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CONTRIBUTION TO THE HYDROBIOLOGY OF THE YORK RIVER: PREDICTING SURFACE MIXED LAYER DEPTH

The College of William and Mary in Virginia Ph.D. 1986

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CONTRIBUTION TO THE HYDROBIOLOGY OF THE YORK RIVER: PREDICTING SURFACE MIXED LAYER DEPTH

A Dissertation
Presented to
The Faculty of the School of Marine Science
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Doctor of Philosophy

by
Donald Max Hayward
1986

APPROVAL SHEET

This dissertation is submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy

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Approved, May 1986

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DEDICATION

This dissertation is dedicated to Madelyn and Lauren.

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ACKNOWLEDGEMENTS

I must acknowledge my debt to those who co-authored this work in its published form. I am particularly indebted to K.L. Webb and L.W. Hass for support, companionship, criticism and motivation; they asked good questions. The foresight and perseverance of J.D. Boon, III in the collection and analysis of local tidal data at Gloucester Point and the ambition and imagination of K.D. Friedland who also wanted to sample the York River at impossibly short intervals are hereby recognized.

In addition I acknowledge a singular debt to C.S. Welch whose question for my comprehensive examination precipitated much of the work presented here. I quote the question in full:

> The rationale for the scientific examination of a given entity (e.g. sample, water body or set of parameters within a model) always includes an assumption, sometimes implicit, that the results from the particular examination can be applied to a wider set of entities. In general, the greater the set of entities to which the result can be applied, the stronger the justification is for the examination. For example, if the yield of a set of seeds is used to predict the yield of a larger area, the result is considered increasingly useful as the larger area progresses from a garden to a field, county, or agricultural region. The same principle applies to studies of the York River. The weight of justification for the studies increases as the applicability of the results becomes wider.
>
> One result of studies in the York River is that the water column destratifies during the summer months in the lower part of the estuary in synchrony with the spring/neap tidal cycle. Your task, should you agree to accept it, is to prepare a written discussion of the applicability of this result.
>
> Within the discussion, the topics of theoretical concepts, physical description and estimation of the reange of applicability should be treated separately. In the theoretical section, factors which might influence the occurence and timing of destratification should be introduced, and the appropriate relations between them should be addressed. These might include, in part, the effects of channel geometry, horizontal density gradient, amplitudes of tidal heights and currents, heating and cooling, and the equation of state for salt water. The physical description should compare the York to other estuaries in ways which are theoretically significant. These comaprisons would be based on observed and literature values of salinity, estimated basin runoff, annual temperature cycles, _etc_. Finally, comparisons should be made with other systems (or other times) in which destratification has been documented to occur, or not occur. In this way, the ranges for the occurence of destratification, and hence the applicability of the York River observations, can be estimated.

As such a synthesis has not, to my knowledge, been done, the resulting discussion has potential for publication. You are free to use any source of information, including people open to you. Of course, you will acknowledge help and cite references.

Acknowledged.

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ABSTRACT

Destratification in the York River, USA, during high spring tides is the result of the interruption of normal two-layer estuarine flow by advection of relatively fresh water into the River mouth from the Chesapeake Bay. This is due to the presence of a longitudinal salinity gradient in the Bay and a difference of tidal current phase between the River and the Bay. Similar behavior is seen in other subestuaries of the Chesapeake Bay and may be common in subestuary-estuary interactions.

Correlation and regression analysis are used to examine relationships between stratification variation in the lower York River and a variety of tidal and environmental parameters. A bulk measure of statification was derived from near surface (1, 3, and 5 m) and deep (12 m) salinity samples collected approximately every third day at a station in the lower river for a total of 156 observations over a 434 day period from February 1982 to April 1983. The environmental and tidal factors which were evaluated were assessed on a daily basis and incorporated a variety of lags, polynomial functions and functional transformations. The factors included wind speed and direction, fresh water river flow from both the York and Rappahanock Rivers, water temperature, mean sea level and the following tidal parameters: observed and predicted daily mean and maximum high and low tide height, flood, ebb, and combined flood and ebb tidal ranges for the York River at Gloucester Point and for Hampton Roads. The results indicate that: (1) almost all of the tidal range or high tide height factors tested are equally strongly correlated with salinity difference, being associated with as much as 48% of the variation in that value; (2) that a combination of functions of tidal range and mean sea level at Gloucester Point are associated with more than 70% of the variation; and (3) that with the addition of wind stress terms as much as 80% of the variation can be included in the model. Over a range of observed salinity differences from 0.01 to 11.06 per mille the 25 term model predicts a range of -1.01 to 11.09 per mille with a root mean squared error (RMSE) of 0.99 per mille. A model predicting variation in surface mixed layer depth (SMLD) from salinity difference is also presented.

CONTRIBUTION TO THE HYDROBIOLOGY OF THE YORK RIVER: PREDICTING SURFACE MIXED LAYER DEPTH

INTRODUCTION

The influence of tides on estuarine processes has long been of interest to estuarine hydrographers and biologists. Recently it was shown that moderately stratified subestuaries of the lower Chesapeake Bay undergo periods of destratification (i.e. surface to bottom salinity differences less than 1 per mille) which correlate with the occurrence of high spring tides (Haas, 1977). For example, the lower York River becomes vertically homogeneous three to four days after the predicted tide height exceeds 0.8 m (Haas, 1977) and homogeneity persists for three or more days. These events are not correlated with changes in fresh water flow into the River (Haas, 1977). Some of the significant consequences of destratification events in the York River include a periodic resupply of oxygen in the bottom water with an accompanying renewal of nutrients near the surface (D'Elia, et. al., 1981; Phoel, et. al., 1981; Webb and D'Elia, 1980), and changes in primary productivity including blooms of dinoflagellates and other phytoplankton (Haas, Hastings, and Webb, 1981). A conceptual model of the causes of these destratification events is presented in Chapter I.

Previous studies of the spring tide associated destratification phenomenon in the York River have related salinity difference with tidal height and predicted tides. Efforts to sample salinity difference have lacked either sufficient frequency (i.e. >= 0.25 per day) or duration (i.e. >= 1 year) to properly address the potential effect of nonpredictable and seasonal environmental factors such as fresh water flow and wind on the rapid destratification process in this estuary. The availability of a longer term set of observations of reasonable frequency has permitted analysis of the effects of several factors on the process of vertical mixing in the lower York River. Factors examined include observed and predicted tidal ranges and heights and nontidal sea level at Gloucester Point and Hampton Roads, water temperature, wind speed and direction, and fresh water discharge of the York and Rappahanock Rivers. A description of the analysis and the resulting empirical models is presented in Chapter II.

CHAPTER I

YORK RIVER DESTRATIFICATION: AN ESTUARY-SUBESTUARY INTERACTION

Two theoretical discussions of spring-neap tidally related stratification variations have been reported (Bowden and Hamilton, 1975; Godfrey, 1980). Both of these models describe reductions in stratification which coincide with the occurrence of strong tidal currents and do not persist in the absence of such currents. This coincidence is in contrast to destratification in the lower York River, where vertical homogeneity first appears a few days after the onset of strong tidal currents and persists for several days thereafter (Haas, 1977; Haas, Holden, and Welch, 1981). Although Godfrey's model, which made vertical salinity distribution dependent on tidal current velocity and logitudinal salinity gradient, did not reproduce the York River type of destratification, he went on to suggest that vertical homogeneity could be understood if the longstream salinity gradient went to zero. The salt balance equation in his model would then fail up to about one tidal excursion length from the estuary mouth because some water swept out of the river on the ebb tide would be replaced by different water on the flood (Godfrey, 1980).

A conceptual model for the onset and disappearance of vertical homogeneity in the York River is therefore as follows: 1) Destratification commences when spring tides exceed a critical height and relatively fresh water from the Chesapeake Bay is advected into the mouth of the York River. 2) This produces a reduction or possibly a reversal of the pressure gradient driving estuarine circulation. The concomitant diminution of two-layer circulation reduces the tendency toward statification by limiting the importation of more saline bottom water. 3) This permits establishment of homogeneity by the unopposed action of normal mixing processes enhanced by strong spring tidal currents. 4) Destratification ceases when the decrease in tide height following spring tides halts the advection of the fresher water into the York River. 5) This allows the re-establishment of a normal horizontal salinity gradient which produces the eventual re-initiation of two-layer estuarine circulation and vertical salinity stratification.

This hypothesis developed from the examination of salinity data (Figs. 1A,1B) collected during intensive studies of two destratification events which were predicted on the basis of earlier work (Haas, 1977; Haas, Holden, and Welch, 1981). The intrusion of relatively fresh water which initiated the destratification process is indicated by the sharp downward displacement of isohalines on 16 August 1978 and 26 August 1980. In each case, this was followed by a progressive reduction of stratification in the water column. As expected, the introduction of fresher water into the River mouth caused a reversal of the longitudinal salinity gradient producing a mid-river salinity maximum. This condition is illustrated in Table 1 where York River salinity values at 1 m depth are shown for the period 0-3 days following the intrusion of fresher water observed on 25 August 1980 (Fig. 1B). The data indicate a reversal of the normal longitudinal salinity gradient as far as 18 km upriver. A similar reversal was observed on several occasions between 15 and 20 August 1978 (Haas, Holden and Welch, 1981).

Figure 1. Salinity data from the York River Mouth for the periods 16-23 August 1978 (A) and 25 August-1 September 1980 (B). Salinity is per mille. The arrows indicate the dates of maximum spring tide. $\bar{\Delta}$ is the daily mean of 1 m to bottom differences in salinity. Periods of ebb (E) and flood (F) are indicated. Points indicate measurements. Data for Figure 1a are from (Haas, Holden and Welch, 1981). Data for Figure 1b were collected from the R.V. <u>Retriever</u> using an ICTI, on loan from The Johns Hopkins University, which was lowered through the water column.

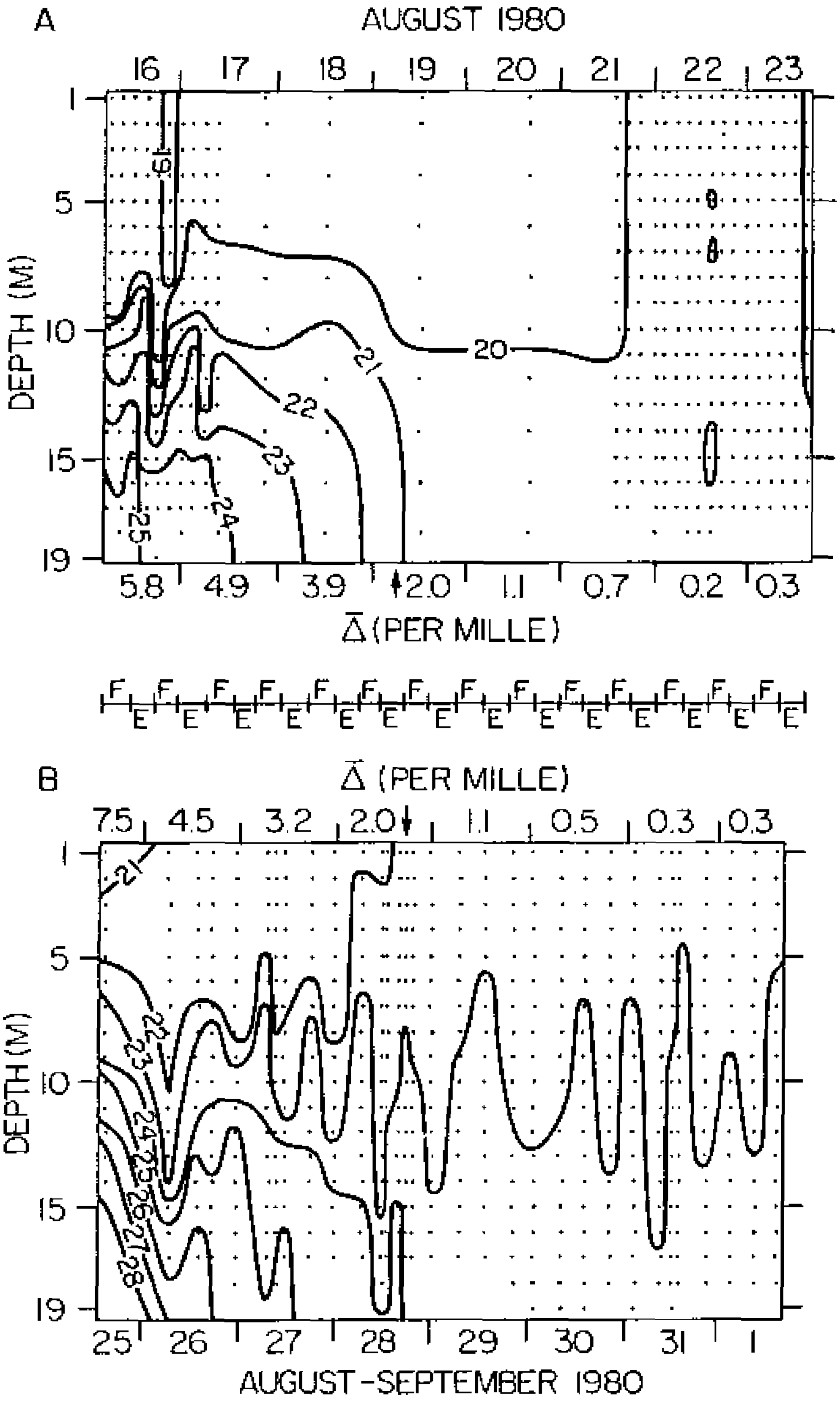

A
AUGUST 1980
16
17
18
19
20
21
22
23
DEPTH (M)
1
5
10
15
19
19
20
21
22
23
24
25
5.8
4.9
3.9
2.0
1.1
0.7
0.2
0.3
$\bar{\Delta}$ (PER MILLE)
F
E
B
$\bar{\Delta}$ (PER MILLE)
7.5
4.5
3.2
2.0
1.1
0.5
0.3
0.3
21
22
23
24
25
26
27
28
25
26
27
28
29
30
31
1
AUGUST-SEPTEMBER 1980

Table 1. Salinity data for the York River 25-28 August 1980. Depth is 1 M and all stations are in mid-channel.

DISTANCE UPRIVER KM	SALINITY PER MILLE			
	25 August	26 August	27 August	28 August
0.00	20.5	21.0	21.0	21.8
3.38	--.-	--.-	21.6	22.4
5.66	--.-	23.7	21.8	22.3
8.33	--.-	--.-	22.0	22.4
12.34	21.3	24.1	23.3	--.-
18.09	22.5	--.-	--.-	--.-
22.53	--.-	--.-	21.7	--.-
30.18	20.3	--.-	20.0	--.-

Data at 0.00 km are the same as at 1 m in Fig. 1b. Other data were collected from the R.V. Pumpkin using a YSI model 33-S-C-T, with the probe lowered through the water column. Values were standardized to the ICTI used on the R.V. Retriever (Fig. 1).

The reversal of the longitudinal salinity gradient is also evident from the behavior of the 23 per mille isohaline in the 1980 data (Fig. 1B). The assumption is made that the salinity changes at the station are largely caused by water of differing salinity being advected up and down the River by tidal currents. Depressions in the isohaline, indicating the presence of fresher water, coincide with slack before ebb through August 28, the date of highest tidal heights. After that date the 23 per mille isohaline shows a phase reversal. The depressions are coincident with slack before flood, indicating the re-establishment of the normal longitudinal salinity gradient. While tidal heights were increasing there was a continuing source of fresher water. As tidal heights recede, water of greater salinity is once again present in the River mouth.

The only reasonable source for the relatively fresh water is the Chesapeake Bay. An upriver source is discounted first because the water is introduced into the River mouth on flood tide (Fig. 1B), and second because the nearest riverine source of water of comparable salinity is approximately 30 km upriver (Table 1). On the other hand, because the salinity distribution in the Chesapeake Bay is characterized by a decrease northward (Pritchard, 1952; Pritchard, 1967), fresher Bay water is not far from the River mouth. For example, paired samples taken during a period of mean tidal range, 10 and 16 July 1980, in the River mouth and near New Point Comfort, an area less than 12 km northeast (Fig. 2), revealed a mean salinity difference of 1.2 per mille (Table 2).

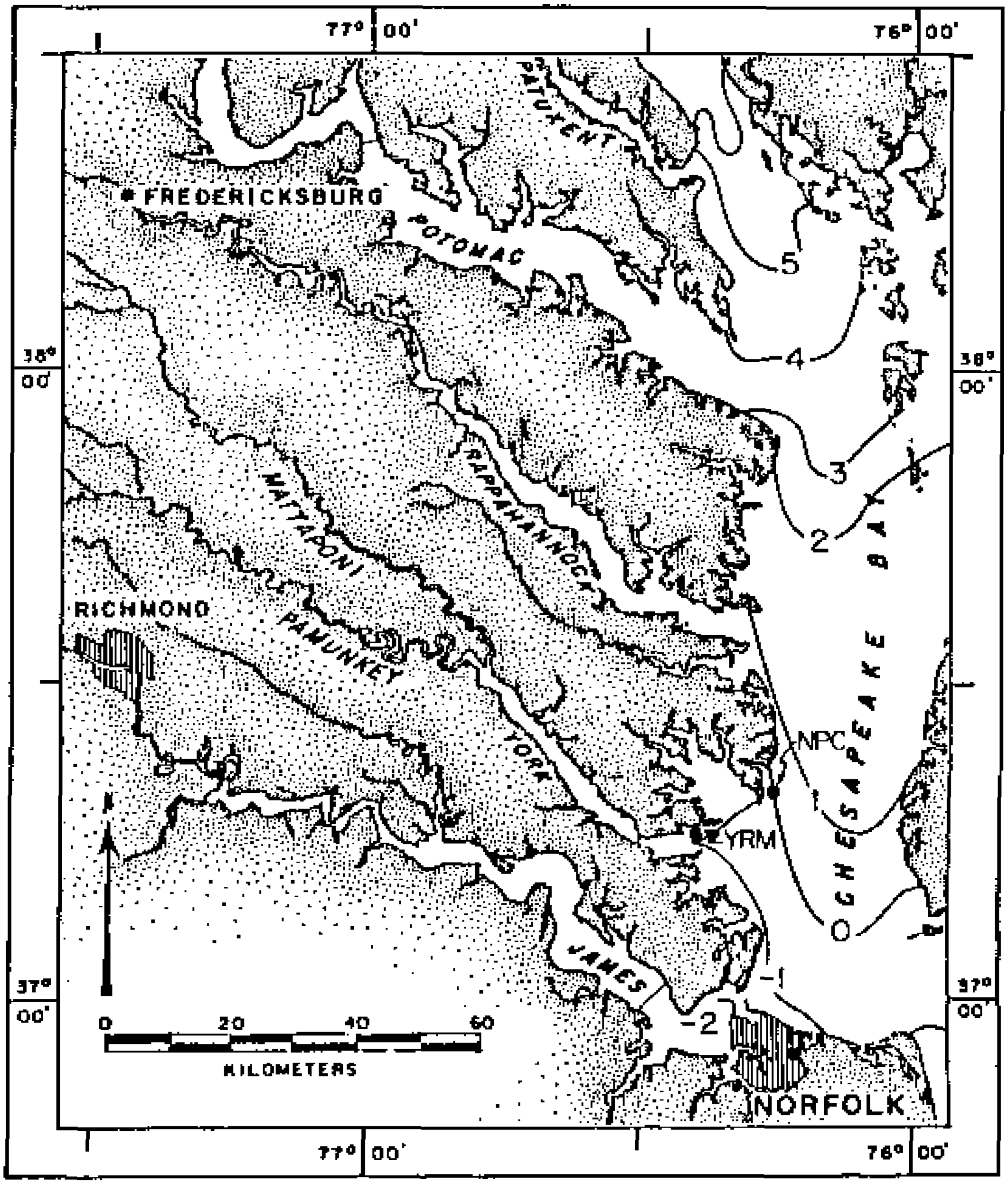
Table 2. Station data from the York River mouth (YRM) and the Chesapeake Bay near New Point Comfort (NPC) July 1980. Depth is 1 m.

STATION	DATE	MORNING		EVENING	
		TEMPERATURE	SALINITY	TEMPERATURE	SALINITY
YRM	7-10-80	26.43	20.86	25.89	20.91
NPC	7-10-80	25.34	19.41	24.72	19.46
YRM	7-16-80	27.35	20.62	28.95	20.45
NPC	7-16-80	25.77	19.32	26.99	19.83

Instrumentation for these data was as for figure 1b. Pairs of values were taken daily during the period 11-16 July 1980 from the R.V. Judith Ann. Data were taken first at the York River Mouth station and then at the the New Point Comfort station.

The tidally synchronized advection of the relatively fresh water into the River mouth during sufficiently strong spring tides occurs as a result of the relationship of the tidal current phases of the River and the Bay. An examination of cotidal lines in the lower Chesapeake Bay (Fig. 2) illustrates that areas at and near the River mouth reach maximum flood current 1-2 hours earlier than the adjacent Bay areas. Thus, as tides are flooding in the River mouth, the current in the adjacent Bay water is near slack before flood, at the seaward most point

Figure 2. Chesapeake Bay, cotidal lines for slack before flood and station locations. YRM = York River mouth station, NPC = New Point Comfort station (After Seitz, 1971).

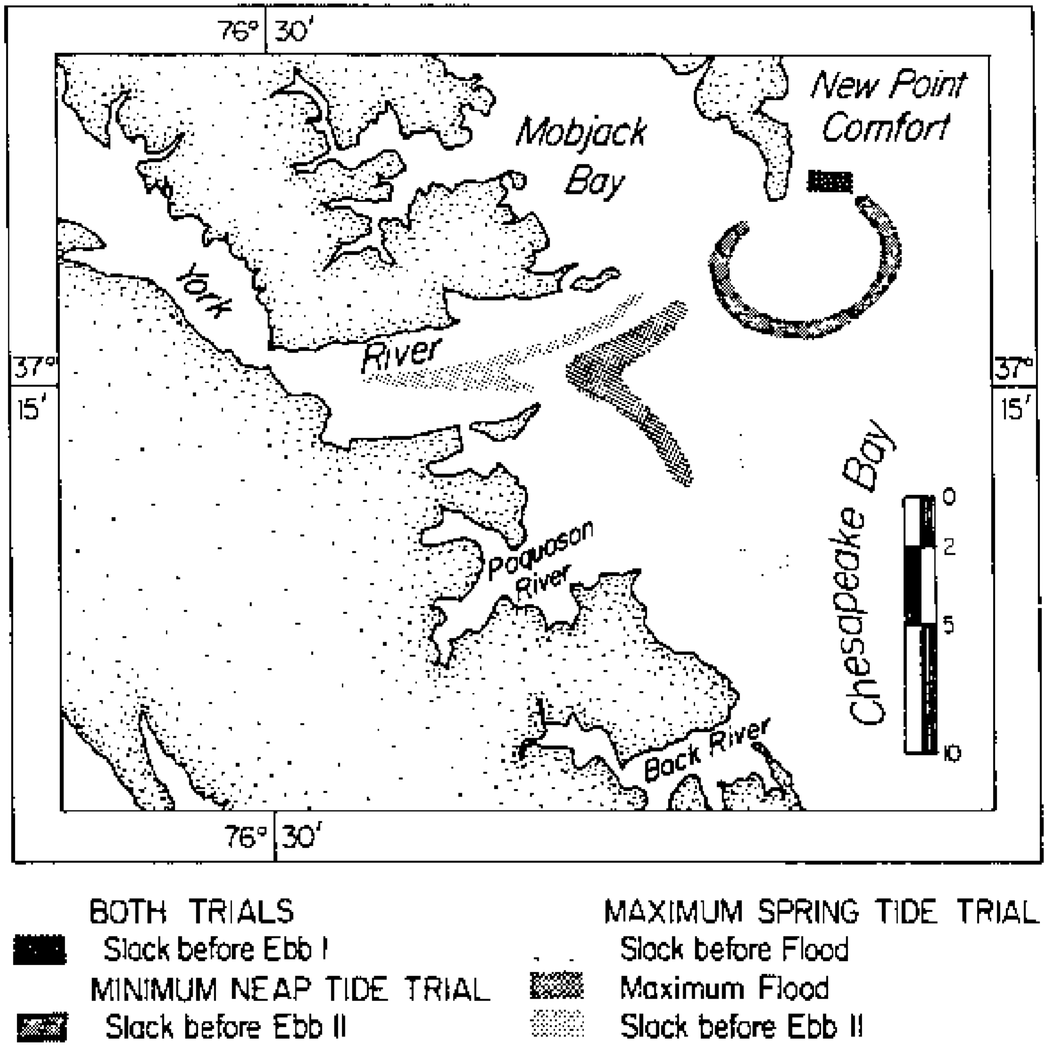

77° 00'
76° 00'
38° 00'
37° 00'
FREDERICKSBURG
PATUXENT
POTOMAC
RAPPAHANNOCK
MATTAPONI
PAMUNKEY
YORK
JAMES
RICHMOND
NORFOLK
CHESAPEAKE BAY
NPC
YRM
5
4
3
2
1
0
-1
-2
N
0
20
40
60
KILOMETERS

of its tidal excursion, and the water being drawn into the lower River is derived from the least saline Bay water passing the River mouth during the semi-diurnal tidal cycle. The volume of water moving into the River and therefore the tidal current speed as well as tidal excursion are expected to vary proportionally more than the tidal height (Haas, 1977). Therefore, it is hypothesized that during neap or mean tidal cycles the tidal excursion is insufficient to introduce relatively fresh water into the River. Spring tides, however, with increased currents and proportionally greater excursion in both the River and the Bay, will provide relatively more fresh water to the River mouth.

As a means of testing the hypothesis, surface markers were placed in the Chesapeake Bay Hydraulic Model of the U.S. Corps of Engineers, Stevensville, MD. The experiment was performed during tests of low flow conditions. During simulated spring tides, markers placed at the approximate location of the New Point Comfort station (Fig. 3) on the model were carried into the York River mouth in a single tidal cycle. During neap tidal cycles, they were transported only 15-20% of the distance.

Figure 2 illustrates that Bay-subestuary current phase relationships similar to those observed for the York River are also observed in the James, Rappahannock, and Patuxent Rivers, but not the Potomac River. Haas (1977) reported that the James and Rappahannock Rivers exhibit destratification events similar to those observed in the York. Additional information indicates that the Patuxent River also destratifies periodically during spring tides when fresh water flow is sufficient for a stratified system (Domotor and D'Elia, unpub.). Destratification has not been reported in the Potomac River.

Figure 3. Distribution of surface markers during hydraulic model spring/neap tidal simulations. Markers were introduced for both trials (Near minimum neap tide and near maximum spring tide) at the New Point Comfort location (Slack before ebb I). They were tracked to their position after one complete tidal cycle (Slack before ebb II). Intermediate positions are indicated for the maximum spring tide trial. The fields indicated are estimates of marker distribution made from 35 mm slide photographs. They are not intended to imply a uniform or continuous distribution within the fields, but to show approximate extent.


76° 30'
37° 15'
New Point Comfort
Mobjack Bay
York River
Poquoson River
Back River
Chesapeake Bay
0
2
5
10
BOTH TRIALS
■ Slack before Ebb I
MINIMUM NEAP TIDE TRIAL
▨ Slack before Ebb II
MAXIMUM SPRING TIDE TRIAL
. . Slack before Flood
▨ Maximum Flood
░ Slack before Ebb II

CHAPTER II

EMPIRICAL MODELS OF STRATIFICATION VARIATION IN THE YORK RIVER ESTUARY, VIRGINIA, USA

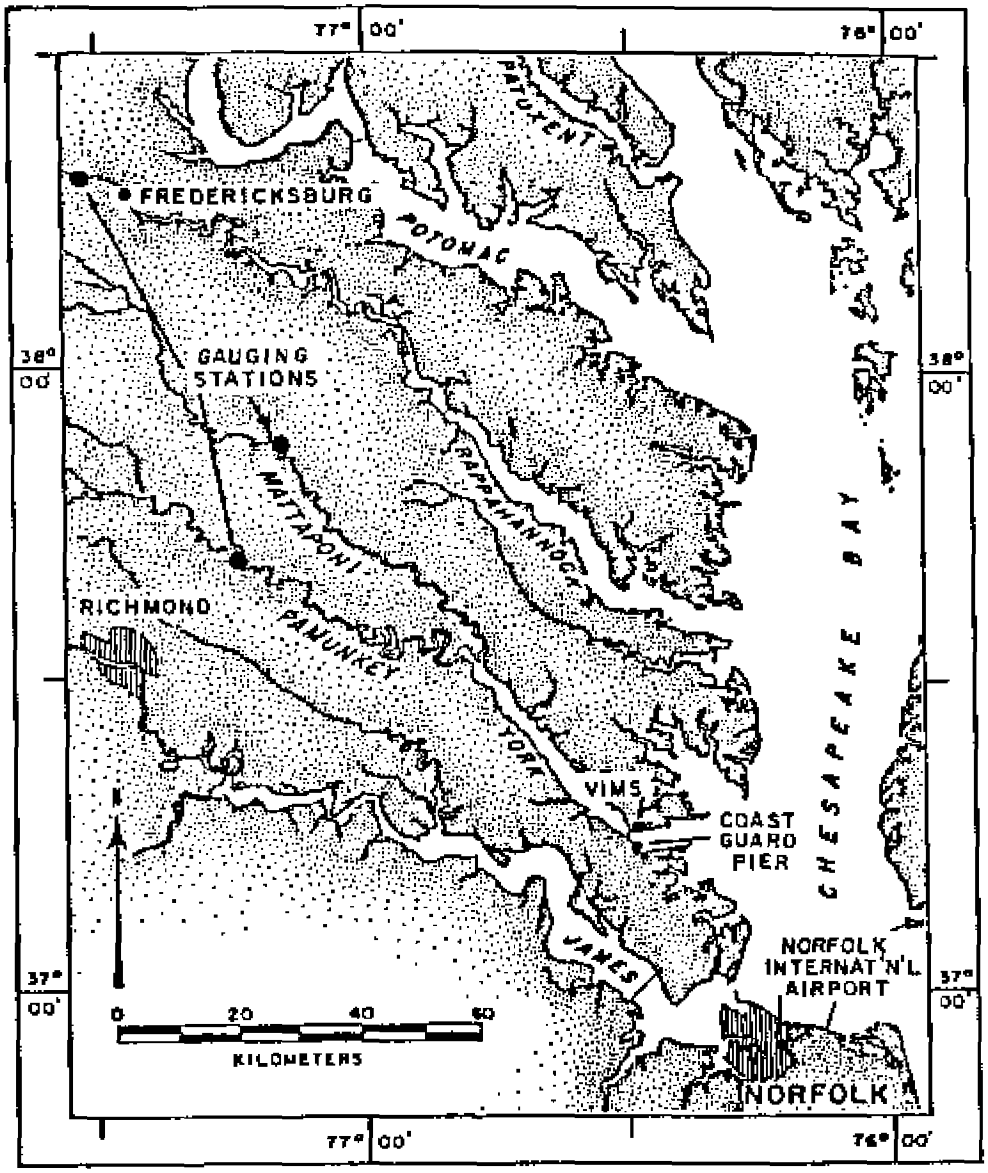
This work was conducted as part of a study of variations in phytoplankton population and productivity in the lower York River, the results of which are in preparation. The purposes of the models are primarily to provide a basis for interpolation of values for salinity difference between samples and estimate surface mixed layer depth (SMLD) over the extent of the study, and secondarily to aid in predicting stratification conditions for future studies.

Methods

From February 12, 1982 to April 4, 1983 water samples were collected at 1, 3, 5 and 12 m depths from a pier at the United States Coast Guard Reserve Training Center at Yorktown, Virginia (Fig. 4). This pier provided land based access to both surface and normally subhalocline water in the lower York River throughout the entire year. Samples from the top three depths were collected with a closing water bottle while samples from 12 m were collected with a hand vacuum pump attached to a plastic tube with the inlet located approximately one meter above the bottom. Samples were stored in glass bottles until analyzed with a Beckman Induction Salinometer, Model RS-7B, which provides a precision of 0.01 per mille. All samples were collected at slack before ebb and sampling frequency varied from 0.29 to 1.0 per day and included 157 observations over a period of 434 days. The station was also occupied on 13 occasions from 31 August to 30 September 1983 to collect data for a verification study. Wind speed and direction were taken from the Local Climatological Data, Monthly Summary, for Norfolk, Virginia, International Airport, 45 km from the sampling site (Fig. 4). Resultant direction and resultant speed were used (NOAA, 1982, 1983). Fresh water river flow data were supplied by the U.S. Geological Survey in Richmond, Virginia and were from gauging stations on the Pamunkey and Mattaponi Rivers, primary tributaries of the York River, about 120 km upstream of the sampling site, and the Rappahanock River near Fredericksburg, Virginia (Fig. 4). The Rappahanock River flow was included because of the possibility that fresh water influx to the Chesapeake Bay near the mouth of the York River might influence stratification within the river (Hayward et al., 1982). Both the Pamunkey and Mattaponi records contained sequences of anomolous or missing data. In order to generate a complete record for York River flow, estimates of Mattaponi flow were made from Pamunkey flow and vice versa to fill in. The regression model explained 60% of the variation in 318 daily mean flows. Estimates were necessary for 116 of 868 daily mean flows.

Observed daily nontidal sea levels and tidal ranges were from the tidal record collected at the Virginia Institute of Marine Science 1.9 km from the sampling site (Fig. 4). Tidal heights were recorded at 6 minute intervals on a Fischer-Porter tide gauge located at the end of

Figure 4. Regional Map showing locations of: Sampling station (Coast Guard Pier); Tide gauge station (VIMS); Wind measurement station (Norfolk International Airport); and Flow gauging stations for the Paumunkey, the Mattaponi, and the Rappahannock (Fredericksburg) Rivers.

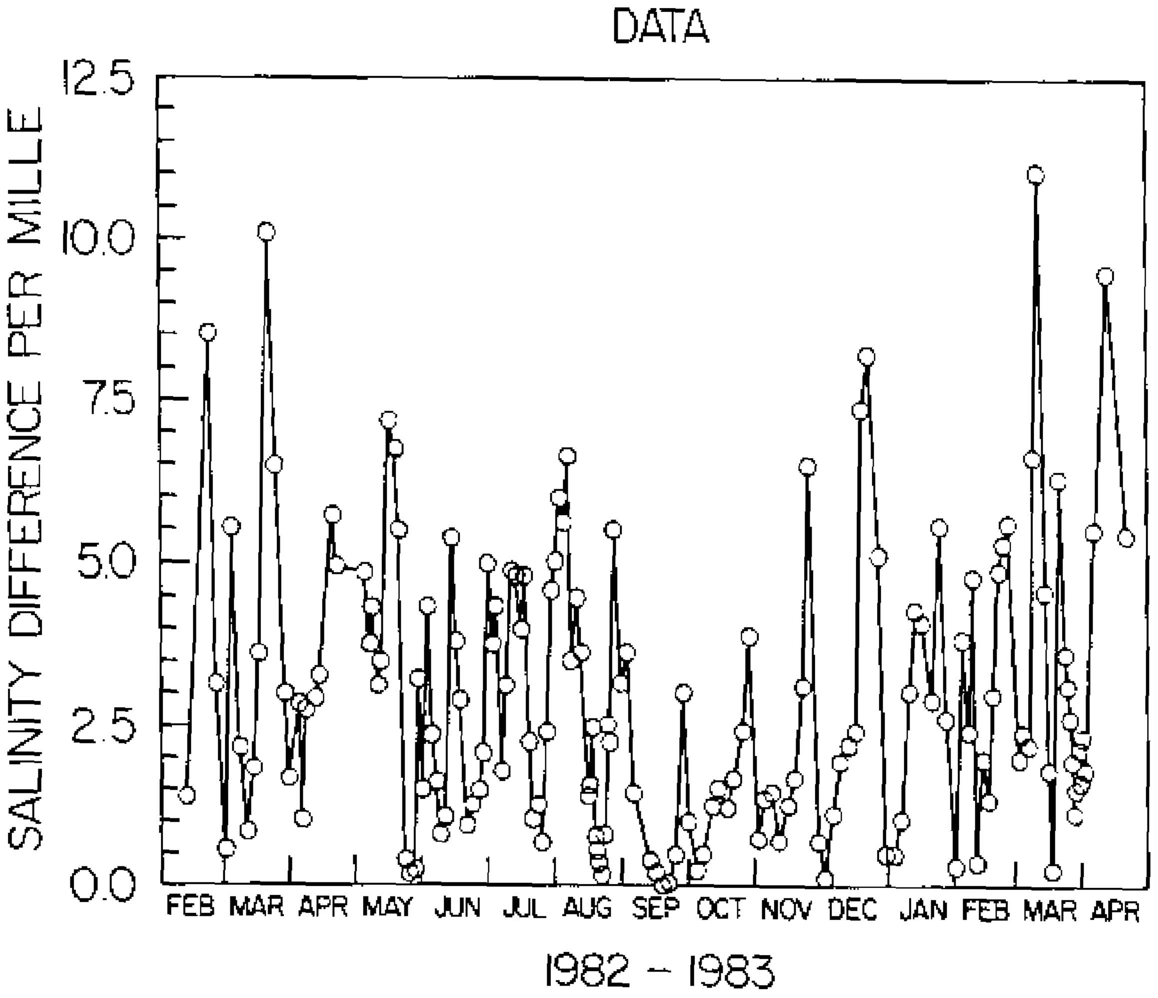

77° 00'
76° 00'
38° 00'
37° 00'
PATUXENT
FREDERICKSBURG
POTOMAC
GAUGING STATIONS
RAPPAHANNOCK
MATTAPONI
RICHMOND
PAMUNKEY
YORK
VIMS
COAST GUARD PIER
CHESAPEAKE BAY
JAMES
NORFOLK INTERNAT'N'L AIRPORT
NORFOLK
0
20
40
60
KILOMETERS

the VIMS pier at Gloucester Point. After the records were edited for anomolous and missing data, hourly heights were produced using a 5 point moving average with a one hour step interval, effectively removing high frequency "noise" while leaving tidal frequencies at virtually full response. Accuracy was maintained through frequent time and height comparisons between recorded data and external reference readings and was normally better than ±0.02 m. Predicted tidal heights were calculated using procedures described in Boon and Kiley (1978). Daily nontidal sea levels were calculated from predicted and observed hourly heights using the filter proposed by Doodson and Warburg (1941), centered on 1200 hours of each day.

The dependent variables for the correlation and regression analyses were measures of salinity stratification calculated as either (1) the difference between the mean of the salinities at 1, 3, and 5 m and the salinity at 12 m or (2) the difference between the salinity at 1 m and the salinity at 12 m. The first was more strongly correlated and unless otherwise noted will be the value intended when salinity difference is indicated. The data (Fig. 5) clearly indicate strong fortnightly as well as seasonal variation.

All aspects of the tidal signal used as factors in the model were assessed on a daily basis to correspond with the comparable values for wind and fresh water flow. Mean daily tidal range was calculated by summing two flood tide ranges (low height to high height) and two ebb tide ranges (high height to low height) and dividing by four. For days with less than 2 highs or 2 lows, immediately preceding or immediately following low or high heights from the following or previous day were used to make a full complement of ranges. Mean daily flood and ebb

Figure 5. Line graph of salinity differences per mille from February 1982 to April 1983. Circles indicate data points.


DATA
SALINITY DIFFERENCE PER MILLE
0.0
2.5
5.0
7.5
10.0
12.5
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1982 – 1983

ranges were calculated using the appropriate two of those four. Extreme daily ranges were selected as the greatest of the ranges in a given catagory. If only one range in a catagory was completely within a given day, that range was used. Mean and extreme daily high and low tidal heights were calculated or selected respectively from the appropriate heights when two were available. If only one occurred, that one was selected. The resulting tidal factors were lagged 0 to 12 days for correlation analysis. Unweighted moving averages of 2 to 7 days lagged 0 to 5 days were also subjected to correlation analysis.

Because of the possibility that wind induced large scale water movement in the Chesapeake Bay near the river mouth, as well as direct stress of wind axial to the river, might influence stratification within the river (Hayward _et al._, 1982), calculated stress of wind from nonaxial as well as axial directions was examined for relation to stratification variation. A directional wind stress for each day and each direction was calculated by weighting the square of the resultant daily wind speed by a directional coefficient based on the vector component of the resultant direction in the direction of interest raised to the fourth power (See equation 4). Powers 1 through 6 were tested, 4 was found to give the best model fit. This directional coefficient weighted winds at the direction of interest by a factor of 16 and wind 180° from the direction of interest by 0. The directional weighting was appropriate because of the asymmetry of geomorphology of the river basin, the Chesapeake Bay and their connections and the assumed corresponding asymmetry of fetch. Directional coefficients were calculated at 15 degree intervals from 0 degrees as well as axially to the lower and upper river basins. The axial directions of the upper river basin, up river from Gloucester Point, were considered to be 140° and 320°, and the lower basin, down river from Gloucester Point, to be 83° and 263° after Kiley (1980). The resulting weighted wind stress factors were lagged 0 to 9 days for analysis.

Correlation analysis of fresh water flow was performed with flows lagged 0 to 30 days for the York River and 0 to 80 days for the Rappahanock River, as well as with flows catagorized by value and lagged. The results suggested that lag was related to flow volume logarithmically, therefore fresh water flow factors for use in the model were generated using variable lags calculated by the following algorithm;

$$\text{Variable Lag} = \text{Maximum lag} - (\text{Scaling Factor} * \text{Log10}(\text{Fresh Water Discharge } m^3 s^{-1}) \quad (1)$$

The Maximum lag vs Scaling factor space was systematically searched for optimum correlation with the residuals from a model containing tidal and wind stress terms. A variable lag was calculated from the flow for each calendar day and added to that day to determine an effective date for that flow. All flows for each effective date were summed and a five-day moving average was calculated to smooth the resulting signal. Descriptive statistics for the unlagged and lagged fresh water flows and other factors used in modeling are presented in Table 3.

Initial correlation analyses and multiple regression analyses were performed using SPSS procedures (Nie, et.al., 1975; Hull and Nie, 1981). The search for optimum correlation between calculated effective fresh water flow and salinity difference was a grid search programmed by the author. The fit of SMLD to salinity difference was calculated using the gradient-expansion algorithm for a least-squares fit of a non-linear function found in Bevington (1969).

Table 3. Descriptive Statistics for factors included in modeling.

Factor	Maximum	Minimum	Mean
Salinity difference	11.06	0.01	2.929
Rappahanock River flow, unlagged	515.4	4.2	42.2
Rappahanock River flow, variably lagged	256.2	3.8	40.4
York River flow, unlagged	318.5	3.2	49.3
York River flow, variably lagged	200.0	1.1	43.1
Observed mean sea level	1.62	0.46	0.889
Predicted mean sea level	0.40	0.16	0.357
Observed daily extreme tidal range	1.20	0.45	0.816
Predicted daily extreme tidal range	1.13	0.49	0.795
Temperature in surface mixed layer	28.8	2.9	16.2
Resultant wind speed	46.0	1.0	14.6

Units are as follows: Salinity difference, per mille; Fresh water flows, m^3s^{-1}; Sea level, meters above mean low water; Tidal range, meters; Temperature, degrees Celcius; Wind speed kmh^{-1}. Tidal observations are for Gloucester Point.

Salinity difference is limited at the low extreme by zero and at the upper extreme by the salinity value of ocean water, and tidal range as well as nontidal sea level were negatively correlated with salinity difference but have very similar limit characteristics. That is, exponentially increasing values of salinity difference were associated with predictor values approaching zero almost asymptotically. In order to overcome this numerical sticking point, these tidal factors were scaled and complemented, *i.e.*

$$\text{predictor} = 1 - \frac{\text{factor value}}{\text{scaling constant}} \qquad (2)$$

where the scaling constants were close to the maximum values for these factors found in the data and were estimated by iterative approximation. The predictors thereby generated tend to keep the high order transforms very close to zero over a broad region. This provides a good approximation of the nearly asymptotic zero limit for salinity difference while producing very large values in association with very small tidal ranges.

The process for generating the regression model included: 1) initially setting high probability levels (P = 0.2) and presenting range and sea level factors to the SPSS stepwise selection procedure. Terms were raised to higher powers as long as the fit was improved at that probability level; 2) Using the terms selected, and adding the wind terms, the probability level was lowered (P = 0.1) and the backward elimination procedure was used; and 3) Finally the power to which each of the range and sea level terms was raised was varied and changes which improved fit were kept.

Results

The results of the initial correlation analyses are presented in Table 4. Aspects of tidal range and height were examined. Lagged daily values were generally correlated at about -0.60, with a lag of around 2-3 days. Notable exceptions are observed mean and extreme high tide height values from Gloucester Point (GP.OMHH and GP.OXHH) which correlated best at 0 and 1 days with much lower correlations of -0.26. Apparently the noise from non-astronomical factors strongly masked any predictive capacity in this signal. Also of interest is the positive correlation with predicted extreme low tide height at Hampton Roads (HR.PXLH). Lower low tides are associated with high tidal ranges which are associated with lower salinity differences.

Table 4. Best simple correlations of salinity differences with non-averaged and unweighted moving averages of various tidal aspects lagged by various amounts.

	SALINITY DIFFERENCE I (N=157)					SALINITY DIFFERENCE II (N=147)				
	NON-AVERAGED		UNWEIGHTED AVERAGE			NON-AVERAGED		UNWEIGHTED AVERAGE		
Tidal Aspect	Lag	Corr	Lag	Aver	Corr	Lag	Corr	Lag	Aver	Corr
GP.OMR	3	-0.603	0	7	-0.655	3	-0.598	0	7	-0.646
GP.PMR	3	-0.637	0	7	-0.655	2	-0.616	1	4	-0.632
HR.PMR	3	-0.632	0	7	-0.651	3	-0.612	1	4	-0.627
GP.OXR	4	-0.601	0	7	-0.675	1	-0.541	0	7	-0.648
GP.PXR	3	-0.641	0	7	-0.671	3	-0.619	0	7	-0.648
HR.PXR	3	-0.622	0	7	-0.648	3	-0.600	0	7	-0.625
GP.OMFR	2	-0.592	0	7	-0.662	2	-0.610	0	7	-0.654
GP.PMFR	3	-0.633	0	7	-0.653	3	-0.612	0	7	-0.630
HR.PMFR	3	-0.631	0	7	-0.650	3	-0.611	0	7	-0.625
GP.OXFR	4	-0.622	0	7	-0.675	2	-0.574	0	7	-0.654
GP.PXFR	2	-0.561	0	7	-0.656	2	-0.611	0	7	-0.637
HR.PXFR	4	-0.613	0	7	-0.654	2	-0.600	0	7	-0.629
GP.OMER	3	-0.588	0	7	-0.642	3	-0.588	0	7	-0.630
GP.PMER	3	-0.641	0	7	-0.656	3	-0.619	1	4	-0.635
HR.PMER	3	-0.633	0	7	-0.651	3	-0.614	1	4	-0.630
GP.OXER	4	-0.594	0	7	-0.658	3	-0.574	0	7	-0.632
GP.PXER	3	-0.646	0	7	-0.670	3	-0.626	0	7	-0.647
HR.PXER	3	-0.628	0	7	-0.656	3	-0.613	0	7	-0.639
GP.OMHH	1	-0.216	0	7	-0.231	0	-0.253	0	7	-0.246
GP.PMHH	3	-0.615	2	3	-0.613	2	-0.601	1	4	-0.598
HR.PMHH	2	-0.654	1	4	-0.656	2	-0.634	1	4	-0.630
GP.OXHH	1	-0.205	0	7	-0.247	1	-0.266	0	7	-0.258
GP.PXHH	3	-0.626	2	3	-0.626	3	-0.614	1	4	-0.613
HR.PXHH	3	-0.648	1	4	-0.662	2	-0.627	1	4	-0.643
HR.PXLH	4	0.221	3	2	0.219	3	0.216	2	3	0.212

Salinity difference I = salinity at 12m - mean of salinity at 1m,3m,5m. Salinity difference II = salinity at 12m - salinity at 1m. Tidal aspect legend: GP = Gloucester Point, HR = Hampton Roads, O = Observed, P = Predicted, M = Daily mean, X = Daily extreme, F = Flood, E = Ebb, H = High or Height, L = Low, R = Range, ie. tidal height difference between a low and a subsequent high, or vice versa as appropriate. Consecutive averages are unweighted moving averages ending on the day designated as Lag and including the number of days designated as Aver, eg. those designated (0\|7) indicate an average of the 7 consecutive days ending with the day on which the salinity measurements were taken, (2\|3) indicates a 3 day average ending 2 days before the salinity measurement.

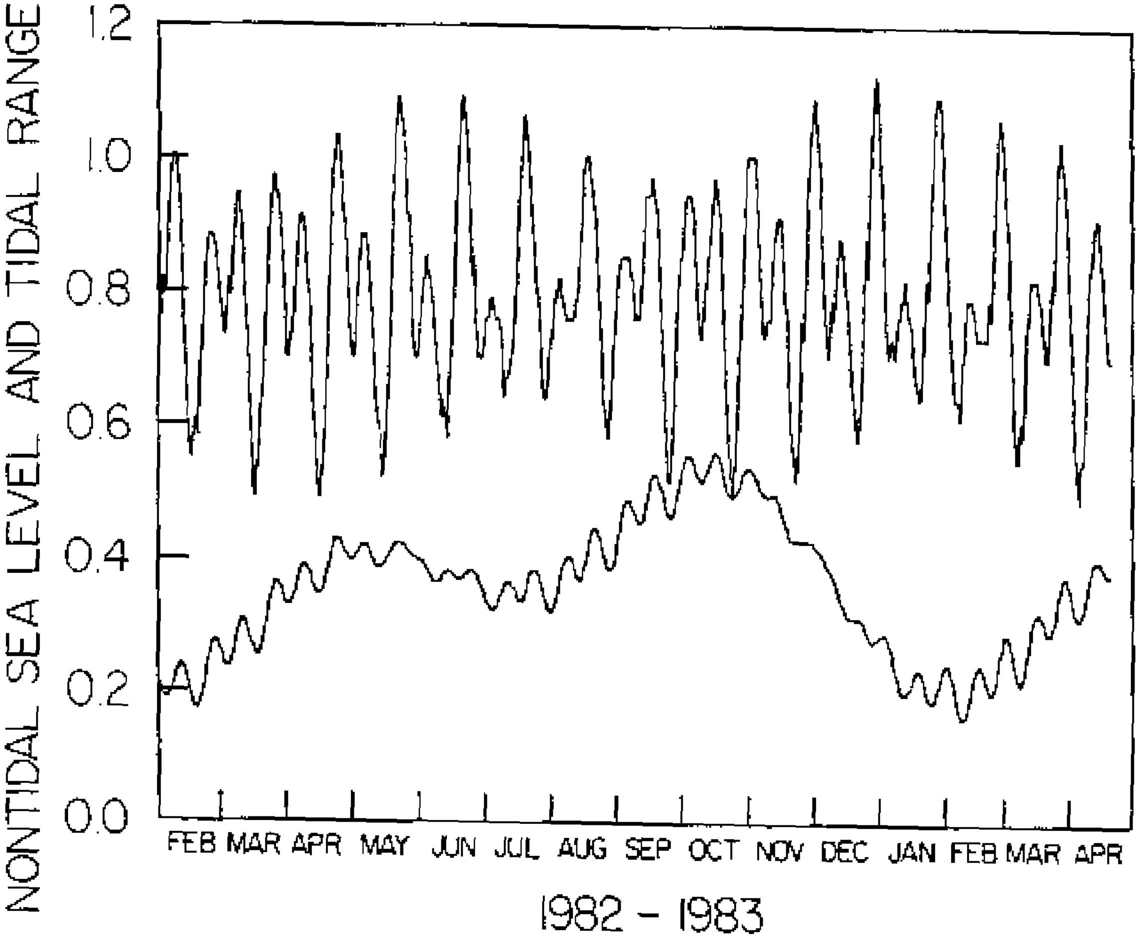
The best correlations are generally with unweighted moving averages 7 days long, centered on day 3. Shorter spans of 4 and 3 days are centered on days 2-3. The strongest associations overall are seen in the extreme observed and predicted ranges at Gloucester Point (GP.OXR and GP.PXR) with 7 day averages centered on day 3, giving correlations of -0.675 and -0.672 respectively. These factors were therefore selected for use in the regression models. The predicted tidal range signal for the period of the study which was used in this study is shown in Fig. 6. Observed tidal factors produced models which fit the data much less well than those constructed with predicted values under the same constraints of significance (Table 4).

The association of the salinity difference with tidal range was found to be non-linear. Models constructed from simple lagged extreme tidal range and nontidal sea level were associated with central values fairly well, producing R^2 values of about 0.50, but tended to severely under predict the large positive extremes (Table 5). The use of higher order transforms of lagged range and nontidal sea level improved the overall fit by more than 15% and particularly improved the estimates of the high extremes while slightly degrading the low extreme estimates (Table 5). Models constructed with high order transforms of the scaled and complemented predictors produced an additional improvement of about 20% in the fit and very good prediction of the highest salinity differences (Table 5).

A model composed exclusively of predicted tidal range factors is associated with 50% of the variability in (Table 5) and reproduces the dominant fortnightly pattern of variation in salinity difference (Fig. 7a,c). It does not, however, reflect the seasonal variations well.

Figure 6. Predicted tidal functions at Gloucester Point. The upper line represents daily extreme tidal range. The lower line represents daily nontidal sea level.

PREDICTED TIDAL FUNCTIONS AT GLOUCESTER POINT



Possible candidate predictors for this seasonal variation were water temperature and mean sea level (Fig. 6). Water temperature was found to be essentially unrelated to salinity difference, while the inclusion of nontidal sea level terms produced a 15% improvement in model fit and brought the predicted seasonal variation into very close accord with the observed values (Table 5, Fig. 7b,d).

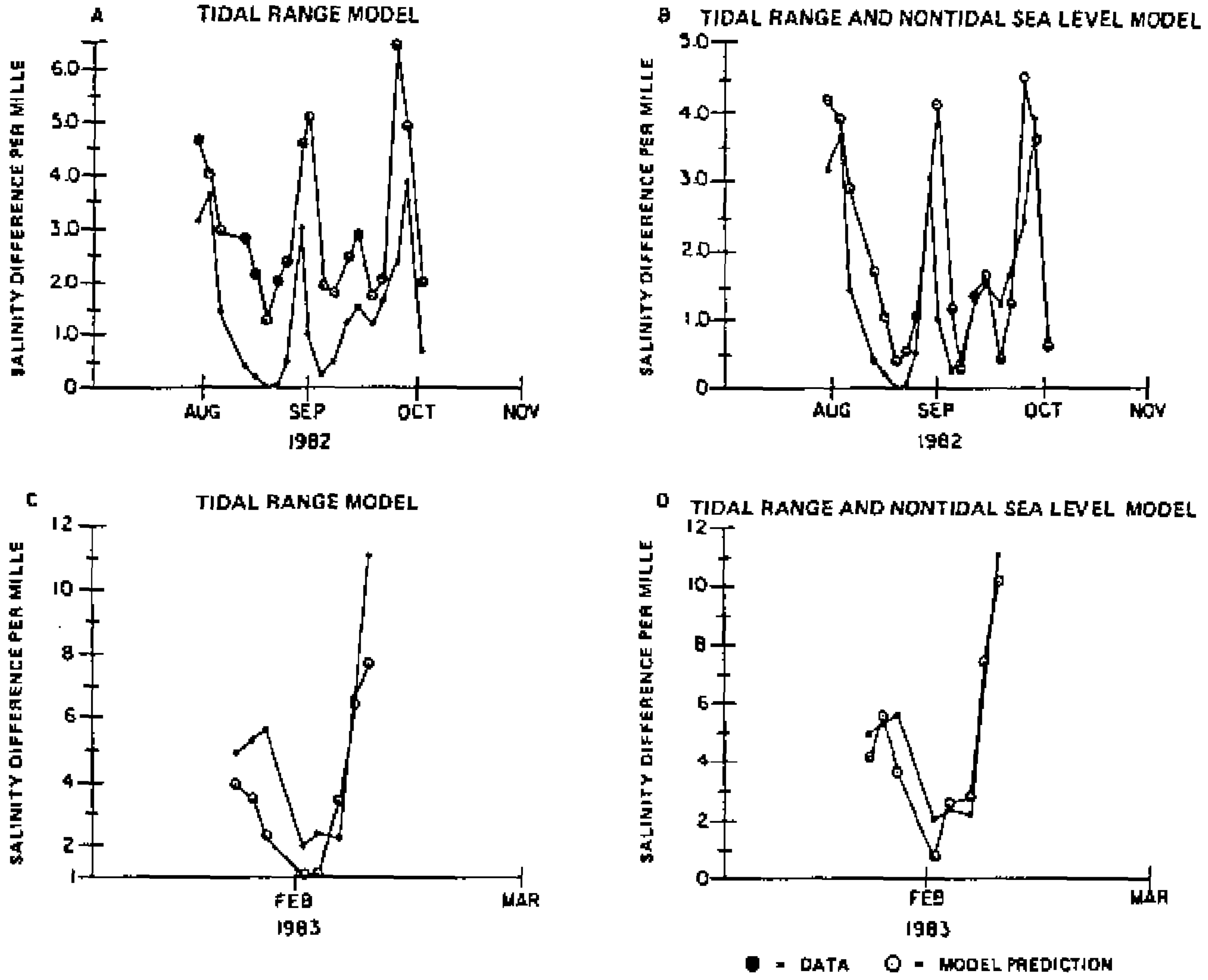
Table 5. Comparison of the results of various models.

Model description	Maximum predicted salinity difference	Minimum predicted salinity difference	R^2	RMSE
<u>Observed salinity difference</u>	<u>11.06</u>	<u>0.01</u>		
Predicted tidal aspect models:				
Range only model: (complemented, high order)	7.69	0.41	0.50	1.55
Range and mean sea level models:				
Uncomplemented first order	6.53	-0.51	0.51	1.55
Uncomplemented high order	7.26	-0.72	0.59	1.43
Complemented high order	10.24	-0.61	0.67	1.26
Range, mean sea level, and wind: (complemented, high order)	11.09	-1.01	0.80	0.99
Observed tidal aspect model:				
Complemented, high order, range and mean sea level	10.03	-0.03	0.59	1.46

Predicted salinity differences and root mean squared error (RMSE) are per mille.

Wind stress factors which correlated most strongly with salinity differences were those axial to the upper and lower York River basins and from the North and Northeast. Wind blowing axially down the upper basin lagged 0-2 days is positively correlated with salinity difference

Figure 7. Comparison of model predictions using only tidal range factors with predictions using both tidal range and nontidal sea level factors. The top figures, 7A and 7B, illustrate the improvement for the fall season while the bottom figures, 7C and 7D, illustrate the improvement for spring, demonstrating the seasonal influence of nontidal sea level.

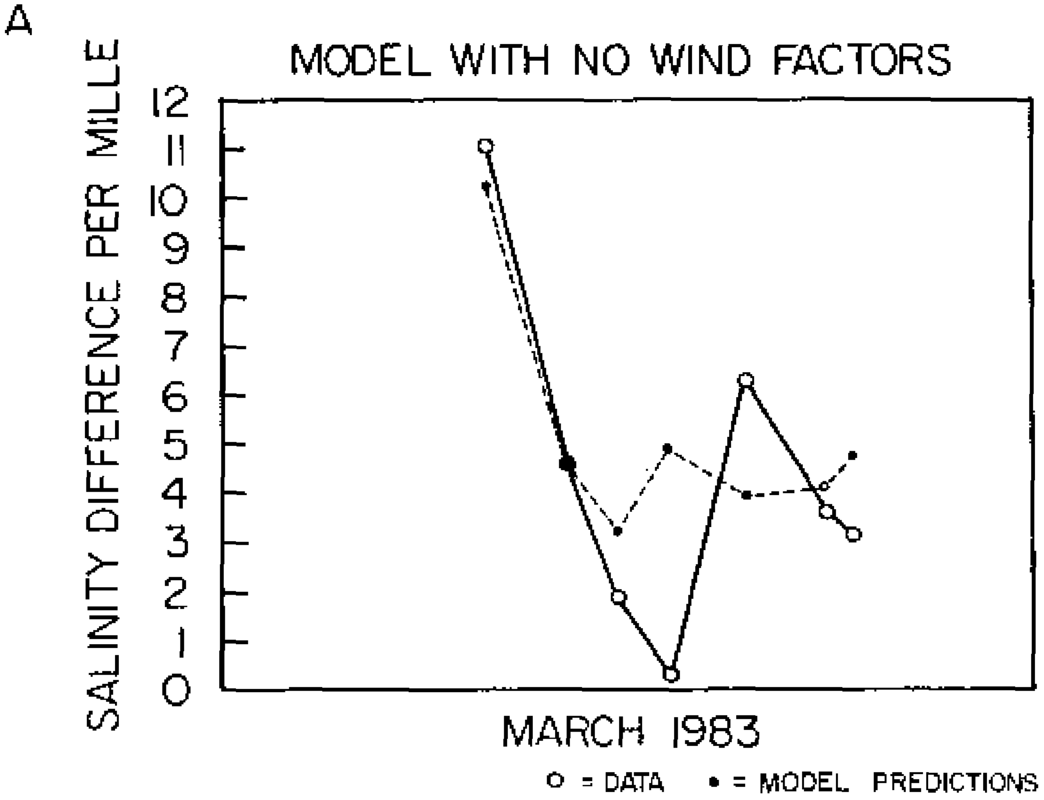

A
TIDAL RANGE MODEL
SALINITY DIFFERENCE PER MILLE
6.0
5.0
4.0
3.0
2.0
1.0
0
AUG
SEP
OCT
NOV
1982
B
TIDAL RANGE AND NONTIDAL SEA LEVEL MODEL
SALINITY DIFFERENCE PER MILLE
5.0
4.0
3.0
2.0
1.0
0
AUG
SEP
OCT
NOV
1982
C
TIDAL RANGE MODEL
SALINITY DIFFERENCE PER MILLE
12
10
8
6
4
2
1
FEB
MAR
1983
D
TIDAL RANGE AND NONTIDAL SEA LEVEL MODEL
SALINITY DIFFERENCE PER MILLE
12
10
8
6
4
2
0
FEB
MAR
1983
● = DATA
○ = MODEL PREDICTION

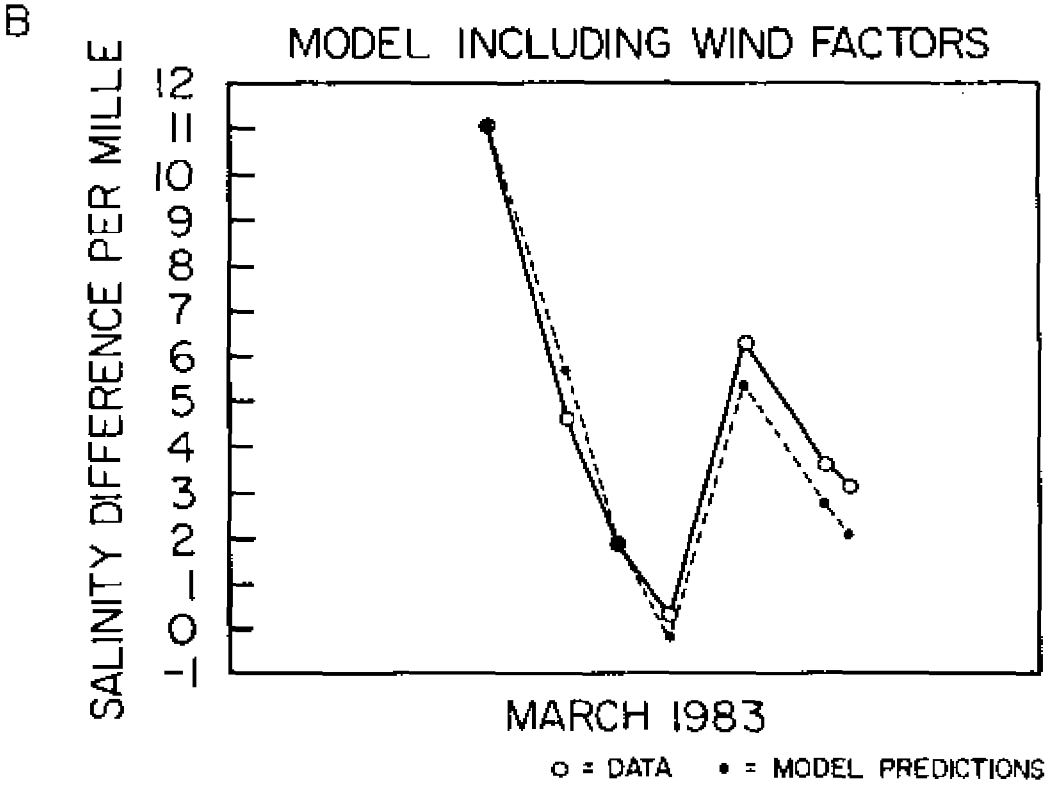
possibly indicating increased flow of surface fresh water into the lower river. This effect was found by Kiley (1980) in the correlation of wind stress and current meter data. Wind from the North, Northeast, axial to the lower river, and blowing up the upper river generally show negative correlations with salinity difference when lagged 0-2 days, indicating direct mixing and possibly the enhanced transport of fresher water into the river from the region of the Chesapeake Bay just northeast of the river mouth, reducing or reversing the horizontal salinity gradient in the river (Hayward, et.al., 1982). Three-day lags show some reversals in correlation, possibly indicating the presence of some rebound phenomenon, ie. the river emptying after a wind driven filling episode or *vice versa*.

The addition of wind stress terms enabled the model to make much better predictions of some obvious anomalies. For example, in March 1983 (Fig. 8a,b), where the residual is reduced from -4.59 to 0.50 per mille by the addition of the effect of 40 kmh^{-1} northeast wind event which occured on the previous day. The inclusion of wind stress terms improved the overall fit by 20%.

In spite of the efforts made to relate fresh water flow to salinity difference no significant correlation could be found. The best correlation for York River flow was found with a maximum lag of 24.18 days and a scaling factor of 4.12. The longest lag generated from the data was 22 days, the shortest was 14 days and the lag of the mean value was 17 days. The variation in salinity difference associated with York River fresh water flow was $< 0.1\%$ and the significance of the association was $P > 0.8$; therefore, it was not included as a term in the complete model. The best correlation for the Rappahanock River flow was

Figure 8. Comparison of model predictions using only tidal factors with those using both tidal and wind factors. The improvement in fit demonstrates the influence of wind in cases which cannot be predicted by tidal factors.


A
MODEL WITH NO WIND FACTORS
SALINITY DIFFERENCE PER MILLE
12
11
10
9
8
7
6
5
4
3
2
1
0
MARCH 1983
○ = DATA
• = MODEL PREDICTIONS


B
MODEL INCLUDING WIND FACTORS
SALINITY DIFFERENCE PER MILLE
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
MARCH 1983
○ = DATA
• = MODEL PREDICTIONS

found with a maximum lag of 55.01 days and a scaling factor of 7.32. The longest lag generated from the data was 50 days, the shortest was 35 days and the lag of the mean value was 43 days. The variation in salinity difference associated with Rappahanock River fresh water flow was < 0.25%, and the significance of the association was P > 0.2, and it also was not included in the final model. This lack of association in spite of flow variations over two orders of magnitude may be due to the low absolute magnitude of the flow. Hydrodynamic model studies of the James River (C. Cerco, pers. com.) indicate that the maximum flows recorded in the York River system during this study would not be be large enough to cause changes in salinity difference sufficient to produce significant association.

The final model (Fig. 9) includes 25 terms: 7 tidal range terms, 8 mean sea level terms, and 10 wind stress terms. The tidal terms are all individually significant at $P < 0.02$, and the wind terms at $P < 0.05$. An F statistic for the model was calculated, F(4.07,77,79), $P < 1.0E^{-8}$. Coefficients for the model are presented in Table 6. The form of the model is:

$$SD(d) = C + \sum a_i R(d-L1_i)^{b_i} + c_j M(d-L2_j)^{e_j}$$
$$+ f_k V(d-L3_k)^2 [1 + \cos D(d-L3_k)]^4 \quad (4)$$

where:

$SD(d)$ = Salinity difference on the day of interest.

C = Constant.

a_i = Regression coefficient for the ith Range constituent.

$R(d-L1_i)$ - Scaled and complemented predicted extreme tidal range on the day $L1_i$ days before the day of interest, i.e., $1 - \frac{\text{Range}}{0.98}$.

$L1_i$ - Lag for the ith Range constituent.

b_i - Power to which the ith Range constituent is raised.

c_j - Regression coefficient for the jth Sea Level constituent.

$M(d-L2_j)$ - Scaled and complemented predicted Mean Sea Level on the day $L2_j$ days before the day of interest, i.e., $1 - \frac{\text{Level}}{0.43}$

$L2_j$ - Lag for the jth Sea Level constituent.

e_j - Power to which the jth Sea Level constituent is raised.

f_k - Regression coefficient for the kth Wind Stress constituent.

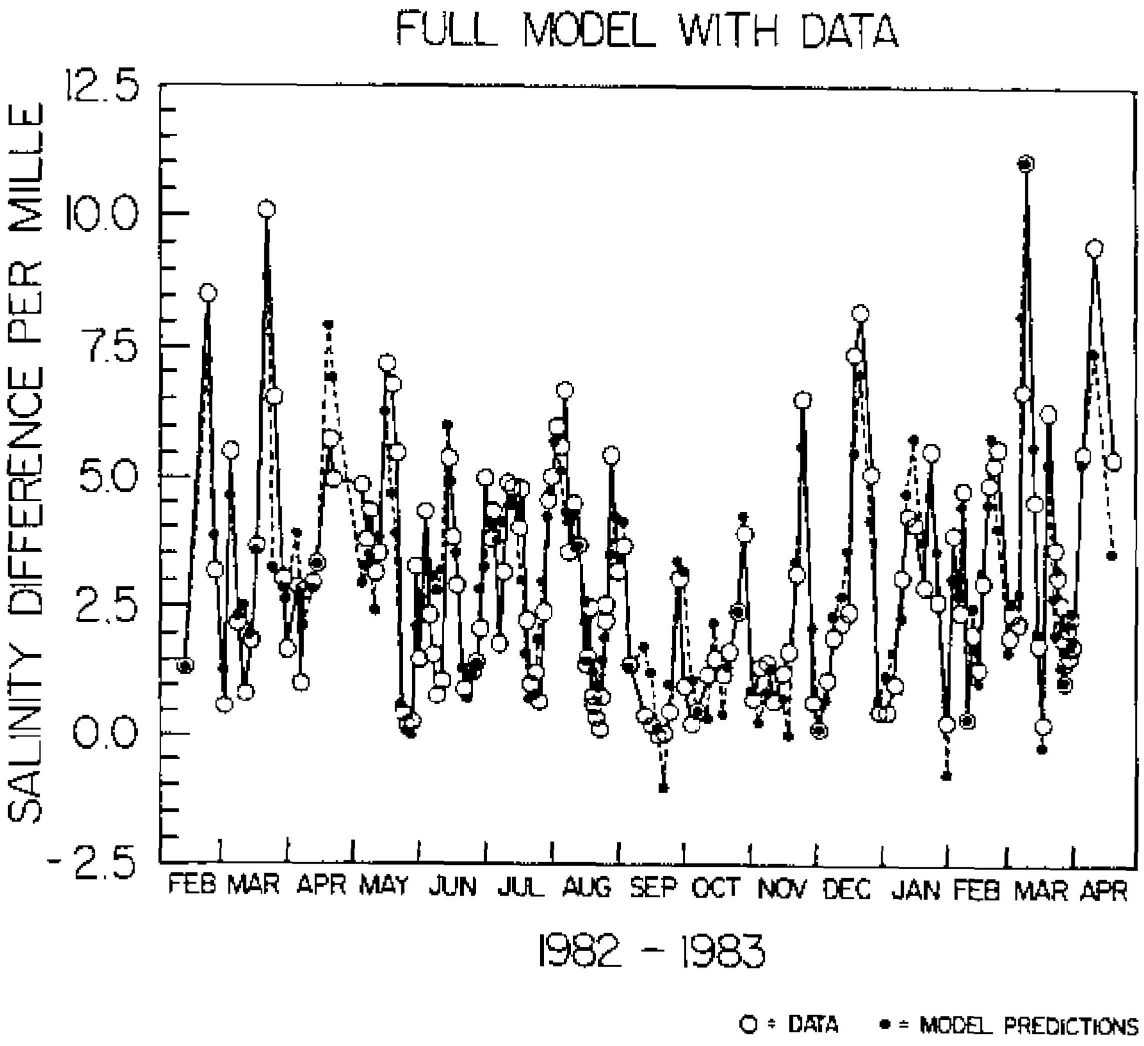
$V(d-L3_k)$ - Resultant wind speed on the day $L3_k$ days before the day of interest.

$D(d-L3_k)$ - Resultant wind direction on the day $L3_k$ days before the day of interest.

$L3_k$ - Lag for the kth Wind Stress constituent.

The predictive skill of the model was tested against a set of 13

Figure 9. Comparison of all data points with corresponding values predicted by the full model.


FULL MODEL WITH DATA
SALINITY DIFFERENCE PER MILLE
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
1982 - 1983
○ = DATA
• = MODEL PREDICTIONS

observations taken in August-September 1983. The RMSE for this set was 1.2 per mille.

Table 6. Coefficients for terms included in the full model.

					Significance
Range Terms:					
	i	$L1_i$	b_i	a_i	
	1	5	1	7.59704	0.0000
	2	0	1	10.27152	0.0000
	3	0	3	-59.63675	0.0000
	4	1	5	609.55842	0.0001
	5	6	19	0.11394E+07	0.0045
	6	1	9	-5411.37775	0.0049
	7	2	4	-66.21355	0.0165
Sea Level Terms:					
	j	$L2_j$	e_j	c_j	
	1	4	3	257.01694	0.0000
	2	5	3	-413.37466	0.0000
	3	6	1	5.62696	0.0000
	4	6	3	160.48822	0.0000
	5	0	5	-295.14167	0.0000
	6	2	7	-885.06131	0.0004
	7	1	6	721.60371	0.0014
	8	4	6	173.99482	0.0072
Wind Stress* Terms:					
	k	$D(d-L3_k)$	$L3_k$	f_k	
	1	83	1	-0.23072E-03	0.0000
	2	45	3	-0.60460E-03	0.0007
	3	320	0	0.21325E-03	0.0018
	4	0	0	0.14609E-03	0.0029
	5	0	3	0.40860E-03	0.0036
	6	263	2	-0.16598E-03	0.0038
	7	83	3	0.44177E-03	0.0042
	8	0	2	-0.10743E-03	0.0280
	9	320	3	-0.20834E-03	0.0346
	10	320	2	0.15570E-03	0.0477
Constant				-0.15819	0.5198

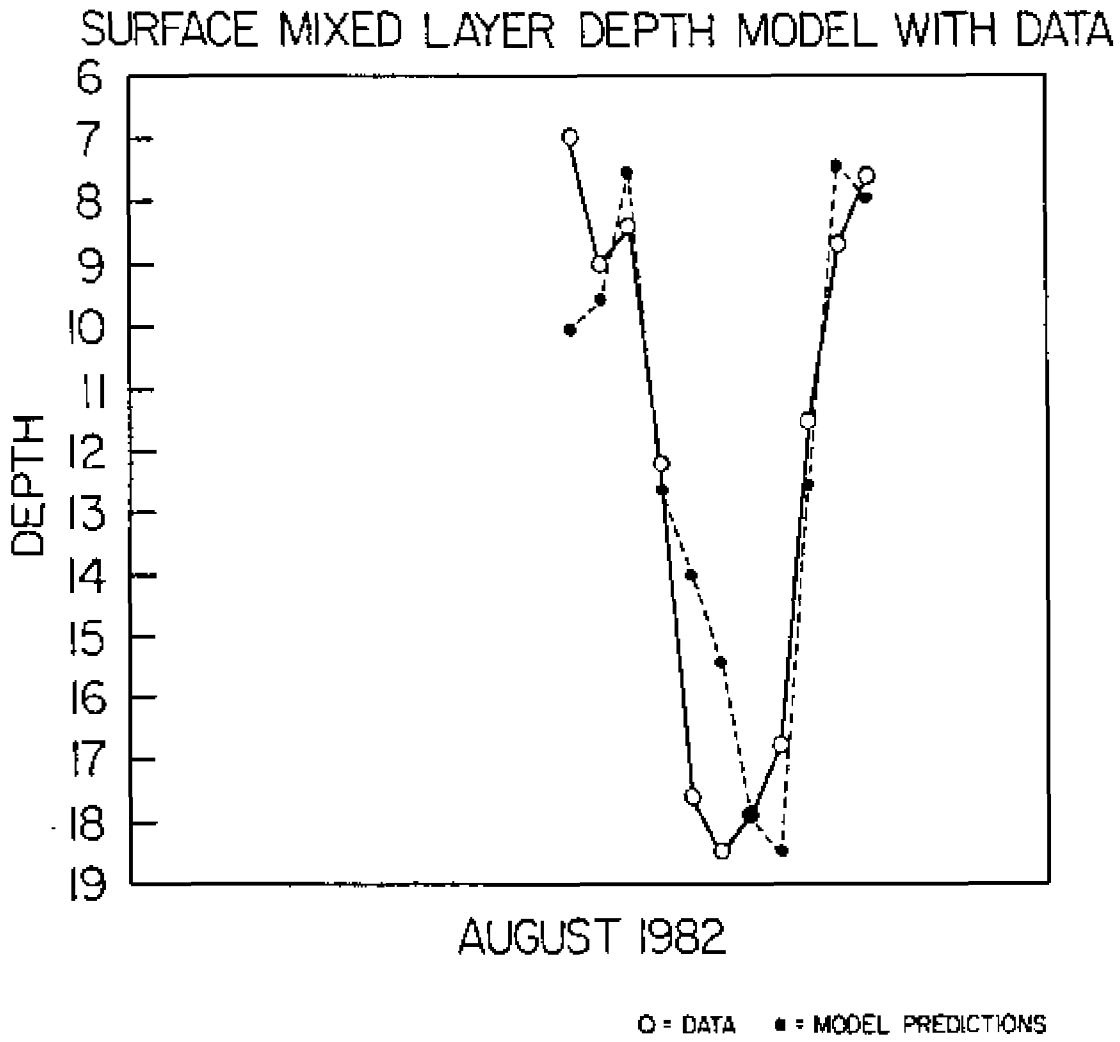
* Wind stress coefficients assume wind speed in kmh^{-1}.

Salinity difference is valuable to biologists as an indirect indicator of turbulent mixing above the halocline. Another parameter of interest which might be estimated from salinity difference is the depth to which that mixing extends. With SMLD defined as the first depth at which a salinity gradient of 0.2 per mille per 0.1 m is encountered, and using a set of data limited to those days for which salinity profiles with 0.1 m depth resolution were available ($N = 11$), SMLD was modeled as a function of salinity difference. The following equation accounts for 81% of the variation in SMLD at a significance level of $P < 0.1$ (Fig. 10).

$$\mathrm{SMLD} = e^{(3.0666\ -\ 0.6064(\text{salinity difference}^{0.6528}))} \qquad (4)$$

For a salinity difference of 0 per mille this function predicts a maximum mixing depth of 21.47 m which is aproximately the maximum depth of the lower York River. For the mean salinity difference found in this study, 2.929 per mille, it predicts a SMLD of 6.32 m.

Figure 10. Comparison of surface mixed layer depth model predictions with data values.


SURFACE MIXED LAYER DEPTH MODEL WITH DATA
DEPTH
6
7
8
9
10
11
12
13
14
15
16
17
18
19
AUGUST 1982
O = DATA
● = MODEL PREDICTIONS

DISCUSSION

Although the regression model of salinity difference is only associative, it can be used as a tool for testing hypothetical influences, e.g. fresh water flow and temperature. It has been possible to eliminate all the tested factors except tidal range and mean sea level as the dominant predictable influences. Due to the irregular increase of the perimeter of the tidal basin with increased tide height, tidal volume is expected to vary proportionally greater than the variation in tidal range and mean sea level. The regression polynomial, with high order terms in tidal range and mean sea level, may be seen as an estimate of the portion of the tidal volume function dependent on tide height. This supports Haas' (1977) suggestion. The indication that tidal volume and the strongly related factors of tidal excursion and velocity are the most revelant has led to the following, which supports and extends the suggestions made by Godfrey (1980) and extends the hypothesis offered in Chapter I, as a general statement of the York River destratification mechanism.

If the relationship between an estuary and sub-estuary is such that there is a tidal current velocity phase difference between the two bodies, and the estuary is characterized by a longitudinal salinity gradient, and there is a semilunar tidal signal, then, during any given semilunar cycle, following maximum spring tides, vertical homogeneity can be expected to occur in the sub-estuary at least up to the head of the maximum tidal excursion from the estuary/sub-estuary interface.

As stated in Chapter I, the phase difference and the longitudinal salinity gradient in the Bay implies that water which is brought into the river at the beginning of each flood tide is the least saline at the estuary/sub-estuary interface during that tidal cycle. Further, this least saline water is carried to the greatest extent of the tidal excursion away from the interface, up the river. This is true for every tidal cycle, but during the increasing portion of the semilunar variation it implies that at slack before ebb on successive tides water of lower and lower salinity will be found further and further into the sub-estuary. Examination of Figure 1B shows that before the maximum spring tide, minimum salinity was seen at the York River Mouth during ebb flow, indicating that the point of minimum salinity was even further up river at slack before flood. When the semilunar variation decreases, water which is of greater salinity than that of the previous tide will be found at the point of maximum excursion which will be moving down the sub-estuary toward the estuary/sub-estuary interface. The reversal of the longitudinal salinity gradient indicated in Figure 2B shortly after maximum spring tide indicates that the point of maximum excursion has passed below the York River Mouth station.

During maximum semilunar tides, the lower sub-estuary up to the length of the tidal excursion will be flushed with exogeneous water masses, the volumes of which will be proportional to the tidal volumes.

The major difference between this description of the mechanism of the changes in the Lower York River and that presented in Chapter I is primarily a matter of perspective. Whereas the first presentation of the destratification mechanism focused primarily on the processes of vertical mixing which occur within the River as a result of an event at the River mouth, this second explication is intended to point to the intrusion of exogenous water at all depths as far up the River as the length of the maximum tidal excursion at maximum spring tides and therefore the continuous flushing of the lower river during tides of relatively large tidal volume.

This suggests that biological study might fruitfully shift from exclusive concentration on the reponses of planktonic organisms to a new regime to include an effort to take into account the flux of such organisms through the system.

Vertical homogeneity seems to extend much further up the river (more than 20 km; Haas, Holden and Welch, 1981) than the farthest recorded point of minimum salinty (12 km; Table 1). This suggests that both mechanisms of salinity structure change (destabilization due to the reversal of the longitudinal salinity gradient and flushing) are operating.

CONCLUSIONS

The significance of variations in vertical stratification for the timing, magnitude, and distribution of primary production in coastal waters has long been recognized (Riley, 1942; Sverdrup, 1953). Only recently, however, has the potential significance of vertical mixing processes in regulating estuarine production been generally recognized. For example, the frequency of vertical mixing may be directly related to the productivity of estuarine systems (Legendre, 1981). Because phenomena such as destratification which are driven by the neap-spring tidal cycle may contribute to relatively high frequency vertical mixing in estuaries, a better understanding of the role of neap-spring cycles in regulating estuarine hydrography will not only contribute to the theory of estuarine hydrodynamics but can be expected to have broad implications for understanding biological processes in estuaries as well.

While neither of the models presented in Chapter II can be considered causal, the strong associations which have been shown demonstrate their broad usefulness. As the major portion of variation can be predicted from astronomical tide predictions, salinity difference, and secondarily, SMLD, can be predicted for the indefinite future. This predictive capability will be helpful for water quality managers concerned with predicting pollution impact as well for as experimentally oriented estuarine scientists concerned with surface mixed layer planktonic phenomena. With the addition of wind stress factors even more precise hindcasting can be accomplished which will enable managers to assess major changes in the mixing pattern.

APPENDIX A

DATA FOR CHAPTER I

I. Data for figure 2.A. Station data from the York River mouth 16 August 1978 to 24 August 1978. Values are per mille.

DATE	16AUG78	16AUG78	16AUG78	16AUG78	16AUG78	16AUG78
TIME	07:00	10:00	13:00	16:00	19:00	22:00
TIDE STATE	3		7	1		
1.0	19.34	19.00	19.48	19.28		
2.0	19.37	19.02	19.47	19.30	19.27	18.67
3.0	19.40	19.02	19.62	19.31	19.28	18.81
4.0	19.40	19.06	19.63	19.29	19.27	18.83
5.0	19.40	19.11	19.77	19.37	19.26	18.88
6.0	19.39	19.24	19.72	19.40	19.25	18.90
7.0	19.43	19.31	19.99	19.50	19.26	18.91
8.0	19.45	19.45	20.00	20.73	19.26	18.90
9.0	19.60	19.67	21.43	22.78	19.33	20.59
10.0	21.78	21.80	21.43	22.92	19.49	21.26
11.0	22.86	22.49	22.95	23.07	19.63	21.43
12.0	23.16	22.69	23.75	23.38	20.44	22.13
13.0	23.96	23.17	24.37	23.57	21.33	23.12
14.0	24.18	24.27	24.87	23.93	22.28	23.54
15.0	24.67	24.58	25.10	23.95	23.30	23.86
16.0	25.26	24.64	25.15	24.00	24.02	24.10
17.0	25.32	25.04	25.18	24.51	24.37	24.72
18.0		25.44	25.17		24.42	
19.0					24.42	

DATE	17AUG78	17AUG78	17AUG78	17AUG78	17AUG78	21AUG78
TIME	01:00	04:00	07:00	10:00	14:00	17:00
TIDE STATE				3	4	6
1.0				19.28	19.62	
2.0	19.23	19.19	19.25	19.28	19.62	18.67
3.0	19.22	19.32	19.24	19.28	19.62	18.81
4.0	19.22	19.35	19.28	19.28	19.62	18.83
5.0	19.27	19.56	19.37	19.35	19.62	18.88
6.0	19.28	20.07	19.46	19.72	20.08	18.90
7.0	19.43	20.33	20.03	20.27	19.85	18.91
8.0	20.05	20.91	20.26	20.43	19.62	18.90
9.0	20.46	21.62	20.59	20.66	19.74	20.59
10.0	21.35	22.86	21.56	20.97	19.74	21.26
11.0	22.21	23.51	21.93	22.16	19.74	21.43
12.0	22.86	23.65	21.87	22.54	20.20	22.13
13.0	23.52	23.67	21.94	22.97	20.20	23.12
14.0	23.95	23.95	22.36	23.03	20.32	23.54
15.0	24.42	23.96	24.50	23.19	20.43	23.86
16.0	24.43	24.02	24.54	23.56	20.43	24.10
17.0	24.47	24.09	24.56	24.15	20.20	24.72
18.0	24.46			24.23		
19.0						

DATE	21AUG78	22AUG78	22AUG78	22AUG78	22AUG78	22AUG78
TIME	20:00	00:00	02:00	05:00	08:00	11:00
TIDE STATE	8	3	4	6	8	1
1.0	20.90	20.08	20.55	20.66	20.78	20.55
2.0	20.66	20.55	20.55	20.66	20.66	20.43
3.0	20.66	20.55	20.55	20.66	20.55	20.55
4.0	20.78	20.55	20.43	20.78	20.55	20.55
5.0	20.66	20.55	20.66	20.90	20.55	20.66
6.0	20.66	20.43	20.66	20.90	20.55	20.55
7.0	20.66	20.20	20.66	20.78	20.66	20.55
8.0	20.66	20.43	20.66		20.55	20.43
9.0	20.66	20.43	20.66	20.90	20.55	20.55
10.0	20.66	20.55	20.55	20.90	20.55	20.43
11.0	20.66	20.55	20.55	20.78	20.55	20.43
12.0	20.66	20.55	20.55	20.66	20.66	20.32
13.0	20.66	20.55	20.43	20.90	20.55	20.32
14.0	20.78	20.55	20.66	20.78	20.55	20.20
15.0	20.78	20.55	20.66	20.90	20.66	20.32
16.0	20.78	20.66	20.66	21.01	20.66	20.43
17.0		20.66	20.78	21.25	20.66	20.55
18.0		20.66			20.78	20.55

DATE	22AUG78	22AUG78	22AUG78	22AUG78	23AUG78	23AUG78
TIME	14:00	17:00	20:00	23:00	02:00	05:00
TIDE STATE	3	5	7	8	3	5
1.0	20.43	19.74	20.66	20.66	20.08	20.08
2.0	20.20	19.74	20.66	20.66	20.08	20.08
3.0	20.20	19.85	20.66	20.66	20.32	20.20
4.0	20.08	20.05	20.66	20.66	20.55	20.43
5.0	19.97	19.97	20.55	20.66	20.20	20.43
6.0	20.08	20.20	20.43	20.66	20.32	20.43
7.0	19.85	20.20	20.90	20.78	20.32	20.55
8.0	20.08	20.32	20.90	20.78	20.43	20.55
9.0	20.20	20.32	20.66	20.66	20.43	20.66
10.0	20.20	20.43	20.66	20.66	20.43	20.66
11.0	20.20	20.43	20.66	20.66	20.43	20.66
12.0	20.08	20.43	20.66	20.66	20.43	20.66
13.0	20.08	20.43	20.43	20.66	20.43	20.66
14.0	19.97	20.43	20.43	20.66	20.43	20.66
15.0	19.97	20.43	20.43	20.66	20.55	20.66
16.0	19.97	20.43	20.43	20.66	20.55	20.66
17.0	20.08	20.43	20.43	20.66	20.55	20.66
18.0	20.20	20.66				

DATE	23AUG78	23AUG78	23AUG78	24AUG78	24AUG78	24AUG78
TIME	08:00	11:00	14:00	09:00	10:00	15:00
TIDE STATE	7	8	3	7	8	3
1.0	20.66	20.65	20.21	19.62	19.85	20.08
2.0	20.66	20.55	19.85	19.74	19.85	19.85
3.0	20.66	20.55	19.73	19.74	19.85	19.85
4.0	20.66	20.55	19.73	19.74	19.73	19.97
5.0	20.66	20.55	19.97	19.74	19.85	20.08
6.0	20.43	20.55	19.97	19.74	19.73	19.97
7.0	20.43	20.55	19.73	19.74	19.85	20.08
8.0	20.43	20.55	19.73	19.74	19.85	19.97
9.0	20.32	20.55	19.73	19.85	19.85	20.08
10.0	20.43	20.55	19.73	19.74	19.85	20.08
11.0	20.43	20.43	19.73	19.74	19.85	20.08
12.0	20.43	20.43	19.73	19.74	20.08	20.08
13.0	20.43	20.55	19.85	20.08	20.20	20.43
14.0	20.43	20.55	19.85	20.66	20.43	21.71
15.0	20.43	20.43	19.85	21.01	21.13	22.06
16.0	20.43	20.43	19.85	21.48	21.25	22.76
17.0	20.32	20.43	19.85	22.76	23.10	23.81

II. Data for figure 2.B. Station data for the York River mouth 21 August 1980 to 1 September 1980. Values are per mille.

DATE	21AUG80	25AUG80	26AUG80	26AUG80	26AUG80	26AUG80
TIME	08:00	15:30	07:40	14:00	17:30	23:25
TIDE STATE		7	2	6	8	4
0.0	20.20					
0.5		20.31	20.97	20.69	21.26	
1.0	20.10	20.34	20.92	20.70	21.26	21.11
2.0		20.61	21.03	20.87	21.27	21.14
3.0	21.50	21.03	21.05	21.13	21.29	21.14
4.0		21.30	21.08	21.17	21.28	21.23
5.0	23.20	21.74	21.07	21.38	21.29	21.25
6.0		22.38	21.10	21.54	21.38	21.26
7.0	22.80	22.81	21.11	21.92	23.12	21.28
8.0		23.53	21.30	22.68	23.17	21.30
9.0	25.20	23.67	21.54	23.20	23.35	23.29
10.0		24.85	21.71	23.33	23.39	23.67
11.0	26.00	25.49	22.12	23.76	23.71	23.88
12.0		26.50	22.34	24.62	24.14	24.70
13.0		26.84	22.41	24.74	24.57	24.77
14.0		27.02	22.75	25.29	24.70	24.79
15.0		27.64	24.13	25.62	25.42	24.96
16.0			24.89	26.00	25.48	25.32
17.0			25.57	26.22	25.44	25.45
18.0						25.45

DATE	27AUG80	27AUG80	27AUG80	27AUG80	28AUG80	28AUG80
TIME	07:30	09:10	11:30	18:10	00:15	07:30
TIDE STATE	8	2	4	8	4	8
1.0	21.58	21.54	21.25	21.73	21.60	21.74
2.0	21.67	21.53	21.36	21.73	21.62	21.78
3.0	21.69	21.54	21.34	21.71	21.62	21.87
4.0	21.73	21.56	21.32	21.68	21.62	21.96
5.0	22.22	21.57	21.44	21.67	21.63	22.40
6.0	22.58	21.59	21.52	21.86	21.64	22.65
7.0	23.28	21.62	21.71	22.40	21.65	22.77
8.0	23.39	21.73	21.77	22.98	21.67	22.87
9.0	23.41	21.96	21.90	22.97	21.77	22.95
10.0	23.53	22.32	22.04	23.32	21.79	23.18
11.0	23.58	23.16	22.13	23.52	21.98	23.52
12.0	23.94	23.41	22.21	23.66	23.13	23.58
13.0	24.11	23.89	23.93	23.98	23.40	23.57
14.0	24.29	23.99	24.23	24.26	23.41	23.59
15.0	24.74	24.01	24.53	24.68	23.74	23.71
16.0	24.74	24.19	24.57	24.76	23.82	23.97
17.0	24.72	24.24	24.68	24.79	23.95	24.08
18.0		24.29				

DATE	28AUG80	28AUG80	28AUG80	28AUG80	28AUG80	29AUG80
TIME	12:30	13:15	17:00	18:47	20:00	01:00
TIDE STATE	4	4	7	8	1	4
1.0	21.67	21.73	21.93	21.98	22.00	22.09
2.0	21.73	21.72	21.92	21.97	22.00	22.10
3.0	21.77	21.99	21.93	21.97	22.01	22.16
4.0	21.74	22.04	21.92	21.98	22.03	22.25
5.0	21.75	22.37	22.05	21.98	22.50	22.32
6.0	22.08	22.35	22.15	22.00	22.59	22.33
7.0	22.37	22.42	22.23	22.43	22.64	22.36
8.0	22.47	22.43	22.43	22.72	22.69	22.37
9.0	22.53	22.50	22.65	22.85	22.72	22.37
10.0	22.56	22.63	22.89	23.03	22.91	22.38
11.0	22.57	22.75	22.95	23.32	22.99	22.39
12.0	22.57	23.15	23.01	23.41	23.05	22.39
13.0	22.58	23.20	23.37	23.49	23.45	22.41
14.0	22.57	23.21	23.73	23.57	23.52	22.70
15.0	22.62	23.24	23.77	23.69	23.66	23.09
16.0	23.37	23.25	23.77	23.72	23.67	23.12
17.0	23.51	23.32		23.74		23.20
18.0	23.54					

DATE	29AUG80	29AUG80	29AUG80	30AUG80	30AUG80	30AUG80
TIME	08:10	14:00	21:00	02:11	09:00	14:30
TIDE STATE	8	4	8	4	8	4
1.0	22.05	22.13	22.31	22.38	22.48	22.47
2.0	22.09	22.13	22.30	22.38	22.52	22.50
3.0	22.13	22.47	22.32	22.41	22.52	22.55
4.0	22.32	22.64	22.33	22.41	22.52	22.51
5.0	22.56	22.73	22.32	22.43	22.52	22.63
6.0	22.57	22.77	22.33	22.44	22.52	22.71
7.0	22.58	22.77	22.40	22.45	22.53	22.78
8.0	22.63	22.76	22.69	22.63	22.53	22.82
9.0	22.74	22.76	22.67	22.69	22.53	22.82
10.0	22.79	22.77	22.67	22.72	22.59	22.82
11.0	22.99	22.79	22.69	22.72	22.61	22.82
12.0	23.05	22.81	22.88	22.72	22.76	22.84
13.0	23.18	22.83	22.91	22.76	22.80	22.84
14.0	23.30	22.86	22.94	22.90	22.83	22.84
15.0	23.39	22.92	22.93	22.98	22.86	22.84
16.0	23.42	22.97	23.00	22.99	22.90	22.85
17.0	23.41	23.09	23.08	22.99	22.90	22.86
18.0			23.05	22.98	22.89	22.87
19.0				23.00	22.90	22.92
20.0				23.00	22.90	22.97

DATE	30AUG80	31AUG80	31AUG80	31AUG80	31AUG80	31AUG80
TIME	20:45	03:10	09:55	13:00	14:15	22:00
TIDE STATE	8	4	8	2	4	8
1.0	22.47	22.60	22.52	22.54	22.61	22.56
2.0	22.48	22.60	22.51	22.53	22.60	22.56
3.0	22.48	22.62	22.55	22.54	22.61	22.57
4.0	22.48	22.62	22.54	22.55	22.78	22.56
5.0	22.48	22.65	22.56	22.54	22.73	22.57
6.0	22.48	22.68	22.59	22.58	22.81	22.56
7.0	22.49	22.75	22.58	22.61	22.81	22.68
8.0	22.49	22.76	22.61	22.67	22.83	22.65
9.0	22.56	22.76	22.60	22.76	22.83	22.66
10.0	22.64	22.85	22.62	22.88	22.83	22.67
11.0	22.64	22.88	22.67	22.92	22.85	22.69
12.0	22.69	22.89	22.67	22.96	22.87	22.70
13.0	22.70	22.89	22.70	22.99	22.92	22.70
14.0	22.76	22.89	22.71	23.01	22.97	22.74
15.0	22.79	22.86	22.71	23.01	22.98	22.75
16.0	22.80	22.87	22.71	23.02	22.99	22.75
17.0	22.80	22.87	22.74	23.02	23.00	22.76
18.0	22.80	22.89	22.75	23.02	23.02	22.79
19.0		22.90		23.02		

DATE	01SEP80	01SEP80	01SEP80
TIME	04:30	10:30	16:00
TIDE STATE	4	8	4
1.0	22.67	22.56	22.67
2.0	22.67	22.58	22.67
3.0	22.67	22.57	22.67
4.0	22.67	22.62	22.71
5.0	22.68	22.60	22.73
6.0	22.68	22.62	22.77
7.0	22.68	22.65	22.77
8.0	22.69	22.68	22.78
9.0	22.73	22.69	22.80
10.0	22.88	22.68	22.83
11.0	22.89	22.69	22.82
12.0	22.90	22.71	22.80
13.0	22.90	22.72	22.81
14.0	22.88	22.75	22.82
15.0	22.90	22.75	22.84
16.0	22.93	22.78	22.99
17.0	22.94	22.80	23.09
18.0	22.93	22.83	23.10

APPENDIX B

DATA FOR CHAPTER II

YEAR	DAY OF YEAR	DELTA SALINITY OBS	PRED	SALINITY PER MILLE 1M	3M	5M	BOTTOM	TEMPERATURE DEGREES C 1M	3M	5M
1982	43	1.39	1.45	19.91	20.14	21.27	21.83	4.4	4.1	4.3
1982	49	-.--	-.--	--.--	--.--	--.--	--.--	5.0	4.9	4.5
1982	54	8.52	6.56	--.--	--.--	--.--	27.11	4.7	4.6	4.5
1982	57	3.13	4.60	--.--	--.--	--.--	23.28	5.0	5.0	5.0
1982	61	0.57	3.10	--.--	--.--	--.--	20.75	5.5	5.4	5.3
1982	64	5.52	4.62	--.--	--.--	--.--	25.28	5.5	5.4	5.4
1982	68	2.16	2.44	--.--	--.--	--.--	21.39	5.7	5.7	5.6
1982	71	0.85	2.28	--.--	--.--	--.--	19.65	7.2	6.6	6.3
1982	74	1.85	2.55	--.--	--.--	--.--	19.40	8.5	8.4	8.3
1982	76	3.64	3.59	--.--	--.--	--.--	19.87	8.5	8.5	8.5
1982	81	10.08	8.00	--.--	--.--	--.--	25.55	8.5	8.0	8.0
1982	84	6.51	3.39	--.--	--.--	--.--	23.14	9.4	9.3	9.2
1982	88	3.00	2.55	15.24	15.47	17.70	19.14	8.7	8.5	8.5
1982	90	1.69	2.35	17.00	17.15	17.45	18.89	9.2	8.9	8.5
1982	95	2.85	3.97	15.72	15.79	17.02	19.03	10.2	10.1	10.1
1982	96	1.05	3.32	18.15	18.12	18.09	19.17	10.1	10.1	10.1
1982	98	2.76	2.79	15.48	15.31	17.14	18.74	7.0	7.5	8.0
1982	102	2.93	2.50	16.52	16.50	16.78	19.53	10.8	10.7	10.0
1982	104	3.29	3.07	17.00	17.11	17.29	20.42	10.7	10.4	10.3
1982	110	5.72	7.32	17.35	17.36	17.48	23.12	13.1	12.9	12.8
1982	112	4.96	6.04	17.09	17.19	17.24	22.13	--.-	--.-	--.-
1982	123	-.--	-.--	17.48	--.--	17.91	--.--	16.5	16.3	15.6
1982	125	4.86	2.55	17.29	17.37	17.57	22.27	16.0	16.0	16.0
1982	127	3.75	2.96	17.60	17.77	17.83	21.48	17.5	17.6	17.5
1982	129	4.35	2.41	17.89	17.82	17.88	22.21	17.4	17.5	17.6
1982	131	3.13	2.21	17.84	17.73	17.72	20.89	18.1	18.1	18.0
1982	133	3.49	3.44	17.61	17.56	17.63	21.09	19.8	19.8	19.8
1982	137	7.17	5.98	18.29	18.22	18.17	25.40	22.0	21.8	21.6
1982	139	6.75	4.50	18.29	18.18	18.23	24.98	21.1	21.1	21.4
1982	141	5.51	3.35	19.24	19.15	19.15	24.69	20.2	20.2	20.3
1982	144	0.42	0.42	19.93	20.07	20.10	20.45	21.3	21.1	20.8
1982	146	0.19	-0.02	20.11	20.03	20.07	20.26	21.7	21.6	21.3
1982	148	0.27	0.12	19.63	19.66	19.72	19.94	22.7	22.5	22.1
1982	150	3.24	1.50	18.87	19.07	19.50	22.39	23.9	23.7	23.3
1982	152	1.52	2.41	19.39	19.38	19.45	20.93	23.6	23.6	23.3
1982	154	4.34	2.94	18.87	19.06	19.37	23.44	23.6	23.6	23.6
1982	156	2.36	3.31	18.70	19.16	19.27	21.40	23.2	23.2	23.4
1982	158	1.63	2.87	19.00	18.96	18.97	20.61	22.4	22.5	22.4
1982	160	0.82	3.02	18.81	18.88	18.98	19.71	23.9	23.5	23.1
1982	162	1.09	3.36	19.04	18.97	18.92	20.07	23.7	23.5	23.4
1982	165	5.40	5.36	17.79	17.74	17.96	23.23	23.1	23.0	22.8
1982	167	3.83	4.50	18.45	18.43	18.48	22.28	22.5	22.4	22.5
1982	169	2.91	3.43	17.29	17.30	17.97	20.43	23.4	23.3	23.3
1982	172	0.95	0.96	18.01	18.06	18.18	19.03	24.0	24.0	23.9
1982	174	1.26	0.49	17.70	17.81	18.02	19.10	24.2	24.1	24.1
1982	176	1.27	0.92	17.64	17.73	18.20	19.13	25.3	25.0	24.7
1982	178	1.49	1.15	17.18	17.40	17.85	18.97	26.3	25.3	25.3
1982	180	2.10	2.80	17.76	17.70	17.75	19.84	26.9	26.6	26.2
1982	182	5.01	3.25	17.15	17.05	17.06	20.10	25.1	25.4	25.2

YEAR	DAY OF YEAR	DELTA SALINITY		SALINITY PER MILLE				TEMPERATURE DEGREES C		
		OBS	PRED	1M	3M	5M	BOTTOM	1M	3M	5M
1982	184	3.79	3.88	18.06	18.08	18.22	21.91	25.1	25.1	25.2
1982	186	4.36	4.07	19.24	19.21	19.22	23.58	24.5	24.6	24.7
1982	188	1.83	4.32	19.04	19.02	19.07	20.87	25.7	25.4	25.7
1982	190	3.13	3.61	18.49	18.61	19.05	21.85	26.8	26.9	27.2
1982	193	4.90	4.00	19.45	19.53	19.71	24.46	27.5	26.7	26.7
1982	195	4.80	4.33	19.25	19.42	19.65	24.24	26.8	26.6	26.9
1982	197	3.99	4.02	19.47	19.41	19.50	23.45	26.3	26.2	26.2
1982	199	4.81	2.61	19.75	19.74	19.77	24.56	26.9	26.9	26.9
1982	201	2.26	1.56	20.28	20.46	20.57	22.70	27.7	27.8	27.7
1982	203	1.05	0.84	20.91	21.18	21.62	22.29	27.4	27.2	27.2
1982	205	1.28	1.01	20.44	21.32	21.49	22.36	27.7	27.6	27.4
1982	207	0.69	1.64	20.27	20.99	20.47	21.27	29.1	29.2	28.1
1982	209	2.43	2.65	20.48	20.51	20.41	22.90	28.1	28.2	28.3
1982	211	4.60	4.24	20.03	20.05	20.32	24.73	26.7	26.8	26.8
1982	213	5.04	4.49	19.32	19.23	19.43	24.37	26.6	26.6	26.6
1982	215	5.99	5.20	19.26	19.35	19.50	25.36	26.7	26.9	27.1
1982	217	5.61	5.00	19.43	19.60	19.81	25.22	27.8	27.5	27.6
1982	219	6.66	3.97	19.40	19.38	19.57	26.11	27.8	27.7	27.8
1982	221	3.53	3.74	20.01	20.12	20.18	23.63	27.8	27.4	27.8
1982	223	4.49	3.48	19.64	19.66	20.03	24.27	26.3	26.4	26.4
1982	225	3.66	3.35	19.49	19.79	20.16	23.47	26.0	25.4	25.2
1982	228	1.42	2.15	19.74	19.84	20.02	21.29	24.9	25.0	25.1
1982	229	1.58	1.71	20.00	20.00	20.01	21.58	25.2	25.2	25.2
1982	230	2.49	1.18	20.09	20.10	20.11	22.59	25.1	25.1	25.1
1982	231	0.78	1.40	20.03	20.13	20.24	20.91	25.8	25.3	25.2
1982	232	0.57	1.03	19.98	20.06	20.10	20.62	25.7	25.6	25.5
1982	233	0.38	0.92	19.46	19.60	19.67	19.96	25.5	25.6	25.6
1982	234	0.17	0.93	20.21	20.13	20.10	20.32	25.5	25.6	25.6
1982	235	0.14	1.13	20.01	20.11	20.17	20.24	25.7	25.6	25.5
1982	236	0.80	1.30	19.74	19.68	19.86	20.56	26.3	26.1	25.7
1982	237	2.55	1.37	19.59	19.62	19.78	22.21	26.2	26.1	26.1
1982	238	2.26	1.79	19.31	19.10	19.85	21.68	26.8	26.4	25.6
1982	240	5.49	3.22	18.44	18.64	18.80	24.12	25.7	25.6	25.3
1982	243	3.18	4.17	19.66	19.63	19.88	22.90	24.1	24.1	24.3
1982	246	3.65	3.89	21.18	21.17	21.40	24.90	24.8	24.8	25.0
1982	249	1.45	2.87	21.46	21.47	21.51	22.93	24.8	24.8	25.2
1982	252	-.--	-.--	21.72	21.69	21.73	--.--	25.1	24.9	24.9
1982	256	0.42	1.69	21.12	21.29	21.35	21.67	22.8	22.9	23.1
1982	259	0.22	1.07	21.03	21.19	21.29	21.39	26.0	25.8	25.6
1982	262	0.01	0.38	21.06	21.01	21.16	21.09	24.6	24.6	24.8
1982	265	0.06	0.52	21.04	21.04	21.08	21.11	22.9	22.6	22.4
1982	268	0.51	1.07	20.81	20.83	20.88	21.35	22.7	22.7	22.9
1982	272	3.04	3.11	20.16	20.17	20.25	23.23	21.5	21.5	21.7
1982	274	1.03	4.15	20.62	20.66	20.65	21.67	21.2	21.2	21.0
1982	278	0.25	1.16	20.57	20.59	20.59	20.83	22.2	22.2	22.6
1982	281	0.51	0.28	20.45	20.44	20.47	20.96	22.8	23.0	23.0
1982	285	1.26	1.40	20.74	20.71	20.78	22.00	21.0	20.5	21.0
1982	288	1.55	1.66	20.77	20.76	20.80	22.33	--.-	--.-	--.-
1982	292	1.23	0.41	21.15	21.14	21.24	22.41	18.1	18.0	17.9

YEAR	DAY	DELTA		SALINITY PER MILLE				TEMPERATURE		
	OF	SALINITY						DEGREES C		
	YEAR	OBS	PRED	1M	3M	5M	BOTTOM	1M	3M	5M
1982	295	1.69	1.25	21.01	20.98	21.04	22.70	17.0	17.0	17.2
1982	299	2.44	4.54	19.13	19.09	19.91	21.82	13.4	13.5	13.7
1982	302	3.92	3.57	20.32	20.37	20.36	24.27	13.9	14.0	13.9
1982	306	0.73	0.66	21.46	21.46	21.43	22.18	16.4	16.1	16.3
1982	309	1.38	-0.29	21.39	21.38	21.36	22.76	15.3	15.4	15.6
1982	313	1.48	0.57	21.36	21.28	21.20	22.76	14.1	14.3	14.5
1982	316	0.72	1.44	21.87	21.87	21.96	22.62	14.3	14.2	14.3
1982	320	1.25	0.92	21.10	21.11	21.17	22.38	11.9	11.8	11.9
1982	323	1.70	1.29	20.91	20.92	21.06	22.66	12.3	12.3	12.4
1982	327	3.13	3.81	20.86	20.94	21.14	24.11	13.3	13.2	13.0
1982	330	6.51	5.36	20.49	20.80	20.76	27.19	10.6	11.1	11.1
1982	334	0.69	1.96	21.61	21.64	21.67	22.33	11.9	11.8	12.0
1982	337	0.13	-0.06	21.50	21.58	21.59	21.69	12.3	12.2	12.4
1982	341	1.14	0.48	20.95	20.95	21.02	22.11	12.7	12.7	12.8
1982	344	1.95	2.20	20.33	20.80	21.04	22.67	10.9	10.7	10.7
1982	348	2.21	2.80	20.15	20.22	20.86	22.62	7.0	7.0	7.5
1982	351	2.44	2.98	20.1	20.33	20.49	22.85	8.1	8.1	8.2
1982	354	7.38	4.32	20.31	20.35	21.74	28.18	7.0	6.9	7.2
1982	357	8.21	6.90	20.76	20.58	20.63	28.87	7.0	6.9	7.1
1982	362	5.12	4.51	20.75	21.00	21.22	26.11	9.1	9.1	9.1
1982	365	0.50	1.00	21.97	21.84	21.95	22.42	7.6	7.6	7.9
1983	4	0.50	1.76	21.65	21.68	21.69	22.17	7.3	7.6	7.8
1983	7	1.05	2.23	21.21	21.53	21.39	22.43	7.6	7.7	8.1
1983	11	3.05	2.73	21.06	21.05	21.06	24.11	7.6	7.6	7.8
1983	14	4.29	4.21	20.29	20.48	20.92	24.85	5.4	5.8	6.2
1983	17	4.09	5.21	20.40	20.38	20.47	24.51	5.1	5.1	5.3
1983	21	2.91	3.80	19.51	19.58	20.14	22.65	2.7	3.0	3.0
1983	25	5.57	4.54	20.42	20.37	20.61	26.04	3.8	3.9	3.9
1983	28	2.64	3.73	21.42	21.31	21.26	23.97	4.0	4.0	4.0
1983	32	0.30	-1.00	21.68	21.66	21.70	21.98	5.2	5.2	6.0
1983	35	3.88	1.52	20.87	20.85	20.85	24.74	5.4	5.4	5.6
1983	38	2.44	2.39	21.25	21.29	21.23	23.70	4.1	4.2	4.2
1983	40	4.80	4.58	19.49	19.49	20.06	24.48	3.8	3.8	3.9
1983	42	0.38	2.71	21.97	21.97	21.94	22.34	3.5	3.5	3.5
1983	45	2.01	5.03	20.27	20.34	20.36	22.33	3.4	3.4	3.6
1983	47	1.37	2.54	20.35	20.35	20.57	21.79	4.1	4.0	4.3
1983	49	2.99	2.76	20.31	20.31	20.36	23.32	4.5	4.4	4.9
1983	52	4.91	4.14	18.94	19.35	19.86	24.29	5.9	5.3	5.5
1983	54	5.30	5.55	19.25	19.31	19.96	24.81	6.0	5.9	5.8
1983	56	5.61	3.60	19.09	19.16	19.27	24.78	5.6	5.6	5.6
1983	59	-.--	-.--	19.81	19.85	20.25	--.--	5.6	5.4	5.4
1983	61	2.00	0.69	18.84	18.23	18.82	20.63	6.5	6.5	7.0
1983	63	2.40	2.61	18.56	18.64	19.34	21.25	8.9	8.5	8.3
1983	66	2.22	2.76	18.21	18.60	19.16	20.88	9.6	9.0	8.7
1983	68	6.65	7.49	17.15	17.99	17.46	24.18	9.3	9.3	8.9
1983	70	11.06	10.24	15.61	15.48	15.67	26.65	8.9	8.9	8.8
1983	73	4.58	4.62	18.13	17.98	18.38	22.74	8.0	7.9	8.3
1983	75	1.83	3.21	18.58	18.57	18.60	20.41	8.7	8.7	8.6
1983	77	0.27	4.86	18.96	18.97	19.02	19.25	8.8	8.9	9.1

YEAR	DAY OF YEAR	DELTA SALINITY		SALINITY PER MILLE				TEMPERATURE DEGREES C		
		OBS	PRED	1M	3M	5M	BOTTOM	1M	3M	5M
1983	80	6.30	3.93	19.28	19.32	19.36	25.62	11.5	11.6	12.5
1983	83	3.62	4.10	16.72	19.34	19.95	22.29	--.-	--.-	--.-
1983	84	3.12	4.74	17.85	17.68	17.72	20.87	--.-	--.-	--.-
1983	85	2.60	4.23	16.39	18.25	19.33	20.59	--.-	--.-	--.-
1983	86	1.96	3.34	18.03	18.06	18.10	20.02	--.-	--.-	--.-
1983	87	1.13	1.19	18.34	18.67	18.86	19.75	--.-	--.-	--.-
1983	88	1.50	1.64	18.13	18.15	18.26	19.68	--.-	--.-	--.-
1983	89	2.15	1.42	17.67	17.67	17.68	19.82	--.-	--.-	--.-
1983	90	1.63	2.09	17.90	18.13	18.13	19.68	--.-	--.-	--.-
1983	91	2.33	2.20	19.70	19.69	19.79	22.06	--.-	--.-	--.-
1983	92	1.82	2.02	17.58	18.36	18.91	20.10	--.-	--.-	--.-
1983	96	5.53	5.20	14.26	16.10	17.11	21.35	11.0	10.6	10.0
1983	102	9.50	6.82	13.93	14.06	15.11	23.87	11.0	11.0	11.0
1983	111	5.44	3.17	12.02	12.26	14.50	18.37	11.8	11.3	10.5

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