8-1972

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by

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Virginia Department of Highways Contract No. 0664-504-101 PE101

Special Report in Applied Marine Science
and
Ocean Engineering
Number 24
of the
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

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Director

August, 1972

PHYSICAL AND GEOLOGICAL STUDIES

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ACKNOWLEDGEMENT

We wish to express our appreciation to Mr. Evon Ruzecki, VIMS, for his advice and help in planning this study, and to Mr. Billy Bobb and Mr. Robert Boland of the U. S. Corps of Engineers of Waterways Experiment Station, Vicksburg, Mississippi for their assistance in the hydrualic model study.

The funding of the major portion of this research by the Highway Department of Virginia is appreciated.

SUMMARY AND RECOMMENDATIONS*

The model tests show no drastic changes will result from building any of the three proposed bridge-tunnel configurations. The tidal heights will be changed very little. The average change of 0.1 ft for a total tidal range of 2.5 ft is a change of only 4%. The only exception to this is that Configuration A with Craney Island extended will lower the tidal heights at Newport News Point by 0.35 ft, which is a change of about 15%. Similarly, there is very little change to the overall salinity structure in the Hampton Roads area near Craney Island. Only in the near vicinity of the islands and causeways will the mixing caused by the obstructions to the flow change the salinity patterns, and then the change will be small (less than 0.5 ppt).

*Taken from an August 1, 1972 letter from William J. Hargis, Jr., Director of the Virginia Institute of Marine Science to the Virginia Department of Highways.

The current regime will be altered in ways that are to be expected. Configurations A and B will reduce the area through which the flow must pass as it comes around Newport News Point. The maximum velocities on both ebb and flood are therefore greater due to the constriction. The maximum velocities are increased from around 1.75 fps to about 2.5 fps. Similarly, the flow over Hampton Flats will be restricted by Configuration C, and the velocities will increase slightly as a result (from slightly over 2 fps to around 2.35 fps). The surface-current studies indicate that the flow will be directed by the pilings for the bridge, but this effect was exaggerated in the model since blades, rather than a row of piles, were used.

The effects of the Craney Island extension will not be especially large either. In essence, all that will happen is that the flow from the Nansemond River into the main channel will be "streamlined". The region that will be filled in presently has low velocities in general and, during flood tide, has a large eddy. The results obtained using the present conditions as baseline and those including the Craney Island extension are, for all practical purposes, identical, and there will be no further discussion of the extension.

A general understanding of the flow patterns can be obtained from the drogue field studies and the model confetti studies. Because of the Hampton Roads geometry, the change from ebb tide to flood tide does not occur simultaneously throughout the test area. Rather, the flood tide on Hampton Flats begins several hours before flood in the main channel. Thus the flood tide is the predominant tide for Hampton Flats. The drogue study and the model tests both indicate that the water on the flats funnels into a small area near the point. The higher flows associated with this phenomenon presumably maintain the small channel which is about 1,000 yards offshore near the point.

Configurations A and B will alter this flow pattern by blocking the channel. Since the water will continue to flow past this area, the channel will probably shift its location. In addition, the extension of Newport News Point by these peninsulas will cause eddies to form downstream, near the coal piers on flood tide and on Hampton Flats during ebb. These eddies are expected to increase the deposition of sediments. The gilsonite studies also indicated that there will be increased deposition on Hampton Flats in the near-shore regions. However, there was a slight decrease in the amount of material settling in the main channel for these configurations.

Plan D, which was not tested in the hydraulic model and will shift the Small-Boat Harbor entrance, is expected to behave much like Configurations A and B. A jetty is necessary, however, for safety considerations of the ships using the harbor and to keep the movement of sediment along the beach from blocking the channel.

Configuration C could increase the shoreline erosion because of the increased velocities associated with the constriction of the flow over the Hampton Flats area and also because the bridge pilings will direct the flow towards the shore.

We recommend conducting further studies to investigate the local effects near the islands and the pilings. The confetti tests indicated there will be a wake behind the islands, and the gilsonite studies showed some deposition on either side. The construction of the second I-64 crossing presents a unique opportunity to study a similar problem in the near vicinity of the proposed crossings. We recommend studying the I-64 project so the information will be available for the project at hand.

Records of the construction of those islands will be helpful to indicate necessary precautions for construction. In addition, the prevailing flow pattern and the makeup of the bottom sediments must be considered to best eliminate problems.

PART I

JAMES RIVER HYDRAULIC MODEL TESTS, THE EFFECTS OF THREE PROPOSED TUNNEL ISLAND-CAUSEWAY STRUCTURES IN THE NEWPORT NEWS-PORTSMOUTH REGION

by

B. J. Neilson, A. Y. Kuo, and C. S. Fang

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A. INTRODUCTION

Three scientists and twelve technicians from the Virginia Institute of Marine Science conducted three series of tests in the James River Hydraulic Model, Vicksburg, Mississippi, from May 15 through May 30, 1972. The purpose of the hydraulic model studies was to determine the effects of proposed I-664 river crossing structures on the tides, currents, and distribution of sea salts and sediments in the reach between Old Point Comfort, and the existing James River Bridge. Two basic model-basin configurations were considered. The first was the present basin configuration, including the new islands under construction for the I-64 Hampton Roads Bridge-Tunnel crossing and the second James River Bridge crossing. The second configuration was identical to the first, but added a westward triangular extension of the Craney Island disposal area.

Three of the tunnel-island configurations were tested separately for each basin configuration. The tunnel-islands were located between Newport News Point and Craney Island according to drawings furnished by the Virginia Department of Highways (Figure 1).

Three series of tests were conducted for each of eight configurations:

1) hydraulic tests where tides, currents, and salinities were measured;

2) shoaling tests where distribution of shoaling material was determined; and

3) photographic tests where surface current patterns were determined.

The tests began after a verification test was run to assure the proper initial adjustment of the model. Each test in the present series was preceded by a stabilization period in which the model was run until equilibrium conditions were achieved. Throughout the whole series of model tests, the freshwater inflow at Richmond, Virginia, was maintained at 7500 cfs, which is the average yearly freshwater flow and was recommended by the experienced Army Engineers at the Waterways Experiment Station. The freshwater inflow from the Appomattox, Chickahominy, and other tributaries were properly scaled, resulting in a 9500 cfs freshwater-flow near Hampton Roads. The model was operated with a mean tide and ocean-sump salinity adjusted to mean-flow conditions.

B. EXPERIMENTAL PLANNING AND PROCEDURES

1. PLANNING

Four transects were used to gather the appropriate and necessary data. Two transects were in the immediate vicinity of the crossing corridor and the other two were located further upstream and downstream. In addition, several single-point stations were used to study special points (Figure 2). A point near the Hampton Roads Bridge Tunnel (Station 1) and a point near the James River Bridge (Station 7) were used as control points. The currents were measured at Station 1 during the entire period of current measurements, and slack-water salinities were gathered from both Stations 1 and 7 during the salinity measurements. For all other stations, the currents and salinities were measured over a two-tidal-cycle period. Tidal heights were measured at the three tide-gauge stations (shown in Figure 2) over three tidal cycles.

Currents were measured every half hour, following standard WES procedures, and the salinities were measured hourly. Data sheets were designed and reproduced to conform to the anticipated data-collection program. Tidal-height readings were recorded on the standard Waterways Experiment Station (WES) form.

A grid (Figure 3) was designed for the shoaling studies. The purpose of the grid was to provide areas from which the gilsonite could be "vacuumed" so the major features of the shoaling can be seen from the data collected. The grid was centered on the crossing corridor, using lines through the Configuration A and C tunnel islands as the north-south axes and also the east-west axes. The areas near the tunnel islands were small, and the size increased as the area became increasingly remote from the island and causeway region.

It was understood that the shoaling tests were somewhat qualitative in nature. Because the water depth is so shallow in areas such as the Hampton Flats, the velocities are not sufficient to move the gilsonite to any great extent. Therefore, a photograph was taken after each shoaling study. In this manner, some of the small-scale features were recorded which would otherwise be lost in the numerical data.

2. TEST SCHEDULE

April 27 through May 14 —
Model Preparation (clean and verify the model, construction of test islands and causeways)

EXPLANATION OF STUDY CODE

1: present basin configuration
2: with Craney Island extension
A, B, C: Proposed bridge-tunnel configurations
X: Baseline configuration
H: Hydraulic test
G: Gilsonite test

May			
15	Test:	1-A-H	
16	Test:	1-B-H	
16		1-C-H	
16		1-X-H	
17	Test:	1-X-G	aborted — due to mechanical problems and improper techniques
	Test:	1-X-G	
	——	——	salinity samples processed
18	Photography tests — all configurations — salinity samples processed		
	Test:	2-A-H	
19	Test:	2-B-H	
		2-C-H	
		2-X-H	
20	Test:	2-X-G	
22	Test:	2-A-G	
		2-B-G	
23	Test:	2-C-G	
		1-A-G	
24	Test:	1-B-G	
		1-C-G	aborted due to mechanical failure
25	Test:	1-C-G	

3. TEST PROCEDURES

a. Hydraulic Tests

1) Run model to equilibrium conditions (4-6 hrs);
2) Measure for basic basin configuration
   a) currents
   b) tidal heights
   c) salinities
3) Insert proposed islands (A);
4) Run model to achieve equilibrium state for bridge-tunnel configuration (2-3 hrs max);
5) Repeat step 2);
6) Repeat steps 3)-5) for the second configuration (B);
7) Repeat steps 3)-5) for the third configuration (C);
8) Insert Craney Island extension;
9) Repeat steps 1)-7).

b. Shoaling Tests

1) Run the model for 24 tidal cycles to achieve equilibrium condition;
2) Add gilsonite along transect from Craney Island to Newport News Point continuously for 3 tidal cycles;
3) Add gilsonite along channel from Hampton Roads Bridge-Tunnel to James River Bridge, continuously for six tidal cycles;

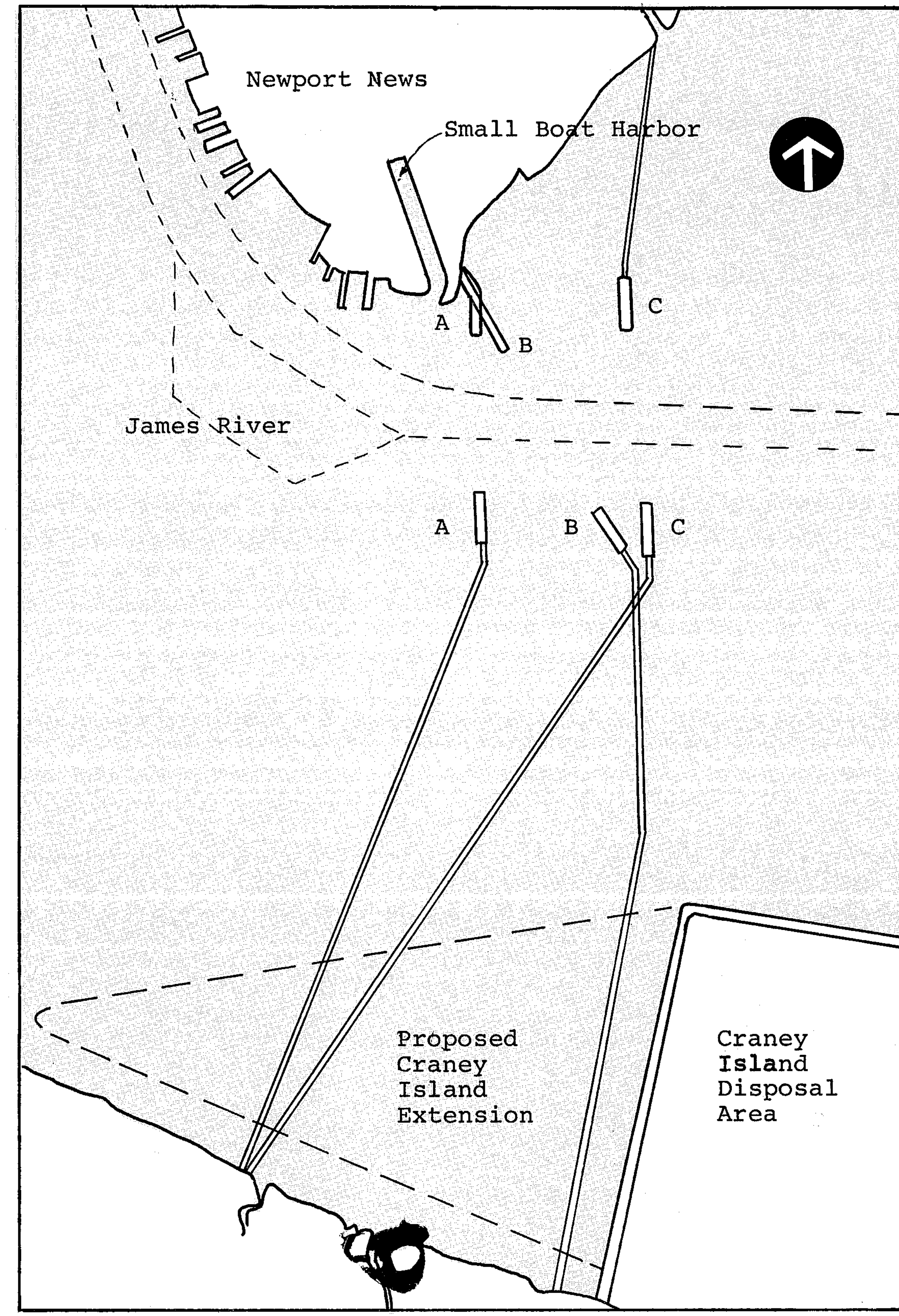


Figure 1 — Tunnel-Island Configurations

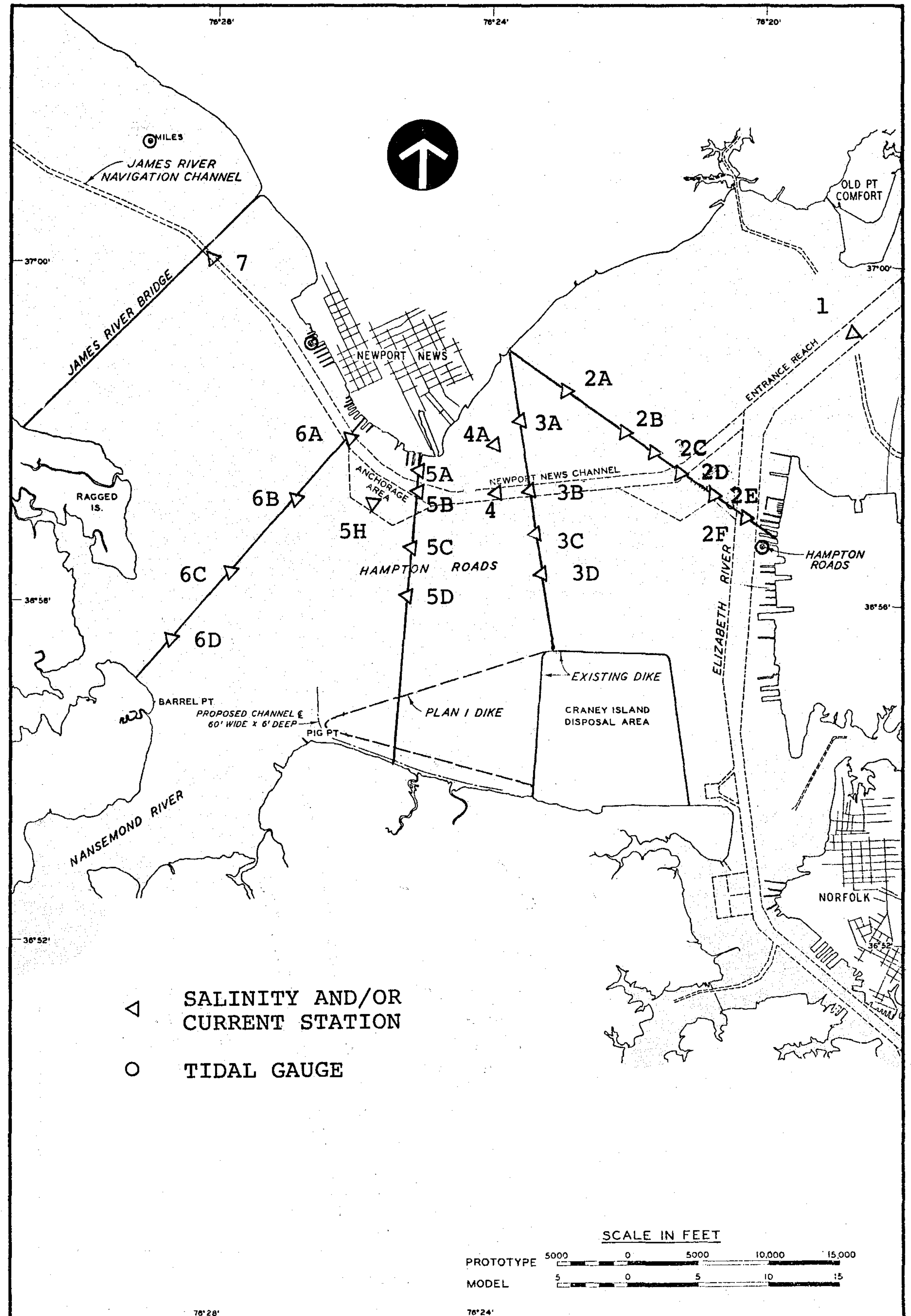


Figure 2 — Measuring Station Locations

4) Run model for 12 tidal cycles to achieve equilibrium distribution of gilsonite;
5) Stop tides and freshwater flow, insert dam at James River Bridge;
6) Photograph
7) Collect gilsonite from the model;
8) Measure gilsonite collected from each of the grid regions;
9) Repeat steps 1)-8) for each of eight combinations as shown below:

	Base	Tunnel (A)	Tunnel (B)	Tunnel (C)
Present Config.	1X	1A	1B	1C
Present + C.I. extension	2X	2A	2B	2C

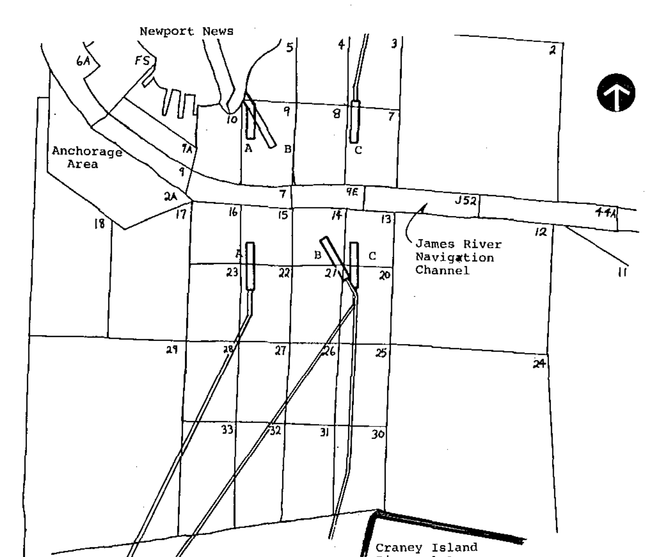


Figure 3 — Grid Designed for Gilsonite Studies

C. EXPERIMENTAL METHODS AND INSTRUMENTS

1. TIDE MACHINE

The tidal heights were controlled by having a constant inflow from the sump to the ocean-side of the model and by varying the heights of the outlet gates to change the outflow. The tidal gauge near Thimble Shoals was used as the control gauge. The operator maintained the tidal heights at that point to duplicate the standard tidal-height curve. Both curves were plotted continuously at the control desk.

Tidal clocks were used which gave both the time in the tidal cycle and the number of the tidal cycle since the machine was started. The tidal clock was 12½ hours to the cycle (Figure 4).

Lights are located near sampling points. These lights are controlled by the tidal machine and come on for 10 seconds and then go off for 8 more seconds, with 18 seconds in the model corresponding to one-half hour in the real world. A complete tidal cycle took 7 minutes and 26 seconds.

The model is started by filling the section downstream from the James River Bridge with salt water and the portion upstream from the bridge with fresh water. At a given point in the tidal cycle, a gate located just upstream from the bridge is removed. The model must then be allowed to reach an equilibrium state before sampling can begin. This period of time is dependent on the fresh water inflow. Three hours (real time) were allowed as a minimum for a 7500 cps inflow at Richmond, and more time was usually given.

At least an hour was allowed for equilibrium conditions when islands and bridges were changed.

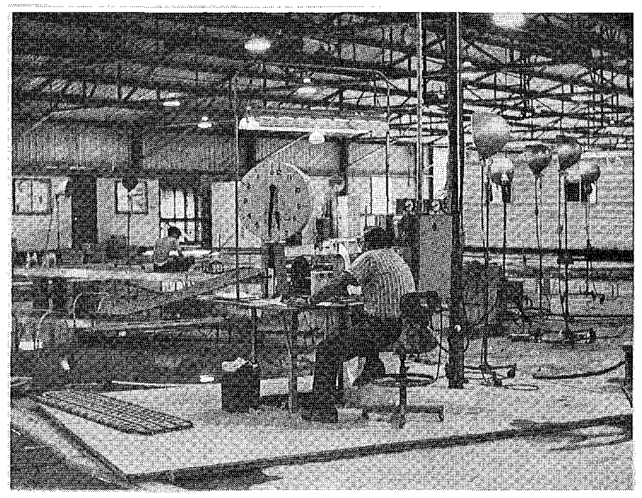


Figure 4 – The Control Panel for the Tide Machine. The tidal clock gives both the tidal hour and the cycle number.

2. SALINITY MEASUREMENTS

Salinity samples were collected hourly, the surface and mid-depth samples were collected on the hour, and the bottom samples were collected on the half hour. Samples were collected by withdrawing about 5 cc of water into a burette (Figure 5) and then placing the sample in a glass vial in a rack. The racks of vials were marked so that the samples could be identified as to station, study, and tidal hour.

The salinity at the Atlantic-Ocean-end of the model was maintained at a constant value (24.2 ppt). The model operator periodically checked the salinity and, when necessary, added salt to the sump. The salt came in 100-lb bags, and was mixed into the water by continuously circulating the water in the sump.

It is very important to take samples at the same point in space. The horizontal location is important, of course, but the vertical location is even more important since it is more difficult to

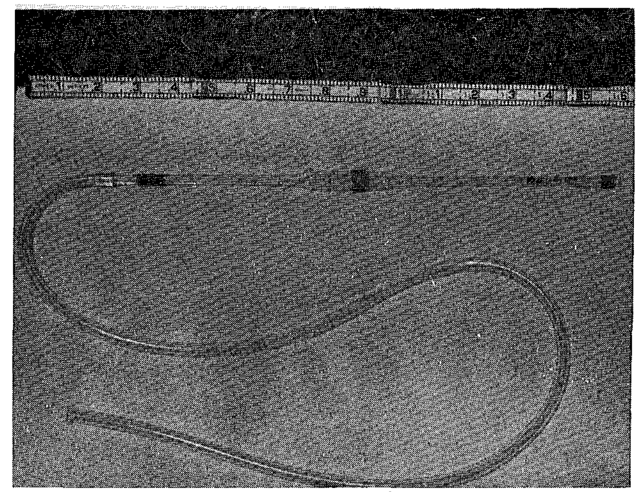


Figure 5 – Pipette and Tubing used to Collect Salinity Samples

duplicate. Care must be taken when withdrawing samples from the surface layers to be sure the pipette is immersed to the same depth and the sample is withdrawn gently. If the sample is withdrawn very quickly, it is likely to have come from the layers below the surface rather than the surface.

Similarly, when sampling at the bottom it is possible to bias the samples by prematurely placing the pipette in the water since the tube will fill with water at a different time and point from that desired. However, the bottom samples are more accurate since the elevation is fixed. Samples withdrawn from any other depth are likely to show variations because of changes in the sampling level as well as from differences caused by time in the tidal cycle. In general, the disturbances were kept to a minimum by placing the pipette into the water in as smooth a fashion and for as short a period of time as possible.

The WES salinometers, which measure the electrical conductivity of the sample, are easy to operate. Thus the process is a two-step one; first the conductivity reading and then the change to salinity using calibration curves applicable to each conductivity probe (see Figure 6).

While salinity samples were being collected along the transects close to the tunnel islands, high- and low-water slack samples were taken at Stations 1 (Hampton Roads Bridge Tunnel) and 7 (James River Bridge). Thus we have a check to see whether the salinity distribution varied from tidal cycle to tidal cycle in a test. Ideally, one would take salinity samples at all stations simultaneously. However, since that would take a very large number of persons, the samples were taken transect by transect, moving from the Hampton Roads Bridge-Tunnel upstream towards the James River Bridge.

The slack-water salinities should be constant throughout each testing period. There were some errors due to judgment involving the exact time of slack water and errors in the analysis procedures. However, these errors seem to be random in nature and there are no recognizable trends to the data. That is, the salinity did not tend to increase or decrease with time. The salinities for the bottom measurements normally did not vary more than 0.2 ppt above or below the average value of 21 ppt, while the top measurements did vary up to 0.7 ppt above and below the average value of 18 ppt.

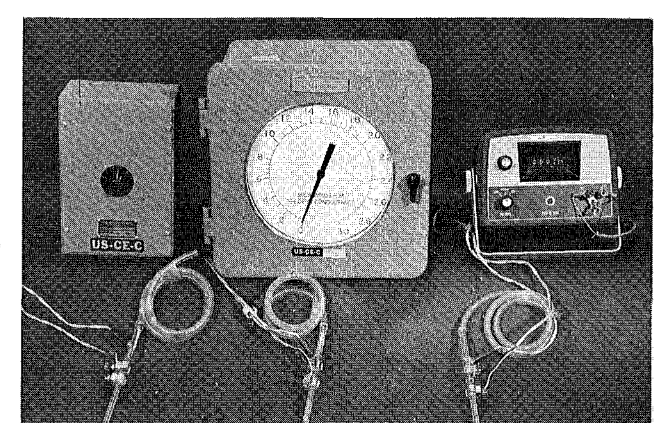


Figure 6 – Salinometry Equipment, including three conductivity probes and digital read-out

3. TIDAL HEIGHTS

Tidal heights were measured for three tidal cycles at three tidal gauge stations (one is shown in Figure 7): Hampton Roads (HR) which is located in Norfolk at the Navy Shipyards on the Elizabeth River; Newport News (NN) which is located at the Newport News Shipyards and Dry Docks in Newport News; and Miles (MI) which is located just upstream from the James River Bridge on the Newport News side of the channel.

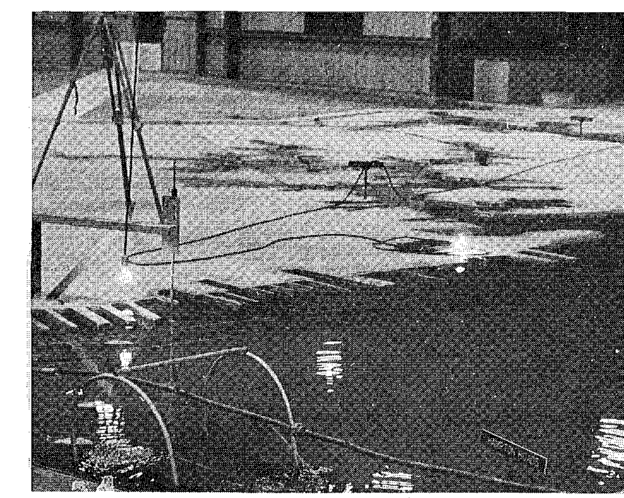


Figure 7 – The Hampton Roads Tide Gauge. Two of the lights used to signal time intervals can be seen, one immediately beside the tide gauge. The gilsonite distribution line is in the foreground.

The tidal heights were measured in the model by lowering a pointed rod until the tip touched the water surface. Surface tension caused the water surface to be disturbed when the point touched the surface, and this effect was easily noticed. Thus the readings were easy to take, and reproducibility was good from both the human and the machine standpoints. The primary source of error was involved with time lags between the time the light went on and the time the point actually touched the water surface. Ideally the time lag would be constant, so that no matter what it were, one would get good readings, only with a slight phase change. However, it was very difficult to maintain a constant time lag, since one did not know just how far above the water surface the point was when he lowered it. If one lowered the point rapidly, it was likely to overshoot and get a lower reading. However, if one lowered the point slowly, there could be a several-second delay before the surface was pierced. When the tide was rising or falling rapidly, this delay could cause an appreciable error. However, the tidal-height readings were very consistent from cycle to cycle, with the estimated error less than ± 0.1 ft.

The tidal stations in the model are permanently-placed stations. The vernier scales for the gauges were adjusted so mean low-water fell on an integer on the large scale. This point was then used as the zero reading or reference height. The vernier scale gives the 0.1-ft readings for the prototype and the large scale gives the integer foot-readings.

4. CURRENT VELOCITIES

The current-meters used in this study have been used extensively and proved satisfactory by WES for hydraulic model tests. Figure 8 shows a picture of a current-meter, which is a kind of miniature cup anemometer. The meter has five cups, and the total diameter of the disc is about 1.5 inches. Speeds can be read with reasonable accuracy to the nearest 0.1 of a revolution at low speed and 0.2 of a revolution at high speed, although the WES calibration curves are rated in steps of a quarter revolution.

In the present studies, a simple technique was devised by VIMS to measure the current directions. Direction rosettes were placed on the model floor underneath the current-meters (Figure 9) and a piece of thread was attached to the rear of the meter bracket. The meter was rotated with the changing direction of tidal current such that it always faced the current. The thread trailing behind the meter indicated the

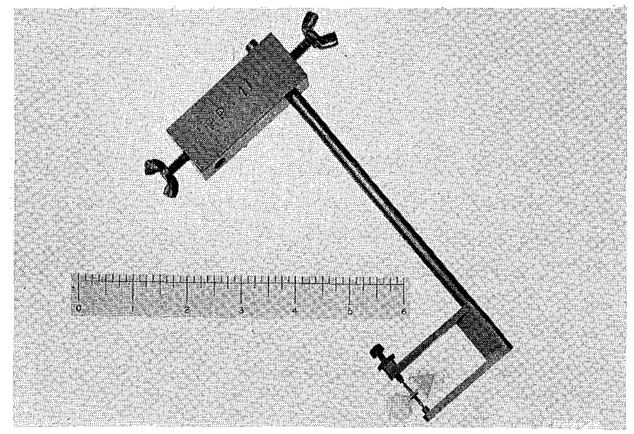


Figure 8 — Hydraulic-Model Current-Meter used by Waterways Experiment Station

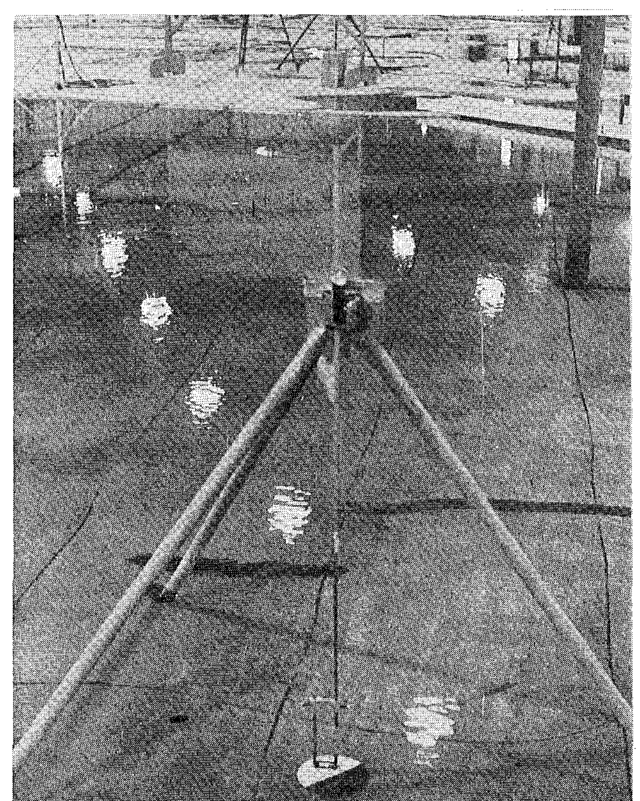


Figure 9 — Current Meter in Position for Measurement. The tripod is positioned so the current meter is directly above the direction rosette.

current direction. At most stations where the current direction did not vary widely and frequently, the direction reading could be accurate to ± 15°.

At Stations 2C, 2D, 2E, 2F, 3B, 4, 5B, 5H, 6A, and 7 where the water depths permitted, the current velocities were measured at the surface, mid-depth, and bottom. Only the mid-depth or surface and bottom currents were measured at the shallow stations, depending on the water depths.

The currents were measured every half hour, following standard WES procedures. The numbers of revolutions were counted during the 10-second interval over which the lights controlled by tidal machine were on. The revolution readings were recorded and later converted to prototype ft/sec (fps) through calibration tables. The velocities thus obtained correspond to velocities averaged over 16.5 minutes in the prototype.

5. SURFACE-CURRENT MEASUREMENT
(Confetti Time-Lapse Photography)

The surface currents were measured using time-lapse photography and confetti on the water surface to trace out the pathlines. A strobe light flashed near the end of the three-second photographing interval, marking the end-point of the path line. This technique gives very good synoptic data since the current speeds and directions for the entire area photographed can be seen easily. The method is also a quantitative one; the time of film exposure is known, and a length scale is included in the photo, so the velocity at any given point can be calculated.

The cameras were positioned on catwalks above the model, and almost any coverage desired could be provided. The time-lapse photos were taken every hour (prototype time), giving thirteen photos per tidal-cycle.

6. GILSONITE STUDIES

The testing procedures for gilsonite studies were outlined in Paragraph B.3.b. After the model was flooded and the tide machine started, it was necessary to wait until equilibrium conditions were reached. These conditions occurred when the salinity structure had developed to the point where the changes from one tidal cycle to another were minimum. For these tests, 24 tidal cycles were allowed.

The gilsonite was maintained in a 5% slurry in a large circular tank equipped with a rotor. The slurry was injected into the model via ½-inch pipes about 18 inches above the water surface, with holes spaced about 1 ft apart (Figure 10). Catwalks were placed near the gilsonite injection lines for access to immediately clear the holes if they were plugged with larger pieces of gilsonite.

Gilsonite was injected for three tidal cycles through a pipe running perpendicular to the channel from a point halfway between the Small-Boat Harbor and Salters Creek to a point near Hoffler Creek just west of Craney Island. At the completion of this injection the lines were flushed with clear water for one tidal cycle. Gilsonite was then injected for six tidal cycles through the pipe following the main channel, from just upstream from the James River Bridge to just upstream from the Hampton Roads Bridge-Tunnel. When this was completed the line was again flushed with clear water for another tidal cycle.

The amount of gilsonite added varied from 44,000 to 48,000 cc, with the percent recovered in the "vacuuming" ranging from 39% to 46%. The distribution of gilsonite injected probably varied somewhat as well, but after the first aborted test, the gilsonite tank was cleaned and the flow of slurry from the pipes was, in general, quite uniform. Thus, variations from test to test were probably minimal.

Figure 10 — Gilsonite Injection (A dark cloud of gilsonite can be seen, as a stream of slurry from the injection line enters the main channel.)

The catwalks were removed after the gilsonite was injected. It was necessary to use an arrangement for catwalks that allowed for their removal with a minimum of disturbance to the model. The model was run for a period to allow the gilsonite to settle out and remain in that place. Usually little gilsonite was being transported after two or three cycles, but twelve tidal cycles were given to this equilibrium period. At the end of this time, the dike was inserted just upstream of the James River Bridge and the tide machine was turned off. It was at this point that a photograph of the model was taken. While the "vacuuming" gives quantitative results, small-scale features are lost unless a very small grid is used. The photographic record permits an examination of these features (such as scour or deposition near causeways and islands) and comparisons between the various configurations.

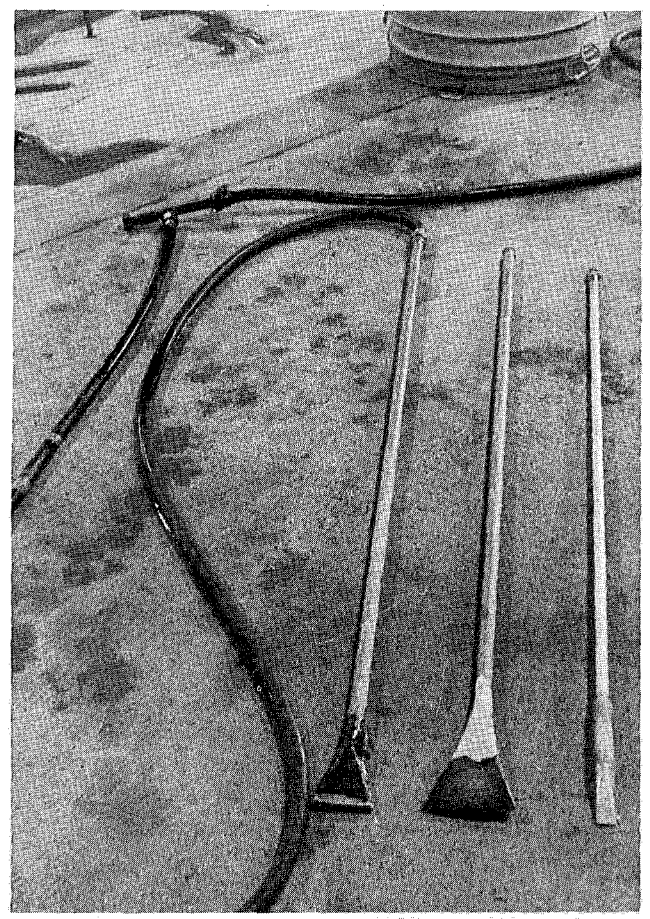


Figure 11 — Hydraulic-Model Aspirator Used by Waterways Experiment Station, showing additional nozzles of varying size.

Figure 11 is a photo of the aspirators used to collect the gilsonite from the model. The aspirator works by the venturi principle. Water flowing through the hose is accelerated by a local constriction as it passes through a T-coupling. This causes a pressure drop, sucking in water and gilsonite from the "leg of the T". The aspirator is equipped with special nozzles to facilitate picking up the gilsonite. The discharge is kept in large tubs, the tubs being marked with tags on the handles. Figure 12 shows an aspirator in action.

Once all the gilsonite was collected, the samples were "poured down". The pouring-down procedure involved pouring off the excess water in the tubs and combining the samples collected from the same area. The final volumes of gilsonite slurry from each area, usually less than two liters, were poured into graduated cylinders. The standard WES procedures for the measuring were then followed. This entailed labeling the cylinder of slurry with the appropriate area and time, and allowing it to sit for ten minutes. At this point, it was rotated through 180 degrees to give a level surface to the gilsonite. The slurry was allowed to settle for another 20 minutes, for a total settling time of thirty minutes, at which time the reading was taken (Figure 13). In general, the same people performed the same task each study so that variations from person to person were minimized.

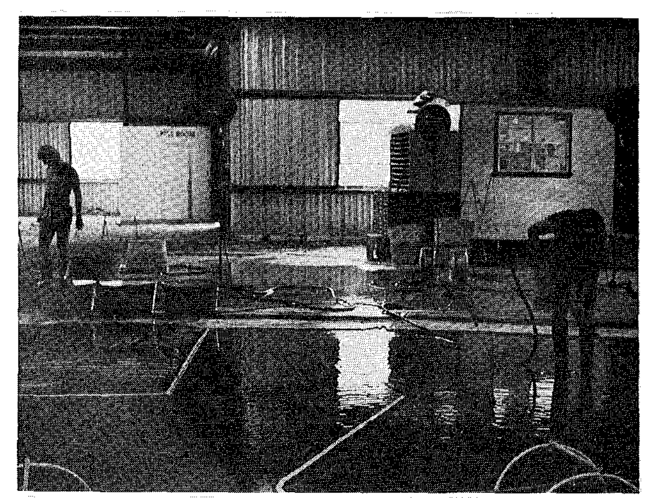


Figure 12 — An Aspirator in Use, the tubs used to collect the slurry are at the left rear.

D. RESULTS AND DISCUSSIONS

The experimental data is presented in tabulated form in Part IV of this Appendix. The raw data was punched into computer cards with all of the pertinent information, such as test case, station number, tidal hour, etc.

1. SALINITIES

The salinity data presented was averaged for two tidal cycles. The data can be considered to be accurate to 0.2 ppt for bottom salinities and to 0.7 ppt for surface salinities.

The salinities at Stations 2B, 3A, 3D, 4, 5A, 6A, and 6C are shown as a function of time in Figures 14 through 29. The salinity structure of the whole Hampton Roads area was not significantly changed by the addition of any of the proposed tunnel islands and causeways.

Figure 13 — Measuring the Gilsonite Collected

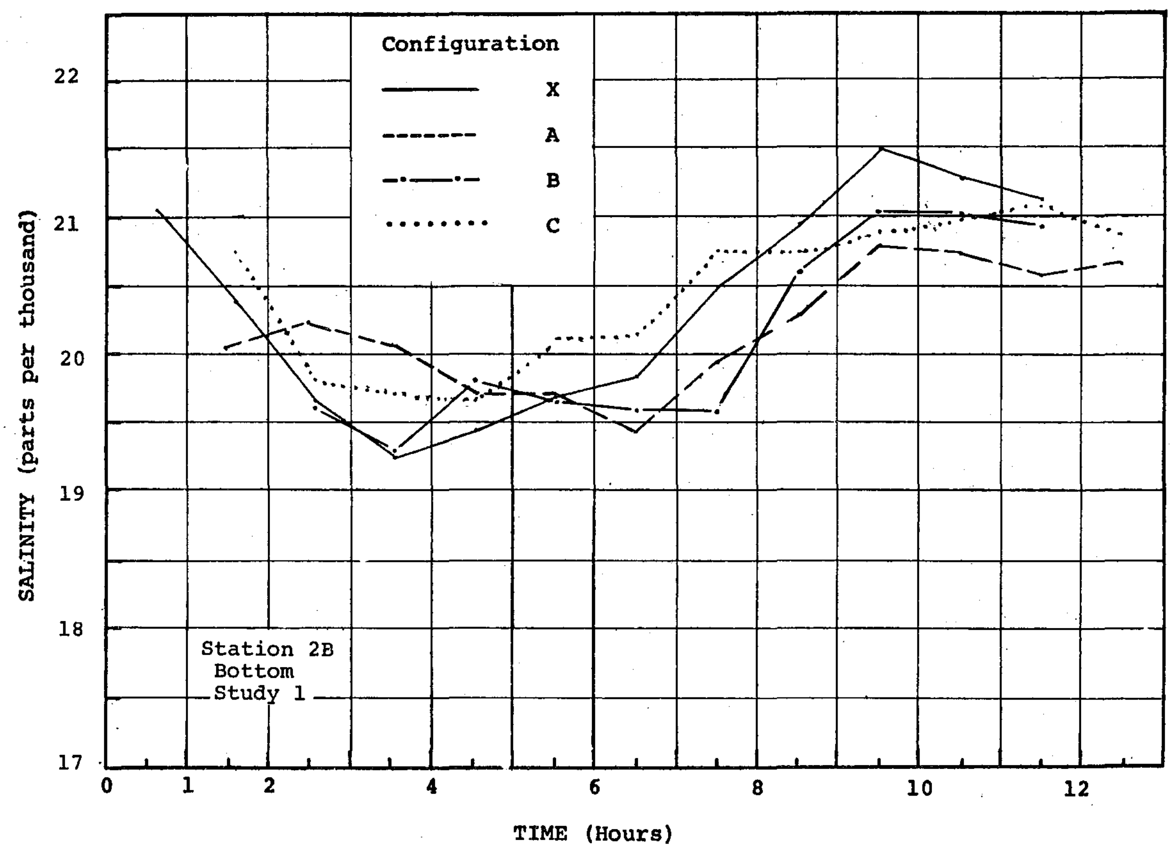


Figure 14 – Bottom Salinity Variation over a tidal cycle at Station 2B without Craney Island extension

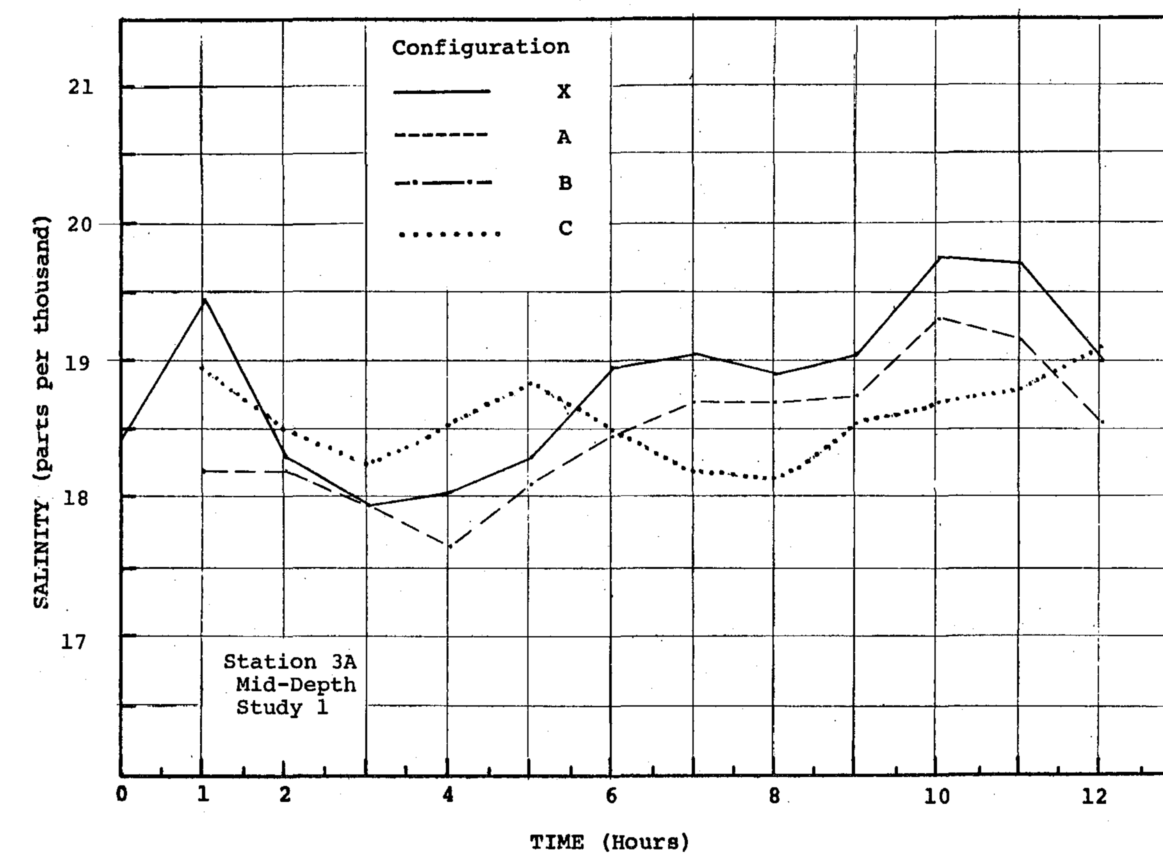


Figure 16 – Mid-Depth Salinity Variation over a tidal cycle at Station 3A without Craney Island extension

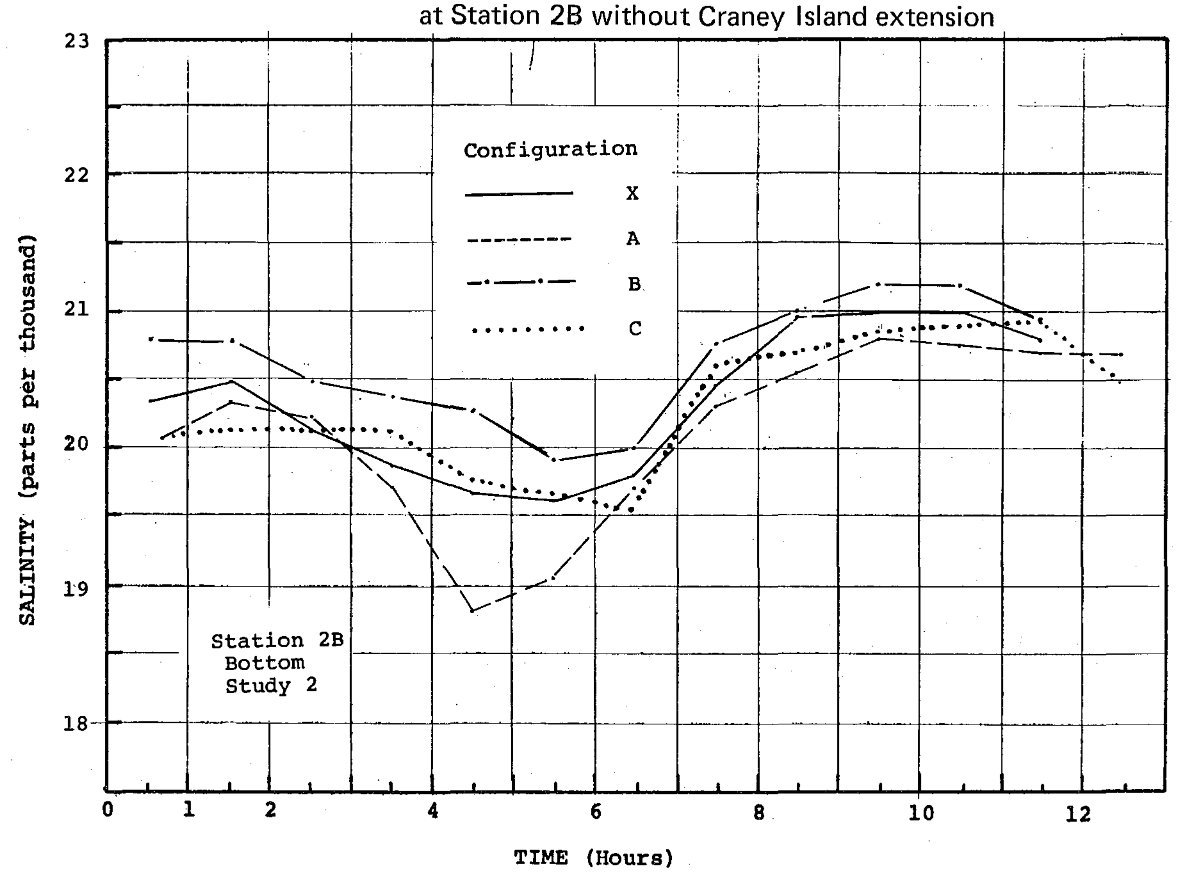


Figure 15 – Bottom Salinity Variation over a tidal cycle at Station 2B with Craney Island extension

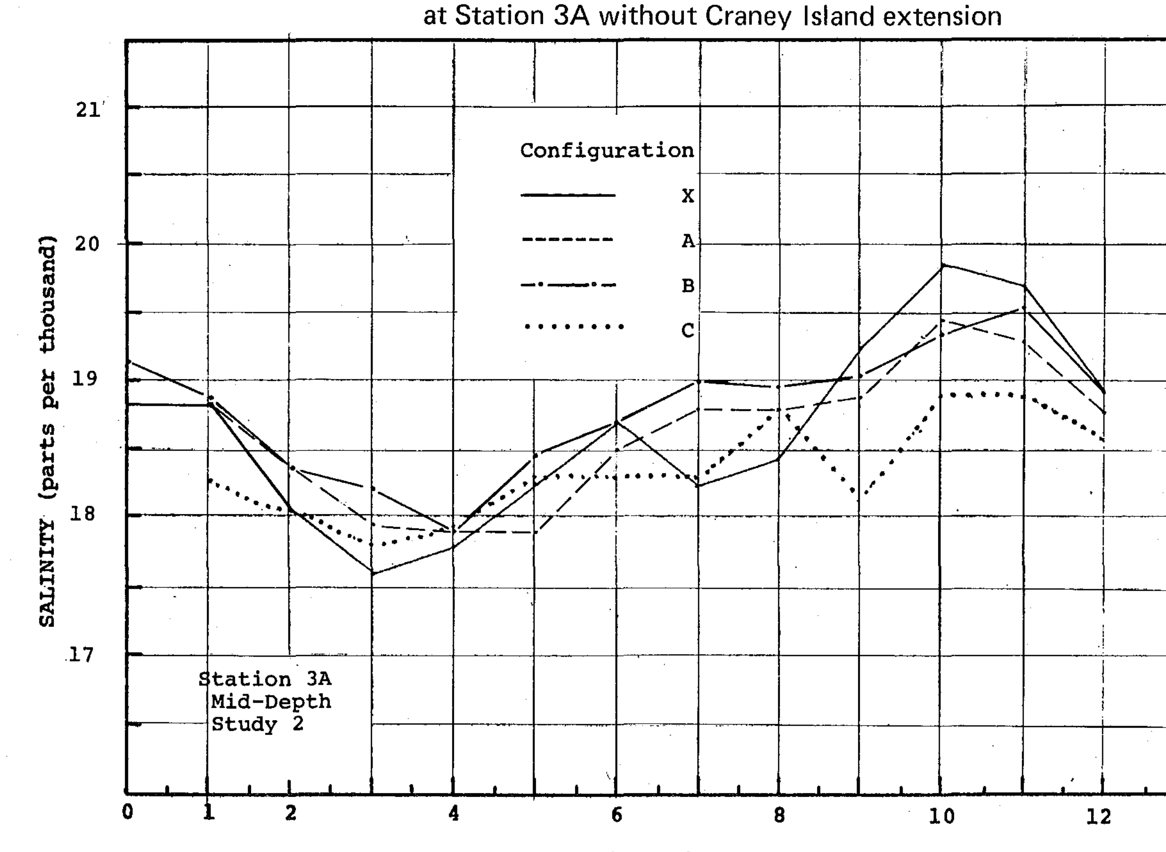


Figure 17 – Mid-Depth Salinity Variation over a tidal cycle at Station 3A with Craney Island extension

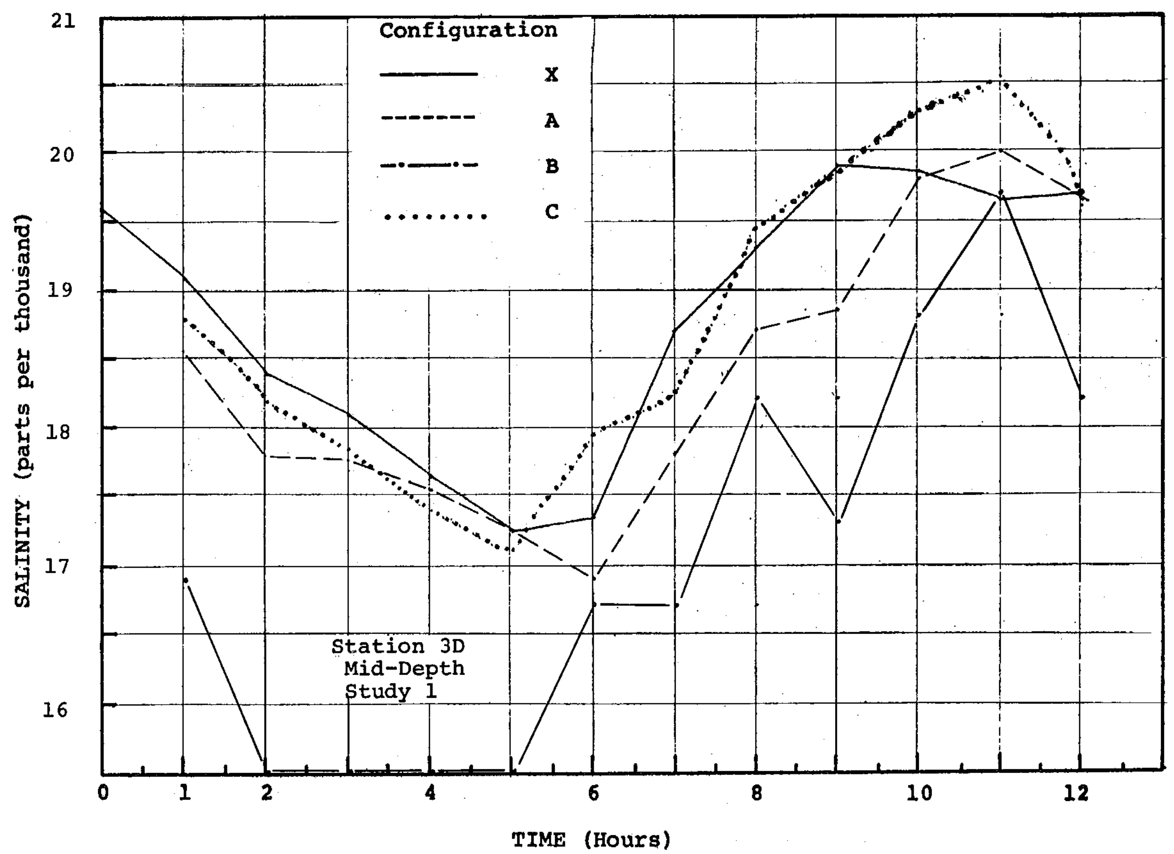


Figure 18 – Mid-Depth Salinity Variation over a tidal cycle at Station 3D without Craney Island extension

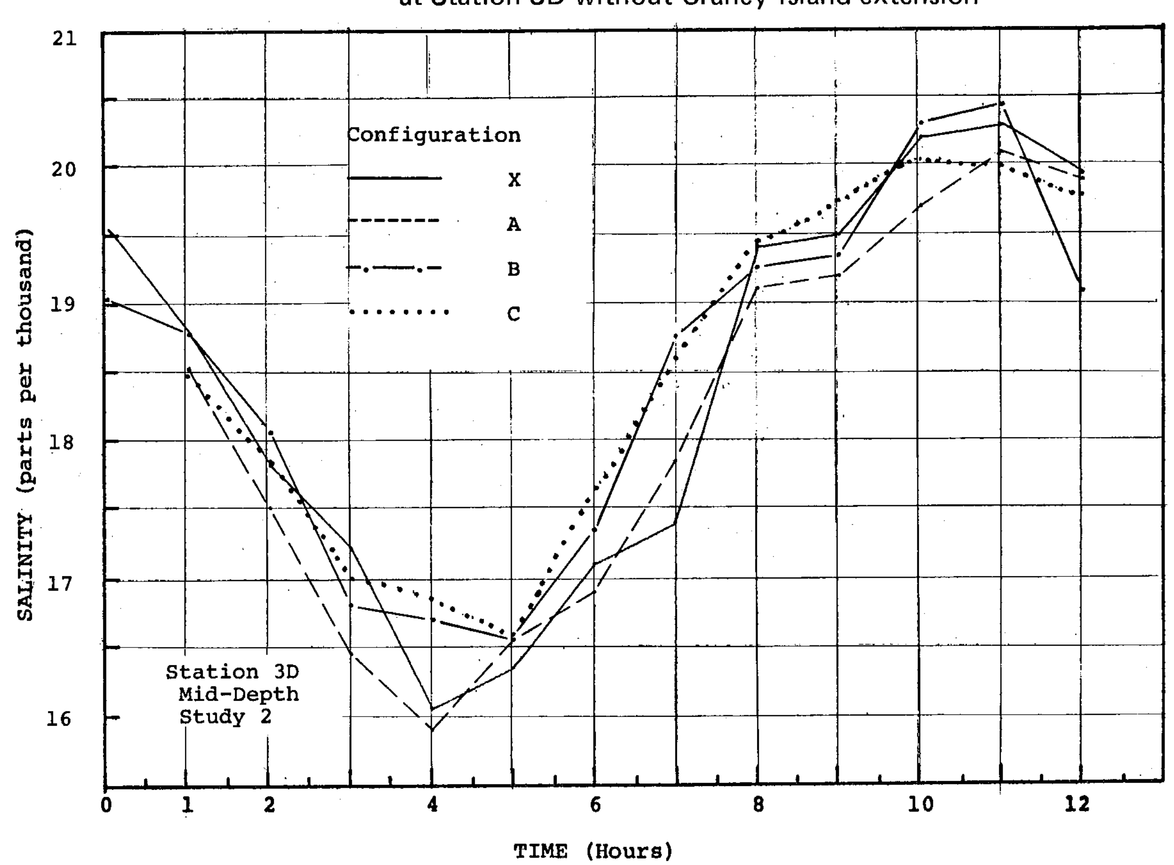


Figure 19 – Mid-Depth Salinity Variation over a tidal cycle at Station 3D with Craney Island extension

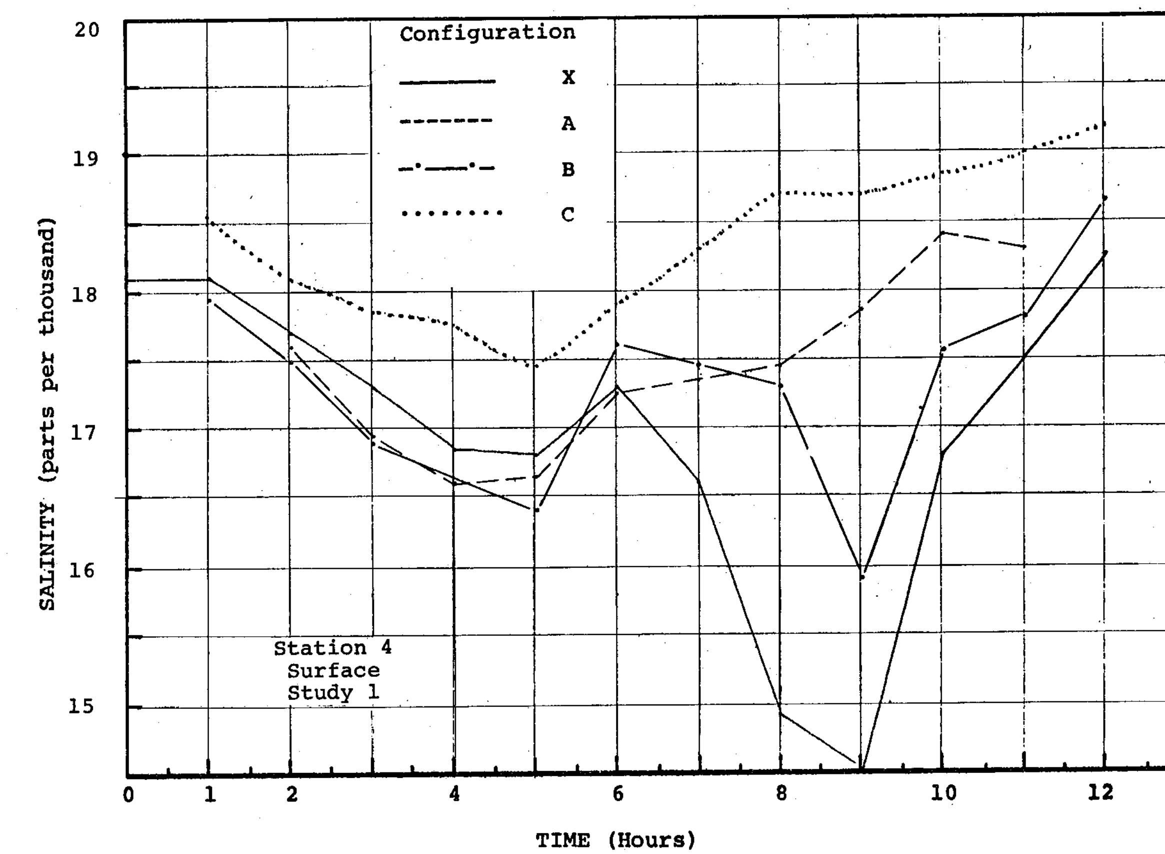


Figure 20 – Surface Salinity Variation over a tidal cycle at Station 4 without Craney Island extension

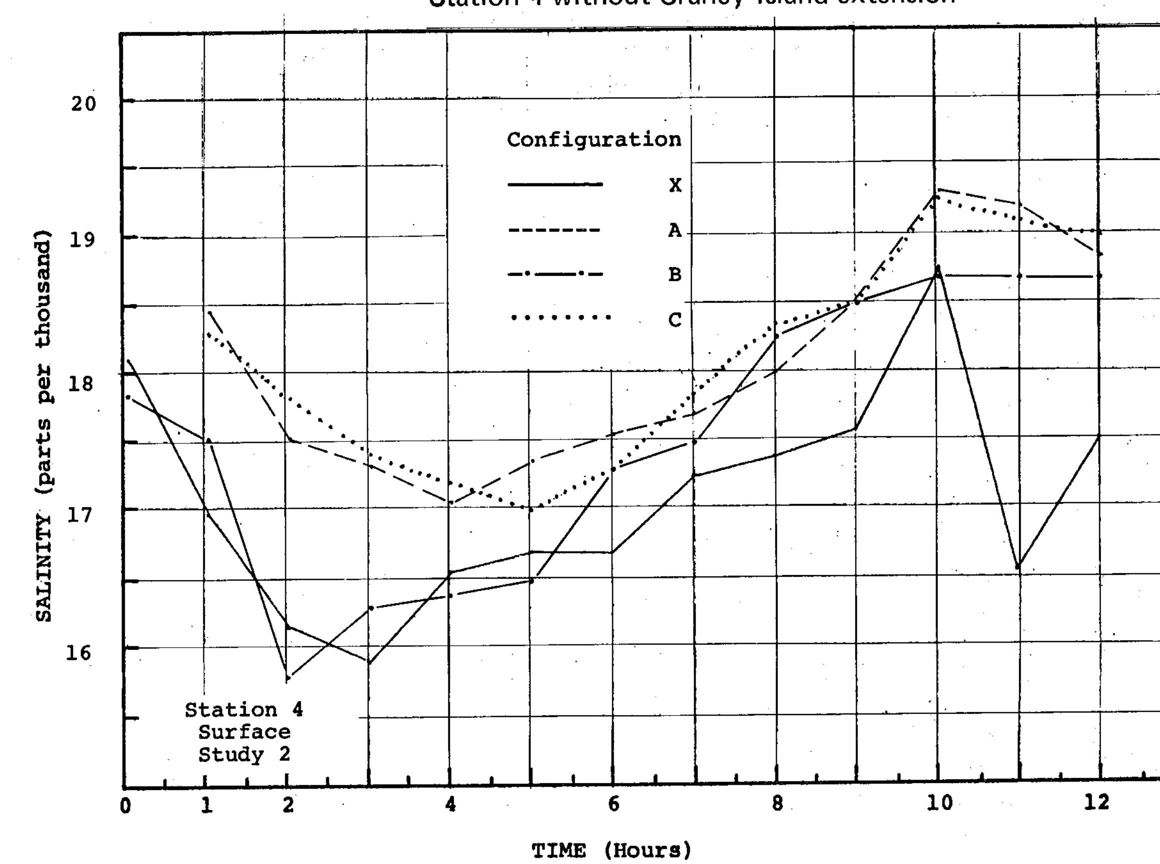


Figure 21 – Surface Salinity Variation over a tidal cycle at Station 4 with Craney Island extension

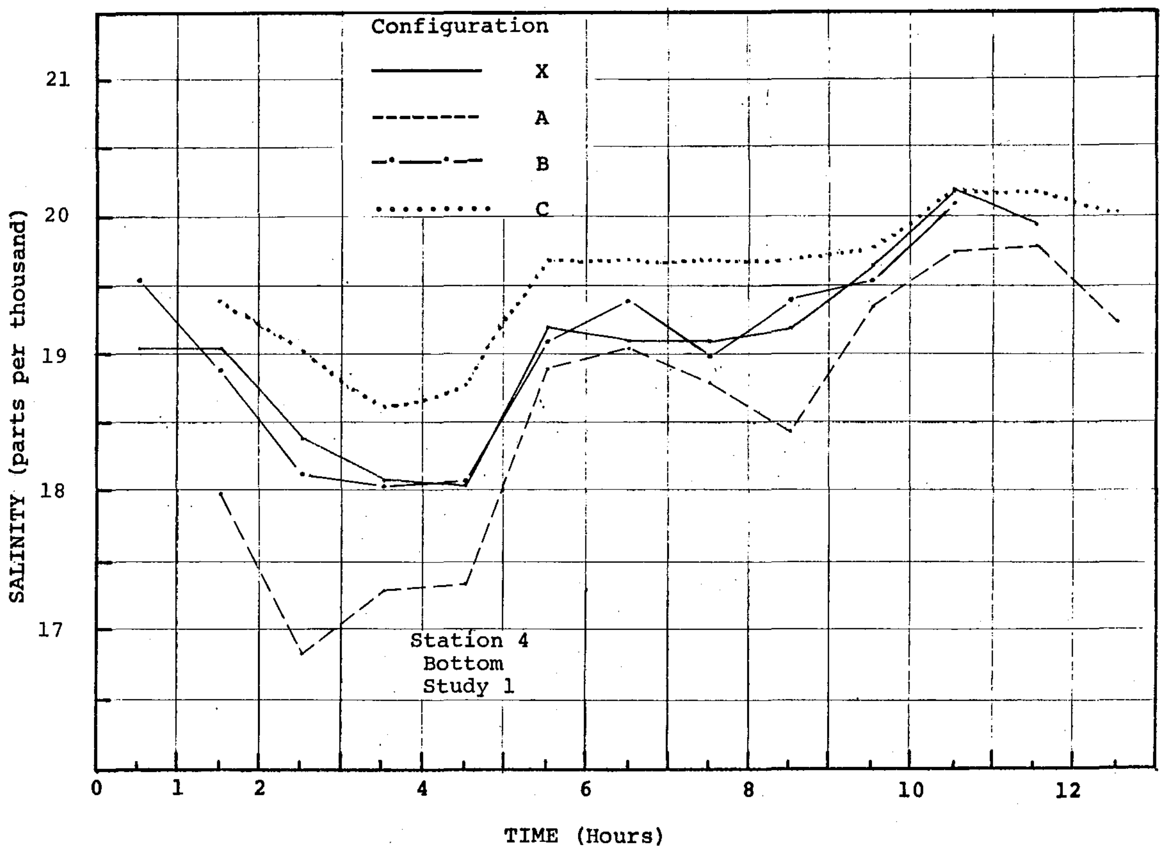


Figure 22 – Bottom Salinity Variation over a tidal cycle at Station 4 without Craney Island extension

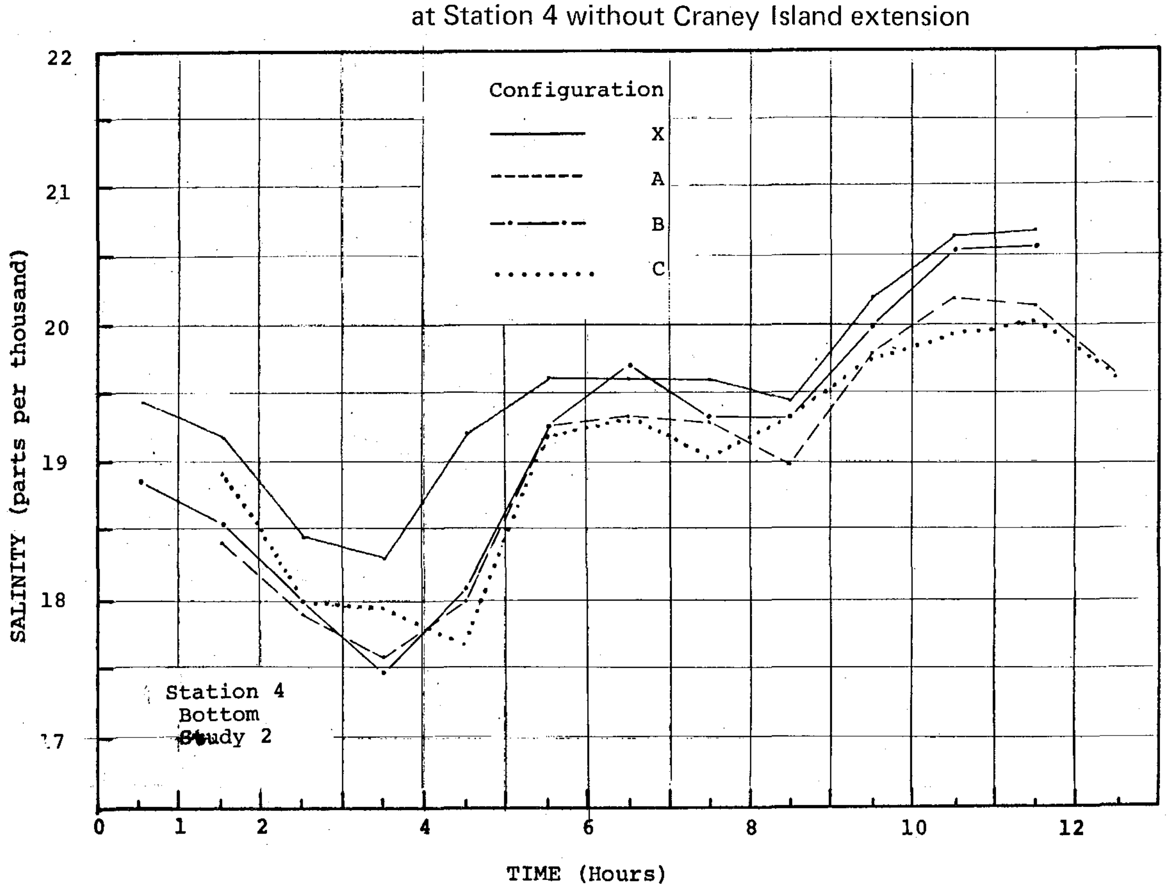


Figure 23 – Bottom Salinity Variation over a tidal cycle at Station 4 with Craney Island extension

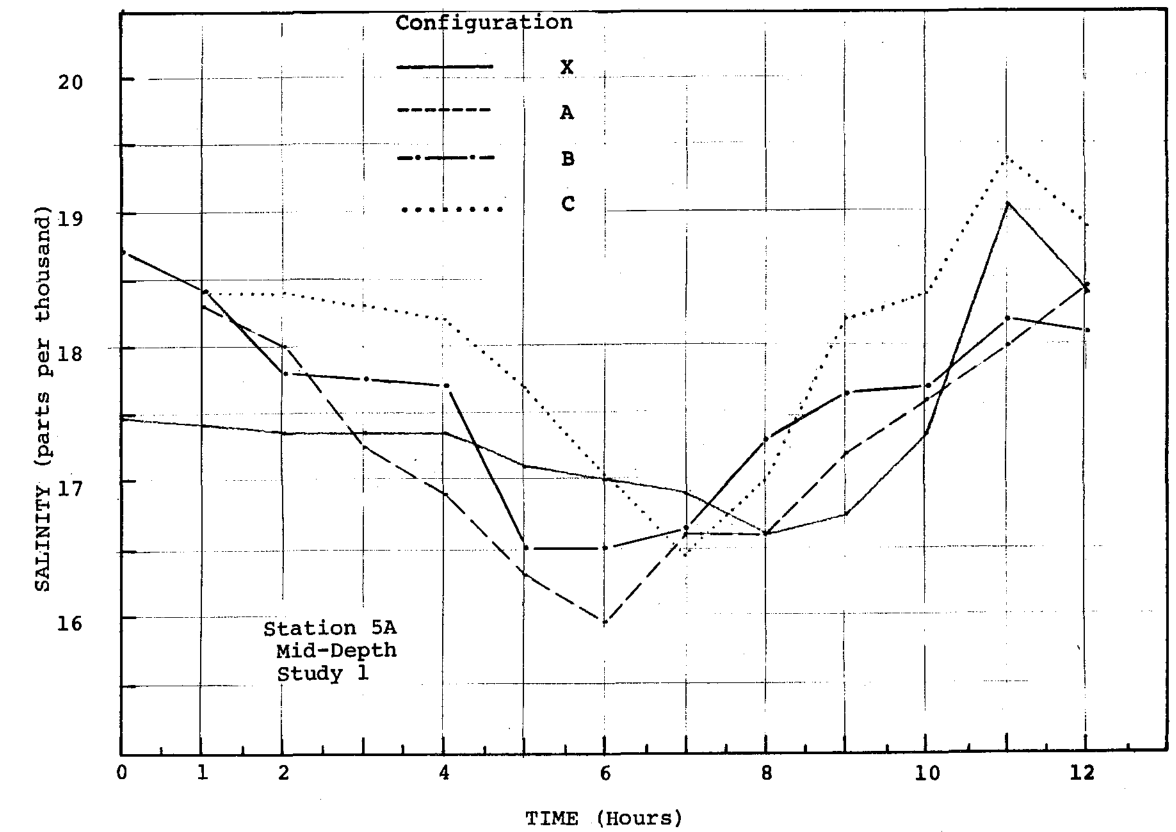


Figure 24 – Mid-Depth Salinity Variation over a tidal cycle at Station 5A without Craney Island extension

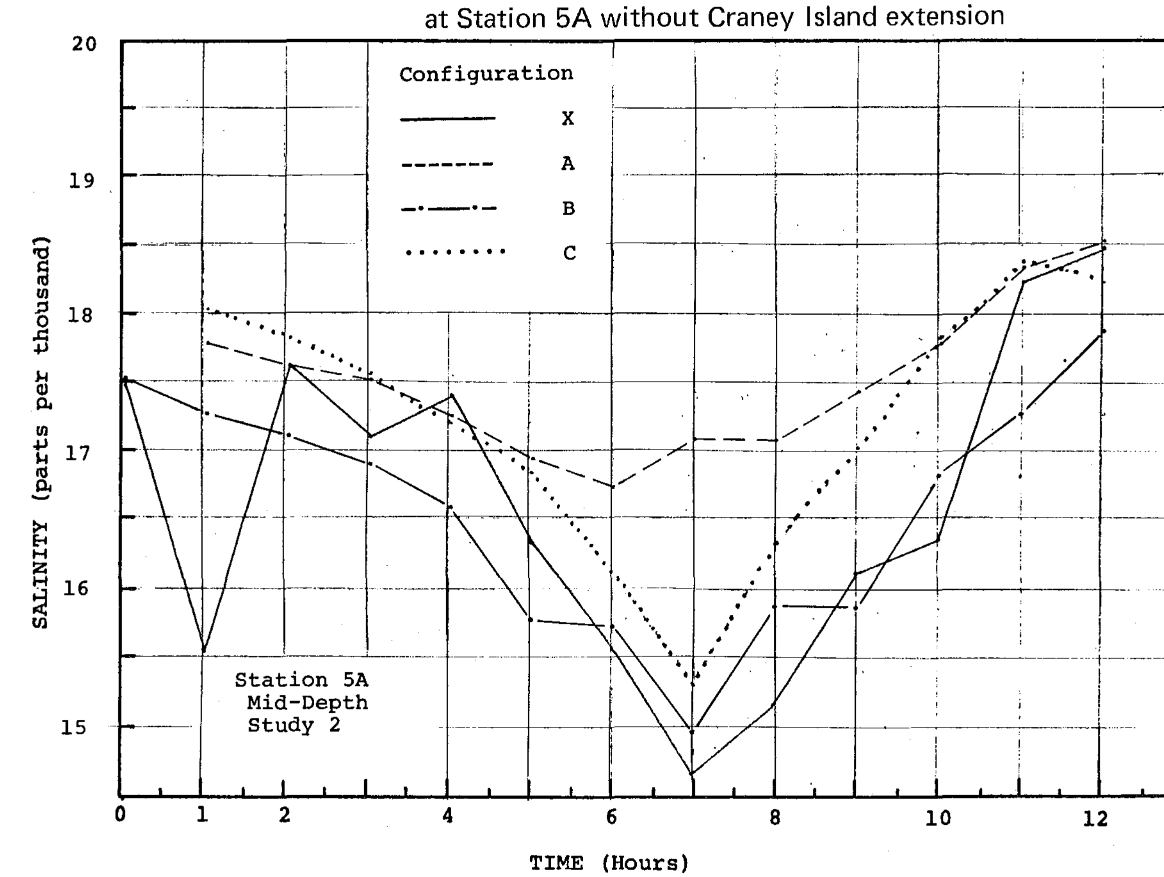


Figure 25 – Mid-Depth Salinity Variation over a tidal cycle at Station 5A with Craney Island extension

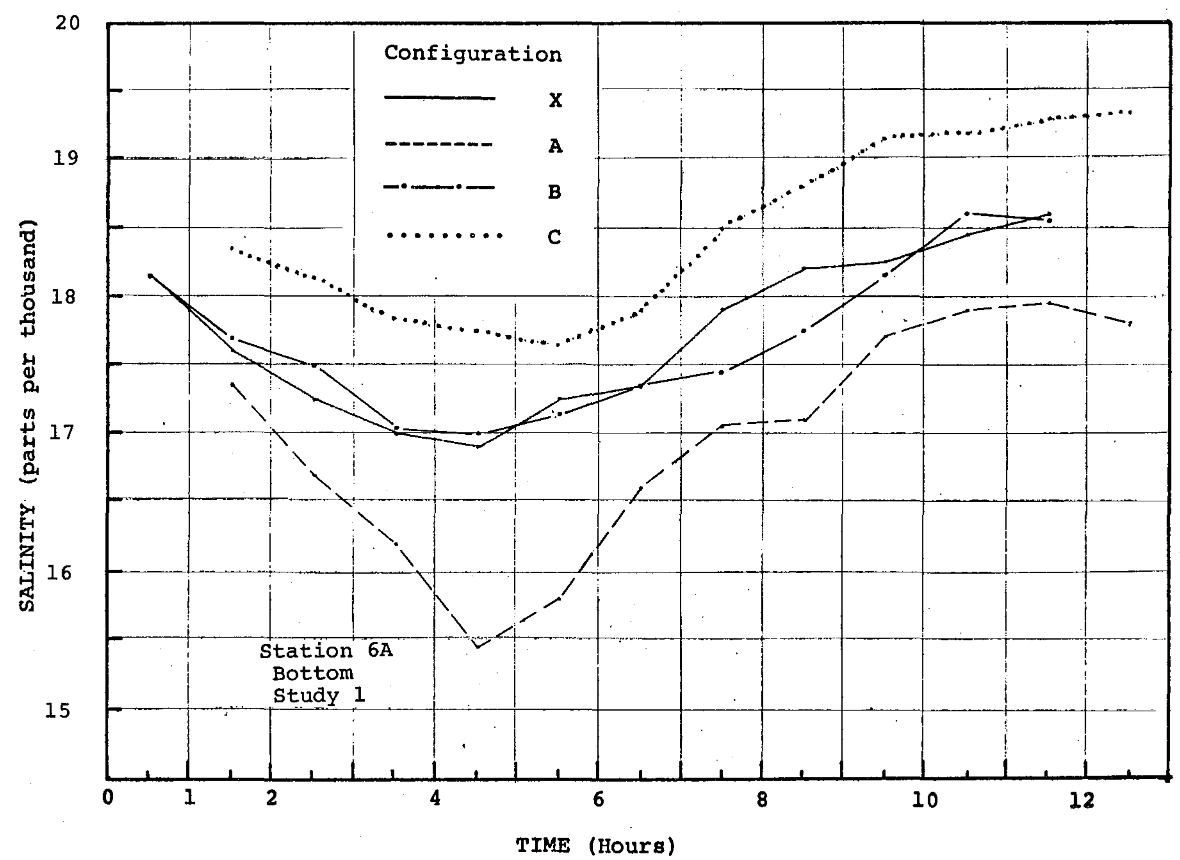


Figure 26 — **Bottom Salinity Variation** over a tidal cycle at Station 6A without Craney Island extension

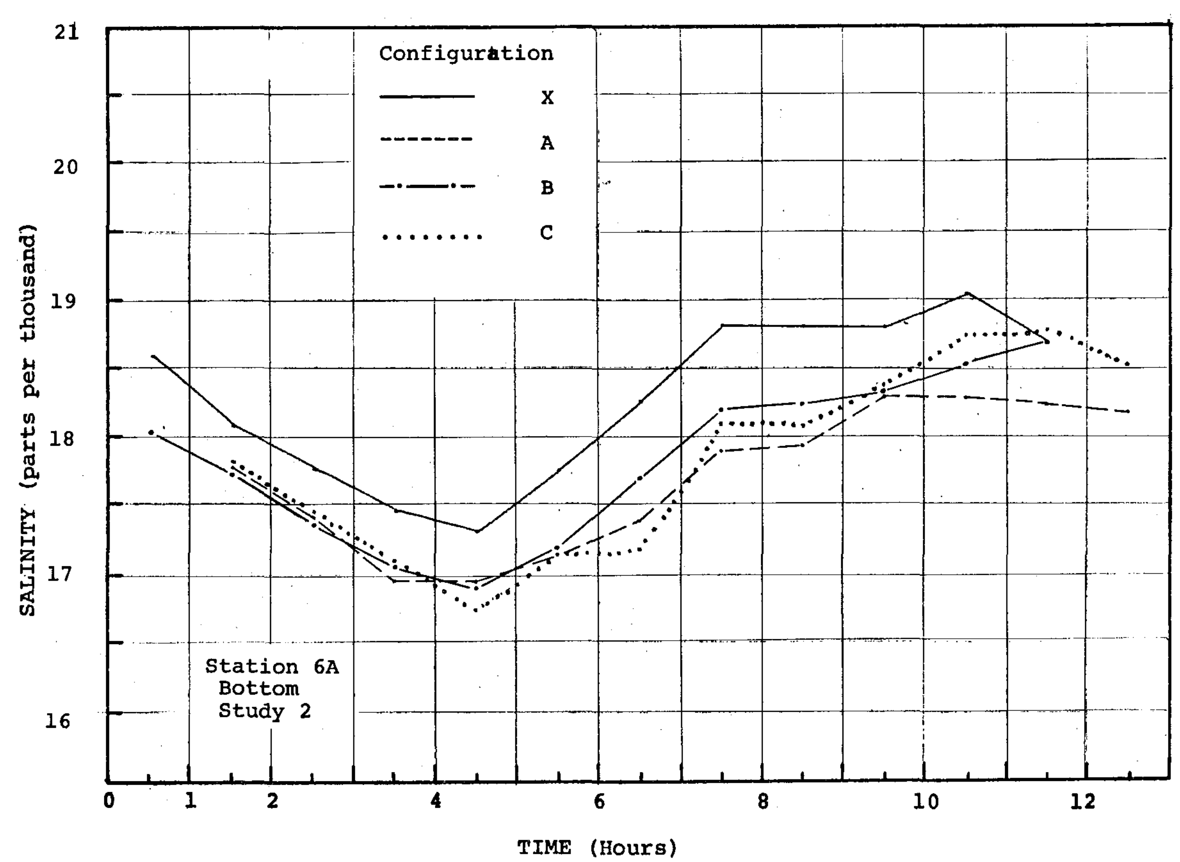


Figure 27 — **Bottom Salinity Variation** over a tidal cycle at Station 6A with Craney Island extension

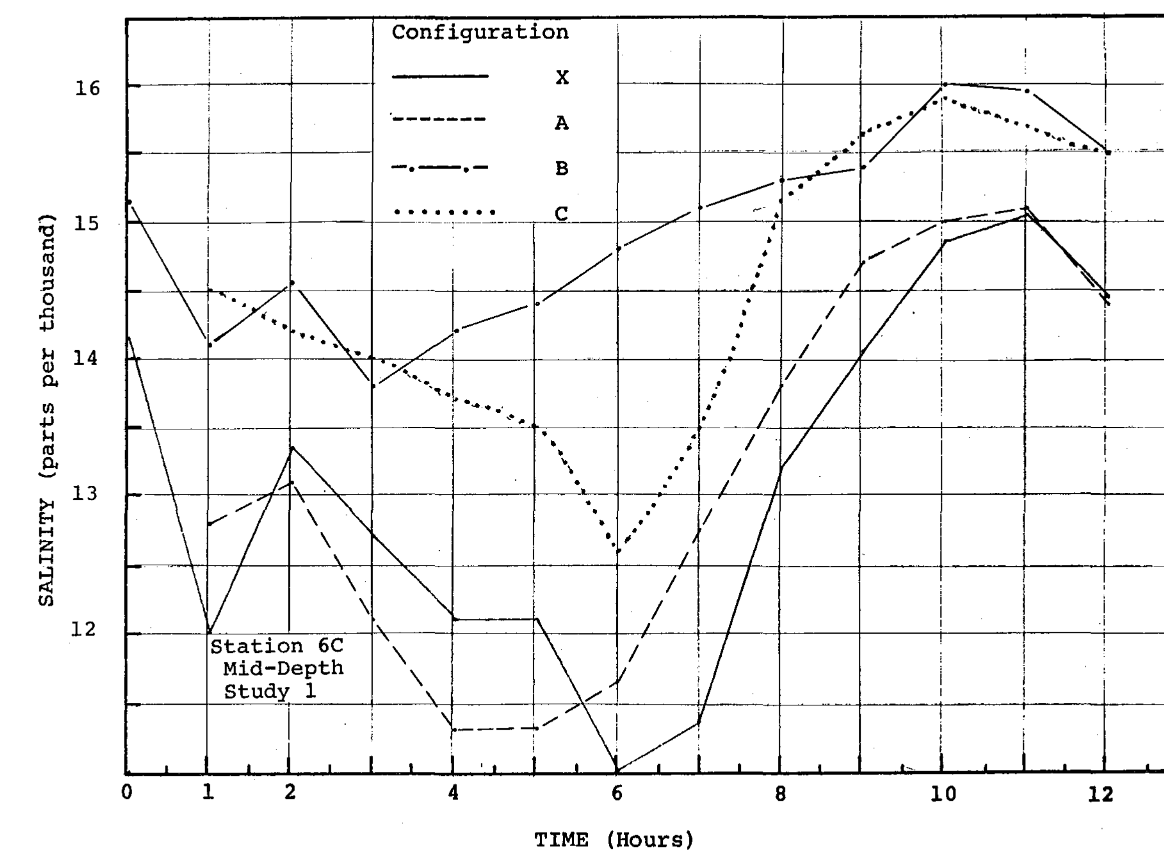


Figure 28 — **Mid-Depth Salinity Variation** over a tidal cycle at Station 6C without Craney Island extension

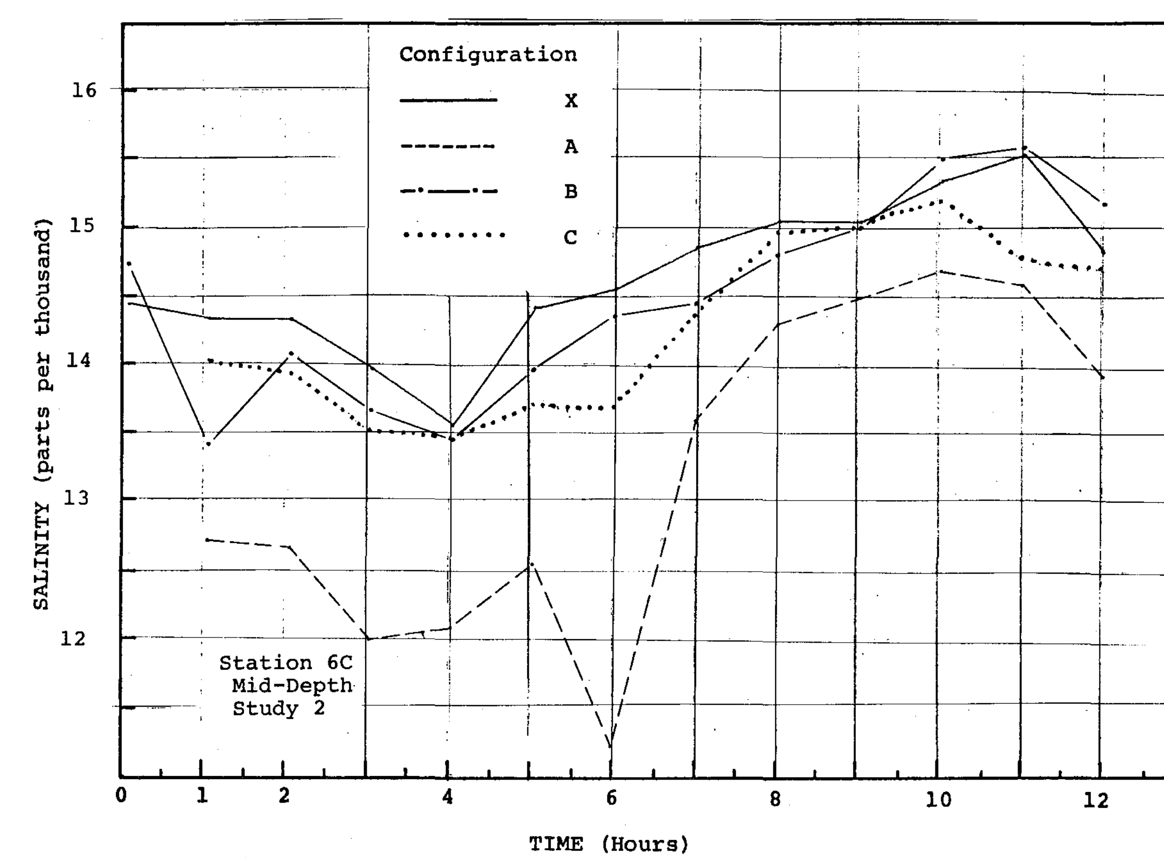


Figure 29 — **Mid-Depth Salinity Variation** over a tidal cycle at Station 6C with Craney Island extension

2. TIDAL HEIGHTS

The tidal-height data was averaged for three tidal cycles. The expected error of these data is less than 0.1 ft.

The tidal variations at the Newport News tide-gauge station are shown in Figures 30 and 31.

In general, only very slight changes in tidal heights were caused by adding the bridge-tunnel structures. The following Tables I and II summarize the increase (plus) or decrease (minus) in tidal heights from the two basic configurations.

The change from existing conditions to those with Craney Island extended did not change the baseline tidal heights at Miles and Hampton Roads, but raised the average tidal reading at Newport News by slightly over 0.2 ft.

3. CURRENTS

During the entire period when currents were being measured, the current was monitored at Station 1, near the Hampton Roads Bridge-Tunnel, with readings being taken at the surface and the bottom on alternate tidal cycles. Thus, there is a check on the reproducibility of the model. As might be expected, the accuracy of the readings increases with current speed. The standard deviation for speeds less than 2 fps (prototype) is on the order of 0.25 fps, while the standard deviation for speeds over 2 fps is on the order of 0.15 fps.

These errors are caused by a variety of factors. Variations in the model operation and problems such as dirt collecting in the pivot points of the current-meter and increasing friction so the calibration was no longer accurate are possible mechanical sources of error. In addition, there are human errors involved in taking the readings, such as not reacting to the light changes, and estimating the fractions of a revolution.

The data is averaged for two tidal cycles, and the points can be considered to be accurate to about 0.2 fps. Sample data-points are shown in Figures 32 through 59. These figures show the velocity variation with time for Stations 2B, 2D, 3A, 3D, 4, 4A, 5A, 5B, 5D, and 6A.

4. SURFACE CURRENTS

The confetti time-lapse photographs give very good synoptic views of surface-current patterns. Several features of the current distributions should be noted.

a. Tides

The time of slack water before flood does not progress up the main channel as a wave. Rather slack water occurs first in the Hampton River area and progresses both upstream and out toward the channel. Slack water in the Craney Island and Elizabeth River Channel areas occurs several hours after slack water has occurred in the Hampton River area.

b. Tides/Eddies

The differential time of slack water creates a situation in which the water near the Newport News shore floods before the water in the main channel. This looks slightly like an eddy but is not one. However, Configurations A and B will extend Newport News Point nearer to the main channel and will alter the flow so that eddies will, in fact, develop in the Hampton Flats area. Qualitative sketches of streamline patterns are reproduced from confetti photographs and shown in Figures 60 and 61 for flood- and ebb-tide respectively. The eddies which developed off the coal piers during flood tide are much smaller than those that developed on Hampton Flats during ebb tide. The scale of the eddies on Hampton Flats is on the order of one to two miles.

c. Wakes

The tunnel islands will be located on either side of the Newport News Channel. Thus each of them will resemble an obstacle in an otherwise uniform-flow field. The confetti photos show that vortices will develop downstream of the islands, and that something like the classical Kàrmàn Vortex Street exists. That is, eddies will be shed from the island, alternating from one side to the other. These vortices will travel downstream, giving a series of vortices with alternating sense of rotation as shown in Figures 60 and 61. These vortices seem to persist for up to a mile or more downstream of the islands.

5. GILSONITE TESTS

The numerical data for the deposition of gilsonite in each grid area are presented in Part IV of this Appendix. The data are tabulated in such a way that comparisons between different bridge-tunnel configurations are easily made. Figures 62 to 68 are graphical representations to show the distribution of deposition or scouring under various configurations. The ratios given in the figures show the increased deposition attributable to the particular configuration over the base, or no-change, configuration.

The patterns of gilsonite deposition were noted to be very similar for each of the configurations regardless of whether Craney Island is extended. That is, the deposition and scour patterns for 1A and 2A are very similar, while 1A and 1B are not. Figures 69 through 71 show the comparisons of deposition patterns between configurations with and without the Craney Island extension.

While the distribution of the gilsonite along the channel varied from test to test, the total percentage of gilsonite collected in the channel did not vary greatly from test to test. However, the percentage for Configurations A and B was slightly lower than that for the baseline study and Configuration C. This indicates that maintenance dredging of the shipping channel in the vicinity of Newport News Point will not be changed appreciably. The locations which required dredging might be shifted upstream or downstream, but the volume of material to be dredged will be relatively constant for all three bridge-tunnel configurations.

More discussions based on the results of gilsonite tests are given in Part II of this Appendix.

TABLE I

AVERAGE CHANGE IN TIDAL HEIGHTS, WITHOUT CRANEY ISLAND EXTENSION

Station	Tidal Range	Configuration A	B	C
HR	2.50′	+0.11′	−0.01′	−0.03′
NN	2.60′	−0.09′	−0.06′	−0.08′
MI	2.63′	+0.10′	−0.01′	0′

TABLE II

AVERAGE CHANGE IN TIDAL HEIGHTS, WITH CRANEY ISLAND EXTENSION

Station	Tidal Range	Configuration A	B	C
HR	2.53′	−0.04′	+0.07′	+0.02′
NN	2.57′	−0.35′	+0.04′	−0.03′
MI	2.70′	−0.01′	+0.02′	+0.02′

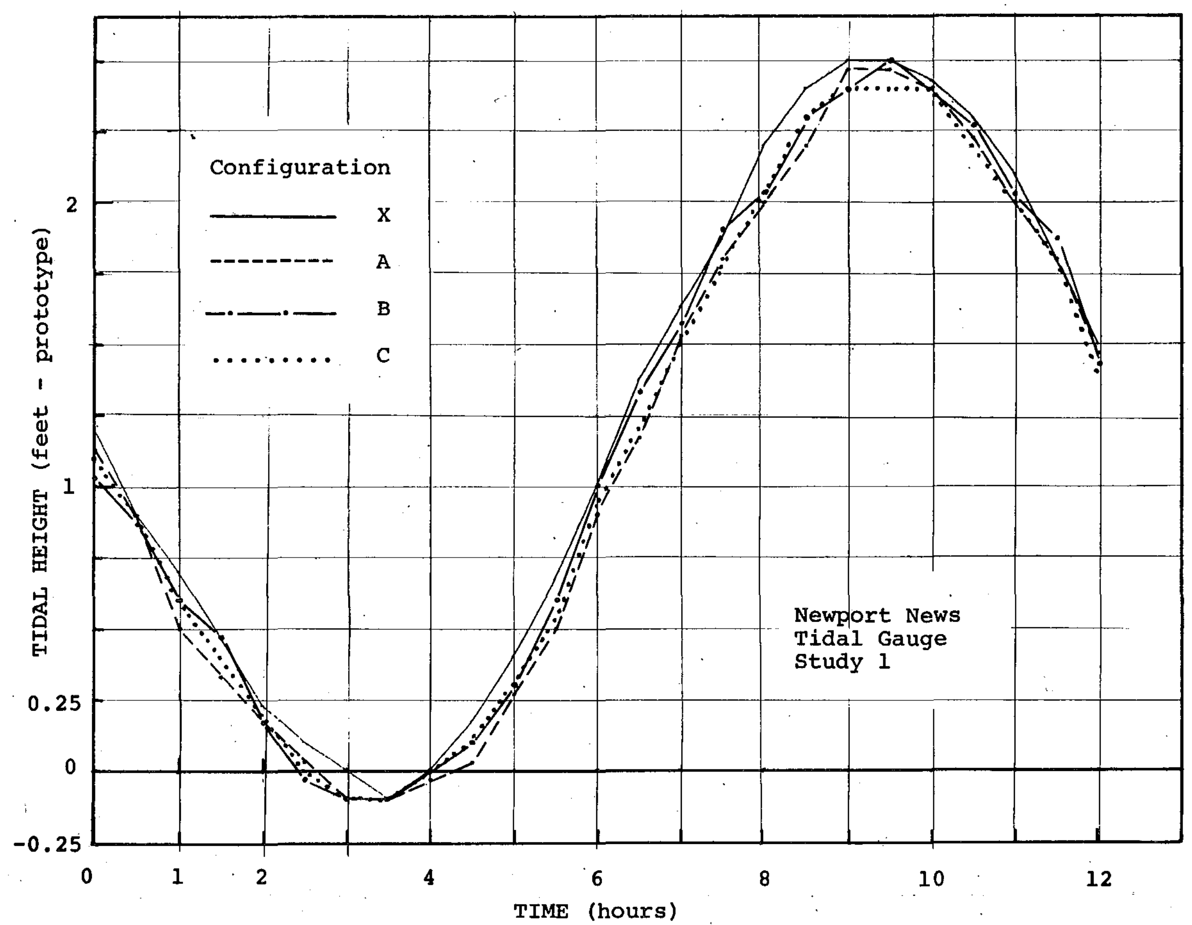


Figure 30 – Tidal Heights at Newport News Point without Craney Island extension

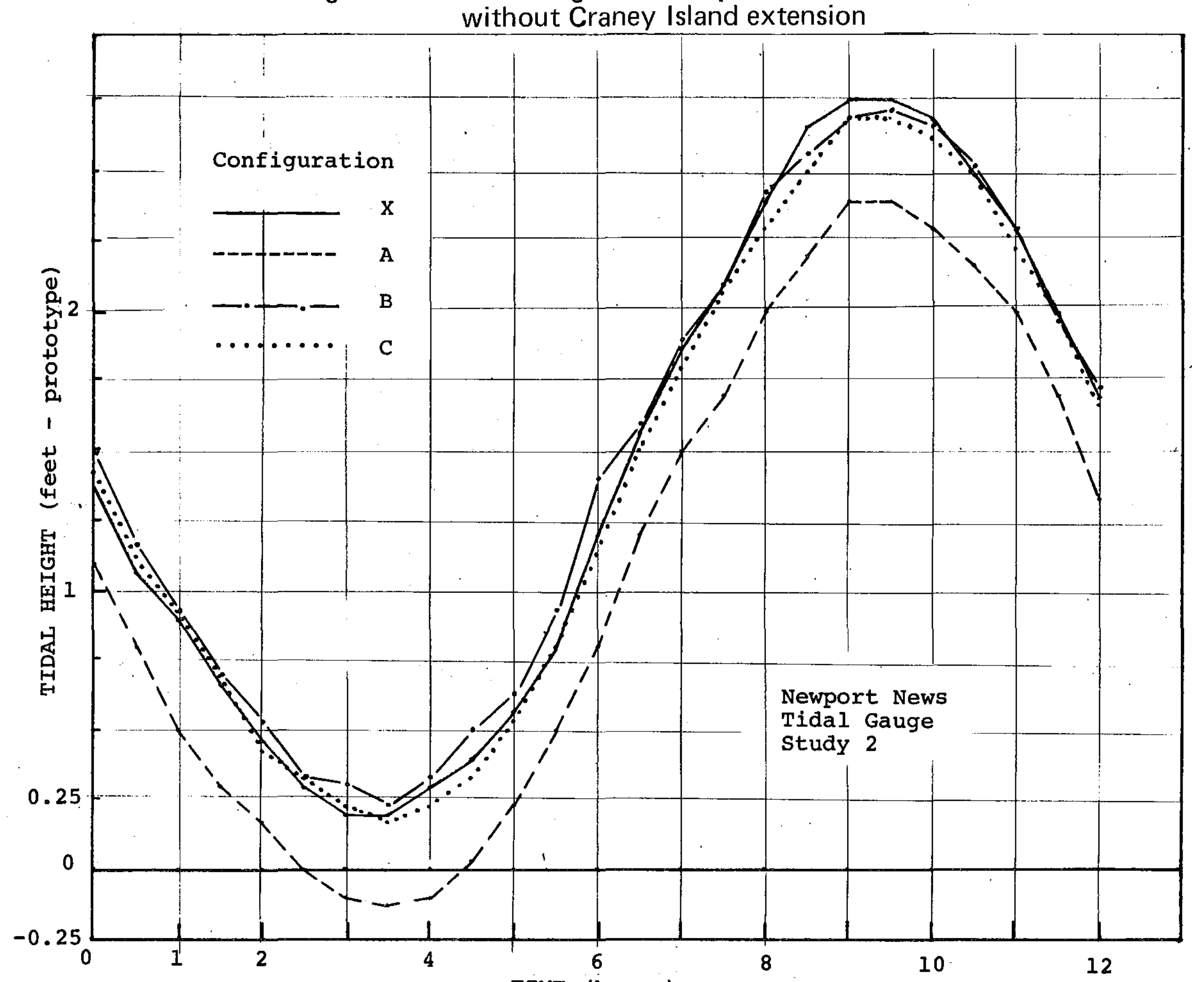


Figure 31 – Tidal Heights at Newport News Point with Craney Island extension

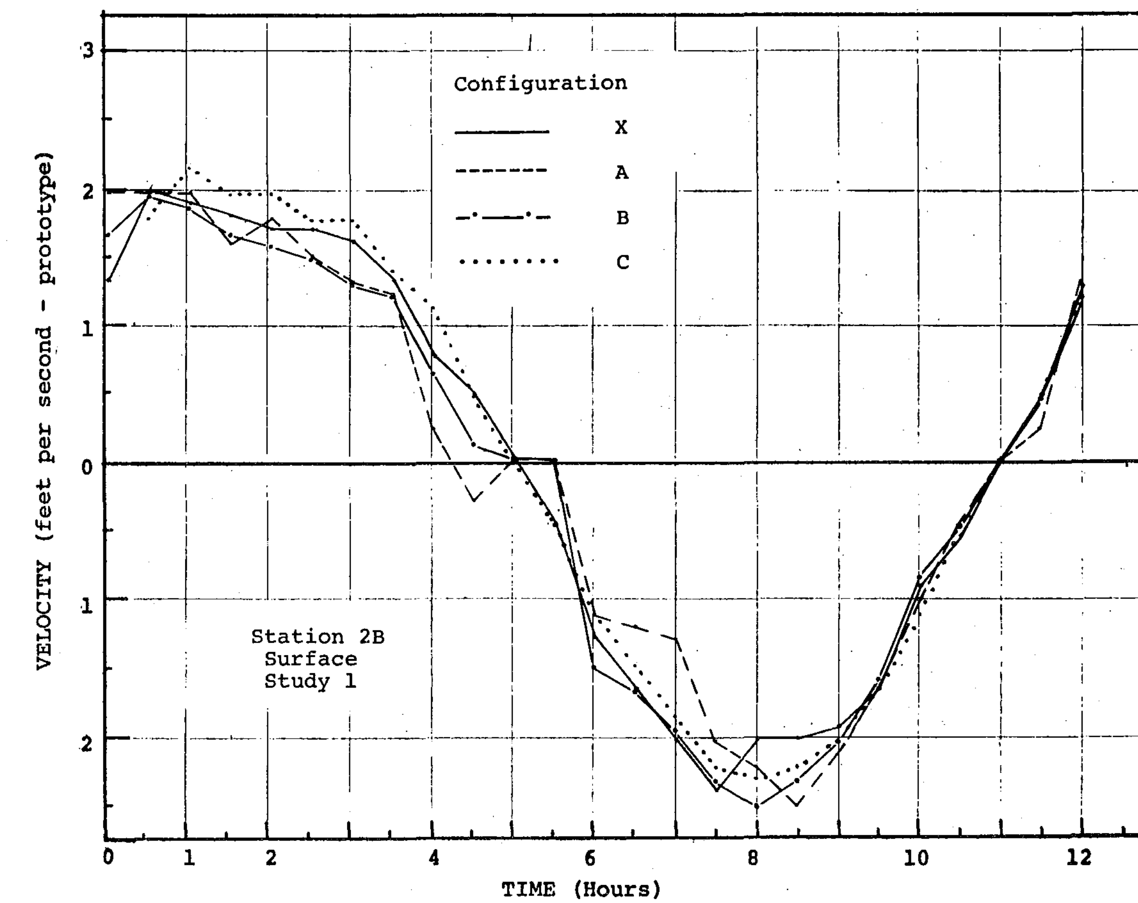


Figure 32 – Surface-Velocity Variation over a tidal cycle at Station 2B without Craney Island extension

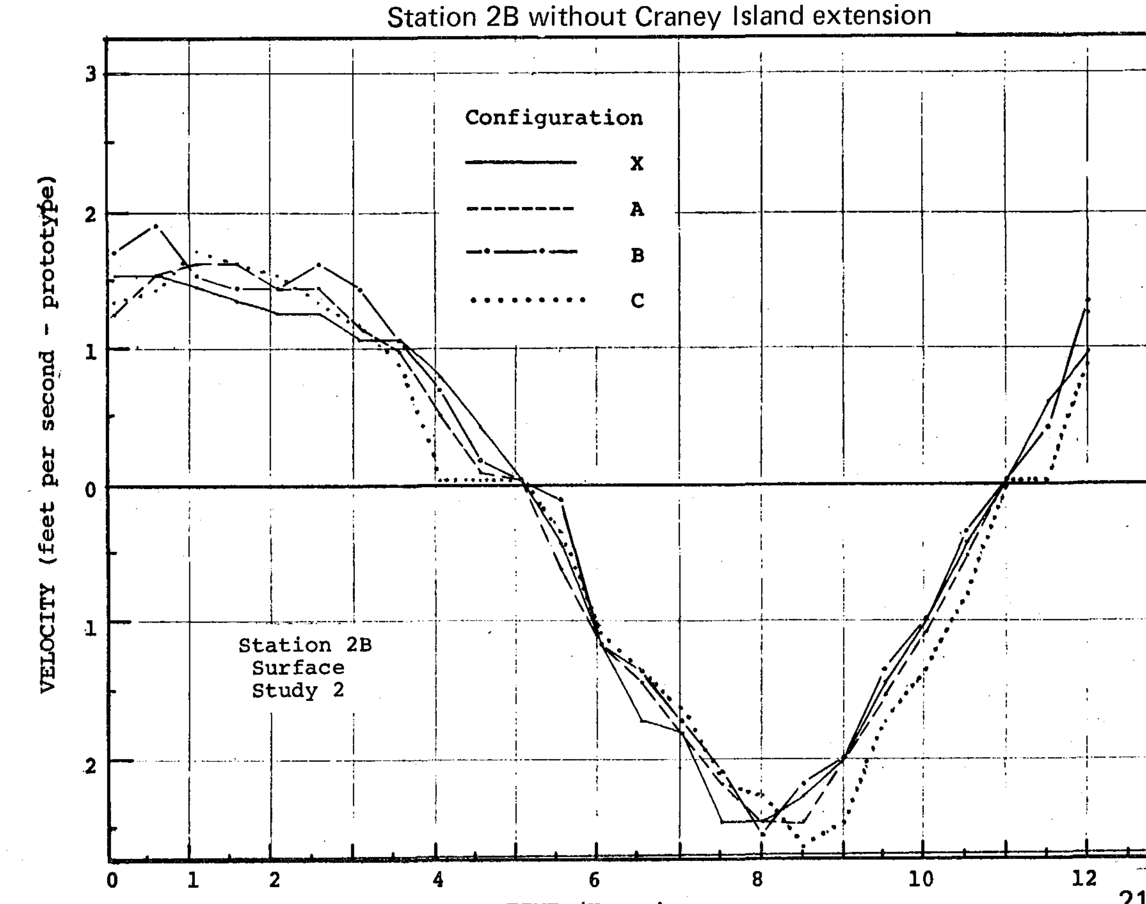


Figure 33 – Surface-Velocity Variation over a tidal cycle at Station 2B with Craney Island extension

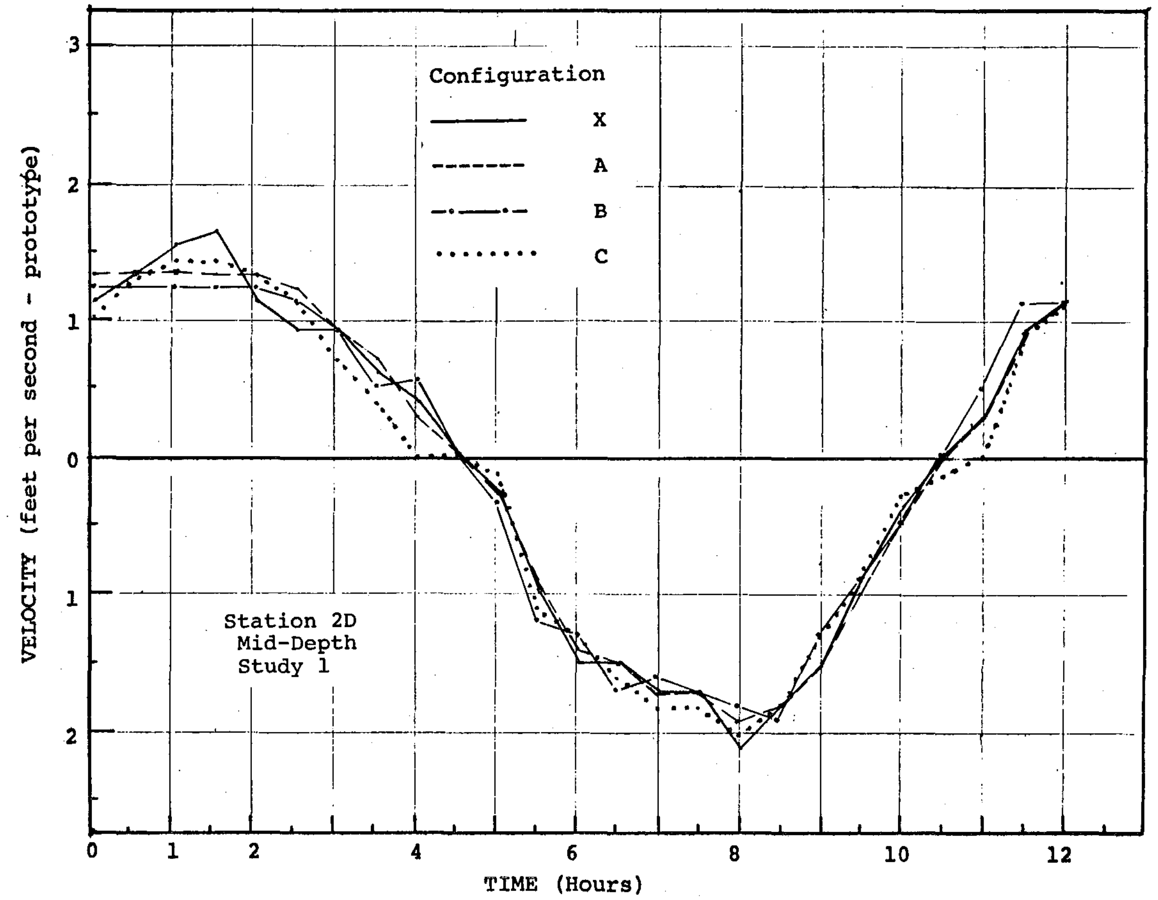


Figure 34 – Mid-Depth Velocity Variation over a tidal cycle at Station 2D without Craney Island extension

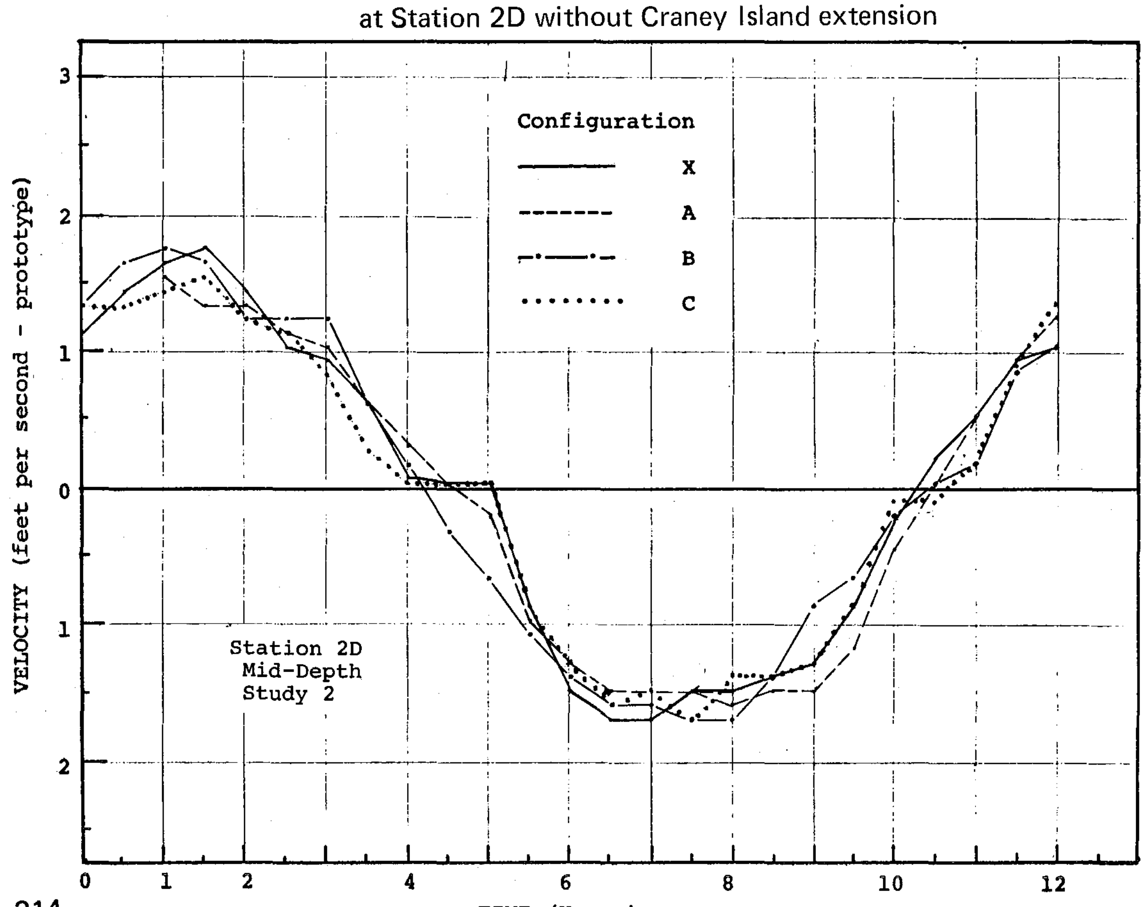


Figure 35 – Mid-Depth Velocity Variation over a tidal cycle at Station 2D with Craney Island extension

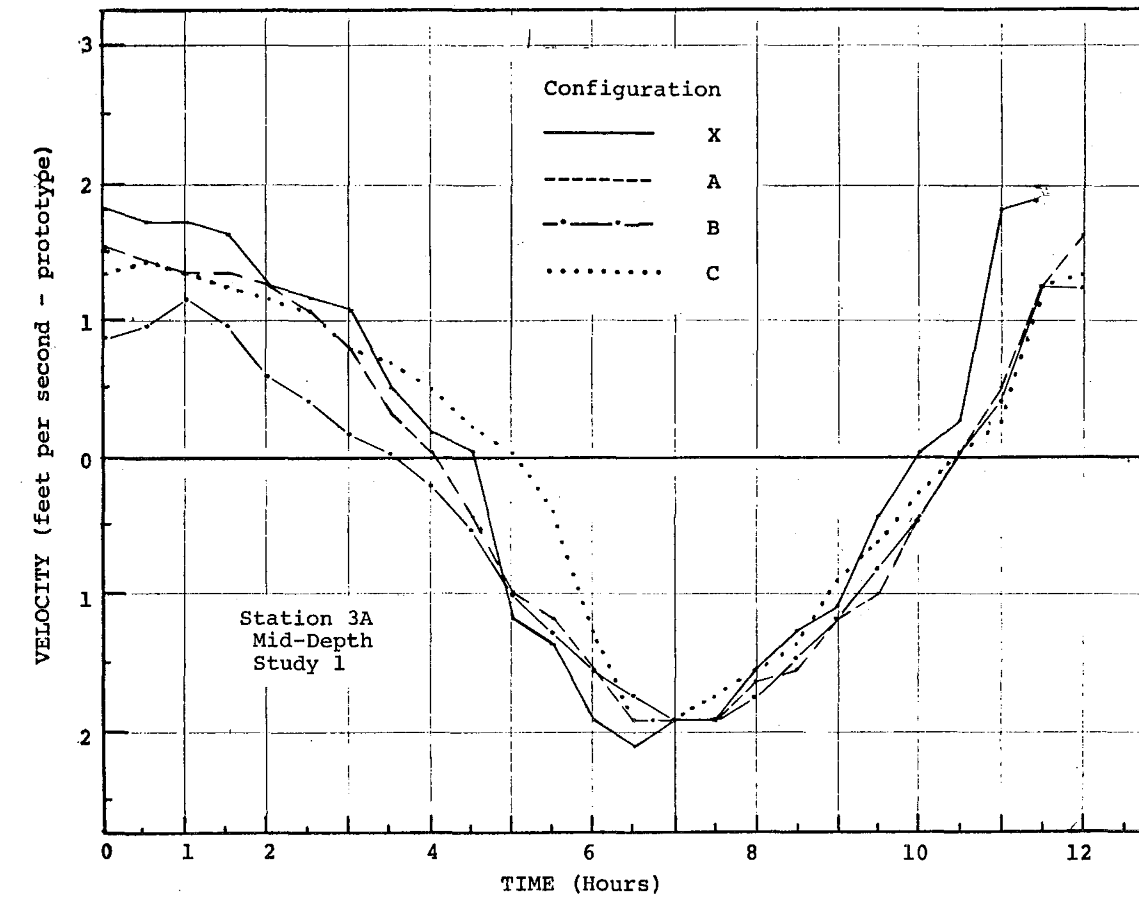


Figure 36 – Mid-Depth Velocity Variation over a tidal cycle at Station 3A without Craney Island extension

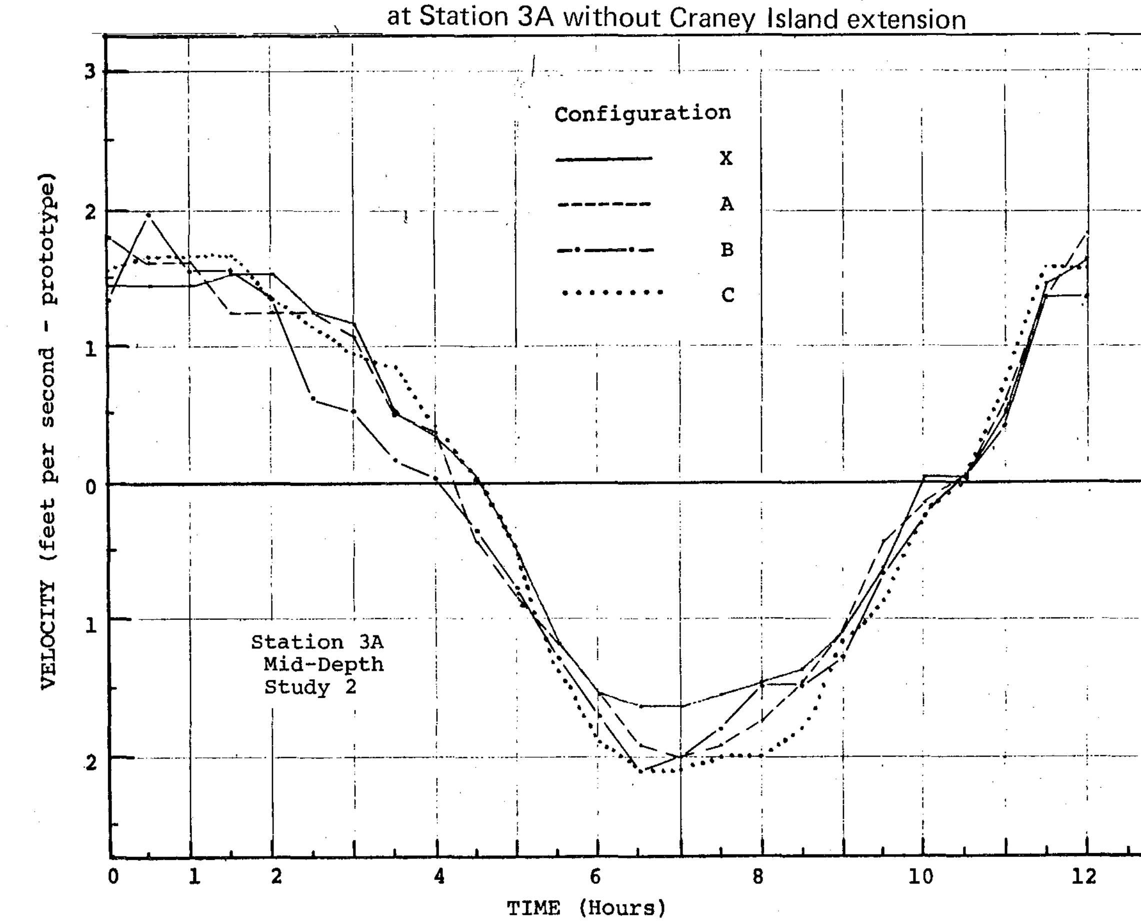


Figure 37 – Mid-Depth Velocity Variation over a tidal cycle at Station 3A with Craney Island extension

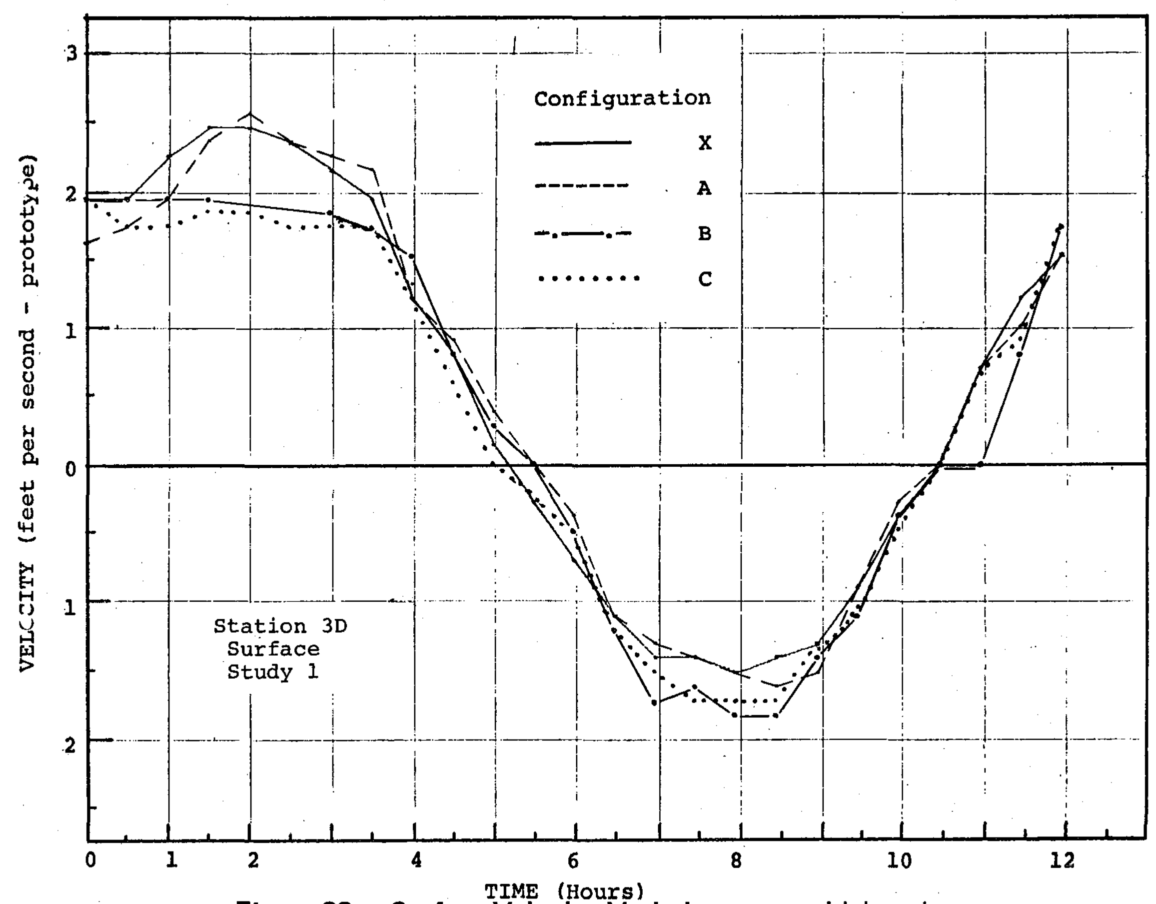


Figure 38 — **Surface-Velocity Variation** over a tidal cycle at Station 3D without Craney Island extension

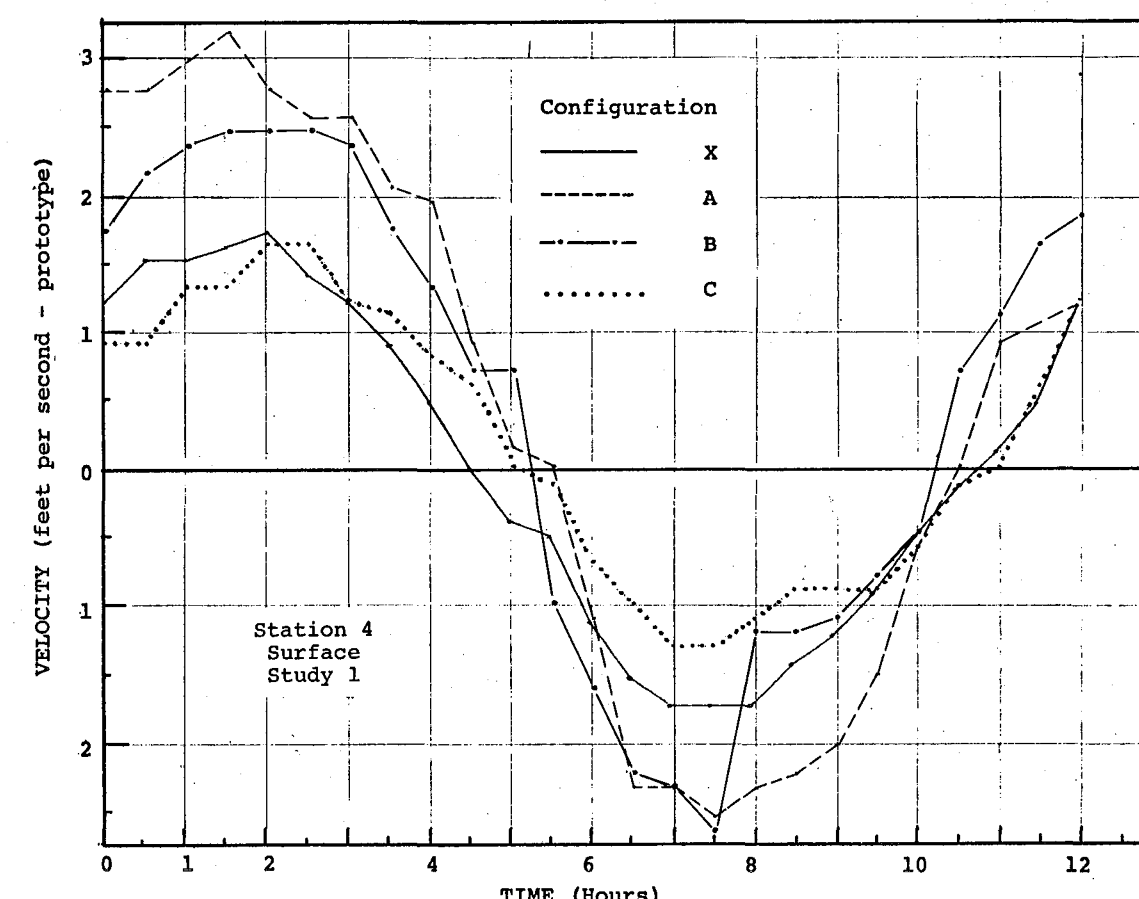


Figure 40 — **Surface-Velocity Variation** over a tidal cycle at Station 4 without Craney Island extension

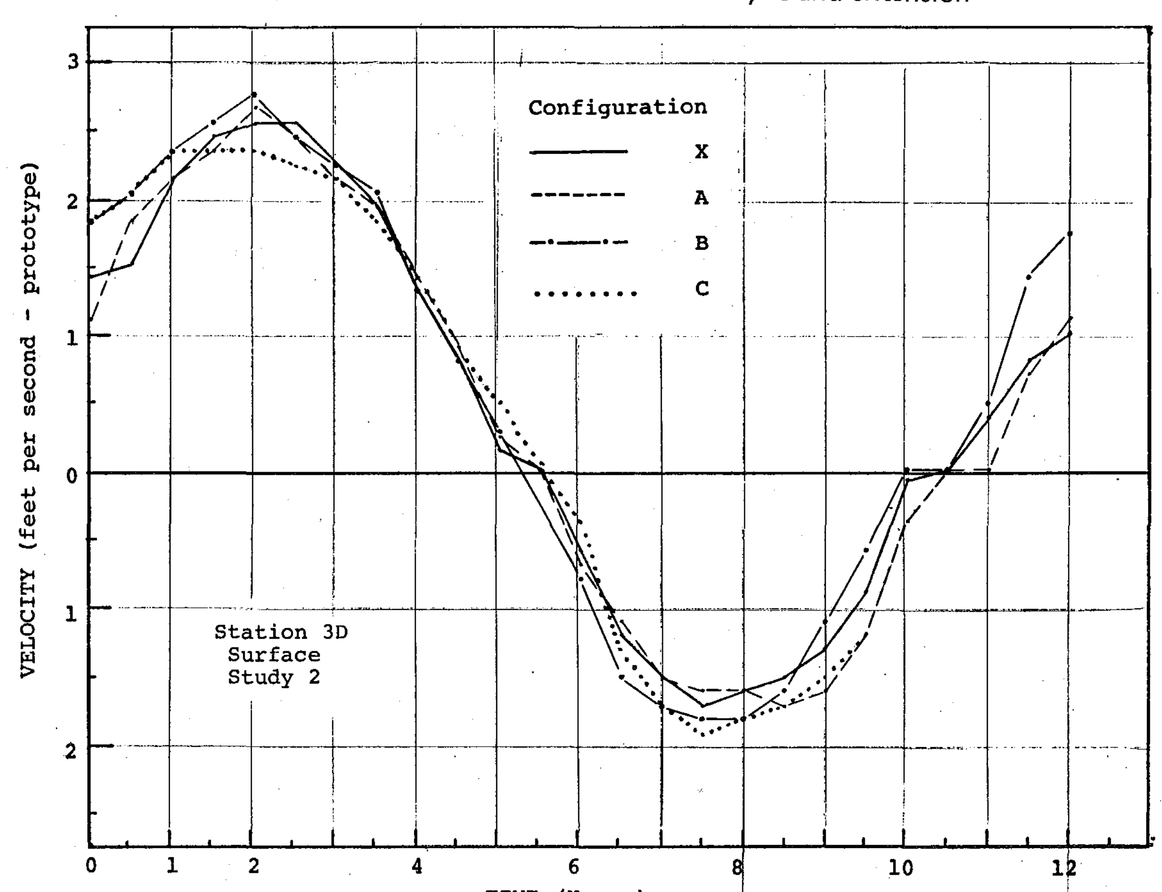


Figure 39 — **Surface-Velocity Variation** over a tidal cycle at Station 3D with Craney Island extension

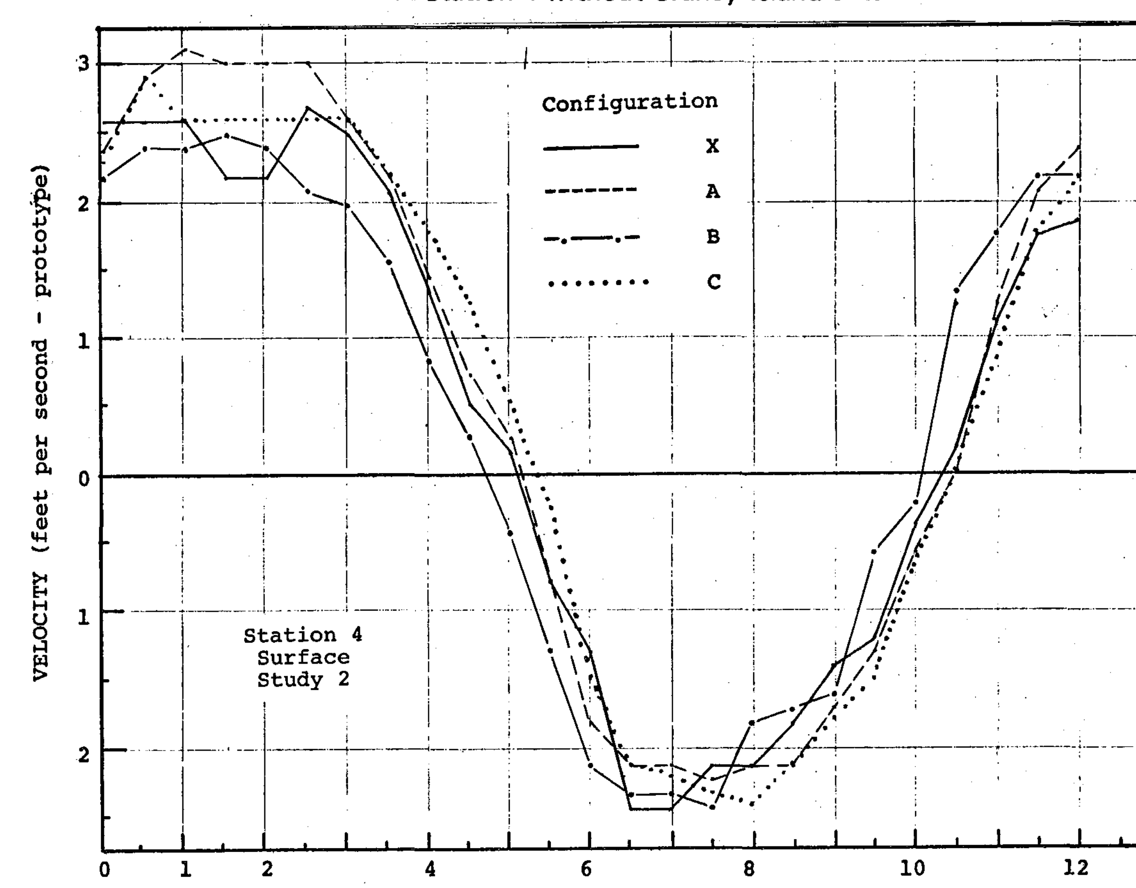


Figure 41 — **Surface-Velocity Variation** over a tidal cycle at Station 4 with Craney Island extension

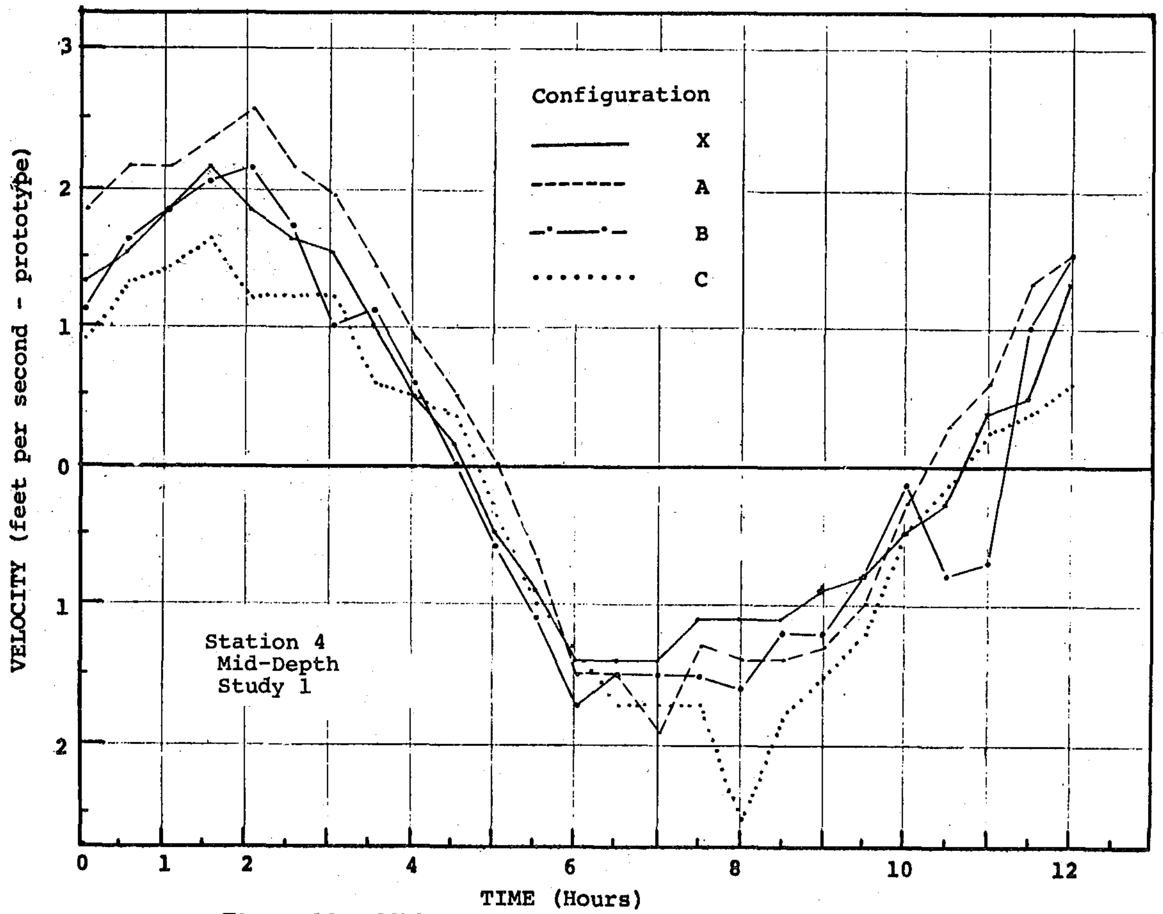


Figure 42 – Mid-Depth Velocity Variation over a tidal cycle at Station 4 without Craney Island extension

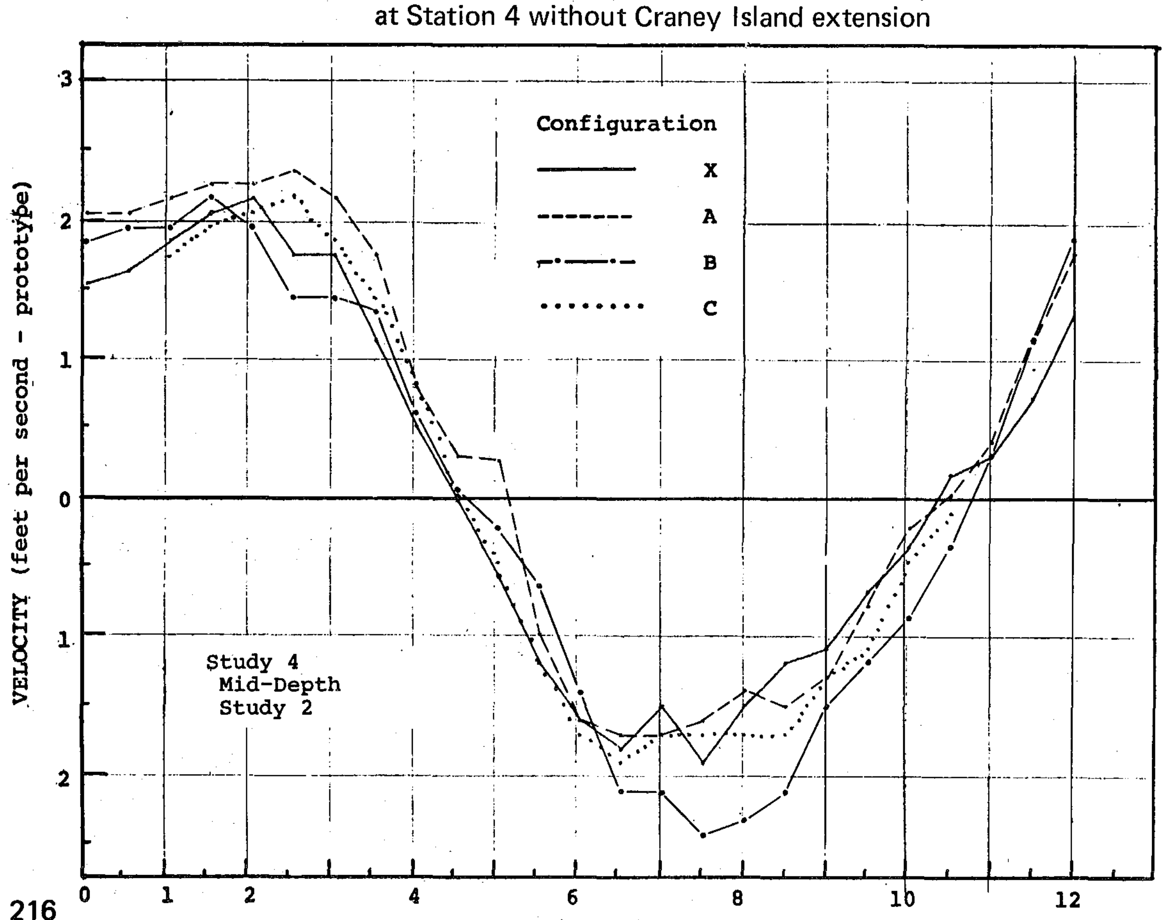


Figure 43 – Mid-Depth Velocity Variation over a tidal cycle at Station 4 with Craney Island extension

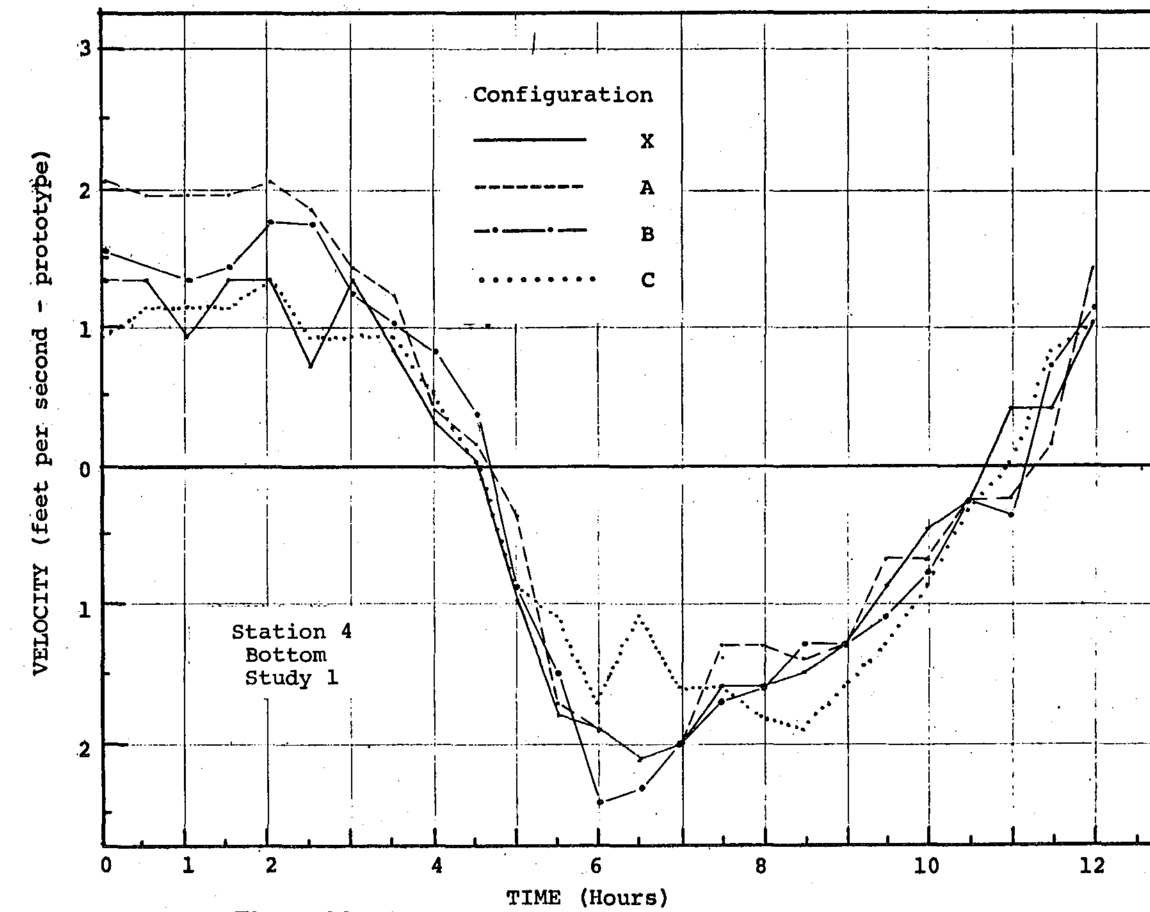


Figure 44 – Bottom-Velocity Variation over a tidal cycle at Station 4 without Craney Island extension

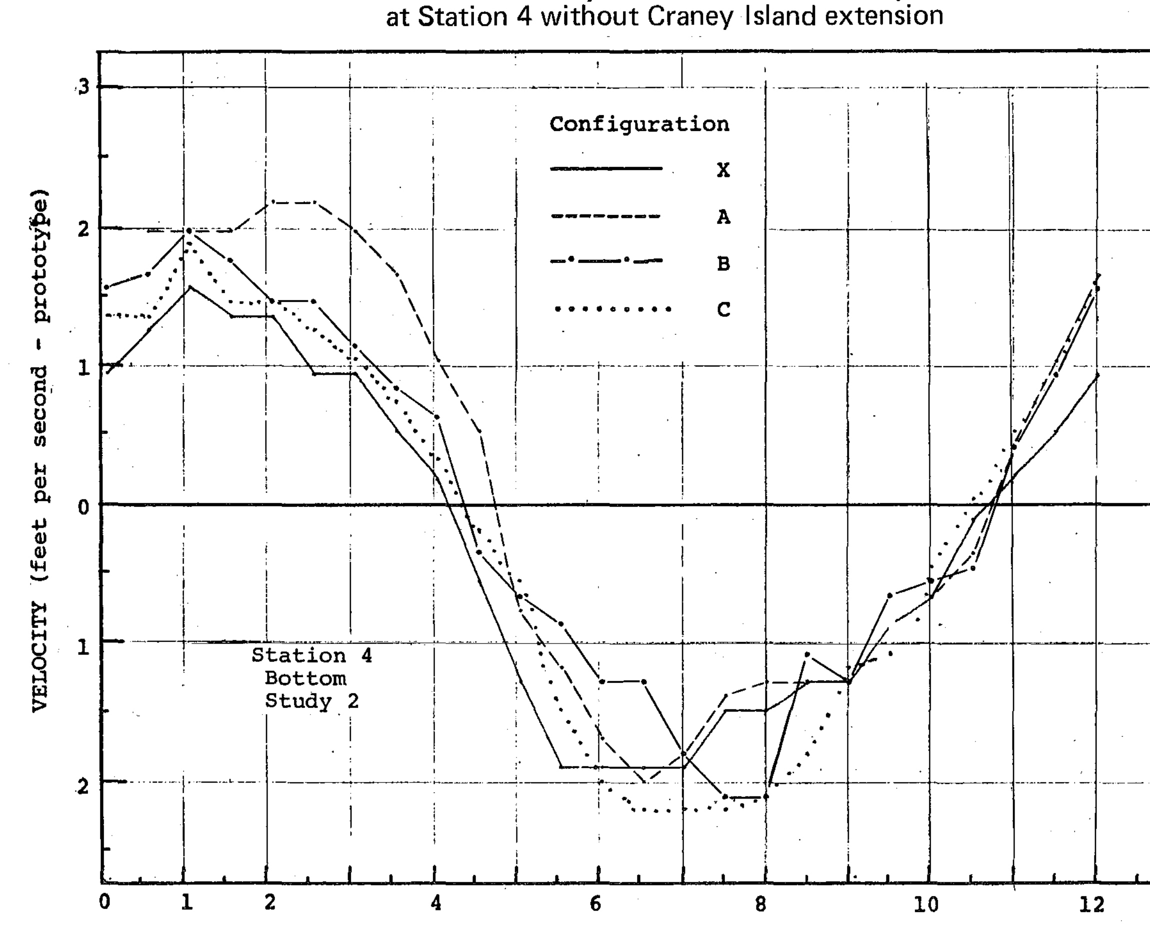


Figure 45 – Bottom-Velocity Variation over a tidal cycle at Station 4 with Craney Island extension

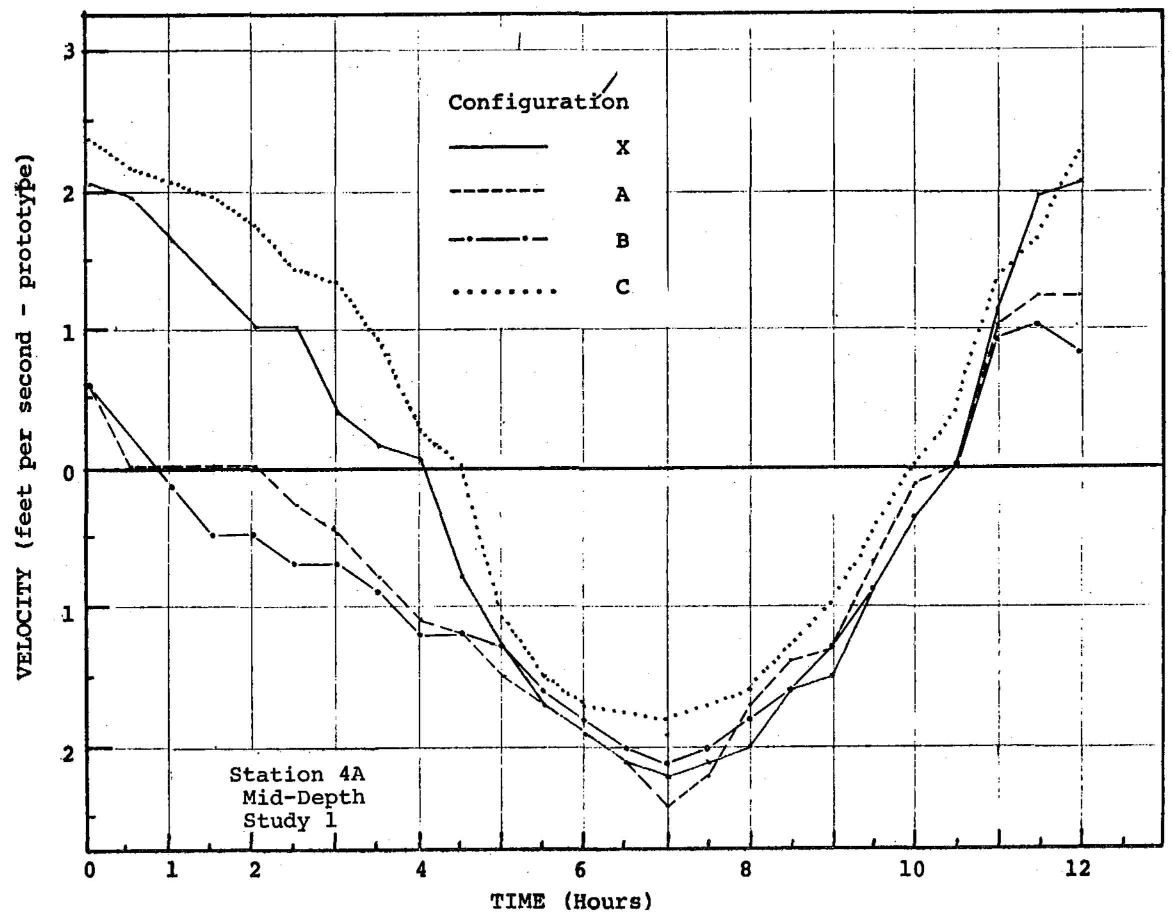


Figure 46 — **Mid-Depth Velocity Variation** over a tidal cycle at Station 4A without Craney Island extension

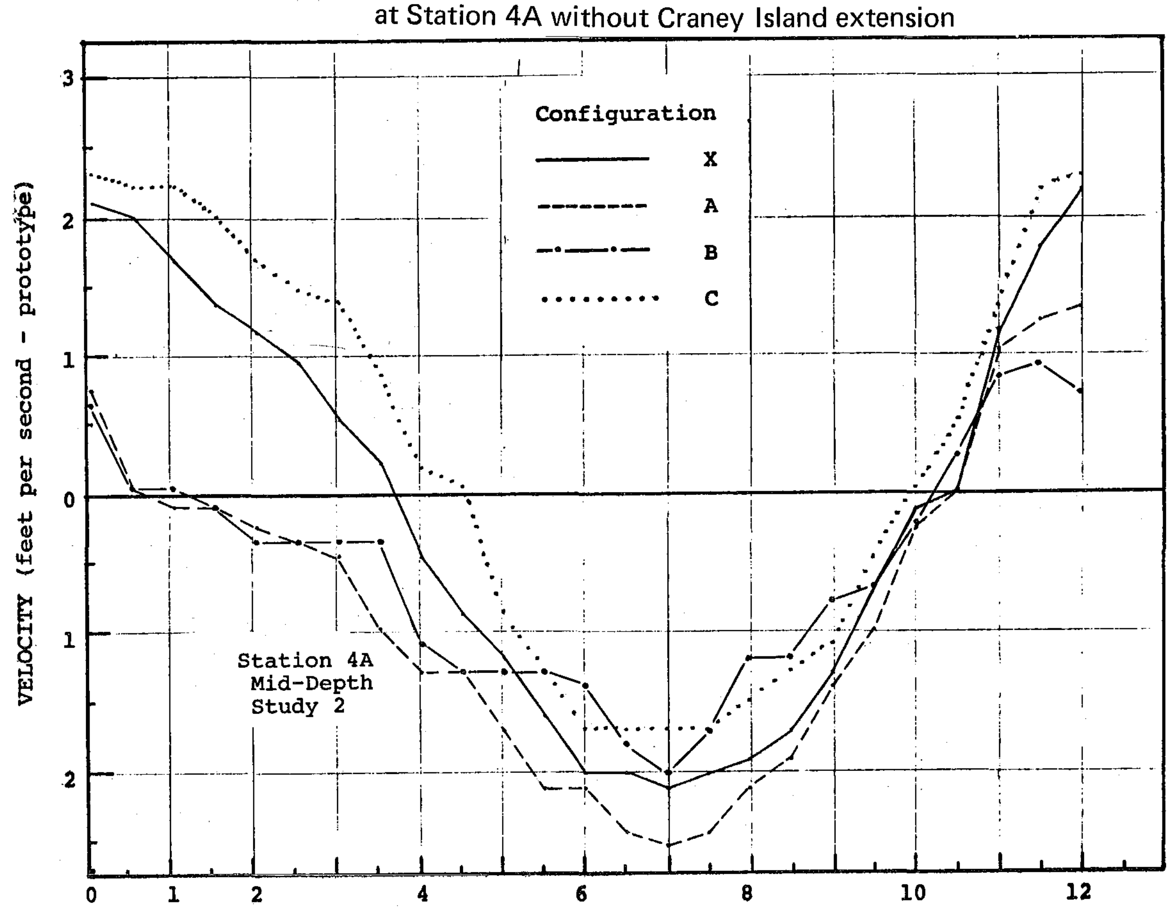


Figure 47 — **Mid-Depth Velocity Variation** over a tidal cycle at Station 4A with Craney Island extension

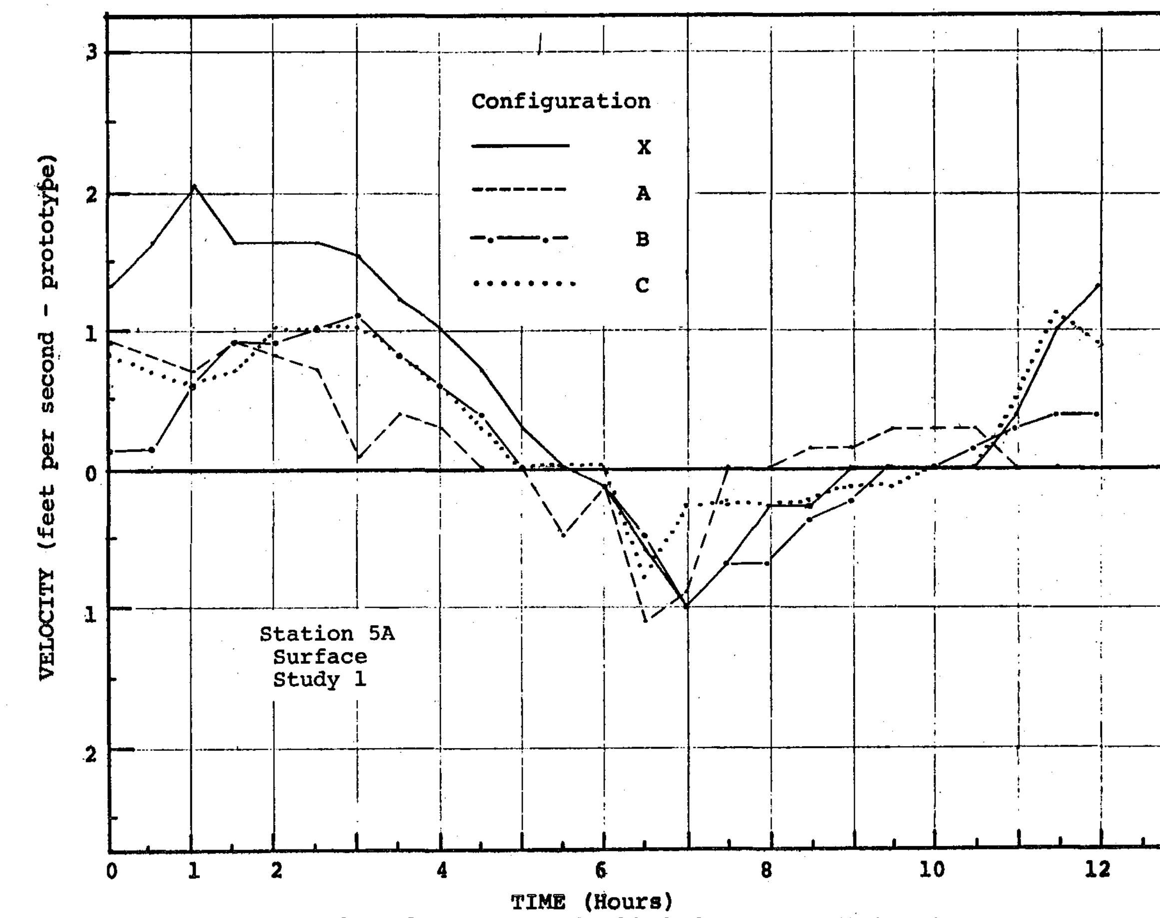


Figure 48 — **Surface-Velocity Variation** over a tidal cycle at Station 5A without Craney Island extension

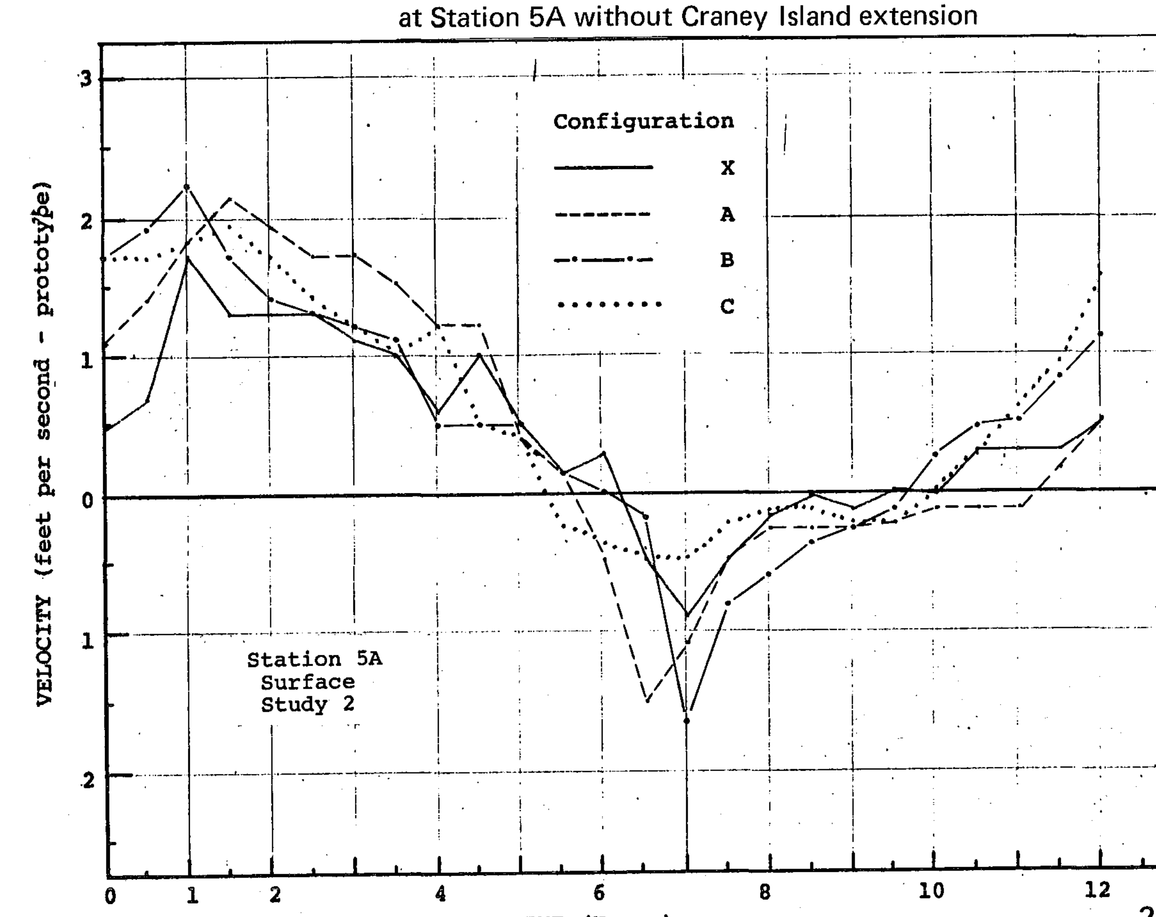


Figure 49 — **Surface-Velocity Variation** over a tidal cycle at Station 5A with Craney Island extension

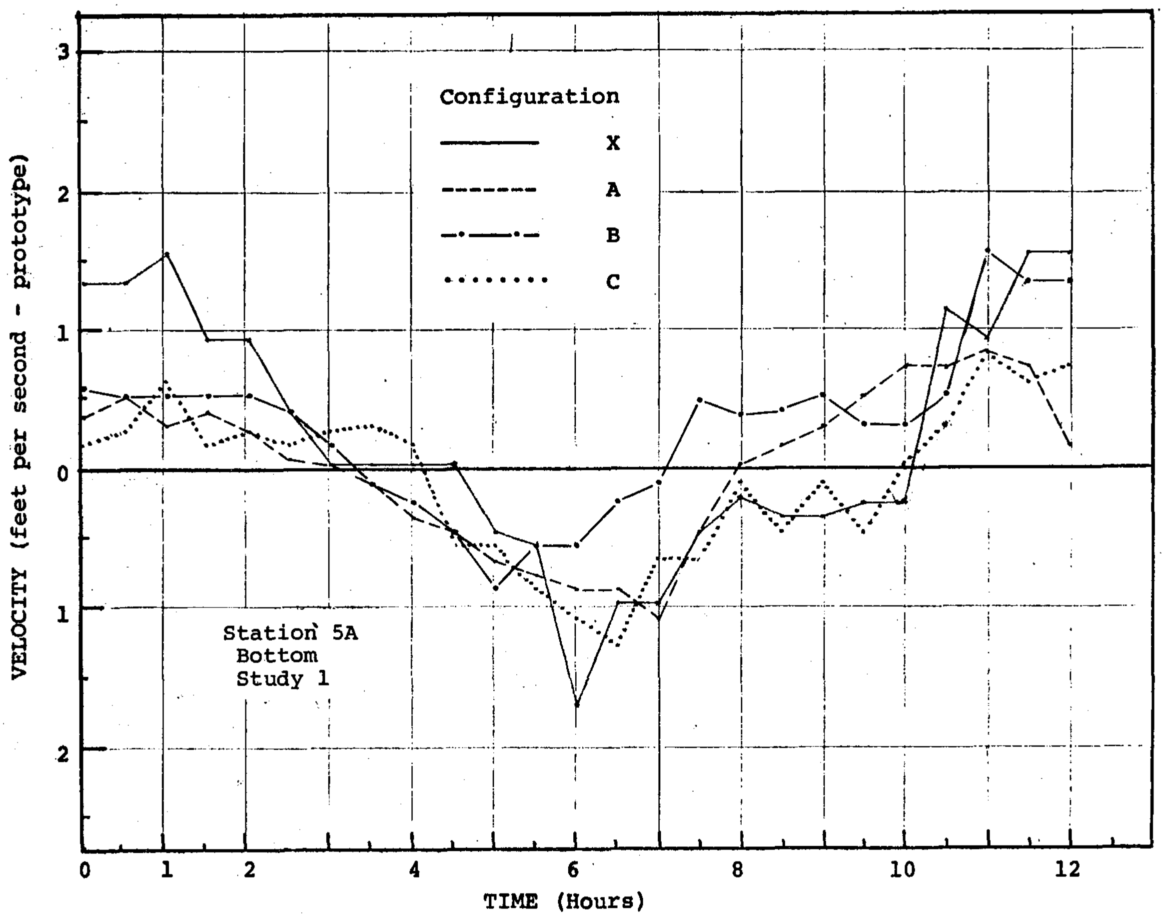


Figure 50 – **Bottom-Velocity Variation** over a tidal cycle at Station 5A without Craney Island extension

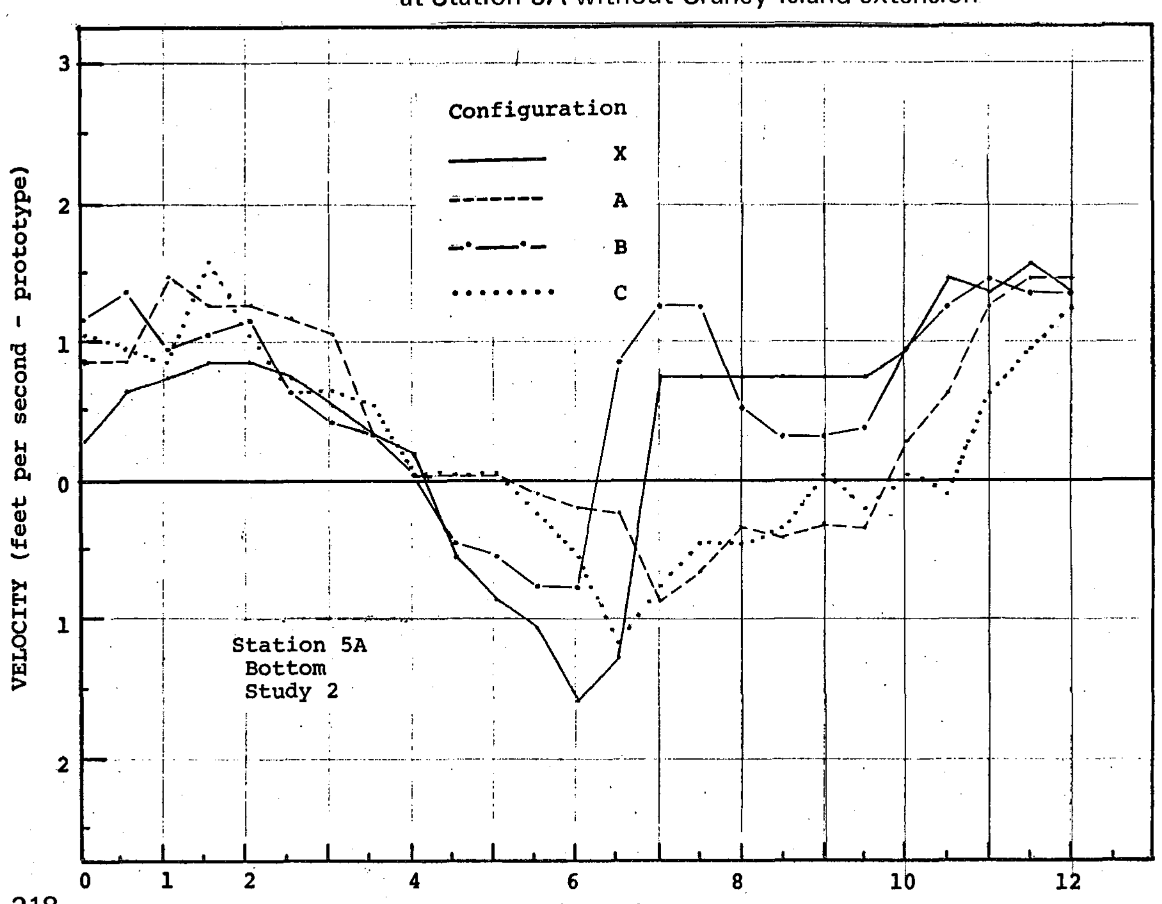


Figure 51 – **Bottom-Velocity Variation** over a tidal cycle at Station 5A with Craney Island extension

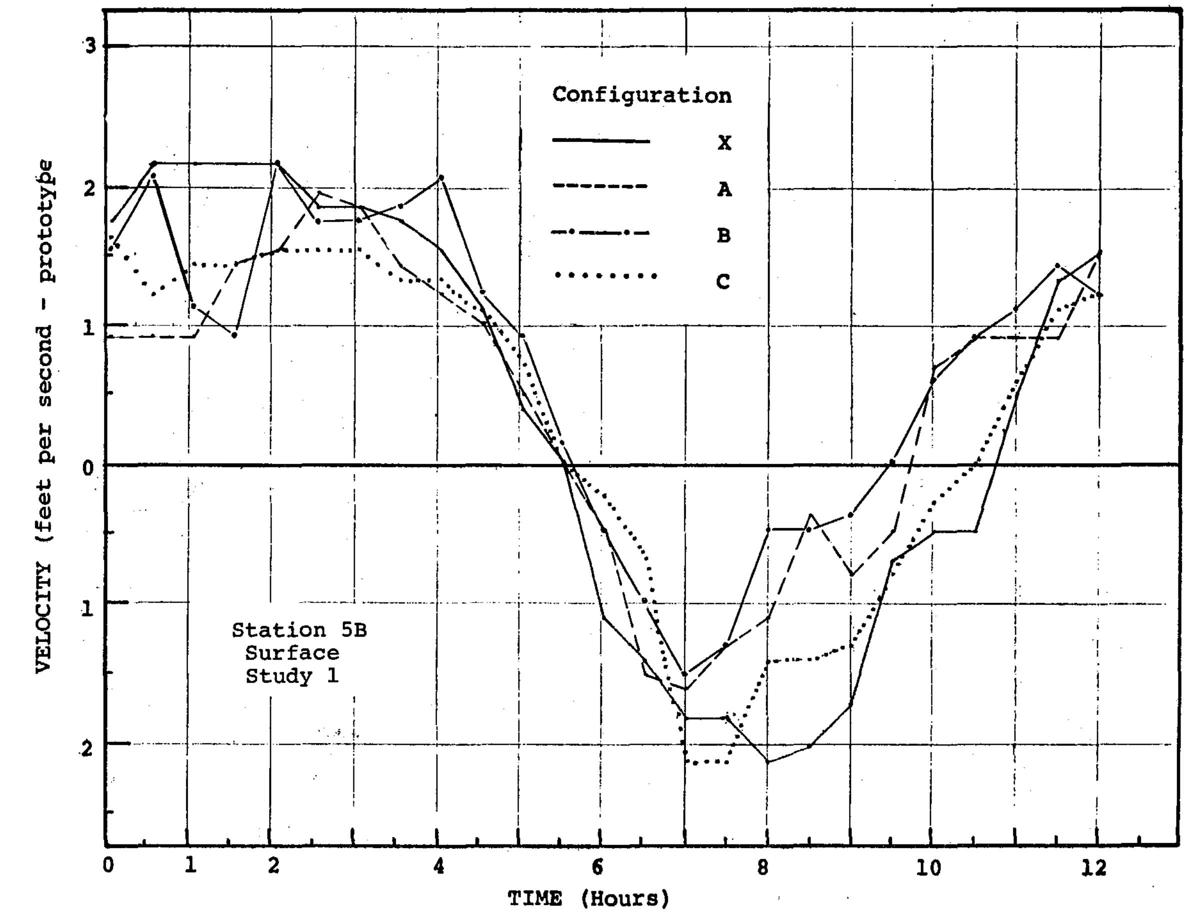


Figure 52 – **Surface-Velocity Variation** over a tidal cycle at Station 5B without Craney Island extension

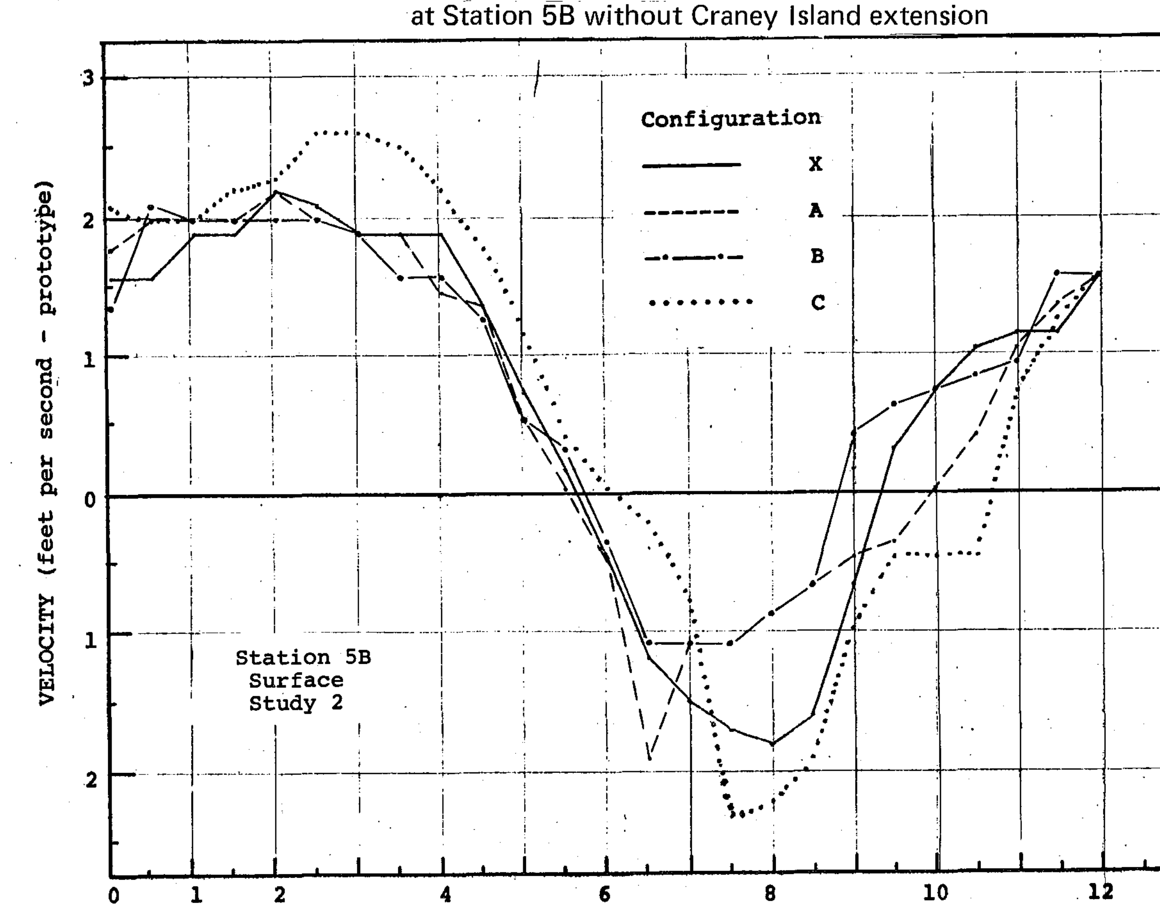


Figure 53 – **Surface-Velocity Variation** over a tidal cycle at Station 5B with Craney Island extension

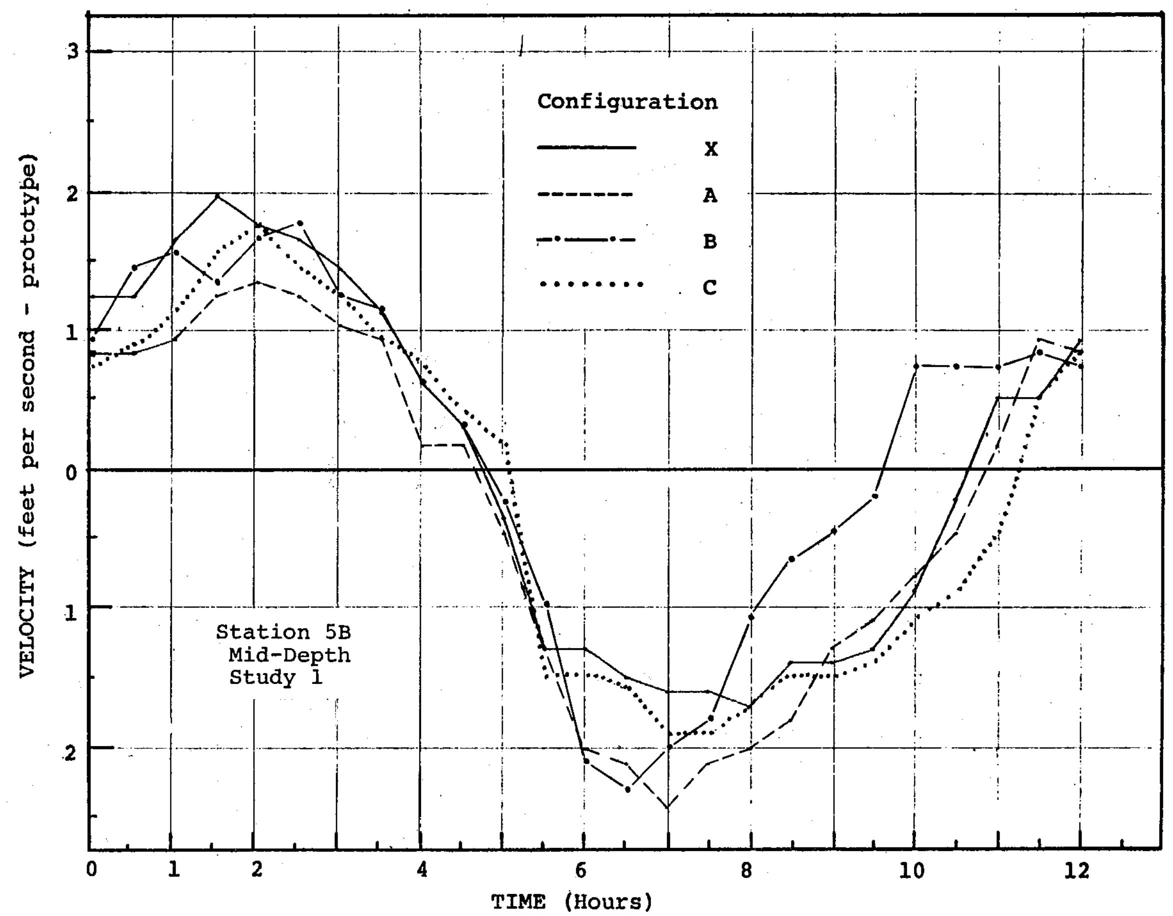


Figure 54 – Mid-Depth Velocity Variation over a tidal cycle at Station 5B without Craney Island extension

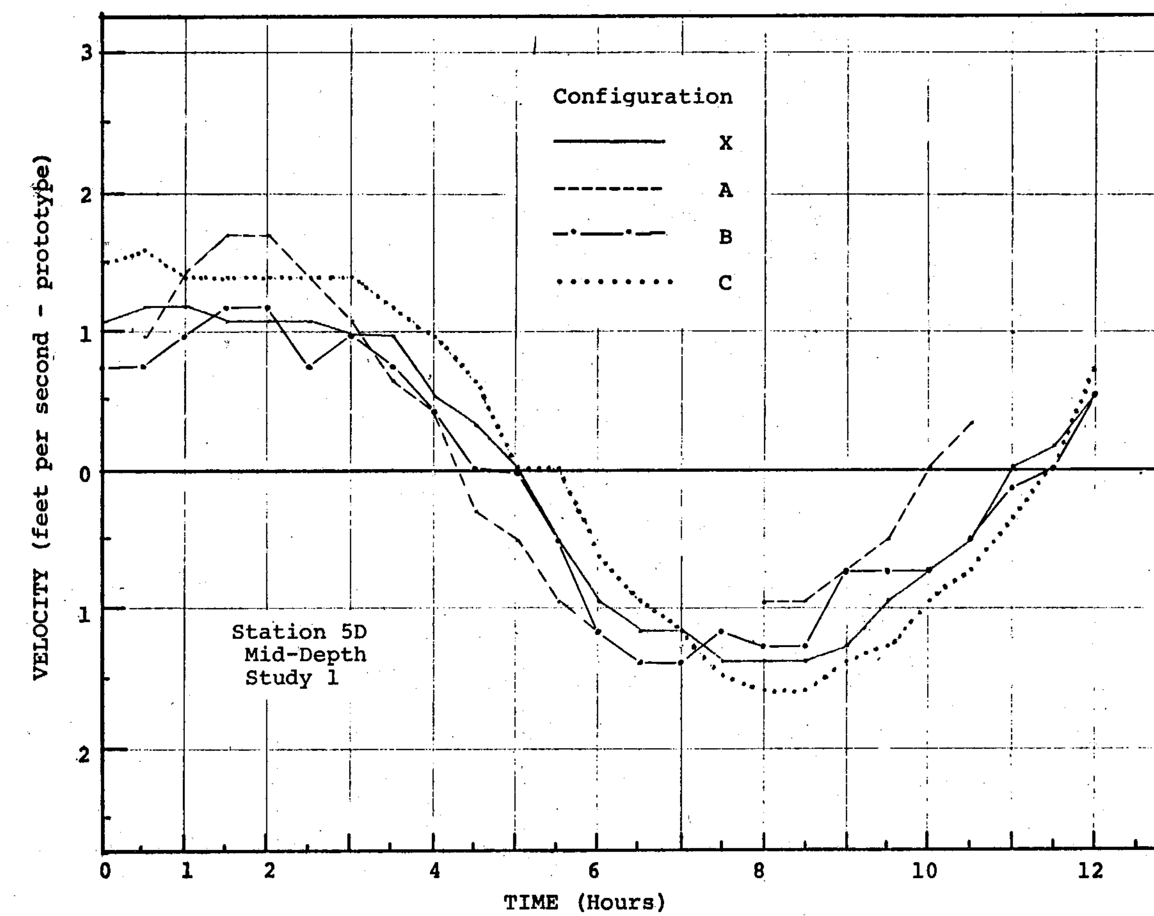


Figure 56 – Mid-Depth Velocity Variation over a tidal cycle at Station 5D without Craney Island extension

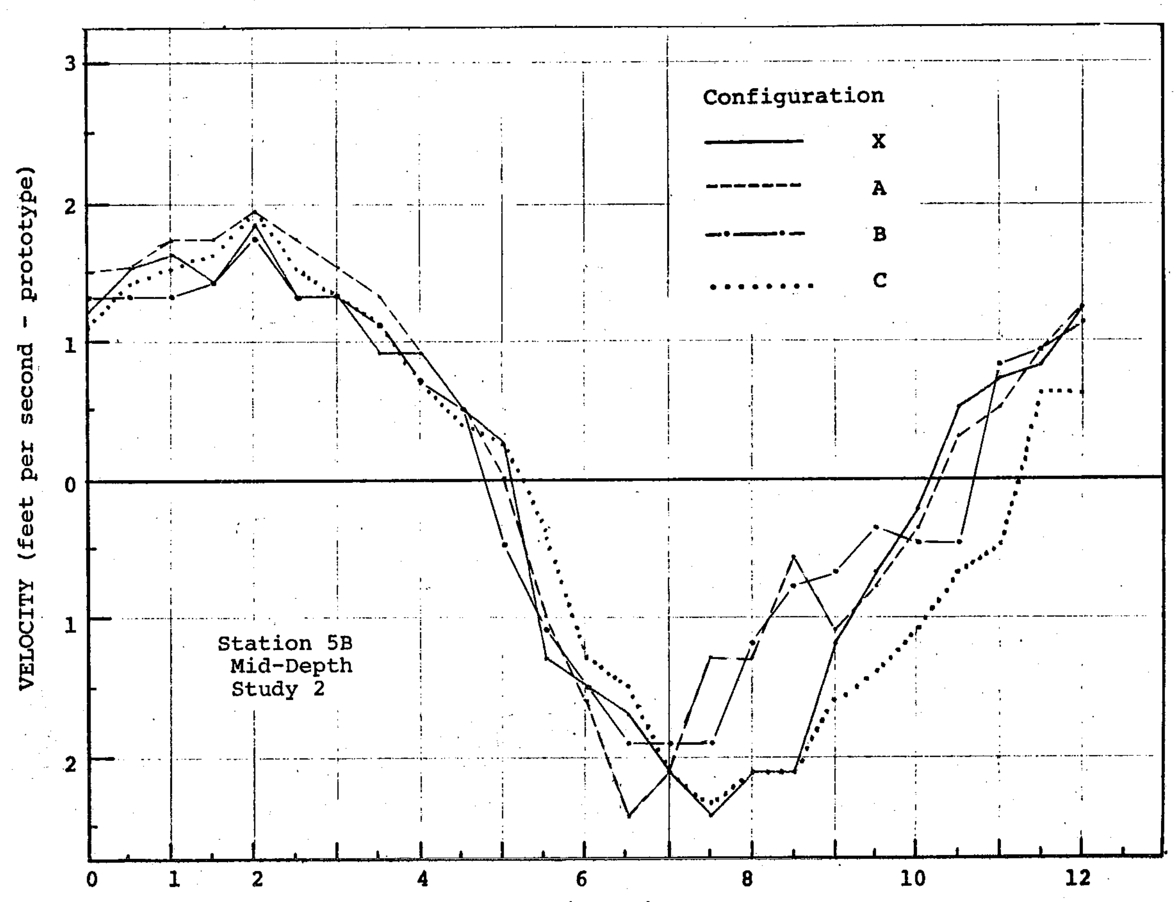


Figure 55 – Mid-Depth Velocity Variation over a tidal cycle at Station 5B with Craney Island extension

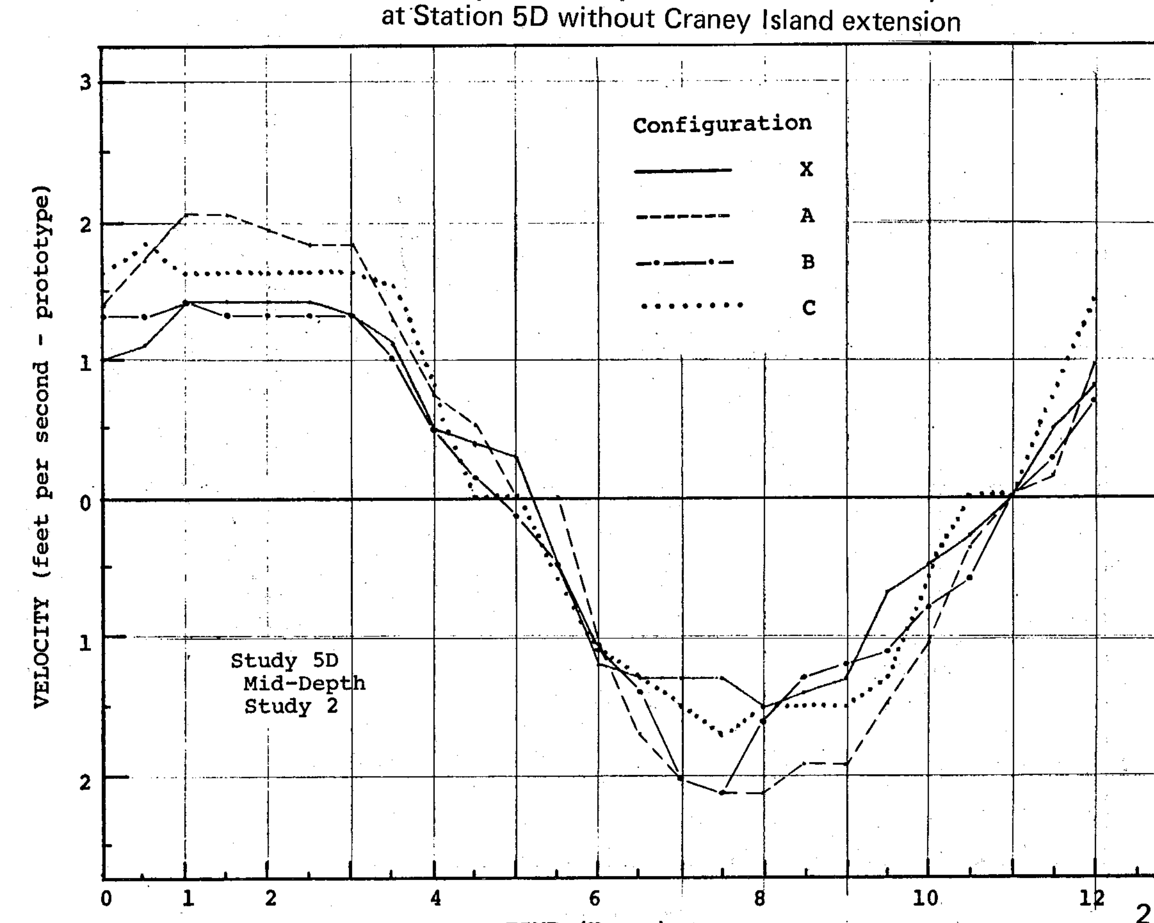


Figure 57 – Mid-Depth Velocity Variation over a tidal cycle at Station 5D with Craney Island extension

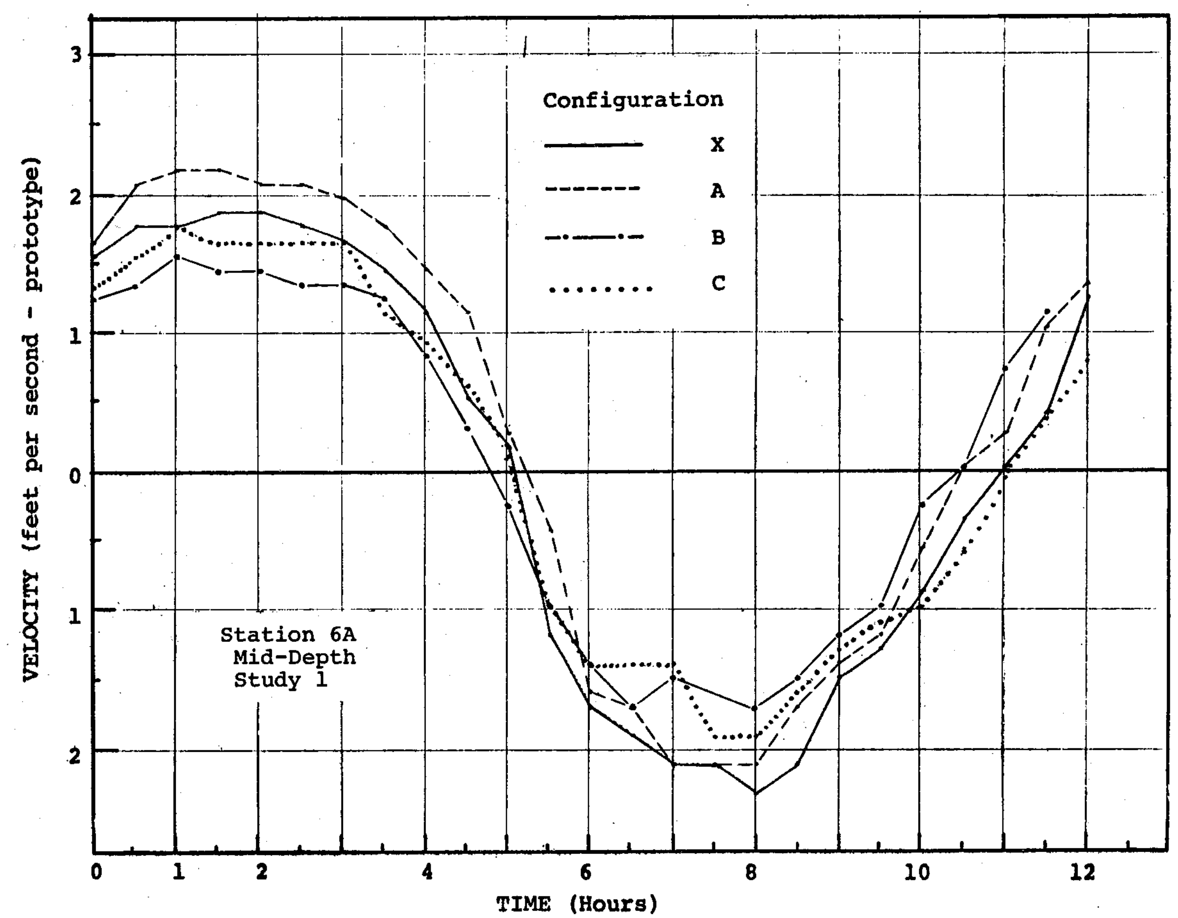


Figure 58 – Mid-Depth Velocity Variation over a tidal cycle at Station 6A without Craney Island extension

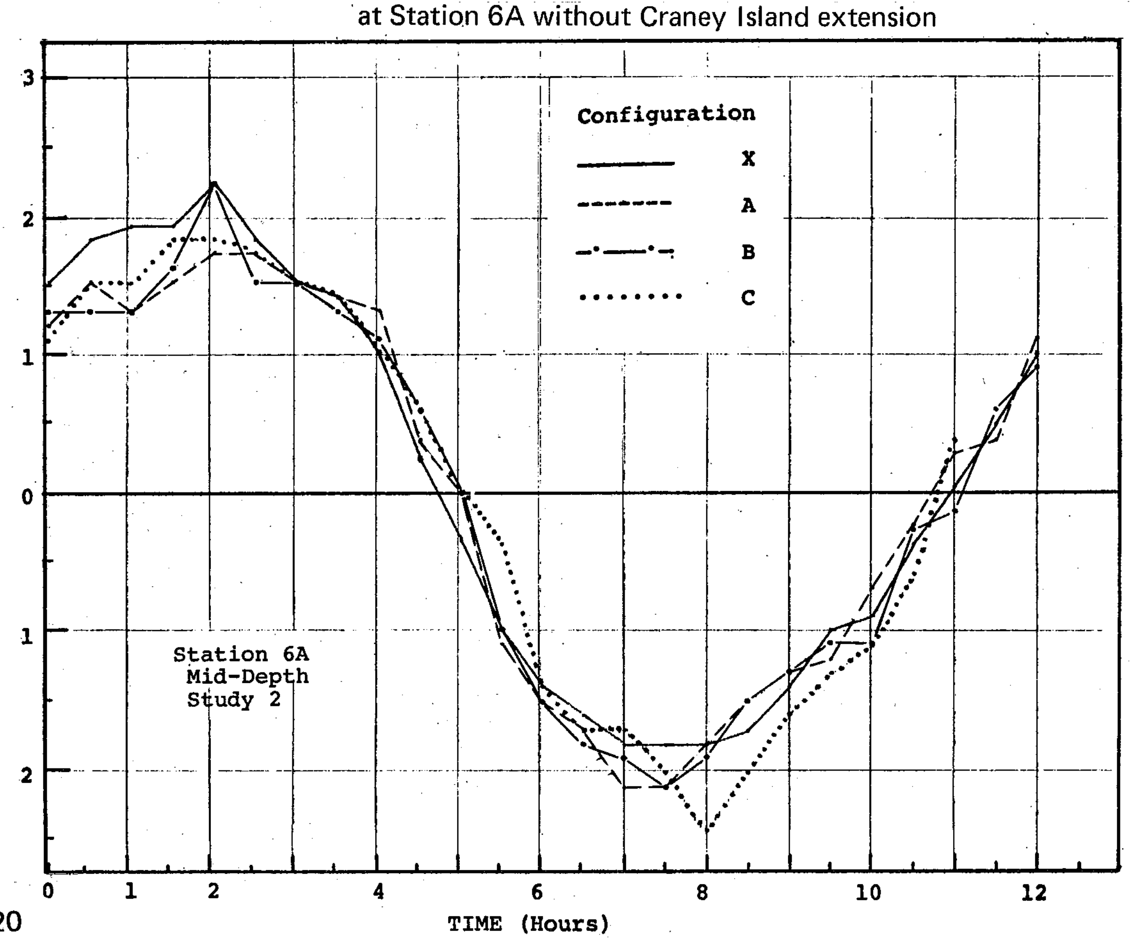


Figure 59 – Mid-Depth Velocity Variation over a tidal cycle at Station 6A with Craney Island extension

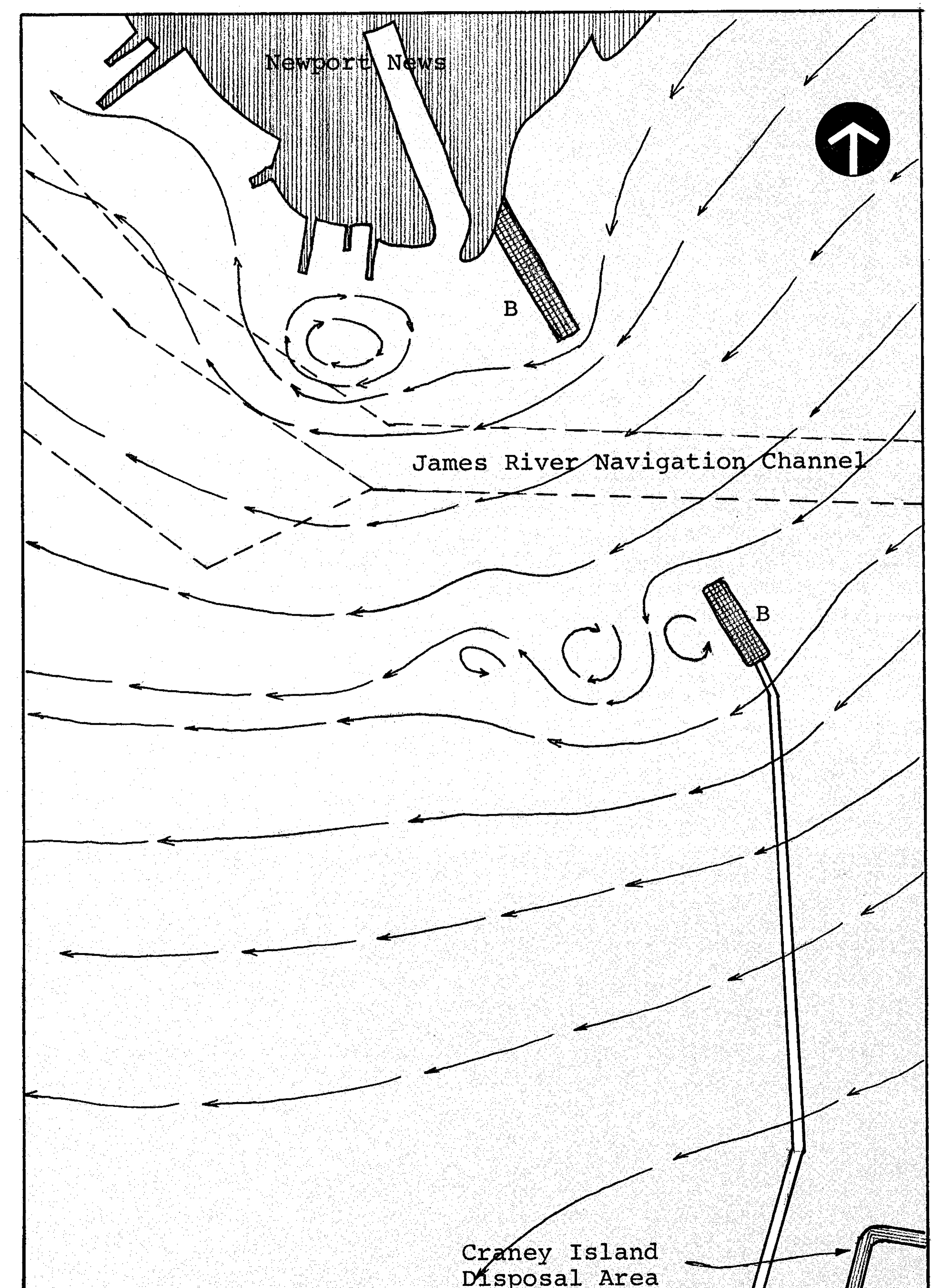


Figure 60 – Streamline Patterns taken from confetti photographs of flood tide

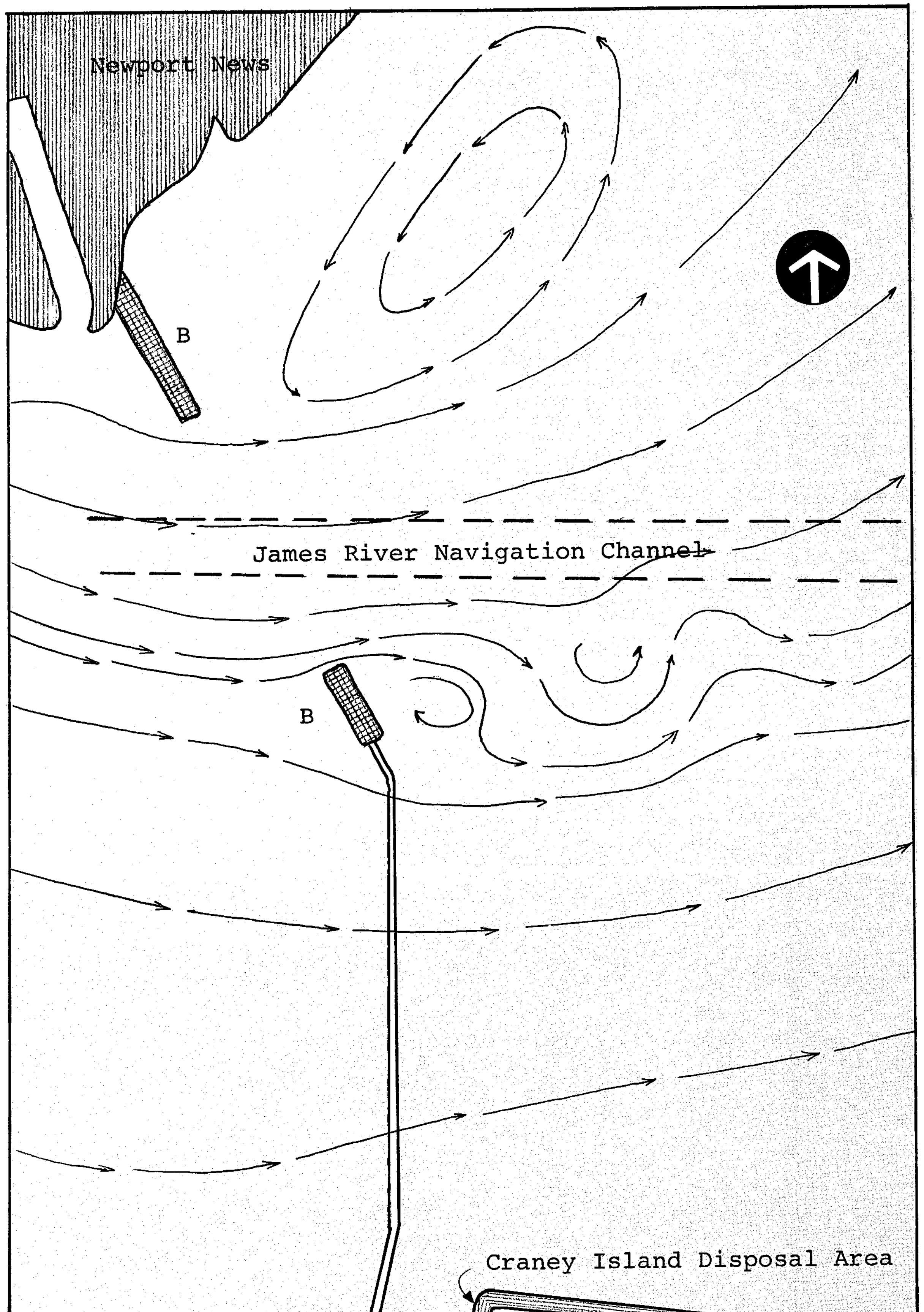


Figure 61 — Streamline Patterns taken from confetti photographs of ebb tide

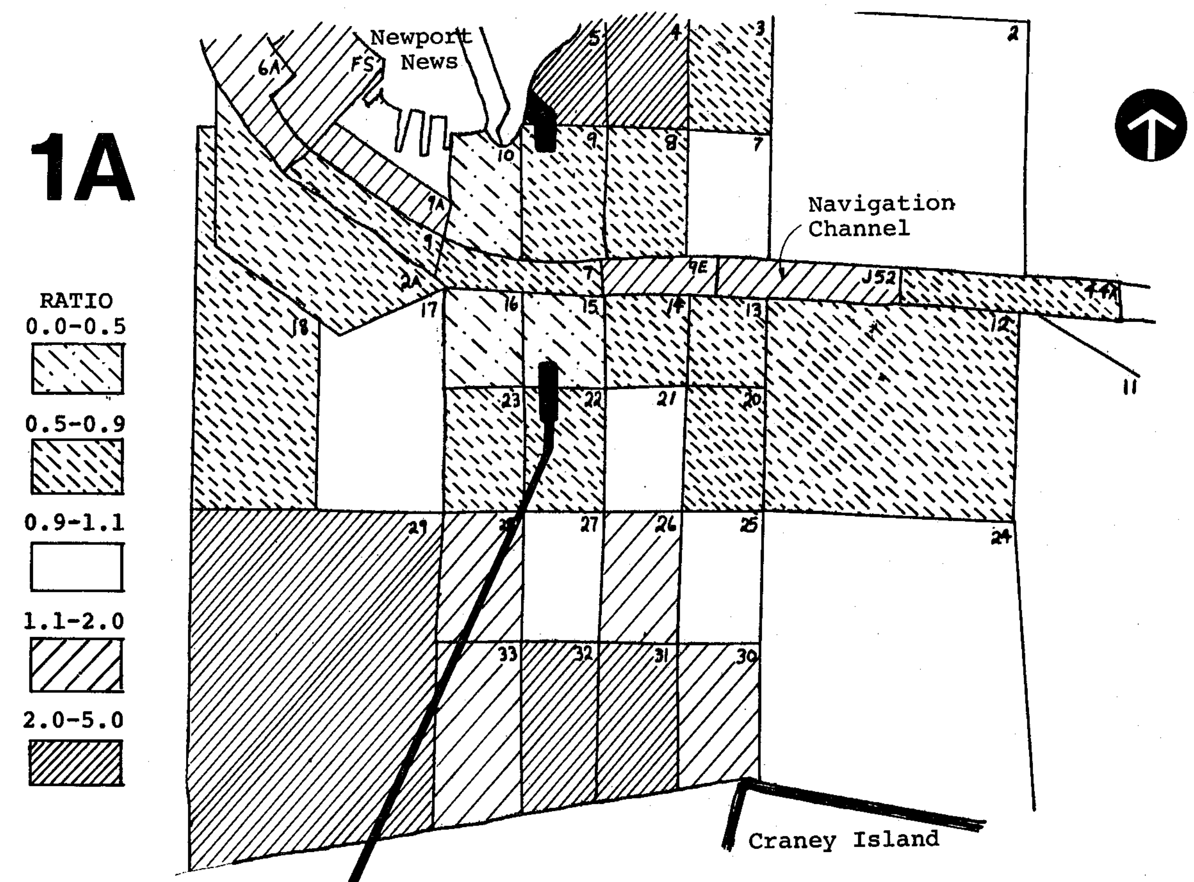


Figure 62 — Gilsonite Distribution for Configuration A without Craney Island extension

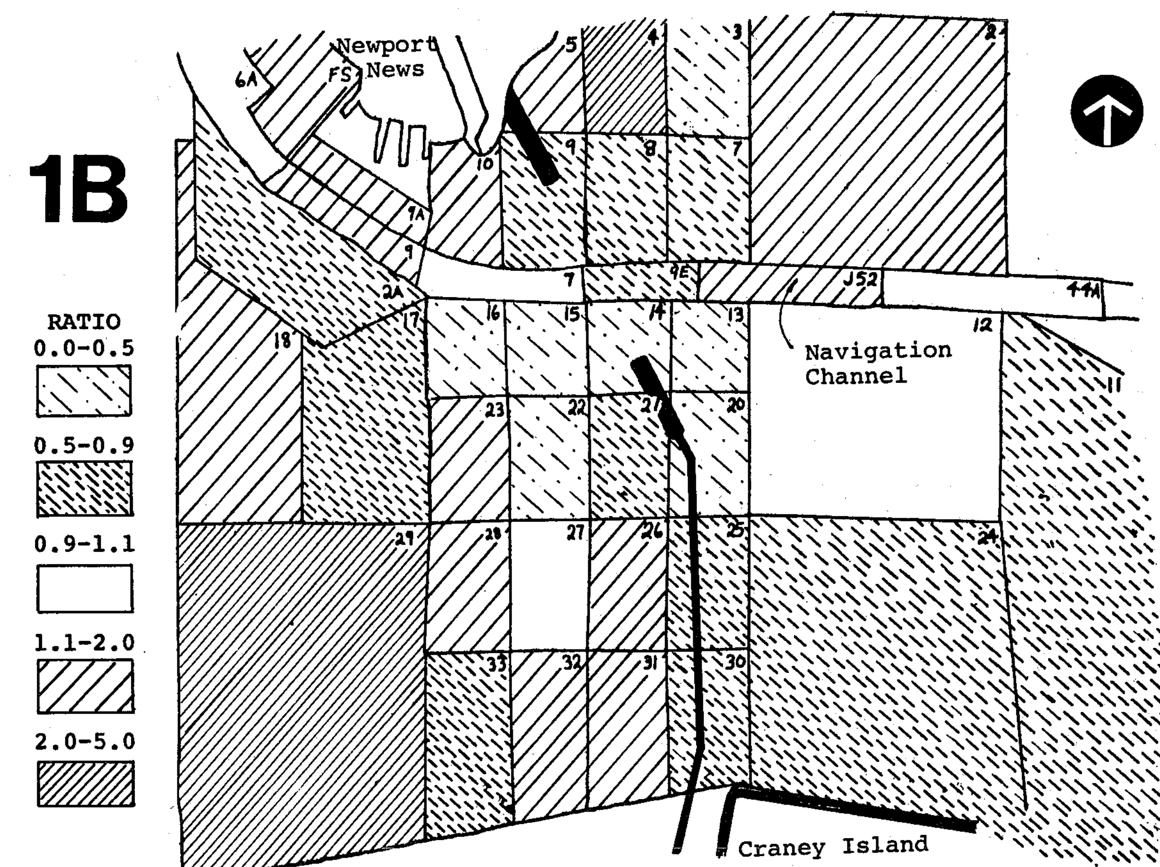


Figure 63 — Gilsonite Distribution for Configuration B without Craney Island extension

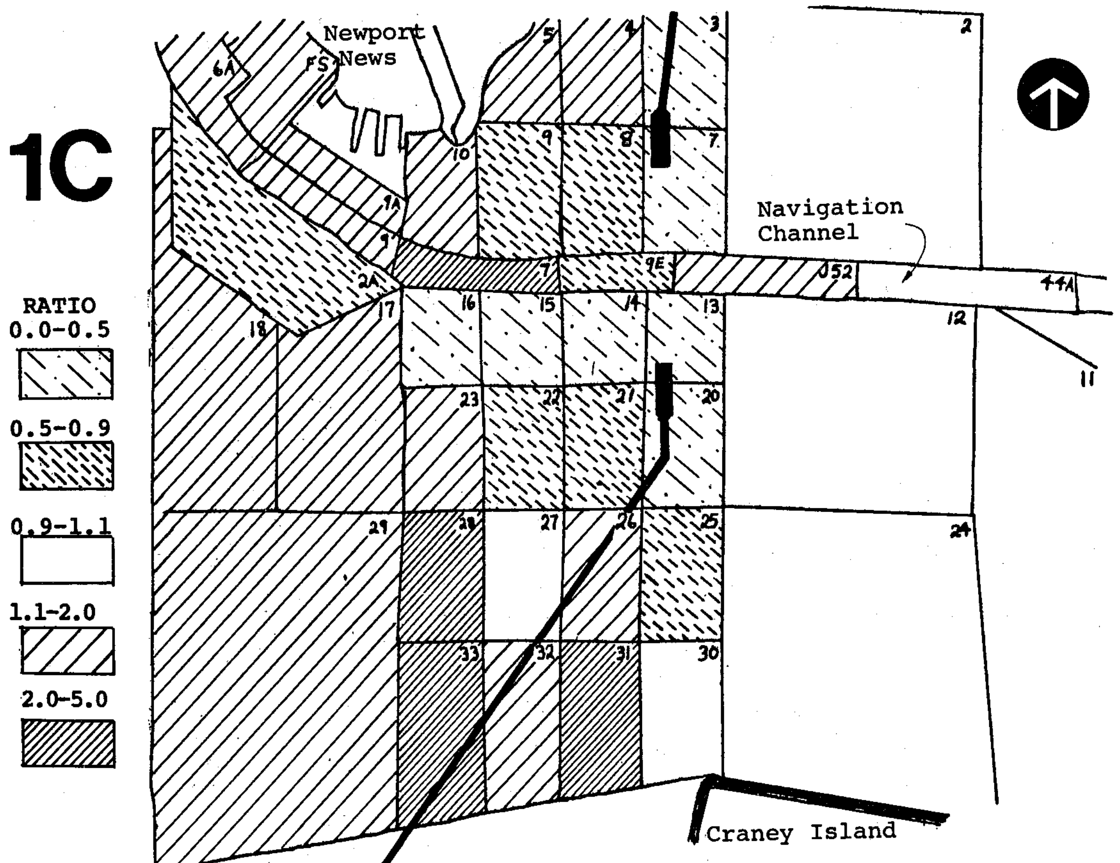


Figure 64 – Gilsonite Distribution for Configuration C
without Craney Island extension

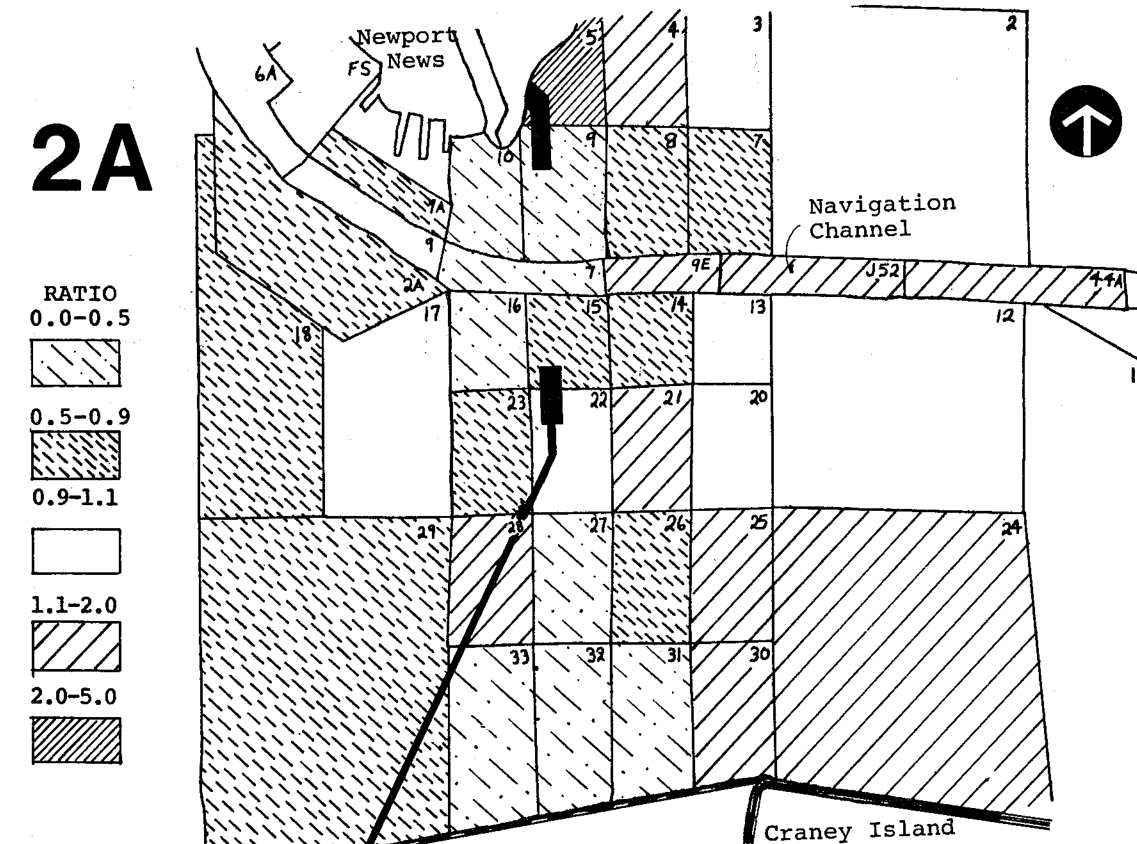


Figure 66 – Gilsonite Distribution for Configuration A
with Craney Island extension

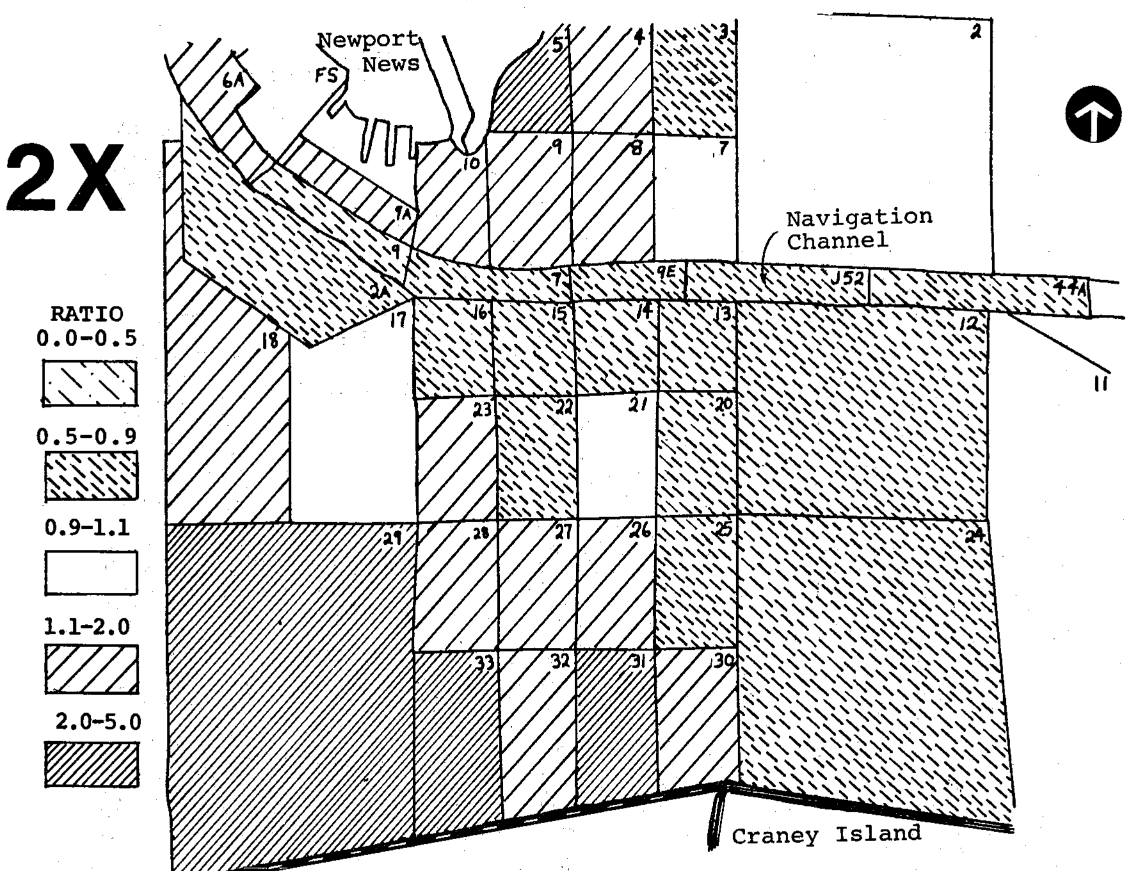


Figure 65 – Gilsonite Distribution for Configuration X
with Craney Island extension

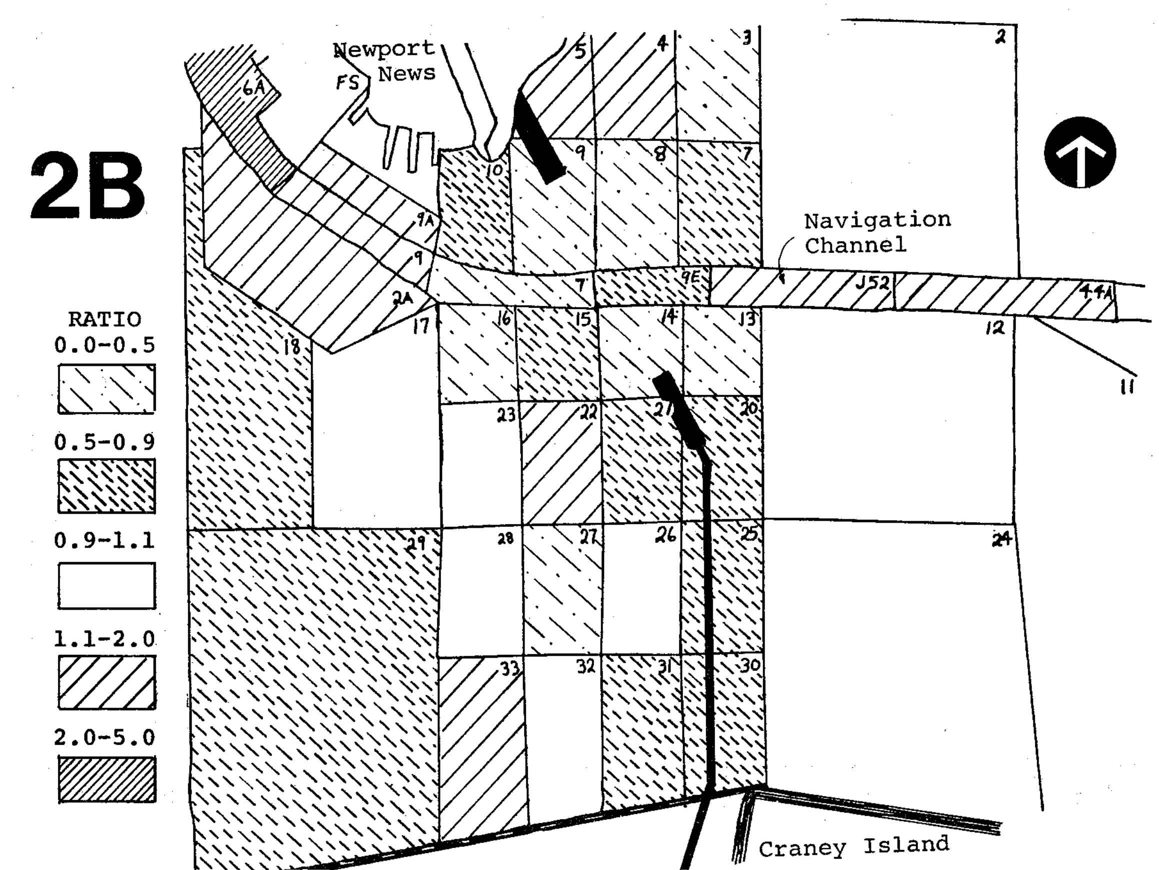


Figure 67 – Gilsonite Distribution for Configuration B
with Craney Island extension

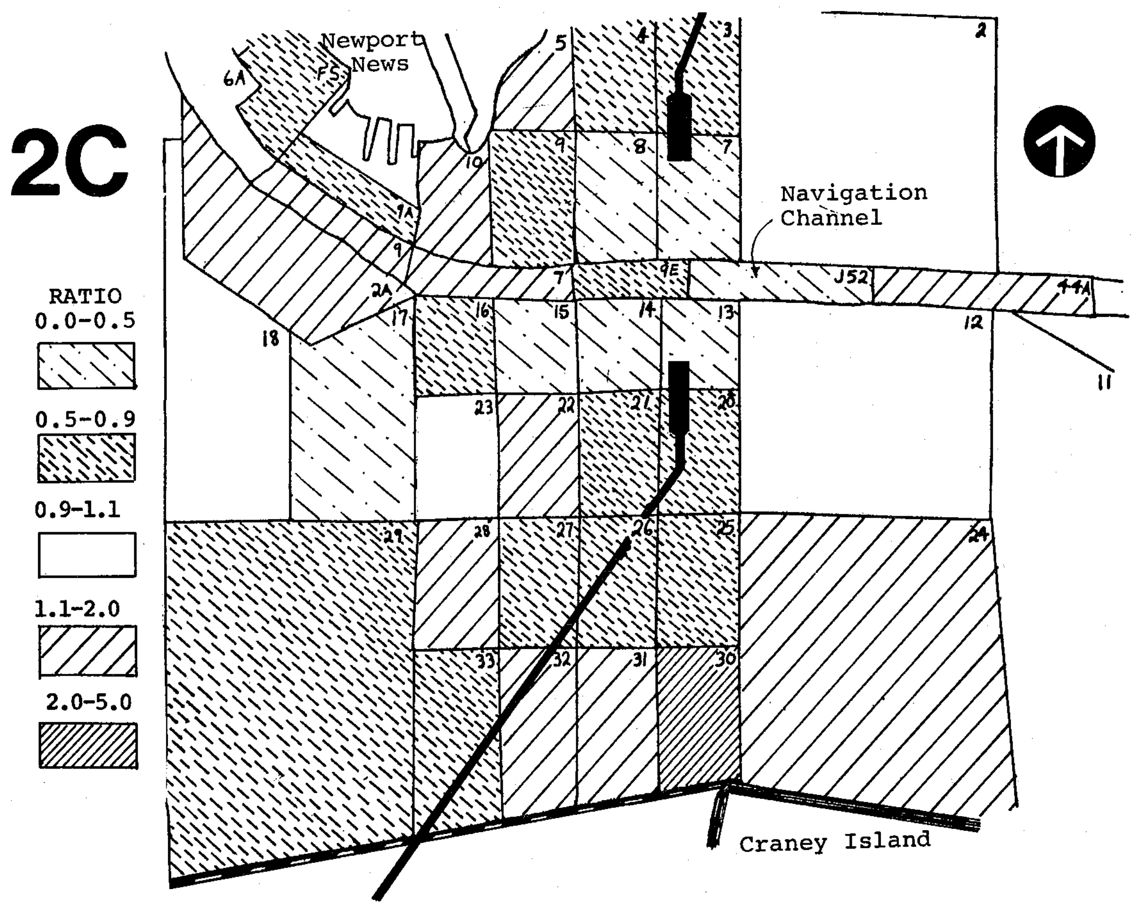


Figure 68 — Gilsonite Distribution for Configuration C with Craney Island extension

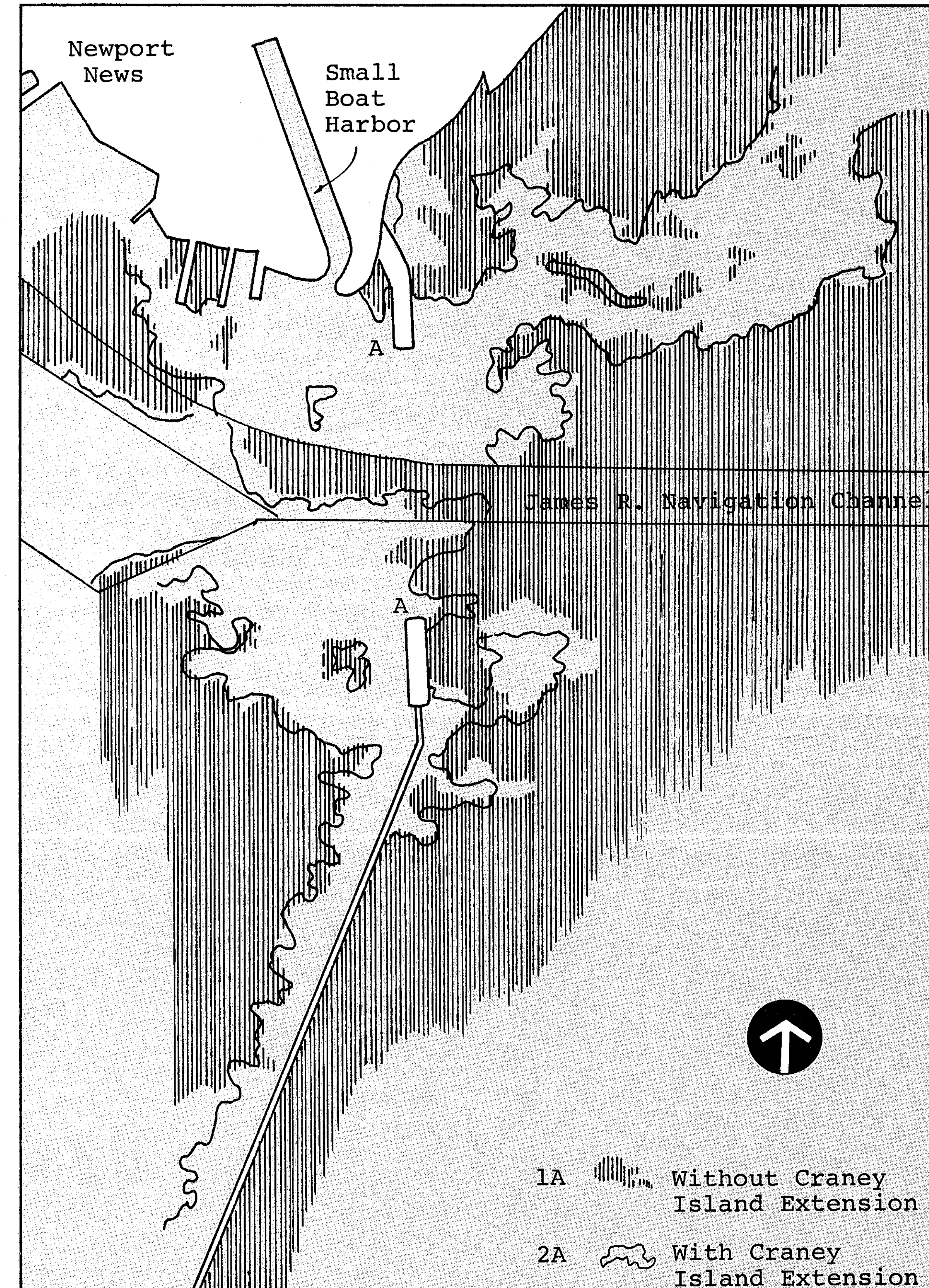


Figure 69 — Comparison of Gilsonite Deposition Patterns for Configurations 1A and 2A

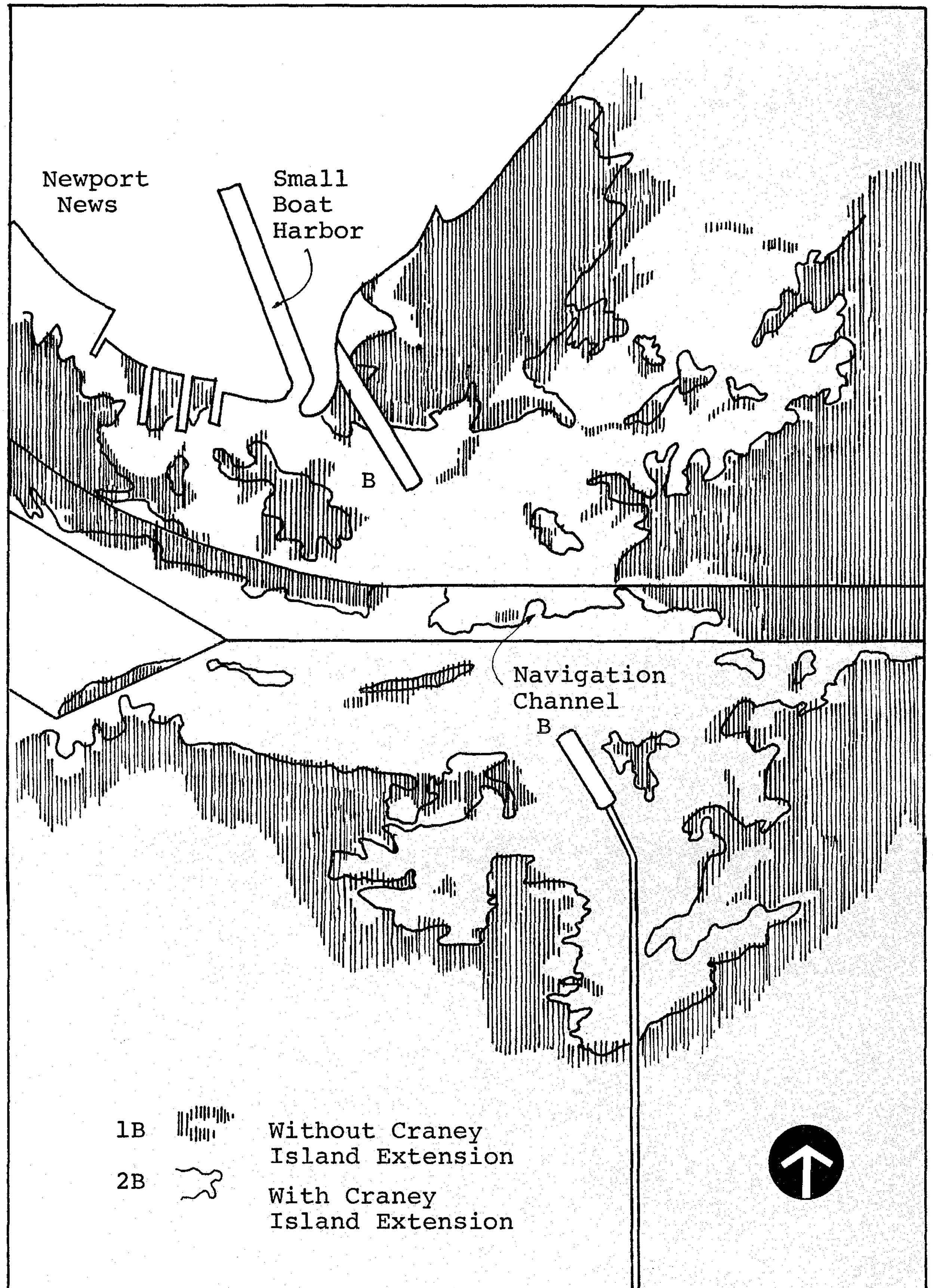


Figure 70 – Comparison of Gilsonite Deposition Patterns for Configurations 1B and 2B

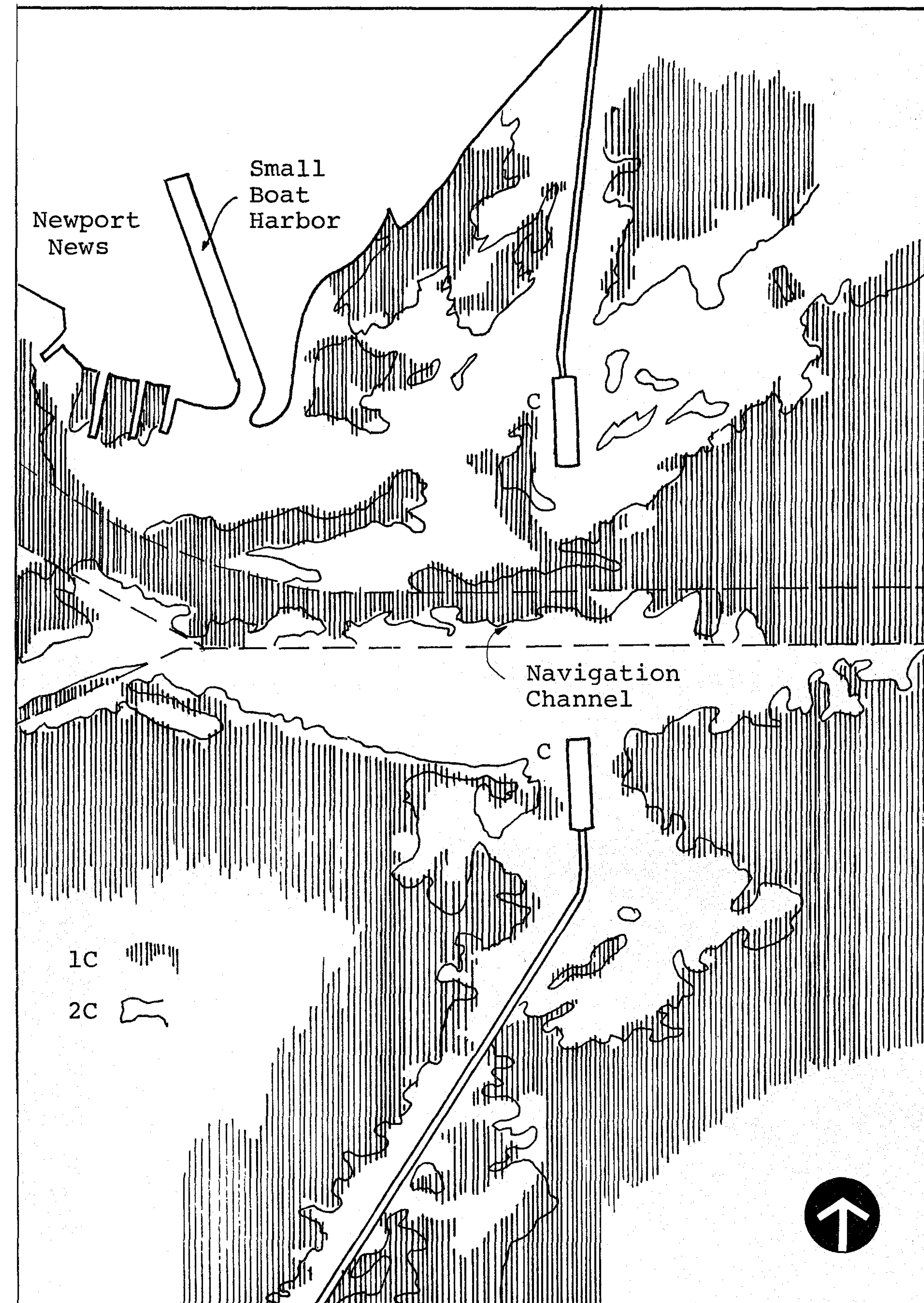


Figure 71 – Comparison of Gilsonite Deposition Patterns for Configurations 1C and 2C

PART II

IMPACT ON SHORELINE, HAMPTON FLATS AND NEWPORT NEWS POINT AREA

by

R. J. BYRNE

TABLE OF CONTENTS

A. INTRODUCTION

The following elements of the problem are considered, to assess the impact the proposed bridge-tunnel may have on the shoreline and the shallow bottoms of the Hampton Flats area:

1. Investigation of the shoreline history from 1854 to the present (1972);

2. Investigation of the cut-and-fill history of the Hampton Flats area from Hampton River to Newport News Point;

3. Investigation of the recent dredging activities in the vicinity of Newport News Point;

4. An interpretation of the hydraulic model tests with respect to the effects the various possible routings may have on the shoreline and bottoms region;

5. Discussion of the impact of proposed configurations on the shoreline and Hampton Flats; and

6. A partial assessment of the potential benefits for recreational utilization of the shoreline given the positions of the tunnel islands.

These elements are each considered in turn and then integrated in the Discussion section of the report.

B. SHORELINE HISTORY FROM HAMPTON RIVER TO NEWPORT NEWS POINT

It is relevant to consider the recent shoreline history of the area as background information for answering the question as to what the expected effect of the proposed bridge-tunnel configuration will be on shoreline response. The following input elements were used to derive the shoreline history:

1. Shoreline (MHW) positions as given on the registered boat sheets of hydrographic surveys for the years 1854, 1918, and 1966. These surveys were conducted by the National Ocean Survey (formerly Coast and Geodetic Survey).

2. Aerial Photographs of 1937, 1953, 1958, 1959, and 1963.

3. Interviews with the local residents as to when various shoreline protection works were installed.

4. Field investigation on the present condition of the shoreline with particular reference to existing engineering structures, and to the location of existing beaches.

A word of caution is in order with respect to using historical map data when discussing shoreline stability. Shoreline erosion or accretion is generally not a process which occurs at a constant rate. Thus, when shoreline positions are compared over a long time interval, such as 50 years, average erosion rates must be treated with reservation. On the particular region of Hampton Flats it is known that widespread modifications occurred during the hurricane of August, 1933. The effects of such an individual storm are masked by the fact that we are using shoreline positions from 1854, 1918, and 1966.

For purposes of discussion the study area has been divided into nine shoreline zones as depicted in Figure 1. The shoreline positions for the years 1854, 1918, and 1966 are also shown. These are:

Zone 1. Zone 1 extends about 650 ft northeast from the radio tower. The shoreline consists primarily of riprap and dumped fill, much of which is recent. The bank is steep with no beach area. The 1937 aerial photographs indicate a narrow beach existed at that time. Comparison of the shoreline positions indicate the present Newport News

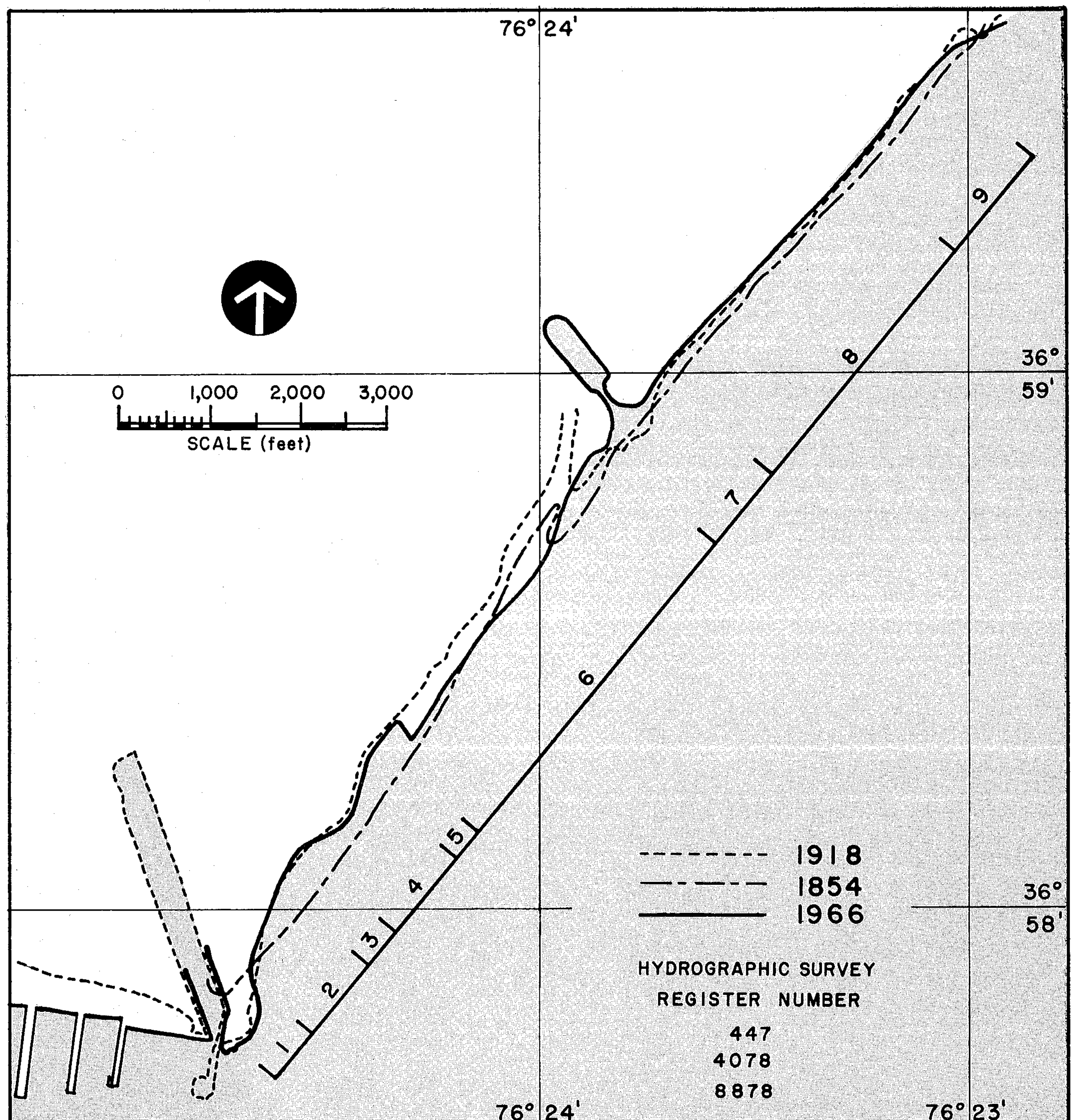


Figure 1 — Historical Shoreline Positions and Shoreline Zone Locator

Point was formed between 1854 and 1918. We do not know if the accretion was natural. Comparison of the 1918 and 1966 shoreline positions suggests the area has been filled during this time interval.

Zone 2. This zone, about 1,000-ft long, fronts Lincoln Park and has a natural beach with gentle slope. The beach is about 30-ft wide with a backshore bank increasing in height to about 6 ft. The beach forms one boundary of the park. Comparison of the shoreline positions of 1918 and 1966 indicate the shoreline has been eroding somewhat on the western half of the zone (about 2 ft/yr). Inspection of the 1937 aerial photograph confirms the existence of a beach of about the same width as present. The comparison of the shoreline positions in 1854 and 1918 indicate dramatic erosion during that time span which locally averaged as high as 6 ft/yr.

Zone 3. Zone 3 is about 450-ft long. Within this area the beach narrows and is gradually replaced by riprap which is wider than the beach. Replacing the bank behind the beach is a recently constructed (1971) retaining wall built at the back of an apartment complex under construction. Inspection of the shoreline positions between 1918 and 1966 indicates this shoreline has been stable during that time span.

Zone 4. Zone 4 is about 1,000-ft long. This zone begins on the west with a small (50-ft long) beach which grades to riprap with large accumulations of old brick, cinder block, and concrete. The areas near the water show a bed of fine silt and mud. The bank on the western half of the sector is low. The eastern half of this sector belongs to the factory located at Wickham Ave.

The eastern sector bank is much higher than the western and it appears to be formed of spoil from the channel dredging in front of the factory. Comparison of the 1918 and 1966 shoreline positions indicates the shoreline has been stable during that time period.

Zone 5. This zone, about 350-ft long, is fronted by a bulkhead built before 1937. This area fronts a factory which was engaged in producing small military craft in WW II. In 1940-1941 a steel jetty was placed just east of the factory and a channel dredged to a depth of 8 to 10 ft. No dredging has been done in the area since that time. Inspection of Figure 1 indicates the shoreline has been stable between 1918 and 1966.

Zone 6. This zone, approximately 4,000-ft long, is bounded on the east by Salters Creek and on the west by an approximately 4,000-ft-long steel jetty. This segment of the shoreline is a fairly attractive beach area that has been formed by accretion against the jetty on the western boundary. As previously mentioned the jetty was constructed in 1940-1941. The sequence of aerial photos indicates the jetty was full by 1963 and thereafter has by-passed sand. Of the total 4,000-ft length the western three-quarters (3,000 ft) has experienced accretion. The 1,000 ft just west of the entrance to Salters Creek has experienced some erosion during this period, and this has been checked by the installation of fill and riprap.

Zone 7. This zone includes the entrance to Salters Creek which has been stabilized by stone jetties. The channel to Salters Creek was dredged to its present position sometime during the period 1937 to 1953. Prior to this action Salters Creek fronted the shoreline as a marsh area and in 1918 the entrance of the creek was about 1,000 ft to the west of its present position (Figure 1). Salters Creek is used as a small-boat harbor, with yearly dredging to maintain an entrance depth of minus 4-ft mlw. The sediment at the mouth during our inspection was silt and clay with large organic content. The eastern jetty is trapping some sand but it is not full, so little sand is by-passing to the west via beach drifting.

Zones 8 and 9. The August, 1933 hurricane completely destroyed the beach areas of Zones 8 and 9. Residents gave up their pier rights and the City of Newport News built a stone and cement bulkhead from Salters Creek to the City boundary (beginning of Zone 9). Hampton built a wooden retaining wall about ten years later. According to local residents the beach had been 25 to 30 ft wide before the storm. The area is presently fronted by a sand bottom grading to fine silt offshore, but there is no beach at high tide.

Of the nine zones considered, only Zones 2 and 6 have usable beaches at the present time. Thus, our consideration of the impact of the bridge-tunnel must pay particular attention to these areas as well as general attention to the entire region in terms of possible beach development in the future.

C. CUT AND FILL ON HAMPTON FLATS AREA

The available historical hydrographic surveys were compared to see whether significant erosion or accretion trends exist on the Hampton Flats area. Three surveys (1966, 1918, and 1854) were chosen for detailed examination with emphasis on the region west of 76°23′ West Longitude to Newport News Point. This region is the one most susceptible to influence from the bridge-tunnel islands and causeway.

Three sub-areas shown in Figure 2 warrant particular examination.

1. Newport News Bar on the southwest corner of Hampton Flats.

2. The channel (herein called the Newport News Bar Channel) which lies between the Bar and Newport News Point.

3. The nearshore bottom with depths less than −6 ft (MLW) between Newport News Point and Salters Creek.

The channel, B, is a feature formed and maintained by the dominant flood currents over the lower Hampton Flats. Figure 2 shows the surface area of the Flats decreases as Newport News Point is approached from the northeast. The flood currents accelerate in the approach, resulting in the formation and maintenance of the channel.

Cross sections were prepared as shown in Figures 3a and 3b to assess the cut and fill history. The origin for the cross sections is 36°57.5′ North Latitude, with the lines of the cross sections falling on the meridians as labelled in Figure 2. Depths are relative to mean low-water.

Sub-area A. Newport News Bar has decreased in width and length from 1854 to 1918 to 1966. The depth of the crown of the bar has remained constant (see cross sections 76° 23.5′ West through 76°24.25′ West). The decrease in length has occurred from both ends of the bar, but the dominant reduction has occurred on the northeast end.

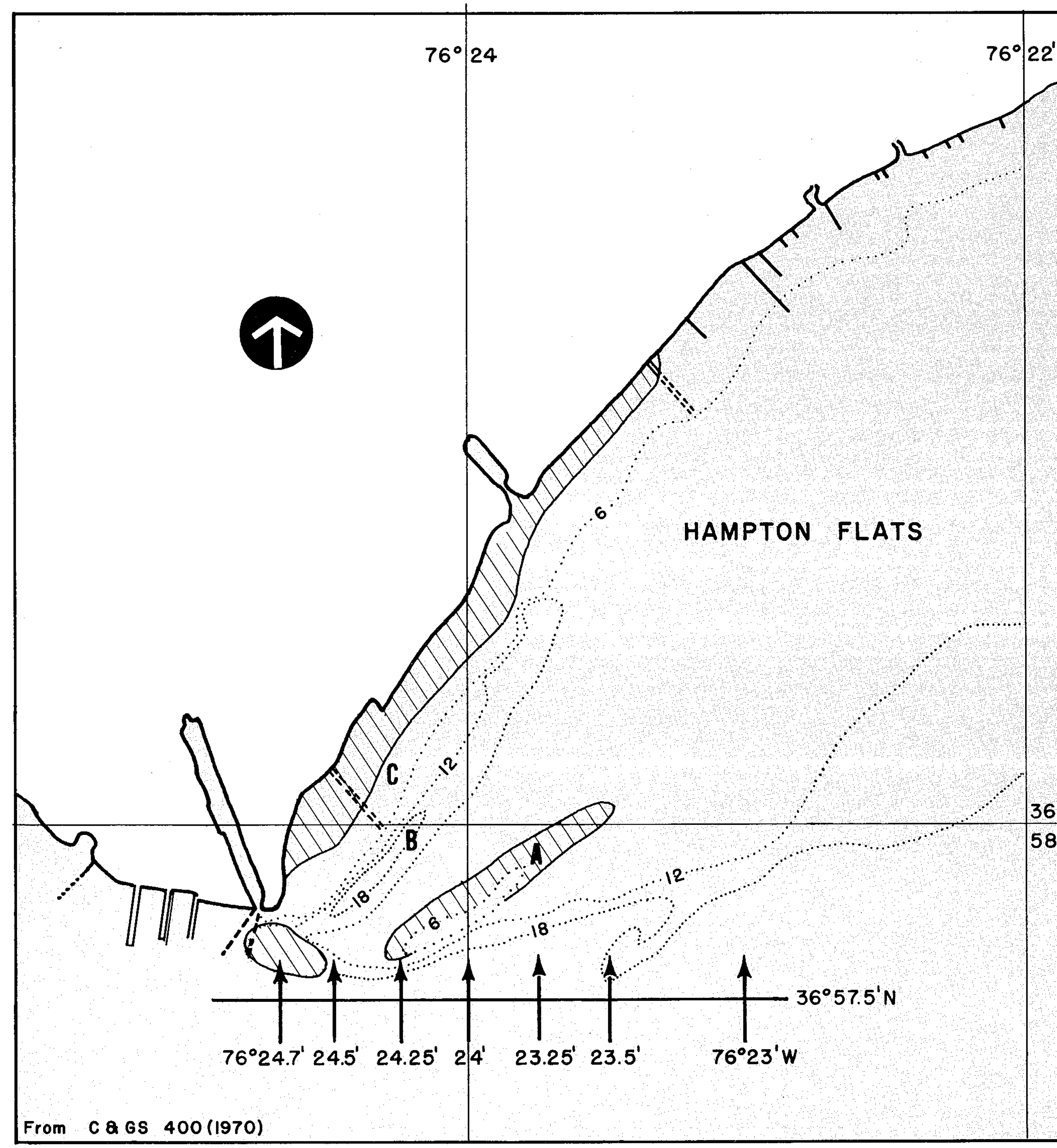


Figure 2 — Areas of Erosion on Hampton Flats Between 1854 and 1966 (hatched) and location indicator for profiles shown in Figure 3a and 3b.

Sub-area B. The channel has not changed appreciably since 1854. The portion of the channel with depths greater than 18 ft decreased in length between 1854 and 1918. In 1854 the deeper hole in the channel extended further to the northeast. The position of the 12- and 18-ft contours shows no significant change between the 1918 and 1966 surveys.

Sub-area C. Inspection of Figures 3a and 3b shows there has been net *erosion* of the shallow zone near the shoreline. In 1854 the mean low line intersected what is now about the –3 ft contour. The zone of bottom-cutting extends to about 800–1,000 ft from the present shoreline.

The cross-hatched areas in Figure 2 indicate the approximate boundaries where there has been bottom erosion between the 1918 and 1966 surveys. In addition to the two locations already mentioned (Newport News Bar and the shallows near the shoreline) some erosion has occurred (–2 ft) in the region directly south of Newport News Point.

Aside from the locations mentioned there has been virtually no change over the extensive Hampton Flats area where the depth is about 10 or 11 ft.

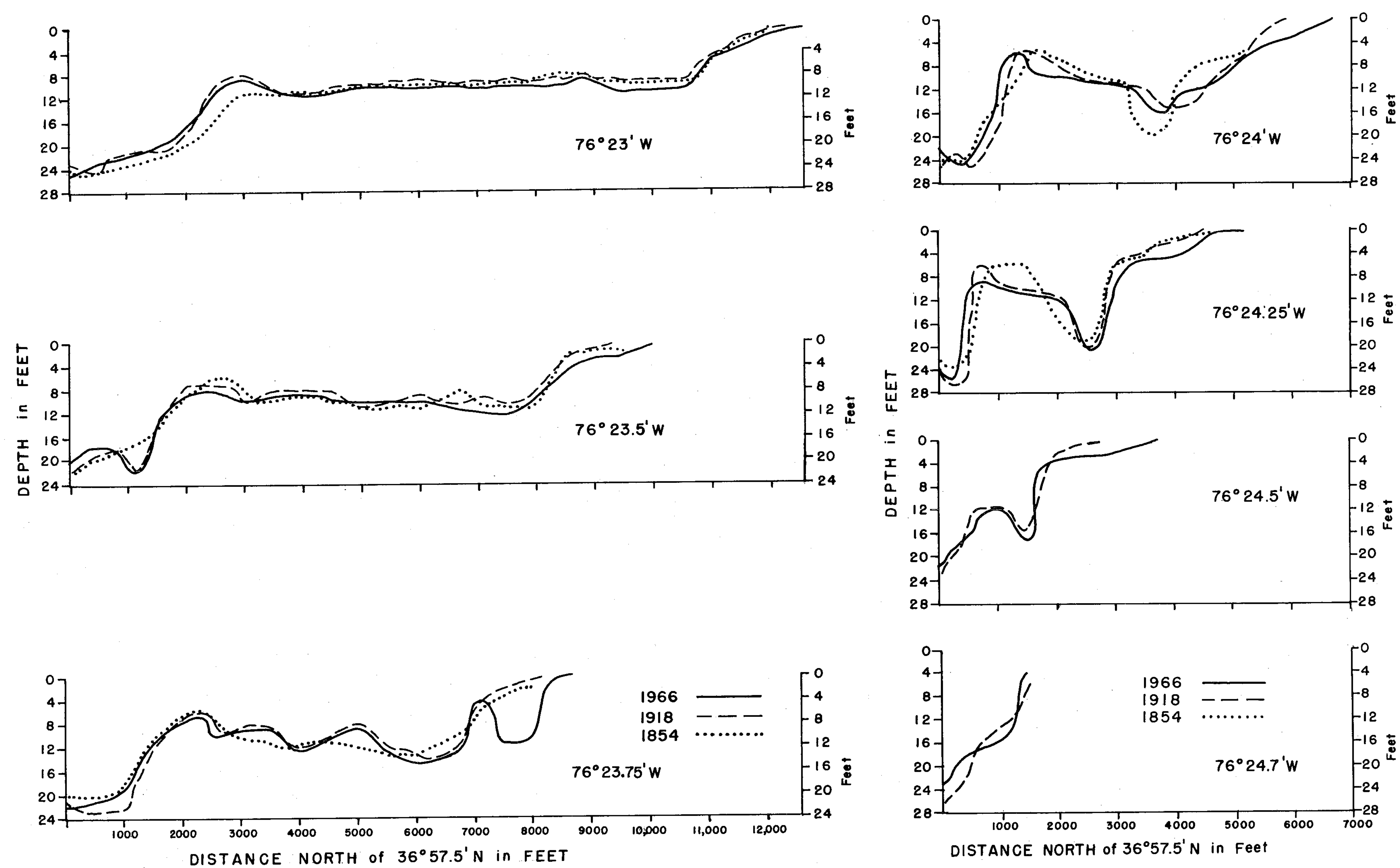


Figure 3a&b – Profile Lines of Comparative Hydrography Across Hampton Flats for years 1854, 1918, and 1966.

D. DREDGING IN THE VICINITY OF NEWPORT NEWS POINT

Investigation reveals that there is little dredging activity northeast of Newport News Point; annual dredging at the mouth of Salters Creek is the only relevant location on Hampton Flats. The entrance channel is maintained at a depth of –4 ft relative to mean low-water.

Since some of the possible locations of the bridge-tunnel islands will affect the circulation to the west of Newport News Point the recent dredging history at Coal Piers Nos. 14 and 15 and Piers Nos. 8 and 9 was studied. This was possible because of the thoughtful cooperation of the C&O Railway which operates the piers. The C&O dredging records were examined for the period of 1957 through 1969. The data, in summarized form, are listed below for Piers Nos. 14 and 15:

Pier 14 west side – 3,200 cu yd/yr (deposition rate about 10 inches per year)
east side – 5,750 cu yd/yr (deposition rate about 17 inches per year)
Pier 15 west side – 3,300 cu yd/yr (deposition rate about 10 inches per year)
east side – 3,100 cu yd/yr (deposition rate about 11 inches per year)

In arriving at the above average figures, the cases where the pier slips were deepened to accommodate deeper-draft vessels were eliminated since our goal was to estimate the annual sedimentation rates. It should be emphasized that the figures are only estimates. It is, however, evident that the dock area is a high-deposition zone at the present time.

E. INTERPRETATION OF MODEL RESULTS ON HAMPTON FLATS AND WEST OF NEWPORT NEWS POINT

The two aspects of the model studies which are relevant to the effect of the proposed structures on the shoreline and the Hampton Flats-Newport News Point area are the pathline photographs and the Gilsonite tests. As previously mentioned, three bridge-tunnel configurations were run in the model in addition to the baseline tests without structures. These are shown in Figure 4. Another configuration has been proposed since the model tests were run (also shown in Figure 4, Plan D) but since it is similar to Plans A and B in most aspects the circulation and Gilsonite results may be expected to be quite similar.

1. PATHLINE STUDIES

The pathline photography was examined to see if any given proposed location of the bridge-tunnel structure affected the circulation in such a way as to enhance erosion or deposition since either, depending upon the particular location, could be a disbenefit.

Examination of the pathline results for the various plans with and without the Craney Island extension indicated no significant differences in the circulation on Hampton Flats or in the immediate vicinity of Newport News Point. Thus the discussion from this point on will apply to either case.

The baseline tests agreed qualitatively with the field study of currents on Hampton Flats (drogues) so we can have reasonable confidence in the model results for those cases concerning Plans A, B, and C. Plan D will behave as Plans A and B. The drogue and the baseline test show that the transition from ebb- to flood-flow occurs earlier (1 to 2 hours) on Hampton Flats than in Newport News Shipping Channel. Thus the southwestern half of Hampton Flats experiences a dominance of flood over ebb currents.

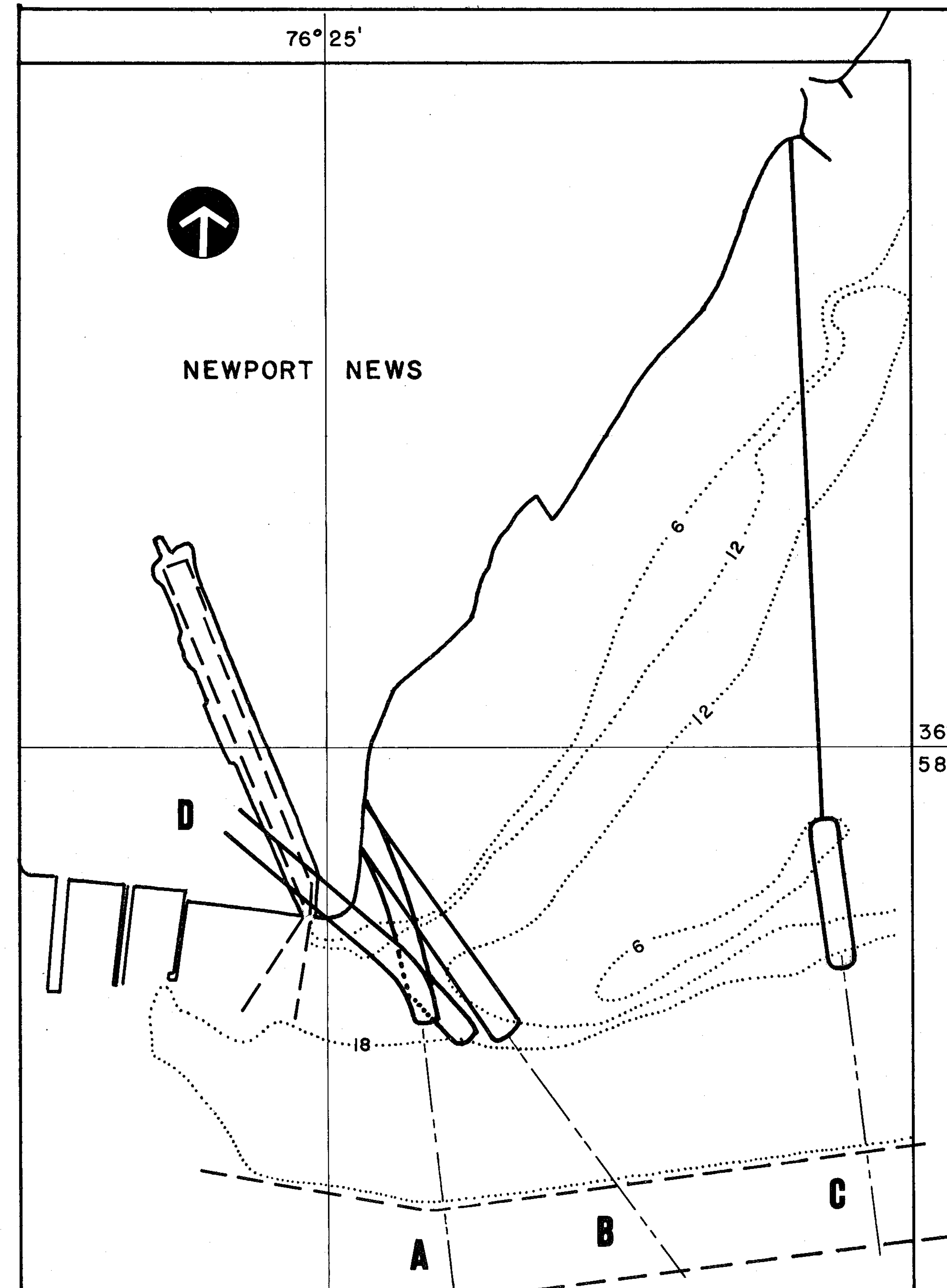


Figure 4 – Various Proposed Tunnel-Islands and Causeway Configurations on Hampton Flats; Plans A, B, C, and D.

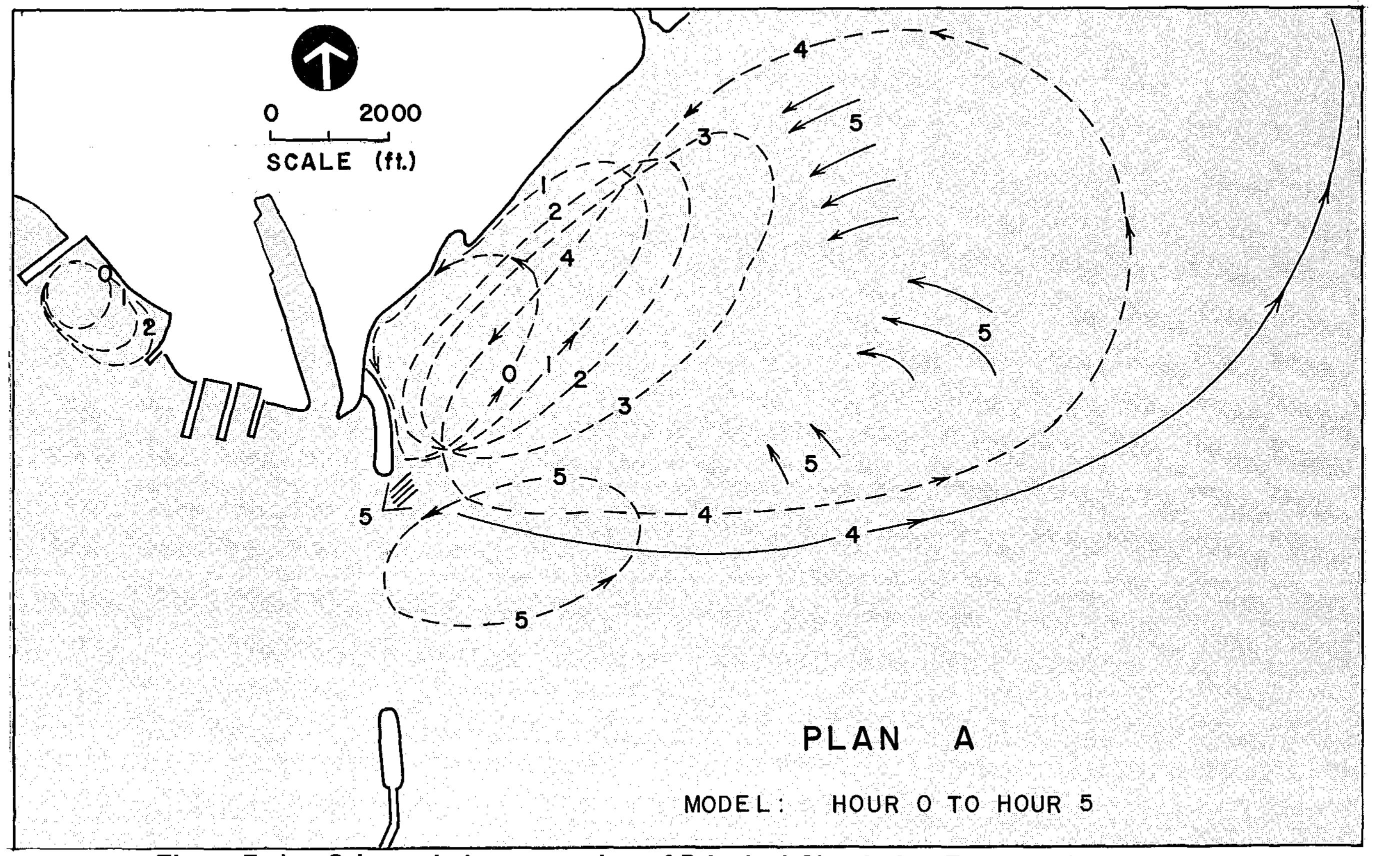
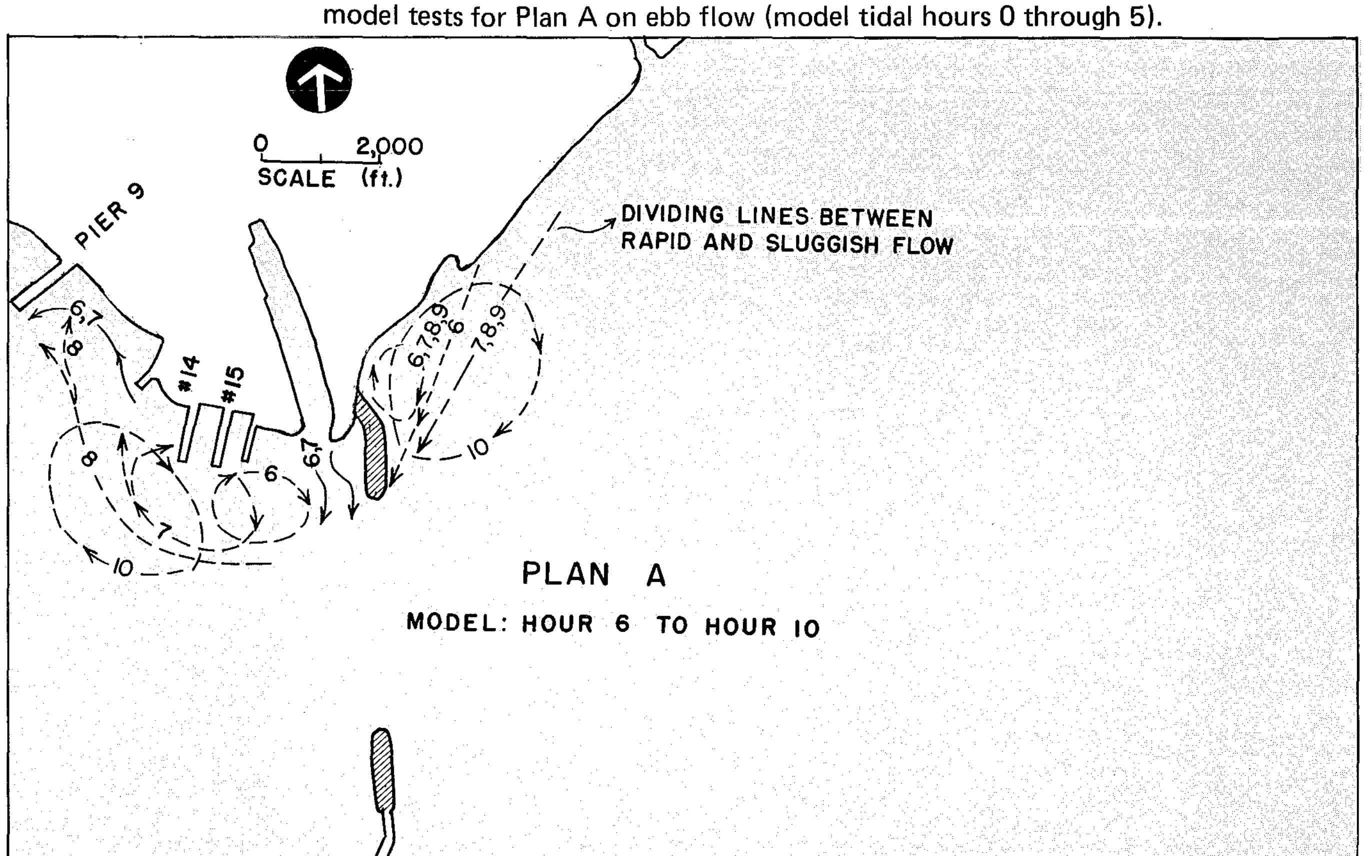


Figure 5 a) – Schematic Interpretation of Principal Circulation Features shown in model tests for Plan A on ebb flow (model tidal hours 0 through 5).



(Figure 5 b) – Flood Flow (model tidal hours 6 through 10).

Many of the pertinent features of the circulation for Plans A, B, and C are schematically summarized in Figures 5-7.

a. Plans A, B, and D

These plans are similar in their effects on the circulation. The detailed effect of Plan D will depend on whether the bridge-tunnel island terminates at a position given by Plan A or that of Plan B.

These three plans result in two important changes in the circulation which will have an effect on erosion and sedimentation on Hampton Flats and in the dock area west of Newport News Point. Eddies will form on Hampton Flats on the ebb current and to the west of Newport News Point on the flood. Furthermore, the tunnel islands will block the Newport News Bar Channel which was presumably formed by the normally convergent currents on Hampton Flats during flood. This will result in very fast currents at the end of the structure. The expected results of this alteration of flow are discussed later.

The general configuration of the eddies is shown in Figures 5 and 6. The model times 0 to 12 hours are related to the Newport News tide station and Hampton Flat currents as shown in Table I.

The general dimensions of the counter-clockwise eddies for model hours 0 through 5 are shown in Figures 5a and 6a. In both cases the eddies increase in size from hour 0 to hour 4. By the time of hour 4 the entire lower Hampton Flats appears as an eddy. This is due to the combined effects of the eddy generation and the fact that floods start earlier on the Flats than in the Newport News Channel. At hour 5 there is a general flood current running over Hampton Flats with a sluggish ebb flow in the Newport News Channel. At hour 5 the eddy moves to a position over the channel as it dissipates. From hour 0 through hour 3 the shadow zone of the eddy extends to or beyond Salters Creek with sluggish currents.

TABLE I
RELATIONSHIP BETWEEN MODEL HOURS AND THE NEWPORT NEWS TIDE

Model Hour	Newport News Tide feet in prototype relative to MLW	Hampton Flats Current
0.0	1.20	max. ebb
0.5	0.90	
1.0	0.70	
1.5	0.47	
2.0	0.23	
2.5	0.10	
3.0	0.00	
3.5	–0.10	
4.0	0.00	about slack on Flats, still ebb in N. N. Channel
4.5	0.17	
5.0	0.40	flood on Flats, going toward slack in N.N. Channel
5.5	0.67	
6.0	1.00	flood throughout but higher speed on Flats
6.5	1.37	
7.0	1.63	
7.5	1.87	
8.0	2.20	
8.5	2.40	
9.0	2.50	
9.5	2.58	
10.0	2.43	going slack on Flats
10.5	2.30	
11.0	2.10	ebb on Flats and N. N. Channel
11.5	1.80	
12.0	1.50	

The generalized circulation for model tidal hours 6 through 10 are shown in Figures 5b and 6b. In both Plans A and B the tunnel islands divert the flood current *east* of Newport News Point and there is a clockwise eddy fronting the Lincoln Park area. The currents on the shore side of the eddy zone tend to be sluggish. There is also a formation of eddies west of Newport News Point. In this case the rotation is counter-clockwise and the center of rotation progresses to the west as the tidal hour goes from 6 to 9. The region in which these counterclockwise eddies form is a zone of sluggish flow in the base test as well; the principal difference between the base condition and that of Plans A and B is that the zone of sluggish flow *is enlarged.*

b. Plan C

The principal differences between Plan C and the baseline test are the tendency for the causeway support-structures to act as flow-straighteners and the acceleration of the flow around the tunnel island located on the Newport News Bar. During the times of ebb current (Figure 7a) the flow which normally runs sub-parallel to the Hampton Flats shoreline will be diverted about 20 degrees clockwise as it passes through the causeway. This will result in low currents in the vicinity just northeast of Salters Creek. On the flood-current phase (Figure 7b) diversion will again occur, with the flow changing direction by 20 to 30 degrees toward shore. This diversion, coupled with the acceleration around the bridge-tunnel island, will tend to focus the flood currents toward the shoreline zone southwest of Salters Creek. This focusing will enhance the potential for shoreline erosion.

It is very important to note that the causeway piling was modelled using a sheet of material in place of six pegs in a line. Thus the diversion of flow in the model may be exaggerated relative to the proposed design. There is little question, however, that some diversion will occur with the line of eight pilings. This effect can be eliminated by designing the support piling so the line of centers is parallel to the shoreline.

2. GILSONITE STUDIES

The Gilsonite studies were run in the model to gain some *qualitative* insights into the variations in sedimentation patterns for the different possible routing configurations. Such studies have limited usefulness, however, since the Gilsonite particles do not behave in the same manner as natural sediment particles in the prototype environment. The model studies, likewise, do not give any insights into erosion since the bed of the model is not deformable. In particular, the Gilsonite tests fail to model the real situation in shallow areas such as Hampton Flats since the total prototype transport is a result of the combined effects of wave stirring and tidal currents. The Gilsonite tests are useful in showing the tendency for increased or decreased sedimentation relative to the base test, however.

The region of concern in this discussion is the Hampton Flats area and the area fronting and including the C&O Railway coal piers. The ratio of the amount of Gilsonite deposited in each of the three plans tested to the amount deposited in the base test is shown in Figure 8 for various sub-regions. This data, in tabular form, is given in Table II.

The results for any given block cannot be taken literally, but trends are noteworthy. Blocks 4 and 5, for example, do show enhanced sedimentation for Plans A and B as would be expected from the pathline studies, which indicated the formation of eddies on ebb flow and a zone of reduced speeds on the flood. A similar trend appears in Block 9A where increased sedimentation may be expected because of the eddies in the lee of the tunnel island on flood current. Block 10 is enigmatic in that Plan A indicates quite low sedimentation relative to Plan B. The relative increase for Plan C in Blocks 9 and 10 may be caused by the focusing effect of the tunnel-island and flow-diversion by the causeway on flood current since the intensified current will sweep material from the Flats.

Inspection of Blocks 2 and FS show essentially the same values for all three plans as might be expected, since these are on the periphery of the regions most directly influenced by the tunnel-island locations.

F. DISCUSSION OF EXPECTED EFFECTS FROM PLANS A, B, C, AND D

Before discussing the details for each plan it is useful to summarize our understanding of the nearshore processes operative on the Hampton Flats area.

The tidal flow over Hampton Flats is such that flood currents dominate over ebb currents. Winds from the northeast through the east to southwest have sufficient fetch to generate waves capable of stirring the bottom sediments on the Flats. Given the frequency and intensity of winds in the area (U. S. Corps of Engineers, 1970) coupled with tidal currents, the direction of *net* bottom sediment-transport should be to the southwest from the Flats.

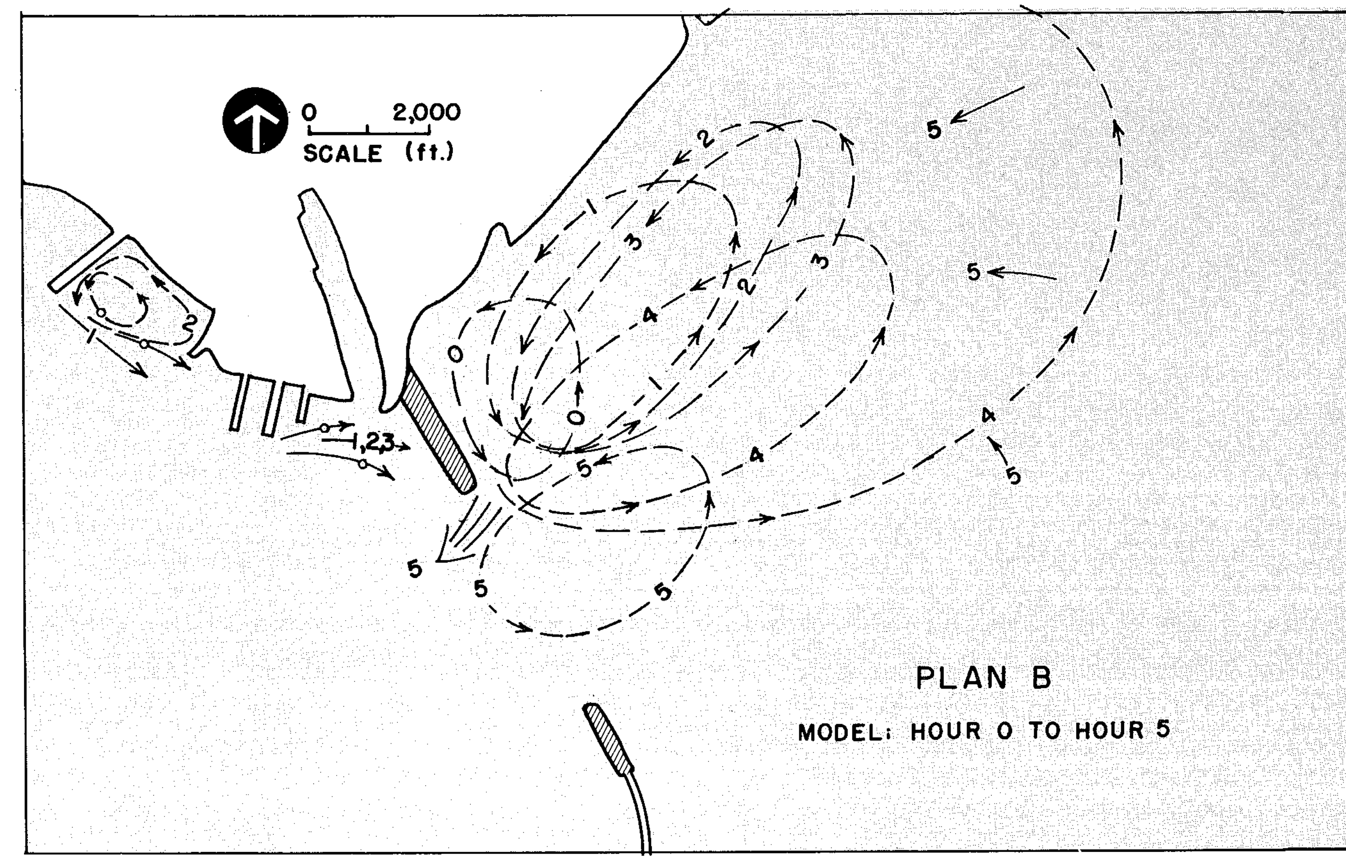


Figure 6 a) – Schematic Interpretation of Principal Circulation Features shown in model tests for Plan B on ebb flow (model tidal hours 0 through 5).

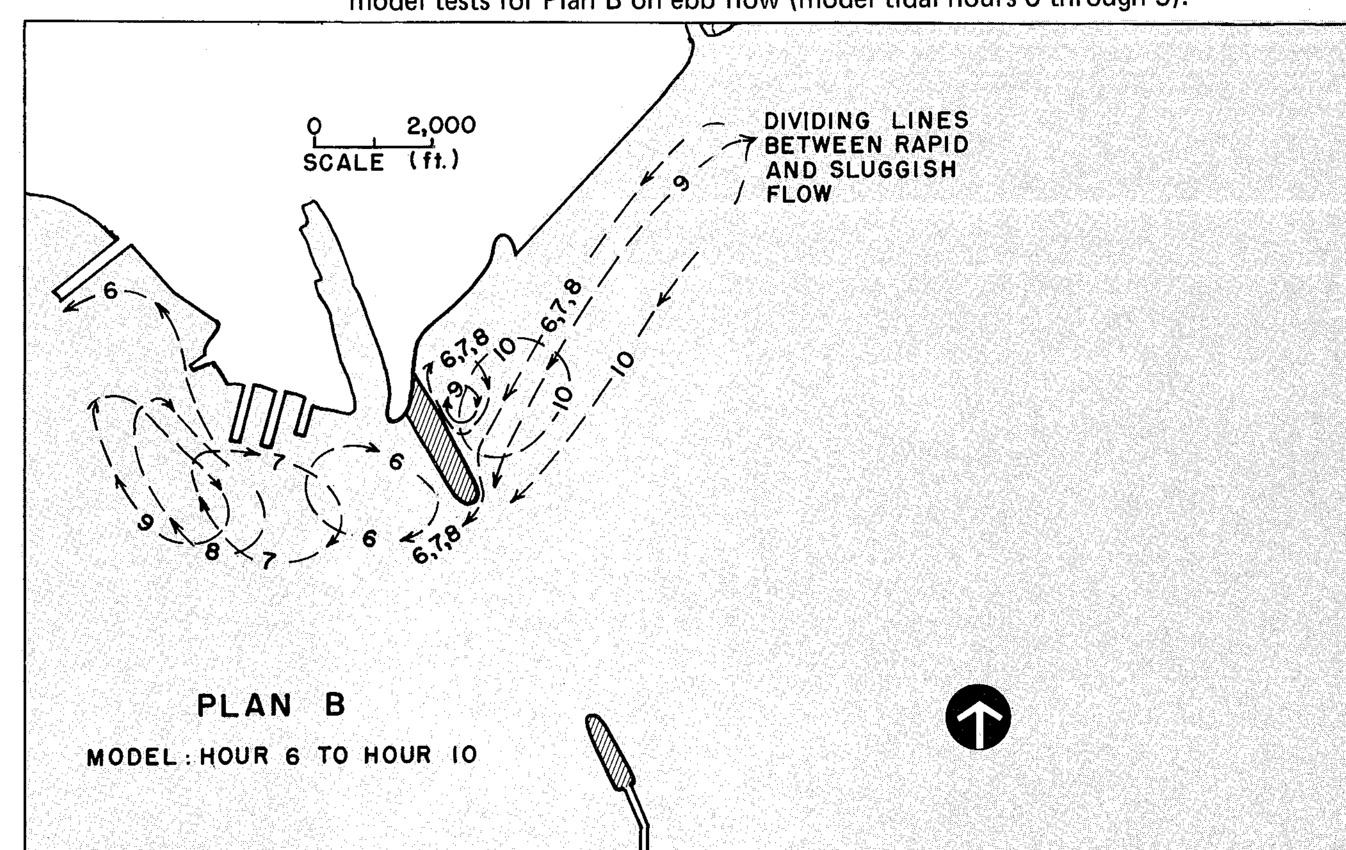


Figure 6 b) – Flood Flow (model tidal hours 6 through 10).

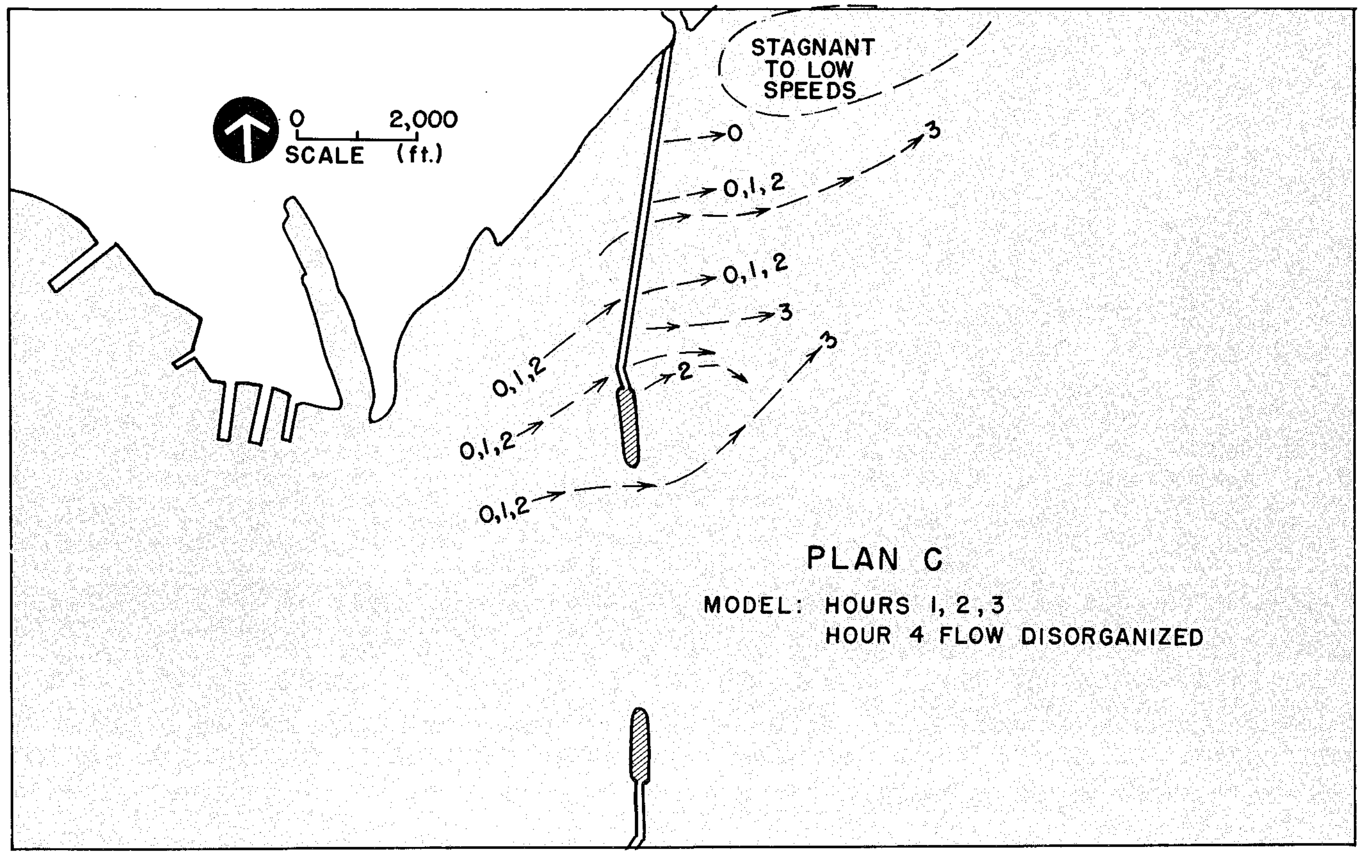


Figure 7 a) – Schematic Interpretation of Principal Circulation Features shown in model tests for Plan C on ebb flow (model tidal hours 0 through 4).

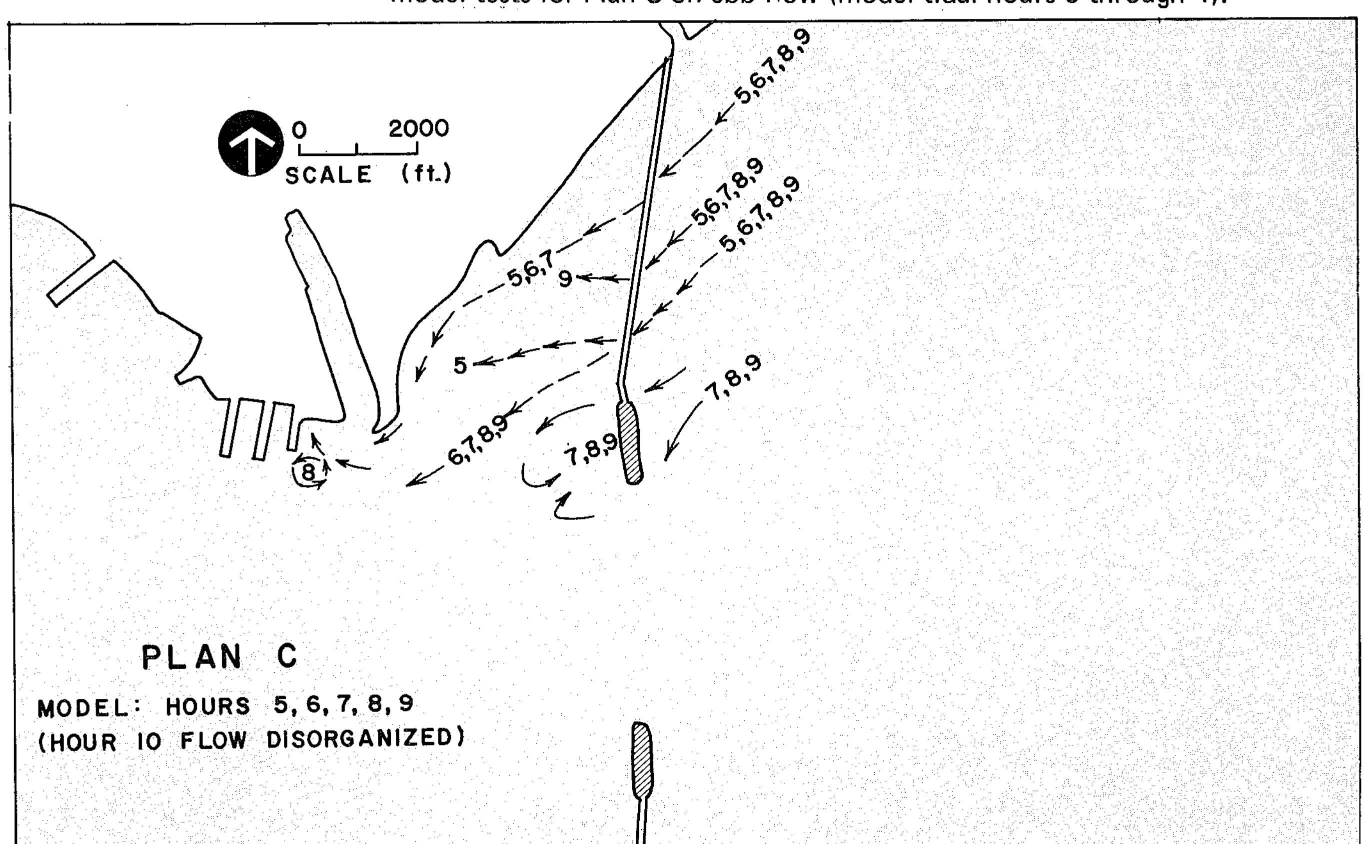


Figure 7 b) – Flood Flow (model tidal hours 5 through 10).

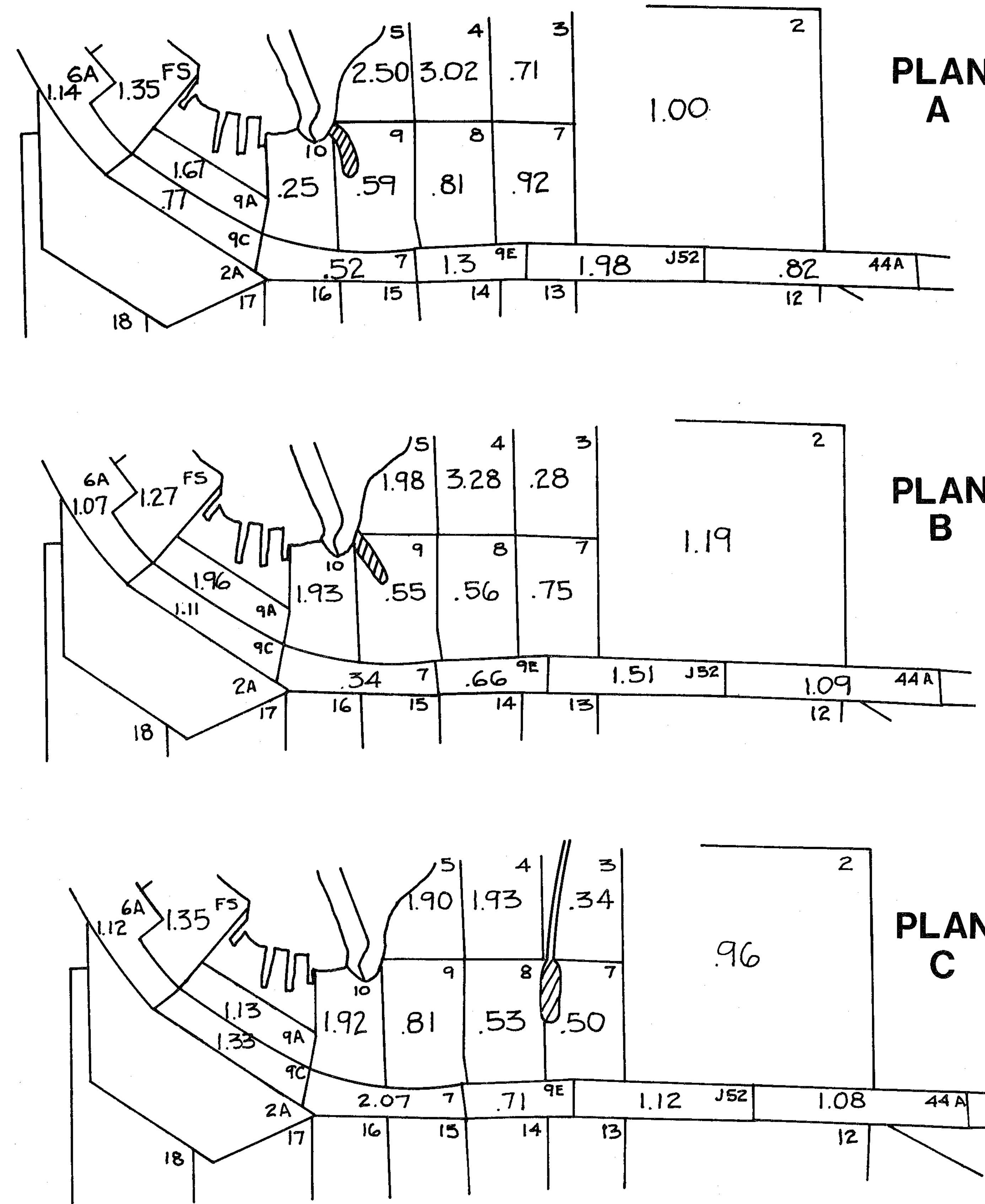


Figure 8 – Ratio of Amounts of Gilsonite Deposited in Each of Plans A, B, and C relative to amount deposited in base test.

TABLE II

RATIO OF AMOUNTS OF GILSONITE DEPOSITED IN EACH OF PLANS A, B, AND C RELATIVE TO THE AMOUNT DEPOSITED IN THE BASE TEST

Block	Plan A	Plan B	Plan C
2	1.00	1.19	.96
3	.71	.28	.34
4	3.02	3.28	1.93
5	2.50	1.98	1.90
7	.92	.75	.50
8	.81	.56	.53
9	.59	.55	.81
10	.25	1.93	1.92
9A	1.67	1.96	1.13
FS	1.35	1.27	1.35
9C	.77	1.11	1.33

Waves generated by winds from the northeast to east result in longshore currents which drift beach material along the shoreline from the northeast to the southwest. Winds from the south to southeast drift material in the opposite direction, but the field evidence and wind statistics indicate *net movement of beach materials is to the southwest.*

The present channel between the Newport News Bar and the shoreline of Hampton Flats has, in all likelihood, formed in response to the convergence of the flood currents on the southwest one-third of Hampton Flats. This channel is incised into a stratum of fine sand and silt.

The expected effect of the proposed structures on the shoreline and Hampton Flats bottom and to the west of Newport News Point are summarized in Table III and are discussed below.

1. PLANS A AND B

The area between the shore and the Newport News Bar Channel should become a zone of deposition because of the formation of eddies to the northeast of the tunnel-island locations of these plans. Also the islands will act as jetties and trap the sand now in the littoral-drift system. These expected consequences will be beneficial since the sand will nourish (directly or indirectly by pumping) the beach at Lincoln Park.

Since the tunnel islands will block the dominant flood-channel and since the island will cause intensification of the flood currents at the tip, it is reasonable to predict that the channel will shift position and occupy a new position at the tip of the tunnel island. This expectation should be included in the island design.

The combined results of the pathline and Gilsonite studies also give some indications that sedimentation is likely to be enhanced near and around the coal piers (No. 14 and No. 15). Prediction in this case is difficult but such enhancement should be assumed, to be conservative.

2. PLAN D

The principal difference between Plan D and Plans A and B is that the entrance to Newport News Creek must be relocated to the eastern side of Newport News Point. This will put the entrance in a zone of expected sedimentation, and large maintenance dredging is expected to be required to maintain navigable depths. In addition, incoming boats will not have much maneuvering room with heavy winds from the northeast. A boat will be set on the rocks quickly if it experiences a power failure in such circumstances. Both of these problems will be solved by installing a jetty on the eastern side of the entrance to the harbor. Although the details of the jetty design will require further study, a 1,000-ft jetty will probably be required.

3. PLAN C

The pathline studies show the causeway pilings and the tunnel island on Newport News Bar will tend to divert the flood current *toward* the shoreline from Salters Creek to Newport News Point. The effects of the causeway pilings are exaggerated in the model since sheets were used to simulate the rows of pilings. However,

TABLE III

IMPACT OF PROPOSED STRUCTURES
On Shoreline, Hampton Flats, and Newport News Point Area

Plan	"E" Expected Effects East of Newport News Point	"W" Expected Effects West of Newport News Point	Comments
A	1. Sedimentation on Hampton Flats between shore and Newport News Bar Channel from tunnel island and Salters Creek 2. Trapping of sand in littoral drift between tunnel-island and jetty at Wickham Ave. (BENEFIT) 3. Shift in position of Newport News Bar Channel to tip of tunnel-island with high current speeds at tip.	1. Probably enhanced sedimentation in region fronting and including C&O Piers 14 and 15	
B	1. "As in A". 2. "As in A". 3. As above but increased intensity	1. As in A	
D	1.) 2.) – As in A and B 3.) 4. New entrance to Newport News Creek in zone of expected sedimentation, therefore shoaling of entrance may be serious	1. As in A and B	Both the boat access and shoaling problems could be corrected by a properly designed jetty on the northeast side of the new entrance to Newport News Creek
C	1. On flood current the causeway pilings and the tunnel island on Newport News Bar tend to focus the current against the shoreline from Salters Creek to Newport News Point. The intensified currents, coupled with dominant wave energy from easterly quadrants will cause increased beach erosion. 2. On ebb current the causeway pilings divert flow away from shoreline east of Salters Creek causing sluggish currents nearshore. This does not constitute a serious problem but may enhance shoaling at Salters Creek entrance.	1. No significant effects expected	If the causeway piling alignment is changed to be parallel with the shoreline the problems arising from diverting the flow can be virtually eliminated. The flood current around Newport News Point will still be somewhat increased due to construction of flow by tunnel island. From the point of view of providing safest access to Salters Creek it would be preferable to have causeway on east side of Salters Creek entrance so that boats making the entrance have the causeway upwind and upcurrent during the most hazardous time when flood current and east or northeast winds conjoin. The configuration of Plan C will block the view of Old Point Comfort and lower Hampton Roads to those users of the shoreline at Lincoln Park and other areas between Salters Creek and Newport News Point.

some diversion effect may be expected in the real case. On ebb-current the causeway pilings will divert the flow away from the shoreline east of Salters Creek and cause sluggish currents which may enhance shoaling at Salters Creek entrance.

The problem of flow diversion can be corrected by aligning the line of centers of the pilings parallel with the shoreline.

It will be preferable to have the causeway on the *east* side of Salters Creek from the point of view of providing safest access to Salters Creek so that boats making for the entrance will have the causeway upwind and upcurrent during the most hazardous time when the flood current and east or northeast winds conjoin.

Finally it is worth mentioning that if Plan C is adopted, the view from the beach areas between Salters Creek and Newport News Point will be compromised by the causeway.

G. POTENTIAL BENEFITS OF PLANS A, B, AND D

The shoreline from Newport News Point to Lincoln Park is aesthetically displeasing at present. Adopting Plans A, B, or D (with a jetty on the east side of the relocated entrance to Newport News Creek) will offer the opportunity to construct an attractive beach by natural accretion and/or artificial means using the tunnel island (or jetty in Plan D) as the western flank. The nearshore bottom is a fine sand with gentle slope to a distance of about 1,000 ft from the shoreline which will make an attractive beach.

The tunnel islands or jetty can also be designed for access to serve as a fishing pier which will enhance the recreational potential of the area.

H. REFERENCES

Virginia Beach, Virginia Feasibility Report for Beach Erosion Control and Hurricane Protection, U. S. Army Corps of Engineers, Norfolk District, Sept., 1970.

PART III

DROGUE STUDY, HAMPTON FLATS AND NEWPORT NEWS POINT

by

C. S. WELCH

TABLE OF CONTENTS

A. INTRODUCTION

The tidal flow in the James River in the vicinity of Newport News Point and Hampton Flats has been observed to be non-symmetric and complex in the James River Model. A study was made using drogued buoys to determine the actual tidal flow in this region. This determination has formed an important measure with which the flow variations in the model caused by various proposed alterations in the local topography can be compared.

The tidal portion of the current is dominant in this region with speeds of 1 m/sec common during maximum ebb and flood. The mean flow is much more gentle during normal conditions. Because the maximum effect is likely to be associated with maximum velocities on a modification of the river such as a bridge-tunnel, this study was restricted to the current patterns and maximum velocities of the flood and ebb portions of the tidal cycle.

The semi-diurnal tidal wave in the Hampton Roads area is not a simple wave running up and down the river. It is now a nearly amphidromic system with Newport News Point corresponding to an amphidromic point. The tide on Hampton Flats turns from ebb to flood more than two hours before the tide in mid-channel turns, while the tide at the shipyard turns more than an hour after the mid-channel tide turns. Despite the complex pattern of tidal phases over the area, the tidal currents at any given point in the area are essentially linearly polarized with little rotary motion. This linear polarization is evident in the 1964 VIMS OJR study (Shidler and MacIntyre – 1967). Consideration of an ebb or flood regime is possible at any point, even though a given regime cannot be applied to the area either as a whole or as a given transect.

The length scale of motions is harder to specify than the time scale. On one hand, there is the broad expanse of the Hampton Flats with a typical width of one nautical mile. On the other hand, there is a complex of three channels and bars between Newport News Point and Newport News middle ground. These have a typical width of only a few hundred yards. Several experiments were performed to adequately specify the flow patterns in the area of concern.

B. EQUIPMENT AND TECHNIQUE

The surface currents were monitored by drogued buoys set within the top meter of the water column. The buoys, designed and built by NASA Langley Research Center, were styrofoam disks about 2 ft in diameter and 1 ft thick (Figure 1a). They were painted different colors for identification purposes. Directly below each buoy was suspended a metal current-cross two feet high and four feet across, weighted so as to allow only one or two inches of freeboard to the buoy (Figure 1b). A radar transponder antenna was mounted on each buoy, with its associated power pack and transceiver contained within the buoy. Each transceiver operated on a different frequency for radar-plot identification purposes. A mobile radar unit from the NASA Wallops Island Station was stationed on the dike at Craney Island (opposite Norfolk) at the south side of Hampton Roads, to follow and plot the tracks of the buoys as they drifted.

The buoys were launched at the required locations from a boat equipped with davits and hand-winches generally as nearly simultaneously as possible, and were allowed to drift uninhibited during the course of each experiment as much as possible. One boat was assigned to each two drogues to keep visual track of them, to protect them from marine traffic and fouling on marine structures, and to recover them at the close of each experiment.

C. RESULTS

The results are divided into the flood and ebb patterns. The flood tracks are shown in Figure 2. The four buoys were deployed in a line perpendicular to the streamlines of the flow. The four buoys traveled at different speeds, and all converged off Newport News Point to progress nearly along the same stream line up the James River about one mile from the shipyard. The experiment was terminated at this point before the tide again turned to ebb.

Figure 3 shows a large downstream acceleration of the two outermost buoys (C and D) just before they rounded the point and a larger deceleration just after they rounded the point. A secondary increase and decrease in speed in all four buoys at the same upstream points is evidence of a wake structure behind Newport News Point during flood tide. It is also noted that three tracks (A, C, and D) remain uncrossed even though two of them are less than 20 meters apart during their runs past the shipyard. The fourth crosses over and back across two of the three, indicating a time-dependent pattern of streaklines associated with late flood-stage.

The flow from a similar downstream-flow (ebb) experiment is substantially different from the upstream flow (Figure 4). Four buoys were deployed in a line perpendicular to the current off the shipyard. The two closest to the shipyard (A and one not shown) were swept under piers. After rounding the Point, the remaining buoys drifted far off Hampton Flats toward the existing Hampton Roads Bridge-Tunnel. The shadow-zone behind Newport News Point was studied with another deployment of four buoys (E, F, G, and H), three of which went inside the Newport News Bar and one of which went outside the bar.

The ebb flow-pattern converges towards the shore (under the docks) on the shipyard side of Newport News Point. After passing the Point, most of the current swings wide and stays well away from Hampton Flats. One notable buoy (D) headed for the Norfolk Navy installation and eventually became fouled on one of the ships at a pier there. The surface-flow thus appears to go through the water-land boundary at Norfolk. It probably "folds under" at that boundary and flows out the Elizabeth River channel. Over Hampton Flats, the flow is much slower than off the flats. The flow seems to separate at the Newport News Bar with a zone of sharp horizontal shear in the lee of the bar. Hampton Bar also seems to be directly in the lee of Newport News Bar during ebb tide. Finally, one of the buoys (B) traveled directly down the ship channel except for a small part of its path. During this shallower part of its path, it slowed down appreciably, its speed increasing as soon as it reached the deep water of the channel again (Figure 5). This indicates that the dominant part of the retarding force on the surface flow is the friction of the bottom. This also indicates that the percentage of total flow in the ship channel is much larger than the ratio of the area of the ship channel to the area of the total cross section.

Another part of the study focused attention on the shallow natural channel at the southwestern end of Hampton Flats near Newport News Point. The results from the VIMS *James River Study of 1964* show that the tidal cycle in this channel is characterized by larger flood than ebb velocities, in contrast to nearly every other station in the Hampton Roads area including other areas of Hampton Flats. The flow converges and accelerates in the channel during flood much more than during ebb. (Compare track A during flood with track E during ebb.) It appears that the channel is associated with tidal-flood conditions.

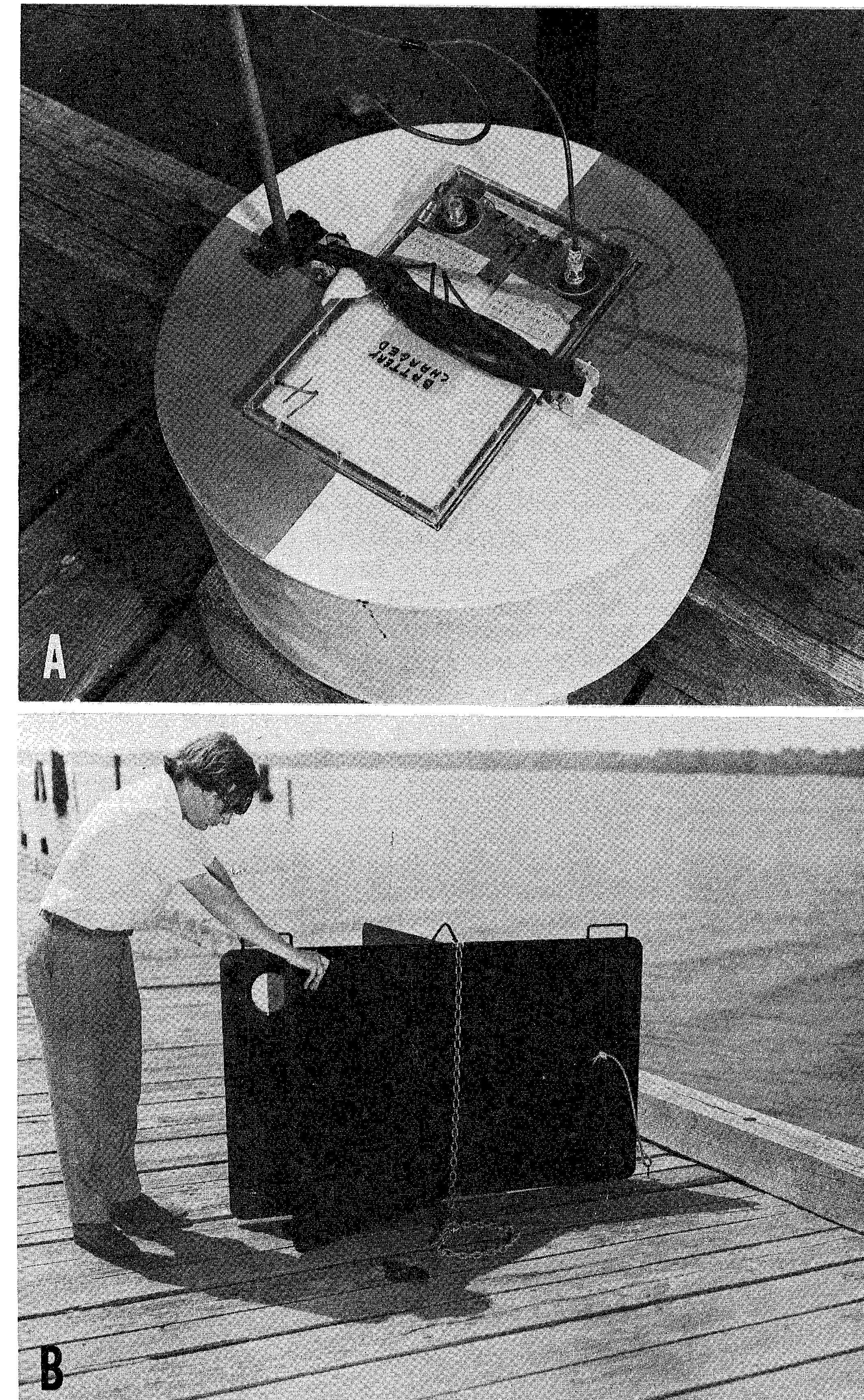


Figure 1 – The Drogued Buoy used in the Current Studies. Figure 1a shows the surface buoy with the electronics and battery case and the base of the 8-ft antenna. Figure 1b shows the current cross used. The cross can be folded flat for ease of handling and storage.

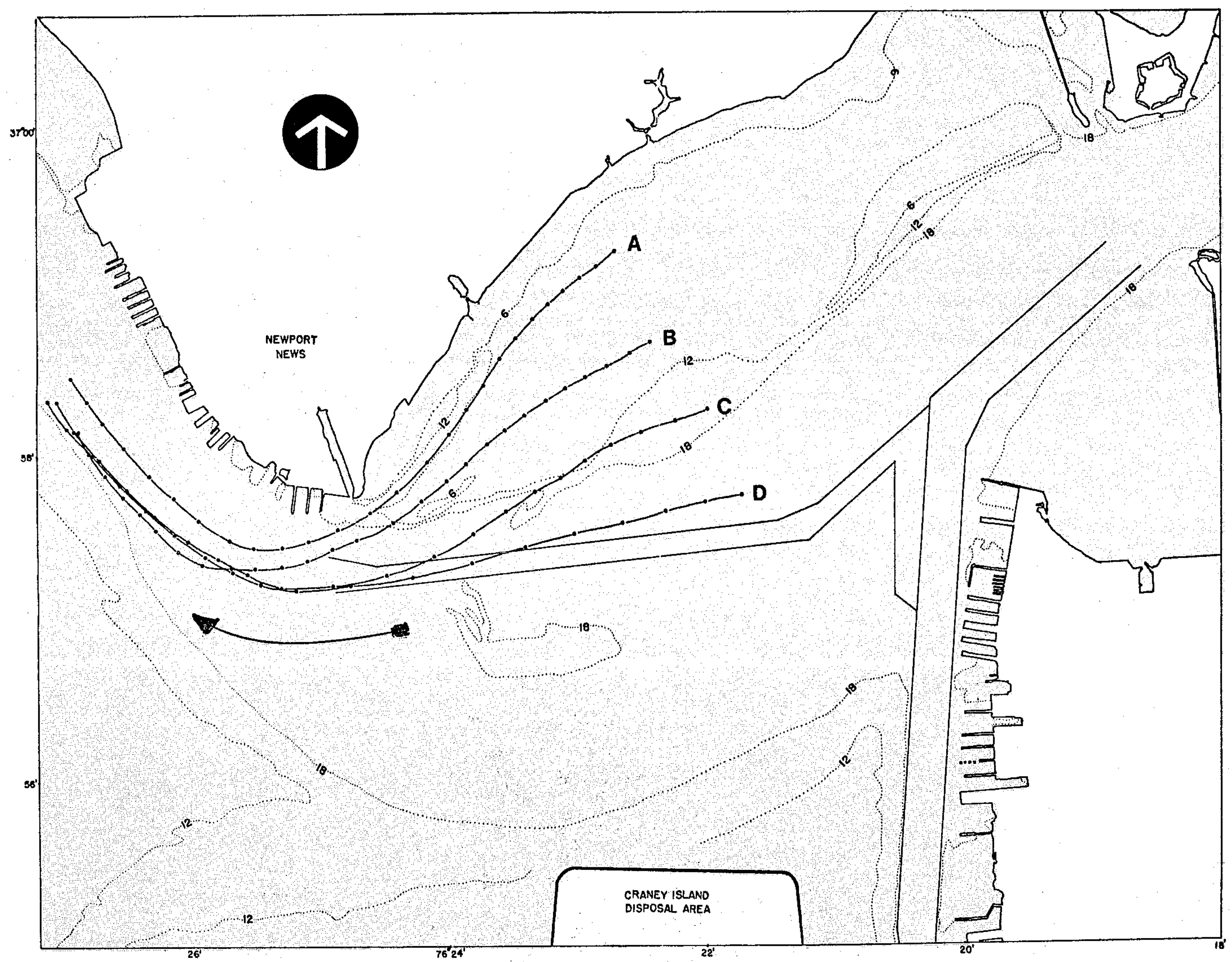


Figure 2 – Drogue Tracks Showing Surface Streaklines during flood tide over Hampton Flats. (Dots on lines represent 10-minute intervals.)

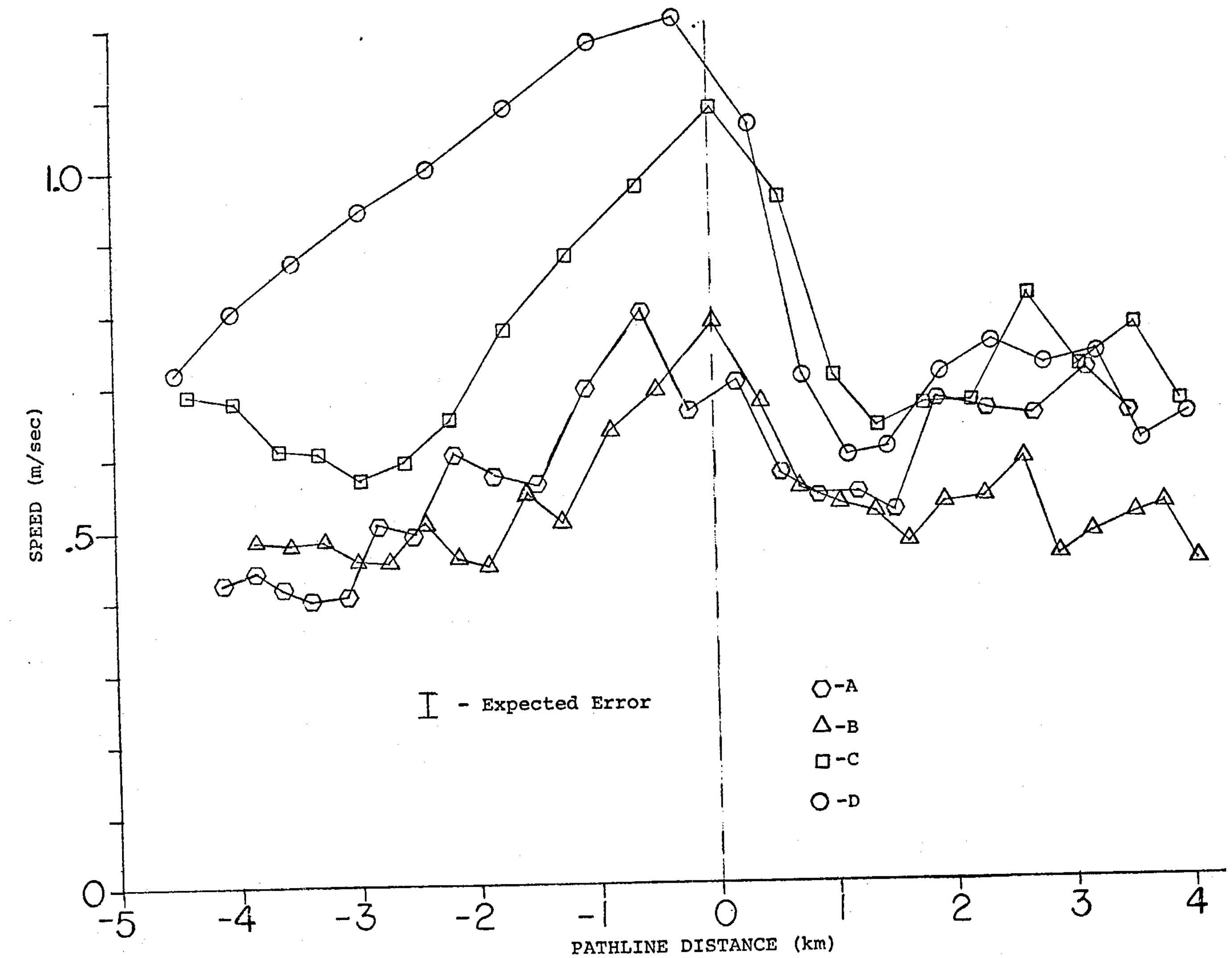


Figure 3 – Speeds of Drogues During Flood Tide over Hampton Flats as a function of distance traveled. Tracks are aligned so 0 km is at Newport News Point. Note local minimum of speeds about +1.5 km for all four drogues.

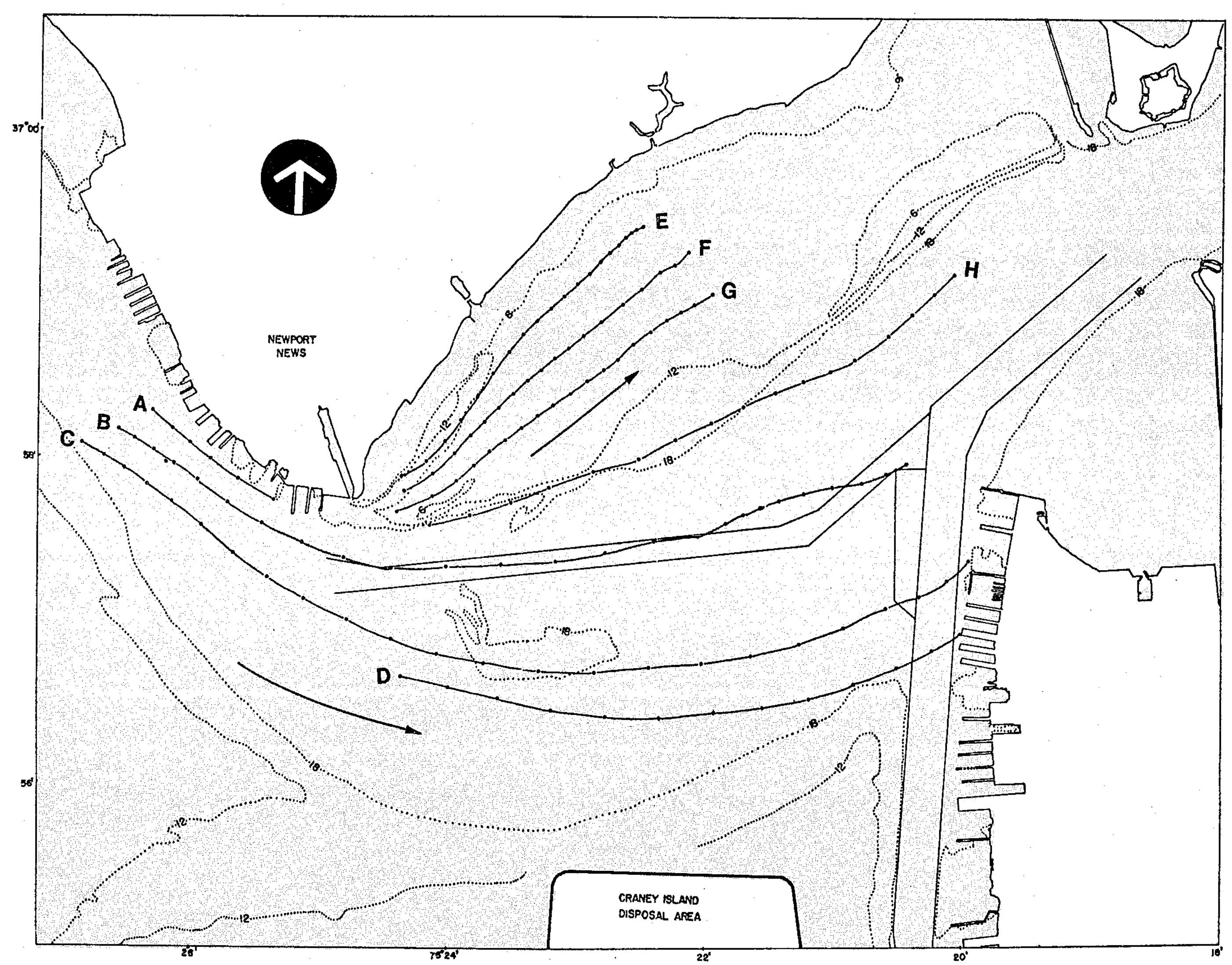


Figure 4 — Drogue Tracks Showing Surface Streaklines during ebb tide in Hampton Roads. Dots on lines represent 10-minute intervals. Tracks A-D and E-H were obtained on separate runs.

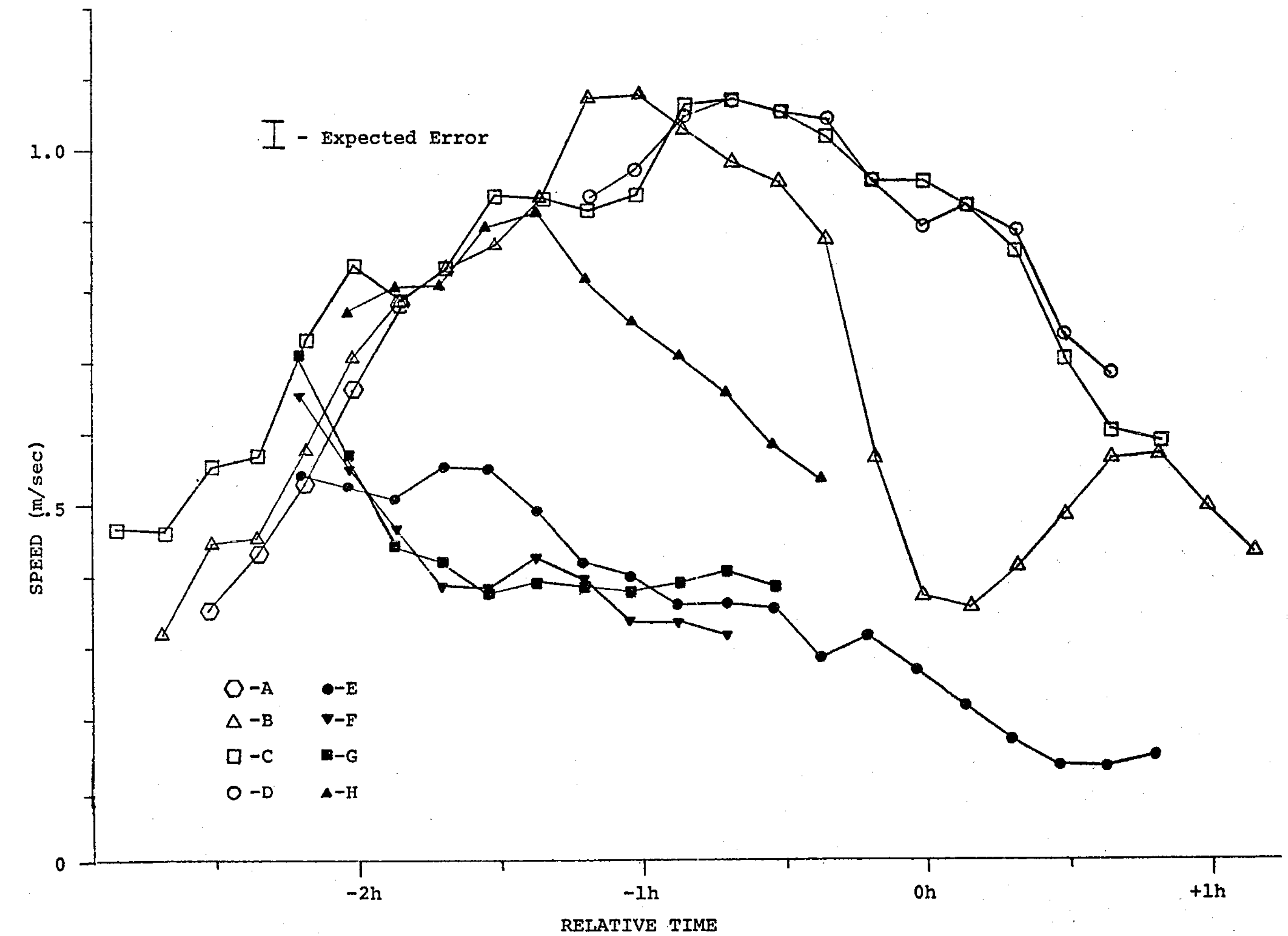


Figure 5 — Speeds of Drogues During Ebb Tide as a function of time with respect to full ebb at Chesapeake Bay entrance. The phase-lag between Hampton Flats and the rest of the James River is clearly seen.

D. CONCLUSIONS

From the character and features of the ebb-and-flood tidal flow near Newport News Point, several changes can be expected to occur if the proposed bridge-tunnel island configurations are built. The most apparent effect will be an increase in flow-velocity on both the flood and ebb cycles if the available channel is constricted. This increase in velocity can be expected to increase the amplitude of the wake effect during flood tide and also the inertial assymetry of the flow around the Point, particularly if the island is made an extension of the Point. This will result in a larger amount of water "folding under" at Norfolk on ebb. A less-apparent effect is the likely change in the relative phase of tidal-current reversals from Hampton Flats to the James River Bridge. This effect and its associated impact are difficult to judge from the drogue data.

If the natural inshore channel is blocked by the bridge-tunnel island, the flow during flood will be substantially altered, perhaps with the channel reforming offshore from the new island. If the island constricts the flow but is located across a trestle from Newport News Point, an increase in velocities can be expected around the Point.

A minimum impact on the flow pattern is expected if the proposed tunnel island is located over, and oriented parallel to, the Newport News Bar.

E. REFERENCE

Shidler, J. K. and W. G. MacIntyre, "Operation James River – 1964" VIMS *Data Report No. 5,* Gloucester Point, Va., October, 1967.

PART IV

HYDRAULIC MODEL TEST RESULTS

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TABLES

FIGURES

TABLE I

JAMES RIVER MODEL GILSONITE STUDY

	Study 1X			Study 1A			Study 1B			Study 1C		
Area	Raw	Pct.	Ratio	Raw	Pct.	Ratio	Raw	Pct.	Ratio	Raw	Pct.	Ratio
TLIN	47950.	100.00	1.00	43676.	100.00	1.00	43840.	100.00	1.00	43922.	100.00	1.00
1	143.	0.29	1.00	90.	0.20	0.69	140.	0.31	1.07	130.	0.29	0.99
2	2100.	4.37	1.00	1930.	4.41	1.00	2300.	5.24	1.19	1859.	4.23	0.96
3	485.	1.01	1.00	317.	0.72	0.71	125.	0.28	0.28	152.	0.34	0.34
4	328.	0.68	1.00	905.	2.07	3.02	985.	2.24	3.28	580	1.32	1.93
5	210.	0.43	1.00	480.	1.09	2.50	382.	0.87	1.98	367.	0.83	1.90
6	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
7	745.	1.55	1.00	625.	1.43	0.92	515.	1.17	0.75	342.	0.77	0.50
8	385.	0.80	1.00	285.	0.65	0.81	200.	0.45	0.56	189.	0.43	0.53
9	360.	0.75	1.00	195.	0.44	0.59	182.	0.41	0.55	268.	0.61	0.81
10	170.	0.35	1.00	40.	0.09	0.25	300.	0.68	1.93	300.	0.68	1.92
11	617.	1.28	1.00	530.	1.21	0.94	480.	1.09	0.85	550.	1.25	0.97
12	1670.	3.48	1.00	1230.	2.81	0.80	1390.	3.17	0.91	1440.	3.27	0.94
13	415.	0.86	1.00	220.	0.50	0.58	67.	0.15	0.17	105.	0.23	0.27
14	455.	0.94	1.00	285.	0.65	0.68	57.	0.13	0.13	58.	0.13	0.13
15	505.	1.05	1.00	145.	0.33	0.31	105.	0.23	0.22	73.	0.16	0.15
16	400.	0.83	1.00	50.	0.11	0.13	109.	0.24	0.29	153.	0.34	0.41
17	310.	0.64	1.00	260.	0.59	0.92	223.	0.50	0.78	340.	0.77	1.19
18	112.	0.23	1.00	83.	0.19	0.81	125.	0.28	1.22	128.	0.29	1.24
19	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
20	305.	0.63	1.00	245.	0.56	0.88	138.	0.31	0.49	135.	0.30	0.48
21	222.	0.46	1.00	215.	0.49	1.06	150.	0.34	0.73	147.	0.33	0.72
22	223.	0.46	1.00	180.	0.41	0.88	190.	0.43	0.93	185.	0.42	0.90
23	167.	0.34	1.00	133.	0.30	0.87	200.	0.45	1.30	196.	0.44	1.28
24	1320.	2.75	1.00	1105.	2.52	0.91	940.	2.14	0.77	1240.	2.82	1.02
25	370.	0.77	1.00	325.	0.74	0.96	265.	0.60	0.78	260.	0.59	0.76
26	170.	0.35	1.00	240.	0.54	1.54	285.	0.65	1.83	215.	0.48	1.38
27	270.	0.56	1.00	225.	0.51	0.91	232.	0.52	0.93	272.	0.61	1.09
28	135.	0.28	1.00	175.	0.40	1.42	220.	0.50	1.78	263.	0.59	2.12
29	193.	0.40	1.00	413.	0.94	2.34	460.	1.04	2.60	325.	0.73	1.83
30	163.	0.33	1.00	170.	0.38	1.14	80.	0.18	0.53	150.	0.34	1.00
31	95.	0.19	1.00	245.	0.56	2.83	140.	0.31	1.61	251.	0.57	2.88
32	135.	0.28	1.00	255.	0.58	2.07	153.	0.34	1.23	215.	0.48	1.73
33	120.	0.25	1.00	210.	0.48	1.92	60.	0.13	0.54	425.	0.96	3.86
44AC	0.	0.00	0.00	360.	0.82	0.82	480.	1.09	1.09	475.	1.08	1.08
J52C	0.	0.00	0.00	865.	1.98	1.98	665.	1.51	1.51	495.	1.12	1.12
1X2C	1480.	3.08	1.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
9EC	0.	0.00	0.00	570.	1.30	1.30	290.	0.66	0.66	315.	0.71	0.71
7C	0.	0.00	0.00	230.	0.52	0.52	150.	0.34	0.34	910.	2.07	2.07
1X7C	1640.	3.42	1.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
9C	810.	1.68	1.00	575.	1.31	0.77	827.	1.88	1.11	990.	2.25	1.33
9AC	400.	0.83	1.00	610.	1.39	1.67	720.	1.64	1.96	415.	0.94	1.13
2AC	1440.	3.00	1.00	730	1.67	0.55	832.	1.89	0.63	1150.	2.61	0.87
FSC	0.	0.00	0.00	590.	1.35	1.35	560.	1.27	1.27	595.	1.35	1.35
6AC	1755.	3.66	1.00	1835.	4.20	1.14	1720.	3.92	1.07	1815.	4.13	1.12
COLL	20823.	43.42	1.00	18171.	41.60	0.95	17435.	39.76	0.91	18473.	42.05	0.96

	Study 2X			Study 2A			Study 2B			Study 2C		
Area	Raw	Pct.	Ratio	Raw	Pct.	Ratio	Raw	Pct.	Ratio	Raw	Pct.	Ratio
TLIN	44087.	100.00	1.00	44224.	100.00	1.00	45073.	100.00	1.00	43785.	100.00	1.00
1	125.	0.28	1.00	45.	0.10	0.35	70.	0.15	0.54	95.	0.21	0.76
2	2100.	4.76	1.00	2060.	4.65	0.97	1990.	4.41	0.92	1985.	4.53	0.95
3	350.	0.79	1.00	160.	0.36	0.45	147.	0.32	0.41	220.	0.50	0.63
4	505.	1.14	1.00	860.	1.94	1.69	705.	1.56	1.36	405.	0.92	0.80
5	500.	1.13	1.00	1130.	2.55	2.25	595.	1.32	1.16	620.	1.41	1.24
6	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
7	715.	1.62	1.00	560.	1.26	0.78	520.	1.15	0.71	305.	0.69	0.42
8	505.	1.14	1.00	270.	0.61	0.53	190.	0.42	0.36	245.	0.55	0.48
9	430.	0.97	1.00	153.	0.34	0.35	198.	0.43	0.45	320.	0.73	0.74
10	195.	0.44	1.00	93.	0.21	0.47	165.	0.36	0.82	293.	0.66	1.51
11	520.	1.17	1.00	525.	1.18	1.00	500.	1.10	0.94	480.	1.09	0.92
12	1085.	2.46	1.00	1115.	2.52	1.02	1186.	2.63	1.06	1050.	2.39	0.97
13	243.	0.55	1.00	240.	0.54	0.98	82.	0.18	0.33	100.	0.22	0.41
14	280.	0.63	1.00	240.	0.54	0.85	40.	0.08	0.13	55.	0.12	0.19
15	285.	0.64	1.00	150.	0.33	0.52	157.	0.34	0.53	100.	0.22	0.35
16	285.	0.64	1.00	58.	0.13	0.20	126.	0.27	0.43	195.	0.44	0.68
17	285.	0.64	1.00	310.	0.70	1.08	286.	0.63	0.98	128.	0.29	0.45
18	175.	0.39	1.00	142.	0.32	0.80	131.	0.29	0.73	190.	0.43	1.09
19	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
20	242.	0.54	1.00	245.	0.55	1.00	136.	0.30	0.54	123.	0.28	0.51
21	220.	0.49	1.00	253.	0.57	1.14	140.	0.31	0.62	145.	0.33	0.66
22	155.	0.35	1.00	150.	0.33	0.96	192.	0.42	1.21	218.	0.49	1.41
23	190.	0.43	1.00	165.	0.37	0.86	186.	0.41	0.95	185.	0.42	0.98
24	1030	2.33	1.00	1222.	2.76	1.18	1115.	2.47	1.05	1385.	3.16	1.35
25	285.	0.64	1.00	420.	0.94	1.46	260.	0.57	0.89	240.	0.54	0.84
26	265.	0.60	1.00	140.	0.31	0.52	255.	0.56	0.94	160.	0.36	0.60
27	420.	0.95	1.00	175.	0.39	0.41	170.	0.37	0.39	240.	0.54	0.57
28	210.	0.47	1.00	303.	0.68	1.43	210.	0.46	0.97	230.	0.52	1.10
29	749.	1.69	1.00	650.	1.46	0.86	625.	1.38	0.81	510.	1.16	0.68
30	233.	0.52	1.00	295.	0.66	1.26	200.	0.44	0.83	533.	1.21	2.30
31	353.	0.80	1.00	165.	0.37	0.46	282.	0.62	0.78	442.	1.00	1.26
32	175.	0.39	1.00	62.	0.14	0.35	168.	0.37	0.93	270.	0.61	1.55
33	315.	0.71	1.00	152.	0.34	0.48	450.	0.99	1.39	270.	0.61	0.86
44AC	305.	0.69	1.00	430.	0.97	1.40	358.	0.79	1.14	560.	1.27	1.84
J52C	500.	1.13	1.00	590.	1.33	1.17	715.	1.58	1.39	185.	0.42	0.37
1X2C	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
9EC	445.	1.00	1.00	510.	1.15	1.14	290.	0.64	0.63	330.	0.75	0.74
7C	685.	1.55	1.00	298.	0.67	0.43	170.	0.37	0.24	875.	1.99	1.28
1X7C	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00	0.	0.00	0.00
9C	655.	1.48	1.00	640.	1.44	0.97	940.	2.08	1.40	880.	2.00	1.35
9AC	605.	1.37	1.00	510.	1.15	0.84	720.	1.59	1.16	450.	1.02	0.74
2AC	973.	2.20	1.00	850.	1.92	0.87	820.	1.81	0.82	1120.	2.55	1.15
FSC	660.	1.49	1.00	600.	1.35	0.90	490.	1.08	0.72	550.	1.25	0.83
6AC	1855.	4.20	1.00	1870.	4.22	1.00	1651.	3.66	0.87	1935.	4.41	1.05
COLL	20108.	45.60	1.00	18804.	42.51	0.93	17631.	39.11	0.85	18622.	42.53	0.93

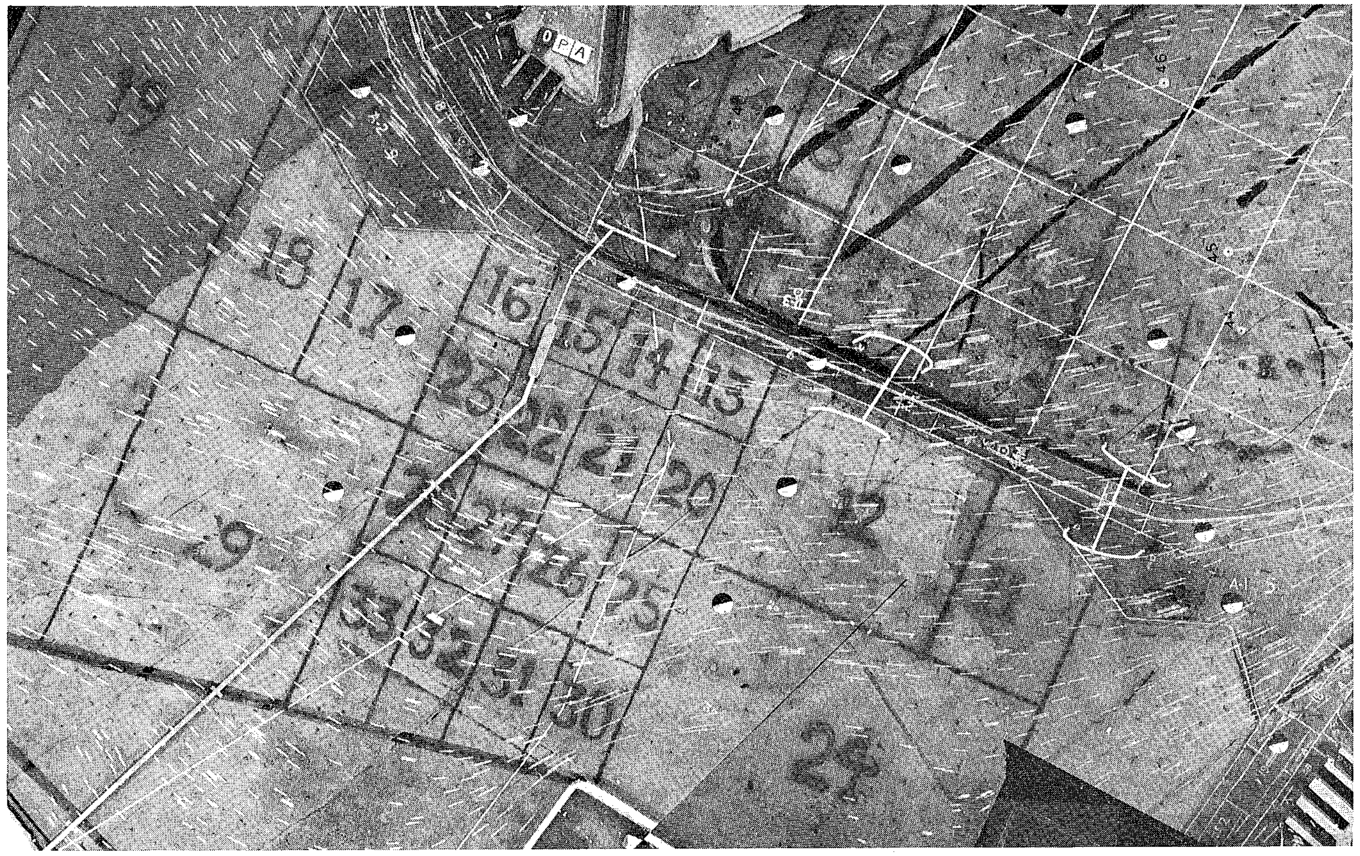

Figure 1 – Beginning of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

Figure 2 – Second Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

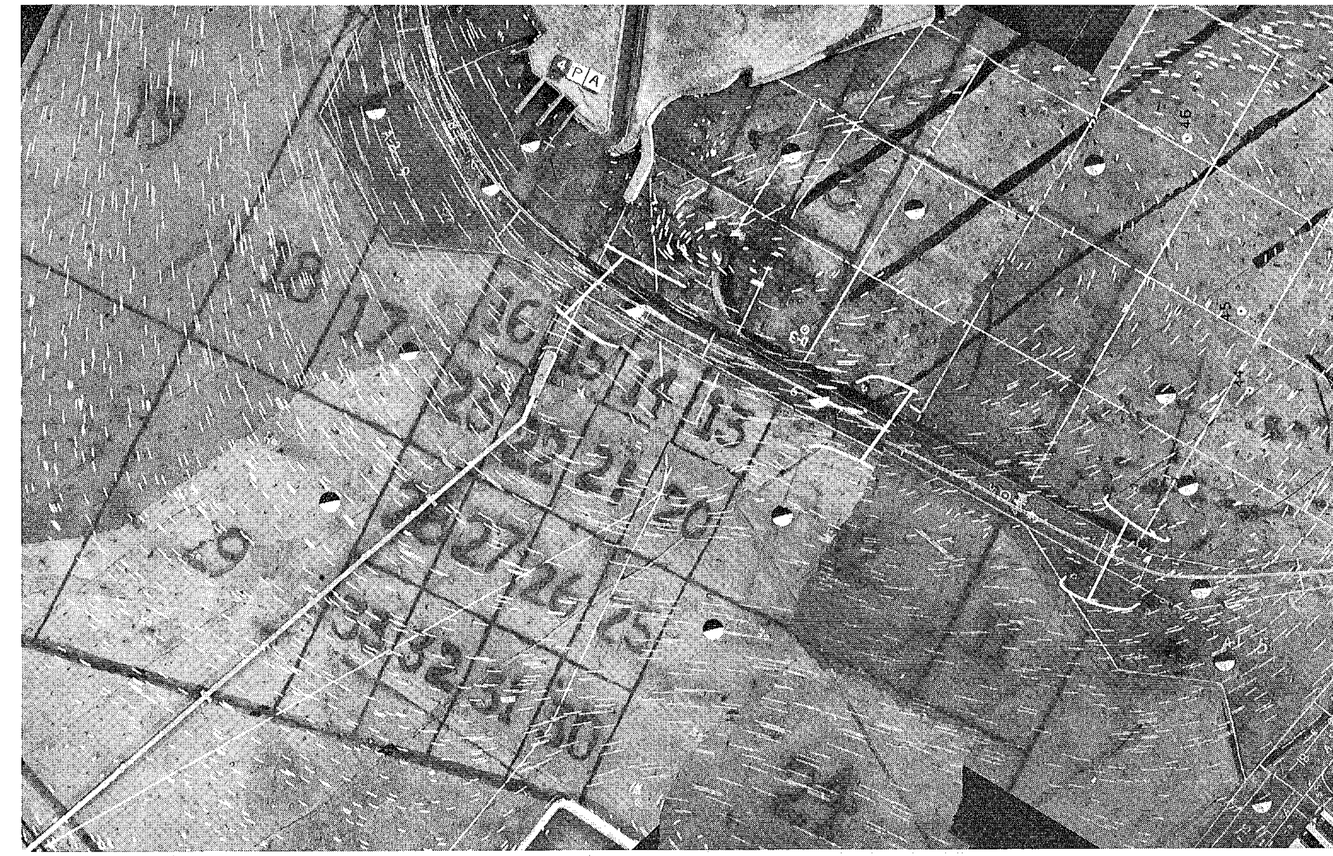

Figure 3 – Fourth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

Figure 4 – Fifth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

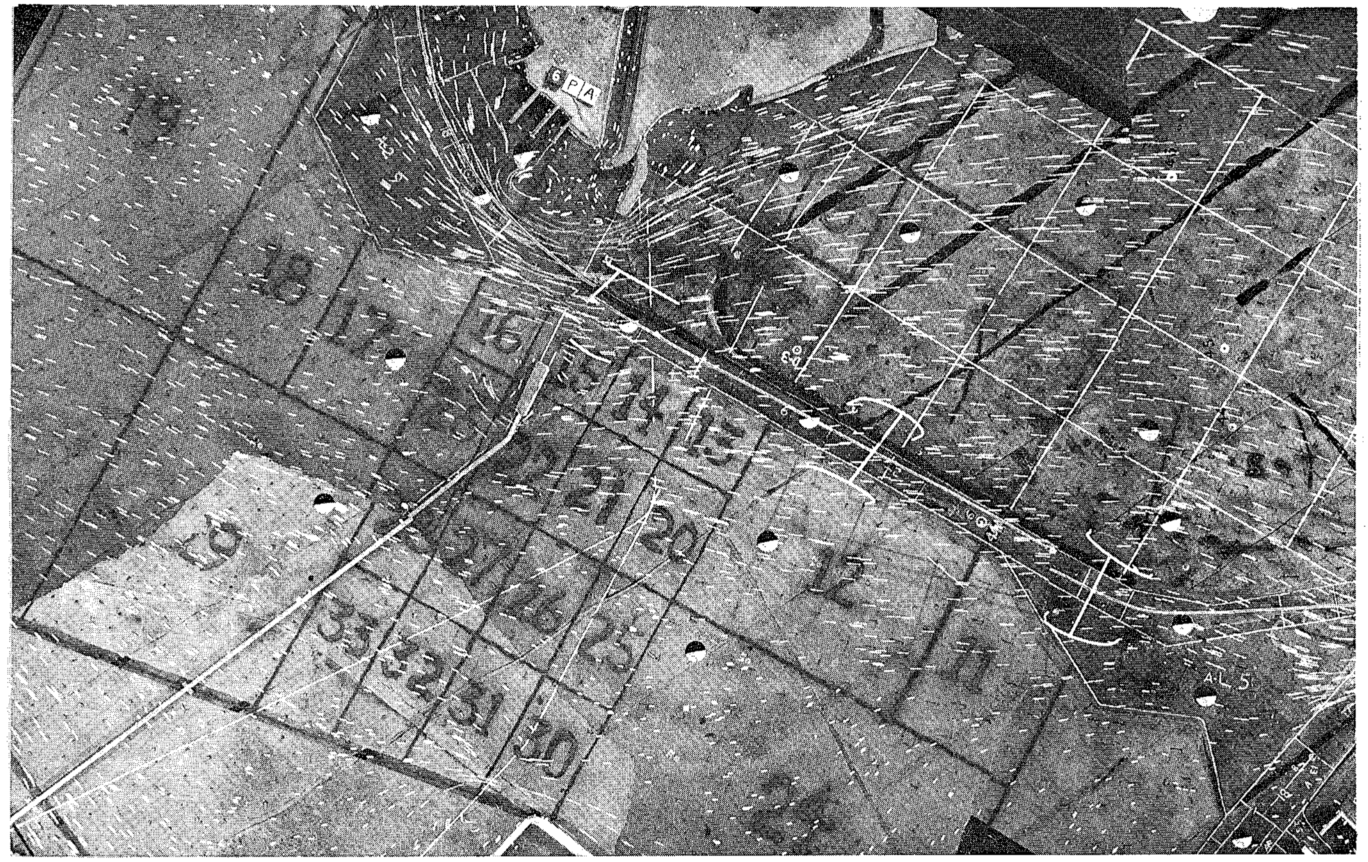

Figure 5 – Sixth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

Figure 6 – Eighth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

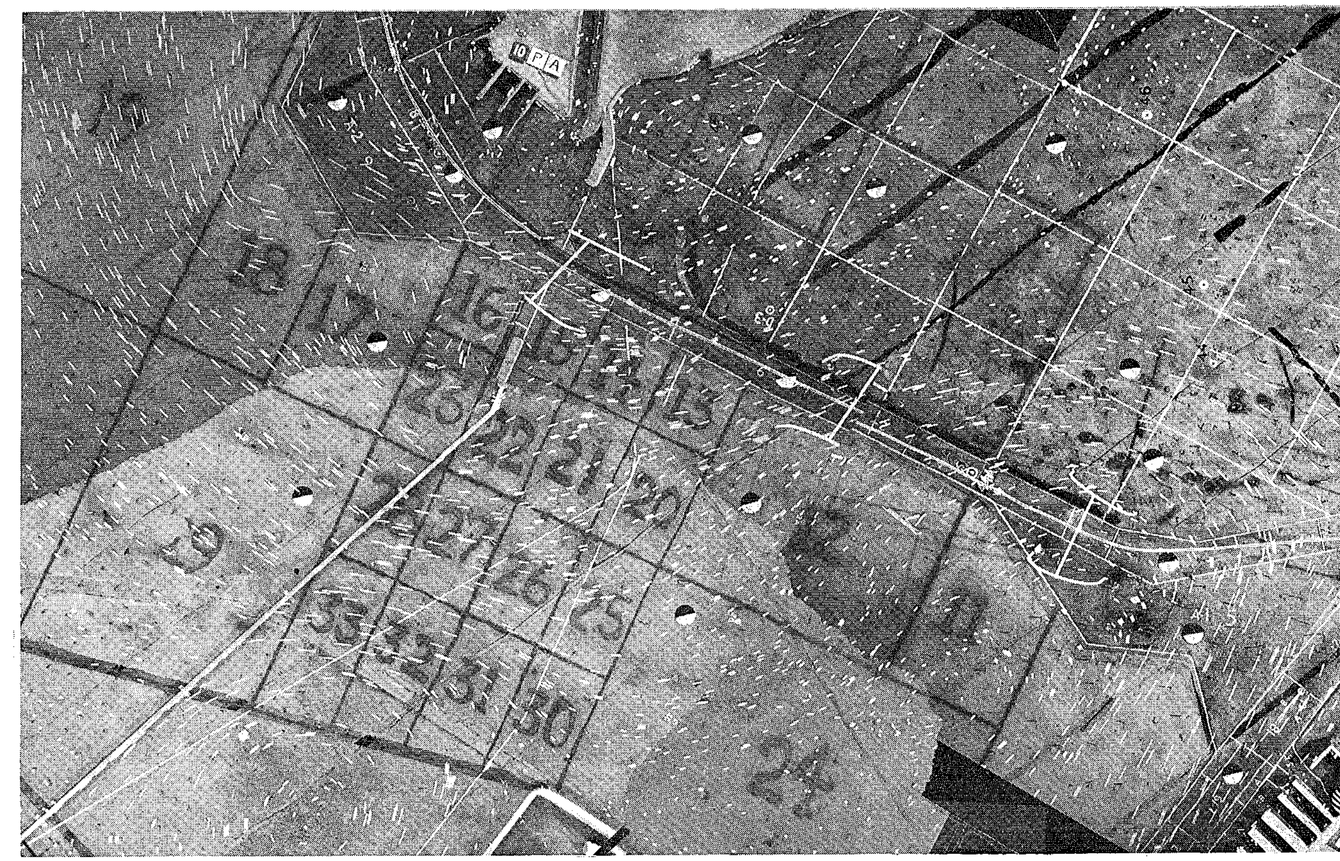

Figure 7 – Tenth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A

Figure 8 – Twelfth Hour of Tidal Cycle, Typical Confetti Time-Lapse Photograph of Configuration 1A