentrations frequently varied over a factor of four near the bottom and a factor of two or three in the surface waters. In the Tappan Zee and Haverstraw

Bay, the concentration appeared to be positively correlated to the wind speed due to local resuspension by surface waves. The seasonal variation in the suspended sediment concentrations was about one and a half times greater than the variation over a tidal cycle.

Five axial transects were included in Olsen's sampling (1979) between October 1975 and March 1977. High concentrations of suspended sediments were generally found in a broad region from the George Washington Bridge to Haverstraw Bay within which the concentrations in isolated samples sometimes exceeded 200 mg/l.

Arnold (1982) sampled the surface and bottom waters at 16 stations on five cruises between October, 1978 and April, 1980. The average suspended sediment concentrations of 182 samples from all five cruises was 30 mg/l ranging from an average value of 17.1 mg/l for the October, 1978 cruise to 37.6 mg/l for the cruise in October, 1979. This material had an average weight loss on ignition of 22% ranging from about 10% to 30%. With the exception of the samples collected in April, 1980, analysis of the samples collected on the other cruises (October, 1978, April, 1979, August 1979, and October, 1979) showed elevated concentrations of suspended sediments near the upstream limit of sea salt at the time. This was between 30 and 80 km from the Battery. The samples were widely spaced, however, and other peaks in the turbidity appeared simultaneously in other places in the estuary. As a result, these observations provide only

modest evidence for the existence of an estuarine turbidity maximum at the limit of sea salt in the Hudson River.

Other samples have recently been reported by Hirschberg and Bokuniewicz (1991). These results will be discussed here in the context of the earlier observation.

Methods

Samples were taken at up to 22 stations along the thalweg of the Hudson River estuary between the Lower Bay and the Tappen Zee Bridge (Hirschberg and Bokuniewicz, 1991). Navigation was done with respect to known landmarks or the locations of navigational buoys; above the Battery horizontal sextant angles were taken.

At each station, approximately 500 ml samples of water were pumped usually from four depths for the determination of suspended sediment concentrations. In the laboratory, samples were filtered completely through preweighed 0.45-micrometer nucleopore filters rinsed with distilled water three times, air dried and dessicated for several days, and weighed to one hundred-thousandth of a gram. Some samples were subsequently reweighed to insure that desiccation had been complete. The pump was onboard and the water velocity in the hose was about 100 cm/sec (Arnold, 1982). The expected maximum settling velocity of suspended particles was about 2 cm/sec so that the flow velocity in the hose was sufficiently high to prevent the fractionation of suspended particles in the hose due to settling. Sufficient time was allowed after pumping was initiated at a particular depth to completely flush the hose. Samples were kept in the dark to inhibit algal growth before processing. Temperatures and salinity were recorded in the field using a Beckman Salinometer. The Beckman Salinometer (Model RS5-3) used a DC Wheatstone Bridge incorporating thermistors to measure water temperature. Conductivity measurements were made with an inductive cell and combined internally with the temperature measurement to display salinity values directly. The nominal accuracy in salinity was ±0.3 parts per thousand and in temperature, ±0.5°C. Values are reported here as recorded with one excess significant figure for the purposes of calculation. In some cases, salinities were determined instead with a refractometer or by silver-nitrate titration. The silver nitrate solution used in the chlorinity titrations was calibrated against IAPSO standard sea water. Uncertainties in the titrated values were ±0.1 parts per thousand.

Results

An averaged salinity section is shown in Figure 1. The study area did not extend to the limit of sea salt; the lowest salinities were about 7 parts per thousand reaching levels of over 29 parts per thousand 60 km downstream. The average salinity distribution shows relatively strong vertical stratification. Salinity differences between the surface and bottom exceeded 3 parts per thousand and reached values as high as about 10 parts per thousand. The strongest stratification was along the Manhattan shoreline.

The averaged distribution of suspended sediment showed a general increase in levels of suspended sediment concentrations upstream from 5 mg/l in the vicinity of the Narrows (Figure 2). A turbidity maximum was found in the vicinity of the George Washington Bridge. At the bottom in this area, suspended sediment concentrations exceeded 40 mg/l. The concentrations decreased downstream to about 5 mg/l at the Narrows and upstream to about 15 mg/l in the Tappen Zee. This feature appeared to be part of a larger turbidity maximum whose structure extended northward beyond the study area but it was most intense along the Manhattan shoreline where the vertical salinity stratification was strongest.

Discussion

These samples offer the best resolution of the turbidity structure in the lower Hudson River estuary and they are consistent with earlier samplings of this distribution (e.g., Olsen, 1979 and Arnold, 1982). There appeared to be a broad turbidity maximum extending from about midway along the shoreline of Manhattan at least into Haverstraw Bay. The highest levels of suspended sediment and the most intense gradients were found in the vicinity of the George Washington Bridge. This feature is not always found, however. Samples taken in May, 1981, for example, showed little evidence of any structure to the turbidity distribution, and the data of earlier investigators seemed to indicate that other areas of elevated turbidity can occur elsewhere in the river at the same time (Arnold, 1982).

There are two principal mechanisms by which turbidity maxima can be formed and maintained in estuaries (Dyer, 1986). Either or both could be active in the Hudson River estuary. First, in many estuaries a residual "estuarine" circulation is superimposed on the tidal stream. The estuarine circulation is characterized by a landward flow of saline bottom water and a corresponding seaward flow of fresher surface water. Near the landward limit of sea salt in the estuary, the flow of bottom water must well up into the surface water. This vertical advection of water inhibits particle settling and maintains elevated levels of suspended sediment concentrations in the vicinity of the landward limit of sea salt. The turbidity maxima in the Rappahannock River and Chesapeake Bay are thought to be formed in this way. Since the gravitational circulation is driven by differences in the water density, the correspondence of the turbidity maximum in the Hudson River with strong vertical salinity gradients may indicate that a residual circulation plays a role in its formation.

Turbidity maxima can also be formed in the absence of residual circulation by asymmetries in the tidal currents. In many estuaries, the flood tide is stronger but of shorter duration than the ebb tide, and the period of slack water at high tide is longer than it is at low tide. The transport of sediment is not linearly related to the water discharge so the stronger flood tide produces a net landward motion of suspended sediment which can settle more easily during the

longer period of slack water at high tide. The Severn and the Gironde river estuaries are examples of estuaries in which this mechanism appears to be the primary cause of the turbidity maximum. The tidal asymmetry in the Hudson River is not as great as it is in either the Severn or the Gironde river estuaries but the tidal discharge in the Hudson is large compared to the freshwater discharge. The fact that elevated levels of turbidity were sometimes found north of the landward limit of sea salt may indicate a tidal mechanism. Tidal currents are active in the River all the way to Albany while the residual circulation driven by saline density differences can only be active in the lower Hudson.

The interplay of these hydrodynamic mechanisms is complicated by the distribution of sediment sources to the suspended sediment distribution. Local resuspension could also produce elevated levels of turbidity or there may be an input of excess turbidity from the Manhattan shore. In addition, there is some evidence to indicate that lateral variations in the levels of suspended sediment are relatively large due, perhaps, to more intense resuspension along the shallow river banks. Lateral advection of turbidity could be influencing the appearance of the maxima. This has been shown to be the case in the St. Lawrence River estuary, but it has not been examined in the Hudson.

Conclusions

The available evidence suggests that the Hudson River estuary has a broad turbidity maximum extending to the landward limit of sea salt but which intensifies in a relatively small area around the George Washington Bridge. The average concentrations of suspended sediment exceed 40 mg/l in this area but individual values can exceed 200 mg/l. The feature, however, is not always well formed. The mechanism by which the turbidity maxima is formed and maintained in the Hudson is unknown. Residual circulation, tidal asymmetry as well as local sources of suspended material and resuspension could all play a role.

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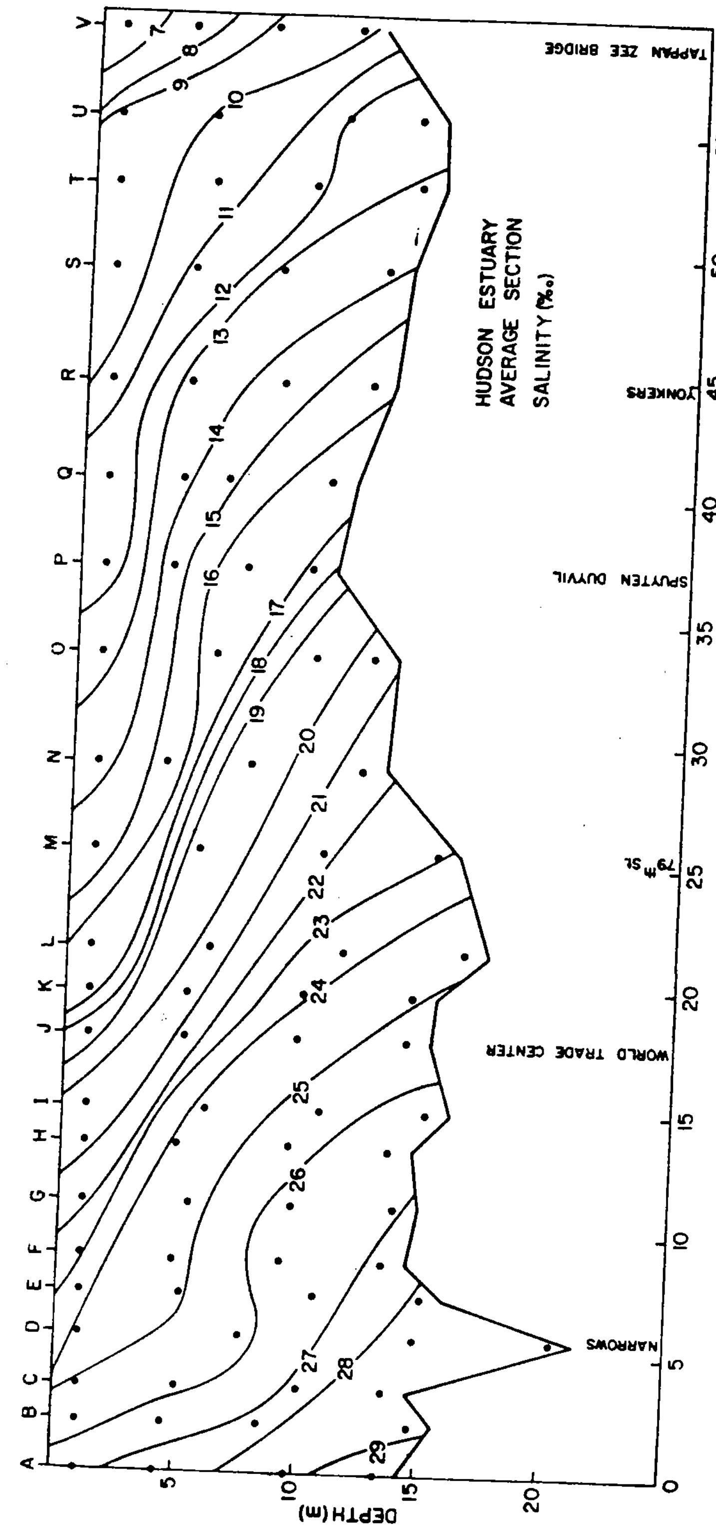

Figure 1. Average axial salinity section.

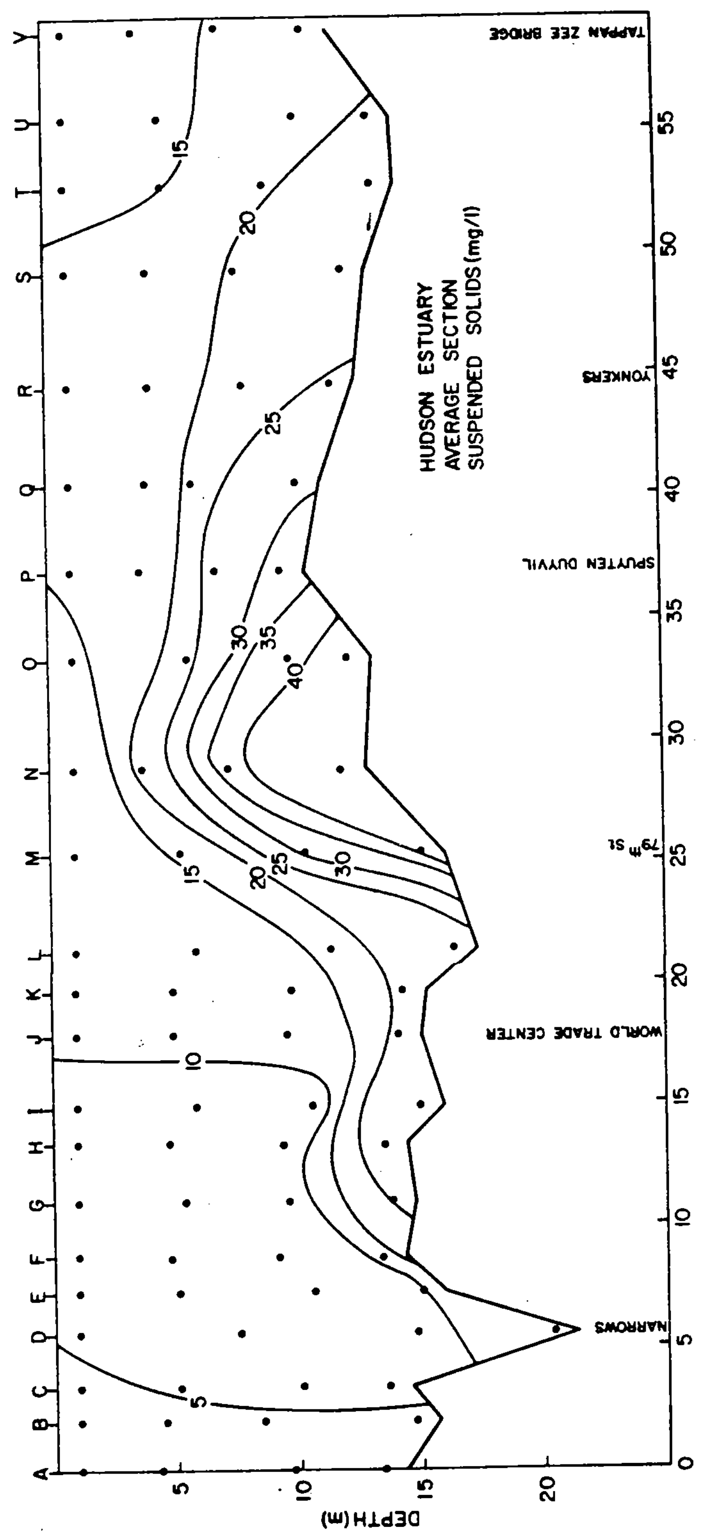

Figure 2. Average axial suspended sediment distribution.