Final Report

Impact of Little Pike's Inlet on Tides and Salinity in Moriches Bay

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STATE UNIVERSITY OF NEW YORK
STONY BROOK, NY 11794-5000

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Daniel C. Conley

Marine Sciences Research Center, State University
of New York, Stony Brook, NY 11794-5000

1. BACKGROUND

The Northeaster which initially struck Long Island on 11 December 1992 caused a breach in the barrier island at Westhampton Beach which came to be known as Little Pike's Inlet. The inlet eventually grew to an approximate width of 600m (2000 ft) and impacted, in an conspicuous manner, both the island itself as well as structures on the island where the breach occurred. During the nine months of the inlets existence, over 100 homes were destroyed, and overland access to the western half of Westhampton Beach was lost when 1 km (3000 ft) of Dune Road was eroded. When the inlet was finally filled, the U.S. Army Corps of Engineers required over 880,000 cubic meters (1.1 million yd^3) of sediment to replace the sand which had washed either into the ocean or Moriches Bay, While the impacts to Moriches Bay and the mainland communities north of the bay may also be large, they are not of such a dramatic nature and require detailed monitoring in order to be reasonably quantified. Of these impacts, two are most likely to be of an easily detectable nature, namely the impacts on the bay tidal range and water salinity. The present study is therefore intended to provide a determination of the effects of Little Pike's Inlet on the tidal range and salinity in Moriches Bay.

In a relatively small and shallow estuarine body such as Moriches Bay in which the area covered by the bay is too small to generate its own tidal potential, fluctuations in the height of the water surface are driven wholly as a response to the ocean tides seaward of the bay. As the rising tide in the ocean creates a water surface elevation difference between the bay and the ocean, the bay responds by allowing ocean water to flow through inlets into the bay. Similarly, as the ocean tide recedes, the bay responds by trying to "dump" bay water into the ocean through the inlets. How fast and how well the bay can respond to the ocean tides is fully determined by the inlets connecting the bay to the ocean. These inlets are a bottleneck which tend to restrict the flow of water, thereby preventing the full ocean tide from being communicated to the bay. One of the largest factors controlling how much of the tide is transmitted is the size and number of inlets with larger and more numerous inlets resulting in a greater tidal range being transmitted into the bay.

The salinity or concentration of salt within such a body of water represents a balance between the amount of fresh water entering the bay from precipitation, runoff and ground water infiltration; the amount of evaporation occurring; and the amount of salt water being mixed into the bay from the ocean. A change in any of these sources would be expected to alter this balance giving rise to a change in salinity. The amount of salt water mixed into the bay is predominately a function of the volume of water entering and leaving the bay through the inlets. As it is this volume which enters and leaves the bay which gives rise to the tidal range in the bay, it is clear that a change in the dimensions or number of inlets in a barrier island system would result in an alteration of the tidal range in the bay and that such an alteration could lead to a change in the salinity of the bay.

Anyone who has had their path blocked or experienced flooding due to the incursion of sea water at a particularly high tide can understand the added danger that increased tidal ranges can bring to coastal communities. Dramatic changes in salinity can bring similar harm to living organisms and thus the ecosystems in the bay. Many of these estuarine communities flourish in a limited salinity range. Changes in that range can have dramatic impacts on the community of plants and animals, affecting growth rates, the nature of the food supply and the size and composition of the predator population. It is with this motivation in mind that the investigator, at the request of the Governor's Coastal Erosion Task Force, instituted a program designed to determine the physical impacts of Little Pike's Inlet on Moriches Bay.

2. MEASUREMENTS

As no regular monitoring program was in place in Moriches Bay when the breach occurred in December of 1992, it was not possible to determine the effects of the inlet merely by measuring water parameters with the inlet open. The measuring scheme that was therefore adopted was based on the knowledge that the new inlet was scheduled to be closed by human intervention. It was decided that measurements taken after the breach occurred and prior to inlet closure could be considered to be representative of Moriches Bay with an additional inlet at Pike's Beach. A second set of measurements following the closure of Little Pike's Inlet would be considered representative of the more recently typical Moriches Bay geometry with only one ocean opening inlet at Moriches Inlet.

Tidal measurements

Water surface elevation measurements were made adjacent to the Westhampton Yacht Squadron which lies almost due north of Little Pike's Inlet at Speonk Point in the village of Remsenburg (Figure 1). A self recording Fisher Porter model 35-1550 float type tide gauge was mounted on a jetty wall in about 1 m of water. The instrument was set to record measurements continuously every 15 minutes. The instrument was monitored weekly and the paper tape containing the readings removed monthly. The tape readings were entered into a computer using an electronic reader after which the data was analyzed digitally on a work station at the Marine Sciences Research Center (MSRC). The instrument was in place from 1 April 1993 until 5 January 1994 and a complete record was obtained during this period (Figure 2). The vertical position of the instrument was determined by surveying from local benchmarks and all measurements are given relative to NGVD.

In order to determine which portion of the ocean tidal signal was transmitted into the bay, simultaneous measurements of local ocean tides are required. These were collected using an Endeco model 1032 auto recording absolute pressure sensor which was bottom mounted approximate one kilometer (3000 ft) from shore in 8.8m (29 ft) of water at Westhampton Beach. The water surface displacement (tides) at this location were calculated by subtracting the atmospheric pressure from the total recorded pressure resulting in local sea surface elevation. Sea level atmospheric pressure was obtained from from the

National Climatic Data Center records for Islip, NY. The first deployment of this instrument occurred from 19 April until 20 May in which a full 31 days of data recorded every 10 minutes were collected. The subsequent deployment from 21 May until 24 Sept. was unsuccessful due to the loss of the instrument. At this point, it was determined that in order to limit instrument loss, the remaining ocean tides would be calculated from National Oceanographic and Atmospheric Administration (NOAA) tide data at Sandy Hook, NJ and Montauk Point, NY using a transfer function calculated from previously recorded tidal data. The transfer function was calculated by computing the amplitude and phase of 25 tidal constituents for both the Westhampton Beach data and the NOAA data [Boon & Kiley, 1978]. The transfer function was then calculated to be the ratio of the two amplitudes and the relative phase differences between them. Residual sea surface elevations were assumed to be long period effects which would be felt synoptically by all three locations [Wang, 1979], although with separate amplitudes, which were determined from the relative magnitude of the residual variance in the original observations. The remaining tidal signal at Westhampton Beach was calculated by applying the transfer function to the recorded NOAA data at Sandy Hook. The computation was performed daily using a sliding 31 day window centered about the day being calculated. The difference between the tidal range derived from measurements at Westhampton Beach and the range derived from calculated data was less than 0.5% of the range. Comparisons of ranges derived from calculations using NOAA data from Montauk Point and Sandy Hook differed by less than 1% of the range.

Salinity measurements

The salinity measurements were collected using Aandera model RCM4 current thermosalinigraphs with the current component of measurement disabled. These sensors were shore mounted in approximately one meter of water with the sensing elements approximately 0.35 m (1.15 ft) above the bottom. The instrument housings were attached either to pilings or instrument mounts which remained in the measurement location for the duration of the observations. These sensors measure temperature and conductivity. Combining these two quantities and the universal equation of state for seawater [Pritchard, 1978] it is possible to calculate the salinity of the water. The sensors were set to record measurements every 10 minutes and could record data for over two months at this data rate. In order to assure the accuracy and reliability of these measurements, the instruments were visited weekly, at which time a second set of measurements was collected using a manually operated Beckman Salinometer model RS5-3. At the same time, a water sample from the same location was also collected at each location and the sensors were cleaned to ensure proper measurement. The water sample was analyzed at the MSRC to provide a third control on the salinity measurements performed in the field. These backup measurements were used as controls to ensure that the Aanderas were operating properly and to determine the amount of drift when they were not. Each instrument was replaced by another approximately every five weeks when the old instrument was returned to the MSRC for data retrieval and sensor servicing.

Due to the spatial nature of the salinity response in Moriches Bay, where regions closer to the sources of salt water may be of different salinity than regions closer to the freshwater input, it was decided to place two sensors within Moriches Bay. One instrument was located adjacent to the tide gauge in the eastern half of Moriches Bay at Speonk

Point (Figure 1) and a second in the western half of Moriches Bay at Forge Point (Figure 1). These two instruments could now provide information about what kind of variation in salinity was experienced over the extent of Moriches Bay. Since the goal of this portion of the project was to determine the effects on salinity of Little Pike's Inlet, a method was required to determine which changes were due to the inlet and which were from other causes. From the original discussion it can be understood that changes in precipitation, evaporation, groundwater levels, storm activity and ocean tidal ranges may all affect salinity in the bay. However, all these factors would tend to act on a regional basis and affect all the local estuarine bodies similarly. For this reason a third instrument was placed in a nearshore location on Pine Neck Point at the western end of Shinnecock Bay. This location was chosen because it represents a shallow estuarine environment similar to the other two locations, yet the only contact between Shinnecock and Moriches Bay is through the long and narrow Quantuck Canal, which could be expected to prevent any effects of Little Pike's Inlet from being transmitted. This station therefore represents the control for the system and any changes at Speonk and Forge Points can be contrasted against changes at this location to determine whether such changes can be attributed to Little Pike's Inlet.

3. DATA ANALYSES

The nine months of tide data are shown in Figure 2 where the final breach closure is indicated by the arrow. While exact details are difficult to discern in this figure, it seems clear that the tidal signal undergoes a significant change about this time with the tidal excursions leaving much more "white paper" in the figure following the closure. While many factors affect tidal fluctuations, the quantity we are concerned about in this work is the transmission of tidal energy from the ocean into the bay. Tidal transmission is generally defined as the percentage of the ocean tide range which is observed in the bay. The tide range is defined as the difference between mean high water and mean low water, where, in general, these quantities are calculated over a full 18.6 year tidal epoch [Pugh, 1987]. In order to have numbers that are meaningful for this work, we shall define the tide range to be the difference between mean high water and mean low water as calculated over a 29 day period. Figure 3a is a plot of the ocean tide range using a sliding 29 day window on the calculated tide data discussed in the previous section. Figure 3b shows the tide range as calculated from the tide data at Speonk Point. Figure 3c shows the tidal transmission, which is quite simply the ratio of parts b and a, respectively.

Salinity measurements required a fair amount of processing and analysis prior to interpretation. The raw temperature and conductivity values had to be converted into calibrated values after which any observed sensor drifts were removed. These temperature and conductivity values could now be used to calculate raw salinity values. This data was subsequently cleaned by interpolating across any instrument noise or small sections of lost data. Data loss occurred for two major reasons; the first was the water temperature drifting above or below the temperature range of the instrument and the second was instrument malfunction. While daily high and low temperatures drifted out of range at the start of winter and summer, at no time did it prevent collection of reasonable data during some part of every day. Instrument failure, on the other hand, resulted in the total loss of data during the period of failure. The largest such loss occurs at the control site at Pine Neck Point from 29 June through 31 August 1993. A smaller loss occurred at this site in late October, while no such losses were experienced at the other two sites. Fortunately, the data return from all instruments at all locations was adequate to detect any significant trends in the salinity following the breach closure on 25 September 1993.

In order to remove the short-period daily fluctuations in the salinity signal and to reduce the greater than 32000 data points collected at each location, we have averaged all the values in a day to arrive at a time series of daily averages. These values at each of the three stations are plotted in Figure 4.

4. DISCUSSION

In interpreting the results of this project it is important to keep in mind the course of events during the development of the inlet. An analysis of monthly aerial photographs of the inlet indicates that following the initial opening on 11 December 1993, the breach went through a period of rapid expansion, opening to approximately 150 m (500 ft) wide by February. This rate of expansion kept apace for the next couple of months, attaining a width of about 400 m (1400 ft) by the start of this project on 1 April. The growth rate slowed after this with the breach attaining a maximum width somewhere around 520 m (1700 ft) in late June. The emergency breach filling project commenced in July with initial work concentrated on building up the work site location and stockpiling sand. By August, the breach width had been narrowed to approximately 330 m (1100 ft) and was reduced only an additional 60 m (200 ft) through the month of August. The most rapid progress occurred during the month of September when the inlet decreased from a width of approximately 280 m (900 ft) on 11 September to complete closure on 25 September. In brief, during the period of this experiment from April 1993 to January 1994, the inlet experienced a period of slow expansion from April to July, slow reduction from July through August and extremely rapid reduction during the month of September after which the inlet remained closed. Although little or no control on the depth of the inlet exists, it is safe to assume that the deepest section of the inlet continued to erode and deepen until near the end of the filling process.

Several aspects of this inlet history can be observed in Figure 3. During the entire period of the experiment, the ocean tide range, as expected, remained constant at approximately 1.1 m (3.6 ft). The bay range however was anything but constant. While periods of slight increase and decrease in bay tide range may be discernible in the record during the period of slow inlet growth and reduction from April through August, it is clear that the period of rapid inlet filling during the month of September corresponds to the period of rapid decrease in the bay tidal range. The bay tide range during this period underwent a reduction from approximately 0.80 m (2.6 ft) to 0.62 m (2.0 ft). That this reduction is due to the inlet is supported by the fact that the tidal range in the bay remains constant following the closure of the inlet. This result is fully consistent with the expectation that a decrease in the dimensions of Little Pike's Inlet represents a decrease in the total bay-ocean passageway which results in increased resistance to the transmission of ocean tidal range into the bay, thereby reducing the bay tidal range. This is observed in the results in Figure 3c where tidal transmission is plotted. In this figure the tidal transmission during the month of September drops from a peak of approximately 73% to a value of about 55%. Following the total closure of the inlet, the tidal transmission remains constant at this value of 55%. It is now clear that the presence of Little Pike's Inlet led to an increase in the tidal transmission into Moriches Bay with a peak difference on the order of 30%

relative to the single inlet configuration. This increased transmission results in a greater bay tide range also approximately 30% greater than the range with the single inlet.

It is worthwhile to examine exactly how the 30% change in tidal range is distributed between differences in mean bay surface elevation. A change in tide range which is due to a symmetrical shift in mean low water and mean high water would result in no alteration of the mean surface elevation. Such a situation would result in changes in the mean low and high water, which are half of the magnitude of the total tidal range change. On the contrary, any asymmetry in the changes in mean high and low water leads to an alteration of the mean bay surface elevation. Figure 4 highlights the period from 1 August to 15 November over which bay tides experienced the most rapid change. During this period the tidal range dropped from an average of 0.81 m (2.66 ft) during the month of August to an average of 0.62 m (2.05 ft) during October-November. By observing the mean high and low water during this same period, it would appear that almost all of this difference is due to a shift in the mean high water. Of the 0.19 m (0.61 ft) (Table 1) difference in average tidal range, only 17% or 0.03 m (0.1 ft) is accounted for in the change in mean low water which increased from a level of 0.04 m (0.12 ft) to 0.07 m (0.22 ft) over the same period. The remaining 83% is due to a drop in the mean high water level which fell from an August average of 0.85 m (2.78 ft) to 0.70 m (2.27 ft) during October-November. These observations however neglect what is happening in the ocean during this period. A similar analysis (Table 1) shows that the mean high and low water levels at Sandy Hook dropped 0.07 m (0.23 ft) and 0.09 m (0.28 ft), respectively, over the same period. The relative changes in mean water levels inside the bay can now be seen to be a relative drop in mean high water of 0.09 m (0.28 ft) and a relative increase in mean low water of 0.12 m (0.39 ft). This shift suggests a slight increase in the mean water level in the bay following the closure of the inlet. Determination of the mean water levels during these two periods shows this to be true with the post closure water level, relative to the ocean, approximately 0.02 m (0.08 ft) higher (Table 1).

Table 1

Site	Average Aug Mean High (cm)	Average Oct/Nov Mean High (cm)	Average Aug Mean Low (cm)	Average Oct/Nov Mean Low (cm)	Δ High (cm)	Δ Low (cm)	Mean Aug Elevation (cm)	Mean Oct/Nov Elevation (cm)
Speonk Pt	0.846	0.692	0.037	0.069	-0.154	0.032	0.418	0.377
Sandy Hk	1.111	1.042	-0.324	-0.410	-0.069	-0.086	0.394	0.328

As it has already been discussed that the salinity levels in the bay represent a balance between mixing of saline ocean water with fresh water drainage, the question is raised whether a 30% change in tide range affected the salinity in the bay. Examination of Figure 4 indicates that the answer to this question is mixed. Figure 4 shows the salinity at all locations with the solid line representing a least squares fit to the data from September 1 until the end of the record on 5 January. This line therefore indicates the trend, if any, of salinity levels following the initiation of the rapid decrease in Moriches Bay tide range due to the closure of Little Pike's Inlet. Over this 4 month period, the salinity at Pine Neck Point showed an apparent decrease of approximately 0.16‰ (parts per thousand). This decrease is statistically insignificant meaning that the salinity at our control station experienced no significant change in salinity. This result suggests that either no change occurred in the regional factors affecting salinity or a change among all of them which resulted in no net salinity change. It can thus be assumed that any change in salinity observed in Moriches Bay can be attributed to the breach closure.

The observations at Speonk Point just north of the breach clearly indicate a change in salinity. The trend in salinity over this four month period was for a decrease in the salinity level from a breach closure level of 30.36‰ to a level 28.93‰ for a net drop of 1.42‰. This change is significant, even at the 99% confidence level and is in agreement with the observed decrease in the bay tidal range. Reduced tidal range leads to less mixing of saline ocean water while fresh water input is unchanged resulting in a lowering of the bay salinity. The final measurements confuse the picture showing absolutely no change in the salinity at Forge Point at the far end of Moriches Bay where the salinity remained constant around 28.4‰. This result suggests a limit to the range of effects of Little Pike's Inlet and suggests that processes in this portion of Moriches Bay may be controlled by Great South Bay through the opening at Smith Point. This is supported by the consistently lower salinity values at Forge Point relative to Speonk Point throughout the measurement period prior to the inlet's closure. The data suggests that following the breach closure the salinity at Speonk Point is tending towards the level at Forge Point.

5. CONCLUSIONS

Salinity and tides have been measured in Moriches Bay following the breach of December 1992 that resulted in the formation of Little Pike's Inlet. These measurements continued through the subsequent closure of this inlet in September 1993 and finished in early January 1994. These measurements allowed for the detection of some of the physical effects of such a breach on the environment in Moriches Bay. The first such effect was an increase in the transmission of ocean tides into the bay. At it's peak, the inlet permitted an additional 30% of the ocean tidal range to be transmitted into the bay. This increase was divided relatively evenly between higher highs and lower lows with a slight decrease (0.02 m) in the mean relative water level in the bay. These changes in tidal elevations in the bay did indeed result in a change in the salinity in the bay although this change was not constant throughout the bay. At Forge Point, directly north of the inlet, the salinity dropped 1.42‰ in the four months following the closure of the inlet. At the opposite end of Moriches Bay near the junction with Great South Bay, the salinity at Forge Point exhibited no significant change suggesting a geographic limit to the effects of Little Pike's Inlet.

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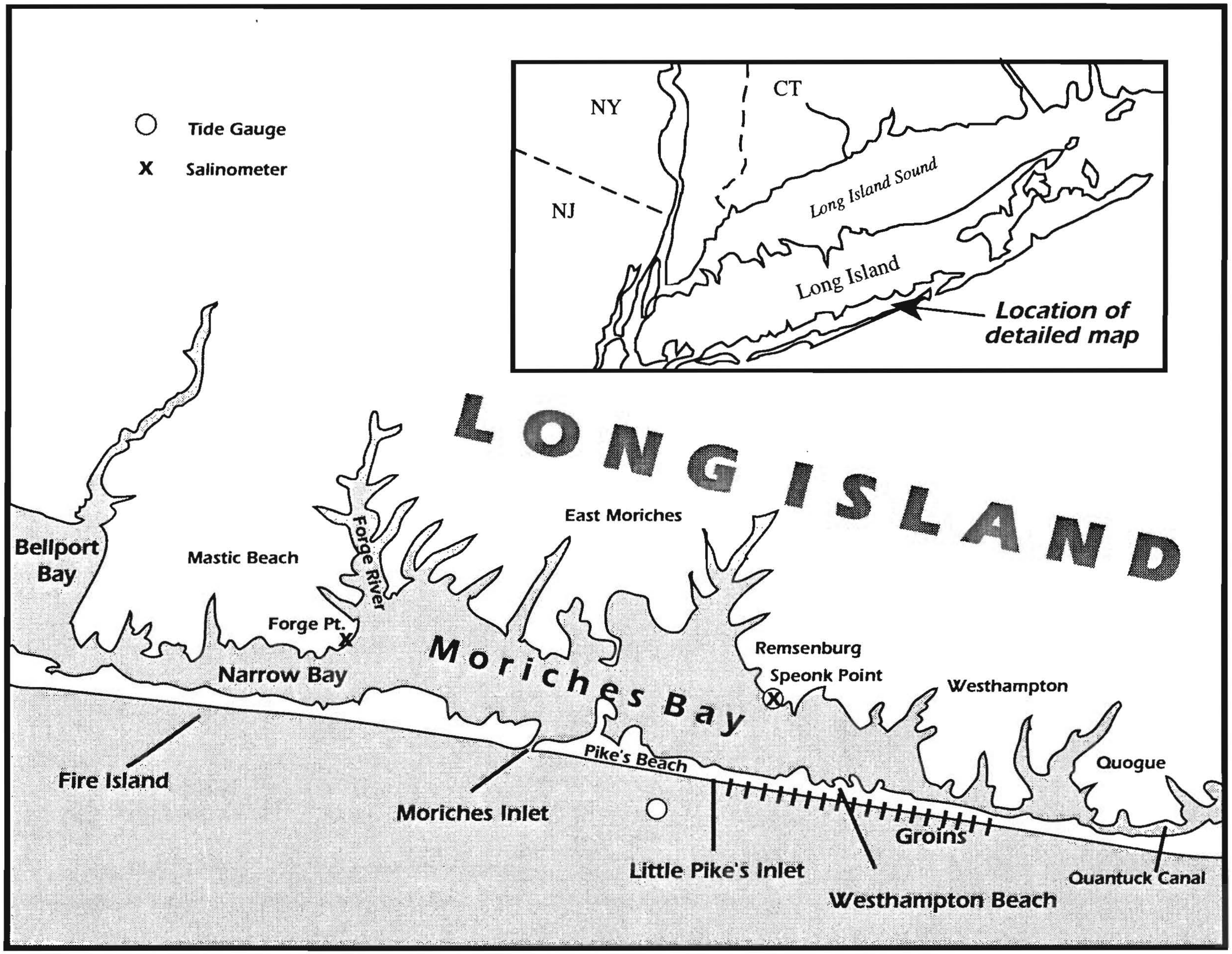

FIGURE 1: Map of Moriches Bay showing inlet and measurement locations. Tide and salinity measurements were made at Speonk Point. Salinity measurements were made at Forge Point. Control measurements were made in Shinnecock Bay, east of Quogue. Ocean tide measurements were collected offshore of Pike's Beach.

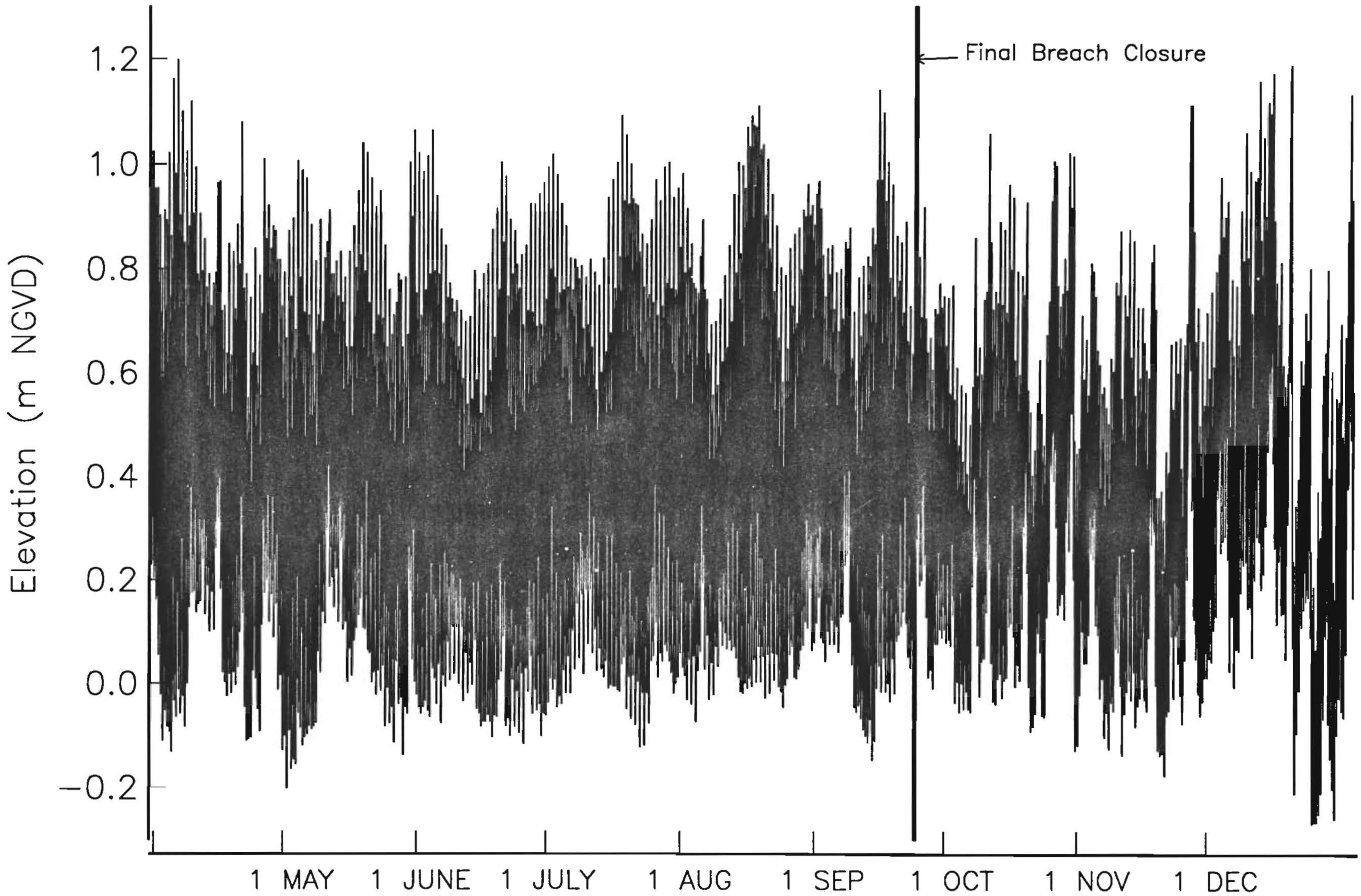

FIGURE 2: Nine months of Moriches Bay Tide data collected at 15 minute intervals at Speonk Point. Little Pikes Inlet was completely closed at time of wide vertical bar."

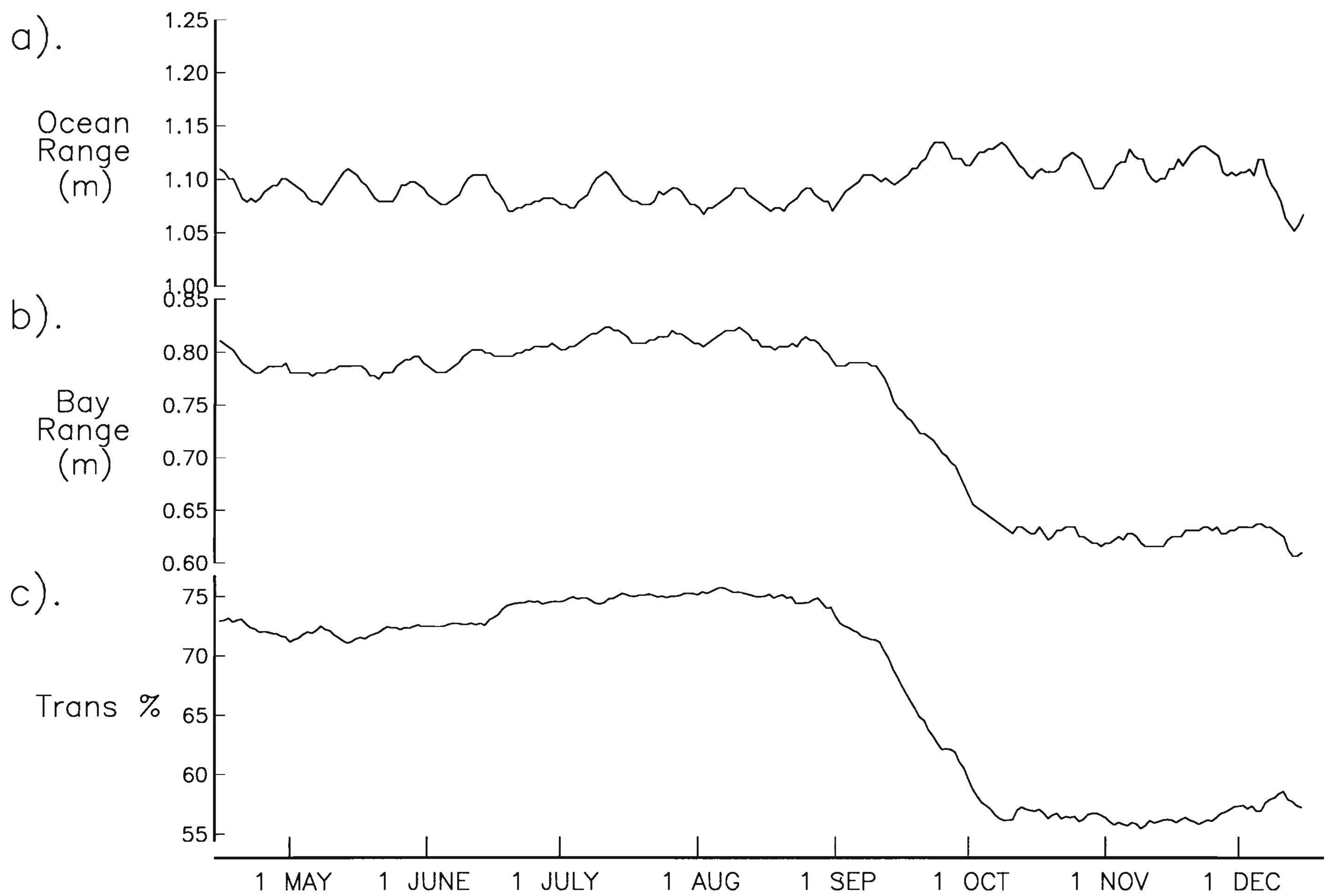

FIGURE 3: Plot of ocean (a.) and Moriches Bay (b.) tidal range and tidal transmission of ocean tides into bay (c.) from 15 April to 15 December 1993. Ranges are calculated over a time centered 29 day period and transmission is the ratio of bay to ocean range.

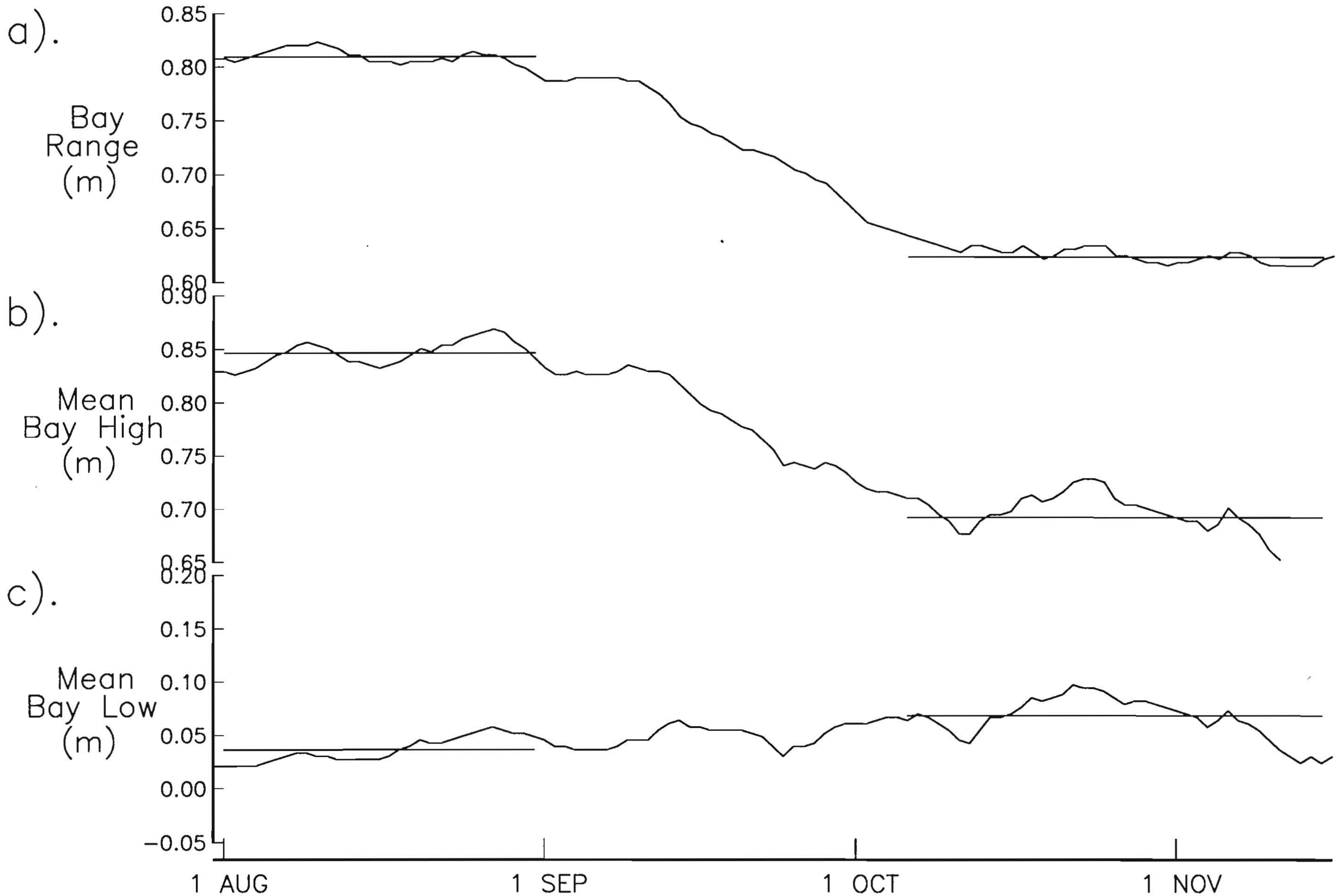

FIGURE 4: Moriches Bay tidal range and mean low and high waters from measurements at Speonk Point. Quantities are calculated as discussed in Figure 3. Straight lines represent the mean during the month of August and from October 15 to November 15.

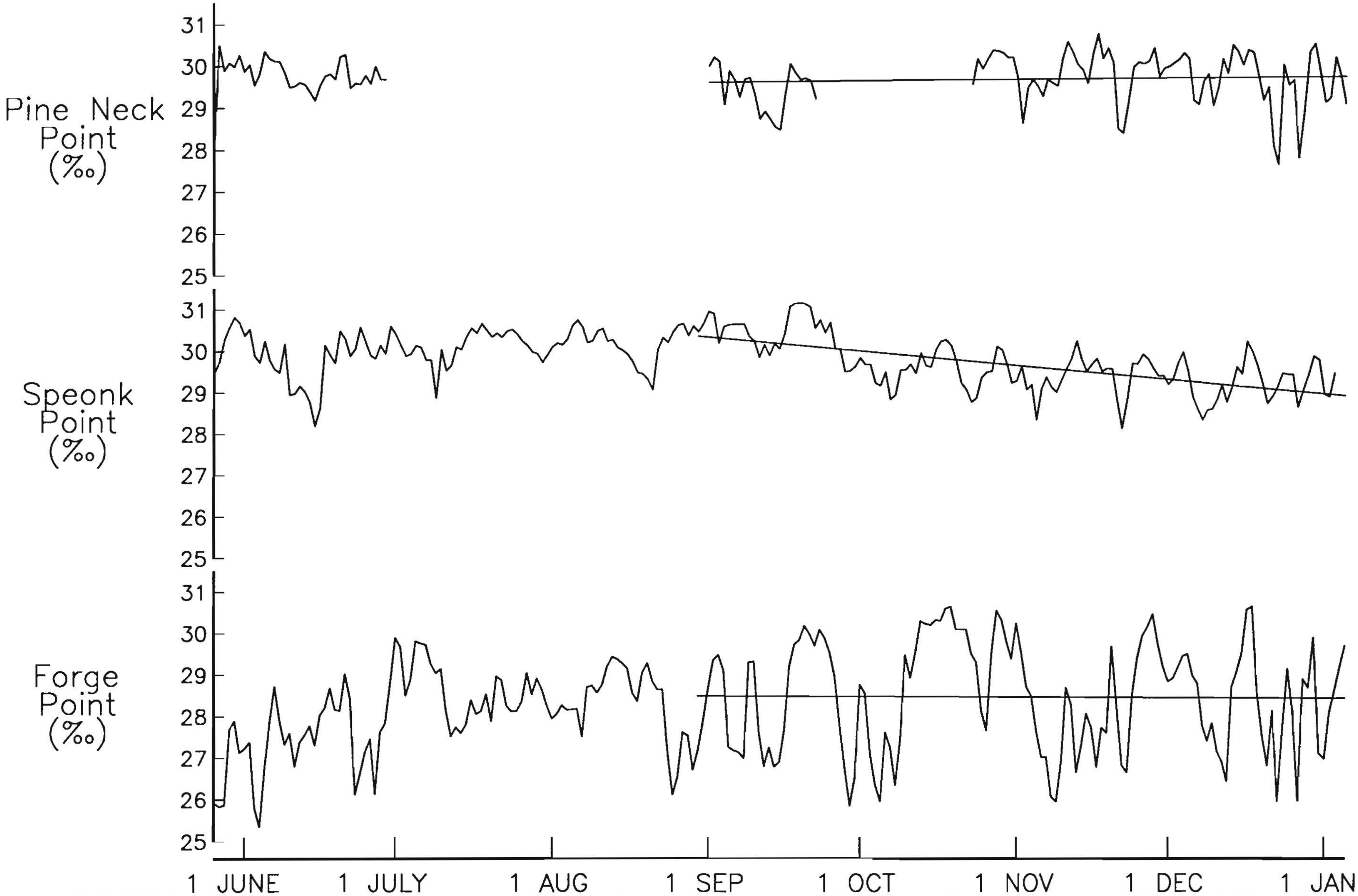

FIGURE 5: Daily averages of salinity at three locations in Moriches Bay and Shinnecock Bay for the period 25 May 1993 to 5 January 1994. Values are in parts per thousand (‰). Straight lines represent trends for period 1 Sept. 1993 to 5 January 1994 as calculated by least squares fit.