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A hydrographical and water quality study during the construction of second Hampton Roads bridge-tunnel

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A HYDROGRAPHICAL AND WATER QUALITY STUDY DURING THE CONSTRUCTION OF SECOND HAMPTON ROADS BRIDGE-TUNNEL

by

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A REPORT TO

VIRGINIA DEPARTMENT OF HIGHWAYS

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CHAPTER 1. SUMMARY AND CONCLUSIONS

1. The circulation in Hampton Roads shows a right-handed dominance: currents are stronger and the flow is greater on the northern side of the channel during flood and on the southern side during ebb. The proposed tunnel-islands will tend to enhance this effect. Flood currents between Newport News Middle Ground and Point will probably increase but the total flow should remain nearly constant. The southern tunnel island is expected to deflect the ebb flow so that both the current speed and the total flow in the natural channel should increase during ebb tide.

2. Strong currents may develop in shallow water, but currents are normally stronger in deeper waters. The flows from shallow areas are sharply deflected when they merge with flows down deep channels. The flow from Hampton Flats during flood tide will probably "spill" over Newport News Bar in a general fashion, but the converging flow could relocate from the existing secondary channel to a new entrance channel for the Small Boat Harbor.

3. Seasonal and yearly variations in the concentration of dissolved oxygen are on the order of several milligrams per liter of DO. The results of water quality monitoring during dredging activities for the second Hampton Roads Bridge-Tunnel indicated that the changes due to the construction were smaller than those which occur naturally. Therefore, from the point of view of dissolved oxygen water quality standards, there appears to be no problem resulting from such dredging activities. It is likely that this is the case because of the many safeguards and precautions taken during construction. It is recommended that these same measures be taken during construction of the I-664 project since they appear to have been effective.

CHAPTER 2. INTRODUCTION

In 1972 studies were conducted to determine the environmental impact of a third crossing of Hampton Roads, a bridge-tunnel connection designated as part of Interstate Highway 664. At the same time, construction had begun for a second bridge and tunnel to parallel the existing Hampton Roads Bridge-Tunnel which was to be incorporated into the Interstate system as I-64. Because this project was only in the initial stages, it was recommended that an evaluation of I-64 be made in order to make recommendations for the design of and construction methods for the I-664 bridge-tunnel. This study deals with the water quality impact of I-64 construction activities and modifications to the circulation due to tunnel islands. The proposed alignment of I-664 and the existing I-64 corridor are shown in Figure 1.

The Hampton Roads Bridge-Tunnel crosses the James River at its mouth, from near Old Point Comfort on the north, past Fort Wool on the southern side of the navigation channel, to the tip of Willoughby Spit. Due west of Willoughby Spit is Sewell's Point, the reference tide station for this region.

The proposed route for I-664 is to leave the Peninsula from the western side of the Small Boat Harbor at Newport News Point, with the southern tunnel island to

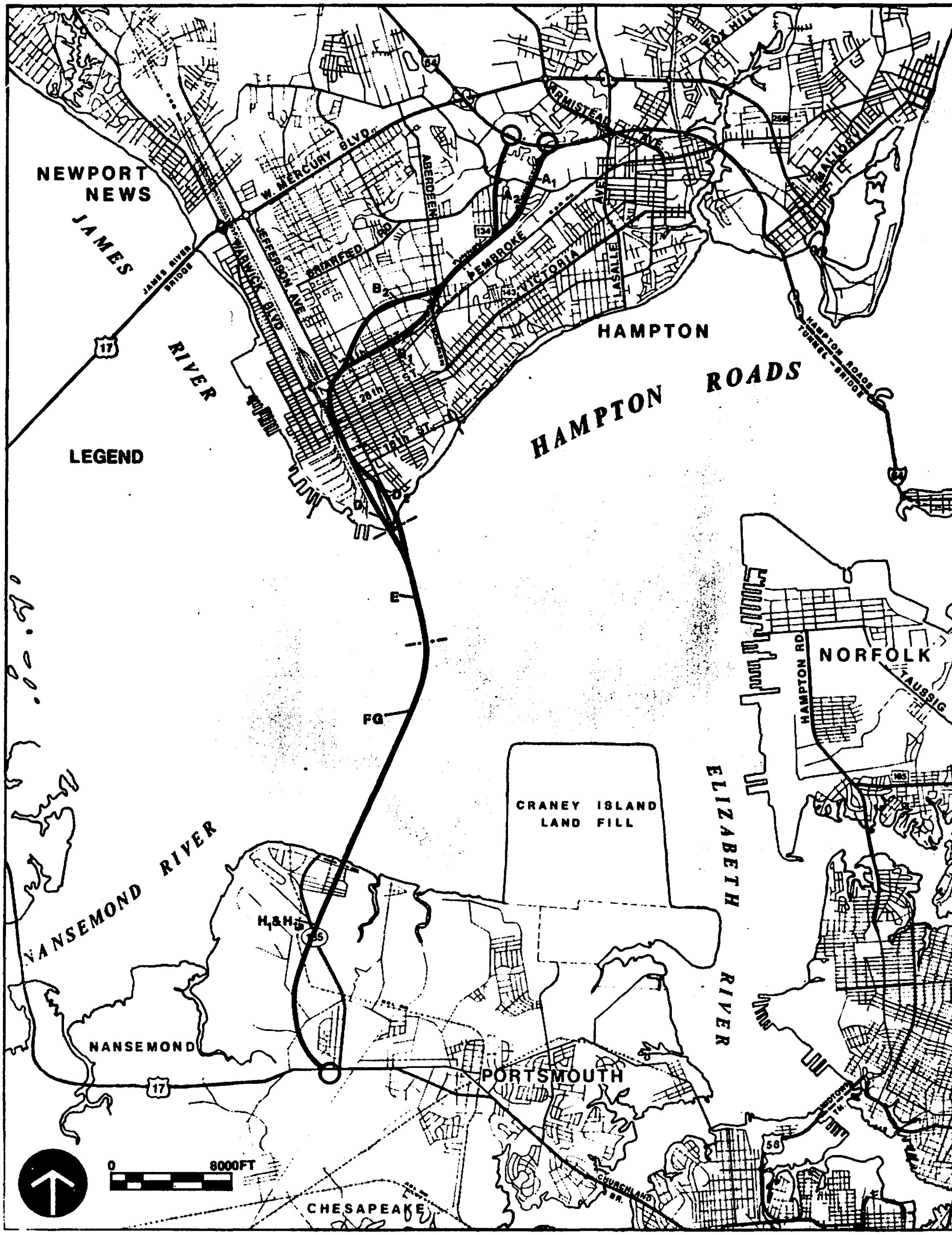


Figure 1. The Hampton Roads area showing the two bridge-tunnel crossings. (From McGaughy, Marshall & MacMillan: Sverdrup & Parcel, 1972).

be northwest of Newport News Middle Ground. The bridge would follow a more or less southwesterly course, passing about a mile to the west of the Craney Island Disposal Area and reaching land approximately a mile east of Pig Point at the mouth of the Nansemond River.

The following chapters will present a description of the hydrography of Hampton Roads, the results of current measurements in the immediate vicinity of the I-64 tunnel islands, and finally, the water quality survey of the I-64 construction.

Current and salinity data which have been reviewed are from a series of Coast & Geodetic Survey studies and VIMS-Physical Oceanography surveys. Model data were collected in the James River Hydraulic Model housed at the Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi. Additional current measurements and water quality samples were made during 1973 and 1974. A more complete,comprehensive and detailed discussion of the circulation in Hampton Roads is contained in Volume 2 of the Virginia Institute of Marine Science--Special Report in Applied Marine Science and Ocean Engineering No. 86.

CHAPTER 3. HYDROGRAPHY OF HAMPTON ROADS

Factors Affecting Tidal Currents

Some of the more important variables affecting tidal currents are freshwater flow, tides and winds. Each of these will be discussed briefly followed by a description of circulation in Hampton Roads.

Freshwater Inflow

The freshwater flow of the entire James River cannot be known precisely since there is no way to gauge the flow in the tidal portions of the river. However, there are methods to estimate the total freshwater inflow. For the James proper, the most downstream gauging station is at Richmond just above the fall line. The long term (37 year) average flow is 7108 cubic feet per second (cfs). If it is assumed that the same ratio of runoff to drainage area is maintained in the estuarine portion of the river as well, then the total freshwater flow of the James is around 11,000 cfs.

The average intertidal volume for the James River has been calculated to be 108 x 10^8 cubic feet (ft^3) (Cronin, 1971). If an average velocity is calculated by dividing this volume by half a tidal cycle (6.4 hours), the flow is 467,000 cfs. If, on the other hand, the flow is assumed to be sinusoidal the maximum flow rate is 736,000 cfs. The obvious conclusion then is that the freshwater flow will normally have little direct effect on tidal currents, since the freshwater flow is only a few percent of the tidal flow. This will not hold true for abnormal conditions like floods, when the freshwater flow is of the same order of magnitude as the tidal flow. For example, during Hurricane Agnes in 1972 the flow at Richmond reached a maximum of around 300,000 cfs. For cases such as these, the freshwater flow will have a direct effect on the currents in the estuarine portion of the river.

In summary, for average conditions the freshwater flow is very small relative to the tidal flows, and therefore has little direct effect on estuarine circulation. Freshwater flow, however, does greatly influence the salinity regime and therefore indirectly has a large effect on circulation. This will be discussed in later sections.

Tidal Height

Changes in tide range, i.e., the distance between high water and low water elevations, change the intertidal volume and therefore the flux of water through the estuary due to tides. As such, it is bound to have an effect on tidal currents and circulation patterns.

Variations in tide range are related to position on the earth and the astronomical forces which cause the tides. For Hampton Roads, the tides are semi-diurnal or twice a day. Successive tides normally show a measurable difference in range and elevation of low and high waters; whereas, alternate tides are more similar. This is referred to as the diurnal inequality, which is related predominantly to location on the earth, and in particular, latitude. The movement of the moon about the earth causes a cyclical variation in the magnitude of the tides that occurs in a sinusoidal fashion with a period of roughly 14 days. At Sewell's Point, the reference station for the region, the average tide range is 2.5 feet. At spring tide the range is 3.0 feet and at neap tide the range is only 2.0 feet. It is clear that the increase in tide range from neap to spring tide is significant and must be accounted for when studying tidal currents.

Data from a 1951 Coast & Geodetic Survey study in Hampton Roads shows that all aspects of the currents vary between spring and neap tides. Not only is there an increase in the maximum speed during both ebb and flood, but the duration of ebb increases as well. The flow directions during neap tides show appreciable variation during the tidal cycle; whereas, during spring tides the flow appears to be more "directed". The obvious conclusion, therefore, is that when comparisons of data are made, either between stations or for different times at one station, data from periods of similar tide range should be compared. Otherwise, the variation due to tide range differences will be included with variations due to other causes.

Winds

The wind, by its very nature, is erratic and therefore very difficult to characterize. The cumulative effect of the wind is a product not only of its speed and direction but also the fetch and duration. Because of the limited time span of most data gathering activities, usually there is insufficient data to measure these wind effects. However, during 1951, there were several periods of high winds while current meters were in place at CGS Station 26. On October 16, 1951, and for three days thereafter, winds of 19 to 38 miles per hour blew from the north to northeast, which is in the upriver direction for the station at which measurements were made. A comparison of the data from the end of this period with data from a period of low variable winds and the same tide range shows an increase in current speeds during flood tide, with the effects being greatest near the surface. Apparently the winds not only increased the surface currents but the total upstream flow as well, and thereby increased the tidal prism. This enlarged tidal prism caused higher than normal ebb velocities which were observed at all depths.

Wiegel (1968, p. 317) states that the wind drift current is zero for depths of 5 feet or more for winds blowing 24 hours or less. Therefore, current measurements made at 2 meters depth should provide information on the currents in the upper layer while still minimizing the wind effect.

When possible, data from periods of high winds should not be used for general studies, but the wind effects are not likely to be of great significance except near the surface and when a long fetch exists, i.e., wind direction and channel axis are parallel.

Description of Tidal Flows in Hampton Roads

In order to view the overall current regime within Hampton Roads, plots of current velocities for maximum ebb and maximum flood were made. Lunar hours 1 and 7 were chosen for times of maximum flood and ebb respectively. Since the time of maximum current varies by two hours or more from Hampton Flats to the James River Bridge there is no single time of maximum current throughout the study area. Generally, however, velocities do not vary significantly within an hour or so of maximum current. With the exception of 4 stations from the OJR study, all data plotted were taken at a depth of 6-8 feet below the surface. At those 4 stations data are from the surface, which probably means 1 to 2 feet deep. These data are plotted in Figures 2 and 3.

Two immediately observable and intuitively obvious points are that currents in the vicinity of the main channel tend to parallel the channel, and velocities near the mouth of the river tend to be greater than elsewhere. The latter is more apparent at ebb than at flood. The increase in

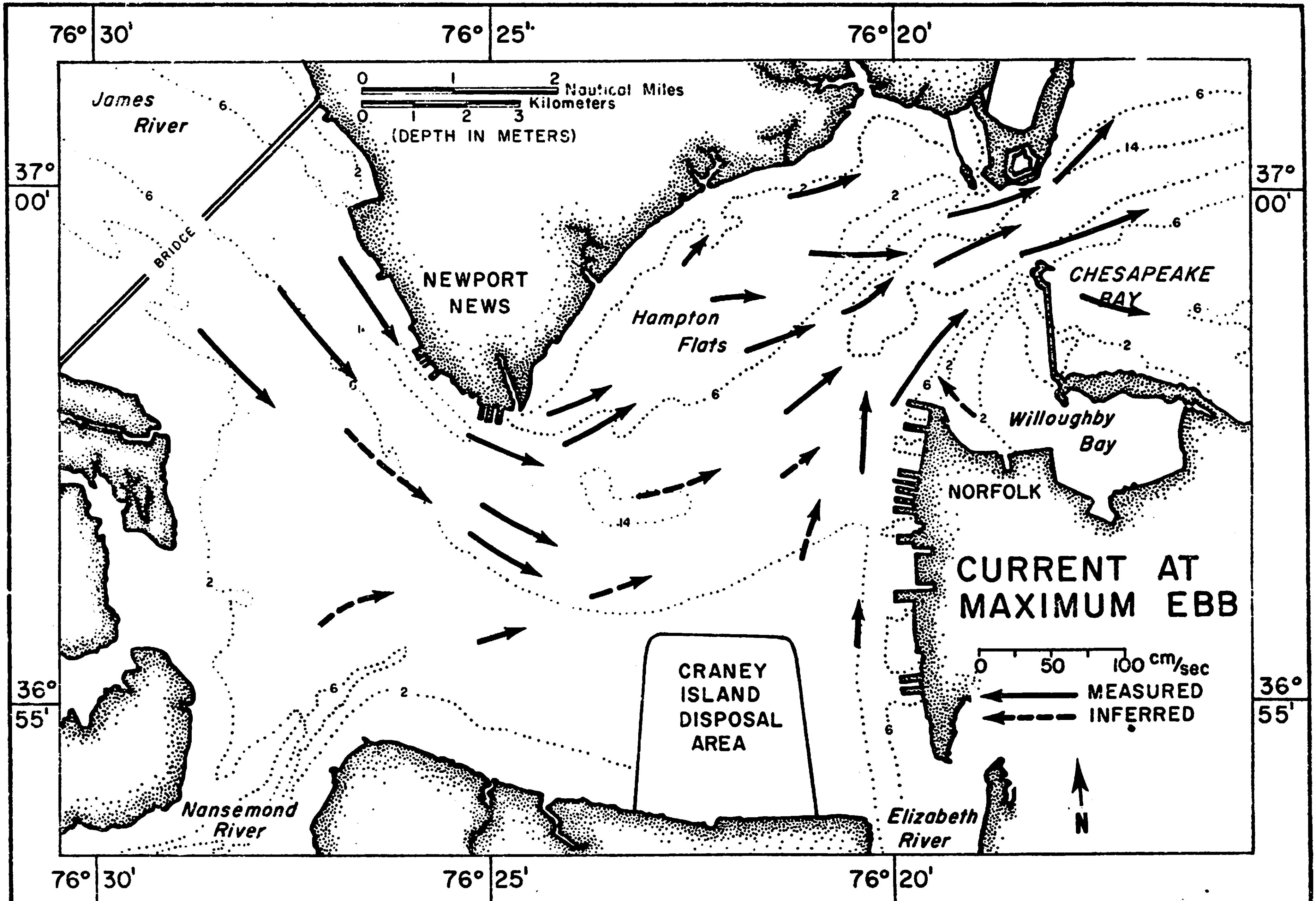


Figure 2. Current velocities at maximum ebb (7 hours after slack before flood at Chesapeake Bay mouth). (From Neilson & Boule, 1975).

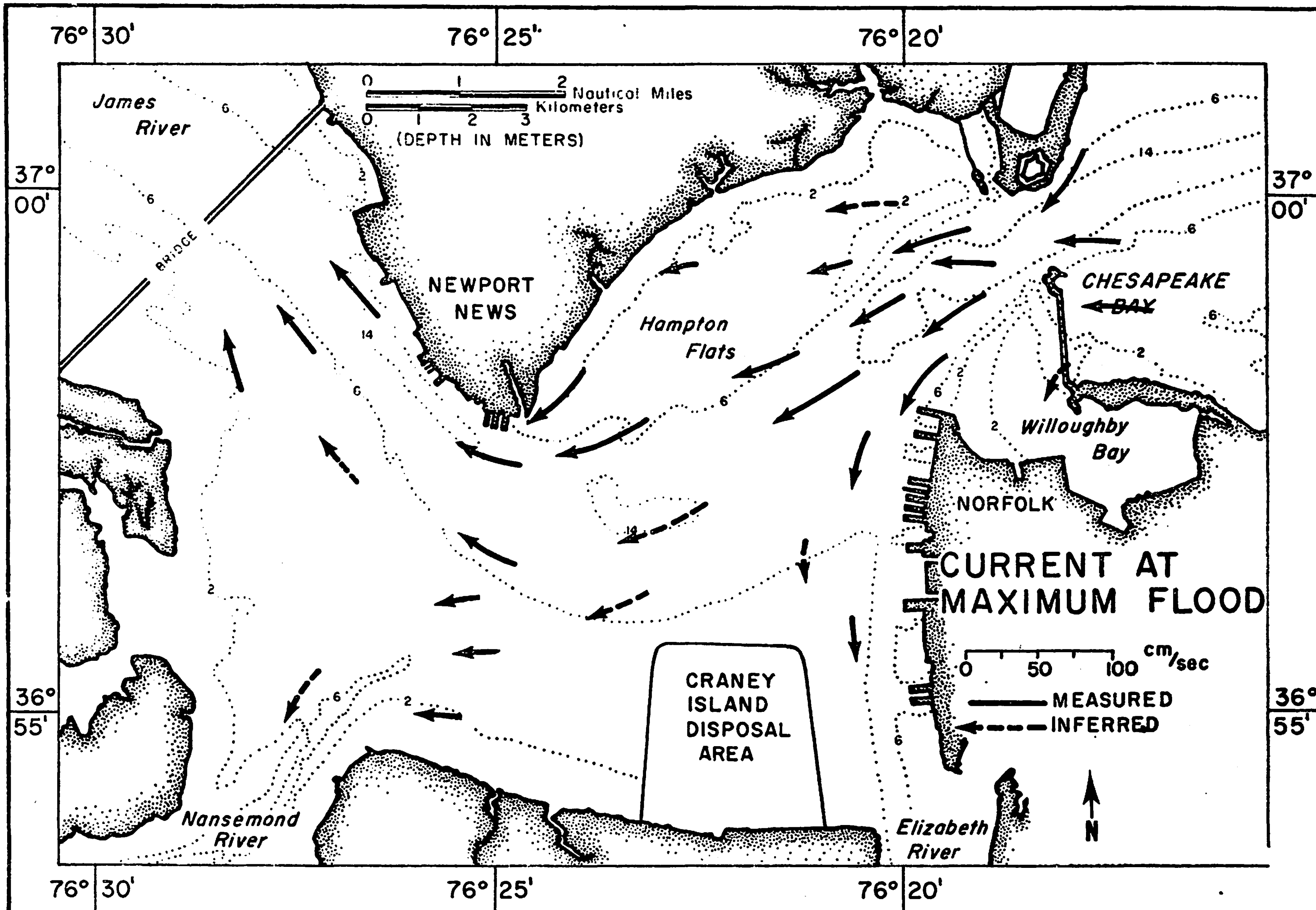


Figure 3. Current velocities at maximum flood (1 hour after slack before ~~flood at~~ Chesapeake Bay mouth). (From Neilson & Boule, 1975).

velocity near the mouth is particularly understandable since the cross-sectional area diminishes by about 50% from that of a transect only 3 miles upstream. (Cronin 1971).

At each station maximum ebb and flood speeds are about equal throughout most of the area. However, south of Hampton Bar and from Fort Wool to the mouth of the Elizabeth River, ebb velocities are noticeably greater than flood.

In noting current directions, it appears that at flood much of the water entering the mouth of the river from the Bay either flows along the navigation channel or across Hampton Flats passing between Newport News Bar and Newport News Point before re-entering the navigation channel and turning sharply northwesterly around Newport News Point.

At ebb, however, the currents do not appear to turn sharply around Newport News Point but rather continue toward the southeast, remaining in the natural channel that runs south of Newport News Middle Ground.

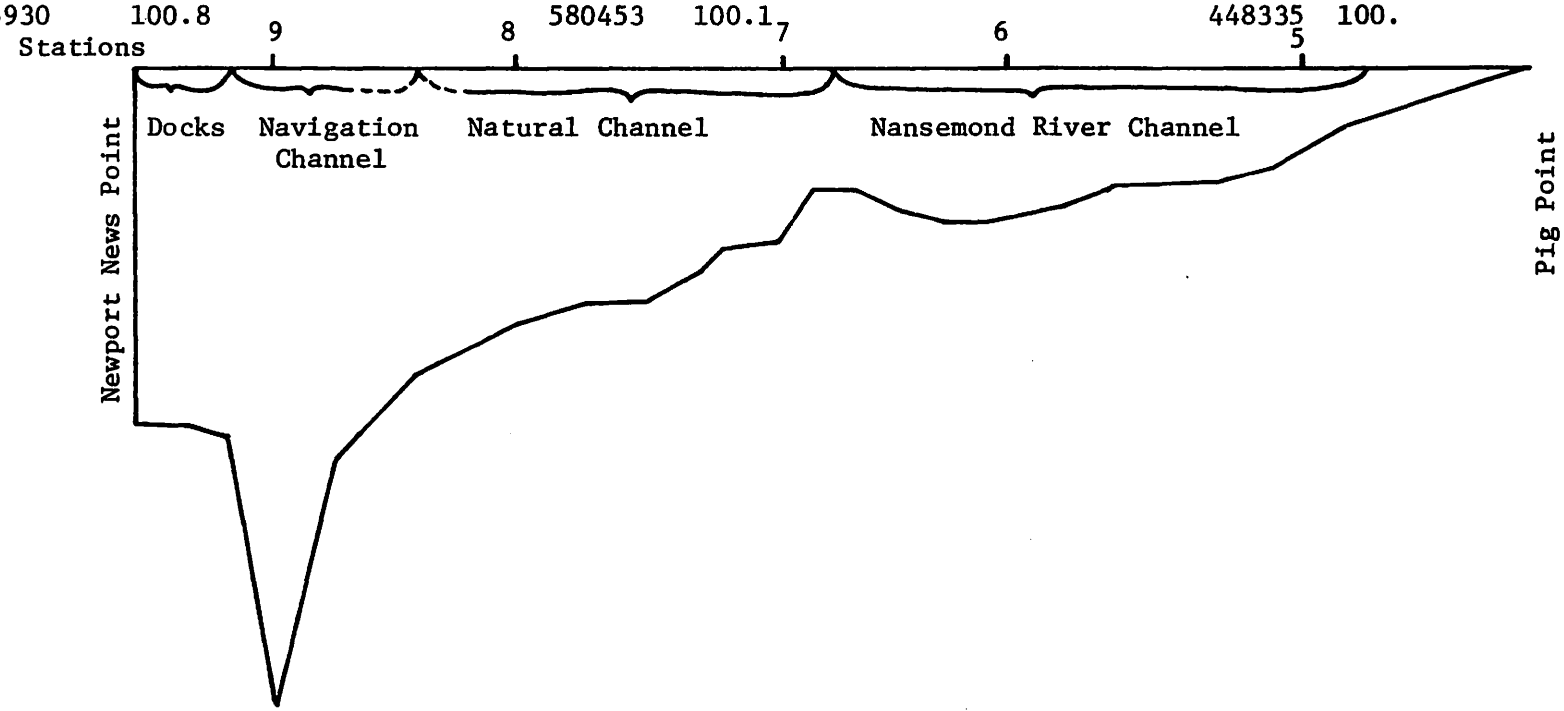
A comparison of flows in this area tends to confirm these observations. Table 1 shows the calculated distribution of flow across a north-south transect from Newport News to Pig Point.

Vertical boundaries of areas represented by each station were chosen either at the shallowest point or based upon the more significant change in slope between two stations. Since the stations along the transect do not represent equal areas the ratio % flow/% area is used to eliminate variations in flow due to variations in area.

Table 1

Distribution of Flow at Transect 1

Station	Cross-Sectional Area (ft^2)	% Total Area	FLOOD Velocity (Vert.Avg.) (fps)	FLOOD Flow (cfs)	FLOOD % Total Flow	FLOOD % Flow / % Area	EBB Velocity (Vert.Avg.) (fps)	EBB Flow (cfs)	EBB % Total Flow	EBB % Flow / % Area
OJR 64										
5	36450	8.5	-0.764	27857	4.8	0.565	0.695	25346	5.7	0.671
6	71265	16.7	-1.066	75969	13.1	0.784	1.027	73164	16.3	0.776
7	39561	10.1	-0.879	34776	6.0	0.594	1.204	47622	10.6	1.05
8	103974	24.4	-1.689	125633	30.3	1.242	1.105	114929	25.6	1.049
9	175680	41.1	-1.515	266218	45.9	1.117	1.066	187272	41.8	1.017
Total	426930	100.8		580453	100.1			448335	100.	



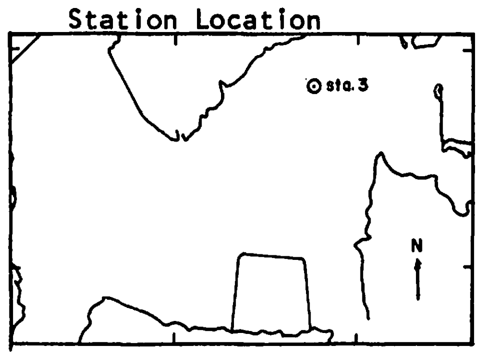
A value of 1 here indicates a calculated flow across the area equal to the average flow calculated from the total transect. Finally the flow is calculated only for an instant (such as maximum ebb and maximum flood and not a total tidal cycle); therefore, flood totals may be greater than ebb totals. For these reasons, inferences are limited. The table does suggest, however, that more water flows south of Newport News Middle Ground than through the navigation channel at ebb. Comparison of the flow/area ratio for flood and ebb indicates that flow south of the Middle Ground increases significantly at ebb tide, while flow in the navigation channel decreases.

At both the east and west ends of Hampton Flats there is a bar separating the flats from the navigation channel to the south and a small channel between the bar and the shore to the north. At flood, water enters the flats over Hampton Bar and the shelf area between Hampton Bar and Newport News Bar. It moves westward and leaves the flats via the channel between Newport News Point and Newport News Bar.

At ebb tide, currents onto the flats are partly through the Newport News Bar channel and partly around the end of the bar. Three stations on the flats suggest, however, that much of the ebbing current leaves the flats before reaching Hampton Bar rather than exiting via the Hampton River entrance channel in a manner similar to the flood currents at the west end of the flats. This is not surprising since the Hampton River channel is much smaller, only 200 feet wide and 12 feet deep; whereas, the Newport News Bar channel is over 600 feet wide and up to 20 feet deep. Changes in ebb current direction at OJR station 3 (located on Hampton Bar near the southwest end) in Figure 4 indicate that the water "backs up" at the east end of the flats, and then "spills" over the bar during ebb tide (note hour 5-9).

The movement of slack water through the study area was described by Welch (Fang et al., 1972) as "a nearly amphidromic system with Newport News Point corresponding to an amphidromic point." While this is an accurate description of that portion of Hampton Roads north of the main navigation channel, it appears to be insufficient to describe the area south of the main channel. Figures 5 and 6 chart this movement.

The turning of the tide at both high and low water begins along the shore of Hampton Flats and moves outward nearly parallel to the shore, taking about two hours to reach the main channel. Slack water appears to be almost instantaneous through most of the natural channel south of Newport News Middle Ground, from the river mouth to just upstream of Newport News Point, and near the mouth of the Nansemond River. The data also suggest that high water slack, but not low water slack, occurs near the mouth of



Numbers indicate lunar tidal hour

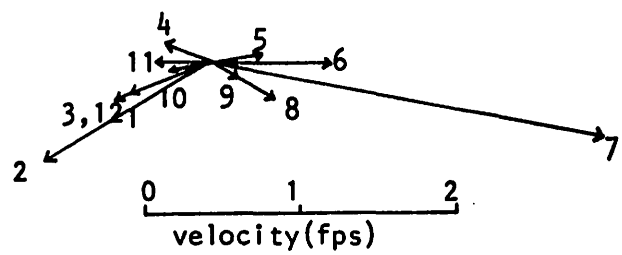


Figure 4. Current velocities for station 3(OJR).

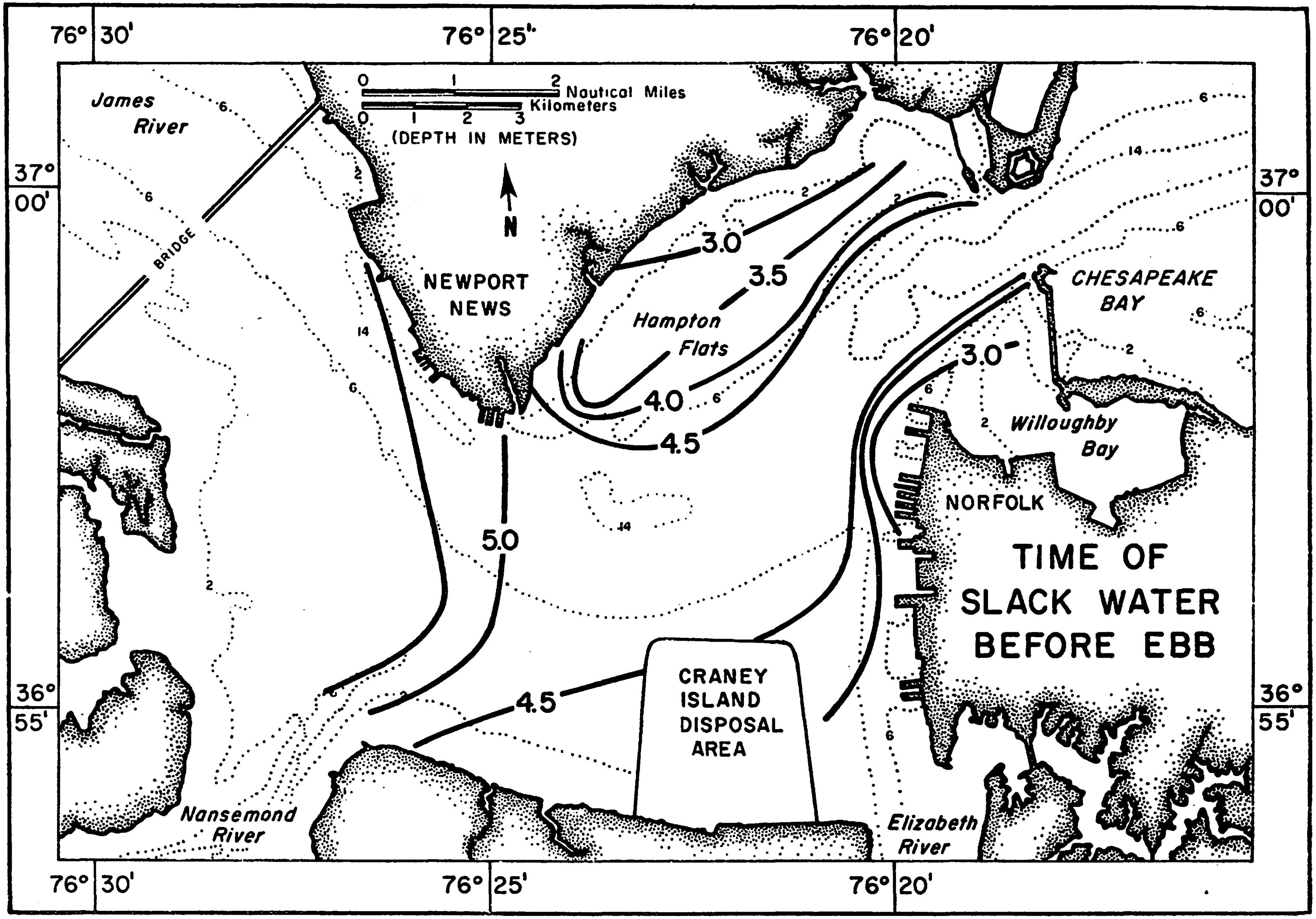


Figure 5. Time of slack before ebb in the prototype. Time is in hours after slack before flood at Chesapeake Bay mouth. (From Neilson & Boule, 1975).

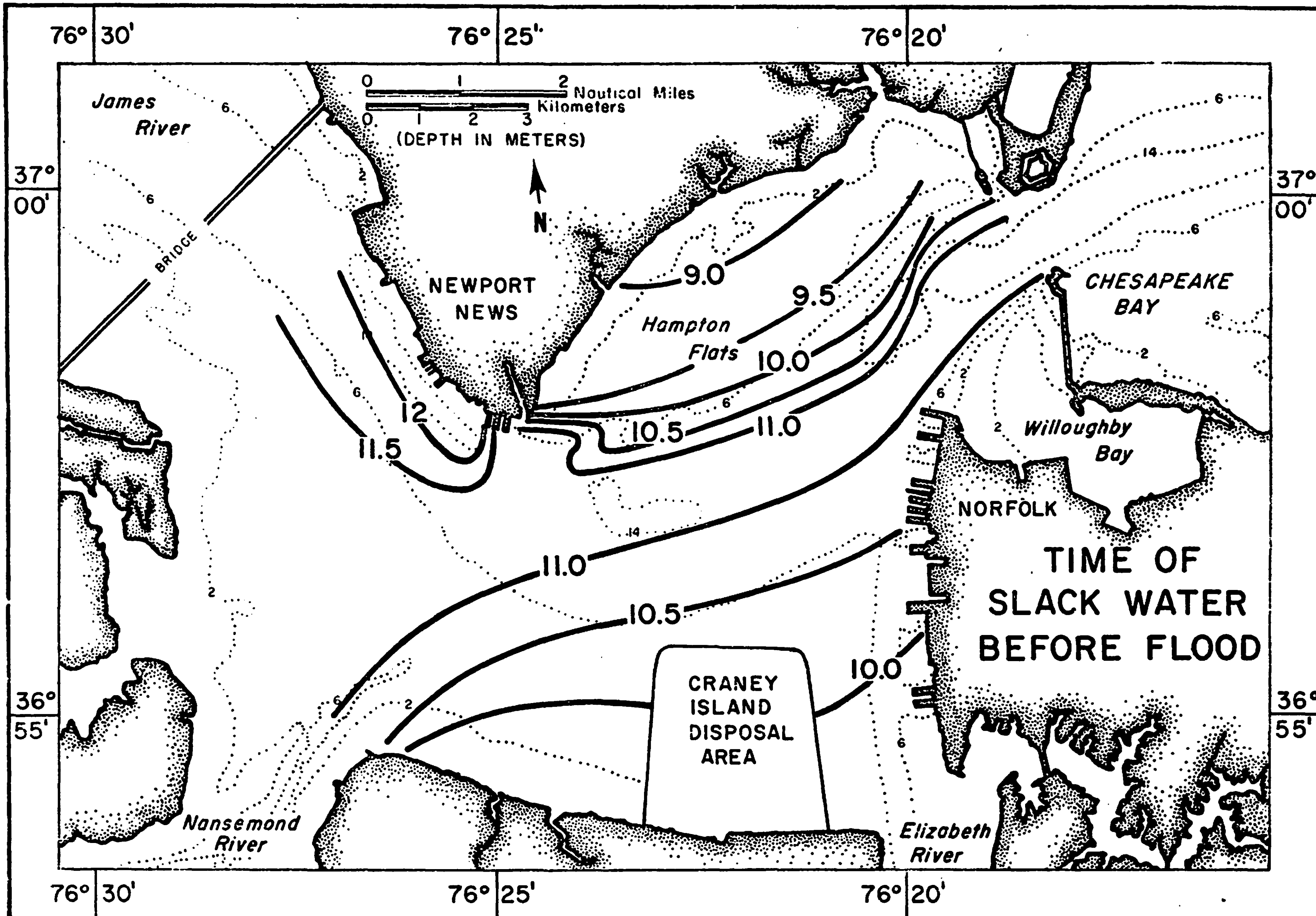


Figure 6. Time of slack before flood in the prototype. Time is in hours after slack before flood at Chesapeake Bay mouth. (From Neilson & Boule, 1975).

Willoughby Bay and north of Sewell's Point at the same time it occurs at the Hampton Flats shoreline.

Each of the three major rivers emptying into Hampton Roads shows a different pattern of slack water movement. Beyond the James River Bridge the movement is fairly regular and continuous up the James River. In the Nansemond however, slack water moves downstream, occurring earlier at Dumpling Island than at the mouth (NOAA, Tide Current Tables, 1971). Finally, in the Elizabeth River, the tide appears to turn almost coincidentally, occurring at the mouth (Craney Island) and well upstream (Gilmerton Highway Bridge) about 20 minutes before it turns midway between at Town Point (NOAA, Tide Current Tables, 1971).

At the Newport News Bar, just southeast of Newport News Point (Figure 6), low water slack over the bar is 0.5 hours behind the main channel only 500 yards to south, 1.5 hours behind the secondary channel less than 400 yards to the north, and coincident with the main channel 1 mile to the west. High water slack for the bar on the other hand is an hour ahead of both neighboring channels and 1.5 hours ahead of the main channel to the west. This means that for at least 2 hours in each tidal cycle the water over the bar is flowing in the opposite direction of the surrounding water. Thus the local current situation just south of Newport News Point is extremely complicated.

In summary, there appears to be a somewhat counter-clockwise circulation in the eastern portion of Hampton Roads.

The entering flood current is from the WSW and flows onto Hampton Flats. Flood currents are dominant in this region, with the flow funneling into the secondary channel between Newport News Bar and Newport News Point. This flow makes a sharp turn upstream immediately after the point, and thereafter follows the main channel. Flow along the southern edge of the navigation channel is modified by the flux into the Nansemond and Elizabeth Rivers.

During ebb, the flow is down the navigation channel from the James River Bridge. Near Newport News Point there is a gradual, rather than sharp, turning towards the river mouth. Thus a large portion of the flow is in the natural channel around the Middle Ground. This flow is deflected to the northeast in part by the discharges from the Nansemond and Elizabeth Rivers. The ebb flow out the river mouth is to the WNW.

Slack water tends to move through the same area in a clockwise fashion, with Newport News Point acting more or less as the center of rotation. Slack water begins in the vicinity of the Hampton River mouth, progresses to the navigation channel, around the point and finally reaches the shipyards. Differences in the time of slack water of an hour or more exist for many points that are quite near (less than a mile apart).

CHAPTER 4. CURRENTS NEAR THE HAMPTON ROADS BRIDGE-TUNNEL

For several decades many investigators have studied the flow of fluids past cylinders, air foils, plates and other obstacles. Typically, the object is regular in shape and the far field flow pattern is also regular, normally with uniform direction and velocity. While of great value for many purposes, this type of study provides little information for the flow past tunnel islands since the islands are not always regular in shape and the far field flow pattern is highly complex. Therefore, field measurements were made to determine the ways in which existing tunnel islands modify the tidal flows in Hampton Roads.

The peninsula on which Fort Monroe is located and which ends at Old Point Comfort shields the region immediately to the west and north from the strong currents typically encountered in the main channel. Furthermore, the tunnel is located only about 250 yards away from this peninsula. The flow patterns around this island are so dominated by the presence of Fort Monroe, that no effort was made to measure the circulation there.

The southern island, on the other hand, lies about one mile north of Willoughby Spit and adjacent to the main channel. Fort Wool, which is only about half as large as the original tunnel island, is connected to the tunnel island by a riprap barrier of rocks weighing several tons each.

The two islands each have an effect on the circulation, but the tunnel island is the more important of the two, especially during ebb tide. Currents in this area were measured extensively.

Flood Tide

During flood tide, water from Chesapeake Bay flows towards Hampton Roads primarily through two channels. The largest portion appears to be coming from the navigation channel in a west-northwesterly direction near the Bay mouth, and it is deflected to a more west-southwesterly direction near Old Point Comfort. The main channel is roughly one mile wide with depths ranging from 40 to nearly 100 feet. A second flow tends to follow the shoreline past Ocean View and along Willoughby Spit. This secondary channel lies several hundred yards from shore and is quite broad but the depths range from less than 10 feet to a maximum of around 25 feet.

Figure 7 shows the maximum flood currents which have been measured in this area. Current measurements were made over at least one tidal cycle and in a few cases, the records were for periods of nearly a month. A right-hand dominance can be seen in the main channel: current speeds near Old Point Comfort are greater than those near Fort Wool. Flood currents in the immediate vicinity of

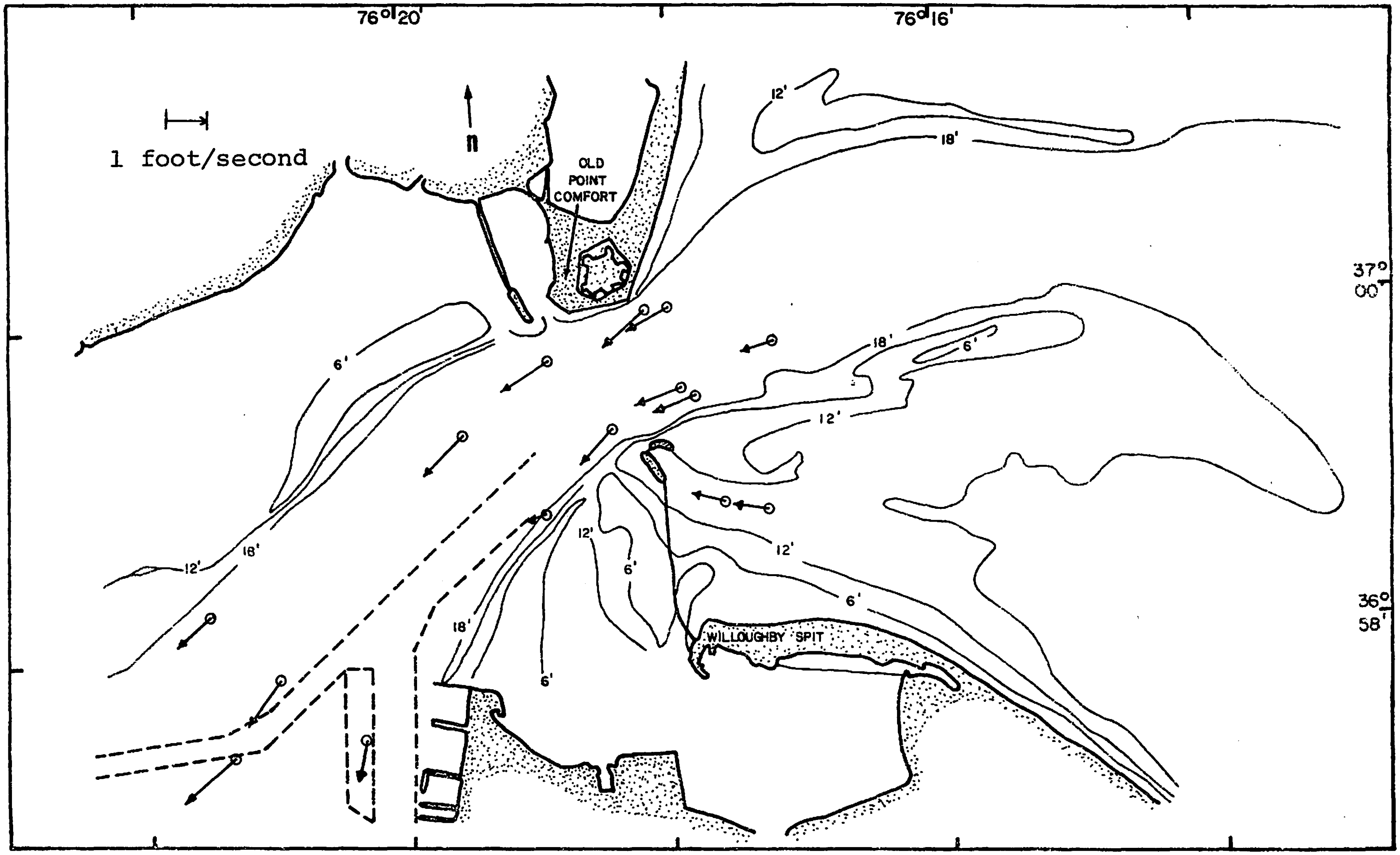


Figure 7. Maximum flood current.

the Fort Wool-tunnel island were measured during the summer of 1974 and these current vectors are shown in Figure 8. It is important to note that the current directions tend to be northwesterly in the area east of the tunnel island and up to the edge of the main channel. The currents across Willoughby Bank are strong, despite the fact that depths are less than 12 feet. From this picture of the local circulation, it is easy to understand why currents between the tunnel island and Fort Wool were very strong. The two islands tend to funnel the flow approaching from this direction. The very large rip-rap blocks which were placed between the two islands, however, block this flow. The current measurement made just to the south of Fort Wool indicates that there is a stagnation zone in the "pocket" that has been created. The direction measured there is opposite that of the main current, and either is unreliable due to the very weak currents and the instrument's sensitivity, or else indicates that some system of eddies and countercurrents is set up.

These two sets of current data have been combined and interpreted as stream lines in Figure 9. The only way that the two sets of data can be consistent is if the secondary current over Willoughby Bank and to the south of the islands is sharply deflected by the flow down the main channel. It has been observed on other occasions and in other locations that currents in deep channels are stronger than those in the shallower areas to either side.

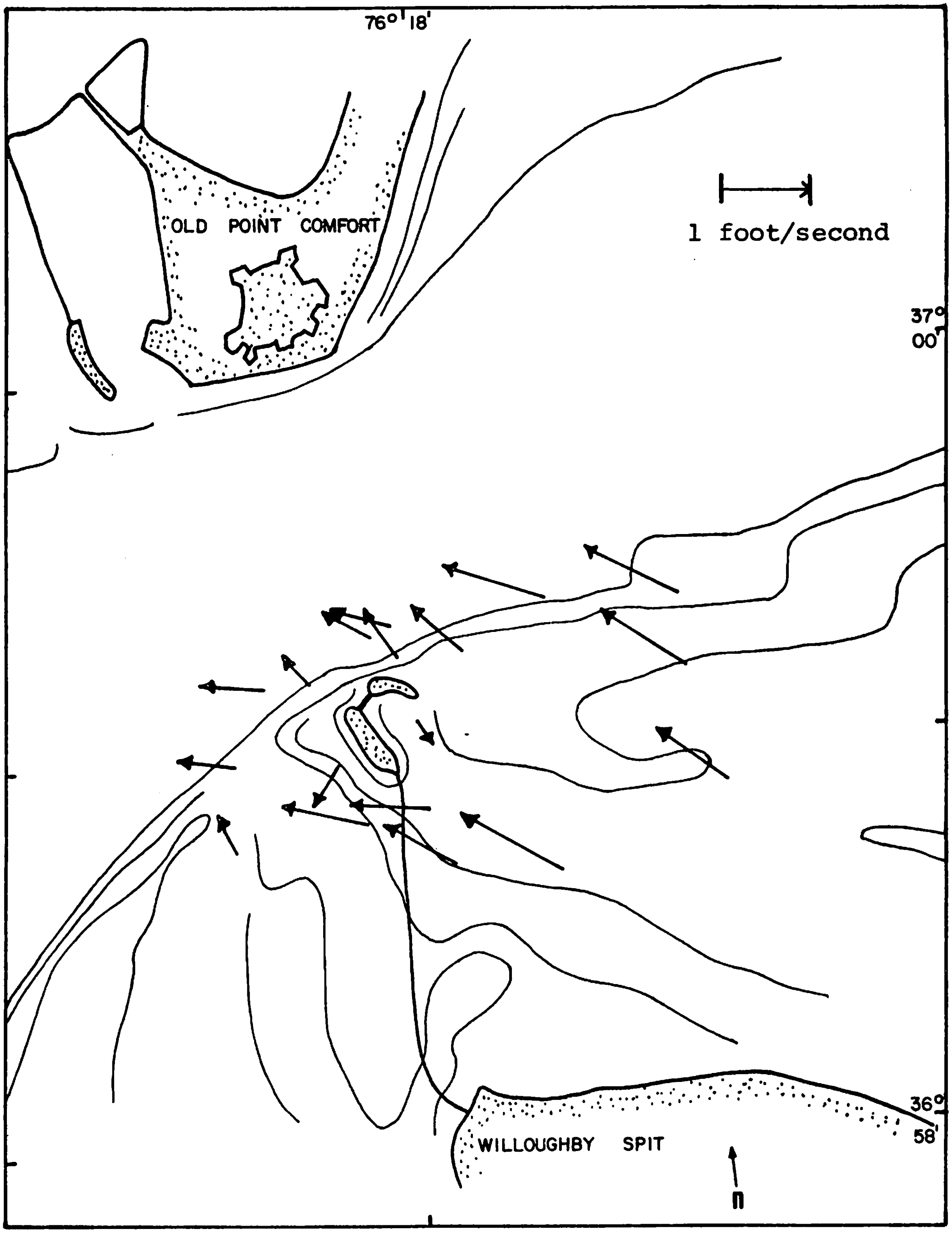


Figure 8. Flood currents near Fort Wool.

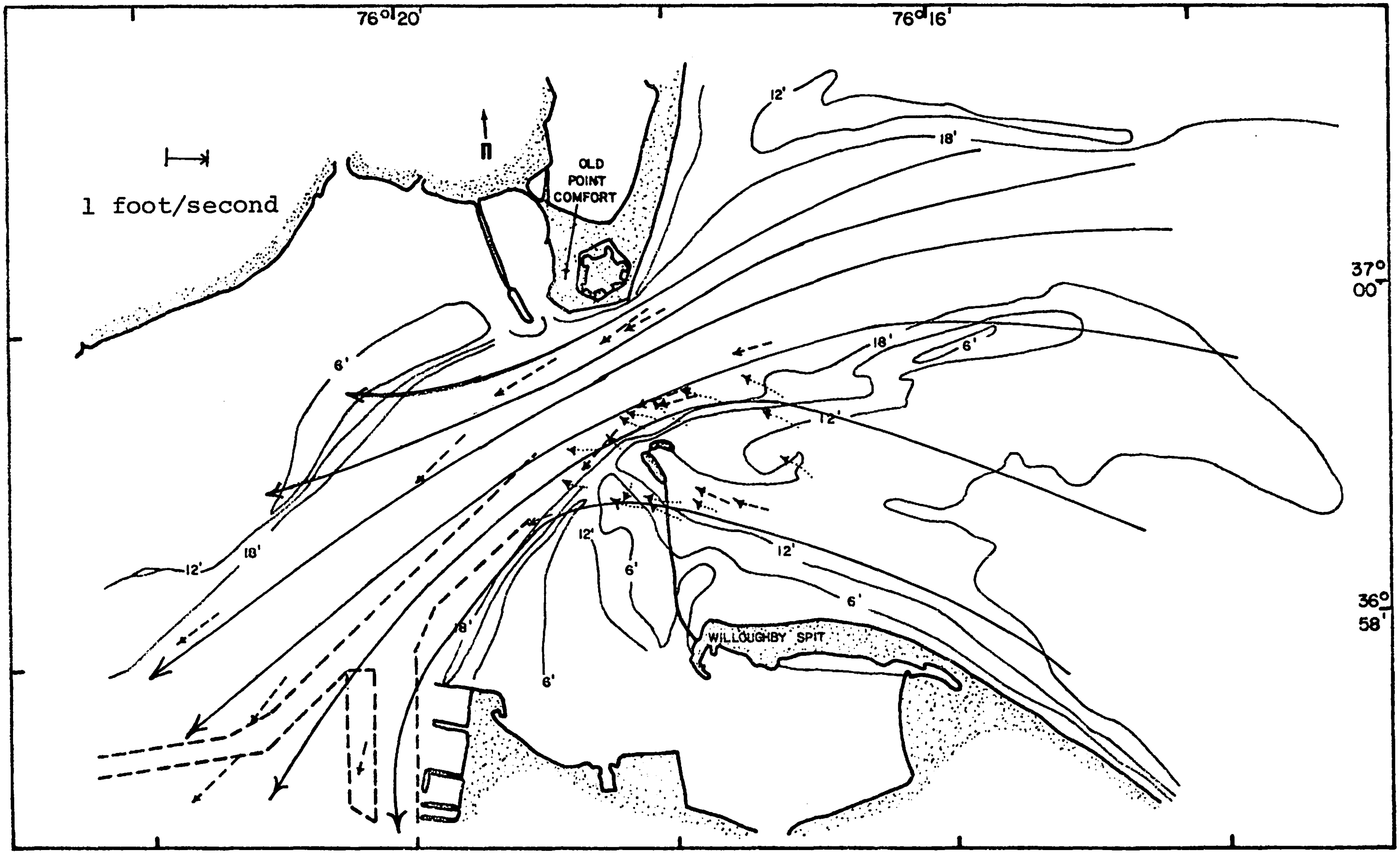


Figure 9. Idealized flood flow.

The average current directions for three stations at the edge of the main channel also show a shift of roughly 15 to 40 degrees for measurements made near the surface and at intermediate depths, as can be observed from the data in Table 2. The flow over Willoughby Bank apparently submerges and deflects the currents at intermediate depths in the main channel.

Ebb Tide

Measurements made in Hampton Roads and Chesapeake Bay at maximum ebb are shown in Figure 10. The dominance of currents on the right hand side of the flow is again evident. Velocities near Fort Wool are significantly greater than those near Old Point Comfort. The currents measured in the immediate vicinity of the island (Figure 11) are strong and on the order of 3 feet per second. There is a divergence of the flow near the northwest corner of the island, with part of the flow deflected toward the main channel, and the rest deflected to the south of the island. Once past the island and Fort Wool, some of the ebbing waters pass over Willoughby Bank and trend to the east-southeast, parallel to the portion passing between the island and Willoughby Spit. The combined flows and interpreted stream lines are shown in Figure 12. It appears that all of the flow is deflected to the southeast. That portion passing

Table 2. Average Flood Current with Depth at Several Stations Near the Edge of the Channel.

Station	Depth	Speed (knots)	Direction
#8	7'	1.35	223
	21'	1.33	262
	35'	1.10	221
#5	6'	1.07	255
	18'	0.94	276
	30'	0.92	269
#27	8'	1.10	251
	24'	1.01	266
	34'	1.03	263

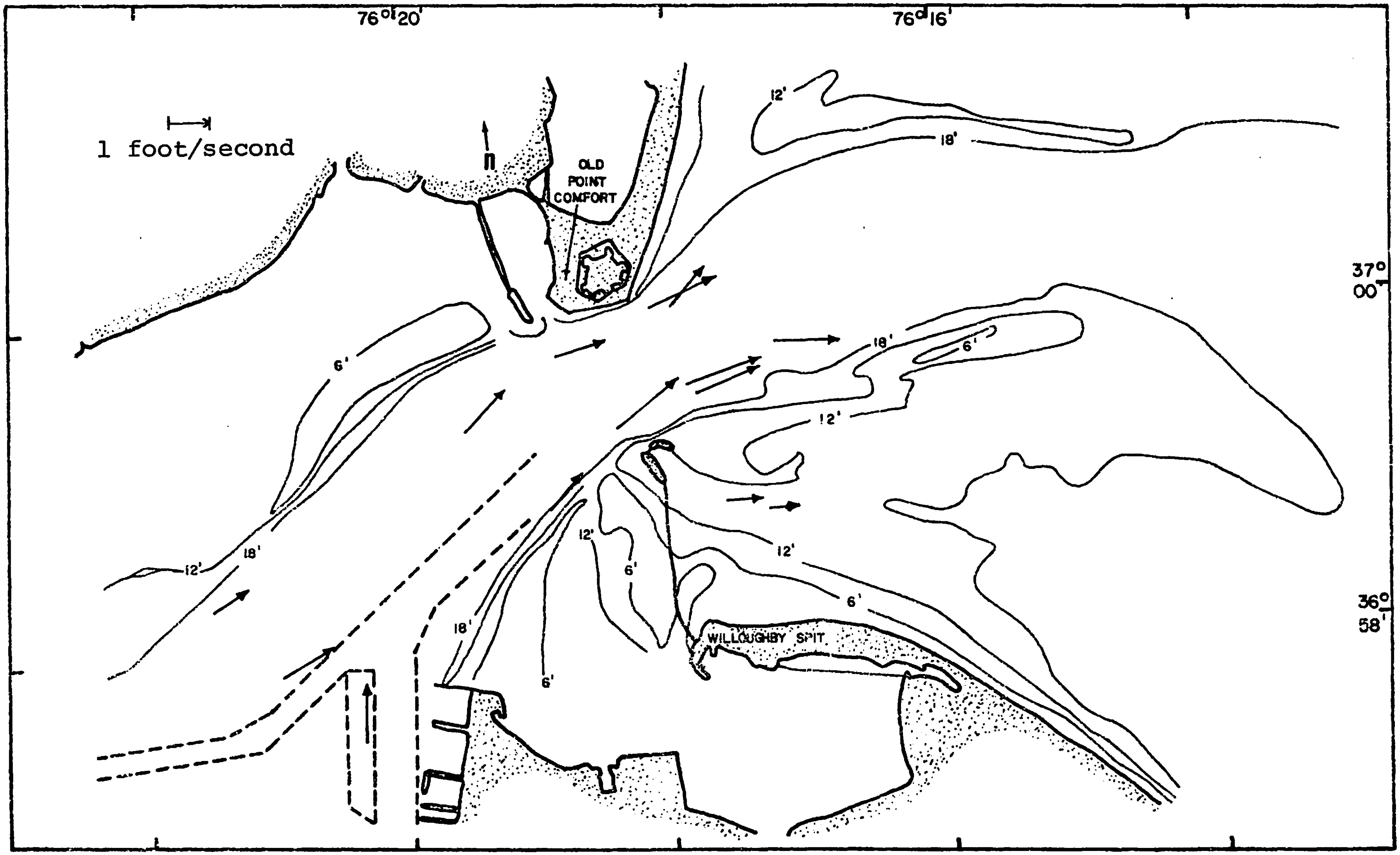


Figure 10. Maximum ebb currents.

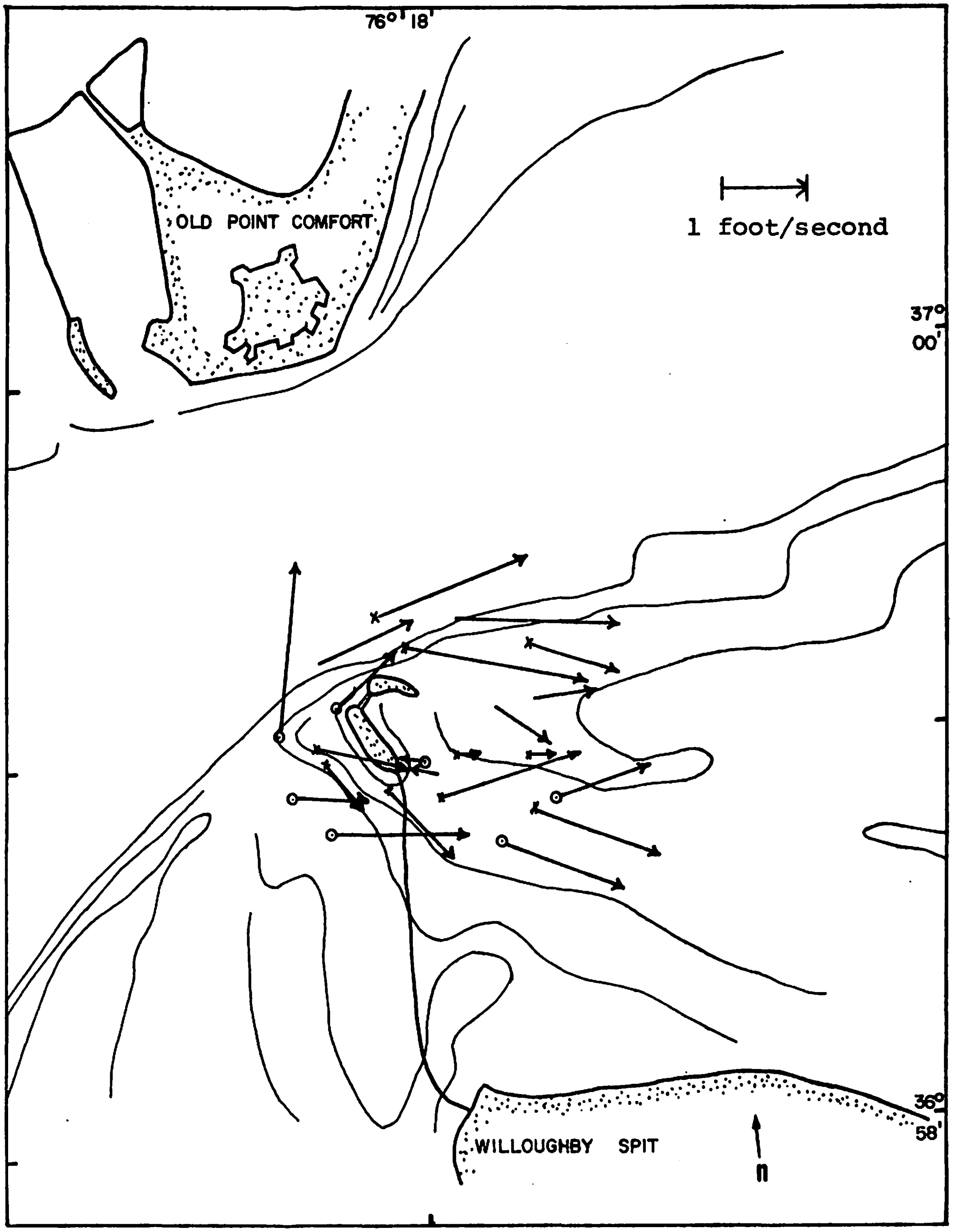


Figure 11. Ebb currents near Fort Wool.

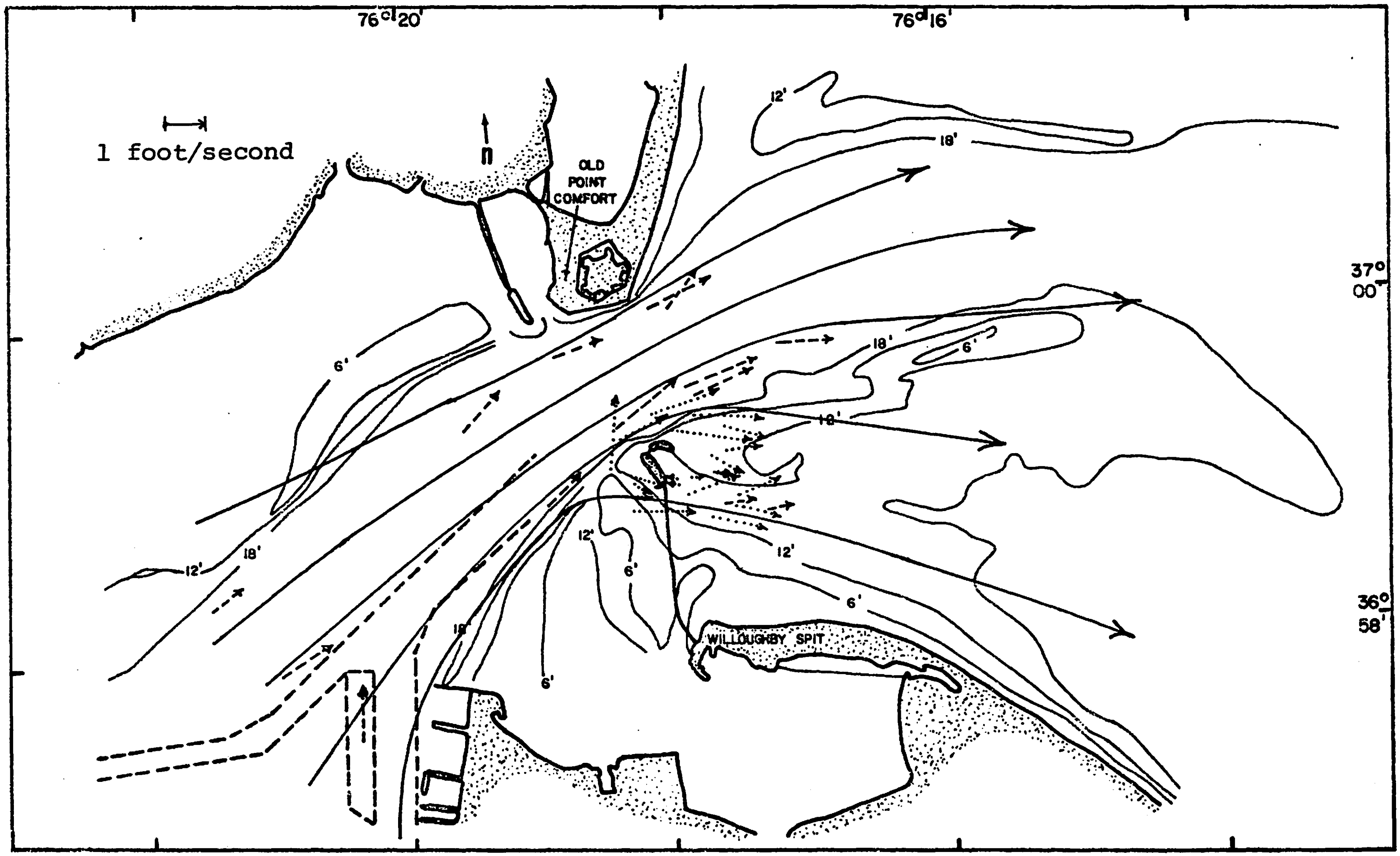


Figure 12. Idealized ebb flow.

between Fort Wool and Willoughby Spit has this orientation as soon as it passes into the Bay, while the part flowing down the main channel is reoriented more slowly and over a greater distance. The ebbing waters from the upper portion of the Bay apparently force the water leaving Hampton Roads towards the shoreline. One very obvious feature which illustrates this is Willoughby Bank. Although the origin of the sand is not known, it is apparent that material is being carried from the Fort Wool area out into Chesapeake Bay. The arcuate form of the shoal provides a record of the direction the currents have taken.

Circulation Near Newport News Point

The proposed configuration for the northern tunnel island for I-664 is shown in Figure 13. The southern island will lie beyond the navigation channel slightly to the west of Newport News Middle Ground and will have a north-northwesterly orientation. The present hydrography of Hampton Roads exhibits a right-hand dominance. That is, currents are strongest and the flows are greatest on the northern side of the channel during flood and on the southern side of the channel during ebb tide (Figures 14 & 15). The general effect of the tunnel islands will be to enhance this dominance. First, the cross-sectional area of the navigation channel between Newport News Point and Middle Ground will be

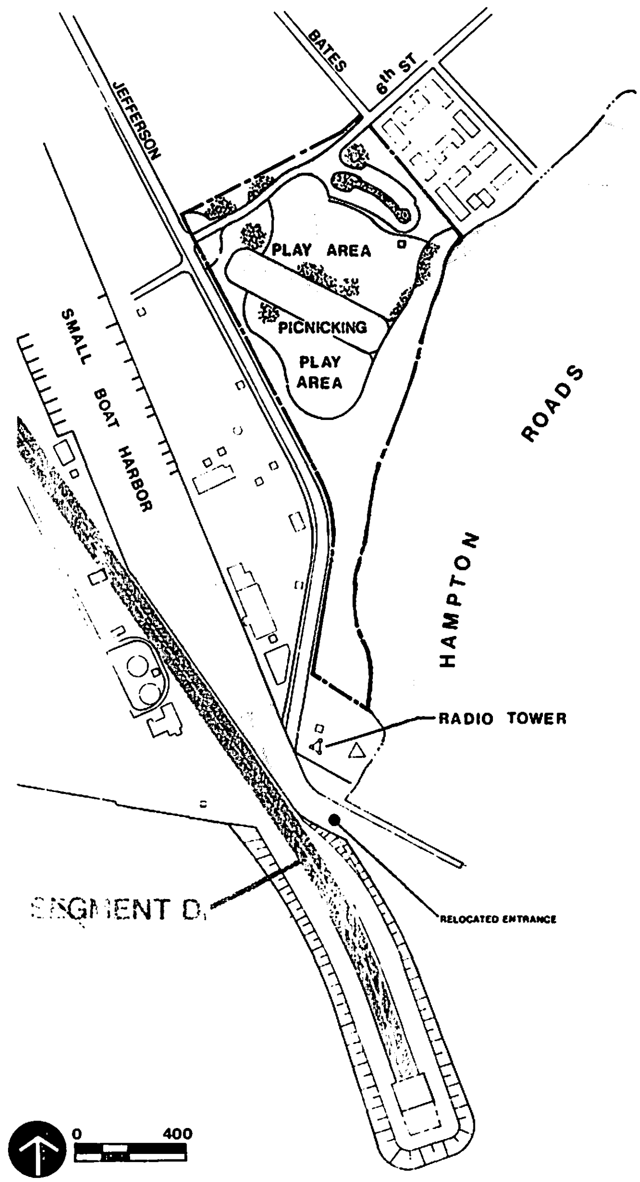


Figure 13. Proposed I-664 modifications to Small Boat Harbor shoreline. (From McGaughy, et.al., 1972).

reduced due to the islands. The southern island will act as a vane deflecting flow to the north as well. The currents in the navigation channel will therefore increase in speed although the total flow should remain nearly constant. During ebb, the axis of the southern island is inclined to the ebbing flow at about a 45° angle, and it should again deflect the flow but this time to the south. It is believed that the total flow through the natural channel south of Middle Ground will increase for ebb tides, and the flow through the navigation channel will decrease slightly as a result. On a more local scale, the southern island will shield the Middle Ground, especially during ebb tide, and these two features may become connected. It appears that the flow during flood tide will parallel the navigation channel and that the flow between the island and the Middle Ground will not be large. This, too, would allow deposition to occur and the Middle Ground and the island to become one feature. If on the other hand, a strong current between them should develop, this will tend to erode away any deposited materials. Dye studies in this area have shown that currents near "Foxtrot" have a somewhat northerly direction during flood. No measurements were made in the immediate vicinity of Middle Ground; however, these northerly currents are not expected there.

The effects near Newport News Point will depend on several factors, such as the design of the jetty to protect

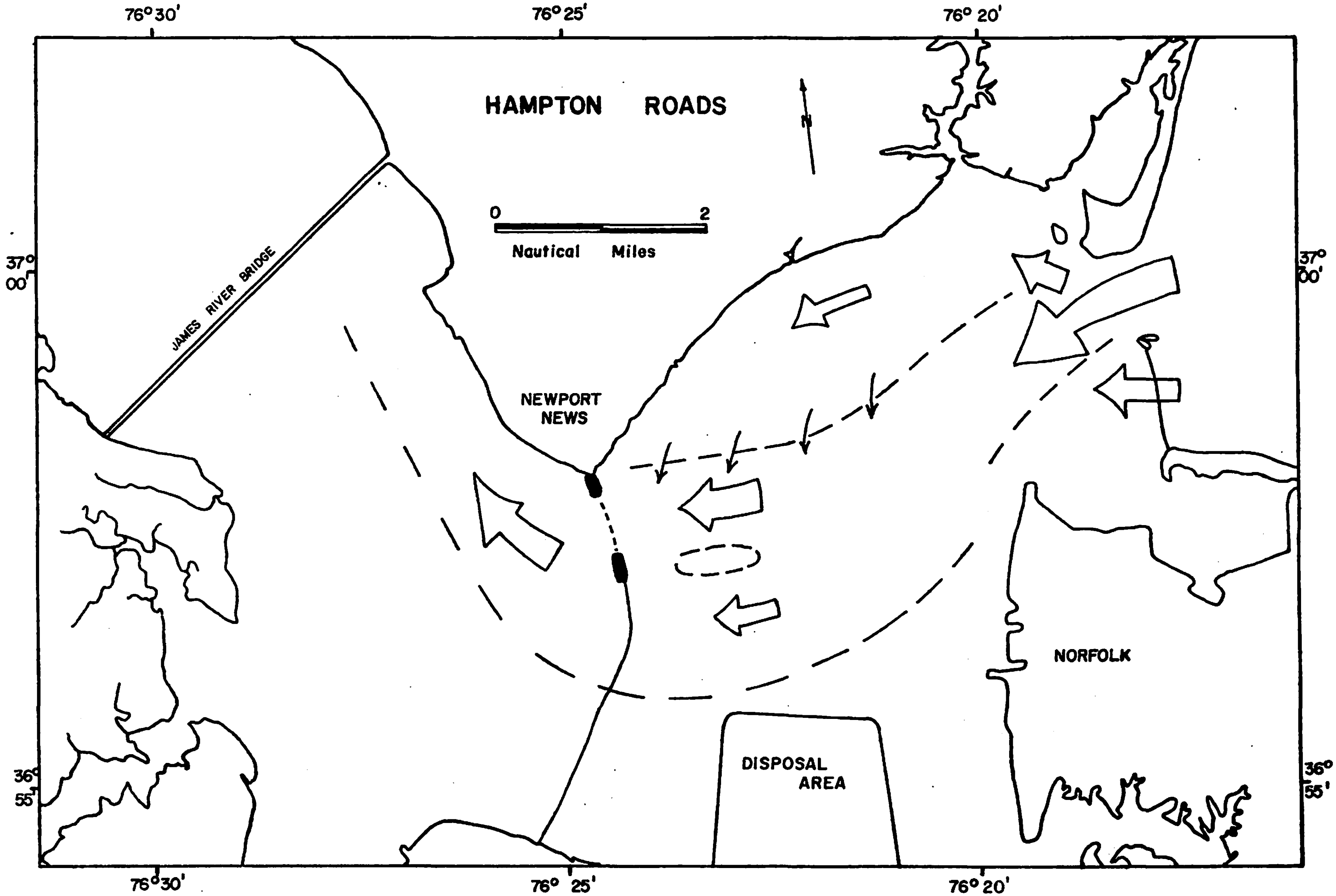


Figure 14. Flood tide.

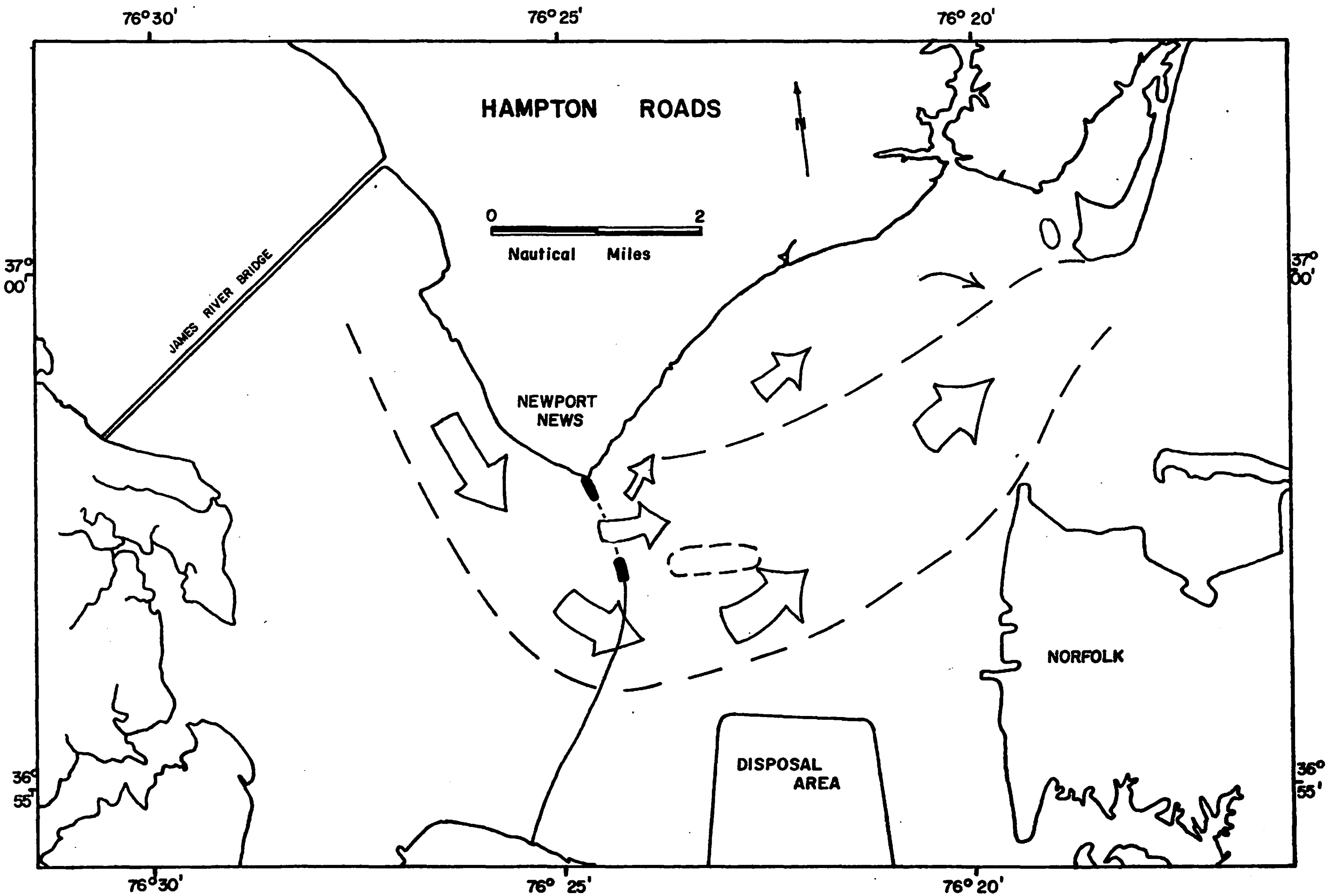


Figure 15. Ebb tide.

the entrance to the Small Boat Harbor. If both the island and the jetty block the secondary channel on Hampton Flats, then the converging flow pattern may be greatly modified, and a more general "spilling" over Newport News Bar may develop. If on the other hand, the jetty is not especially long and there is a dredged channel to the entrance to the Harbor, then the converging flow may follow this course instead of the present one. In either case, the flow during flood tide will be similar to that near Fort Wool - there will be strong currents in shallow waters but these flows will be sharply deflected when they merge with the flow down the main channel.

During ebb tide, there will be variable results of the tunnel island. The island itself does not protrude from the mainland much further than most of the docking piers. However, these piers tend to be supported by pilings rather than solid fill such as the island will have. When freighters are at the docks, the effective shoreline will be at the ends of the piers and island. When no ships are docked at the piers, there could be a flow of water along the shoreline which will be deflected by the island. If this does occur, this flow would tend to remove material from the area and could, in fact, reduce the siltation rate. At this point, this remains a conjecture only.

CHAPTER 5. WATER QUALITY CONSIDERATIONS DURING CONSTRUCTION

A productive ecosystem requires a constant flow of energy and nutrients into the system. In general there will develop equilibrium conditions which utilize both the available energy source (normally sunlight) and the available nutrients in an efficient manner. Man's activities often modify the energy flow and can drastically increase the sources of nutrients. These changes in the amounts and types of constituents in the physical environment will have direct effects on the biological community. The changes in flora and fauna will depend on the intensity and duration of the changes in the physical-chemical environment, and in general, more tolerant species will tend to dominate. If the stresses placed on the system are severe enough, wholesale replacement of the old species by new ones may occur. The goal of this portion of the study has been to determine the changes in the physical environment which can be attributed to the construction activities, to compare these changes to seasonal and yearly variations, and thereby evaluate the impact of bridge-tunnel construction on estuaries.

Dissolved Oxygen

For aquatic systems, dissolved oxygen concentration (DO) is a very important parameter and has been used as a primary water quality indicator for many years. Dissolved oxygen is needed by nearly all higher organisms living in the water, and in a gross sense, the more desirable the organism is to man, the higher will be its dissolved oxygen requirements.

Dredging activities can affect the DO regime of an estuary in several ways. First, a significant portion of the sediments in Hampton Roads is organic. This organic matter is subject to decay by bacteria which in turn use oxygen as their source of energy. BOD, biochemical oxygen demand, is a measure of the demand on DO resources that will be created by the decay of organic matter. Quite often bottom sediments will be rich in nutrients as well, and these can stimulate algal growth. Turbidity on the other hand, tends to decrease algal growth by limiting the depth to which light can penetrate. Other nutrients, necessary for plant growth but needed in only small quantities, the so-called micronutrients, may stimulate or inhibit growth depending on the level that they are present. Toxic materials such as pesticides, heavy metals and chlorinated hydrocarbons also affect the functioning of the biota. In short, the dynamics of the DO regime are quite complicated when examined in great detail. Unfortunately, the background information available for most estuarine systems, including Hampton Roads, is not sufficiently detailed and extensive to warrant such a detailed examination. Consequently, the focus of this study was to examine the dissolved oxygen regime in the vicinity of the construction site with primary emphasis on the physical transport and dispersion of organic matter.

Monitoring of Dredging Activities

Dredging for the second bridge-tunnel began on September 27, 1972 and continued for a year and a month until October 29, 1973. During this time the dredging activity was not continuous but varied due to weather conditions and routine maintenance of equipment. In general the unsuitable materials (e.g. organic mucks and fine sediments) were transported to the Craney Island Spoil Disposal area while the non-organic, coarser sediments were used for fill or were "stored" in the borrow area on Willoughby Bank. Dredging was done with clam-shell buckets. Backfill operations were completed in June 1974.

Monitoring of the dissolved oxygen levels for this project was carried out during the summers of 1973 and 1974. Two types of monitoring were used: water samples were collected from the area several times each month at slack water, and an intensive survey was conducted in September 1973. At this time samples were taken at several depths at each of three locations as shown in Figure 16. Station A ($36^{\circ}58.9'N$, $76^{\circ}17.6'W$) was located in the shallows over

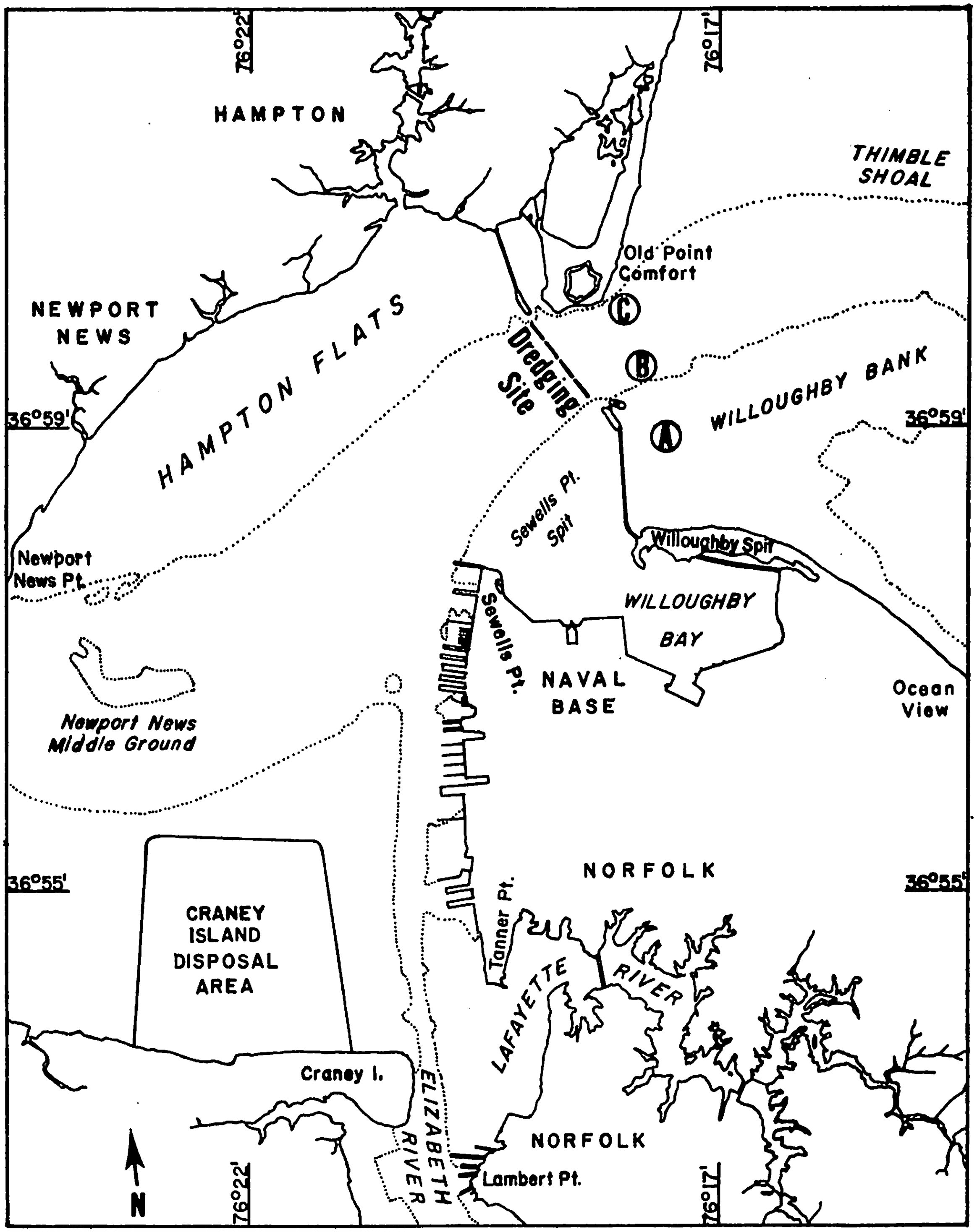


Figure 16. Map of the dredging site and sampling stations.

Willoughby Bank, while stations B ($36^{\circ}59.6'N$, $76^{\circ}17.9'W$) and C ($37^{\circ}00.0'N$, $76^{\circ}18.1'W$) were located in the navigation channel. The location of the monthly slack water station is approximately over the tunnel trench and in mid-channel. DO samples were taken at the surface, mid-depth and bottom of the water column.

It should be noted that the Virginia State Water Control Board has classified the waters of this region as "Class II Estuarine" and has set the water quality standards of 4 mg/ℓ of DO as a minimum and a daily average of not less than 5 mg/ℓ DO.

Natural Variation in Dissolved Oxygen Levels

There are several factors which can cause significant variations in DO levels and which act on the system in a cyclic fashion. A factor which is of obvious concern in any estuarine environment is the tides. In general, tides do not have any direct effect on DO levels but there can be indirect effects. For example, the location of the sampling site relative to sources of BOD will determine when during the tidal cycle low DO levels are likely to be encountered. In addition, the salinity will be highest at high water slack (HWS) and lowest at low water slack (LWS). Since the DO saturation levels decrease with increasing salinity, there is some variation due to the range of salinity levels. The maximum salinity difference likely to occur at any given location is on the order of 5 parts per thousand. For this type of salinity variation, and for typical temperatures, the saturation values will decrease on the order of 0.5 mg/ℓ of DO or less. Therefore, this variation is not likely to be significant in most instances.

Samples taken on July 10, 1971 at the three bridge-tunnel stations are shown in Figure 17. There is no obvious change in DO concentration from HWS to LWS, or in other words, the tidal cycle does not significantly and directly affect the DO regime near the bridge-tunnel. One can note a very slight increase in DO levels in the afternoon hours. This could be due to photosynthetic production of oxygen by algae during the day and respiration of oxygen by the algae during the night. However, this affect is not pronounced and, in general, algae in this region do not change DO levels in any consistent and predictable manner.

Intermediate term variations are not great unless some unusual event, such as Hurricane Agnes, occurs within that time period. Data for high and low water slacks for mid-July 1971 are shown in Figure 18. Although there are trends to each set of data, the actual changes over the 10 day period are not great. The downward trend for the high slack concentrations, especially from the 17th to the 20th, is probably related to increasing water temperatures.

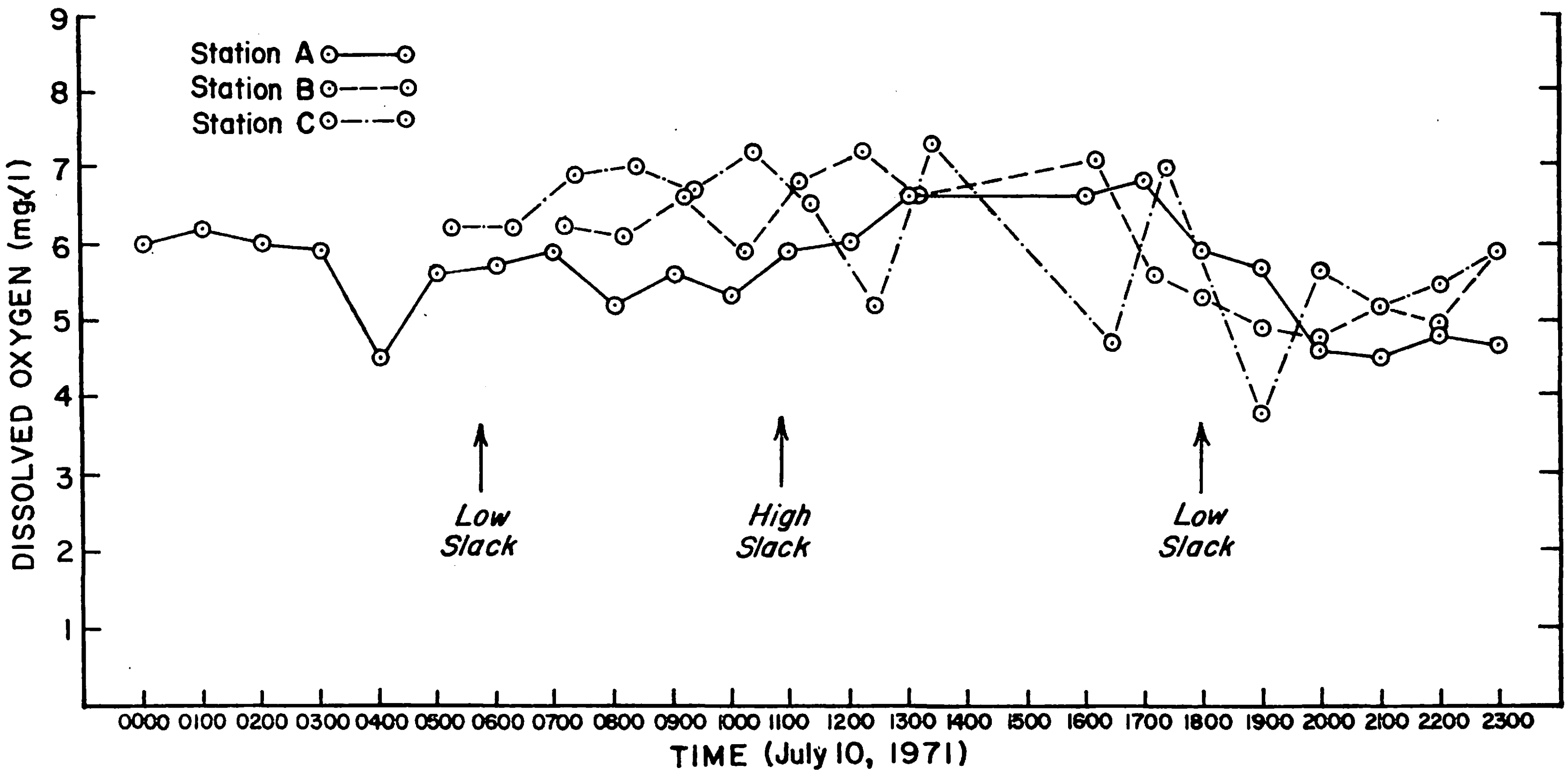


Figure 17. Hourly DO measurements for July 10, 1971 at the mouth of Hampton Roads.

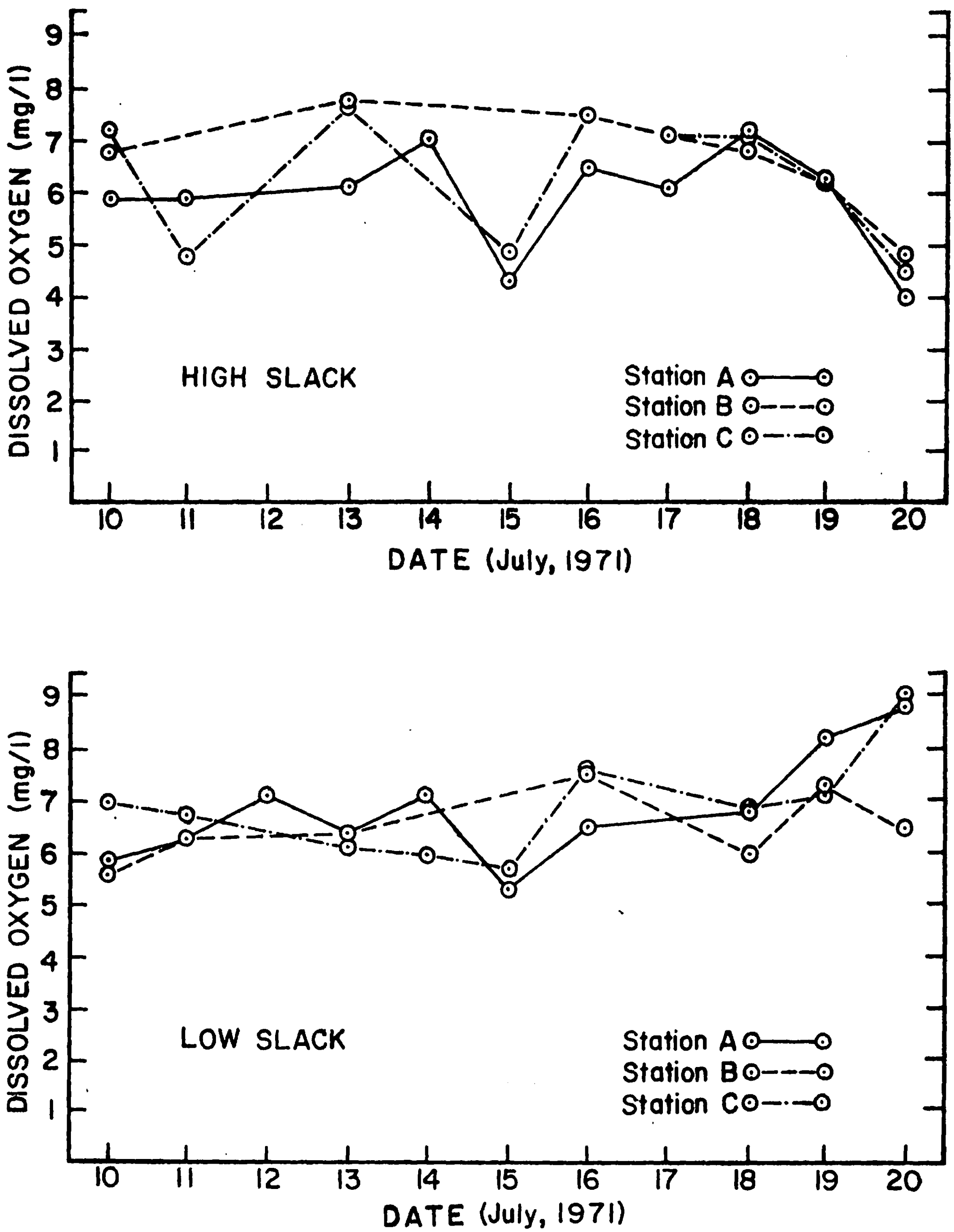


Figure 18. Slack water DO measurements for July 1971 at the mouth of Hampton Roads.

Saturation values for DO vary from 11.3 mg/ℓ for freshwater at 10 degrees Centigrade, a typical winter water temperature, to only 7.6 mg/ℓ for 30°C, a typical summer water temperature. Values for water with 18 parts per thousand of salinity are 10.1 and 6.9 mg/ℓ for the same temperatures. In other words summer saturation values are only about two-thirds of the winter saturation values. A comparable decrease in the observed DO values would be expected.

It is this temperature trend which is probably causing the decrease in high slack DO's. It is not clear why the low slack data for the same period show an upward trend. Several other points are worth noting from these data. First, the day-to-day variations for samples collected at the same tide stage and at the same location are several mg/ℓ of DO. And second, the variations from one station to another on the same transect and at nearly the same time are also several mg/ℓ. These variations can be noted in the hourly data taken on July 10 and shown in Figure 17 as well. For the most part these variations can be attributed to the current patterns.

Tidal flushing promotes mixing and tends to smooth out irregular patterns in the concentration of dissolved substances. In sections of estuaries where the cross-section is narrower, variations across the channel are slight; the estuary is then called sectionally homogeneous. However, when the river channel is several miles wide, it is easy to understand why there can be large changes in water quality from one bank to the other. In addition, the circulation in Hampton Roads is such that the water arriving at adjacent stations may have come from areas many miles apart. For example, the water that leaves the Elizabeth River on ebb tide tends to flow around Sewell's Point and out over Willoughby Bank (Station A). During ebb, the water off Newport News Point will tend to flow down the navigation channel with a large current speed and will pass near Station B. Water on Hampton Flats ebbs with a slower speed and would pass over Station C. Thus one can see that the water which lies over the bridge-tunnel at low water slack has been transported there from widely separated areas. Of course, a great deal of mixing occurs during this process, but the initial differences in water quality are not entirely overcome. Storms, low pressure zones, constant winds from one direction and other meteorological factors modify the typical circulation pattern and the degree of mixing and introduce further variability into the system.

Slack water data for the period June 1971 to August 1974 are shown in Figure 19. The seasonal trend in DO is readily apparent. As noted earlier the primary cause of the seasonal trend is the variation in water temperature and the decrease in the saturation value with increasing temperature and salinity. In addition there is increased bacterial activity at elevated temperatures. For this reason

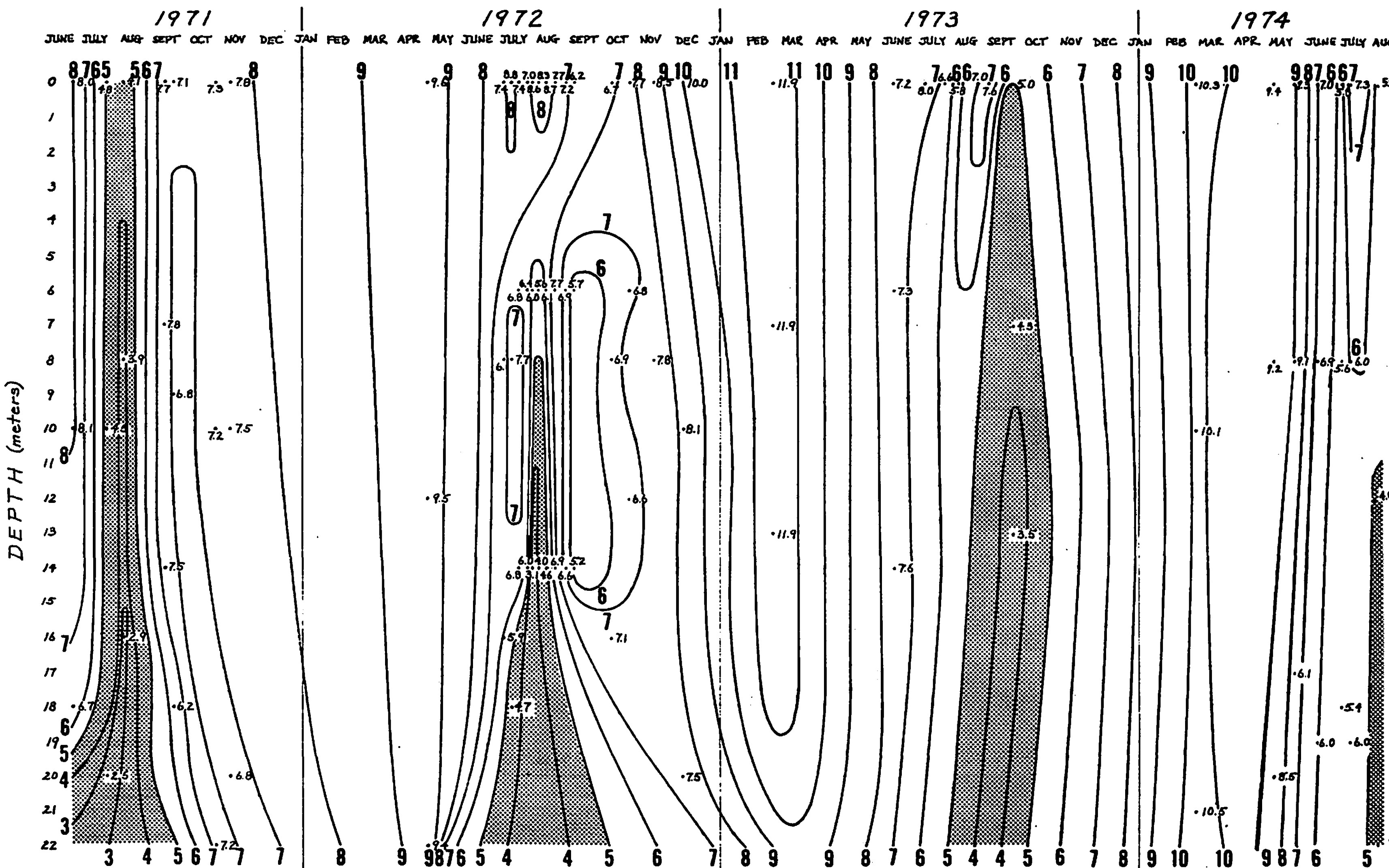


Figure 19. Slack water DO measurements for the period June 1971 to August 1974 at the mouth of Hampton Roads.

sewage treatment plants which employ biological processes are more efficient in the summer and remove a larger portion of the BOD in the sewage. However, many of the treatment plants in the area have only primary (physical) treatment and the increased activity occurs in the estuary rather than in the plant. That means that the region over which the oxygen demand is exerted is reduced, causing a larger decrease in DO in the summer than in the winter for the same BOD loading.

Tidal flows cause mixing but do not entirely eliminate variations in water quality which occur in the water column at any given point. This is due to several factors. In general there will be two more or less distinct layers of water. The upper layer will be fresher and will have a net seaward flow, while the lower layer will be saltier and have a net upstream flow. The halocline, or zone where the salinity changes rapidly, tends to act as a barrier which reduces the mixing between the two layers. Since the primary source of oxygen is the atmosphere, and since molecular diffusion is a very slow process, it is mixing which transports DO to the bottom layer. In addition dead plants and animals normally settle out to the bottom and can exert a significant demand on the oxygen resources. For all of these reasons, DO will tend to be highest at the water surface and lowest near the bottom. This trend is shown in the data given in Figure 19. The bottom layer of water experiences lower DO's sooner and for a longer portion of the year.

There are several months when the existing water quality standards are not met in this region. This appears to be the norm rather than the exception since the low values occurred in 1971, 1972 and 1973, and likewise occurred in 1974 although to a lesser degree.

In summary, there are pronounced natural variations in the DO regime of Hampton Roads. Winter DO concentrations are around 8 or 9 mg/ℓ; whereas, the DO level in the summer usually falls below 5 mg/ℓ for a period of a month or more. Superimposed on this seasonal trend are reasonably large variations due to the circulation pattern in the area and the varying quality of water entering Hampton Roads from the tributaries. Day-to-day variations at any given point and at the same stage of the tide can be as great as 2 or 3 mg/ℓ. The variation across the estuary on any transect for any given time are of an equal size. Variations due to tide stage and vertical stratification exist but are of a smaller order of magnitude.

Affects of Dredging on DO Regime

DO concentrations at the surface near Old Point Comfort measured during slack water runs on the James River for the years 1971, 1973 and 1974 are shown in Figure 20. Data for 1972 have been omitted since Hurricane Agnes occurred during that summer, and therefore, unusual conditions

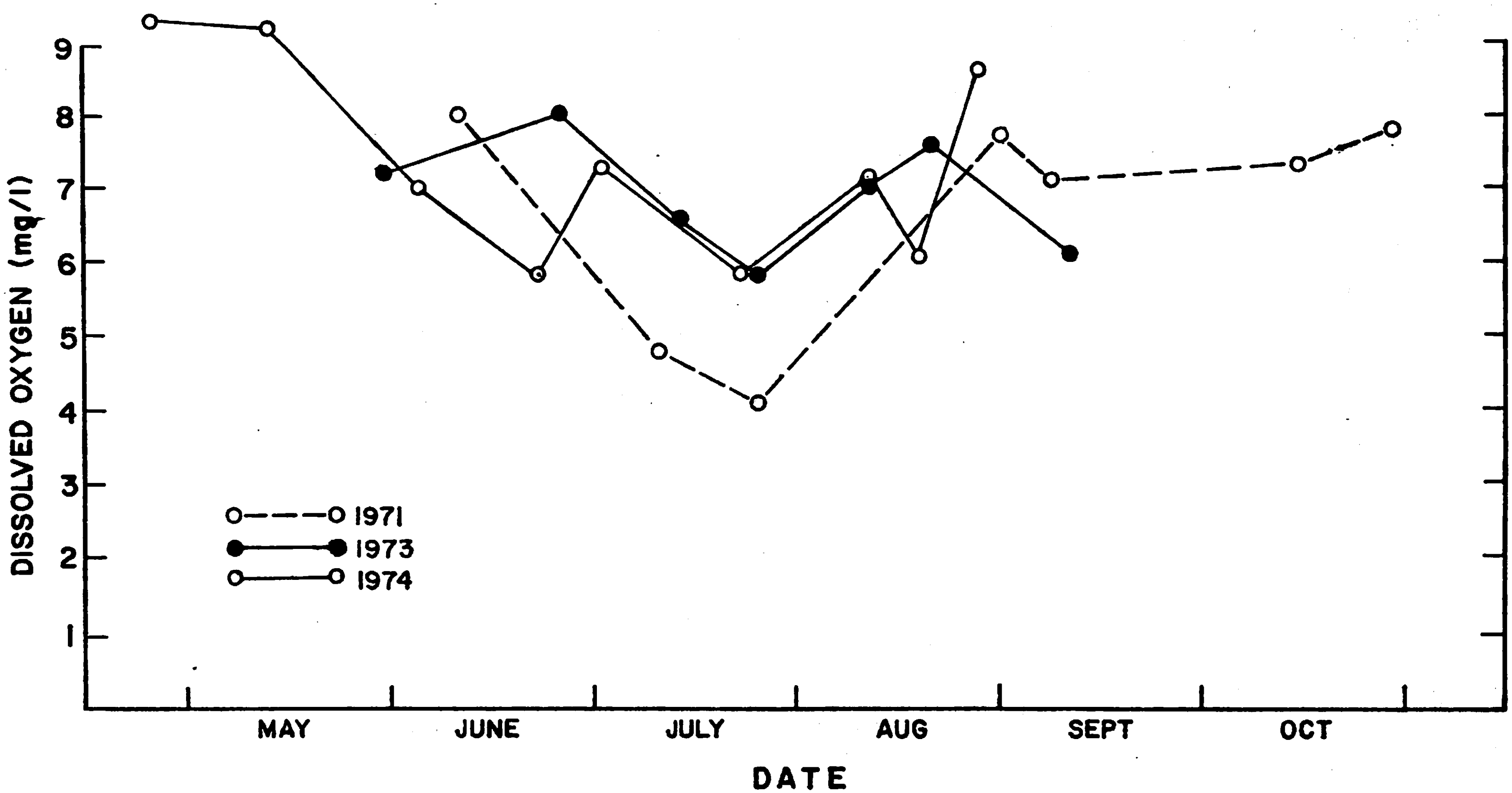


Figure 20. Comparison of slack water DO measurements for typical years (1971 and 1974) and during dredging operations (1973).

existed. The data indicate that the DO levels which existed in 1973 were not unusual and, in fact, were generally higher than those for 1971. All samples collected during 1973 had a DO concentration greater than 5 mg/ℓ.

This shows that the dredging activities did not have any major impact on the DO regime of Hampton Roads. A few simple calculations will help to shed some light on this fact. The mean tidal prism for the James River Estuary (Cronin, 1971) is 305 x 10^6 cubic meters. This is the volume of water which passes through the mouth of the river during an average flood or ebb cycle. In order to have a concentration of any substance of 1 milligrams per liter in this volume of water, 305 metric tons (335 English tons) of that substance are required. Although this volume of water is not "new" each tidal cycle but rather contains much of the water that passed through the area on the previous tidal cycle, it is clear that enormous volumes of dilution water are available. It is not surprising that marked effects were not observed.

Figures 21 and 22 show hourly data for September 12, 1973 and slack water data for the 11th, 12th and 13th of September 1973. The data resemble those given in Figures 17 and 18. Generally, the DO level is between 5 and 7 mg/ℓ and occasionally values as low as 4 mg/ℓ are encountered.

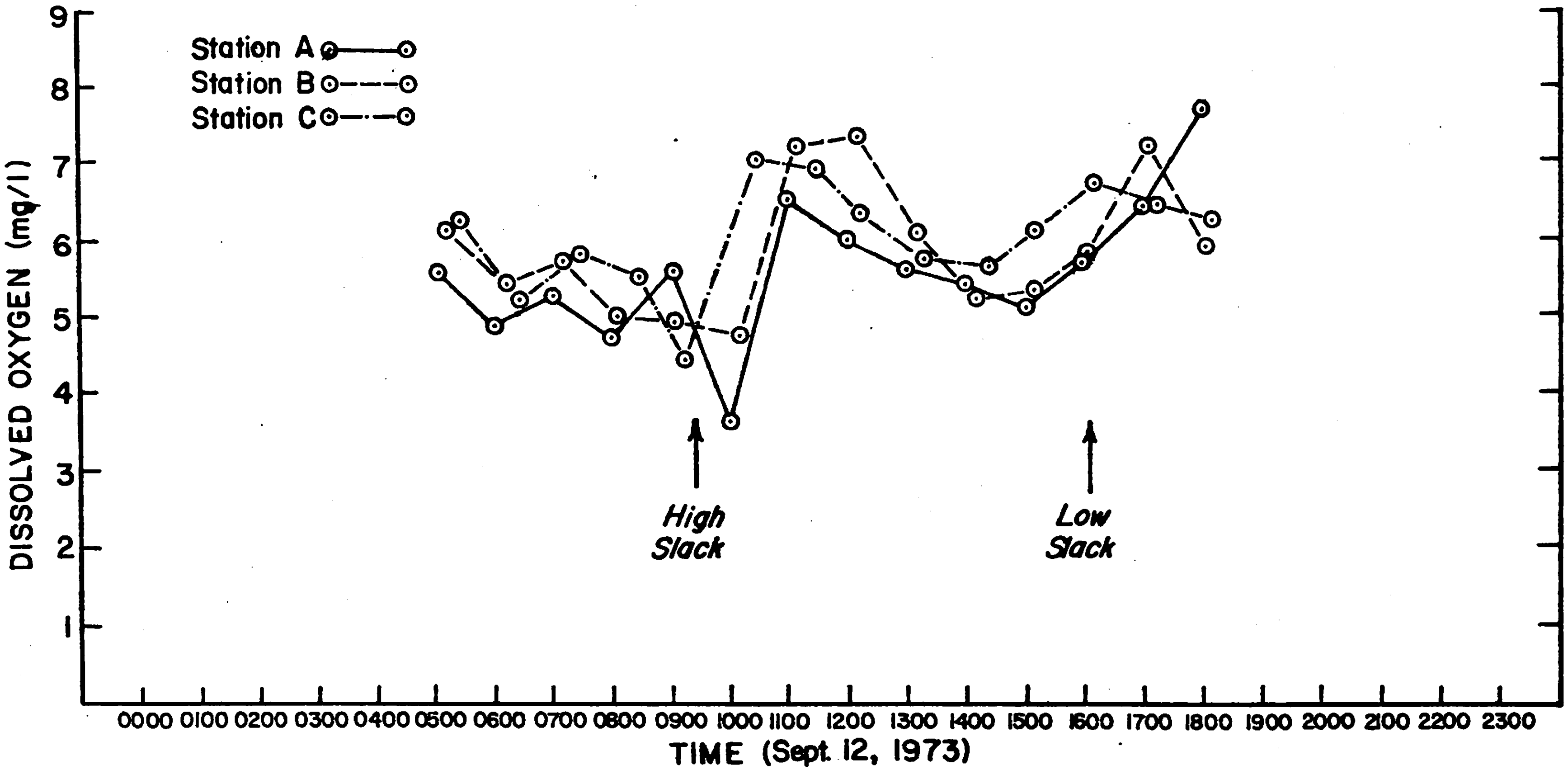
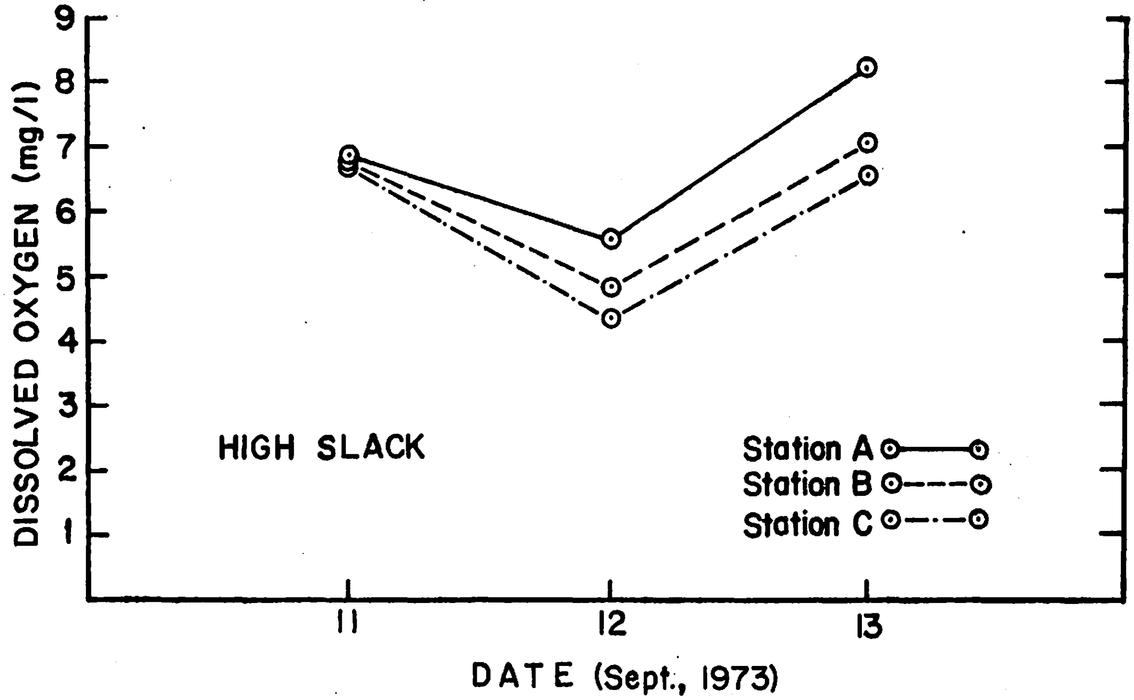


Figure 21. Hourly DO measurements for September 12, 1973 when dredging was taking place.



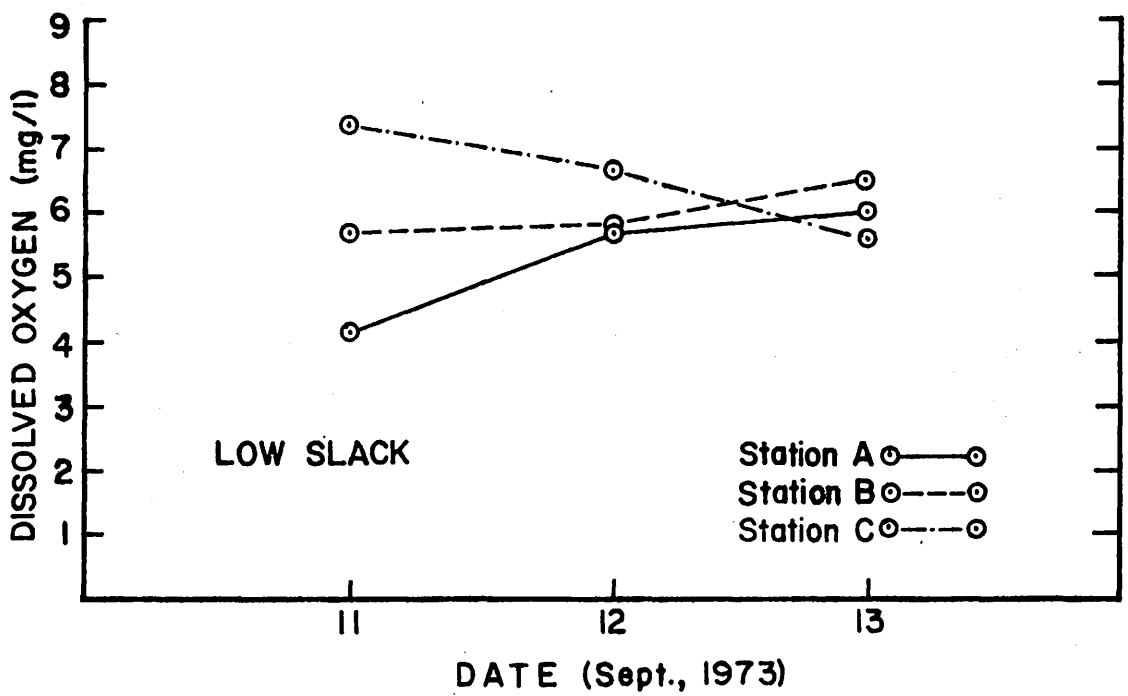


Figure 22. Slack water DO measurements for September 1973 when dredging was taking place.

The hourly data for 1973 show more correlation between stations, but the variations observed cannot be explained by any simple relationship to the tidal stage or time of day. In short, the natural variation of the system is greater than any variation which can be attributed to the dredging activities for the second Hampton Roads Bridge-Tunnel.

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