# ABSTRACT

Title of Document: CIRCULATION AND TRANSPORT PROCESSES FOR THE POCOMOKE RIVER: A TRIBUTARY TO A PARTIALLY MIXED ESTUARY

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One and two-dimensional box models were used to estimate steady state single and two-layer gravitational circulation, transport, and residence times for the Pocomoke River, a tributary estuary on the eastern shore of Chesapeake Bay. Vertical salinity distribution in the narrow deep river varied from well mixed to stratified, both spatially and temporally. Comparison of estimated freshwater inputs to ADCP transport calculations indicates that the surrounding wetlands have the capacity to store and release a substantial amount of water to the river. The models are particularly useful in defining steady-state concentration distributions of dissolved conservative substances entering the river at a given flux. Spring and late summer residence times varied with river flow, as expected, from 52 to 102 days. The exception was 395 days during the summer drought of 1999.

# CIRCULATION AND TRANSPORT PROCESSES FOR THE POCOMOKE RIVER: A TRIBUTARY TO A PARTIALLY MIXED ESTUARY

By

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# Dedication

To my family, Sally, Scott and Matt.

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# Acknowledgements

I wish to express my gratitude to my advisor Dr. William Boicourt for his support, time, patience, and encouragement during this project. I am also grateful to my advisory committee members Dr. Ming Li, and Dr. Lawrence P. Sanford for their insightful comments. This work could not have been completed without help from many people including Carole Derry, Vince Kelly, Steve Suttles, and Tom Wazniak from Horn Point Laboratory, who helped me with numerous questions about the Pocomoke River and its treasure trove of data, data analysis support, and guidance in the use of various analysis support tools. Finally, I wish to express my sincere thanks to my son, Matthew for his editorial comments and suggestions. His support was greatly appreciated.

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## *1.1 Introduction*

The Pocomoke River, a tributary on Chesapeake Bay's eastern shore (Figure 1), is an estuary typical of coastal plain rivers in the region that have moderate tidal fluctuations, are surrounded by agricultural and forested watershed landscape, and have an entrance sill or shallow sound at their mouth (Boicourt et al. 2003). Nutrient levels from agriculture waste, septic systems, and wastewater treatment plants have become major concerns. High nutrient levels were suspected to be the cause of the 1996 and 1997 *Pfiesteria*-like dinoflagellate outbreaks linked to health problems for both fish and humans in the region (State of Maryland Department of Natural Resources, 1998; Blazer et al. 1998). As a result, more stringent controls for animal waste, organic compounds, and trace elements are being considered. These issues make a compelling need to understand the circulation and transfer processes and provide a tool for environmental managers in their decision-making. The study of circulation dynamics and nutrient transport for this type of tributary estuary, however, is limited. The objective of this research project is to account for salt storage, residence time, and circulation of the Pocomoke River and to explain how river geometry, salinity, river flow and other forcing factors affect the mixing process. The river was selected as a representative estuary because of its rich data resources resulting from the past Pfiesteria outbreak studies. The scale of the tributary, its salt distribution, and geometry are suitable for the one and two-dimensional box model approaches of Pritchard (1969), Officer (1980) and Hagy et al. (2000) to estimate advective and nonadvective (diffusion and dispersion) transport. The

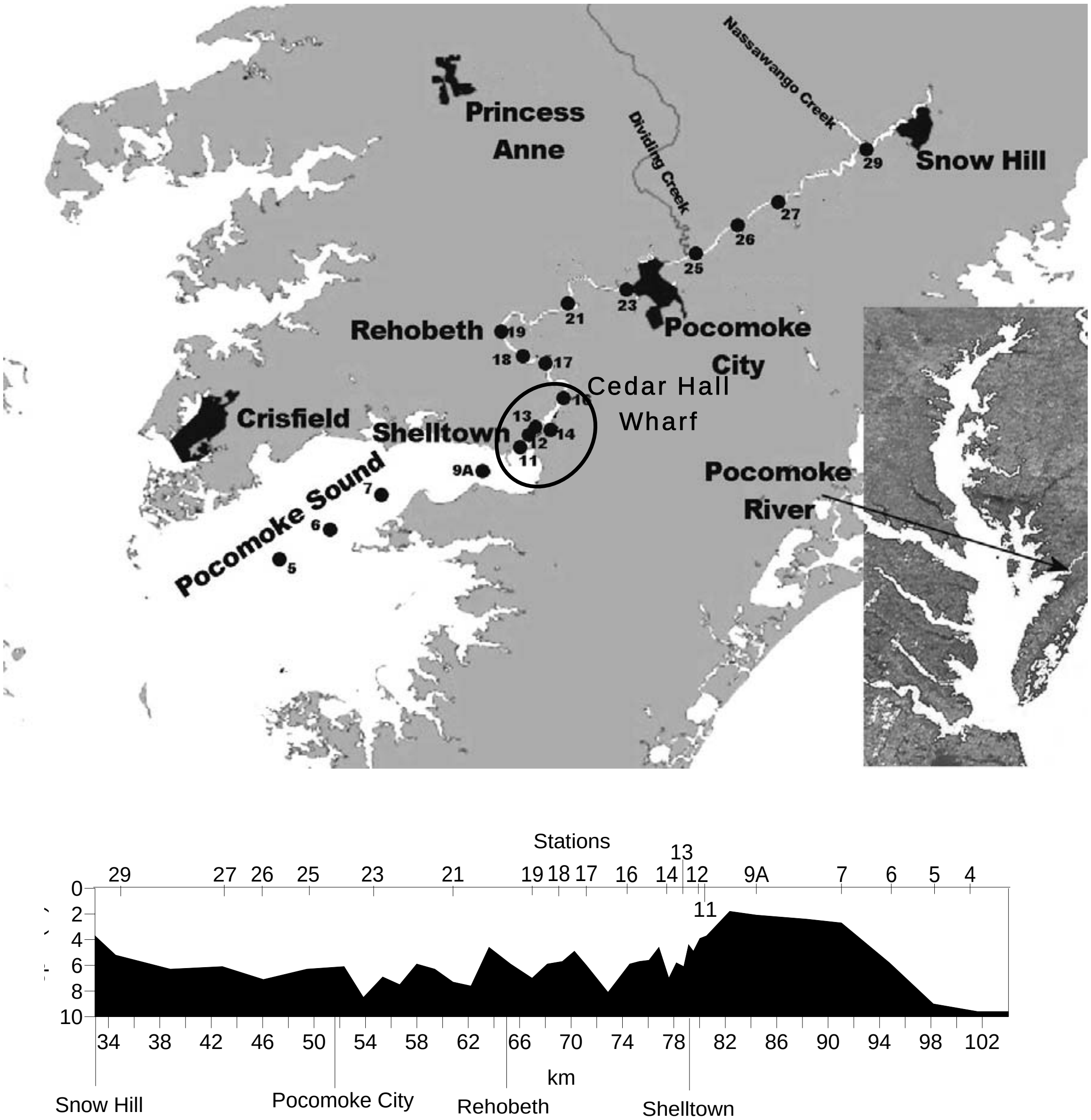


Figure 1: Map and axial view of the Pocomoke River and Sound showing its location within the Chesapeake Bay System and the location of stations where salinity values used for this study were obtained. Salinity data were also obtained from the Maryland Department of Natural Resources' continuous monitoring stations located at Shelltown, Cedar Hall Wharf, and Rehobeth, near stations 13, 16 and 19, respectively. The circled area is a portion of the river affected by the early August 1997 fish kill (Magnien, 2000).

models for this project were particularly useful in accounting for steady state spring and late summer changes, and defining concentration distributions of dissolved conservative substances entering the river at a given flux. Transport estimations calculated with Acoustic Doppler Current Profiler (ADCP) data were generally higher than the characteristic gravitational circulation exchange coefficients represented by the two-dimensional model. Review of the current data suggest that the ADCP measurements may have been influenced by ebb-dominated flow because of the sensor's seaward placement near a bend in the river and higher contributions of water from surrounding wetlands.

### *1.2 Motivation*

During summer and fall, 1997 harmful algal blooms were causing health problems for both fish and humans in the region, including a fish kill involving 10,000 to 15,000 menhaden in the Pocomoke River (Magnien, 2001). Maryland state and local health officials felt that the dinoflagellate *Pfiesteria piscicida* was the likely culprit, based on the presence of sufficiently high densities of *Pfiesteria*-like cells in the water. Magnien suggested the toxic *Pfiesteria* outbreak and fish kill were caused by high nutrient loading from agriculture that could not be consumed by phytoplankton because of lack of light in tea-colored water. This lack of consumption allowed the nutrients to pool and be transported down river to shallower depths more favorable for the growth of *Pfiesteria*. Part of his hypothesis was that low oxygen in the upper river blocked the menhaden from moving to a suitable habitat, thereby concentrating them in the affected portion of the lower river.

There is a variety of hydrodynamic models assessing circulation and net transport. Examples are fully three-dimensional models such as the Princeton Ocean Model (POM), a sigma-coordinate, free-surface, primitive-equation ocean model used for modeling estuaries, coastal regions, and open oceans ((http://www.aos.princeton.edu/ wwwpublic/htdocs.pom). Another advanced model is the Regional Ocean Model System (ROMS), which includes high-order advection schemes; accurate pressure gradient algorithms; several subgrid-scale parameterizations; atmospheric, oceanic, and benthic boundary layers; biological modules; and radiation boundary conditions (Li et al.).

Although quite powerful, the disadvantage of advanced models is the large amount of time and cost involved to develop, construct, calibrate, and validate the model. For this reason, there is a niche for simple models that can be developed quickly and use available data (Sheldon and Alber, 2002). Considering the Pocomoke River's small scale and limited amount of salinity data, the box model method was chosen to represent its steady state circulation transport processes. Box models have been shown to provide reliable and verifiable results for estimates of circulation, water residence times, salinity-inflow relationships, and temporal and spatial scales of pollutant flushing (Officer, 1980). The river is narrow and deep, has a vertical salinity distribution that varies between well mixed to stratified, and its flow characteristics are generally riverine in the upper reaches developing into the classic two-layer flow for the lower portions (Boicourt et al., 2003). Because of the difference in flow characteristics, both one and two-dimensional model configurations were used to represent circulation transport processes. Ketchum (1950) proposed the use of the salt balance in an estuary to describe the exchanges across various cross sections and the resulting fresh and saltwater distribution. He suggested dividing the estuary into segments where he assumed complete mixing at high tide. The lengths of the segments were defined by the average length of the tidal excursion, since this was the largest segment in which complete mixing by the tide could be assumed. Pritchard (1969) described a two-dimensional box model to define the mechanics of pollutant movement and its ultimate discharge to the open ocean. His concept included dividing the estuary into longitudinal segments or boxes, each further partitioned into vertical segments representing net non-tidal flow seaward and landward. Officer (1980) expanded Pritchard's work by developing both one and two-dimensional box model methodology for the transport of conservative and non-conservative quantities. Miller and McPherson (1991) presented a concept using a one-dimensional model to estimate tidal dispersion in Charlotte Harbor, Florida and then estimated residence times by simulation. Their concept was based on the assumption that tidal dispersion at any point in the estuary is independent of river flow. Using a simple mixing equation with observed and constant assumed ocean and river salinities, they derived an equation for tidally average flow of new seawater by a least squares method. The equation was then used to predict estuary salinity at different river inflows. Exchange flows were then used to calculate concentration of a conservative constituent. To ensure reliable estimates of either transit or residence times, the box lengths, i.e. box volumes, were sized so the ratio of inflow during a time step to volume ranged from 0.2 to 0.5. They found that ratios outside the above values might yield over or underestimates of transit times due to numerical stability. A very low ratio indicates that relatively little water is exchanged during a time step. For small boxes, numerical stability is the issue; for larger boxes, the main drawback is lack of spatial resolution (Sheldon and Alber, 2002). Hagy, et al.

(2000) developed a box model based on salinity distributions and freshwater inflow measurements to estimate net non-tidal physical circulation and hydraulic residence times. Because of a sill between the river and estuary that prevented two-layer flow, Hagy used a hybrid box configuration consisting of a single-layer box transitioning into two-dimensional boxes. Sheldon and Alber, (2002) described a box model application based on Miller and McPherson (1991) using smoothed equations to describe the cross sectional area versus distance along the longitudinal axis of the estuary. The purpose was to draw box boundaries along the estuary in order to maintain the freshwater inflow to box volume ratio recommended by Miller and McPherson. This concept allows box boundaries to be drawn at any point along the estuary.

The models used in this paper are both one and two-dimensional and use for the freshwater input the combination of both river flow at the head of the estuary and freshwater runoff from the surrounding shore. The objectives of this research project were to use the Pocomoke River as a representative estuary to examine circulation and salt balance and the role density and currents play. Specifically, the goals were:

- Describe the circulation and salt balance of the Pocomoke River.
- Quantify effects that various forcing variables have on circulation, stratification, and vertical mixing.
- Develop a circulation model that is useable for other similar tributary estuaries.
- Investigate whether the model would be applicable for nutrient transport.

### *1.3 Pocomoke River Setting*

The Pocomoke River drainage basin, including Pocomoke Sound and tributaries, covers 2139 km2 (Seitz 1971). The river originates in the Great Cypress Swamp along the Delaware-Maryland border, and meanders seaward approximately 117 km draining portions of Sussex County, Delaware; Wicomico, Worchester, and Somerset Counties, Maryland; and Accomack County, Virginia (Lenert, et al., 1999). Land use includes 43% for forests, 25% for agricultural and poultry operations, 21% for open water (including Pocomoke Sound), 8% for wetland and 2% for urban. Wetlands are most extensive in the tidal areas, but are found in the non-tidal areas of the upper basin as well.

The southern side of Pocomoke Sound has a narrow steep-sided entrance channel approximately 30 m deep that shallows out to about 10 m. The cross sectional water depth at station 9, one of the sampling stations located in Pocomoke Sound (Figures 1 and 2) ranges around 1.5 to 2 m. A narrow navigation channel 30 m wide, 1000 m long, and 3 m deep accommodates commercial traffic across the sill on the northern side. Unlike the Choptank and Patuxent Rivers, whose cross sectional areas expand rapidly (Cronin and Pritchard, 1976), the geometry of the Pocomoke River is similar to a pipe with a relatively constant cross sectional area from just below Snow Hill to about 2 km above Shelltown, a distance of about 43 km (Figure 3). From that point, the river opens rapidly into the broad, shallow Pocomoke Sound. Cross sectional views at the mouth of the river (station 11) and station 23, approximately 25 km upriver, are presented in Figure 2.

There has been limited amount of prior work regarding circulation in similar tributary estuaries that have an entrance sill or shallow sound near their mouth. Using drogue trajectories and dye, Carter (1967) suggested that wind, river discharge, and gravitational flow induced three distinctive circulation patterns for the Manokin River (Figure 4). In the deeper outer portion of the estuary, prevailing winds from the southwesterly quadrant produced inflow at the surface and outflow at the bottom. In the river portion freshwater and gravitational effects dictated that the flow be two-layer with no net salt transport. The circulation around the sill area was dependent on the wind and river flow. Sanford and Boicourt (1990) showed that pulsed wind-forced intrusions of salt apparently enhanced gravitational circulation in the Choptank River, another coastal plain river with a primary and secondary entrance sill. Boicourt, et al. (2003) reported that the Choptank River is similar to the Pocomoke River, where the two-layer estuarine region is confined by high river flow and topography between the limit of salt penetration and the point of rapid expansion of cross-sectional area. In both estuaries, the two-layer flow region is not only spatially limited, but also temporally variable. Both the Choptank and Pocomoke estuaries have a one-layer flow in the tidal freshwater reaches, a two-layer flow in the middle portion and a highly periodic pulsed exchange with the main stem estuary at the seaward end.

## *1.4 Observation Programs*

The Pocomoke River has rich data resources resulting from the past *Pfiesteria* outbreak studies. During 1999 through 2001 as part of the ECOHAB grant, an array of fixed sampling stations (Figure 1) was established along the Pocomoke River and Sound. Variables were measured periodically (Table 1) and included temperature, salinity, oxygen, turbidity, PAR, and chlorophyll. In addition, current, tides and wind were

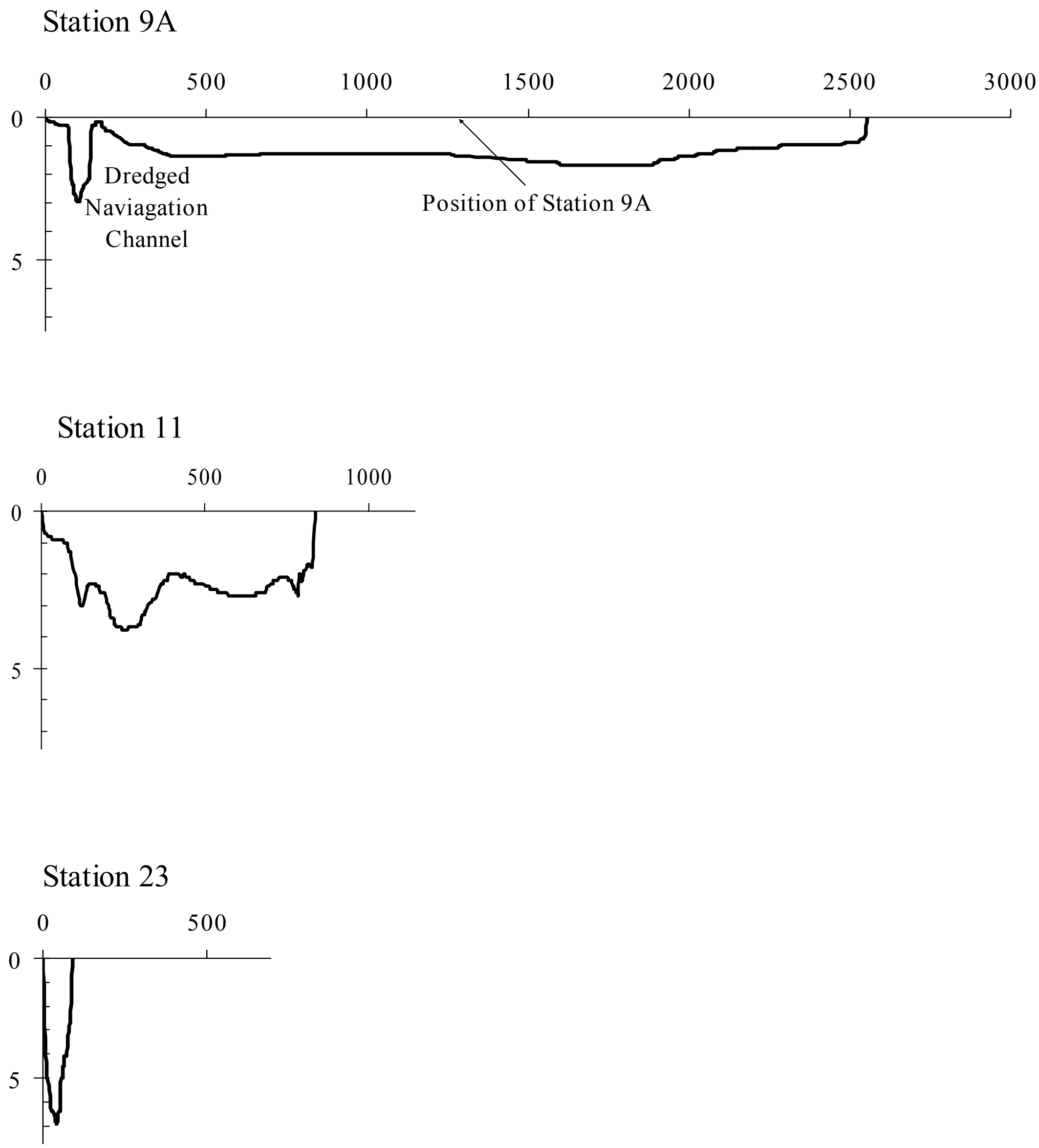


Figure 2: Cross-sectional views for station 9A in Pocomoke Sound, station 11 at the mouth of the river, and station 23 located approximately 25 km upriver from the mouth. The views are upriver.

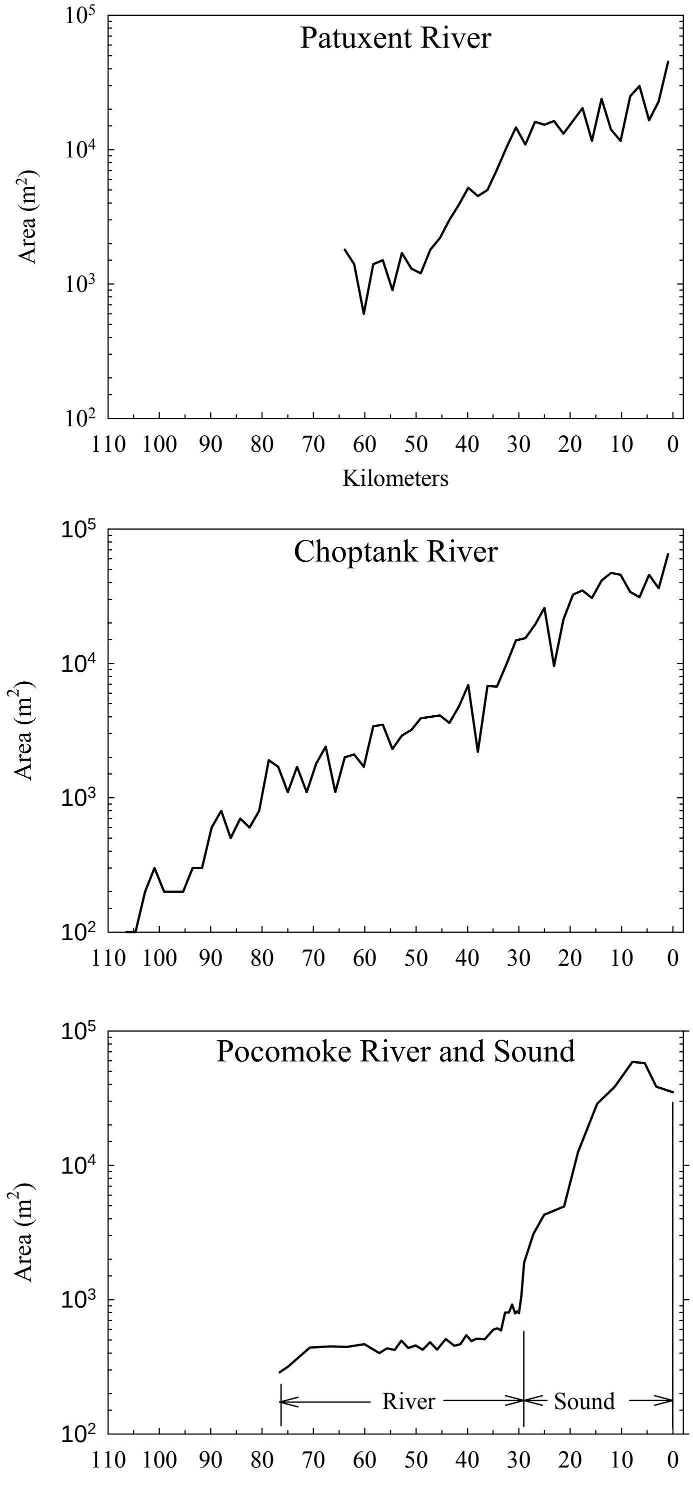


Figure 3: Comparison of cross sectional areas for Patuxent, Choptank, and Pocomoke. For this figure, distances are referenced from the seaward ends of the Patuxent and Choptank Rivers and Pocomoke Sound.

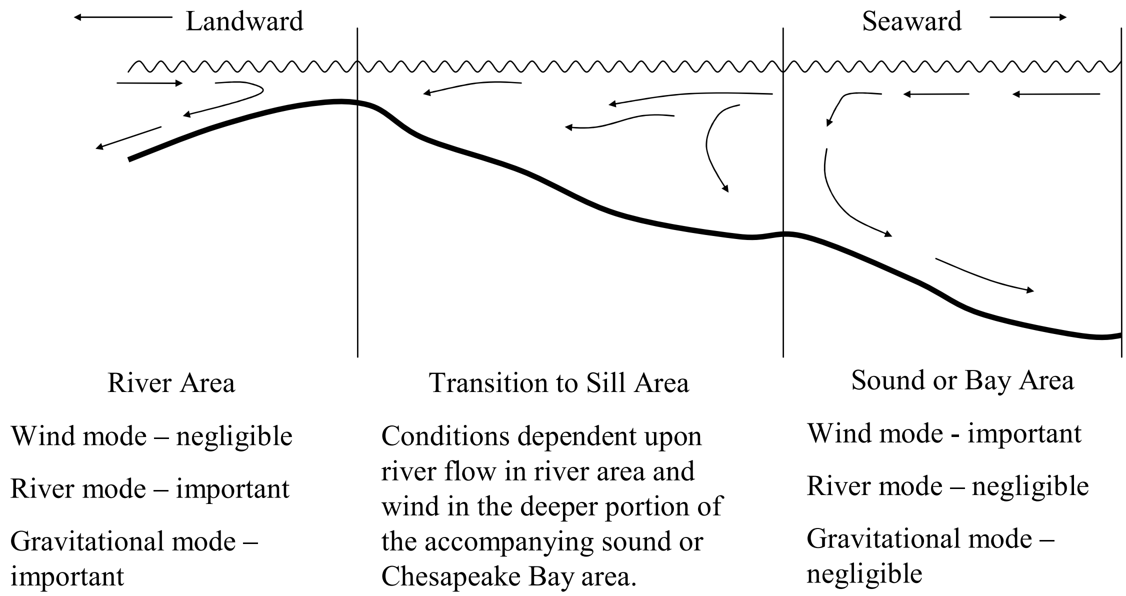


Figure 4: Circulation in Manokin River that prevailing winds from the southwesterly quadrant would have produced (Carter 1967).

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Table 1: Selected stations along the Pocomoke River with salinity data and date collected. Station distances are referenced from the U. S. Geological Survey stream flow gauge 1485000 on the Pocomoke River, near Willards, Maryland.

| | Station | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **29** | **27** | **26** | **25** | **23** | **21** | **19** | **18** | **17** | **16** | **14** | **13** | **12** | **11** | **9A** | **7** | **6** | **5** | **4** | **3** | **2** | **1** |
| | **Distance from Streamflow Gauge 01485000 (km)** | | | | | | | | | | | | | | | | | | **Seaward →** | | | |
| | **34.6** | **42.9** | **46.0** | **49.4** | **55.3** | **60.8** | **67.0** | **69.3** | **71.2** | **74.6** | **77.6** | **78.8** | **79.5** | **80.5** | **84.4** | **91.0** | **94.8** | **98.2** | **101.6** | **104.0** | **106.3** | **109.5** |
| **1999** | | | | | | | | | | | | | | | | | | | | | | |
| **13 May** | X | X | | X | X | | | X | X | | X | X | | X | X | | | X | | | | |
| **18 May** | | | | | | X | | X | X | X | X | X | X | | X | X | | X | | | | |
| **26 May** | | | | | X | X | X | | X | | X | X | | X | X | X | X | X | X | X | X | X |
| **10 Aug** | X | X | | X | X | X | | X | X | X | X | X | X | | X | X | | X | | | | |
| **18 Aug** | | | | | X | X | | X | | X | X | | X | | X | X | | X | | X | | X |
| **7 Sep** | | | | | | | | | | X | | X | X | | X | X | X | | | | | |
| **2000** | | | | | | | | | | | | | | | | | | | | | | |
| **8 May** | X | X | | X | X | X | | X | X | X | X | X | X | | X | X | | X | | | | |
| **22 May** | | | | | X | X | | X | | X | X | X | X | | X | X | | | | | | |
| **9 Aug** | | | | | X | X | | X | | X | X | | X | | X | X | | X | | X | | X |
| **16-Aug** | | | | | | | | | | | | | | | | | | | | | | |
| **21 Aug** | X | X | | X | X | X | | X | | X | X | | X | | X | X | | | | | | |
| **6 Sep** | | | | | X | X | | X | | X | X | | | X | X | X | | X | | | | |
| **2001** | | | | | | | | | | | | | | | | | | | | | | |
| **16 May** | | | X | | X | X | X | | | X | | X | | X | X | X | | | | | | |
| **30 May** | | | | | X | X | X | | | X | | X | | X | X | X | | | | | | |
| **16 Aug** | X | | X | | X | | X | | | | | X | | X | X | X | | | | | | |
| **29 Aug** | | | | | X | | X | | | X | | X | | X | X | X | | | | | | |
| **14 Sep** | | X | | X | X | | X | | | X | | X | | X | X | X | | | | | | |
| **26 Sep** | | X | | X | X | | X | | | X | | X | | X | X | X | | | | | | |

measured for a portion of the time. Supplementary salinity data were obtained from the Maryland Department of Natural Resources (MDNR) continuous monitoring program, which operated three observation sites along the Pocomoke River (Figure 1) from 1998 to 2003 to discern the links between water quality, harmful algal blooms, and fish kills.

# Chapter 2: Methods

## *2.1 Observations*

Profiles of temperature, salinity, oxygen, turbidity, PAR, and chlorophyll were conducted using a SeaBird SBE 25 CTD sonde lowered from an electric winch on various Horn Point Laboratory small workboats. The variables were sampled from surface to bottom at 0.25-sec intervals, which were later converted to 0.25 m depth intervals. Supplementary salinity data provided by the Maryland Department of Natural Resources (MDNR) were measured with an EMPACT YSI 6600 that recorded water temperature, salinity and dissolved oxygen every 15 minutes at Shelltown, Cedar Hall Wharf, and Rehobeth near stations 13, 16 and 19, respectively. The Shelltown and Rehobeth instrumentation were placed one meter below the surface. The depth of the Cedar Hall instrumentation was one meter and the bottom. Bottom mounted 1200-kHz ADCPs located at Shelltown (station 13), Rehobeth (station 19), and Pocomoke Sound (station 6) provided current data, which were compared against advective flow outputs from the models. The ADCP model, Workhorse Sentinel manufactured by RD Instruments, was self-contained with power supply and data recording and storage capability. Tide records, sampled every two minutes, were obtained with a SeaBird SBE 26 Seagauge wave and tide recorder mounted on a piling approximately one meter below the surface at Snow Hill.

## *2.2 Models*

The box models chosen for this study are similar to those described by Officer (1980) and Hagy et al. (2000), using observed salinity, freshwater values, and the salt balance equation to determine the hydrodynamic advective and nonadvective exchange coefficients. The configuration of the models is based on dividing the river into a series of boxes (Figures 5 and 6) that represent flow or flux conditions. When modeling advective and nonadvective exchange coefficients, steady state concentrations, and individual box residence times, box boundaries may be placed arbitrarily (Officer, 1980). Ketchum (1950) on the other hand, proposed dividing the estuary into segments defined by the average length of the tidal excursion, because this was the largest segment in which complete mixing by the tide could be assumed. For the models used in this study, the vertical divisions between horizontally adjacent boxes were locations with available cross sectional width and depth data, thus reducing the amount of bathymetry interpolation required. The models' equations were solved using a spreadsheet program on a desktop computer.

### 2.2.1 One-Dimensional Box Model

The Pocomoke River is similar to the description of a well-mixed estuary where the tidal forces predominate over the freshwater inflow to such extent that the fresh and saltwater are fairly well mixed throughout the vertical (Pritchard, 1965). In narrow, well-mixed estuaries, the major spatial variability occurs along the estuarine axis because of

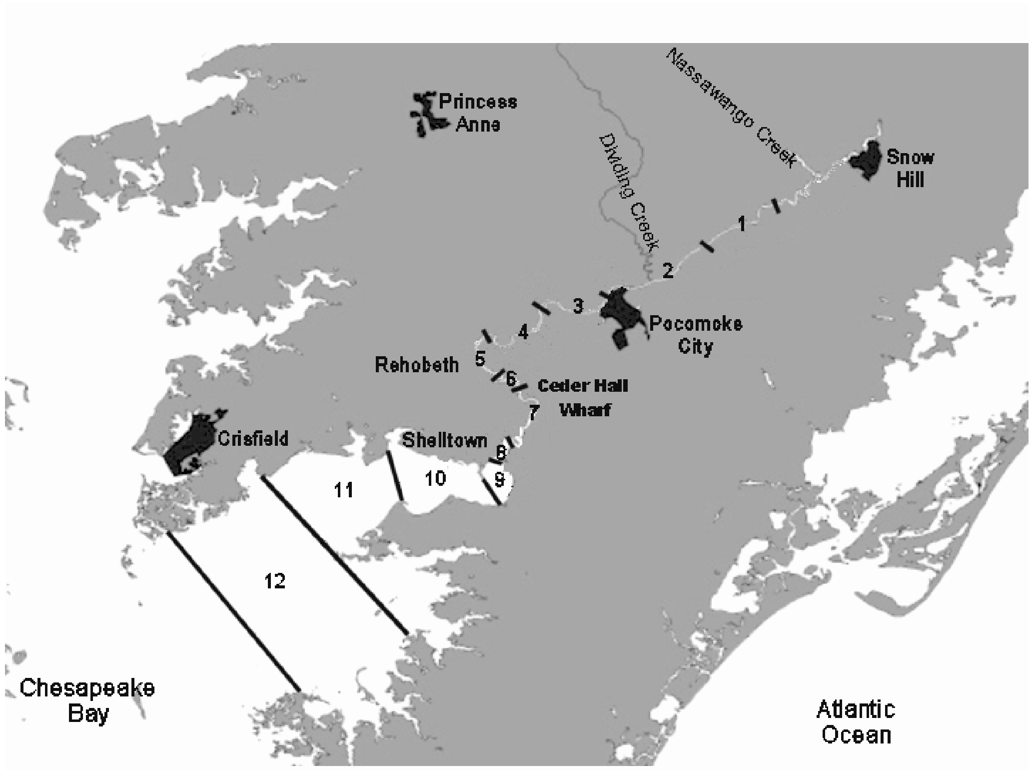



Figure 5: Positions of the vertical boundaries between boxes along the Pocomoke River and Sound.

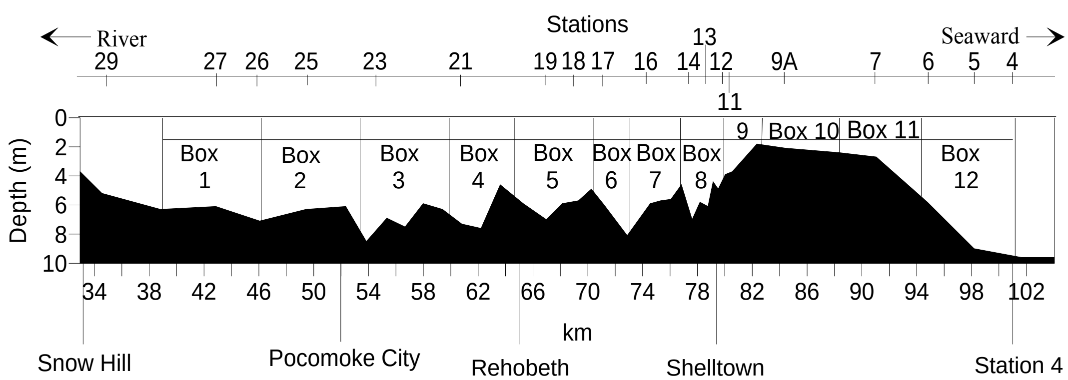
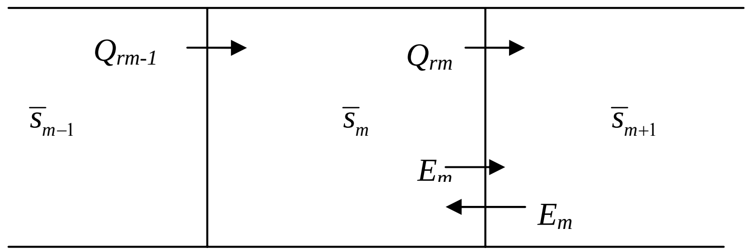
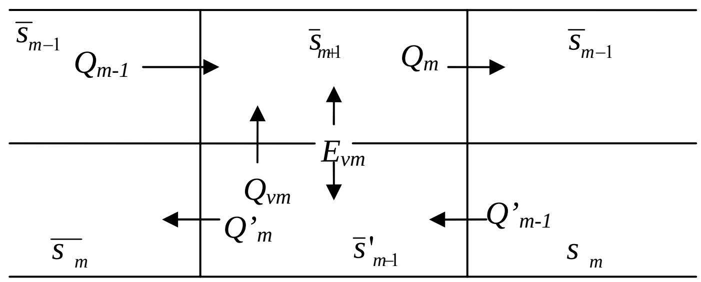


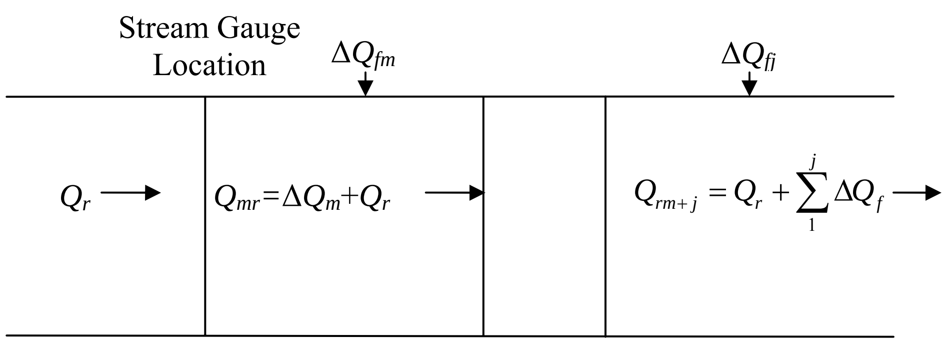

Figure 6: Schematic diagram of the two-dimensional box model that illustrates box boundaries in relation to Pocomoke River bathymetry. The division between the upper and lower boxes represents the average halocline located at 1.5 m, which was determined from salinity distribution records. The names are towns along the Pocomoke River. Station 4 was the outer most station where data were used for this study. The one-dimensional model uses the same vertical boundaries from surface to bottom, but does not include the horizontal division representing the halocline.




One-Dimensional Model (For nonadvective exchange)




Two-Dimensional Model (For advective and nonadvective exchanges)




Freshwater Input (From river and surrounding watershed)

Figure 7: Typical configurations for one- and two-dimensional box models. The exchanges are seaward advective transport $Q_m$, landward advection $Q'_m$, vertical advection $Q_{vm}$, vertical nonadvective exchange $E_{vm}$, and horizontal nonadvective exchange $E_m$, *and* $E_m$. Inputs into the boxes include freshwater input from both river flow and surrounding watershed $Q_{rm}$ and area-weighted salt $\overline{s}$ for a one-dimensional box or $\overline{s}$ or $\overline{s}'$ for the upper or lower boxes of a two-dimensional model. The lower figure illustrates the freshwater input from the river and surrounding watershed $Q_f$.

the balance between advective and turbulent exchange and can be treated as a one-dimensional process (Uncles and Stephens, 1990). Even when conditions are partly mixed, one-dimensional models can provide useful results provided it is understood that their outputs are estimates of cross-sectional averaged quantities. A one-dimensional box model (Figure 7) simulates the estuary with the top boundary representing the water surface, the lower boundary the estuary bottom and the vertical boundary normal to advective flow.

Following Officer (1980) we will start with salt balance equation

$$Q_r \bar{s}_m + E_{m,m+1} \bar{s}_m = E_{m+1,m} \bar{s}_{m+1}, \tag{1}$$

where $Q_r$ is river flow, $\bar{s}_m$ is area weighted mean salinity in box *m*, $\bar{s}_{m+1}$ is area weighted mean salinity in the downstream adjacent box *m*+1, and $E_{m,m+1}$ and $E_{m+1,m}$ are nonadvective exchange coefficients. These coefficients include both the tidal exchange and net circulation effects, which for the Pocomoke River include gravitational flow, wind motion, and fluctuations from the natural oscillation of the Chesapeake Bay (Chuang and Boicourt, 1989). The advection seaward due to river flow entering box *m* is $Q_r \bar{s}_m$. Officer considers the nonadvective exchange coefficients $E_{m,m+1}$ and $E_{m+1,m}$ to be equal because the net turbulent exchange of water on both sides of the vertical box boundary has a net zero change. Consequently, the coefficients can be combined into a single term $E_m$ representing the nonadvective coefficients at the seaward end of box *m*. Hagy et al. (2000) further extended Officer's equation by permitting time-variable salinity and inputs of freshwater into each box. Equation 1 becomes

$$V_m \frac{d\bar{s}}{dt} = E_m(\bar{s}_{m+1} - \bar{s}_m) - Q_{rm} \quad (2)$$

where $V_m$ is volume of box $m$, $Q_{rm}$ is the total freshwater entering the middle of box $m$ from both river flow and the surrounding sides and $\frac{ds}{dt}$ is time-variable salinity. The derivation of $Q_{rm}$ for the model will be discussed later. The limited number of seasonal salinity observations on the Pocomoke River and the elapse time of observations between seasons would not permit calculation of a meaningful $\frac{d\bar{s}}{dt}$, so $V_m \frac{d\bar{s}}{dt}$ was considered zero. Consequently, the nonadvective exchange coefficient becomes

$$E_m = \frac{\bar{s}_m}{\bar{s}_{m+1} - \bar{s}_m} Q_{rm} \quad (3)$$

Box residence time is the average life of a particle in a given volume or box of the estuary. Using Officer's equation (11) for residence time, but substituting freshwater inputs from both river flow and the surrounding watershed $Q_{rm}$ gives

$$\tau_m = \frac{\bar{s}_m V_m}{Q_{rm-1}\bar{s}_{m-1} + E_{m-1,m}\bar{s}_{m-1} + E_{m+1,m}\bar{s}_{m+1}} \quad (4)$$

in which $V_m$ is the volume of box $m$ and $\bar{s}_{m-1}$ is area-weighted salinity in box m-1. The concentration distribution $c_m$ when there is a source of constant concentration at the ocean end of the estuary and none at the river end is

$$c_m = \frac{s_m - s_e}{s_o - s_e} c_o \quad (5)$$

with $c_o$ the constant concentration at the ocean end and $s_o$ and $s_e$ salinity at the ocean end and river end, respectively. Likewise, the distribution when the source of constant concentration is at the river end becomes

$$c_m = \frac{s_o - s_m}{s_o - s_e} c_e \,. \tag{6}$$

In the case where there is constant concentration in an intermediate segment with zero concentration the river and ocean ends, the expression becomes

$$c_{p-1} = \frac{s_{p-1} - s_e}{s_p - s_e} c_p \text{ and } c_{p+1} = \frac{s_o - s_{p+1}}{s_o - s_p} c_p \tag{7}$$

where the source box is *p*.

### 2.2.2 Two-Dimensional Box Model

Hansen and Rattray (1966) in their discussion of estuary classification introduce the fraction of horizontal salt balance ν, which is defined as a function of salinity stratification and convective circulation. When $\nu = 1$, gravitational convection ceases and the upstream salt flux is entirely by diffusion; as ν approaches 0, diffusion is unimportant and the upstream salt flux is almost entirely by gravitational flow. The Pocomoke estuary with its two-layer flow in the middle portion (Boicourt et al., 2003) falls under Hansen and Rattray's Type 2 stratification and circulation classification, initiated by Stommel and Farmer (1952). When Type 2 classification net circulation effects dominate, there is two-layer flow and both advection and diffusion contribute to the upstream salt flux, i.e. ν approaches 0. Two-dimensional box models (Figure 7) are suitable for simulating two-layer gravitational circulation of a stratified estuary with seaward net circulation flux in the upper boxes and landward in the lower boxes. Based on equation 3, Officer (1980) defined the two-layer longitudinal nonadvective tidal exchange coefficients in terms of ν as

$$E_{m-1} = \frac{1}{2}\frac{\nu \bar{s}_{m-1}}{s_m - s_{m-1}} Q_{rm} \text{ and } E'_{m-1} = \frac{1}{2}\frac{\nu \bar{s}'_{m-1}}{s'_m - s'_{m-1}} Q_{rm} \tag{8}$$

where $E_{m-1}$ and $E'_{m-1}$ are opposing nonadvective coefficients at the landward boundary of box *m*. When net circulation effects dominate and there is two-layer flow, i.e. ν approaches 0, both $E_{m-1}$ and $E'_{m-1}$ approach zero and thus are ignored. The seaward or upper layer advective quantity $Q_m$ representing the combined net circulation and river flow to the horizontally adjacent box downstream again following Officer (1980), is

$$Q_m = \frac{\bar{s}'_{m+1}}{\bar{s}'_{m+1} - \bar{s}_m} Q_{rm}\,. \tag{9}$$

Other quantities for two-dimensional box models are:

Landward or lower advective transport

$$Q'_m = \frac{\bar{s}_{m-1}}{\bar{s}'_m - \bar{s}_{m-1}} Q_{rm} \tag{10}$$

Vertical advection coefficient

$$Q_{vm} = Q_m - Q_{m-1} \tag{11}$$

Vertical nonadvective exchange

$$E_{vm} = \frac{\bar{s}_m(\bar{s}'_{m+1} - \bar{s}'_m)}{(\bar{s}'_m - \bar{s}_m)(\bar{s}'_{m+1} - \bar{s}_m)} Q_{rm} \tag{12}$$

Box residence times $\tau_m$ and $\tau'_m$ for upper and lower boxes

$$\tau_m = \frac{(\bar{s}'_m - \bar{s}_m)}{\bar{s}'_m}\frac{V_m}{Q_{rm}} \tag{13}$$

$$\tau'_m = \frac{(\bar{s}'_m - \bar{s}_m)}{\bar{s}_m}\frac{V'_m}{Q_r Z_m}\,. \tag{14}$$

A disadvantage with two-dimensional box models is that when salinity is well mixed and the vertical gradient approaches zero the vertical nonadvective exchange coefficient $E_{vm}$ (Equation 12) becomes indeterminate.

### 2.2.3 Residence Time

Residence time $(\tau_f)$ establishes a time scale for conservative physical transport of river-borne material, such as nutrients, organic matter, or suspended sediment. It is usually calculated according to the fraction of freshwater method outline by Dyer (1997):

$$f = \frac{s_o - \overline{s}}{s_o} \tag{15}$$

with $s_o$ the undiluted Chesapeake Bay salinity and $\overline{s}$ the weighted-average salinity for the river. Thus the flushing time is

$$\tau_r = \frac{fV}{\overline{Q}_{rm}} \tag{16}$$

where $V_m$ is total volume of the river estuary and $\overline{Q}_{rm}$ is average freshwater input.

## 2.3 *Data Requirements*

### 2.3.1 Geometry and Grids

Chesapeake Bay estuary geometry information can be obtained from NOAA NOS navigational charts or from Cronin (1971) or Cronin and Pritchard (1975). For the Pocomoke River, however, these resources did not provide sufficiently fine detail for the upper river to calculate cross sectional areas or volumes needed for box model geometry. As a result, Horn Point Laboratory personnel in 2004 conducted a transverse bathymetry survey at 35 locations from station 9A in the Pocomoke Sound area (designated ‘The Muds’ on the National Ocean Service Chart 12230) to station 30 near Snow Hill (Appendix). After adjusting the river widths and depths to mean tide level, cross-sectional widths in 0.5 m increments were calculated from surface to bottom. Upper and lower box volumes for the two-dimensional model were determined by

$$V_m = \frac{A_{m-1} + A_m}{2} L_m \text{ and } V'_m = \frac{A'_{m-1} + A'_m}{2} L_m \tag{17}$$

with $A_{m-1}$ and $A'_{m-1}$ the top and bottom areas for the landward end of box *m*, $A_m$ and $A'_m$ the areas for the seaward end of box m, and $L_m$ the length of the box. Areas were calculated by summing the appropriate number of 0.5 m incremented area widths for the upper and lower boxes. Volumes for boxes 10, 11, and 12 were calculated using cross sectional area data from Cronin (1971). The volumes for the one-dimensional model were calculated in the same manner, but $A_{m-1}$ and $A_m$ represented total cross sectional areas.

### 2.3.2 Freshwater Input

Daily mean discharge data were obtained from the USGS gauging stations 01485000 on the Pocomoke River and 01485500 on Nassawango Creek, a tributary near Snow Hill, Maryland. The river has no reservoirs and the total surface water use by the three Maryland counties and one Virginia county in the watershed is equivalent to 0.16 $m^3 s^{-1}$ (Hutson et al. 2004), a relatively small amount compared with the yearly average flow rate of 1.5 $m^3 s^{-1}$. The contribution of direct precipitation and evaporation of the water in the estuary was considered negligible since the surrounding watershed area for boxes 1 through 10 was greater than the estuary surface area by approximately a factor of 10. Total freshwater input to each segment included the river flow through the gauged portion plus the cumulative runoff from the lateral river boundaries. Since the gauged flow includes groundwater above the gauging stations these inputs were implicitly included in the runoff below the stations. Freshwater inputs for the model were determine by the cumulative percentage of river flow where

$$Q_{rm} = Q_r \frac{\sum_{0}^{L_m} a}{A_g} \tag{18}$$

with Seitz (1971) providing both the drainage area $a$ per unit length along the river and the drainage area $A_g$ above the gauging stations. $L_m$ is the distance from gauging station 01485000 to the center of the box $m$. At the center of box 8 near Shelltown, the cumulative lateral runoff to head flow is 353%

### 2.3.3 Salinity

Salinity data in 0.25 m depth intervals were averaged to 0.5 m intervals and converted to area-weighted mean values for the top, lower, and combined areas. Area-weighted averages were calculated to account for changes in cross sectional area with depth. Without such a correction, mean salinity would be over estimated, particularly when salinity increases with depth. For a one-dimensional model area-weighted mean salinity was calculated by

$$\overline{s} = \frac{\sum s_{0.5} A_{0.5}}{A_T} \tag{19}$$

where $s_{0.5}$ is salinity at each 0.5 depth interval, $A_{0.5}$ is the cross sectional area for each 0.5 depth interval, and $A_T$ is total cross sectional area. For the two-dimensional model, $\sum s_{0.5} A_{0.5}$ and $A_T$ were calculated separately for both the upper and lower layers.

Tidal excursion or total distance traveled by a water particle from slack water before flood to slack before ebb in the Pocomoke River ranges 3 to 8 km. Since the variables at each station were measured at various times during the tidal cycle, position corrections were required to render them in phase. The corrected position chosen was the point where the measured water column would be when the station experienced maximum flood or ebb current. This assumes that the measured water column is fixed and advected by a sinusoidal tidal current. The commercial tidal current prediction software, Tides and Currents Pro for Windows from Astronomical Algorithms Software, provided the predicted tidal current $U_0$ near station 12 just below Shelltown, along with time of day. Tidal excursion was estimated by integrating the trigonometry expression for current velocity variation from Dyer (1997) with respect to time:

$$x = U_0 \int_{t_m}^{t_O} \sin(2\pi\omega t)dt \tag{20}$$

where $t_m$ is time of maximum current at the station of interest, $t_o$ is time of observation, and $\omega$ is tidal angular frequency. Knowing the time of maximum ebb or flood currents near station 12, the time of maximum current at each station was estimated by

$$t_m = t_s + Cd \tag{21}$$

with $t_s$ the time of maximum flood or ebb current at Shelltown, $C$ the tidal wave celerity, and $d$ the distance of the station to Station 12 as calculated from Table 1. The value $C$ was estimated by dividing the tidal time difference of Shelltown and Snow Hill into the distance between the two locations.

With the observation sites adjusted for tidal excursions, weighted mean salinity values versus adjusted distance graphs similar to Figure 7 were then plotted. Using these

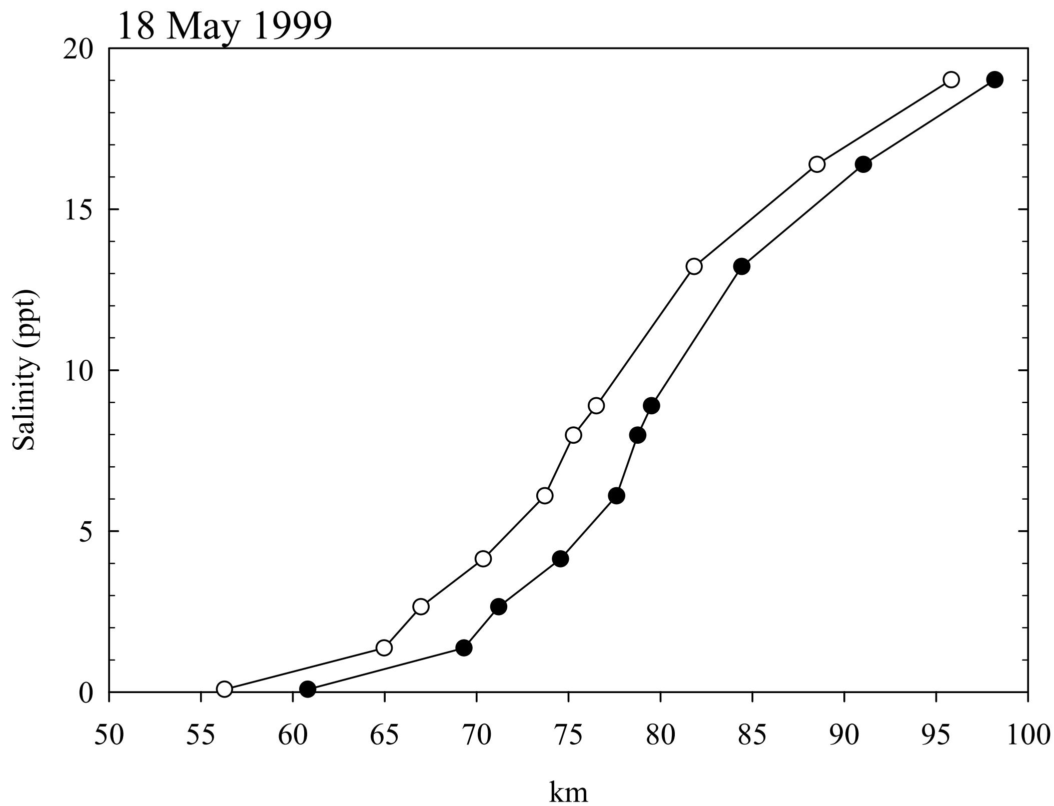



Figure 8: Comparison of area weighted salinity values measured on 18 May 1999 adjusted for tidal excursion -○- and not adjusted for tidal excursion -●- .

adjusted graphs, weighted salinity values at the center of each box in the model were determined by interpolation. In reality, the tidal wave is not purely sinusoidal and the ebb and flood currents differ due to the gravitational currents, wind stress, and the natural oscillation of the Chesapeake Bay. In spite of its crudeness, the correction procedure is deemed warranted because of the possible position error. Corrections typically ranged from 0.5 to 4.5 km.

### 2.3.4 Currents

Normally, a certain amount of data would be set aside to test the models results, but this was not practical with the limited quantity of data available. As an alternative, the advective coefficient results from the model were compared with area-weighted transport values using ADCP data. Using this approach assumes that river current is laterally homogenous and that there are no boundary layer effects. Seaward $Q_{ADCP}$ and landward $Q'_{ADCP}$ transport estimates were calculated by

$$Q_{ADCP} = \sum_{0}^{d_{Trans}} v_{0.5} A_{0.5} \quad \text{and} \; Q'_{ADCP} = \sum_{d_{Trans}}^{d_{Bottom}} v_{0.5} A_{0.5} \qquad (22)$$

where, $v_{0.5}$ is average ADCP current velocity at each 0.5 m depth interval, $A_{0.5}$ is the cross sectional area for each 0.5 m segment, and $d_{\mathrm{Trans}}$ and $d_{\mathrm{Bottom}}$ are the depths where the current changes direction from seaward to landward and the bottom, respectively. Net transport is $Q_{ADCP}$-$Q'_{ADCP}$. Area-weighted averages account for changes in cross sectional area with depth.

ADCP data processing divides the measurements into uniform segments called depth cells or bins. Due to interference caused by side-lobe reflection from the surface and transducer ringing, the depth cells for the top two meters and those within 1.3 m of the bottom were not considered. For those regions, current was assumed constant and the same as those at 2 m and 1.3 m above the bottom. It was felt this was more realistic than attempting to extrapolate values based on the current profiles. Since 0.5 m incremental cross sectional areas are the greatest at the surface, any overestimate in surface current would greatly exacerbate the transport values when using equation 22.

# Chapter 3: Results

The one and two-dimensional box model results presented in this Chapter are steady state simulations for circulation, transport, and residence times. The models for this project were particularly useful in accounting for steady state spring and late summer changes and defining concentration distributions of dissolved conservative substances entering the river at a given flux. Models for this project were particularly useful in accounting for steady state spring and late summer changes and defining concentration distributions of dissolved conservative substances entering the river at a given flux. A description of the model inputs, observed salinity, and freshwater, along with current and tidal results are included.

## *3.1 Freshwater Input*

The 1999 low daily freshwater flow through the Pocomoke River and Nassawango Creek stream gauges reflected the drought experienced by the region (Figure 9) beginning around May and lasting until 17 September when Hurricane Floyd passed through with many areas receiving over ten inches of rain (Eyesonthebay.net, 2005). In 2000, the total average daily flow was the highest of all three years; however, the two highest daily flows during HPL data sampling occurred on 30 May and 16 August 2001, at 3.8 $m^3s^{-1}$ and 9.9 $m^3s^{-1}$, respectively (Table 2). Review of daily precipitation events at Snow Hill in 2001 (Figure 10) against daily Nassawango Creek stream flow data shows that stream flow starts increasing with precipitation and reaches a

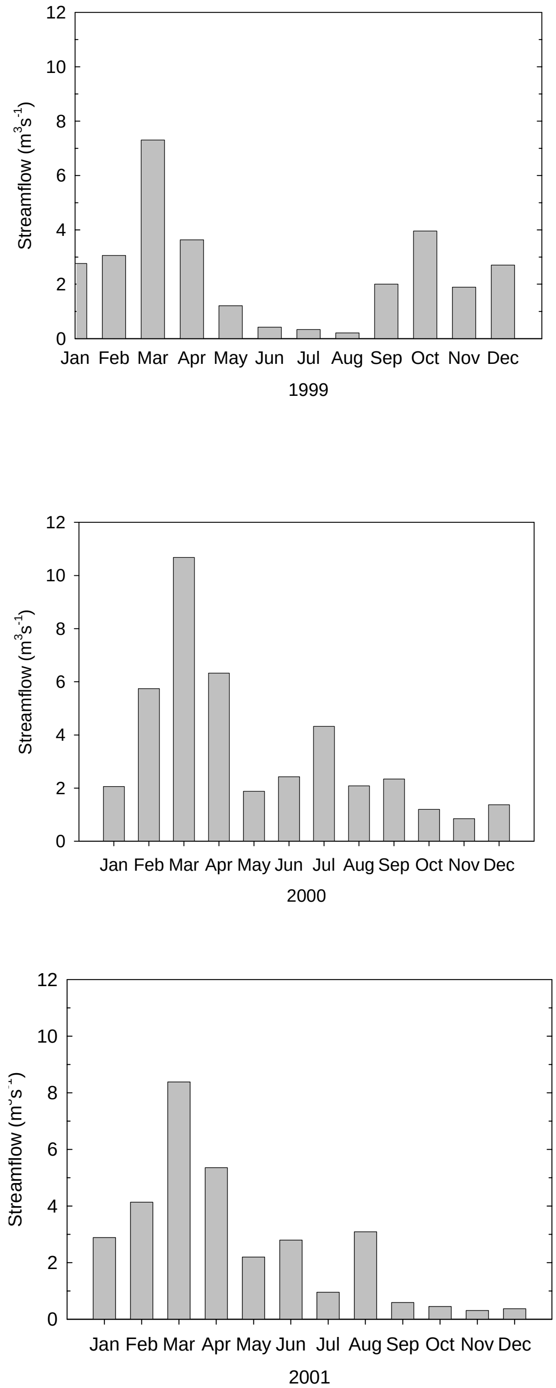



Figure 9: Total average monthly stream flow for 1999, 2000, and 2001 from the gauges near Willards, Maryland on the Pocomoke River and Nassawango Creek near Snow Hill, Maryland.

Table 2: One-day and seven-day average stream flow measured at Pocomoke River and Nassawango Creek gauges prior to salinity observation dates for 1999, 2000, and 2001.

| Stream flow ($m^3s^{-1}$) | | | | | |
|---|---|---|---|---|---|
| **1999** | **Flow** | **2000** | **Flow** | **2001** | **Flow** |
| One-Day Average | | | | | |
| 13 May | 1.1 | 8 May | 2.0 | 16 May | 0.8 |
| 18 May | 0.9 | 22 May | 1.6 | 30 May | 3.8 |
| 26 May | 0.9 | 9 Aug | 2.2 | 16 Aug | 9.9 |
| 10 Aug | 0.2 | 21 Aug | 1.2 | 29 Aug | 1.2 |
| 18 Aug | 0.2 | 6 Sep | 3.1 | 14 Sep | 0.5 |
| 7 Sep | 0.2 | | | 26 Sep | 0.6 |
| Seven-Day Average | | | | | |
| 13 May | 1.3 | 8 May | 2.8 | 16 May | 0.9 |
| 18 May | 1.0 | 22 May | 1.1 | 30 May | 4.6 |
| 26 May | 1.2 | 9 Aug | 3.4 | 16 Aug | 7.1 |
| 10 Aug | 0.2 | 21 Aug | 2.0 | 29 Aug | 1.7 |
| 18 Aug | 0.3 | 6 Sep | 1.9 | 14 Sep | 0.6 |
| 7 Sep | 0.2 | | | 26 Sep | 0.6 |

Table 3: Spring and late summer seasonal averages of Table 2 data

| | Seasonal Stream flow ($m^3s^{-1}$) | | |
|---|---|---|---|
| | **1999 Flow** | **2000 Flow** | **2001 Flow** |
| One-Day Average | | | |
| Spring | 0.9 | 1.8 | 2.3 |
| Late Summer | 0.2 | 2.2 | 3.0 |
| Seven-Day Average | | | |
| Spring | 1.2 | 2.0 | 2.8 |
| Late Summer | 0.2 | 2.4 | 2.5 |

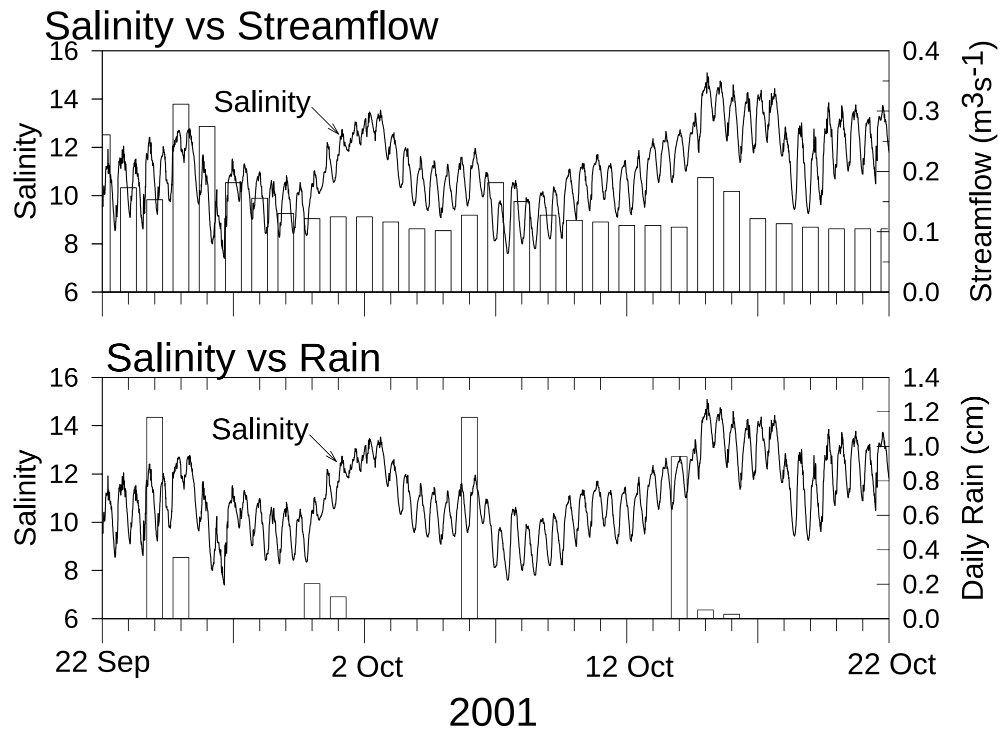



Figure 10: Effect of rain and stream flow effects on salinity. Rain data were collected at Snow Hill, stream flow data were from the Nassawango Creek gauge, and salinity at 1 m continuously measured from station 11 near the mouth of Pocomoke River (Kelly, 2005).

maximum value within a day after the event. The lag between precipitation and change in salinity ranges between 1 to 3.5 days. Although the goal is to maximize the temporal resolution, models are employed in steady state conditions. Given the uncertainties in phasing between the river flow and salinity and assumption of steady state, we chose an adjustment time for the Pocomoke River to be seven days as a conservative time step.

## *3.2 Salinity*

The salinity distribution in the Pocomoke River is dependent on the freshwater inflow, wind, the seiche effects of the Chesapeake Bay, and tidal exchange. Figures 11 - 13 present the axial distribution of salt during spring and late summer of 1999, 2000, and 2001 covering the region from station 4 in Pocomoke Sound to station 29 below Snow Hill. Figure 14 compares ADCP data recorded at approximately the same time of salinity observations at station 13 on 18 May 1999 and 26 September 2001. On 18 May 1999, the ADCP recorded a single-layer current seaward while salinity was observed to be well mixed. On 26 September 2001 both the halocline and transition depth, where current changes from landward to seaward, were approximately 1.5 m. Salinity profiles at station 1 near the mouth of Pocomoke Sound are presented in Figure 15. From an examination of the salinity distribution and profiles, one can observe the following characterization:

1. For 1999 and spring 2000, the total tributary estuary was well mixed, or nearly well mixed.
2. During late summer 2000 and spring and late summer 2001, the river portion of the estuary above station 13 had relatively low vertical gradients, but were

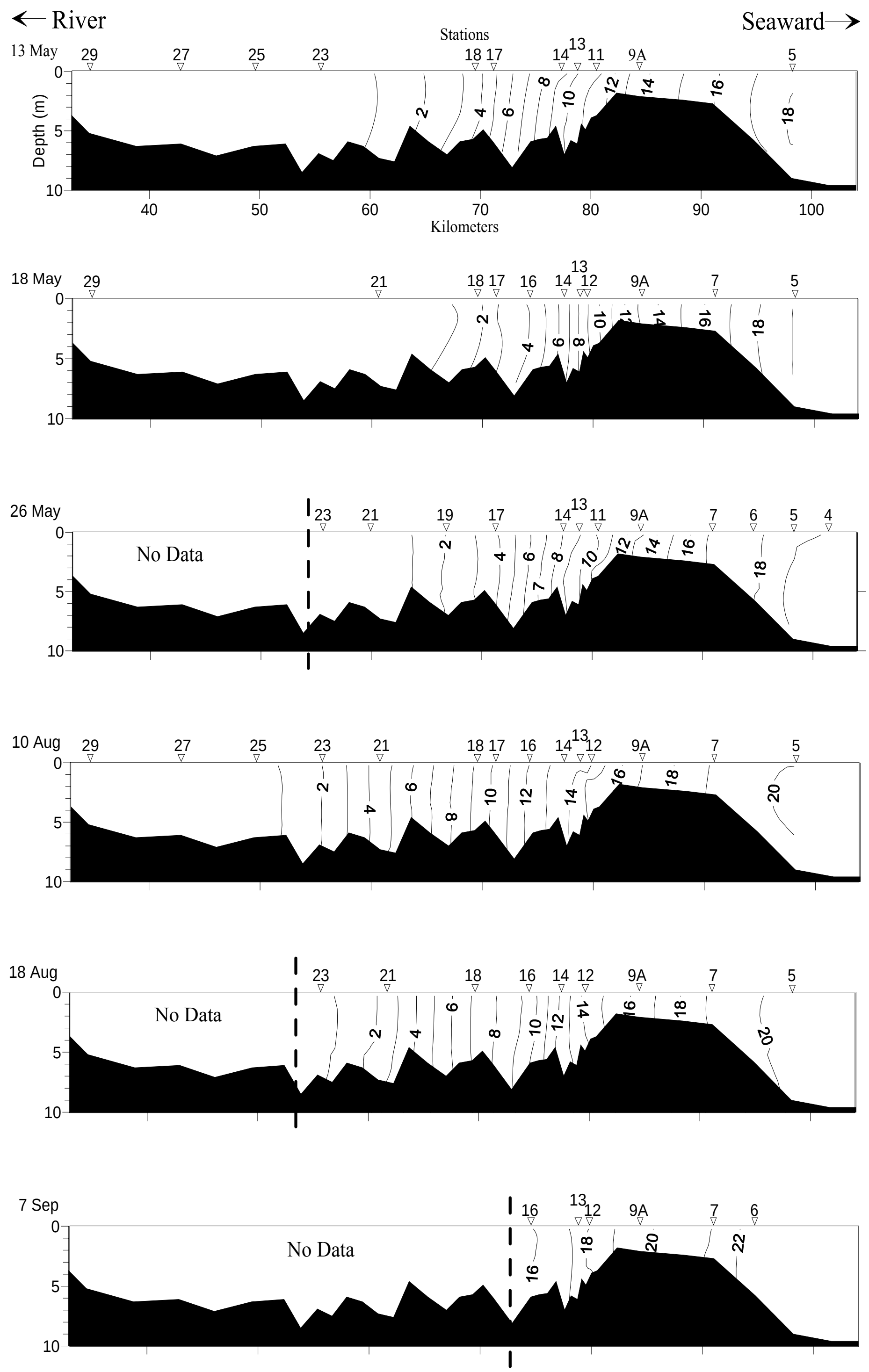



Figure 11: Axial distribution of salinity for the observation dates in 1999. The profiles have not been corrected for tidal excursion. The "No Data" label indicates that no data sampling took place beyond the last station listed upriver.

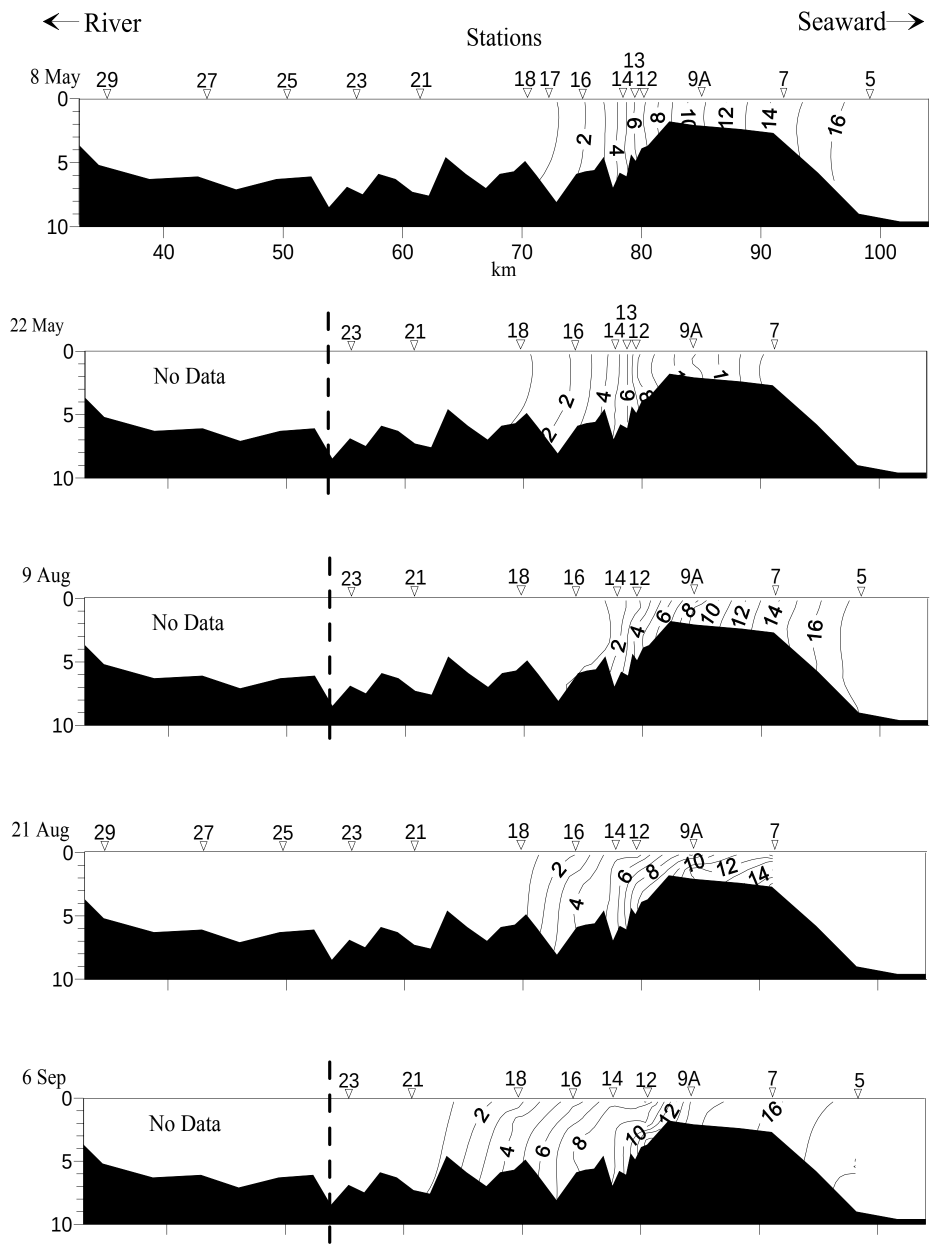



Figure 12: Axial distribution of salinity for the observation dates in 2000. The profiles have not been corrected for tidal excursion. The "No Data" label indicates that no data sampling took place beyond the last station listed upriver.

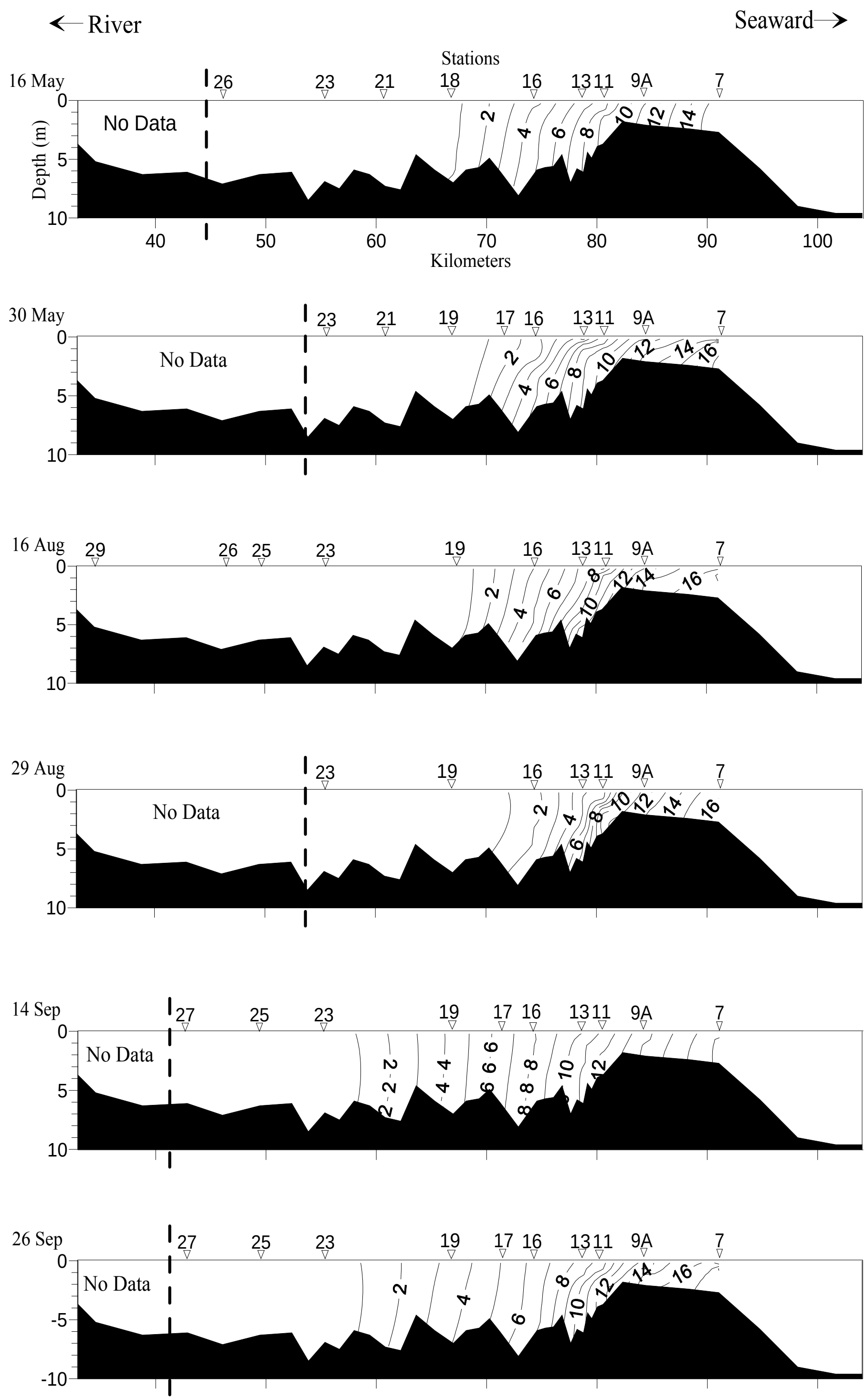



Figure 13: Axial distribution of salinity for the observation dates in 2001. The profiles have not been corrected for tidal excursion. The “No Data” label indicates that no data sampling took place beyond the last station listed upriver.

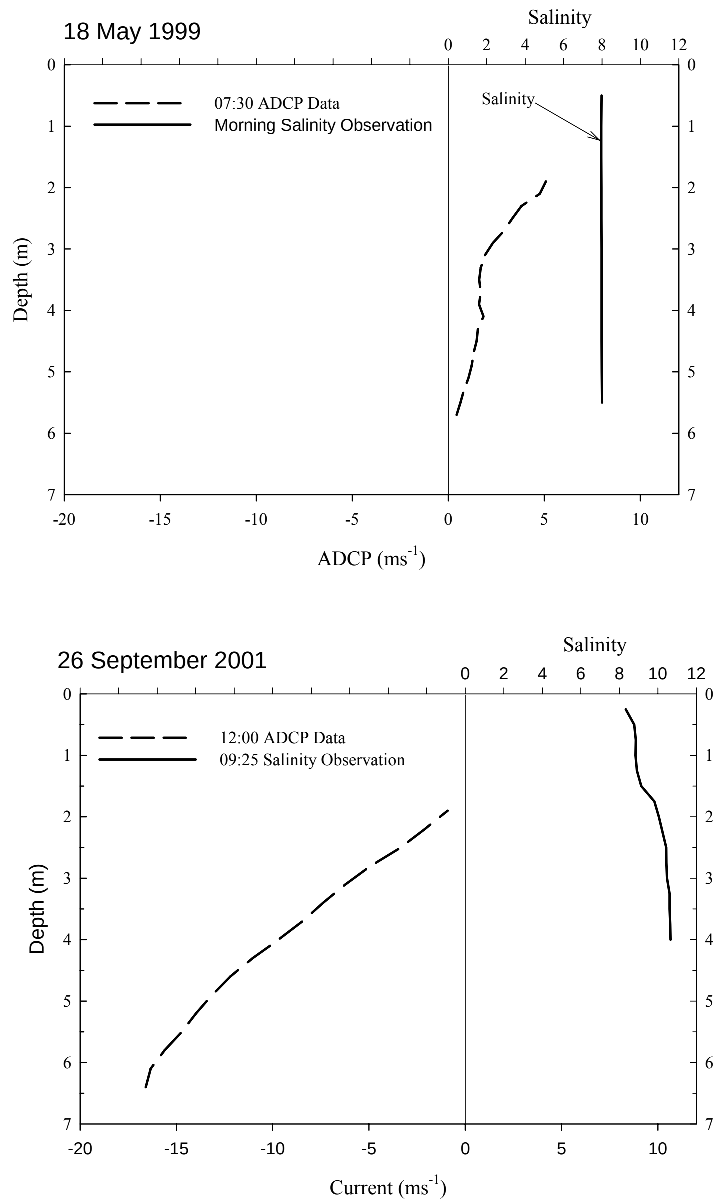



Figure 14: Shelltown (station 13) current and salinity profiles observed at approximately the same time on 18 May 1999 and 26 September 2001.

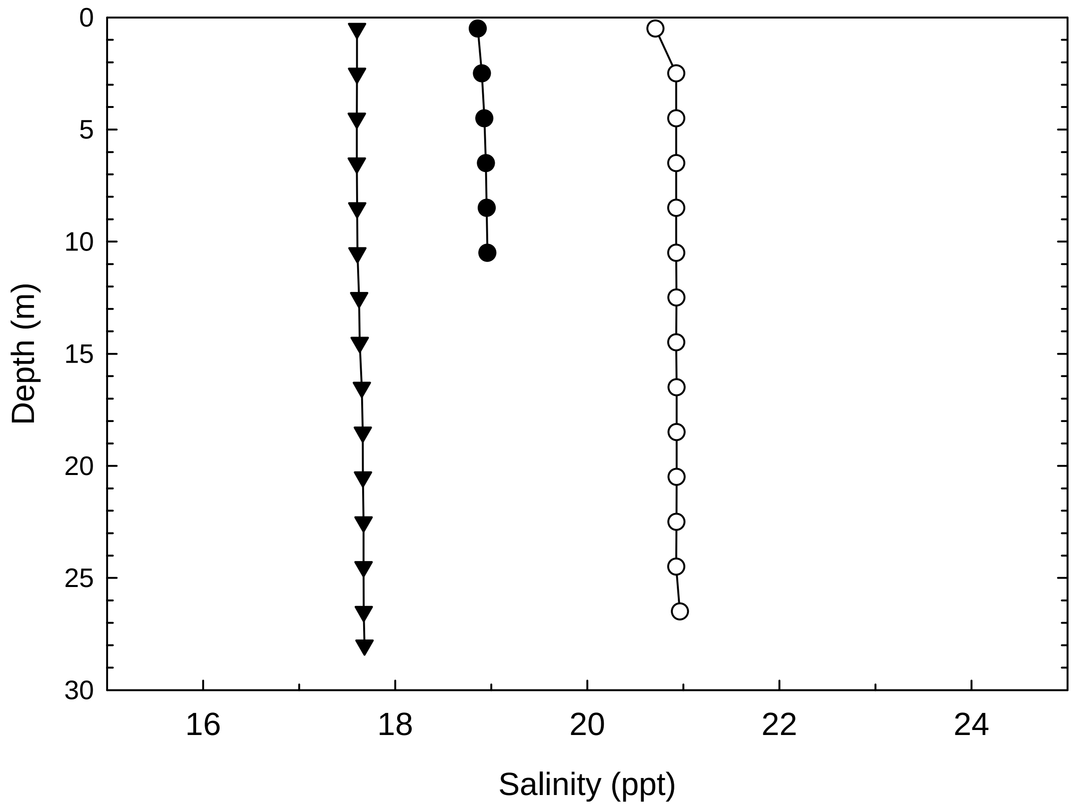



Figure 15: Salinity profiles at station 1 near the mouth of Pocomoke Sound. Profiles were obtained on 26 May 1999 -●-, 18 August 1999 -○-, and 9 August 2000 -▼-.

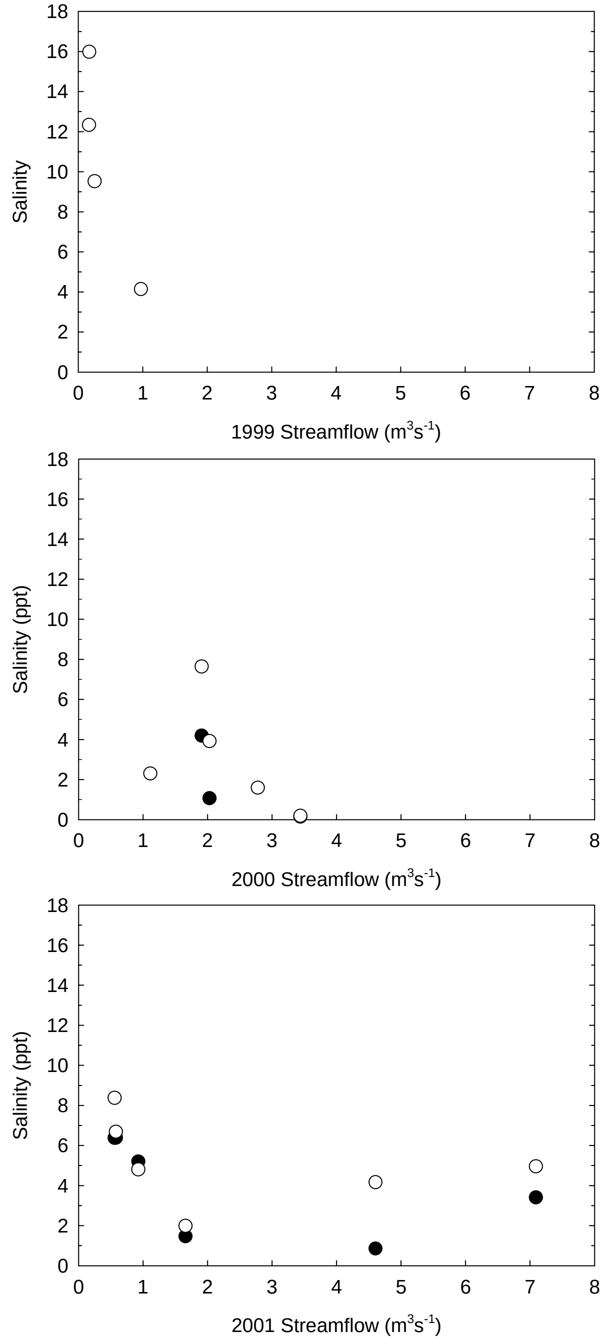



Figure 16: The relationship of salinity and seven-day average stream flow at station 16 during the HPL sampling days for 1999, 2000, and 2001. The Maryland Department of Natural Resources daily average salinity, recorded every 15 s, is ●; HPL data is ○.

greater than those for 1999. The largest vertical gradients were observed in Pocomoke Sound below station 13.

3. A distinct halocline when it occurred varied in location along the estuary and was generally around 1.5 m deep.
4. The mouth of Pocomoke Sound was often well mixed with only occasional weak stratification.
5. As expected salinity varied with stream flow (Figure 16), with higher flow resulting in the lower salinity values at a given location and vice versa.

During the 1999 drought, salt levels were significantly higher up river than those measured in 2000, and 2001. Maryland Department of Natural Resources (Eyesonthebay.net, 2005) reported the 1999 continuously monitored salinity levels at their Cedar Hall Wharf site were 5 ppt higher than average until Hurricane Floyd occurred on 17 September 1999. With this storm came large quantities of rainwater and freshwater runoff, causing a salinity drop to zero at the Rehobeth site, the most distant site from the Bay (Eyesonthebay.net).

## *3.3 Circulation*

Estimates of the advective and nonadvective exchange coefficients were calculated for both the one and two-dimensional models, using data from each HPL survey cruise and then averaged for spring (May) and late summer (August and September) to provide a characterization of seasonal variability. If only one data set existed for a particular season, it was excluded.

### 3.3.1 Gravitational Circulation

The 1999 and 2001 cumulative freshwater input (Figure 17) exhibited a regular seasonal pattern with higher flows in the spring. For 2000, higher freshwater flows occurred during late summer. The two-dimensional model results (Figure 18) represent the characteristic gravitational circulation with the top layer being slightly less saline than the bottom. The increased runoff during August of late summer 2001 (Table 2) resulted in greater gravitational circulation. During the wettest season for each of the three years, all the advective coefficients, $Q$, $Q'$, and $Q_v$, exhibited a slight jump in values around boxes 8 and 9 where the estuary shallows at station 9 from 6 m to 2 m (Figure 6). The large standard deviations for the late summer 2001 advective exchange coefficients is noise, probably from transients such as high water, wind or freshwater pulses. Mass balance between seaward $Q$ and landward $Q'$ advections were confirmed using the Officer (1980) expression $Q_{rm} = Q_m - Q'_{m+1}$. There was good correlation between landward advective transport $Q'$ in individual boxes and freshwater inflow (Figure 19), which would be expected since freshwater is the primary driver in equation (10). Figure (20) shows the relationship between landward advective transports $Q'$ and freshwater input $Q_{rm}$ for 1999, 2000, and 2001, at Rehobeth (Box 5) and Shelltown (Box 8). The Rehobeth data reflects the lower freshwater input because of its location up river. There is little correlation between freshwater flow and Q' at the two locations.

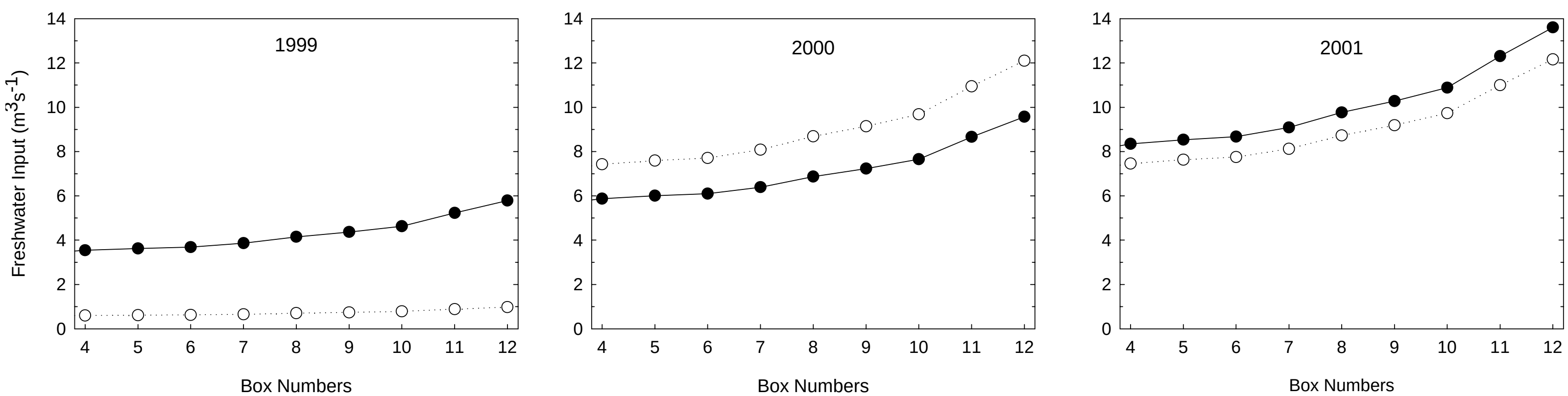



Figure 17: Cumulative freshwater input for 1999, 2000, and 2001. Symbols are -●- for spring and -○- for late summer.

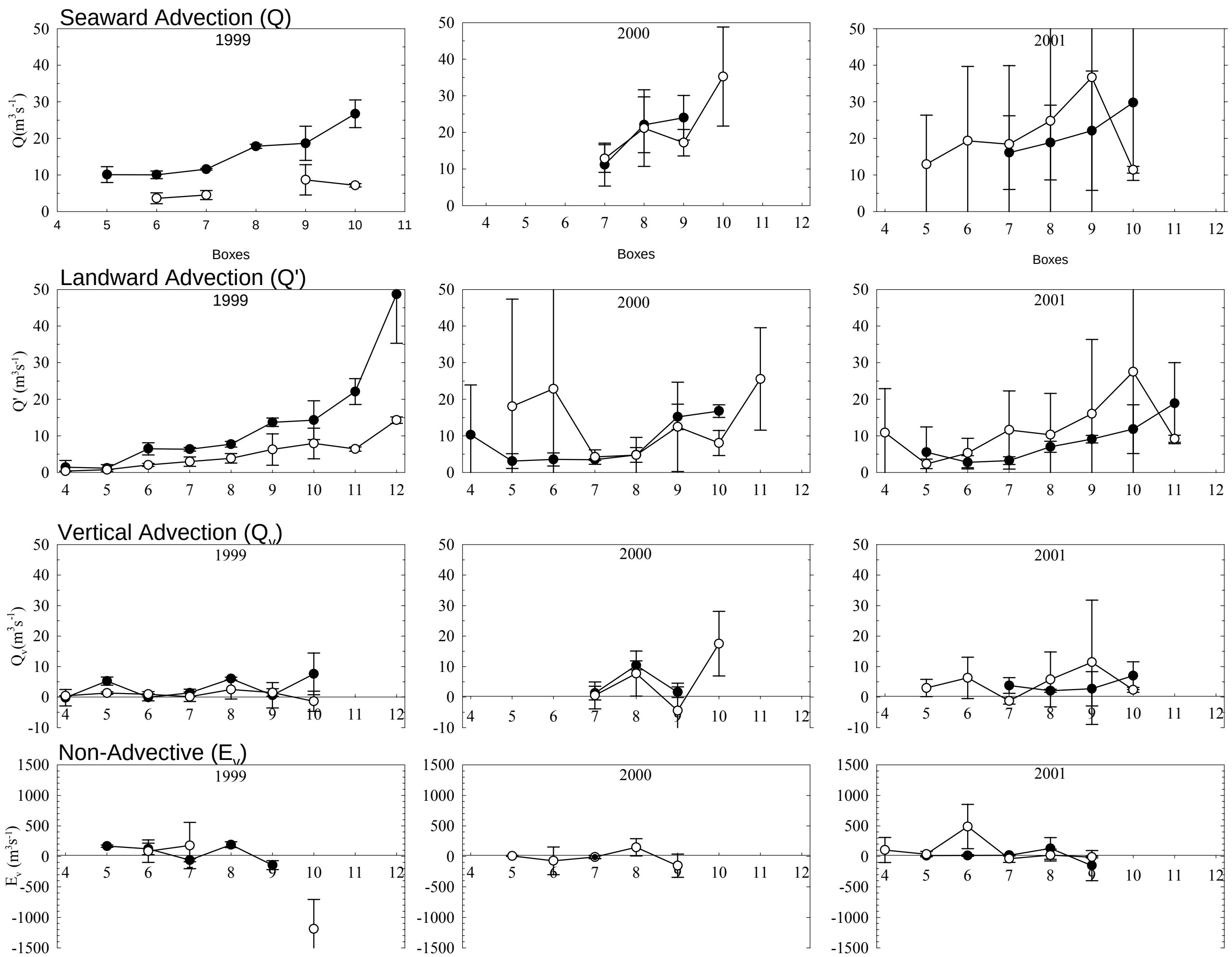



Figure 18: Two-dimensional model advective and nonadvective coefficients for 1999, 2000, and 2001. Symbols are -●- for spring and -○- for late summer. The large standard deviations in 2001 are the result of transients, either river flow, wind or high water events.

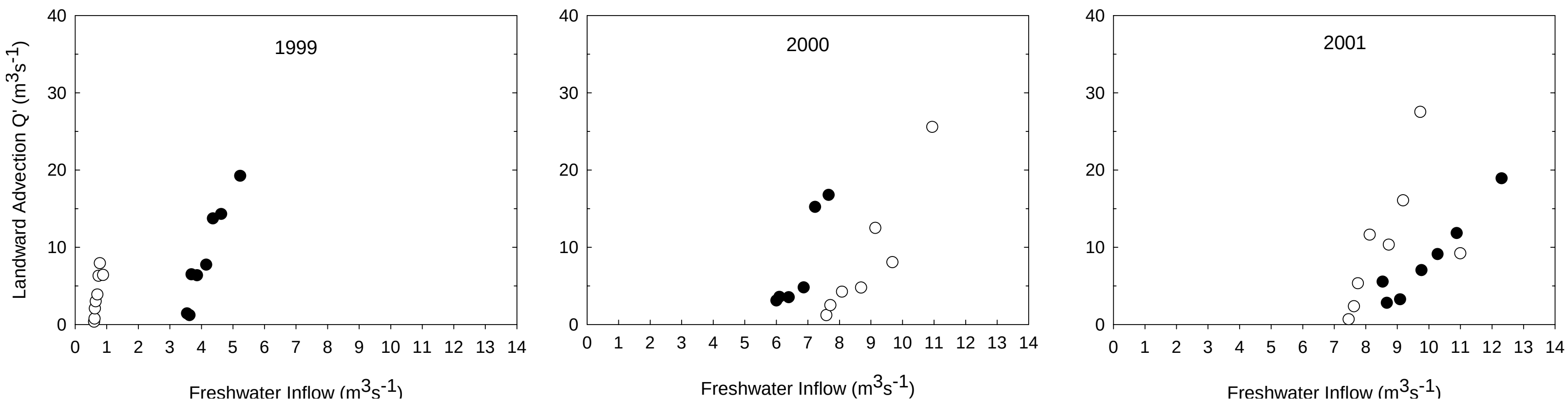



Figure 19: Relationship between freshwater inflow and landward advection in individual boxes. Symbols are ● for spring and ○ for late summer.

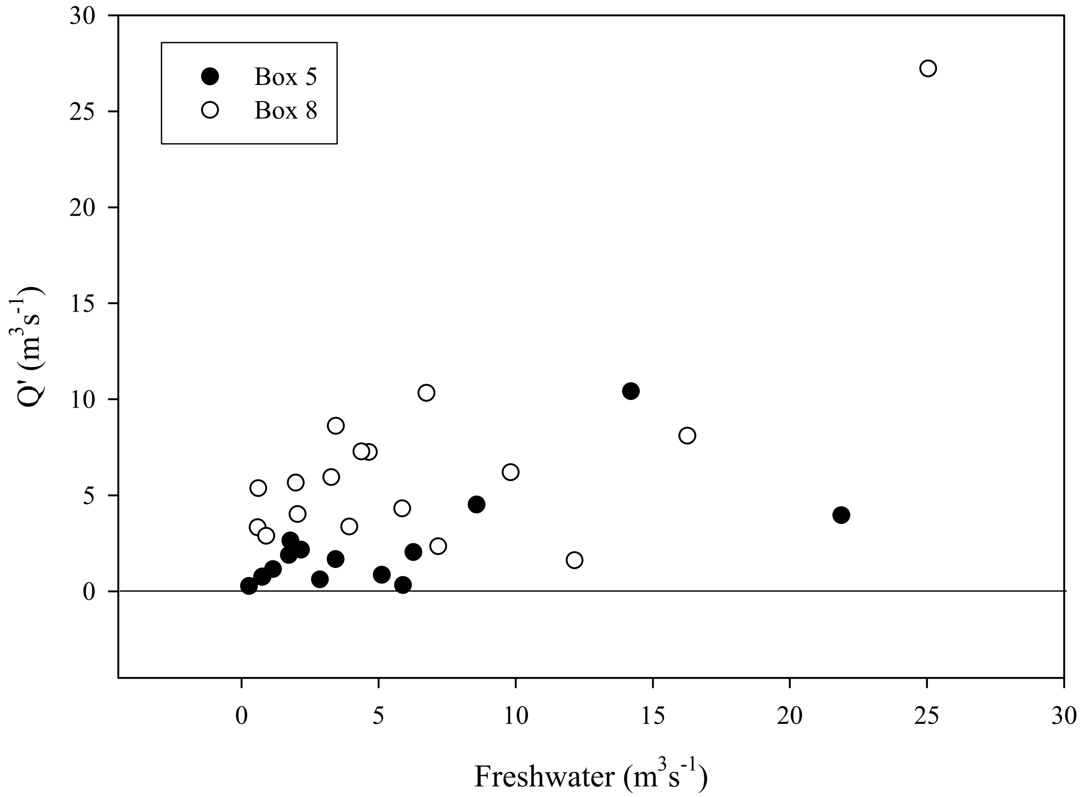



Figure 20: Relationship between freshwater inflow and landward advection Q’ in boxes 5 and 8. Data points represent individual model outputs for 1999, 2000, and 2001 for both boxes 5 and 8.

### 3.3.2 Nonadvective Circulation (Two-Dimensional)

Dyer (1997) points out that the essential part of the gravitational circulation process is mixing between layers. Mixing or turbulent diffusion results from turbulence in both the upper and lower layers and is a two way process in which equal volumes of water is exchanged. Though there is no net exchange of water between the two-layers, salt is transported upwards increasing the potential energy of the water column. The nonadvective vertical coefficients Evm from the two-dimensional model (Figure 18) was about the same for both spring and late summer during all three years. The exception was box 6 in late summer 2001, indicating greater vertical mixing, or turnover of the water column. Figure 13 shows the effects of this mixing with low vertical salinity gradients at station 17 on 14 and 26 September 2001.

### 3.3.3 Nonadvective Circulation (One-Dimensional)

The exchange coefficients for the one-dimensional model (Figure 18), when standard deviation is relatively small, follow closely with the two-dimensional seaward advection Q and the model output pattern for vertical advective Qv. The one-dimensional exchange coefficient Em has to represent both the tidal exchange and gravitational circulation, including vertical advection, which are two-dimensional in character (Ippen, 1966 and Officer, 1980). The values reflect the local effects of shear flow and advective circulation.

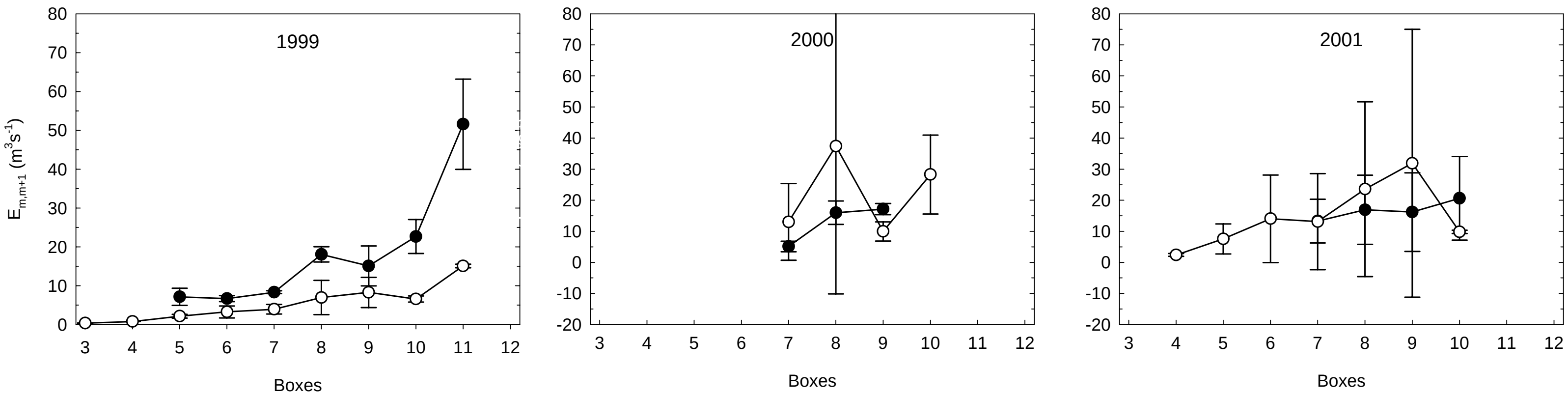



Figure 21: Exchange coefficients from the one-dimensional model. Symbols are -●- for average spring and -○- for late summer.

### 3.3.4 Passive Transport

Table 5 contrasts concentrations of a conservative quantity if it were added at a constant flux to either end of the estuary or to an arbitrary location along the estuary, in this case, box 5. With the flux input at box 5, the highest concentration upriver was in box 4 during late summer 1999 with the lowest river flow. Interestingly, the box concentrations down river are similar to those seasons with higher freshwater flows. As one would expect, the tracer flux required to maintain a concentration in Box 5 was dependent on river flow. One of the problems with this concentration approach is what Officer calls boundary effects. Although the point of entry and flux input from a point source might be known, nutrient input from agriculture runoff are difficult to determine.

### 3.3.5 Flushing Time and Box Residence Time

Table 5 compares individual box residence times for both the one-dimensional and two-dimensional models. These values represent the expected amount of time that a particle will remain in an individual box. The calculations do not take into account that most of the flows out of boxes are into other boxes and only the end boxes exchange with the environment outside the model. Particles may move upstream as well as downstream and may visit some boxes several times before exiting the estuary (Sheldon and Alber, 2002). The residence time for one-dimensional boxes increased significantly as river flow decreased, particularly for late summer 1999. On the other hand, individual box residence times from the two-dimensional model exhibited shorter times for 1999 with low river flows indicating a great deal of vertical mixing, which is evident from the low vertical salinity gradients in Figure 11. Table 6 presents the residence time using Dyer's

Table 4: Concentration distribution (in mass per unit volume) if a tracer were added at a constant flux to maintain a concentration of 1 at either the landward or seaward ends of the model or in box 5.

| Concentration (mass per unit volume) Input at Landward End of Model | | | | | | |
|---|---|---|---|---|---|---|
| | 1999 | | 2000 | | 2001 | |
| Boxes | Spring | Late Summer | Spring | Late Summer | Spring | Late Summer |
| 3 | 1.00 | 1.00 | 1.00 | | | 1.00 |
| 4 | 0.97 | 0.88 | 0.99 | | | 0.96 |
| 5 | 0.87 | 0.72 | 0.96 | | | 0.88 |
| 6 | 0.79 | 0.62 | 0.90 | | | 0.78 |
| 7 | 0.67 | 0.52 | 0.79 | | | 0.68 |
| 8 | 0.52 | 0.40 | 0.56 | | | 0.49 |
| 9 | 0.41 | 0.29 | 0.40 | | | 0.30 |
| 10 | 0.23 | 0.18 | 0.18 | | | 0.06 |
| 11 | 0.07 | 0.06 | | | | |

| Input at Seaward End of Model | | | | | | |
|---|---|---|---|---|---|---|
| | 1999 | | 2000 | | 2001 | |
| Boxes | Spring | Late Summer | Spring | Late Summer | Spring | Late Summer |
| 4 | 0.00 | 0.07 | | 0.00 | 0.01 | 0.00 |
| 5 | 0.09 | 0.23 | | 0.08 | 0.04 | 0.05 |
| 6 | 0.16 | 0.35 | | 0.14 | 0.10 | 0.15 |
| 7 | 0.26 | 0.45 | | 0.24 | 0.20 | 0.26 |
| 8 | 0.41 | 0.58 | | 0.37 | 0.30 | 0.48 |
| 9 | 0.51 | 0.70 | | 0.45 | 0.44 | 0.72 |
| 10 | 0.73 | 0.80 | | 0.77 | 0.69 | 1.00 |
| 11 | 0.90 | 0.93 | | 1.00 | 1.00 | |
| 12 | 1.00 | 1.00 | | | | |

| Input at Box 5 | | | | | | |
|---|---|---|---|---|---|---|
| | 1999 | | 2000 | | 2001 | |
| Box | Spring | Late Summer | Spring | Late Summer | Spring | Late Summer |
| 3 | 0.05 | 0.15 | 0.20 | | | 0.11 |
| 4 | 0.25 | 0.52 | 0.36 | 0.41 | 0.33 | 0.34 |
| 5 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 6 | 0.92 | 0.85 | 0.95 | 0.96 | 0.93 | 0.89 |
| 7 | 0.79 | 0.72 | 0.85 | 0.89 | 0.84 | 0.78 |
| 8 | 0.62 | 0.56 | 0.64 | 0.78 | 0.75 | 0.60 |
| 9 | 0.50 | 0.40 | 0.49 | 0.69 | 0.61 | 0.43 |
| 10 | 0.31 | 0.26 | 0.28 | 0.38 | 0.37 | 0.21 |
| 11 | 0.13 | 0.10 | | 0.13 | 0.08 | 0.02 |
| 12 | 0.04 | 0.02 | | | | |

Table 5: Individual box residence times for both one-dimensional and two-dimensional models.

| | 2-D Model | | | | 1-D Model | |
|---|---|---|---|---|---|---|
| | Spring | | Late Summer | | Spring | Late Summer |
| Box Nos. | $\tau_m$ (hr) | $\tau'_m$ (hr) | $\tau_m$ (hr) | $\tau'_m$ (hr) | $\tau_m$ (hr) | $\tau_m$ (hr) |
| | | | **1999** | | | |
| 5 | 2.4 | 4.4 | | | 58.4 | 191.9 |
| 6 | 1.1 | 1.9 | 2.7 | 4.6 | 21.5 | 65.2 |
| 7 | 1.2 | 2.0 | 2.9 | 4.9 | 34.4 | 92.4 |
| 8 | 3.3 | 5.2 | | 5.5 | 24.1 | 71.5 |
| 9 | 9.0 | 2.8 | 42.3 | 12.7 | 37.9 | 105.2 |
| 10 | 10.8 | 2.0 | 45.0 | 8.2 | 167.9 | 471.6 |
| | | | **2000** | | | |
| 5 | 5.3 | 10.7 | 20.5 | 99.4 | 60.7 | 60.0 |
| 6 | | | 3.4 | 7.5 | 28.7 | 5.5 |
| 7 | 3.6 | 6.7 | 8.5 | 19.4 | 45.4 | 13.9 |
| 8 | 0.6 | 1.0 | 6.9 | 14.2 | 28.1 | 10.5 |
| 9 | 1.3 | 0.4 | 16.0 | 5.7 | 36.5 | 10.9 |
| 10 | 4.2 | 0.8 | 66.5 | 14.4 | | 40.4 |
| | | | **2001** | | | |
| 5 | 6.3 | 13.6 | 7.0 | 13.9 | 5.6 | 11.5 |
| 6 | 4.0 | 8.2 | 1.2 | 2.1 | 5.0 | 3.8 |
| 7 | 8.3 | 17.9 | 2.4 | 4.1 | 7.7 | 8.2 |
| 8 | 4.4 | 9.4 | 8.8 | 14.8 | 6.2 | 11.0 |
| 9 | 8.3 | 3.0 | 29.8 | 10.2 | 8.6 | 14.3 |
| 10 | 27.6 | 5.7 | 120.2 | 24.1 | 18.8 | 50.0 |

Table 6: Residence time for the Pocomoke River using the freshwater fraction method (Dyer, 1997) for boxes 1 through 10 and model input data.

| Residence Time (d) | |
|---|---|
| 1999 | |
| Spring | Late Summer |
| 83.8 | 395.5 |
| 2000 | |
| Spring | Late Summer |
| 69.1 | 52.2 |
| 2001 | |
| Spring | Late Summer |
| 78.0 | 102.0 |

(1999) fraction of freshwater method and the model's input data. The longest residence time, 395.5 days assuming steady state, occurred during the 1999 late summer drought when salinity was higher than normal up river. The shortest residence time was 52.2 days where average salinity was considerably lower than the salinity in the Chesapeake Bay.

### *3.4 Currents and Transport*

Figures 22-24 show ADCP records for depths from 2 m below the surface down to 1.3 m above the bottom, filtered with a Lanczos 34 hour low pass filter to remove tidal oscillations. In general, the records show two-layer flow with wind and seiche effects superimposed. The oscillating current fluctuations, about every two to three days, were consistent with the Chesapeake Bay longitudinal seiche activity described by Chuang and Boicourt (1989). In 1999 at Rehobeth, Shelltown and station 6 (located in mid Pocomoke Sound), the upper and lower current fluctuations were nearly in phase, had approximately the same amplitude, and often exhibited a single layer flow. For both October 2000 and 2001, the gravitational circulation became stronger and was quite significant during January and February 2002. Figure 25 presents the ADCP current data averaged and plotted as profiles. The depth of zero velocity or transition depth between the two flows for 1999 was around 5.5 m, probably because of strong northeast wind (Boicourt et al., 2003) driving water out of the river and Bay. The transition depth at Shelltown in 2000 was approximately 4.5 m and 17 September 2001 through 13 February 2002, was consistently at 3.5 meters. The net current at Rehobeth in May 1999 was seaward indicating that the location was landward of the zone for two-layer flow during the period monitored. Station 6 also had a net current seaward with a weaker lower current.

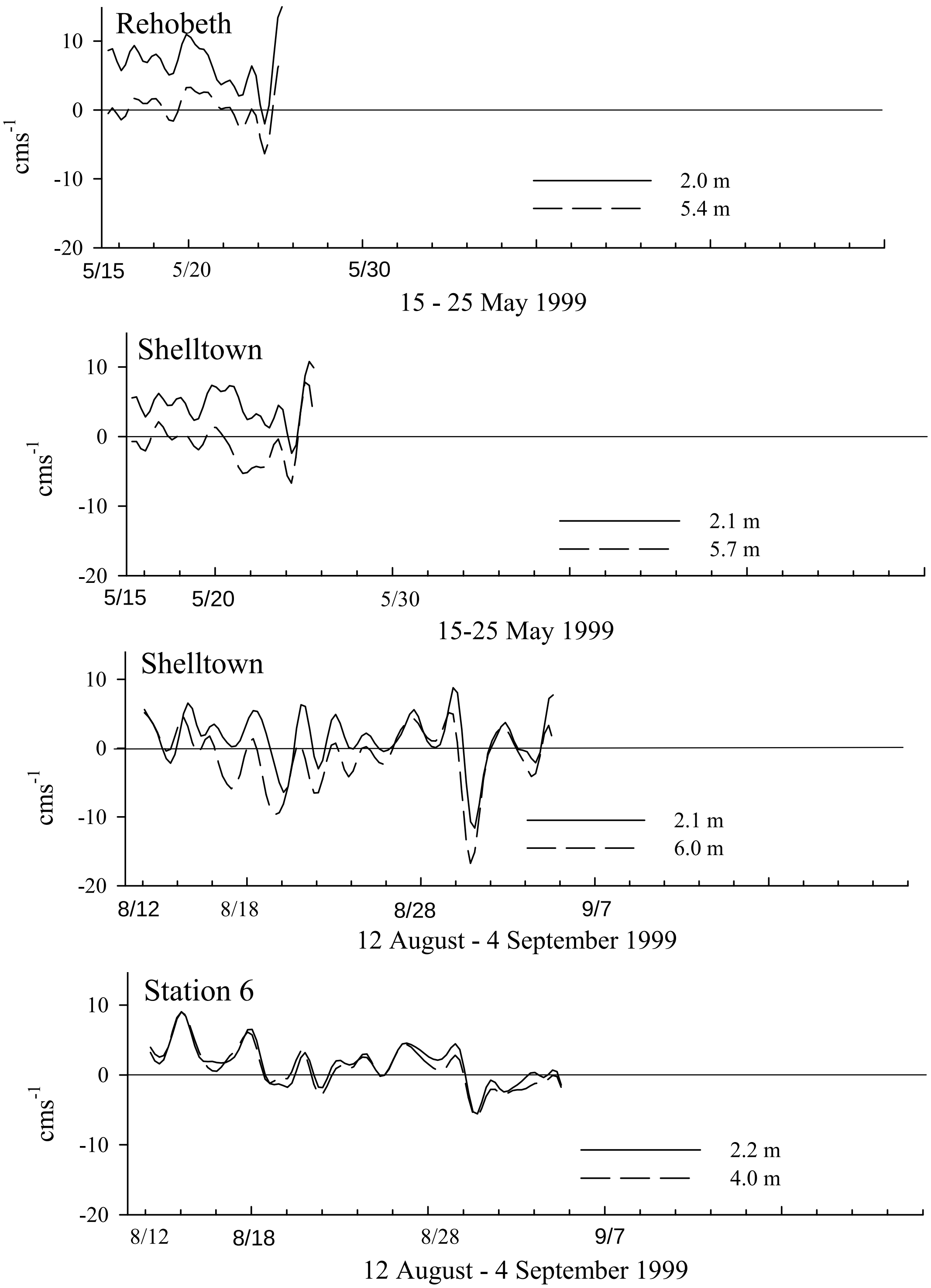



Figure 22: 1999 ADCP data measured at Rehobeth, Shelltown, and Station 6 in Pocomoke Sound. The upper records are at 2 m and lower approximately 1.3 m above the bottom.

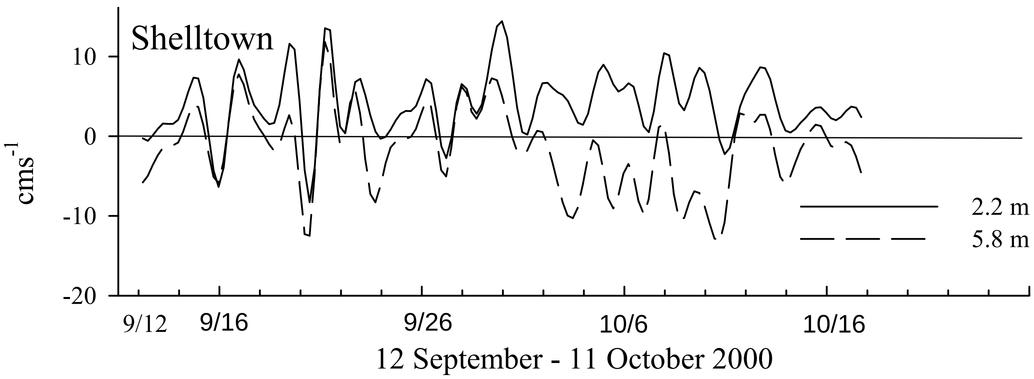



Figure 23: 2000 ADCP data at Shelltown. The upper records are at 2 m and lower approximately 1.3 m above the bottom.

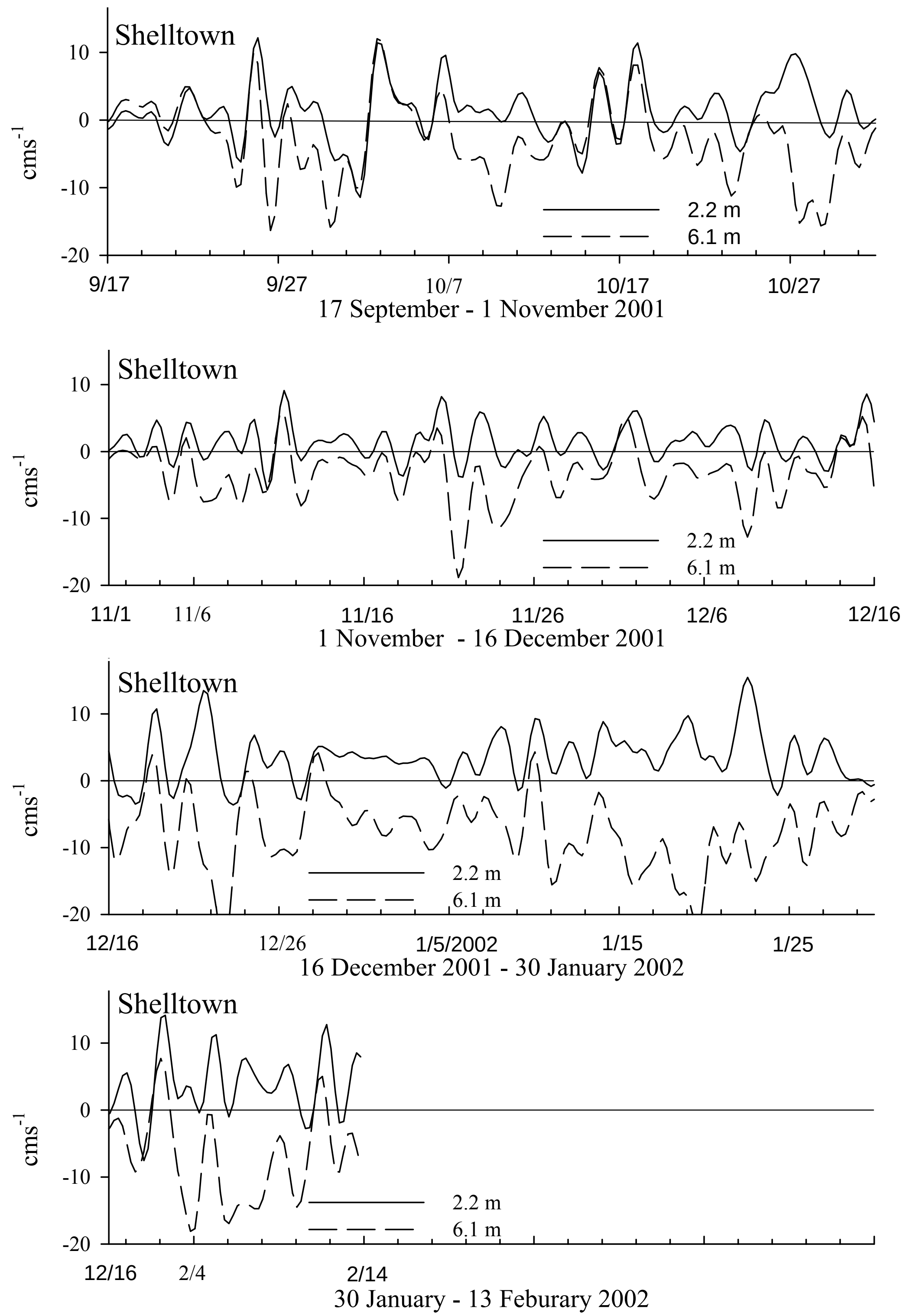



Figure 24: 2001 to 2002 ADCP data at Shelltown. The upper records are at 2 m and lower approximately 1.3 m above the bottom.

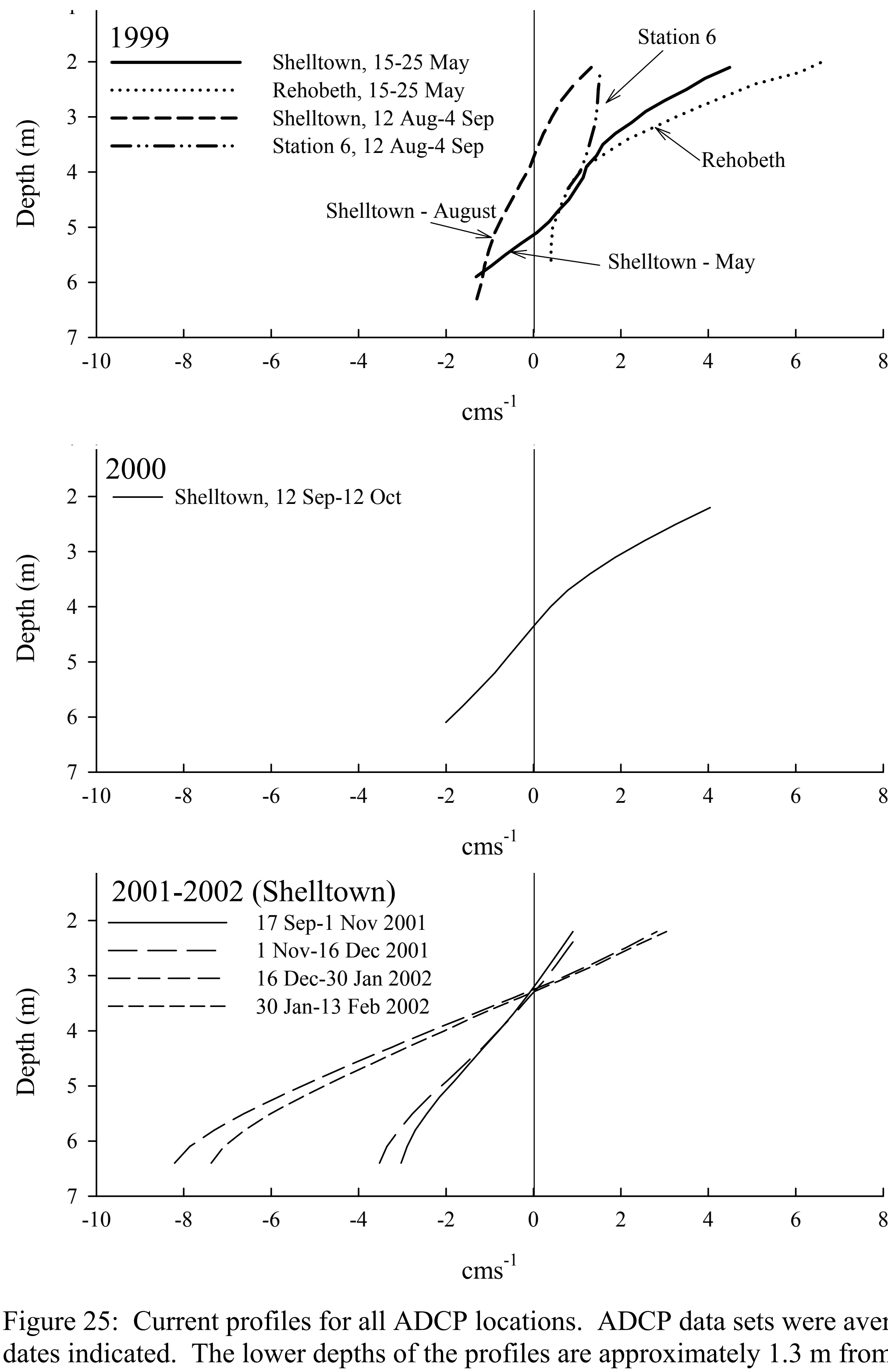



Figure 25: Current profiles for all ADCP locations. ADCP data sets were averaged for dates indicated. The lower depths of the profiles are approximately 1.3 m from the bottom.

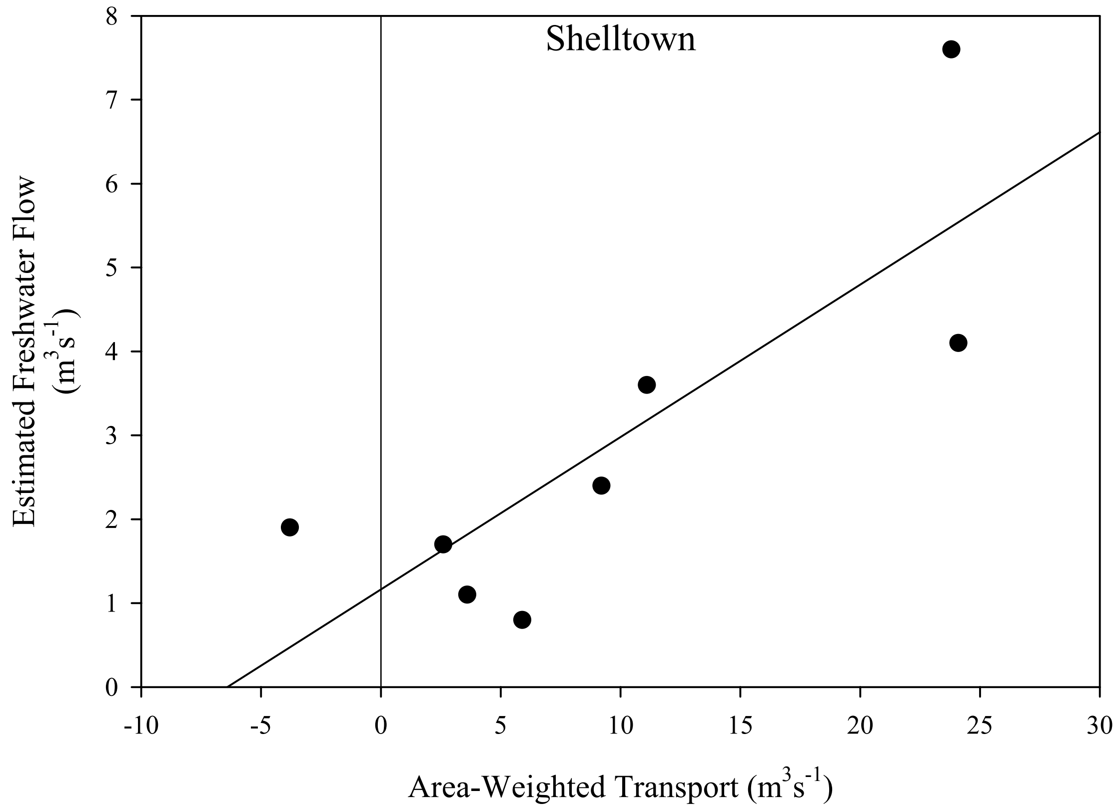



Figure 26: Relationship of freshwater estimates to ADCP area-weighted net transport at Shelltown. $R^2$ equals 0.66. The linear relationship is $y = 0.182x + 1.164$.

Table 7: Comparison of ADCP weighted average net transport calculations and freshwater estimates at Shelltown. Note that the net transport for 17-26 September 2001 is landward.

| ADCP Observation Dates | ADCP Net Transport ($m^3s^{-1}$) | Estimated Freshwater Flow ($m^3s^{-1}$) |
|---|---|---|
| 15-25 May 99 | 24.1 | 4.1 |
| 12 Aug-4 Sep 99 | 5.9 | 0.8 |
| 12 Sep – 11 Oct 00 | 23.8 | 7.6 |
| 17-26 Sep 01 | -3.8 | 1.9 |
| 17 Sep – 1 Nov 01 | 2.6 | 1.7 |
| 1 Nov – 16 Dec 01 | 3.6 | 1.1 |
| 16 Dec – 30 Jan 02 | 9.2 | 2.4 |
| 30 Jan – 13 Feb 02 | 11.1 | 3.6 |

Table 8: Comparison of 2-dimensional model results against ADCP net transport calculations at Shelltown and Rehobeth. Subscript (a) indicates values were calculated with salinity measured on 13, 18 and 26 May 1999, subscript (b) are for values calculated with salinity measured on 10 and 18 August and 7 September 1999, subscript (c) are values using salinity measured on 6 September 2000, and subscript (d) is for calculations using salinity observed on 14 and 26 September 2001

Shelltown

| ADCP Observation Dates | Seaward ADCP Transport ($m^3s^{-1}$) | Seaward Advection Q ($m^3s^{-1}$) | Landward ADCP Transport ($m^3s^{-1}$) | Landward Advection Q' ($m^3s^{-1}$) |
|---|---|---|---|---|
| 15-25 May 99 | 24.2 | $17.9_a$ | 0.1 | $7.7_a$ |
| 12 Aug-4 Sep 99 | 6.7 | $6.9_b$ | 0.7 | $3.8_b$ |
| 12 Sep – 11 Oct 00 | 24.4 | $33.2_c$ | 0.5 | $10.3_c$ |
| 17-26 Sep 01 | 0.3 | $8.3_d$ | 4.1 | $4.8_d$ |

Rehobeth

| ADCP Observation Dates | Seaward ADCP Transport ($m^3s^{-1}$) | Seaward Advection Q ($m^3s^{-1}$) | Landward ADCP Transport ($m^3s^{-1}$) | Landward Advection Q' ($m^3s^{-1}$) |
|---|---|---|---|---|
| 15-25 May 99 | 17.7 | 10.1 | 0 | 1.2 |

To get a sense about the validity of the freshwater estimates entering the estuary, freshwater flows were compared against the area-weighted ADCP net transport calculations (Table 8 and Figure 26). The area weighted net transport values were greater than freshwater estimates by almost a factor of 6. The difference may be attributed to several reasons:

1. The assumption that that current is homogeneous laterally and that there are no boundary effects may not be valid.
2. The ADCP was placed in the river channel near a bend where it could be impacted by ebb-dominated flow (Figure 27). With ebb-dominated flow, current velocities during ebb tide could be higher at the outside of the bend than near its apex.
3. Stokes drift may be a factor. This arises because the discharge per unit time near to high water is greater than that near low water (Dyer, 1997).
4. An underestimation of water contribution from the surrounding wetlands may be a cause. The wetland area surrounding the river from Snow Hill to Shelltown exceeds the river area by a factor of almost 20. Wetlands have a tendency to retain water during the summer, fall, and winter periods. During spring when they are commonly flooded, they tend to release more flow than the surrounding upland (Novotony and Olem, 1994). The freshwater input does not include the possible delayed release of wetland water, which may have accumulated during earlier precipitation events or higher than normal tides. For example, to maintain an ADCP transport difference over the

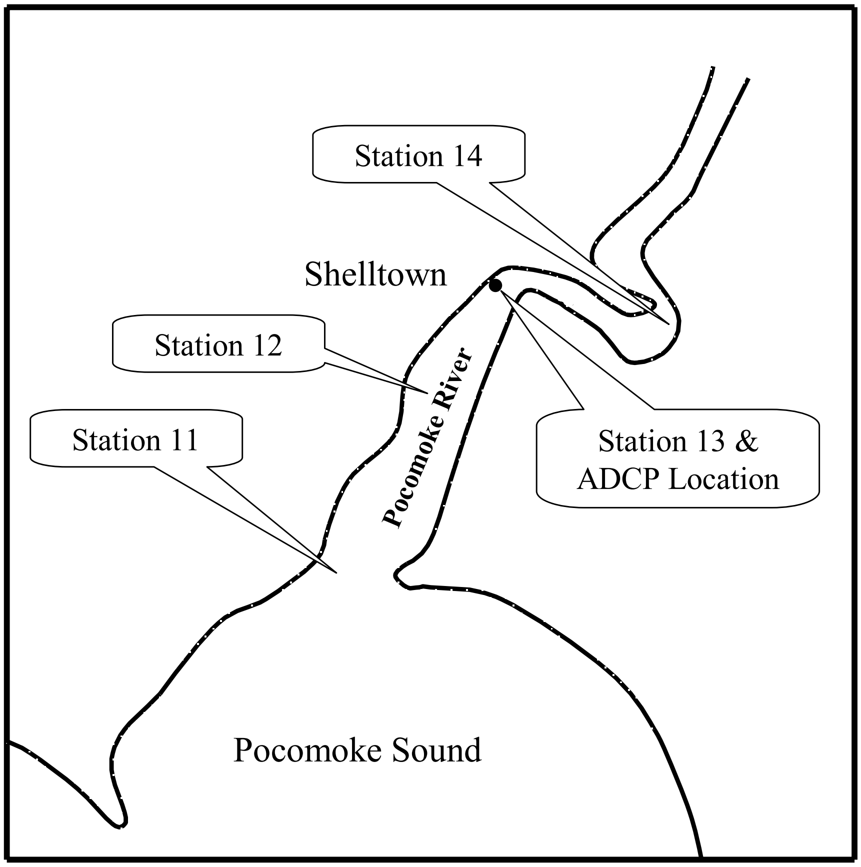
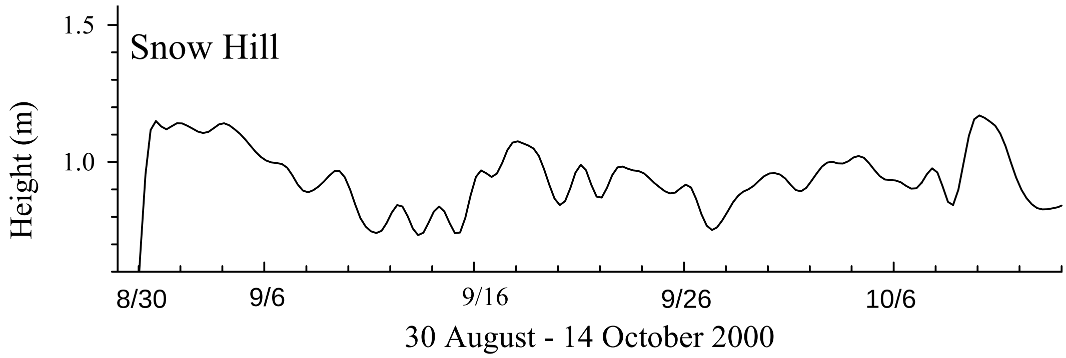


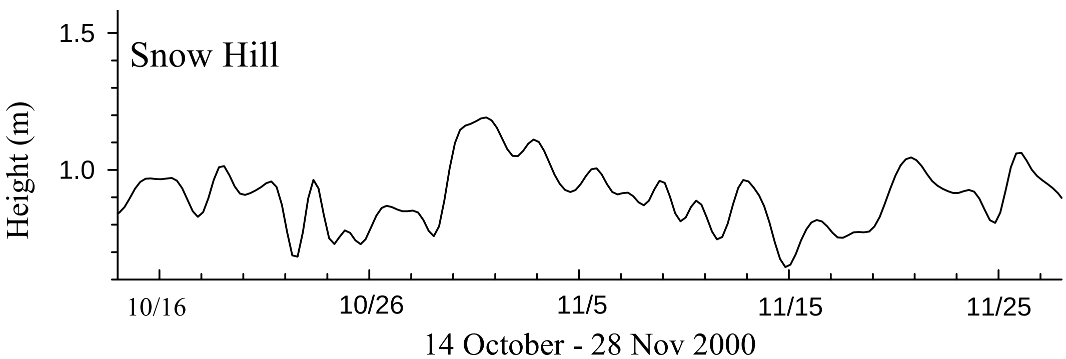

Figure 27: ADCP location in river near Shelltown (station 13) illustrating why the sensor could be influenced by ebb-dominated flow

estimated freshwater flow of 20 $m^3s^{-1}$ for 10 days (Table 7) at station 13, the wetlands would only have to flood by 0.1 m.

Table 9 compares seaward and landward area-weighted ADCP transport calculations to the two-dimensional model advective flows. For May 1999, the area weighted transport calculations were higher than the seaward coefficient *Q* estimated by the model. The May 1999 ADCP flows probably reflected the higher than predicted tides and strong northeast wind driving the water out of the estuary. During September 1999, 2000, and 2001, both the landward and seaward advective coefficients were in the order of magnitude. There was poor comparison between landward advection *Q'* and the landward ADCP transport.

Figure 27 presents the sub tidal record, filtered with a Lanczos 34 hour low pass filter for 30 August through 5 December 2000. Evident are 2 to 2.5 day oscillations of the Chesapeake Bay natural oscillations (seiche) and other wind forced fluctuations having an amplitude about 0.5 m. This suggests that the high water could be stored in the surrounding wetlands.



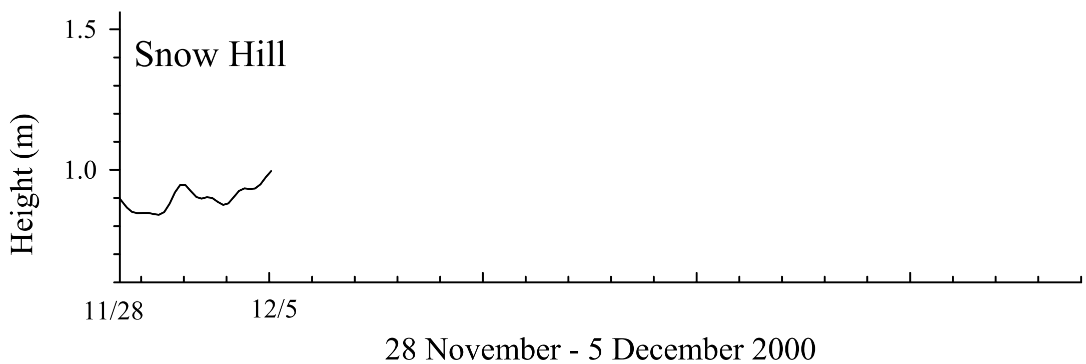




Figure 28: Filtered tidal records at Snow Hill, MD

# Chapter 4: Discussion

The main objective of this research project was to describe the salt balance, structure and transport processes in the Pocomoke River, a coastal plain estuarine tributary on the eastern shore of Chesapeake Bay. While more advanced models may offer greater insight into the details about the movement of materials through estuaries, box models constructed for the Pocomoke River were a simple way to reproduce the essential features of gravitational circulation and transport. The combination output of both the one and two-dimensional models show that the Pocomoke River circulation is similar to that described by Carter (1967) for the Manokin River, where wind, river discharge, and gravitational flow induced three distinctive circulation patterns. The Pocomoke River is also comparable to the Choptank River where the classical circulation domains are limited Boicourt et al. (2003). In both the Choptank and Pocomoke Rivers, the two-layer flow region is not only spatially limited, but also temporally variable, depending on river flow and mixing. The Pocomoke River's salinity stratification, which varied from well mixed to stratified in different segments supported the decision to represent its circulation with both one and two-dimensional box models. A two-dimensional model has the advantage of representing variations in a stratified estuary, however, when conditions are well mixed with zero vertical gradients, the vertical nonadvective exchange coefficient $E_{vm}$ (Equation 12) becomes indeterminate. On the other hand, a one-dimensional box model is suitable for well mixed estuaries, but it cannot simulate two-layer gravitational circulation. Consequently, the two model configurations complemented each other. For tributary estuaries, similar to the Pocomoke River where two-layer flow is spatially variable, a hybrid box model similar to

Hagy, et al. (2000) may be practical. Hagy's model structure was based on the Patuxent River's bathymetry where he used a one-dimensional box to represent the sill between the river and estuary and then transitioned to two-layer boxes for the remainder of the river. For the Pocomoke River, the design of a hybrid box model would not be based on river bathymetry, but on salinity distribution and stratification. The range of well mixed conditions generally begins around station 16 and extends up river to the limit of salt penetration (Figures 11, 12, 13). For these conditions, boxes 1 through 6 could be one-dimensional or single-layer transitioning to two-dimensional for boxes 7 through 12 representing the region with greater stratification. Although there may be instances of stratification further up the river, such as on 6 September 2000 (Figure 12), a hybrid model configuration could generally represent conditions realistically.

Freshwater flow input was based on upriver gauged flow where groundwater was implicitly included in the runoff records. Differences between freshwater flow and net transport (Table 7) indicate that the surrounding watershed contribution downriver, including wetlands, may not be the same as that above the gauging stations. Pocomoke River wetlands comprise about 8% of the watershed area and are mainly in the tidal regions (Lenert et al., 1999) Wetlands and ground water are interconnected, although the connection is poor since the very existence of a wetland usually implies impervious subsoil. If shallow ground water is discharging into a wetland it can also be recharged with surface water (Novotony and Olem, 1994), so total contribution may differ from that above the stream flow gauges. The model does not include the possible delayed release of wetland water accumulated during earlier precipitation events or from tides that are higher than normal. Also, as wetlands flood the effective cross-sectional areas and volumes of the river increase affecting area weighted salinity and residence time calculations (equations 4, 13 and 14). The models use cross-sectional areas and volumes based on river geometry at mean low water, not applicable during high water events. In the future, for rivers with substantial wetlands, further attention should be given to both their water storage and contribution, and change in river geometry when salinity observations are made during higher than normal tides.

Gravitational circulation in estuaries is driven by the longitudinal density gradient that results from differences in density between fresh and saltwater (Pritchard 1965). The source that maintains this gradient is freshwater inflow at the head of the estuary and salt intrusion from the adjacent ocean, but a forced influx of higher salinity at the mouth should act equivalently. With the salinity profile near the mouth of Pocomoke Sound nearly constant (Figure 10*)*, one mechanism discussed by Sanford and Boicourt (1990) is wind-forced intrusion of salt over the entrance sill. Another possibility may be salt through the narrow navigation channel that accommodates commercial traffic across the sill on the northern side of Pocomoke Sound. Although only 30 m wide and 3 m deep, it does provide a conduit to the outer portion of Pocomoke Sound where salinity was well mixed down to 30 m in late summer of 1999 and 2000. The contribution, however, is probably very small since the cross sectional area of the navigational channel is 90 $m^2$, whereas the cross sectional area at the shallow portion of the sill is 4291 $m^2$ (Appendix).

The Pocomoke River seasonal residence times (Table 6) were similar to those for the Patuxent River, calculated by Hagy et al. (2000). The exception was during the drought of late summer 1999 when the Pocomoke River residence time was 395 days. This suggests that during dry seasons, with a significant intrusion of salt the river may be vulnerable to prolonged concentrations of dissolved substances such as nutrients or pollutants. The individual box residence times are relatively short and reflect the effect of mixing. The models were particularly useful in defining steady state concentration distributions of dissolved conservative substances entering the river at a given flux. When flux enters an arbitrary location along the estuary, down river concentrations varied little with river flow.

Future recommended work for the Pocomoke River includes:

1. Obtain additional salinity data to test and verify the results of the models. The salinity should be expanded to include winter and spring seasons.
2. Revise the model to a hybrid configuration encompassing both single layer and two-layer boxes to satisfy variable salinity stratification conditions.
3. Modify the configuration of the model to accommodate data from DNR's three continuous monitoring sites. With the available continuous data, apply rates of salinity change per Hagy et al. (2000).
4. Revise the model for the Choptank River. Data are currently available, including box volumes, weighted mean salinity, and river flow.

## Conclusion

1. Box models constructed for the Pocomoke River were a simple way to reproduce the essential features of gravitational circulation and transport using available observed data sets.

2. For tributary estuaries with spatially variable two-layer flow, both one and two-dimensional models are required and show that the Pocomoke River follows the circulation patterns, described by past investigations.
3. It is important to recognize all the possible sources of freshwater. The proportional contribution of water from surrounding wetlands may be different than that above the stream flow gauges
4. The Pocomoke River residence times ranged between 52 to 102 days with the exception of 395 days during the drought of 1999.

# Appendix: Pocomoke River Bottom Survey

## *Introduction*

Generally, the Chesapeake Bay region estuary geometry is available from appropriate navigational charts or documents describing volumetric or areal measurements such as Cronin (1971) or Cronin and Pritchard (1975). For the Pocomoke River, however, these resources did not provided fine enough details to calculate cross sectional areas or volumes required for model geometry. On 28 June 2004 Horn Point Laboratory personnel measured transverse bathymetry along the Pocomoke River and Sound at various sites, including fixed sampling stations established as part of the 1999-2000 Ecology and Oceanography of Harmful Algal Blooms (ECOHAB) Program grant. The survey ranged from station 9A in the Pocomoke Sound to station 30 near Snow Hill, Maryland (Figure 1).

## *Method*

Equipment used for the survey included a Garmin GPSMAP 135 Sounder and GPS 21 differential beacon receiver that interfaced through a Sea Science Acrobat Control to an IBM T21 Thinkpad Computer. The attachment point for the depth sounder transducer was on the stern of a 21-foot workboat. The survey method at each location consisted of four steps: backing the boat near shore, estimating the distance $\sigma_S$ from shore to the GPS antenna mounted on the boat's windscreen, transiting the boat directly to the opposite shore at approximately 5 knots, and on arrival at the opposite shore estimating its distance $\sigma_E$ from the GPS antenna. Estimating distance to the GPS antenna was sometimes difficult because heavy aquatic vegetation that obscured the solid shoreline. In those instances, best guess was used. Recording of GPS and depth data were at one-second intervals.

Data preparation consisted of first purging the GPS and associated depth data of obvious gross errors and then using the freeware program Corpscon, created by the U.S. Army Topographic Engineering Center, to convert GPS geographic points into UTM or X, Y coordinates. This allows lengths $l_{ij}$ between each GPS position to be calculated by the Pythagorean equation

$$l_{ij} = \sqrt{\Delta X_{ij}^{\ 2} + \Delta Y_{ij}^{\ 2}} \ ,$$

where $\Delta X_{ij}$ and $\Delta Y_{ij}$ are the UTM coordinate differences between neighboring GPS points. Because course corrections due to wind and current causes the transit to be somewhat zigzagged, the summed transit distance

$$L = \sum_{0}^{n-1} l_{ij}$$

with $n$ the number of GPS transit points, is greater than the direct distance

$$L' = \sqrt{\Delta X'^2 + \Delta Y'^2} \ ,$$

calculated between the transit ends with $\Delta X'$ and $\Delta Y'$ the coordinate differences. To reduce the zigzag effect, the lengths between GPS points were corrected by

$$l'_{ij} = l_{ij} - c \ ,$$

where

$$c = \frac{L - L'}{n-1}.$$

The total distance across the river for a station of interest including the estimated intervals from shore at both ends of the transit becomes

$$\sum_{0}^{n-1} l'_{ij} + \sigma_s + \sigma_E \ .$$

Cross sectional areas (Table A1) are calculated by two methods; the vertical trapezoid method and the horizontal trapezoid method. The vertical method (Figure A2 upper panel) calculates individual trapezoidal segment areas using the estimated distances $\sigma_s$ and $\sigma_E$ and the corrected lengths $l'_{ij}$ along with their associated GPS point depths. Summing segment areas provides the total cross sectional area. The horizontal trapezoid method (Figure A2 lower panel) calculates segment areas in 0.5 m increments using estimated distances across the river for each increment. Because the lengths are estimated, the sum of the individual 0.5 m segments from surface to bottom may differ from the vertical method, considered the most accurate.

The depth and width data were standardized to mean tide using the National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) web site (http://co-op.nos.noaa.gov/index.html) for the Chesapeake Bay Bridge Tunnel.

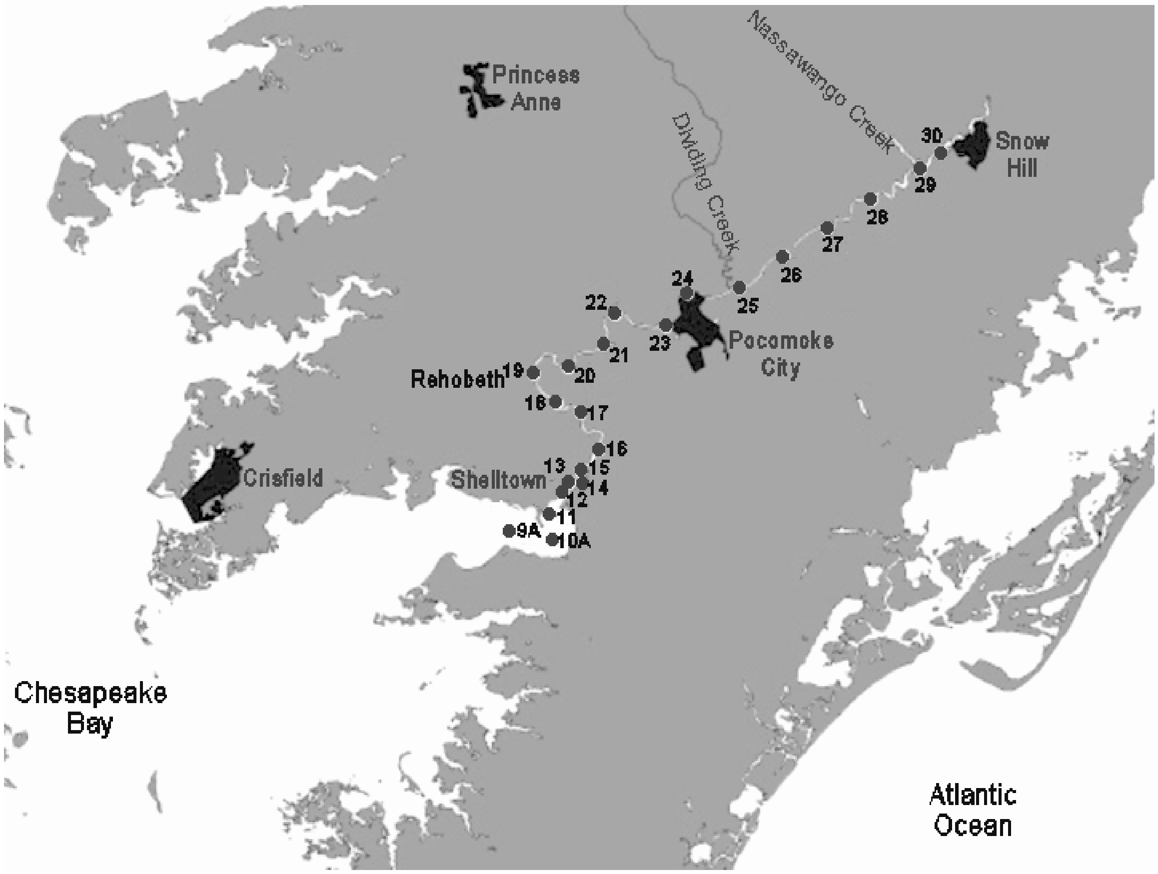



Figure A1. 1999 through 2001 ECOHAB grant fixed sampling stations where cross sectional bottom surveys took place. Those sites not shown are located half way between their neighboring stations, i.e. station 13.5 is half way between stations 13 and 14.

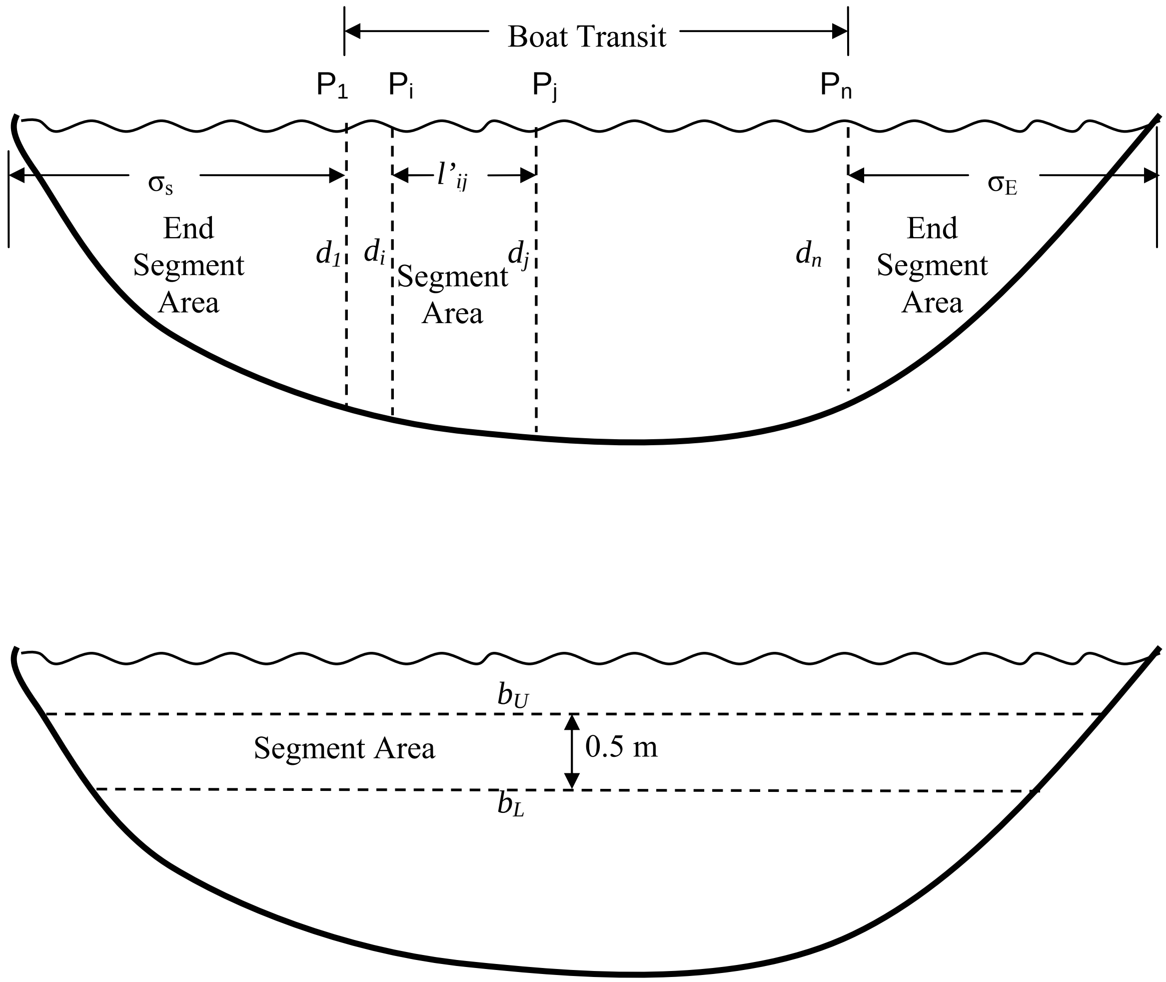



Figure A2. Cross sectional area calculation methods. Upper panel is the vertical method, which calculates end segment areas by $a_s = \frac{1}{2}\sigma_s d_1$ and $a_E = \frac{1}{2}\sigma_E d_n$ and individual segment areas along the boat transit by $a_{ij} = l'_{ij}\frac{(d_i + d_j)}{2}$, where $l'_{ij}$ is distance, corrected for course deviations between neighboring GPS points $P_i$ and $P_j$ and $d_i$ and $d_j$ their associated depths. Summing the individual segment areas provides the total cross sectional area. Lower panel represents the horizontal method that calculates segment areas in 0.5 m increments using $a = 0.5\frac{(b_u + b_L)}{2}$, where $b_u$ and $b_L$ are estimated lengths based on profile depth data.

## *Cross Sectional Areas*

| Station | Latitude | | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|---|
| 9A | 37 | 57.07 | N | 75 40.13 | W | | 0-.5 | 1275 |
| | | | | | | | .5-1.0 | 1236 |
| | | | | | | | 1.0-1.5 | 1067 |
| | | | | | | | 1.5-2.0 | 568 |
| | | | | | | | 2.0-2.5 | 114 |
| | | | | | | | 2.5-3.0 | 32 |
| Total | | | | | | 4281 | | 4291 |
| 10 | 37 | 56.68 | N | 75 39.07 | W | | 0-.5 | 1027 |
| | | | | | | | .5-1.0 | 968 |
| | | | | | | | 1.0-1.5 | 841 |
| | | | | | | | 1.5-2.0 | 220 |
| | | | | | | | 2.0-2.4 | 34 |
| Total | | | | | | 3044 | | 3089 |
| 11 | 37 | 57.85 | N | 75 39.01 | W | | 0.0-0.5 | 417 |
| | | | | | | | 0.5-1.0 | 395 |
| | | | | | | | 1.0-1.5 | 371 |
| | | | | | | | 1.5-2.0 | 340 |
| | | | | | | | 2.0-2.5 | 221 |
| | | | | | | | 2.5-3.0 | 92 |
| | | | | | | | 3.0-3.5 | 47 |
| Total | | | | | | 1887 | | 1883 |
| 11.5 | 37 | 58.04 | N | 75 38.82 | W | | 0.0-0.5 | 236 |
| | | | | | | | 0.5-1.0 | 194 |
| | | | | | | | 1.0-1.5 | 166 |
| | | | | | | | 1.5-2.0 | 153 |
| | | | | | | | 2.0-2.5 | 125 |
| | | | | | | | 2.5-3.0 | 99 |
| | | | | | | | 3.0-3.9 | 100 |
| Total | | | | | | 1078 | | 1072 |

| Station | Latitude | | | Longitude | | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|---|---|
| 12 | 37 | 58.33 | N | 75 | 38.64 | W | | 0.0-0.5 | 122 |
| | | | | | | | | 0.5-1.0 | 110 |
| | | | | | | | | 1.0-1.5 | 99 |
| | | | | | | | | 1.5-2.0 | 95 |
| | | | | | | | | 2.0-2.5 | 92 |
| | | | | | | | | 2.5-3.0 | 88 |
| | | | | | | | | 3.0-3.5 | 77 |
| | | | | | | | | 3.5-4.0 | 57 |
| | | | | | | | | 4.0-4.5 | 38 |
| | | | | | | | | 4.5-4.9 | 15 |
| Total | | | | | | | 796 | | 794 |
| | | | | | | | | | |
| 12.5 | 37 | 58.49 | N | 75 | 38.59 | W | | 0.0-0.5 | 138 |
| | | | | | | | | 0.5-1.0 | 122 |
| | | | | | | | | 1.0-1.5 | 105 |
| | | | | | | | | 1.5-2.0 | 103 |
| | | | | | | | | 2.0-2.5 | 100 |
| | | | | | | | | 2.5-3.0 | 95 |
| | | | | | | | | 3.0-3.5 | 89 |
| | | | | | | | | 3.5-4.0 | 67 |
| Total | | | | | | | 822 | | 819 |
| | | | | | | | | | |
| 13 | 37 | 58.63 | N | 75 | 38.40 | W | | 0.0-0.5 | 111 |
| | | | | | | | | 0.5-1.0 | 99 |
| | | | | | | | | 1.0-1.5 | 89 |
| | | | | | | | | 1.5-2.0 | 84 |
| | | | | | | | | 2.0-2.5 | 80 |
| | | | | | | | | 2.5-3.0 | 75 |
| | | | | | | | | 3.0-3.5 | 67 |
| | | | | | | | | 3.5-4.0 | 59 |
| | | | | | | | | 4.0-4.5 | 50 |
| | | | | | | | | 4.5-5.0 | 39 |
| | | | | | | | | 5.0-5.5 | 24 |
| | | | | | | | | 5.5-6.1 | 10 |
| Total | | | | | | | 781 | | 787 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| 13.5 | 37 | 58.66 N | 75 | 38.08 W | | 0.0-0.5 | 103 |
| | | | | | | 0.5-1.0 | 101 |
| | | | | | | 1.0-1.5 | 99 |
| | | | | | | 1.5-2.0 | 97 |
| | | | | | | 2.0-2.5 | 97 |
| | | | | | | 2.5-3.0 | 94 |
| | | | | | | 3.0-3.5 | 84 |
| | | | | | | 3.5-4.0 | 72 |
| | | | | | | 4.0-4.5 | 66 |
| | | | | | | 4.5-5.0 | 50 |
| | | | | | | 5.0-5.5 | 31 |
| | | | | | | 5.5-6.2 | 26 |
| Total | | | | | 912 | | 919 |
| 14 | 37 | 58.53 N | 75 | 37.80 W | | 0.0-0.5 | 81 |
| | | | | | | 0.5-1.0 | 76 |
| | | | | | | 1.0-1.5 | 73 |
| | | | | | | 1.5-2.0 | 72 |
| | | | | | | 2.0-2.5 | 70 |
| | | | | | | 2.5-3.0 | 66 |
| | | | | | | 3.0-3.5 | 63 |
| | | | | | | 3.5-4.0 | 61 |
| | | | | | | 4.0-4.5 | 59 |
| | | | | | | 4.5-5.0 | 54 |
| | | | | | | 5.0-5.5 | 51 |
| | | | | | | 5.5-6.0 | 47 |
| | | | | | | 6.0-6.5 | 25 |
| | | | | | | 6.5-7.0 | 3 |
| Total | | | | | 800 | | 800 |
| 14.5 | 37 | 58.86 N | 75 | 37.95 W | | 0.0-0.5 | 155 |
| | | | | | | 0.5-1.0 | 146 |
| | | | | | | 1.0-1.5 | 127 |
| | | | | | | 1.5-2.0 | 98 |

| Station | Latitude | Longitude | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|
| | | | | 2.0-2.5 | 81 |
| | | | | 2.5-3.0 | 68 |
| | | | | 3.0-3.5 | 60 |
| | | | | 3.5-4.0 | 43 |
| | | | | 4.0-4.5 | 22 |
| | | | 803 | | 801 |
| Total | | | | | |
| 15 | 37 59.12 N | 75 38.04 W | | 0.0-0.5 | 84 |
| | | | | 0.5-1.0 | 76 |
| | | | | 1.0-1.5 | 71 |
| | | | | 1.5-2.0 | 67 |
| | | | | 2.0-2.5 | 64 |
| | | | | 2.5-3.0 | 60 |
| | | | | 3.0-3.5 | 54 |
| | | | | 3.5-4.0 | 47 |
| | | | | 4.0-4.5 | 37 |
| | | | | 4.5-5.0 | 22 |
| | | | | 5.0-5.5 | 9 |
| Total | | | 600 | | 591 |
| 15.5 | 37 59.46 N | 75 37.53 W | | 0.0-0.5 | 77 |
| | | | | 0.5-1.0 | 75 |
| | | | | 1.0-1.5 | 74 |
| | | | | 1.5-2.0 | 69 |
| | | | | 2.0-2.5 | 65 |
| | | | | 2.5-3.0 | 61 |
| | | | | 3.0-3.5 | 56 |
| | | | | 3.5-4.0 | 50 |
| | | | | 4.0-4.5 | 39 |
| | | | | 4.5-5.0 | 27 |
| | | | | 5.0-5.7 | 19 |
| Total | | | 615 | | 612 |
| 16 | 37 59.84 N | 75 37.33 W | | 0.0-0.5 | 76 |
| | | | | 0.5-1.0 | 70 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 1.0-1.5 | 64 |
| | | | | | | 1.5-2.0 | 60 |
| | | | | | | 2.0-2.5 | 58 |
| | | | | | | 2.5-3.0 | 56 |
| | | | | | | 3.0-3.5 | 52 |
| | | | | | | 3.5-4.0 | 48 |
| | | | | | | 4.0-4.5 | 44 |
| | | | | | | 4.5-5.0 | 37 |
| | | | | | | 5.0-5.5 | 24 |
| | | | | | | 5.5-5.9 | 8 |
| Total | | | | | 600 | | 598 |
| | | | | | | | |
| 16.5 | 38 | 0.40 N | 75 | 37.18 W | | 0.0-0.5 | 53 |
| | | | | | | 0.5-1.0 | 50 |
| | | | | | | 1.0-1.5 | 48 |
| | | | | | | 1.5-2.0 | 43 |
| | | | | | | 2.0-2.5 | 38 |
| | | | | | | 2.5-3.0 | 37 |
| | | | | | | 3.0-3.5 | 35 |
| | | | | | | 3.5-4.0 | 33 |
| | | | | | | 4.0-4.5 | 29 |
| | | | | | | 4.5-5.0 | 25 |
| | | | | | | 5.0-5.5 | 24 |
| | | | | | | 5.5-6.0 | 22 |
| | | | | | | 6.0-6.5 | 19 |
| | | | | | | 6.5-7.0 | 16 |
| | | | | | | 7.0-7.5 | 14 |
| | | | | | | 7.5-8.0 | 13 |
| | | | | | | 8.0-8.8 | 10 |
| Total | | | | | 533 | | 508 |
| | | | | | | | |
| 17 | 38 | 0.99 N | 75 | 37.87 W | | 0.0-0.5 | 71 |
| | | | | | | 0.5-1.0 | 68 |
| | | | | | | 1.0-1.5 | 64 |
| | | | | | | 1.5-2.0 | 57 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 2.0-2.5 | 53 |
| | | | | | | 2.5-3.0 | 44 |
| | | | | | | 3.0-3.5 | 35 |
| | | | | | | 3.5-4.0 | 32 |
| | | | | | | 4.0-4.5 | 30 |
| | | | | | | 4.5-5.0 | 26 |
| | | | | | | 5.0-5.5 | 20 |
| | | | | | | 5.5-6.0 | 11 |
| Total | | | | | 513 | | 512 |
| | | | | | | | |
| 17.5 | 38 | 1.30 N | 75 | 38.14 W | | 0.0-0.5 | 84 |
| | | | | | | 0.5-1.0 | 75 |
| | | | | | | 1.0-1.5 | 68 |
| | | | | | | 1.5-2.0 | 64 |
| | | | | | | 2.0-2.5 | 59 |
| | | | | | | 2.5-3.0 | 50 |
| | | | | | | 3.0-3.5 | 37 |
| | | | | | | 3.5-4.0 | 27 |
| | | | | | | 4.0-5.0 | 27 |
| Total | | | | | 487 | | 491 |
| | | | | | | | |
| 18 | 38 | 1.33 N | 75 | 38.81 W | | 0.0-0.5 | 64 |
| | | | | | | 0.5-1.0 | 62 |
| | | | | | | 1.0-1.5 | 63 |
| | | | | | | 1.5-2.0 | 58 |
| | | | | | | 2.0-2.5 | 54 |
| | | | | | | 2.5-3.0 | 53 |
| | | | | | | 3.0-3.5 | 48 |
| | | | | | | 3.5-4.0 | 43 |
| | | | | | | 4.0-4.5 | 39 |
| | | | | | | 4.5-5.0 | 35 |
| | | | | | | 5.0-5.5 | 21 |
| | | | | | | 5.5-5.7 | 2 |
| Total | | | | | 541 | | 542 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| 18.5 | 38 | 1.78 N | 75 | 39.33 W | | 0.0-0.5 | 71 |
| | | | | | | 0.5-1.0 | 61 |
| | | | | | | 1.0-1.5 | 53 |
| | | | | | | 1.5-2.0 | 49 |
| | | | | | | 2.0-2.5 | 47 |
| | | | | | | 2.5-3.0 | 45 |
| | | | | | | 3.0-3.5 | 42 |
| | | | | | | 3.5-4.0 | 39 |
| | | | | | | 4.0-4.5 | 32 |
| | | | | | | 4.5-5.0 | 20 |
| | | | | | | 5.0-5.5 | 8 |
| Total | | | | | 463 | | 465 |
| | | | | | | | |
| 19 | 38 | 2.37 N | 75 | 39.67 W | | 0.0-0.5 | 51 |
| | | | | | | 0.5-1.0 | 47 |
| | | | | | | 1.0-1.5 | 42 |
| | | | | | | 1.5-2.0 | 40 |
| | | | | | | 2.0-2.5 | 37 |
| | | | | | | 2.5-3.0 | 35 |
| | | | | | | 3.0-3.5 | 34 |
| | | | | | | 3.5-4.0 | 32 |
| | | | | | | 4.0-4.5 | 30 |
| | | | | | | 4.5-5.0 | 28 |
| | | | | | | 5.0-5.5 | 26 |
| | | | | | | 5.5-6.0 | 22 |
| | | | | | | 6.0-6.5 | 19 |
| | | | | | | 6.5-7.0 | 8 |
| Total | | | | | 455 | | 453 |
| | | | | | | | |
| 19.5 | 38 | 2.96 N | 75 | 39.51 W | | 0.0-0.5 | 59 |
| | | | | | | 0.5-1.0 | 57 |
| | | | | | | 1.0-1.5 | 57 |
| | | | | | | 1.5-2.0 | 57 |
| | | | | | | 2.0-2.5 | 57 |
| | | | | | | 2.5-3.0 | 55 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 3.0-3.5 | 52 |
| | | | | | | 3.5-4.0 | 44 |
| | | | | | | 4.0-4.5 | 34 |
| | | | | | | 4.5-5.0 | 26 |
| | | | | | | 5.0-5.5 | 11 |
| Total | | | | | 501 | | 509 |
| | | | | | | | |
| 20 | 38 | 2.72 N | 75 | 38.60 W | | 0.0-0.5 | 59 |
| | | | | | | 0.5-1.0 | 55 |
| | | | | | | 1.0-1.5 | 55 |
| | | | | | | 1.5-2.0 | 55 |
| | | | | | | 2.0-2.5 | 51 |
| | | | | | | 2.5-3.0 | 46 |
| | | | | | | 3.0-3.5 | 44 |
| | | | | | | 3.5-4.0 | 36 |
| | | | | | | 4.0-4.7 | 23 |
| Total | | | | | 431 | | 425 |
| | | | | | | | |
| 20.5 | 38 | 3.15 N | 75 | 38.05 W | | 0.0-0.5 | 48 |
| | | | | | | 0.5-1.0 | 44 |
| | | | | | | 1.0-1.5 | 44 |
| | | | | | | 1.5-2.0 | 44 |
| | | | | | | 2.0-2.5 | 44 |
| | | | | | | 2.5-3.0 | 43 |
| | | | | | | 3.0-3.5 | 41 |
| | | | | | | 3.5-4.0 | 41 |
| | | | | | | 4.0-4.5 | 40 |
| | | | | | | 4.5-5.0 | 34 |
| | | | | | | 5.0-5.5 | 26 |
| | | | | | | 5.5-6.0 | 22 |
| | | | | | | 6.0-6.5 | 10 |
| Total | | | | | 479 | | 482 |
| | | | | | | | |
| 21 | 38 | 3.40 N | 75 | 37.24 W | | 0.0-0.5 | 54 |
| | | | | | | 0.5-1.0 | 51 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 1.0-1.5 | 43 |
| | | | | | | 1.5-2.0 | 39 |
| | | | | | | 2.0-2.5 | 36 |
| | | | | | | 2.5-3.0 | 33 |
| | | | | | | 3.0-3.5 | 33 |
| | | | | | | 3.5-4.0 | 30 |
| | | | | | | 4.0-4.5 | 25 |
| | | | | | | 4.5-5.0 | 22 |
| | | | | | | 5.0-5.5 | 19 |
| | | | | | | 5.5-6.0 | 16 |
| | | | | | | 6.0-6.5 | 12 |
| | | | | | | 6.5-7.0 | 7 |
| | | | | | | 7.0-7.3 | 1 |
| Total | | | | | 421 | | 422 |
| | | | | | | | |
| 21.5 | 38 | 3.87 N | 75 | 36.98 W | | 0.0-0.5 | 50 |
| | | | | | | 0.5-1.0 | 43 |
| | | | | | | 1.0-1.5 | 40 |
| | | | | | | 1.5-2.0 | 38 |
| | | | | | | 2.0-2.5 | 38 |
| | | | | | | 2.5-3.0 | 36 |
| | | | | | | 3.0-3.5 | 30 |
| | | | | | | 3.5-4.0 | 29 |
| | | | | | | 4.0-4.5 | 29 |
| | | | | | | 4.5-5.0 | 25 |
| | | | | | | 5.0-5.5 | 23 |
| | | | | | | 5.5-6.0 | 22 |
| | | | | | | 6.0-6.5 | 17 |
| | | | | | | 6.5-7.0 | 13 |
| | | | | | | 7.0-7.5 | 12 |
| | | | | | | 7.5-8.2 | 13 |
| Total | | | | | 461 | | 456 |
| | | | | | | | |
| 22 | 38 | 4.49 N | 75 | 36.76 W | | 0.0-0.5 | 48 |
| | | | | | | 0.5-1.0 | 46 |

| Station | Latitude | | Longitude | | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1.0-1.5 | 46 |
| | | | | | | | 1.5-2.0 | 46 |
| | | | | | | | 2.0-2.5 | 42 |
| | | | | | | | 2.5-3.0 | 37 |
| | | | | | | | 3.0-3.5 | 36 |
| | | | | | | | 3.5-4.0 | 35 |
| | | | | | | | 4.0-4.5 | 32 |
| | | | | | | | 4.5-5.0 | 29 |
| | | | | | | | 5.0-5.5 | 24 |
| | | | | | | | 5.5-6.0 | 12 |
| Total | | | | | | 430 | | 435 |
| | | | | | | | | |
| 22.5 | 38 | 4.18 N | 75 | 36.00 | W | | 0.0-0.5 | 46 |
| | | | | | | | 0.5-1.0 | 45 |
| | | | | | | | 1.0-1.5 | 45 |
| | | | | | | | 1.5-2.0 | 41 |
| | | | | | | | 2.0-2.5 | 37 |
| | | | | | | | 2.5-3.0 | 37 |
| | | | | | | | 3.0-3.5 | 36 |
| | | | | | | | 3.5-4.0 | 34 |
| | | | | | | | 4.0-4.5 | 32 |
| | | | | | | | 4.5-5.0 | 30 |
| | | | | | | | 5.0-5.5 | 29 |
| | | | | | | | 5.5-6.0 | 27 |
| | | | | | | | 6.0-6.5 | 24 |
| | | | | | | | 6.5-7.0 | 21 |
| | | | | | | | 7.0-7.6 | 14 |
| Total | | | | | | 493 | | 496 |
| | | | | | | | | |
| 23 | 38 | 4.09 N | 75 | 34.97 | W | | 0.0-0.5 | 46 |
| | | | | | | | 0.5-1.0 | 44 |
| | | | | | | | 1.0-1.5 | 41 |
| | | | | | | | 1.5-2.0 | 41 |
| | | | | | | | 2.0-2.5 | 41 |
| | | | | | | | 2.5-3.0 | 40 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 3.0-3.5 | 35 |
| | | | | | | 3.5-4.0 | 31 |
| | | | | | | 4.0-4.5 | 29 |
| | | | | | | 4.5-5.0 | 25 |
| | | | | | | 5.0-5.5 | 21 |
| | | | | | | 5.5-6.0 | 16 |
| | | | | | | 6.0-6.5 | 10 |
| | | | | | | 6.5-6.7 | 1 |
| Total | | | | | 422 | | 422 |
| | | | | | | | |
| 23.5 | 38 | 4.44 N | 75 | 34.34 W | | 0.0-0.5 | 36 |
| | | | | | | 0.5-1.0 | 34 |
| | | | | | | 1.0-1.5 | 34 |
| | | | | | | 1.5-2.0 | 34 |
| | | | | | | 2.0-2.5 | 34 |
| | | | | | | 2.5-3.0 | 34 |
| | | | | | | 3.0-3.5 | 34 |
| | | | | | | 3.5-4.0 | 34 |
| | | | | | | 4.0-4.5 | 31 |
| | | | | | | 4.5-5.0 | 25 |
| | | | | | | 5.0-5.5 | 22 |
| | | | | | | 5.5-6.0 | 20 |
| | | | | | | 6.0-6.5 | 19 |
| | | | | | | 6.5-7.0 | 16 |
| | | | | | | 7.0-7.5 | 13 |
| | | | | | | 7.5-8.0 | 10 |
| | | | | | | 8.0-8.7 | 6 |
| Total | | | | | 446 | | 434 |
| | | | | | | | |
| 24 | 38 | 5.27 N | 75 | 34.03 W | | 0.0-0.5 | 39 |
| | | | | | | 0.5-1.0 | 36 |
| | | | | | | 1.0-1.5 | 36 |
| | | | | | | 1.5-2.0 | 36 |
| | | | | | | 2.0-2.5 | 36 |
| | | | | | | 2.5-3.0 | 35 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 3.0-3.5 | 35 |
| | | | | | | 3.5-4.0 | 33 |
| | | | | | | 4.0-4.5 | 31 |
| | | | | | | 4.5-5.0 | 30 |
| | | | | | | 5.0-5.5 | 26 |
| | | | | | | 5.5-6.0 | 17 |
| | | | | | | 6.0-6.7 | 9 |
| Total | | | | | 391 | | 400 |
| | | | | | | | |
| 25 | 38 | 5.41 N | 75 | 32.30 W | | 0.0-0.5 | 54 |
| | | | | | | 0.5-1.0 | 50 |
| | | | | | | 1.0-1.5 | 51 |
| | | | | | | 1.5-2.0 | 48 |
| | | | | | | 2.0-2.5 | 42 |
| | | | | | | 2.5-3.0 | 39 |
| | | | | | | 3.0-3.5 | 37 |
| | | | | | | 3.5-4.0 | 35 |
| | | | | | | 4.0-4.5 | 33 |
| | | | | | | 4.5-5.0 | 30 |
| | | | | | | 5.0-5.5 | 23 |
| | | | | | | 5.5-6.0 | 16 |
| | | | | | | 6.0-6.3 | 7 |
| Total | | | | | 467 | | 466 |
| | | | | | | | |
| 26 | 38 | 6.55 N | 75 | 30.63 W | | 0.0-0.5 | 50 |
| | | | | | | 0.5-1.0 | 45 |
| | | | | | | 1.0-1.5 | 40 |
| | | | | | | 1.5-2.0 | 40 |
| | | | | | | 2.0-2.5 | 38 |
| | | | | | | 2.5-3.0 | 35 |
| | | | | | | 3.0-3.5 | 32 |
| | | | | | | 3.5-4.0 | 32 |
| | | | | | | 4.0-4.5 | 30 |
| | | | | | | 4.5-5.0 | 27 |
| | | | | | | 5.0-5.5 | 25 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 5.5-6.0 | 22 |
| | | | | | | 6.0-6.5 | 18 |
| | | | | | | 6.5-7.0 | 10 |
| Total | | | | | 442 | | 445 |
| 27 | 38 | 7.51 N | 75 | 28.87 W | | 0.0-0.5 | 47 |
| | | | | | | 0.5-1.0 | 43 |
| | | | | | | 1.0-1.5 | 43 |
| | | | | | | 1.5-2.0 | 43 |
| | | | | | | 2.0-2.5 | 42 |
| | | | | | | 2.5-3.0 | 40 |
| | | | | | | 3.0-3.5 | 40 |
| | | | | | | 3.5-4.0 | 37 |
| | | | | | | 4.0-4.5 | 35 |
| | | | | | | 4.5-5.0 | 33 |
| | | | | | | 5.0-5.5 | 29 |
| | | | | | | 5.5-6.0 | 16 |
| | | | | | | 6.0-6.1 | 1 |
| Total | | | | | 448 | | 450 |
| 28 | 38 | 8.58 N | 75 | 27.16 W | | 0.0-0.5 | 50 |
| | | | | | | 0.5-1.0 | 45 |
| | | | | | | 1.0-1.5 | 43 |
| | | | | | | 1.5-2.0 | 41 |
| | | | | | | 2.0-2.5 | 40 |
| | | | | | | 2.5-3.0 | 38 |
| | | | | | | 3.0-3.5 | 36 |
| | | | | | | 3.5-4.0 | 34 |
| | | | | | | 4.0-4.5 | 31 |
| | | | | | | 4.5-5.0 | 29 |
| | | | | | | 5.0-5.5 | 27 |
| | | | | | | 5.5-6.4 | 25 |
| Total | | | | | 440 | | 440 |
| 29 | 38 | 9.56 N | 75 | 25.68 W | | 0.0-0.5 | 56 |

| Station | Latitude | | Longitude | | Area ($m^2$) Vertical Method | Depth (m) | Area ($m^2$) Horizontal Method |
|---|---|---|---|---|---|---|---|
| | | | | | | 0.5-1.0 | 47 |
| | | | | | | 1.0-1.5 | 41 |
| | | | | | | 1.5-2.0 | 38 |
| | | | | | | 2.0-2.5 | 34 |
| | | | | | | 2.5-3.0 | 31 |
| | | | | | | 3.0-3.5 | 28 |
| | | | | | | 3.5-4.0 | 23 |
| | | | | | | 4.0-4.5 | 16 |
| | | | | | | 4.5-4.9 | 5 |
| Total | | | | | 318 | | 317 |
| | | | | | | | |
| 30 | 38 | 10.06 N | 75 | 24.77 W | | 0.0-0.5 | 69 |
| | | | | | | 0.5-1.0 | 53 |
| | | | | | | 1.0-1.5 | 42 |
| | | | | | | 1.5-2.0 | 39 |
| | | | | | | 2.0-2.5 | 36 |
| | | | | | | 2.5-3.0 | 34 |
| | | | | | | 3.0-3.4 | 16 |
| Total | | | | | 293 | | 288 |

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