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Effluent travel estimates from ships anchored in Chesapeake Bay : a report to the Virginia State Water Control Board

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A Report
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Virginia Institute of Marine Science
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1. Introduction

As the wotld demand for coal has increased, the number of colliers arriving at Hampton Roads, Virginia, to load coal has exceeded the ability of the port to supply the demand. As a result, a substantial backlog of ships waiting to load coal is presently taxing the anchorage capacity of the harbor. A recent estimate is that 130 ships are waiting about 38 days each for their turn at the loading facilities. In addition to the anchorages in Hampton Roads and the lower James River, new anchorages have been opened to accomodate these ships, one on the southern side of the Chesapeake Bay entrance, off Lynnhaven and the other to the west of Cape Charles. Each of these ships, in maintaining a crew aboard, prodoces waste materials of several varities which are mixed with the water surrounding the vessel as it lies at anchor. In order to estimate the impacts which this effluent may have on the various aspects of Chesapeake Bay, it is first necessary to estimate the motion of the effluents subsequent to leaving their ships. This report, based on previous experimental work in the region, is intended to provide such an estimate.

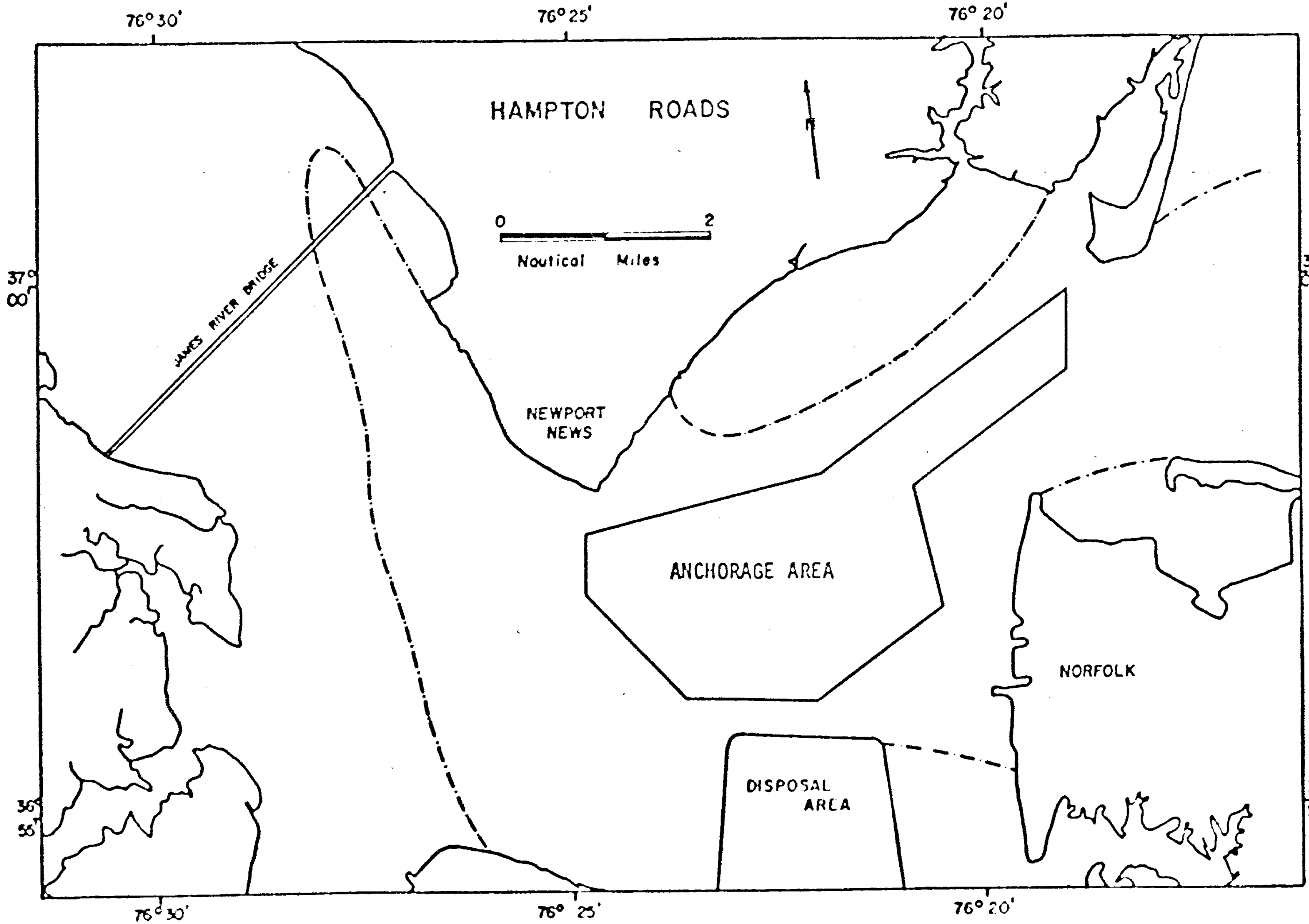
2. The character of currents in the region of interest

The lower Chesapeake Bay and Hampton Roads are both parts of moderately stratified, coastal plain estuaries. The currents which may be expected to carry various materials away from the anchored fleet of colliers are a mixture of tidal currents, estuarine circulation cells, and wind-driven currents. The tidal currents are the strongest, so the areas in question generally experience the semi-diurnal alternation of two ebb, two flood currents each lunar day of 24.8 hours. While this alternating current has the greatest strength, it produces no net flow. Over a time period of several days, weaker parts of the total current account for the greatest part of the total motion of water which has originated at a given point. These portions, the estuarine and wind-driven parts, then become responsible for the ultimate destination of the effluent from the anchored ships. The estuarine flow, relatively slow and steady, varies over periods of weeks in response to variations in fresh water flow from the rivers debouching into Chesapeake Bay. The wind-driven flow, particularly near the surface, responds within hours to changes in the local wind. As a result, it can be predicted, or charted, only to the extent that the local wind can be predicted - generally only a few days ahead at best. Because of the variety of driving agents, the charts prepared for this report are of three kinds: Tidal Excursion Estimates, Mean Surface Current Estimates, and Wind-Driven Current Corrections. The Tidal Excursion Estimates are prepared separately for Hampton Roads and the Lower Chesapeake Bay. A chart for mean surface circulation is prepared only for the Lower Chesapeake Bay, a single estimate being prepared for Hampton Roads. Finally, wind correction magnitude vectors are added to the Tidal Excursion Estimate Charts so that the wind component can be included as needed.

3. Tidal Excursion Estimates

The estimates for tidal excursion are shown for Hampton Roads in Figure 1 and for the lower Chesapeake Bay in Figure 2. In figure 1, the limits of the anchorage area were estimated from anchorages for large vessels marked on Chart C&GS 400. The limits for the tidal excursion were obtained from data and analyses in Neilson (1975), Welch and Neilson(1976), Fang (1972), Kuo and Jacobson (1975), and Munday, et al(1975). The significance of the limit attained during one tidal cycle is that within this area, effluent from the anchorage

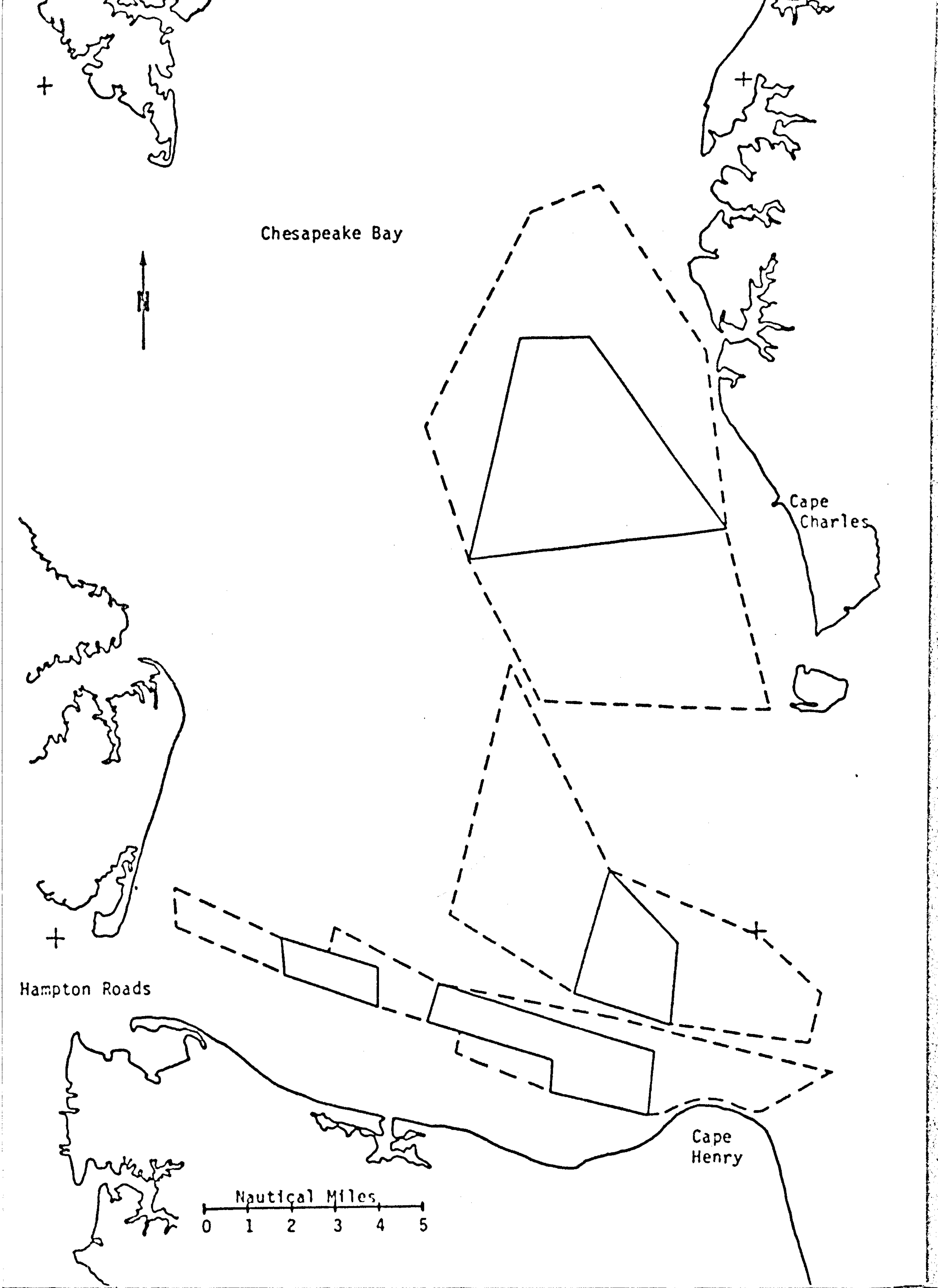
Figure 1. Tidal Excursion Limits for the Anchorage in Hampton Roads. The dashed line shows the limit which can be reached within a period of 6.2 hours for water passing ships within the indicated anchorage. Such water is not expected to pass these boundaries for another 12 hours.



Dashed line corresponds to maximum surface excursion during one tidal cycle area can be carried by the high speed tidal current. Thus, within the maximum excursion area, relatively new effluent (less than 6.2 hours after discharge) can be found. Outside of this area, effluent must be carried by the generally slower estuarine or wind-driven currents, and thus can be expected to be older. Indeed, material should not cross the dashed limit until nearly 18 hours have elapsed since discharge. On figure 1, it is seen that the western shore of the James River, the Hampton Flats region and much of the Elizabeth River are outside the area where new effluent is expected to be found.

In the lower Chesapeake Bay, the amount of analysis that has been done is much less than in Hampton Roads. Hence, a more formal analysis was undertaken, the results of which are presented in Figure 2. In this figure, the southernmost anchorages were obtained from the 1979 issue of the United States Coast Pilot (NOAA/NOS, 1979). The listings for the new anchorages were not given in this document, so they were estimated from personal observations of the waiting coal fleet and informal reports. They are subject to error for this reason, although we believe them to be substantively correct. The currents applied to these anchorage positions are obtained by interpolation of values in the Tidal Current Tables (NOAA/NOS, 1981) to the positions of the corners of the estimated anchorages. Except near Cape Henry, where a curve was required to keep the calculated effluent from crossing a land boundary, the resulting estimates seem not to be subject to substantial error due to curvature of flow, for the scale of the changes in the flow pattern appears to be larger than the calculated excursions. The excursion calculations were made for mean tidal conditions. If they are applied to spring or neap tides,

Figure 2. Tidal Excursion Limits for the Anchorages in the Chesapeake Bay Entrance. The dashed lines show the limit which can be reached within a period of 6.2 hours by water passing ships within the indicated anchorages due to tidal motion alone. Such water is not expected to pass these boundaries for another 12 hours. The anchorages are shown as enclosed solid lines



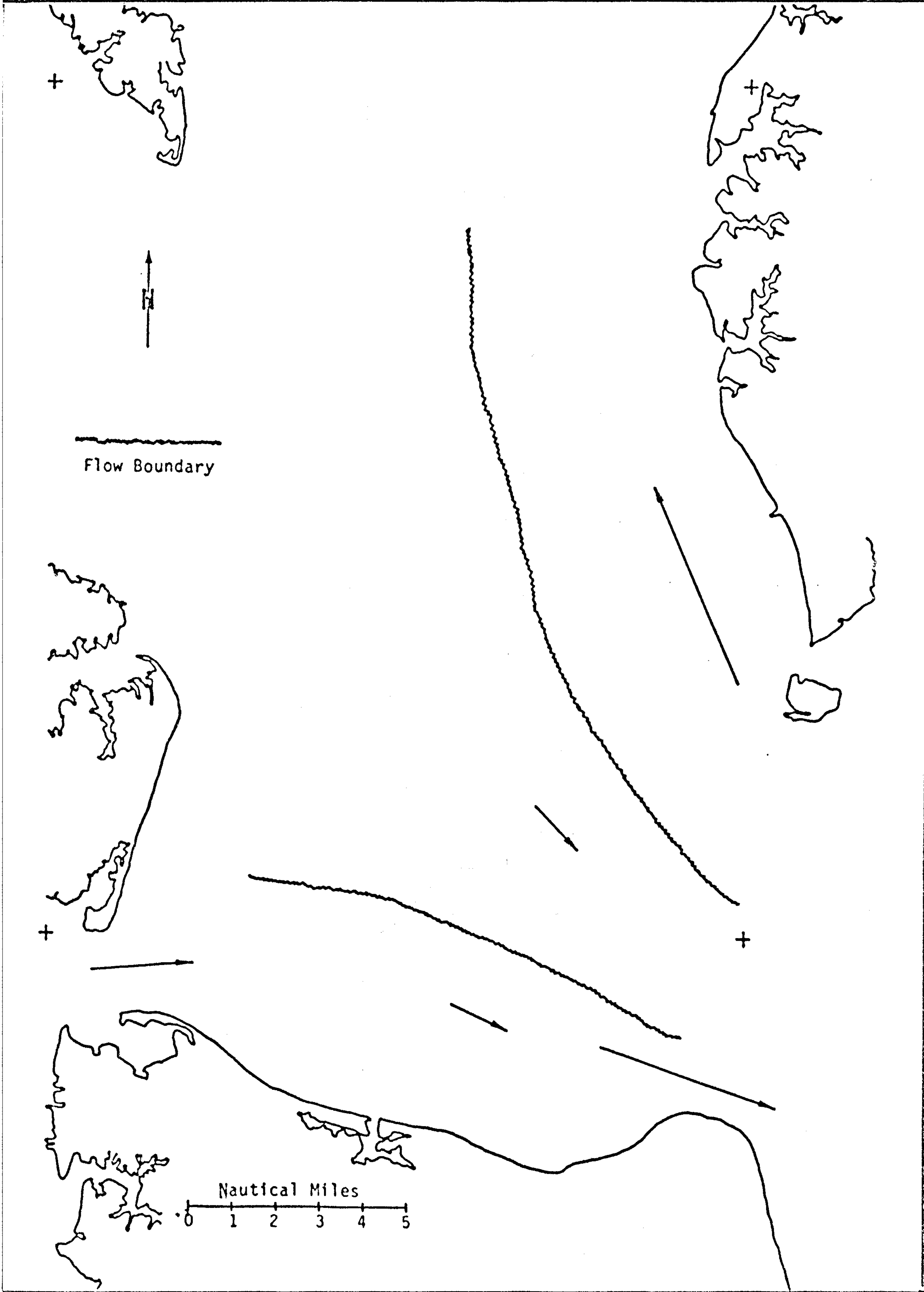
Chesapeake Bay
N
Cape Charles
Hampton Roads
Cape Henry
Nautical Miles
0 1 2 3 4 5

they should be adjusted accordingly.

4. Mean Current Estimates

Estimates for mean values of surface currents in the study area are not so plentiful as those of tidal currents. This is because difficulty of measurement increases and user interest decreases in proportion to the amount that the mean values are smaller than the tidal velocities. The estimates which have been made are presented as excursions over a period of 24 hours in figure 3. In this figure, a surprisingly large inflow is estimated as the average current in the northern part of the Bay entrance. This value is an intermediate value from those reported by Mason (1970) for bottom currents in the northern Bay entrance. The rationale for applying bottom measurements to surface currents, in spite of the qualitative warning given by Mason (1970) is that Boicourt (personal communication) has reported that the major stratification leading to estuarine circulation breaks the surface in the lower Bay. The author has also noticed on several occasions that the water on the northern part of the Bay Entrance is frequently less turbid than that to the south, suggesting an oceanic origin. The flow boundary indicated for the northern part of the Bay is placed where the the estuarine pycnocline is supposed to break the surface. To the south, mean speed estimates are constructed by attributing the difference in mean flood and ebb speeds in the Tidal Current Tables to a mean current, rather than tidal asymmetries. For the mouth of the James River, a value from among those in Nichols (1975) is chosen. The southern of the two flow boundaries is placed where a color boundary is frequently seen in aerial photographs of the Lower Chesapeake Bay. It distinguishes water originating in the James River from that of more northerly sources.

Figure 3. Mean Currents and Flow Boundaries in the Lower Chesapeake Bay. Flow boundaries between entering and exiting water as well as between James River water and Bay proper water are indicated. The arrows represent excursions of water in a period of 24 hours.


N
Flow Boundary
Nautical Miles
0 1 2 3 4 5

5. Wind Driven Currents

The estimate of wind driven currents has been taken from Kiley (1980), who worked on wind-driven currents in the York River. He found that the surface current in the York tended to travel in the direction of the wind at a speed of 2.4% of the wind speed. Other estimates of wind-driven currents have obtained values of 3%, but Kiley was working in a coastal plain estuary rather than in the open ocean, so the lower value is plausibly more applicable to the study region. Even with the lower value of wind-driven current, the importance of wind is shown in figures 4a and 4b, for which wind excursions are estimated for comparison with the Hampton Roads and Chesapeake Bay Entrance charts respectively. The lengths of the wind correction arrows are the excursions due to wind driving which are expected over a period of 12 hours, a period over which the wind may frequently be nearly constant.

To illustrate the affect which winds can have on the spread of effluent originating from one of the anchorages, the tidal excursion limits have been widened by the 12 hour wind excursions in figure 5a for Hampton Roads and 5b for Chesapeake Bay Entrance. The wind speed used in the example is 10 knots and the direction has been chosen to give the largest travel in each direction. In the case of Hampton Roads, the maximum excursion area is increased to include nearly all of the area, while for Chesapeake Bay Entrance, the excursion region becomes continuous across the Bay mouth.

6. Summary and Conclusions

Estimates of excursions which might be made by effluents released from colliers waiting to load coal at Hampton Roads show that tidal alternating currents, estuarine circulation currents and wind drift currents can all play a role in determining the locus at which environmental impact might occur. Charts are provided from which estimates can be made in particular cases.

Figure 4a. Distances of wind-driven excursion in a period of 12 hours. Distances shown are comperable to those in Figure 1 for the indicated wind speeds

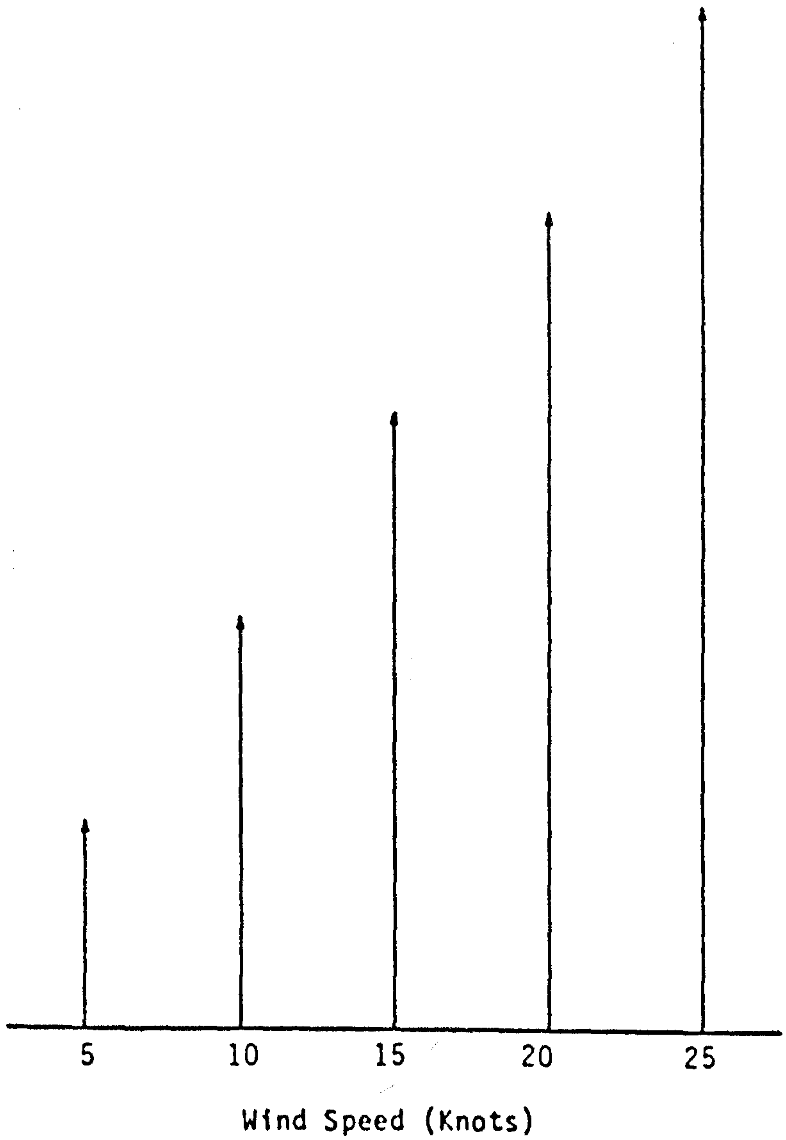


Figure 4b. Distances of wind-driven excursion in a period of 12 hours. Distances shown are comparable to those in Figure 2 for the indicated wind speeds.

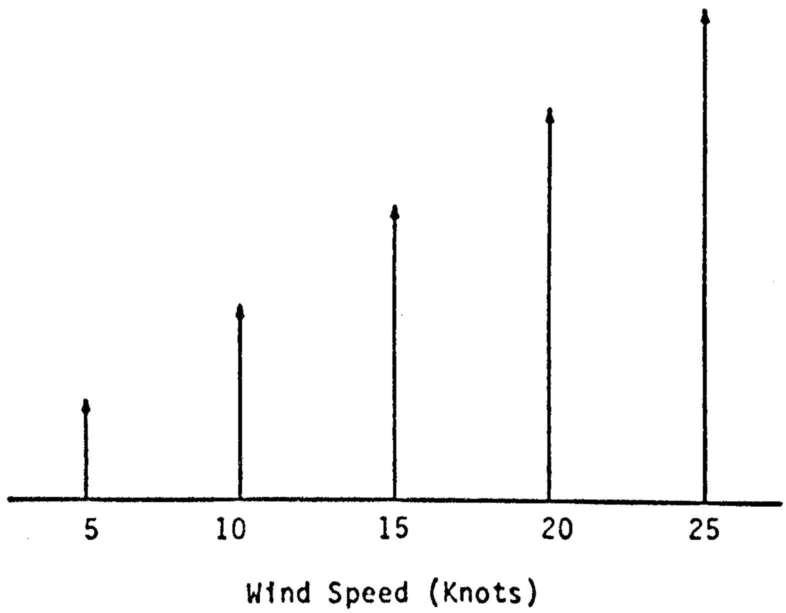
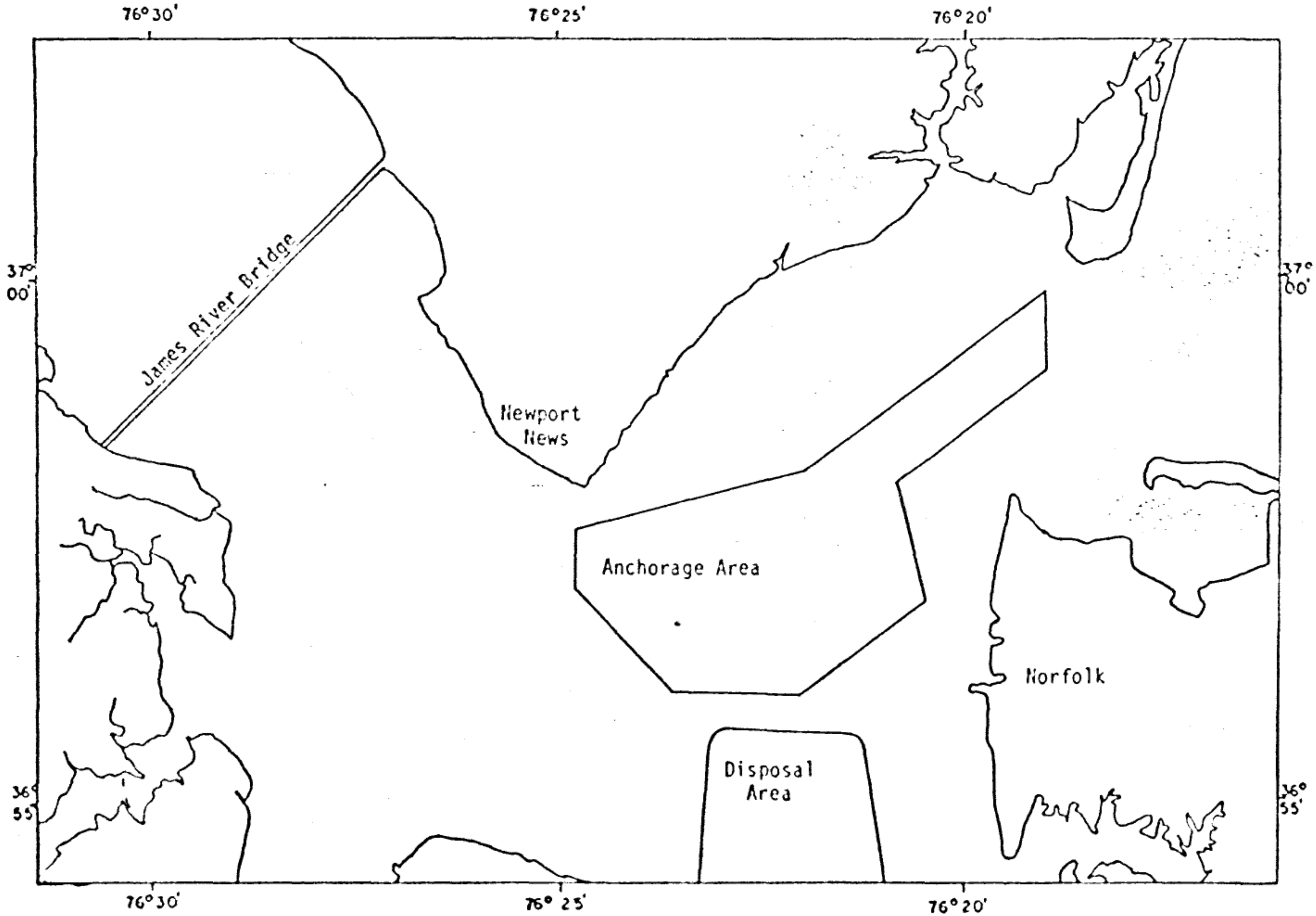
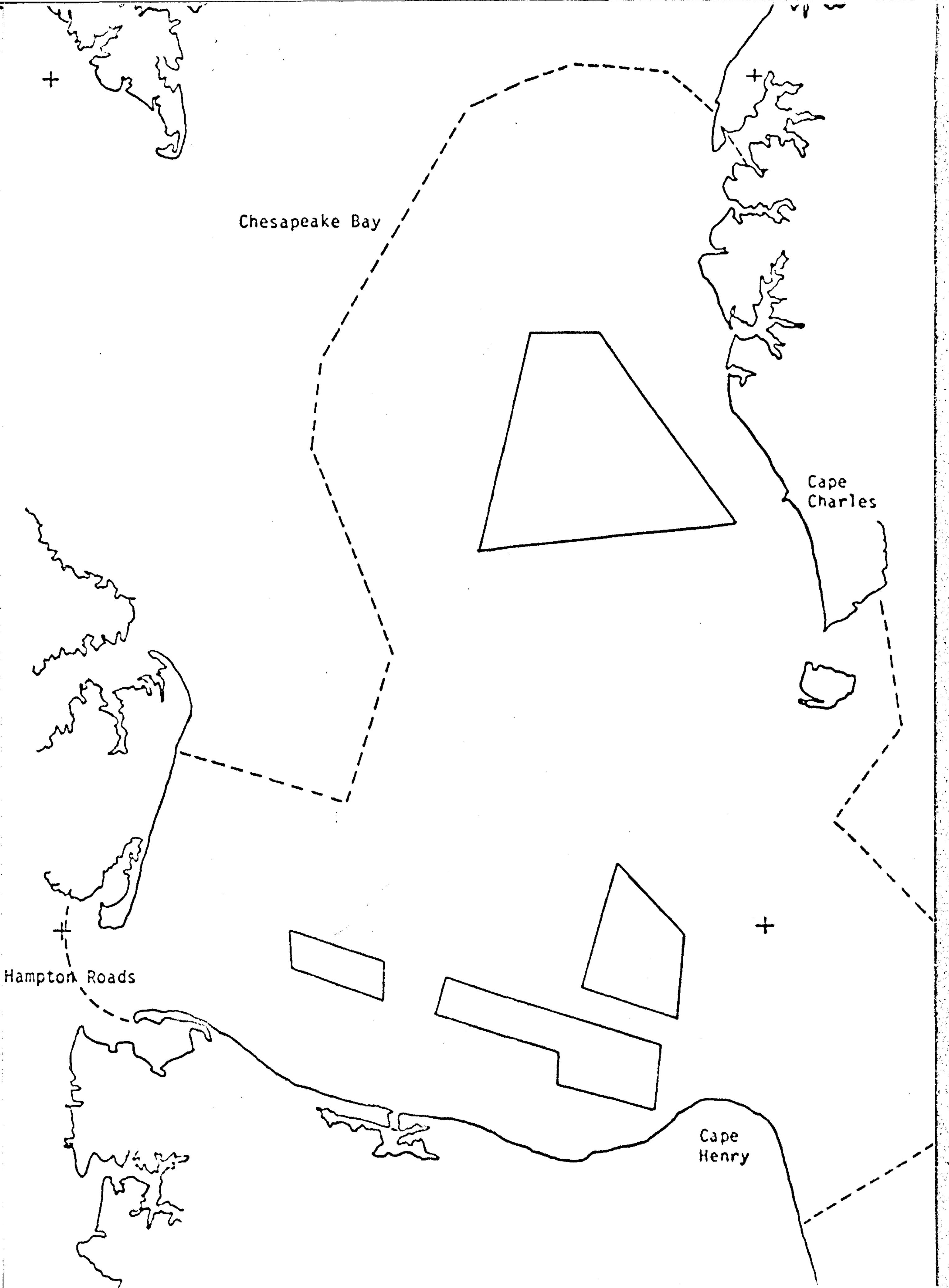


Figure 5a. Boundary of maximum excursion of water originating in the anchorage due to the maximum tidal excursion and a 10 knot wind from the worst case direction for a period of 12 hours in Hampton Roads. Note that nearly all of the area of Hampton Roads lies within the boundary.



76°30'
76°25'
76°20'
James River Bridge
Newport News
Anchorage Area
Norfolk
Disposal Area
37° 00'
36° 55'

Figure 5b. Boundary of maximum excursion of water originating in the anchorages due to maximum tidal excursions and a 10 knot wind from the worst case direction for a period of 12 hours in the Chesapeake Bay Entrance. The zone of possible impact in this case lies across the entire Bay mouth.



Chesapeake Bay
Cape
Charles
Hampton Roads
Cape
Henry

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