James River seed oyster bed project: physical data report, I, 1984-1987

D. Hepworth
Virginia Institute of Marine Science

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JAMES RIVER SHEED OYSTER BED PROJECT

PHYSICAL DATA REPORT II
1984 - 1987

D. Hepworth
and
A. Y. Kuo

Data Report # 31

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia, 23062

June 1989
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INTRODUCTION

The Virginia Institute of Marine Science initiated a study of the "James River Seed Oyster Beds" in July 1984. This was a multi-disciplinary program involving all aspects of marine science: physical, biological, geological, and chemical. The study of river circulation spanned the time period from 1984 to 1987.

Oysters spawn in the James River in summer and early fall. Their larvae stay suspended in the water column and drift with the currents for about 10 to 20 days at which time they attach to a hard surface for permanent residence. The paths of water mass movement during the planktonic stage is thus crucial for oyster recruitment. In fact the pioneer work of estuarine circulation was conducted in the James River (Pritchard, 1952) for the purpose of understanding oyster recruitment processes.

The objective of this circulation study was to delineate the transport pathways of oyster larvae between spawning and settling. Knowledge of larval transport pathways may in turn provide information that can aid in (a) the determination of the primary causes of the decline of oyster production and (b) the rehabilitation of the oyster industry once the causes for decline are determined. In order to attain this objective, it is
imperative to understand the movement of water in the three spatial dimensions and be able to trace these movements through time. Tools with sufficient resolution are not available to resolve the problem with a single stroke. Accordingly, this study was pursued in terms of four projects, which, when integrated, would provide the estimate sought. The first project examined the movement of water masses in the horizontal plane. The second project addressed the variability of the gravitational circulation and water density (salinity) structure in the vertical plane. The third project studied smaller scale motion, such as estuarine fronts and vertical mixing, which were recognized as being potentially important to the concentration (or in some cases dispersion) of oyster larvae. The fourth project addressed the micro-circulation and the sedimentation processes occurring on one of the most important seed rocks, Wreck Shoal.

This data report describes the field measurements and provides graphical presentations of the data of the first two projects, which aimed at the gross scale, sub-tidal circulation. The numerical values of the data are archived and stored on magnetic tapes, which may be retrieved through the VIMS computer system. Some of the results synthesized from these data have been submitted for publication in professional literature.
I. CURRENT MEASUREMENTS

A. Equipment and Deployment

Currents were measured at several locations and at various depths in order to gather information on the three dimensional flow field. The different types of current meters used were the General Oceanic Model 6011, InterOcean Model S4, Endeco Model 105, and a modification of one made by Braincon. The specifics of each type of meter and where they were located are presented in Table 1. From 1984 through 1987, the general periods of successful deployment were:

1. October and November 1984
James River Bridge Area: A string of current meters was deployed in the channel upstream from the James River Bridge at Station B (Figure 1).

2. June and July 1985
(a) Fort Eustis Area: A station was located in the channel at Buoy J30 (designated as 'FE' in Figure 1), about 40 km from the mouth. The
maximum depth at this location was about 10 m below mean low water, as can be seen in the cross sectional profile (Figure 2).

(b) James River Bridge Transect: These five stations were located on a transect across the river approximately 22 km upstream from the mouth (Figure 1). The maximum depth of about 10 m below mean low water was at Station B (Figure 3).

3. June through November 1985
James River Bridge Transect: A long term deployment at Station B was maintained for 6 months. This string of current meters was located in the channel portion of the transect.

4. June and July 1986
Burwell Bay Area: Current meters were deployed at a total of 6 stations on 2 transects (Figure 1). Instrument malfunctions, however, limited the usable data sets to only 5 stations. Maximum depths of about 8 m below mean low water were found in the dredged channel in both transects.

5. June and July 1987
Burwell Bay Area: In a deployment similar to the one in 1986, usable data was collected at 4 stations. Station locations were the same as in 1986.

B. Data Analysis

The currents observed in the James River are primarily along distinct ebb and flood axes. Because of irregular channel topography these axes can
vary with location in the estuary, with depth at the same location, and are not necessarily opposing. The ebb and flood currents can be seen in the stickplots of observed velocities (Appendix A). These vectors (and all others reported in this study) were adjusted from magnetic north to true north by the annual local magnetic variation, which was about 9° west from 1984 through 1987. Currents were edited for wild points before further analysis.

In order to determine the major axis of flow, it is necessary to find the principal axis along which the longitudinal components are maximized. This axis was determined for each location as follows:

\[ A = 0.5 \arctan \left( \frac{2N\bar{E}}{N^2 - E^2} \right) \]

where \( A \) is the angle of principal axis relative to true north, \( N \) is the north-south component, \( E \) is the east-west component, and overbars indicate averaging over all data points. The data points were then split into two groups by a line perpendicular to the principal axis. Ebb and flood axes were determined by calculating the average vector direction for each group of data respectively. The angles of the principal, ebb, and flood axes are presented in Table 2. The relationships between these axes and the observed currents are evident in the scatterplots. Some examples of scatterplots are presented in Appendix B.

Current velocities were resolved into longitudinal and transverse components relative to the principal axis. These components are strongly influenced by the semidiurnal tides, which can be seen in the time series component plots (Appendices C and D). Since the transverse components of
velocity are usually small, only a few samples are presented in Appendix D. Some of the current measurements showed relatively large transverse flows. These appear to have resulted from malfunctions and problems with some of the compasses in the InterOcean meters.

In order to study mean circulation it is necessary to remove the tidal variation from the data. One approach is to apply a low pass filter, which removes variations with frequencies higher than a specified cutoff value. The low pass filtered value for any data point can be generated by applying numerical weights to the sequences of observations extending from that point. With truncation of the sequence at a finite value, the low pass time series can be constructed from:

$$Y_i = \sum_{k=-N}^{N} w_k X_{i+k}$$

where $Y_i$ is the low pass filtered value, $N$ is the length of the sequence known as the span of the filter, $w_k$ is the filter weight, and $X_{i+k}$ are the observations. The low pass filter used for analysis was a modification of one designed by Godin (1972) with weights calculated as follows:

$$w_k = \frac{\sin(2\pi k \omega \Delta t)}{(2\pi k \omega \Delta t)} \cdot \frac{\sin \left(\frac{2\pi k}{2N+1}\right)}{\sin \left(\frac{2\pi k}{2N+1}\right)}$$

for $k = -N$ to $N$

where $\omega$ is the cutoff frequency, and $\Delta t$ is the sampling interval. A sequence of filter weights with $2N+1$ terms was generated and applied to the data. For this study, $N$ was equal to the number of samples in 48 hours, and was $0.0278 \, \text{h}^{-1}$ or a cutoff period of 36 h.
In the lower part of the James River, the low pass filtered longitudinal components generally exhibited a seaward surface flow and landward bottom flow (Appendix E). Variations from this mean pattern were largely the result of meteorological forcing especially by wind and freshwater inputs. Some of these meteorologically driven changes in circulation were examined by Hepworth (1988). The filtered along-channel flows are greater than the transverse components, and only a few of the transverse component plots are presented in Appendix F. Exceptions are apparently due to compass problems. The observed and low pass filtered longitudinal components of flow in the channel near the James River Bridge are displayed for the whole period of deployment (June through November 1985) in Appendix G.
The Study Location - The Lower James River Estuary and Sampling Locations
Figure 2. Cross-sectional profile (facing downstream) and current meter locations at Ft. Eustis transect.
Figure 3. Cross-sectional profile (facing downstream) and current meter locations for transect near James River Bridge.
### TABLE 1

**TYPES AND LOCATIONS OF CURRENT METERS**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>STATION</th>
<th>DEPTH</th>
<th>INSTRUMENT TYPE</th>
<th>SAMPLES EVERY</th>
<th>USABLE DATA FROM - TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Oceanic</td>
<td></td>
<td></td>
<td>Inclinometer with data stored on magnetic tape.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>InterOcean</td>
<td></td>
<td></td>
<td>Electromagnetic with solid state memory.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endeco</td>
<td></td>
<td></td>
<td>Ducted axial propeller with data stored on film.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Braincon(modified)</td>
<td></td>
<td></td>
<td>Savonius rotor with film replaced by solid state memory.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>STATION</th>
<th>DEPTH</th>
<th>INSTRUMENT TYPE</th>
<th>SAMPLES EVERY</th>
<th>USABLE DATA FROM - TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>James River</td>
<td>B</td>
<td>2.4m</td>
<td>General Oceanic</td>
<td>15 min</td>
<td>10/20-11/15</td>
</tr>
<tr>
<td>Bridge</td>
<td></td>
<td>4.9</td>
<td></td>
<td></td>
<td>10/25-11/22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.1</td>
<td></td>
<td></td>
<td>10/19-11/17</td>
</tr>
<tr>
<td>Fort Eustis</td>
<td>J30</td>
<td>1.8m</td>
<td>General Oceanic</td>
<td>30 min</td>
<td>5/26-6/24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.9</td>
<td></td>
<td></td>
<td>6/1-7/1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.7</td>
<td></td>
<td></td>
<td>1</td>
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<td></td>
<td></td>
<td>7.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>James River</td>
<td>A</td>
<td>0.7m</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td>7/2-7/30</td>
</tr>
<tr>
<td>Bridge</td>
<td>B</td>
<td>1.9</td>
<td></td>
<td></td>
<td>7/2-8/8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.1</td>
<td></td>
<td></td>
<td>6/1-11/27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.5</td>
<td>General Oceanic</td>
<td></td>
<td>7/1-8/5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.3</td>
<td></td>
<td></td>
<td>7/1-8/7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.6</td>
<td></td>
<td></td>
<td>7/1-8/8</td>
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<tr>
<td></td>
<td></td>
<td>6.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>1.2</td>
<td>Endeco</td>
<td></td>
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<td></td>
<td></td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>0.2</td>
<td>InterOcean S4</td>
<td></td>
<td>7/2-7/12</td>
</tr>
<tr>
<td>Burwell Bay</td>
<td>A</td>
<td>1.5m</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td>6/24-7/6</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.0</td>
<td>Braincon</td>
<td>34.1 min</td>
<td>6/24-7/24</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.8</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td>6/24-7/10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.6</td>
<td></td>
<td></td>
<td>6/24-7/12</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>1.5</td>
<td></td>
<td></td>
<td>6/24-7/9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.4</td>
<td>Braincon</td>
<td>34.1 min</td>
<td>6/24-7/24</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>1.5</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td>6/24-7/10</td>
</tr>
<tr>
<td>Burwell Bay</td>
<td>A</td>
<td>1.7m</td>
<td>Braincon</td>
<td>34.1 min</td>
<td>6/24-7/23</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.8</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td>6/24-7/27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.9</td>
<td>Braincon</td>
<td>34.1 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.9</td>
<td>InterOcean S4</td>
<td>30 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.5</td>
<td>Braincon</td>
<td>34.1 min</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>1.5</td>
<td></td>
<td></td>
<td>6/25-7/23</td>
</tr>
</tbody>
</table>

I-9
Table 2

Principal Axes and Average Velocity Components

(a) 1984 Current Meter Data

James River Bridge

Late October Through Late November

<table>
<thead>
<tr>
<th>Station/Depth/Start-End Dates</th>
<th>Axes Principal Ebb Flood</th>
<th>Averages Longitudinal Transverse</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 2.4m 10/20-11/15</td>
<td>97 100 275</td>
<td>6.2 cm/s</td>
<td>1,2</td>
</tr>
<tr>
<td>B 4.9m 10/25-11/22</td>
<td>108 105 290</td>
<td>-1.5</td>
<td>1,2</td>
</tr>
<tr>
<td>B 9.1 10/19-11/17</td>
<td>114 117 289</td>
<td>-8.9</td>
<td>1,2</td>
</tr>
</tbody>
</table>

Comments
1 Longitudinal component along principal axis is with ebb positive
2 Average transverse components were not calculated but were of order of 1 cm/s
TABLE 2 (cont'd.)

(b) 1985 CURRENT METER DATA

**FORT EUSTIS**

<table>
<thead>
<tr>
<th>STATION/DEPTH/AXES AVERAGE</th>
<th>START-END DATES</th>
<th>PRINCIPAL EBB FLOOD</th>
<th>LONGITUDINAL</th>
<th>TRANSVERSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE 1.8m</td>
<td>5/26-6/24</td>
<td>174 171 12</td>
<td>16.7 cm/s</td>
<td>3.1 cm/s</td>
</tr>
<tr>
<td>FE 4.9m</td>
<td>6/1-7/1</td>
<td>204 204 25</td>
<td>4.6</td>
<td>1.2</td>
</tr>
<tr>
<td>FE 6.7m</td>
<td>&quot;</td>
<td>216 217 35</td>
<td>2.6</td>
<td>-0.1</td>
</tr>
<tr>
<td>FE 7.9m</td>
<td>&quot;</td>
<td>204 201 28</td>
<td>0.8</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**JAMES RIVER BRIDGE TRANSIENT**

<table>
<thead>
<tr>
<th>STATION/DEPTH/AXES AVERAGE</th>
<th>START-END DATES</th>
<th>PRINCIPAL EBB FLOOD</th>
<th>LONGITUDINAL</th>
<th>TRANSVERSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 0.7m</td>
<td>7/2-7/30</td>
<td>128 131 305</td>
<td>1.3 cm/s</td>
<td>-1.5 cm/s</td>
</tr>
<tr>
<td>A 1.9m</td>
<td>7/2-8/8</td>
<td>126 128 304</td>
<td>0.1</td>
<td>-0.9</td>
</tr>
<tr>
<td>B 1.2m</td>
<td>7/1-8/8</td>
<td>127 128 306</td>
<td>9.0</td>
<td>-0.3</td>
</tr>
<tr>
<td>B 3.1m</td>
<td>&quot;</td>
<td>120 121 300</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>B 6.3m</td>
<td>&quot;</td>
<td>105 106 284</td>
<td>-6.6</td>
<td>-0.9</td>
</tr>
<tr>
<td>B 8.5m</td>
<td>&quot;</td>
<td>101 107 279</td>
<td>-7.4</td>
<td>-1.6</td>
</tr>
<tr>
<td>C 1.5m</td>
<td>7/1-8/5</td>
<td>112 105 307</td>
<td>11.7</td>
<td>7.0</td>
</tr>
<tr>
<td>C 4.3m</td>
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**COMMENTS**

1. LONGITUDINAL COMPONENT ALONG PRINCIPAL AXIS IS WITH EBB POSITIVE
2. TRANSVERSE COMPONENT POSITIVE BETWEEN NORTH AND PRINCIPAL AXIS (FOR THIS DATA, POSITIVE TOWARDS THE EAST)
TABLE 2 (cont'd.)

(b) 1985 CURRENT METER DATA (CONTINUED)

JAMES RIVER BRIDGE TRANSECT STATION B

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COMMENTS
1 LONGITUDINAL COMPONENT ALONG PRINCIPAL AXIS IS WITH EBB POSITIVE
2 TRANSVERSE COMPONENT POSITIVE BETWEEN NORTH AND PRINCIPAL AXIS
   (FOR THIS DATA, POSITIVE TOWARDS THE EAST)
   I-12
TABLE 2 (cont'd.)

(c) 1986 CURRENT METER DATA

BURWELL BAY

LATE JUNE THROUGH LATE JULY

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COMMENTS
1 LONGITUDINAL COMPONENT ALONG PRINCIPAL AXIS WITH EBB POSITIVE
2 TRANSVERSE COMPONENT POSITIVE BETWEEN NORTH AND PRINCIPAL AXIS (FOR THIS DATA, POSITIVE TOWARDS THE EAST)
3 DATA AT 2048 SECOND INTERVAL (AS OPPOSED TO 30 MINUTES)
TABLE 2 (cont'd.)

(d) 1987 CURRENT METER DATA

BURWELL BAY

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COMMENTS
1 LONGITUDINAL COMPONENT ALONG PRINCIPAL AXIS WITH EBB POSITIVE
2 TRANSVERSE COMPONENT POSITIVE BETWEEN NORTH AND PRINCIPAL AXIS (FOR THIS DATA, POSITIVE TOWARDS THE EAST)
3 DATA AT 2048 SECOND INTERVAL (AS OPPOSED TO 30 MINUTES)
4 DATA QUALITY WAS POOR, FILE WAS CONSIDERABLY EDITED
5 DUE TO POOR DATA, COMPONENTS NOT LOW PASS FILTERED

I-14
II. SURFACE ELEVATION MEASUREMENTS

A. Equipment and Deployment

Surface elevation was measured at several locations in the lower James River (Figure 1). The tide gauges used were the Fischer & Porter Model 35C, which records water level at 6-min intervals on a paper tape. These gauges were mounted along the shoreline near Fort Monroe, Newport News Point, the James River Bridge (upriver on both shores), Fort Eustis, and Pig Point. Another gauge was located much further upriver at Kingsland near Richmond. Owing to a variety of circumstances, the records at some stations are not continuous (Table 3).

B. Data Analysis

All gauges were surveyed at the time of installation so elevations could be related to the National Geodetic Vertical Datum (NGVD), which lies relatively close to Mean Sea Level (MSL) in the lower James River. Surface elevation measurements on the hour were determined by computing the five
point average for the 6-min readings centered on that hour. In addition to the observed surface elevations, a low pass filter with the same characteristics as the one applied to current measurements was used to examine the mean or nontidal surface elevations. The observed and low pass filtered surface elevations at sites with useable data are found in Appendix H.
TABLE 3
AVAILABLE SURFACE ELEVATION DATA
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TABLE 3 (cont'd.)

AVAILABLE SURFACE ELEVATION DATA

(c) 1986

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<td>1 JANUARY - 14 AUGUST</td>
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<tr>
<td>FORT EUSTIS</td>
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<td>19 JUNE - 31 JULY</td>
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<tr>
<td>PIG POINT</td>
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<td>1 JANUARY - 7 JANUARY</td>
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<td>23 APRIL - 20 JUNE</td>
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<td>20 JUNE - 10 JULY</td>
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</tbody>
</table>
III. SALINITY MEASUREMENTS

A. Time Series Measurements

In addition to recording currents, the InterOcean S4 instruments also measured conductivity and temperature. These two parameters were converted to salinity in parts per thousand (ppt) using the Practical Salinity Scale 1978 (UNESCO, 1981). The locations and durations of useable data are presented in Table 4. One feature in the salinity records is the variation resulting from the semidiurnal tidal currents (Appendix I). These higher frequency fluctuations were superimposed on longer period changes, which were largely the result of variations in freshwater inputs and the influence of meteorological events. These longer term variations are revealed in the low pass filtered data (Appendix J). A long term record of salinities during summer and fall 1985 is found in Appendix K.
B. Slackwater Surveys

The synoptic gross scale distributions of salinity were obtained through a series of slackwater surveys. These surveys were part of a river-monitoring program jointly sponsored by the Virginia Institute of Marine Science and the State Water Control Board. From 1984 to 1986, the surveys were conducted monthly from March or April to November of each year. Each survey was conducted at a slackwater phase of the tide, slack before flood (SBF) or slack before ebb (SBE), as it propagated upstream from the estuary mouth. Temperature and conductivity were measured, or samples taken, at designated stations along the river. Station locations are shown in Figure 4. In this figure station designation (i.e., 0.00, 17.30, etc.) refers to the distance from the river mouth in kilometers.

In the 1986 surveys, temperature and conductivity were measured with an Applied Micro Systems CTD (Conductivity-Temperature-Depth Probe). Vertical profiles for these variables were recorded every meter from surface to bottom at each designated station. The readings were recorded automatically with a portable personal computer. Prior to 1986, measurements were made with an InterOcean Model 513 CTD. At each station the data were recorded manually every two meters from surface to bottom. Occasionally, water samples were collected for conductivity determination in the laboratory.

Conductivity measurements were converted to salinity employing the Practical Salinity Scale. The salinity distribution for each survey is displayed as isohaline contours in the vertical-longitudinal plane. These contour plots are presented in Appendix L.
**TABLE 4**

**AVAILABLE SALINITY DATA**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>STATION</th>
<th>DEPTH</th>
<th>STARTING AND ENDING DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) James River</td>
<td>A</td>
<td>0.7m</td>
<td>7/2-7/30</td>
</tr>
<tr>
<td>Bridge 1985</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.9</td>
<td>7/2-8/8</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.2</td>
<td>7/1-11/27</td>
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<tr>
<td></td>
<td></td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>0.2</td>
<td>7/2-7/12</td>
</tr>
<tr>
<td>(b) Burwell Bay</td>
<td>A</td>
<td>1.5m</td>
<td>6/24-7/6</td>
</tr>
<tr>
<td>1986</td>
<td>C</td>
<td>1.8</td>
<td>6/24-7/10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.6</td>
<td>6/24-7/12</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>1.5</td>
<td>6/24-7/9</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>1.5</td>
<td>6/24-7/10</td>
</tr>
<tr>
<td>(c) Burwell Bay</td>
<td>B</td>
<td>1.8m</td>
<td>6/24-7/27</td>
</tr>
<tr>
<td>1987</td>
<td></td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.8</td>
<td></td>
</tr>
</tbody>
</table>
Slackwater Survey Stations

Nautical Miles

Kilometers
REFERENCES


APPENDIX A

STICKPLOTS OF CURRENTS
Hourly current at station 'J2', 2.4 m. below surface.
Hourly current at station 'J2', 4.9 m. below water surface.
Hourly current at station 'J2', 9.1 m. below surface.
Fort Eustis, 1.8 m below surface, scale in m/sec
Fort Eustis, 4.9 m below surface, scale in m/sec
Fort Eustis, 6.7 m below surface, scale in m/sec
Fort Eustis, 7.9 m below surface, scale in m/sec
James River Bridge Station A, 0.7 m below surface. Scale in m/sec
James River Bridge Station A, 1.9 m below surface, scale in m/sec
James River Bridge Station B, 1.2 m below surface, scale in m/sec
(continued)
(continued)
James River Bridge Station B, 3.1 m below surface, scale in m/sec
(continued)
JB B 3.1m

(continued)
James River Bridge Station B, 6.3 m below surface, scale in m/sec
(continued)
(continued)
(continued)
James River Bridge Station B, 8.5 m below surface, scale in m/sec
(continued)
(continued)
James River Bridge Station C, 1.5 m below surface, scale in m/sec
James River Bridge Station C, 4.3 m below surface, scale in m/sec
James River Bridge Station C, 5.6 m below surface, scale in m/sec
James River Bridge Station C, 6.6 m below surface, scale in m/sec
James River Bridge Station D, 2.4 m below surface, scale in m/sec
James River Bridge Station E, 0.2 m below surface, scale in m/sec
Burwell Bay Station B, 3.0 m below surface, scale in m/sec
Burwell Bay Station B, 5.5 m below surface, scale in m/sec
Burwell Bay Station C, 1.8 m below surface, scale in m/sec
Burwell Bay Station C, 7.6 m below surface, scale in m/sec
Burwell Bay Station E, 1.5 m below surface, scale in m/sec
Burwell Bay Station E, 3.4 m below surface, scale in m/sec
Burwell Bay Station F, 1.5 m below surface, scale in m/sec
Burwell Bay Station A, 1.7 m below surface, scale in m/sec
Burwell Bay Station B, 1.8 m below surface, scale in m/sec
Burwell Bay Station B, 2.9 m below surface, scale in m/sec
Burwell Bay Station B, 4.9 m below surface, scale in m/sec
M/SEC  STATION B  4.9 M  6/23/87  1025-7/27/87  1355

(continued)
Burwell Bay Station B, 6.9 m below surface, scale in m/sec
Burwell Bay Station C, 1.8 m below surface, scale in m/sec
(continued)
Burwell Bay Station C, 3.5 m below surface, scale in m/sec
Burwell Bay Station C, 5.4 m below surface, scale in m/sec
Burwell Bay Station D 1.5 m below surface, scale in m/sec
APPENDIX B

SCATTERPLOTS OF CURRENTS
JAMES RIVER BRIDGE, STATION B

JULY, 1985
Principal Axis: 127°  
Ebb Axis: 128°  
Flood Axis: 306°
Principal Axis: 120°  Ebb Axis: 121°  Flood Axis: 300°
Principal Axis: 105°  Ebb Axis: 106°  Flood Axis: 284°
Principal Axis: 101°  Ebb Axis: 107°  Flood Axis: 279°
APPENDIX C

LONGITUDINAL COMPONENTS OF CURRENTS

(E designates ebb direction)
Fort Eustis Station, 1.8 m below surface
Fort Eustis Station, 4.9 m below surface.
Fort Eustis Station, 6.7 m below surface
James River Bridge Station A, 0.7 m below surface
James River Bridge Station A. 1.9 m below surface
James River Bridge Station B, 1.2 m below surface
James River Bridge Station B. 3.1 m below surface
James River Bridge Station B, 6.3 m below surface
James River Bridge Station B, 9.5 m below surface
James River Bridge Station C, 1.5 m below surface
James River Bridge Station C, 4.3 m below surface
James River Bridge Station C, 5.6 m below surface
James River Bridge Station C, 6.6 m below surface
James River Bridge Station D, 1.2 m below surface
James River Bridge Station D, 2.4 m below surface
James River Bridge Station E, 0.2 m below surface
Burwell Bay Station A, 1.5 m below surface
Burwell Bay Station B, 3.0 m below surface
Burwell Bay Station B, 5.5 m below surface
Burwell Bay Station C. 1.8 m below surface
Burwell Bay Station E, 1.5 m below surface
Burwell Bay Station E, 3.4 m below surface
Burwell Bay Station F, 1.5 m below surface
Burwell Bay Station A, 1.7 m below surface
Burwell Bay Station B, 1.8 m below surface
Burwell Bay Station B, 2.9 m below surface
Burwell Bay Station B, 4.9 m below surface
Burwell Bay Station B, 6.9 m below surface
Burwell Bay Station C, 1.8 m below surface
M/SEC

E

0.00

-1.00

24 JUNE 26 28 30 1 JULY 3

4 6 8 10 12

14 16 18 20 22

24 26 28

Burwell Bay Station C, 3.5 m below surface
Burwell Bay Station C, 5.4 m below surface
Burwell Bay Station D, 1.5 m below surface
APPENDIX D

TRANSVERSE COMPONENTS OF CURRENTS
James River Bridge Station B, 1.2 m below surface
James River Bridge Station B, 3.1 m below surface
James River Bridge Station B, 6.3 m below surface
James River Bridge Station B, 8.5 m below surface
APPENDIX E

LOW PASS FILTERED LONGITUDINAL COMPONENTS OF CURRENTS

(Positive is in ebb direction)
The longitudinal component of the non-tidal current at 2.4 m depth, starting 0900 hr., Oct. 21, 1984.
The longitudinal component of the non-tidal current at 4.9m depth, starting 2300 hr., Oct. 26, 1984.
The longitudinal component of the non-tidal current at 9.1 m depth, starting 0900 hr., Oct. 21, 1984.
Fort Eustis Station, 1.8 m below surface
Fort Eustis Station, 4.9 m below surface
Fort Eustis Station, 6.7 m below surface
Fort Eustis Station, 7.9 m below surface
James River Bridge Station A, 0.7 m below surface
James River Bridge Station A, 1.9 m below surface
James River Bridge Station B, 1.2 m below surface
James River Bridge Station B, 3.1 m below surface
James River Bridge Station B, 6.3 m below surface
James River Bridge Station B, 8.5 m below surface
James River Bridge Station C, 1.5 m below surface
James River Bridge Station C, 4.3 m below surface
James River Bridge Station C, 5.6 m below surface
James River Bridge Station C, 6.6 m below surface
James River Bridge Station D, 1.2 m below surface
James River Bridge Station D, 2.4 m below surface
James River Bridge Station E, 0.2 m below surface
Burwell Bay Station A, 1.5 m below surface
Burwell Bay Station B, 3.0 m below surface
Burwell Bay Station B, 5.5 m below surface
Burwell Bay Station C, 1.8 m below surface
Burwell Bay Station C, 7.6 m below surface
Burwell Bay Station E, 1.5 m below surface
Burwell Bay Station E, 3.4 m below surface
Burwell Bay Station F, 1.5 m below surface
Burwell Bay Station A, 1.7 m below surface
Burwell Bay Station B, 2.9 m below surface
Burwell Bay Station B, 4.9 m below surface
Burwell Bay Station C, 1.8 m below surface
Burwell Bay Station C, 3.5 m below surface
Burwell Bay Station C, 5.4 m below surface
Burwell Bay Station D, 1.5 m below surface
APPENDIX F

LOW PASS FILTERED TRANSVERSE COMPONENTS OF CURRENTS
James River Bridge Station B, 1.2 m below surface
James River Bridge Station B, 3.1 m below surface
James River Bridge Station B, 6.3 m below surface
James River Bridge Station B, 8.5 m below surface
APPENDIX G

LONGITUDINAL COMPONENTS OF CURRENTS
AT STATION B
(JAMES RIVER BRIDGE TRANSECT)
JUNE THROUGH NOVEMBER 1985
M/SEC

1.00

0.00

-1.00

1JUNE 16 1JULY 13

16JULY 31 3AUG 15 27

2SEPT 14 29 20CT 11

14OCT 29 1NOV 13 25

Current at 1.2 m below surface
Current at 3.1 m below surface
Current at 6.3 m below surface
Current at 8.5 m below surface
Sub-tidal current at 1.2 m below surface
Sub-tidal current at 3.1 m below surface
Sub-tidal current at 6.3 m below surface
Sub-tidal current at 8.5 m below surface
Sub-tidal currents at various depths
APPENDIX H

OBSERVED AND LOW PASS FILTERED

SURFACE ELEVATIONS
Tidal record and residual at Fort Eustis referred to NGVD. (starting 1800 hr, Oct. 19, 1984)
Tidal record and residual at Sewell's Point referred to NGVD. (starting 0000 hr, Oct. 1, 1984)
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 05/09/85 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 06/08/85 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/08/85 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 08/07/85 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 09/06/85 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 10/11/85 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 11/21/85 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 12/21/85 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 10/09/85 0000 EST

NN POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 11/09/85 0000 EST
NN POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 11/21/85 0000 EST

NN POINT

0  5  10  15  20  25  30
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 12/21/85 0000 EST

NN POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 05/23/85 0000 EST

JR BR. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/06/85 0000 EST

JR BR. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 08/05/85 0000 EST
JR BR. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 09/04/85 0000 EST

JR BR. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 10/04/85 0000 EST

JR BR. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 11/03/85 0000 EST
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 11/21/85 0000 EST

RELATIVE TO ZDO

J.H. ER. - N
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 06/12/85 0000 EST
JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/12/85 0000 EST

JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 08/29/85 0000 EST

JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 09/28/85 0000 EST

JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 11/06/85 0000 EST

JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 12/06/85 0000 EST

JR BR. - S
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 05/03/85 0000 EST
FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 05/29/85 0000 EST
FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 06/28/85 0000 EST

FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/28/85 0000 EST

FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 08/27/85 0000 EST
FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 09/05/85 0000 EST

FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 12/05/85 0000 EST

PIG POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 12/19/85 0000 EST

PIG POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 05/08/85 0000 EST

KINGSLAND
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 06/07/85 0000 EST

KINGSLAND
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/04/85 0000 EST

KINGSLAND
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 08/18/85 0000 EST

KINGSLAND
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 01/01/85 0000 EST

SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 01/31/85 0000 EST

SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 03/02/85 0000 EST

SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 04/01/85 0000 EST
SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 05/31/85 0000 EST
SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 06/30/85 0000 EST

SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/30/85 0000 EST

SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 09/28/85 0000 EST
SEWELL'S PT.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 10/28/85 0000 EST

SEWELL'S PT.
Surface elevation (m) vs. elapsed time (days)

Start 11/27/85 0000 EST

Sewell's Pt.
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 01/20/86 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 02/19/86 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 03/21/86 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 04/20/86 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 05/20/86 0000 EST

FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)
START 06/19/86 0000 EST
FT. MONROE
SURFACE ELEV. (m) VS. ELAPSED TIME (DAYS)
START 07/19/86 0000 EST
FT. MONROE
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 06/20/86 0000 EST

FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 07/20/86 0000 EST

FT. EUSTIS
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 01/22/86 0000 EST

PIG POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 04/23/86 0000 EST

PIG POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 05/24/86 0000 EST

PIG POINT
SURFACE ELEV. (M) VS. ELAPSED TIME (DAYS)

START 06/21/86 0000 EST

PIG POINT
APPENDIX I

OBSERVED SALINITIES
James River Bridge Station A, 0.7 m below surface
James River Bridge Station A, 1.9 m below surface
James River Bridge Station E, 0.2 m below surface
Burwell Bay Station C. 7.6 m below surface
Burwell Bay Station C, 1.5 m below surface
Burwell Bay Station C, 1.8 m below surface
Burwell Bay Station E, 1.5 m below surface
Burwell Bay Station F, 1.5 m below surface
Burwell Bay Station B, 1.8 m below surface
Burwell Bay Station B, 4.9 m below surface
Burwell Bay Station C, 1.8 m below surface
APPENDIX J

LOW PASS FILTERED SALINITIES
James River Bridge Station A, 0.7 m below surface
James River Bridge Station A, 1.9 m below surface
PPT

James River Bridge Station E, 0.2 m below surface
Burwell Bay Station A, 1.5 m below surface
Burwell Bay Station C, 1.8 m below surface
Burwell Bay Station C, 7.6 m below surface
Burwell Bay Station E, 1.5 m below surface
Burwell Bay Station F, 1.5 m below surface
Burwell Bay Station B, 1.8 m below surface
Burwell Bay Station B, 4.9 m below surface
Burwell Bay Station C, 1.8 m below surface
APPENDIX K

SALINITIES AT STATION B
(JAMES RIVER BRIDGE TRANSECT)
JUNE THROUGH NOVEMBER 1985
Salinity at 1.2 m below surface
Salinity at 3.1 m below surface
Salinity at 6.3 m below surface
Low pass filtered salinity at 1.2 m below surface
Low pass filtered salinity at 3.1 m below surface
Low pass filtered salinity at 6.3 m below surface
Low pass filtered salinity at various depths
APPENDIX L

GROSS SCALE SALINITY DISTRIBUTION
JAMES RIVER
SALINITY
12 JULY 1984
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH (Kilometers)

DEPTH (m)
JAMES RIVER
SALINITY
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH (Kilometers)

DEPTH (m)
JAMES RIVER
SALINITY
19 JUNE 1985
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH
(Kilometers)

DEPTH
(m)

0
100
150
JAMES RIVER
SALINITY
09 JULY 1985
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH (Kilometers)

DEPTH (m)
JAMES RIVER
SALINITY
14 MAY 1986
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH (Kilometers)

DEPTH (m)

0 10 20 30 40 50 60 70

26 24 22 20 18 16 14 12

2.2 2.5 2.8 3.1 3.4 3.7 4.0

0 5 10 15 20 25 30 35
JAMES RIVER
SALINITY
27 JUNE 1986
SLACK BEFORE FLOOD

DISTANCE UPSTREAM FROM MOUTH
(Kilometers)

DEPTH
(m)

-26 -24 -22 -20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0

0 10 20 30 40 50 60 70 80 90 100
JAMES RIVER

SALINITY SLACK BEFORE FLOOD

23 OCTOBER 1986

DISTANCE UPSTREAM FROM MOUTH (Kilometers)

DEPTH (m)