TIDAL FLOWS IN INDIAN RIVER INLET

June 11, 1983

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Introduction

The determination of the tidal flows into Indian River Inlet and the corresponding tidal prism were determined for June 11, 1983 based on current meter measurements taken over a tidal cycle.

Field Work

On June 11, 1983 from 8:00 A.M. to 8:30 P.M. a field party consisting of University of Delaware and the Delaware Department of Natural Resources and Environmental Control (DNREC) personnel measured tides and tidal currents in Indian River Inlet, Delaware at three locations across the channel.

The tide measurements were made visually using the NOAA tide staff at the U.S. Coast Guard Harbor in the inlet. Figure 1 shows the tide gage record (see Appendix 1). The "zero" on the tide staff is of an elevation 3.57 ft below the National Geodetic Vertical Datum (NGVD) and therefore readings obtained every fifteen minutes throughout the day were corrected to NGVD. During the course of the study, two unequal high tides were recorded and one low tide.

Velocity measurements were made from three DNREC boats anchored across the inlet in a north-south line south of the Coast Guard Station, see Figure 2. This line was chosen for two reasons: (1) the inlet has two major channels at that point, one flood dominant (the south channel) and other ebb dominant (the north channel). A boat was placed in each channel and the third boat was placed over the shoal in the center of the inlet. This way the reading from

a boat in the channel could be assumed to be valid over the cross section of the channel in which it was anchored, (2) the second reason was one of safety; summer boat traffic and the current speeds in the inlet dictated that the boats be anchored in an area where the channel was wide. The boats were anchored fore and aft to maintain position and were equipped with Endeco 110 ducted impellor current meters supplied by Ocean Surveys, Inc. Current readings were taken every fifteen minutes and consisted of a depth and velocity measurement (in kts) at four or more different depths. (See Appendix 2.) As the depth indicators were not precisely calibrated on two of the meters, depths were also determined by the length of line payed out and wire angle. Later analysis provided calibrations for the depth gages. Figure 3 shows a representative current velocity profile measurement for each of the three boats.

Data Reduction

The current meter readings for each boat and each 15 minute reading were fit to a logarithmic velocity profile by assuming the velocity profile could be expressed as

$$U(y/h) = a \ln(y/h) + b \qquad (1)$$

where U is the velocity, y/h is the dimensionless elevation of the current meter from the bottom, which is at depth, h, and a and b are fitting coefficients. The depth h was taken as the mean depth for each station known from channel soundings taken by DNREC earlier that week, corrected for the tide. The coefficients a and b were determined by a least squares procedure for each velocity profile at each time, noting that the depth must be corrected for the

tide. To ensure that the results were reasonable, the arithmetic mean of the velocity data was compared to the depth averaged velocity determined by

$$U_d = \frac{1}{h} \int_0^h U \, dy = b - a \qquad (2)$$

In all cases good agreement was found and the depth averaged velocity was then used for the volumetric calculations. Peak mean velocities were as follows: maximum flood: 3.40 kts in south channel at 8:30 p.m.; maximum ebb: 3.09 kts in north channel at 2:00 p.m.

Tidal flow calculations were done two different ways. The first involved partitioning the inlet cross-section according to size of the channels and using the velocity data for the boat in the particular channel to obtain flow rates. The second, less rational method, involved simply apportioning a third of the inlet's width to each boat. Figure 4 shows the inlet cross-section as determined by the Department of Natural Resources and Environmental Control, State of Delaware. Dashed lines in the figure indicate locations of missing data and our assumed values. Table 1 shows the associated inlet areas (NGVD) and surface widths of these areas using the two methods. The actual cross-sectional areas were corrected for tide by adding an area equal to the tide reading times the length of the cross-section.

Table 1. Apportionment of Channel Cross-section

Allocation	Areas (ft^2)			Surface Width (ft):		
	North	Middle	South	North	Middle	South
Channels	13500	3400	14000	570	250	680
One-third	12860	8100	10200	500	500	500

The tidal flow is calculated for each portion of the cross-section by multiplying the depth averaged flow at a station times the tide-corrected cross-sectioned area. The total flow at that time is then the sum of the flow calculated for each portion of the channel. The total flow is shown as a function of time in Figure 5.

The volume of water leaving Indian River and Rehoboth Bays during ebb tide was calculated by integrating the total flow from slack tide (10:45 a.m.) to the next slack tide (4:45 p.m.). This integration was carried out by Simpson's rule using the total flows shown graphically in Figure 5. The calculated volume for the ebb tidal prism is 2.34×10^9 ft^3 using the cross-sections apportioned by channels and 2.46×10^9 ft^3 using the cross-sections apportioned by width.

Calculating the total volume of water that flowed into Indian River and Rehoboth Bay during the flood tide is complicated by the fact that the morning and evening high tides are of unequal magnitude. Simply calculating the flood volume using the two periods of measured flood tides (incorporating, however, only 6.2 hours of data) yields 2.7×10^9 and 2.6×10^9 using the apportioning method of channels and width, respectively. These flood data are larger than the ebb data due to the fact that the second flood tide was much greater due to the greater tide range. By extrapolating the data of the morning flood tide, a quarter of a tidal cycle is obtained (3.1 hours). Calculating the tidal prism for the expanded data and multiplying by 2 (for a complete flood cycle) yields a morning tidal prism of 2.04×10^9 ft^3. Repeating this operation with the evening flood tide, a tidal prism of 3.30×10^9 ft^3 results. The extrapolation procedure was performed with the channels method.

Discussion

Lanan and Dalrymple (1977) estimated the tidal prism (using only one current meter) to be 9×10^8 ft^3 for a 2.5' tide range at the Coast Guard tide gage. For this study, the maximum tidal prism was 3.30×10^9 ft^3 for a 3.7' tide range (evening tide) and a 2.04×10^9 ft^3 tide range for a 3.2' tide. These figures agree quite well when including the effects of greater tide ranges although less weight should be placed on the Lanan and Dalrymple measurements.

Reference

Lanan, G. L. and R. A. Dalrymple (1977), A Coastal Engineering Study of Indian River Inlet, Delaware, OE Technical Report 14, Delaware Sea Grant College Program, University of Delaware, Newark, Delaware.

Acknowledgement

We would like to thank the following students who participated in the field program: Cindy Eng, Chip Fletcher, Brian Jacobs, Kurt Seigel, Diane Selvaggi, Seung Nam Seo and Charles Wu.

Appendix 1

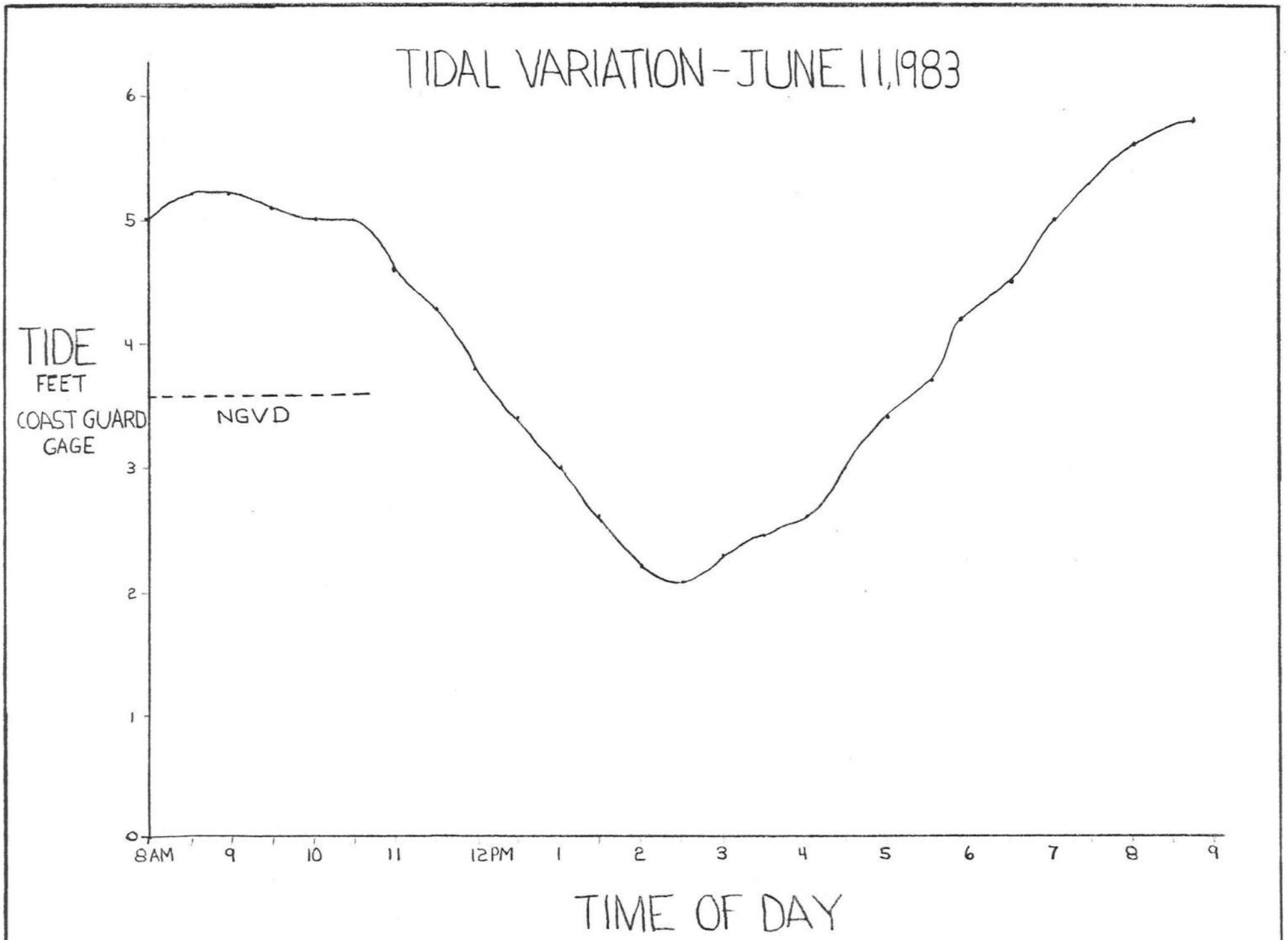

TIDAL VARIATION - JUNE 11, 1983
TIDE
FEET
COAST GUARD
GAGE
NGVD
6
5
4
3
2
1
0
8AM
9
10
11
12PM
1
2
3
4
5
6
7
8
9
TIME OF DAY

Figure 1.

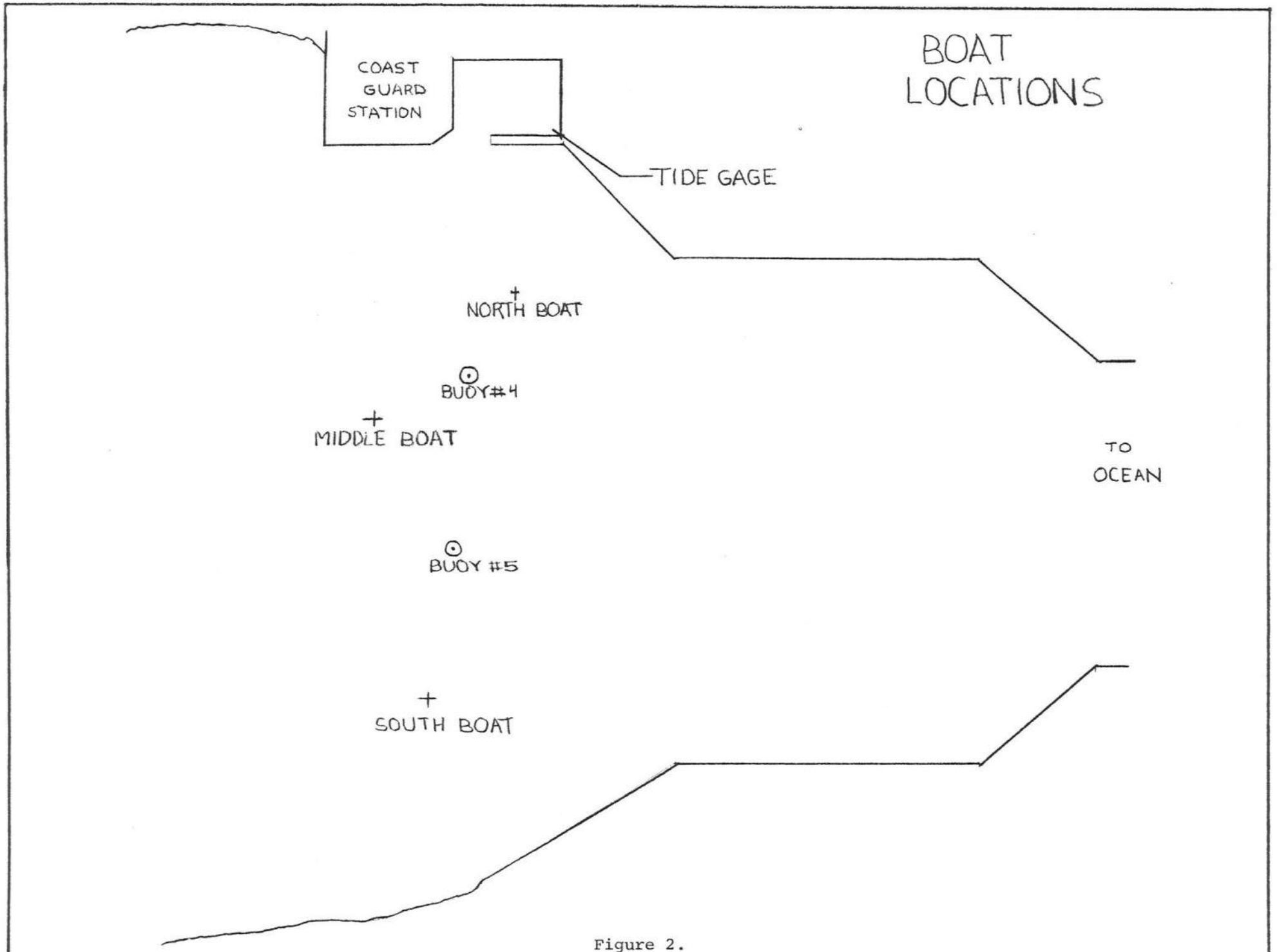
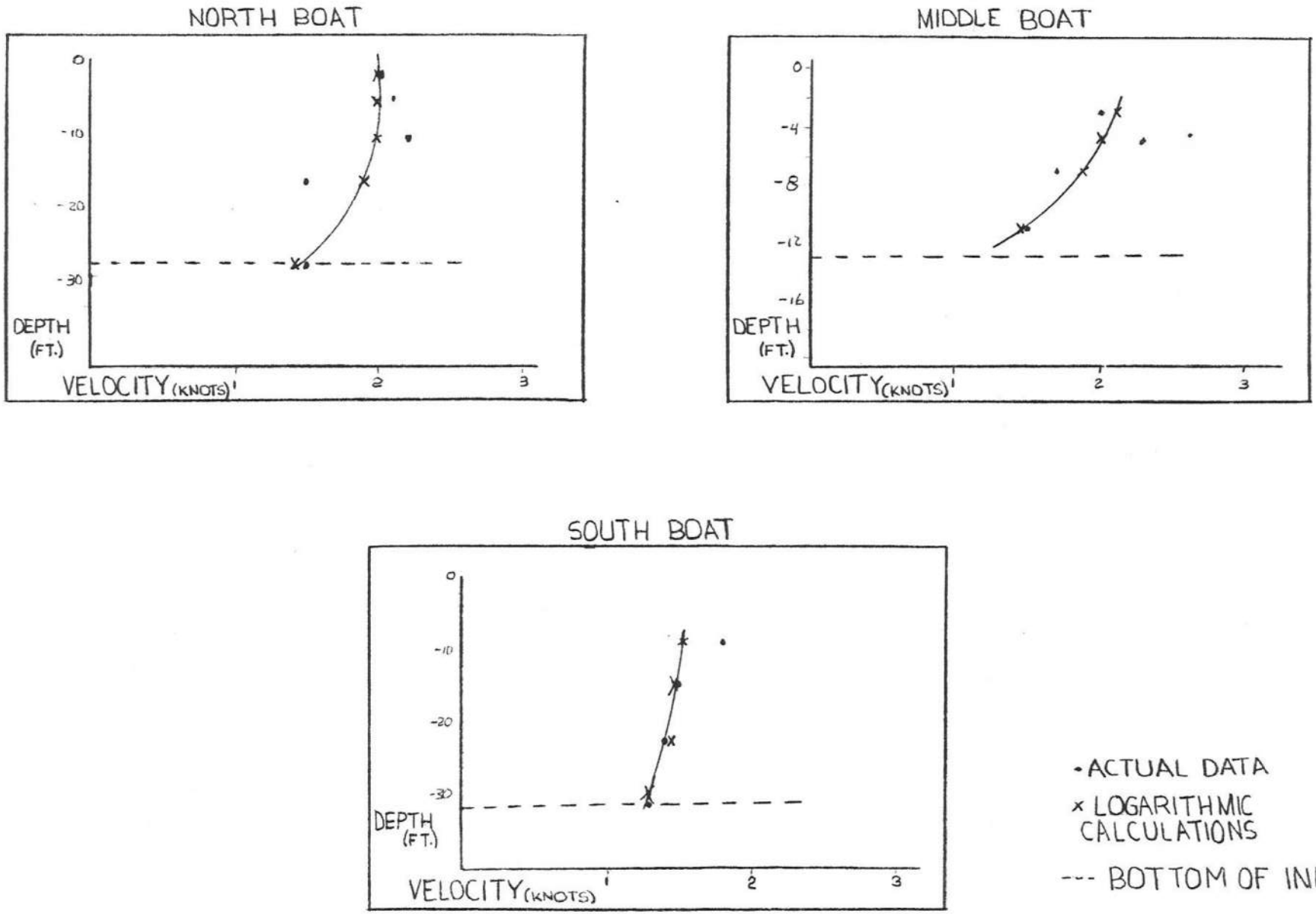

BOAT
LOCATIONS
COAST
GUARD
STATION
TIDE GAGE
NORTH BOAT
BUOY#4
MIDDLE BOAT
TO
OCEAN
BUOY #5
SOUTH BOAT

Figure 2.



COMPARISON OF VELOCITY DATA TO LOGARITHMIC VELOCITY PROFILES AT 12:00 PM

Figure 3.

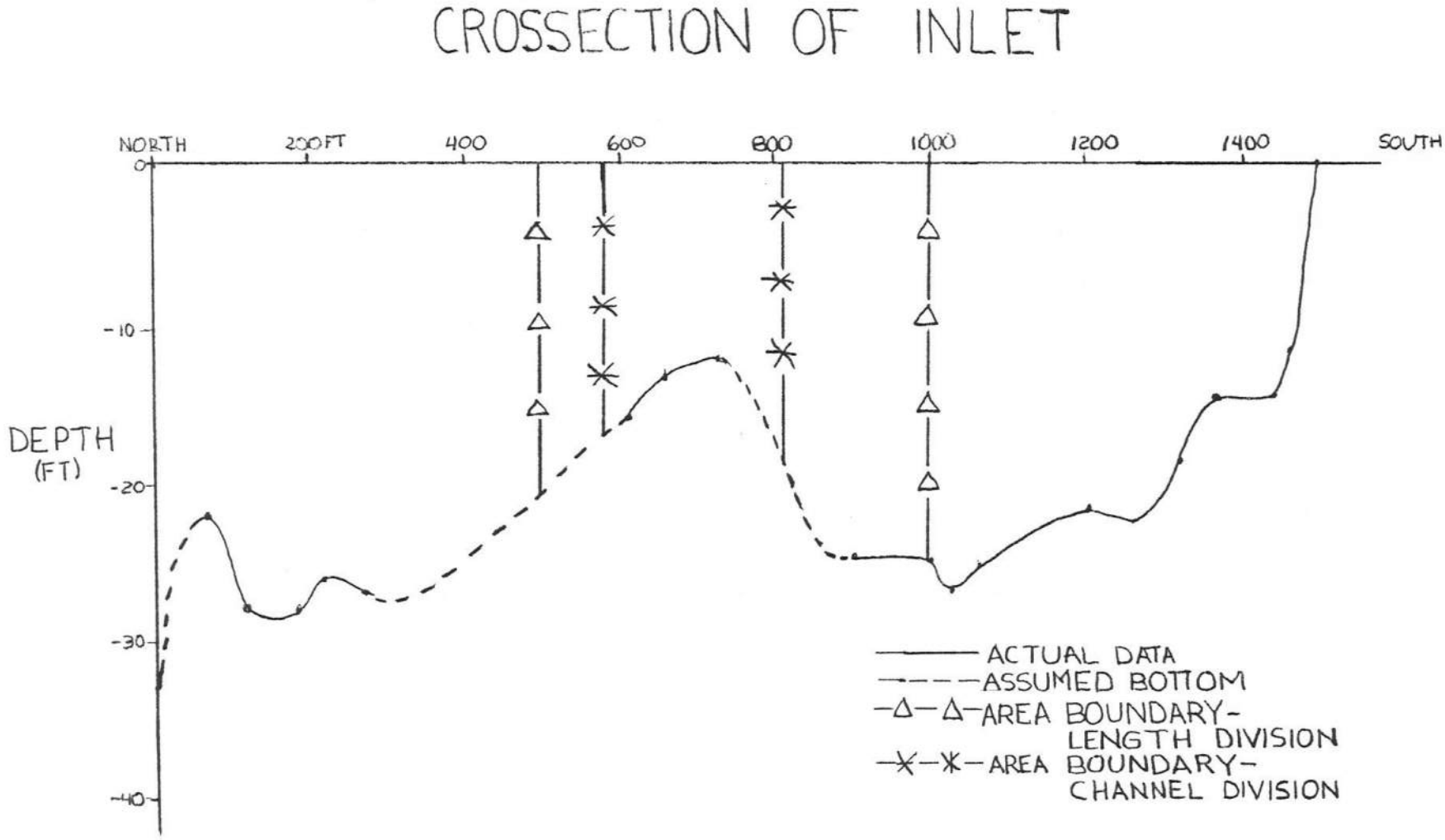
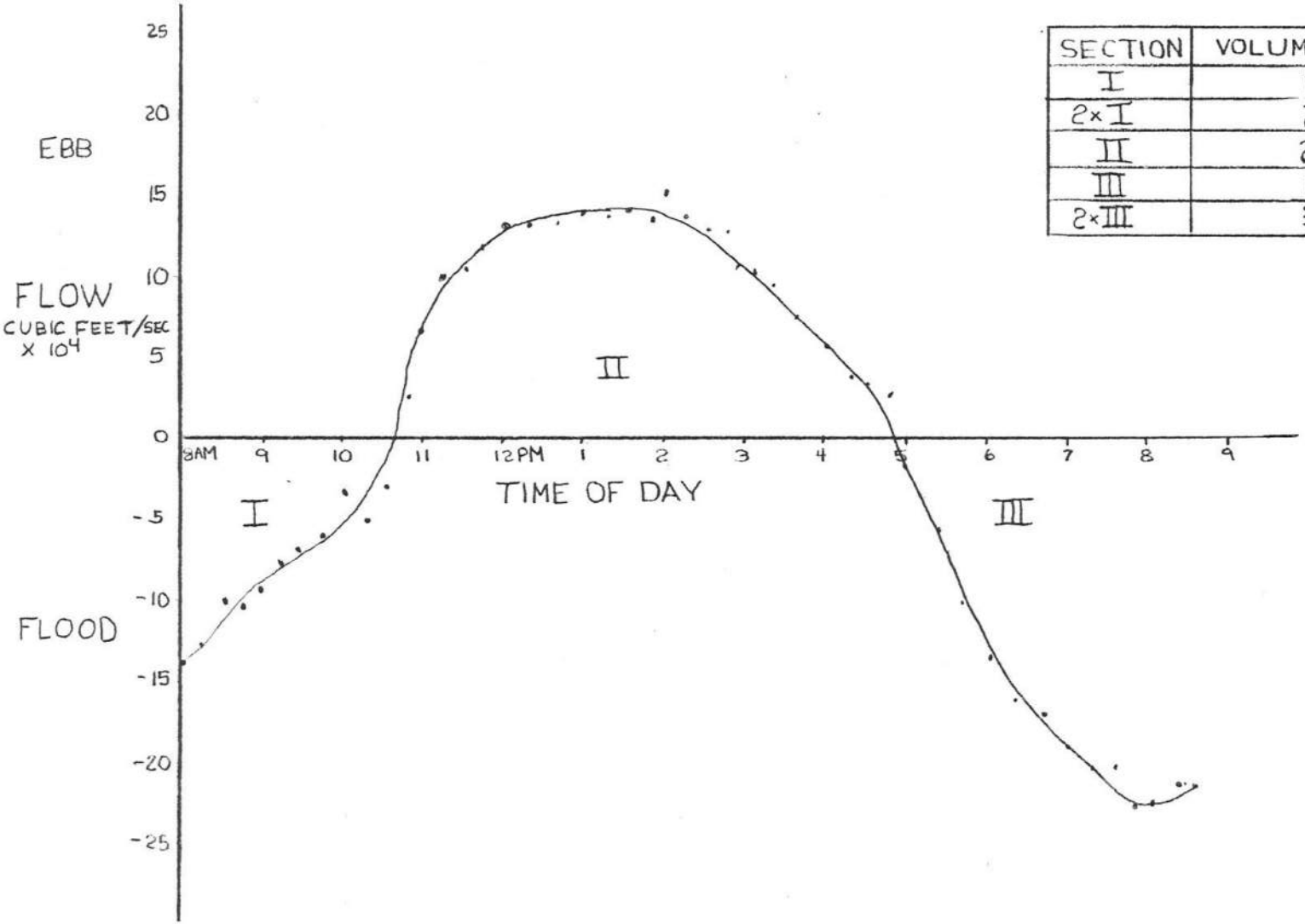

CROSSECTION OF INLET
NORTH
200FT
400
600
800
1000
1200
1400
SOUTH
0
-10
-20
-30
-40
DEPTH
(FT)
ACTUAL DATA
ASSUMED BOTTOM
AREA BOUNDARY-
LENGTH DIVISION
AREA BOUNDARY-
CHANNEL DIVISION

Figure 4.

FLOW THROUGH INLET VS. TIME



SECTION	VOLUME OF WATER
I	1.02×10^9 FT.^{3}
2×I	2.04×10^9
II	2.45×10^9
III	1.65×10^9
2×III	3.30×10^9

Figure 5.

Appendix 2

INDIAN RIVER INLET VELOCITY AND TIDAL DATA

June 11, 1983

Notes: 1. Zero depth denotes surface velocity. This was actually measured at the minimum depth to completely submerge the current meters.

2. Depths shown have been analyzed to show data used in calculations and do not represent actual data taken from current meters.

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
8:00 A.M.	5.0	No Readings		13 9 6 3	1.8 1.8 2.2 2.0	38 25 10	1.45 2.0 2.2
8:15	5.2	25 22 5	1.0 1.55 1.55	12 9 6 3	1.7 1.85 1.8 1.9	40 30 6 0	1.6 2.0 1.7 2
8:30	5.2	25 15 10	.4 1.5 1.4	12 9 6 3	1.7 1.85 1.8 1.9	25.5 22.5 19.5 15 12 9 6 3	1.35 1.40 1.3 1.75 1.7 1.9 2.0 1.8 2
8:45	5.2	25 15 10	1.0 1.15 1.15	11 9 6 3	1.3 1.7 1.8 1.8	25 23 20 15 12 9 6 4 2 0	1.5 1.4 1.3 1.5 1.8 1.9 2.0 1.95 1.7 1.8

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
9:00	5.2	28 17 6	1.1 0.9 1.15	11 9 6 3	1.25 1.45 1.5 1.65	25 22 18 15 12 9 6 4 2 0	1.2 1.35 1.25 1.4 1.3 1.65 1.7 1.6 1.7 1.6
9:15	5.1	26 16 10 5 2	0.7 1.0 0.7 0.8 1.0	11 9 6 3	1.2 1.3 1.3 1.3	30 29 23 18 10 2 0	1.2 1.2 1.25 1.4 1.5 1.5 1.4
9:30	5.1	26 20 15 5 2	0.75 1.0 0.7 0.7 0.95	11 9 6 3	1.0 1.0 1.2 1.15	30 29 28 25 18 11 2 0	1.15 1.2 1.3 1.35 1.3 1.2 1.35 1.2
9:45	5.0	24 20 16 8 2	0.4 0.5 0.6 0.6 0.65	10 8 6 3	0.8 1.0 1.1 1.15	30 28 26 18 11 3 0	.95 1.1 1.0 1.05 1.1 1.1 1.1
10:00	5.0	25 15 10 5	0.1 0.2 0.25 0.2	10 8 6 3	0.45 0.55 0.60 0.60	28 27 26 20 12 4 0	.85 .8 .8 .85 .95 .90 .85

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
10:15	5.0	25 20 15 10 2	0.15 0.2 0.05 0.1 0	9.5 7 5 3	0.25 0.25 0.3 0.3	26 25 21 12 3 0	1.25 1.4 1.45 1.5 1.5 1.55
10:30	5.0	28 16 8 2	0.4 0.3 0.4 0.4	9.5 7 5 3	0.15 0.20 0.25 0.20	25 22 3	0.2 0.25 0.1
10:45	4.8	26 20 12 3	0.55 0.5 0.45 0.55	10 7 5 3	0.60 0.65 0.6 0.7	26 21 12 4	0.45 0.5 0.5 0.4
11:00	4.6	28 16 10 5	1.0 0.8 1.0 0.9	10.5 7 5 3	1.05 1.1 1.2 1.4	26 20 12 4	0.8 1.0 1.1 1.1
11:15	4.4	28 23 16 10 5 2	1.2 1.2 1.0 1.1 1.6 1.5	11 7 5 3	1.2 1.6 1.7 1.5	29 28 25 17 10 4	1.1 1.1 1.4 1.4 1.4 1.4
11:30	4.3	28 20 14 8 2 1	1.5 1.4 1.35 1.3 1.5 1.3	11 7 5 3	1.6 1.9 1.85 1.9	28 25 17 10 3	1.2 1.1 1.35 1.60 1.55
11:45	4.0	28 22 16 10 8 5 2	1.4 1.4 1.2 1.4 1.7 1.9 2.0	11 7 5 3	1.45 1.75 2.15 2.15	29 28 27 22 15 9 3	1.0 1.2 1.3 1.55 1.65 1.8 1.9

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
12:00	3.8	28	1.5	11	1.5	32	1.3
		16	1.5	7	1.7	30	1.3
		10	2.2	5	2.3	23	1.4
		5	2.1	3	2.05	16	1.5
		1	2.0			9	1.8
12:15	3.6	28	1.7	11	1.7	31	1.5
		25	2.0	7	2.2	28	1.3
		18	1.6	5	2.3	21	1.6
		12	1.6	3	2.5	10	1.75
		8	1.7			3	1.85
		5	1.7				
		2	1.9				
12:30	3.4	NO READING		10.5	1.6	30	1.3
				7	2.3	27	1.7
				5	2.5	21	1.7
				3	2.4	14	1.75
						10	1.6
						2	1.8
12:45	3.2	28	2.0	10	1.9	24	1.8
		25	2.0	7	2.2	20	1.7
		20	2.2	5	2.4	16	1.75
		15	1.9	3	2.7	11	2.0
		10	2.3			7	1.9
		5	1.9			1	1.9
		1	2.3				
1:00	3.0	28	2.0				
		25	2.3	10	2.1	30	1.5
		20	2.4	7	2.4	28	1.9
		15	2.4	5	2.65	23	1.9
		10	2.4	3	2.7	20	1.8
		5	2.5			14	1.75
		1				9	1.9
						2	1.9
1:15	2.6	28	2.4	10	2.8	32	1.5
		25	2.3	7	2.5	31	1.6
		20	2.3	5	2.75	27	1.6
		15	2.2	3	2.95	23	1.8
		10	2.3			18	1.9
		5	2.1			15	1.8
		1	2.3			7	2.0
						2	1.9

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
1:30	2.6	NO READING		10 7 5 3	2.3 3.1 2.9 3.25	32 31 30 28 24 20 14 7 2	1.5 1.45 1.6 1.6 1.8 1.6 1.6 2.0 2.0
1:45	2.3	26 20 10 5 1	2.6 2.6 2.4 2.3 2.4	10 7 5 3	2.2 2.6 2.8 2.9	30 26 20 14 10 1	1.4 1.4 1.6 1.6 1.5 1.7
2:00	2.2	28 20 10 5 1	2.5 3.1 3.3 2.8 2.75	9.5 7 5 3	2.1 2.7 2.7 2.8	30 29 28 22 13 9 3	1.4 1.2 1.3 1.5 1.6 1.4 1.4
2:15	2.2	6	2.75	9.5 7 5 3	2.0 2.1 2.6 2.5	30 29 28 22 13 9 2	1.3 1.4 1.45 1.5 1.9 1.6 1.7
2:30	2.1	7	2.3	9.5 7 5 3	2.1 2.3 2.4 2.5	30 27 24 15 9 2	1.4 1.3 1.5 1.6 1.6 1.7
2:45	2.1	4	2.5	9.5 7.0 5.0 3.0	1.6 1.9 2.3 2.5	30 29 28 24 17 9 2	1.2 1.3 1.3 1.4 1.4 1.5 1.4

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
3:00	2.3	6	1.9	9.5 7 5 3	1.6 1.6 2.1 2.2	30 27 26 19 10 3	1.3 1.1 1.1 1.2 1.1 1.0
3:15	2.4	8	1.75	9.5 7 5 3	2.0 2.1 2.6 2.6	30 27 18 10 5	1.0 1.0 1.0 1.1 1.1
3:30	2.45	6	1.75	9.5 7 5 3	1.15 1.40 1.75 1.85	28 26 18 11 3	1.1 1.0 1.1 0.9 1.0
3:45	2.5	10	1.3	9.8 7 5 3	1.25 1.60 1.60 1.70	28 26 19 11 3	0.9 0.9 1.0 0.9 0.9
4:00	2.6	10 5	1.2 1.2	9.0 7.0 5.0 3.0	1.25 1.2 1.2 1.4	28 26 19 11 2	0.8 0.8 0.9 0.7 0.7
4:15	2.9	9 5 2	.8 1.2 1.0	9.0 7.0 5.0 3.0	0.8 0.75 0.95 1.10	27 20 12 3	0.7 0.7 0.6 0.6
4:30	3.0	7 4 1	.5 .5 .7	9 5 1	0.5 0.8 0.8	26 20 12 3	0.4 0.4 0.3 0.3
4:45	3.2	9 4 1	.1 .1 0	NO READING		26 22 14	0.2 0.5 0.3

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
5:00	3.4	18 12 6	.3 .1 .1	9 5 1	0.1 0.1 0.3	26 22 14 4	0.3 0.2 0.2 0.6
5:15	3.5	NO READING		9 1	0.9 0.8	26 22 13 5 0	0.7 0.6 0.9 0.9 1.0
5:30	3.7	21 18 14 10.6 7 4 0	1.0 .25 1.0 .3 .25 .5 .5	9 1	1.2 1.3	30 20 12 6 1	1.0 1.2 1.3 1.1 1.0
5:45	4.0	21 17.6 14 10.6 7 4 0	1.3 1.2 .9 .9 .9 .9 .8	9 0	1.4 1.4	30 26 18 10 4 0	1.2 1.3 1.5 2 2 1.9
6:00	4.2	31.8 28.3 24.7 21 18 14 10 7 4 0	1.7 1.7 1.8 1.9 1.8 1.8 1.75 1.7 1.7 1.4	10 1	1.6 1.8	30 20 14 10 2 0	1.6 1.8 1.8 1.9 2.0 2.0
6:15	4.4	28.3 21 14 7 0	1.2 1.8 1.9 2.1 1.7	10 1	1.7 2.0	30 25 18 12 8 4 0	1.5 1.8 2.1 2.1 2.1 2.2 2.1

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
6:30	4.5	28	2.2	10	2.1	28	2
		21	2.2	1	2.2	20	2.2
		14	2.2			16	2.2
		7	2.4			12	2.5
		0	2.0			8	2.4
						3	2.7
						0	2.7
6:45	4.8	28	2.2	10	2.4	26	2.5
		21	2.5	1	2.3	21	2.4
		14	2.5			18	2.6
		7	2.4			16	2.5
		0	2.1			14	2.4
						10	2.5
						8	2
						2	2.3
						0	2.4
7:00	5.0			10	2.4	26	2.7
		28	2.5	1	2.6	18	2.7
		21	2.6			14	2.7
		14	2.5			12	2.6
		7	2.7			10	3.0
		0	2.1			8	2.8
						4	3.0
7:15	5.1			10	2.5	14	3.1
		28	2.2	1	2.5	10	3.5
		21	2.4			9	3.0
		14	2.6			8	2.9
		7	2.5			1	3.0
		0	2.7			0	3.2
7:30	5.3			10	2.5	16	3
		28	2.6	1	2.9	14	2.9
		21	2.8			12	2.7
		14	2.7			8	3.2
		7	2.5			4	3
		0	2.8			2	3
						1	3
7:45	5.4			10	2.7	16	3.1
		28	2.7	1	2.9	9	3.4
		21	3.1			7	3.5
		14	3.1			4	3.2
		7	2.8			1	3.0
		0	2.6			0	3.4

Time	Tide (ft)	BOAT I (NORTH)		BOAT II (MIDDLE)		BOAT III (SOUTH)	
		Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)	Depth (ft)	Velocity (knots)
8:00	5.6			10	2.3	26	3.1
		28	2.2	1	2.7	18	3.45
		21	2.8			16	3.5
		14	3.0			10	3.45
		7	3.1			5	3.3
		0	2.4			0	3.4
8:15	5.7					28	2.9
		28	1.8	10	2.5	24	3.3
		21	2.5	1	2.8	16	3.3
		14	2.85			12	3.3
		7	2.95			10	3.5
		0	2.5			0	3.3
8:30	5.8			10	2.5	22	3.4
		28	2.5	1	2.8	18	3.5
		21	2.5			10	3.3
		14	2.0			5	3.4
		7	2.6			0	3.6
		0	2.6				