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# Shoreline variations and long-term trends

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## INTRODUCTION

Comparisons among maps and aerial photographs are commonly used to search for trends in the change in shoreline position over time periods of many decades. The technology for making such comparisons is well developed to reduce measurement errors due to scale changes or distortion, but the problem remains of resolving long-term trends in the face of potentially large, interannual variations in the actual shoreline position. This article discusses the shorline variability along the south shore of Long Island at East Hampton, New York, U.S.A. and its impact on the reliability of long-term measurements.

## BACKGROUND

The shoreline at East Hampton, New York, is cut into a sandy, glacial outwash plain. The beaches are typically 60 meters wide, composed of sand with a median grain size of 0.02 mm. The tidal range is about 1 m although non-tidal water level variation in excess of 1 m recur about once a year.

Comparisons of historical shorelines have been done by Taney (1961), Rich (1975 ms), Leatherman and Allen (1985), Dean (1981 ms) and Zarillo (1989). The principal indicators were maps made in 1838 and 1894, and aerial photographs taken in 1933, 1939, 1955, 1961 (after a major storm), 1971, 1976 and 1988. Rates of shoreline changes calculated for different periods and different sections vary widely. At East Hampton, for example, changes ranged from advances at a rate of 3 m/yr to recessions of 7 m/yr.

Shoreline positions are usually drawn along the limit of the water-saturated zone on the beach which is generally taken to represent a high water shoreline. Regardless of the indicator used, there are uncertainties introduced in the rectification of photographs, distortion of images or measurement errors. In the study area, Zarillo (1989) has estimated the accumulated measurement uncertainty at $\pm 40$ feet. If this is taken to represent a 95%-confidence interval in the presence of a normally distributed error, the standard deviation of the measurement uncertainty, $\sigma_0$ , would be 20 feet.

Calculations of the recession rate are made with the assumption that the shoreline on the map or aerial photograph is the average shoreline position over some representative period, say, a year. If only one measurement of the shoreline position (i.e., the photograph or map) is available from that year, that position is the best estimate of the mean position, S. The shoreline changes, $\Delta$ S is $(S_2 - S_1)$over a period P between the time that one shoreline image was made $(T_1)$ and the date of a second image at a later time $(T_2)$. The average rate of shoreline change is $(S_2 - S_1) / (T_2 - T_1)$ or $\Delta S/P$. If the natural variations in S are normally distributed with a standard deviation of $\sigma$, that is, with a variance of $\sigma^2$, then the variance in shoreline position including measurement errors would be $(\sigma^2 + \sigma_0^2)$ and variance in the calculated shoreline change is $(\sigma_2^2 + \sigma_1^2 + 2\sigma_0^2)$. If we can assume that the shoreline variations are statistically stationary, as might be the case if there are not substantial changes in the susceptibility of the beach or the wave climate, then the variance of $\Delta S$ is $2(\sigma^2 + \sigma_0^2)$ or, in other words, its standard deviation, $\sigma_\Delta$, is $1.4\sqrt{\sigma^2 + \sigma_0^2}$. Therefore, it can be said with a confidence of 95% that the true change between the mean shoreline position is within the range $\Delta S \pm 2\sigma_\Delta$. Alternatively, the true, average rate of change in the shoreline position is within $(\Delta S/P) \pm (2.8\sqrt{\sigma^2 + \sigma_0^2}/P)$. In practice, measurements adequate to calculate $\sigma$ are not usually available, but they are for the East Hampton shoreline.

## METHODS

In 1979 a series of 20 stations were established along a three mile stretch of beach. There were groins at each end of the section. Each station was surveyed to a standard benchmark and their location determined in the state plane coordinate system. Over the next 10 years, some of these stations were lost and some abandoned due to reductions in the program, but measurements were made at six stations about every six weeks for the decade.

Beach profiles were recorded using a technique modified from Emory (1961). They were done within an hour of low tide and the width of the beach was calculated to mean sea level, extrapolating the slope of the swash face when necessary. Any linear trend was removed from the time series of beach width at each station. The deviations from the linear trend were calculated, tested for normality and used to calculate a composite standard deviation for the beach width.

RESULTS

The time series of beach widths for each station is given in Figures 1 through 6. The least-squares linear regression line is shown for each as well as the correlation coefficient. Although the coefficients were not high, the correlations were sufficiently strong for this type of environmental data to warrant the removal of the linear trends.

The stations surveyed at East Hampton were plotted on the base maps used by Leatherman and Allen (1985) and the reported, historical shoreline positions (Leatherman and Allen, 1985) were indicated on the graphs of the measured shoreline position at mean sea level determined by the surveys. Because the beach face is relatively steep at East Hampton, this comparison is a reasonable one; since the tidal range is about 3 feet and the foreshore slope is about 0.125, the high tide shoreline would be expected to be only 12 feet landward of the shoreline at mean sea level. In every case, the historical shoreline positions fall within the range of variation of shoreline positions observed during the past decade. Even if the historical shorelines are true high-water shorelines, the range of variation introduces very large uncertainties into long-term recession rates calculated from the historical data. The statistical variation of the shoreline position can be used to quanitfy this uncertainty as follows.

The distribution of residuals was tested for normality using the G-Test which indicated a Guassian distribution. The standard deviation was 50 feet. If the variations were the same around the position of two former shorelines, $S_1$ and $S_2$ and if we assume that the standard deviation of the measurement error is 20 feet, then the standard deviation of their difference would be 76 feet, and we are 95% confident that the actual difference between the mean shoreline positions at two different times are within 152 feet (i.e., two standard deviations) of the measured difference. At this confidence level, the uncertainty in the average rate of retreat is 152 feet/P.

## DISCUSSION

The difference in shoreline position along a 18-mile stretch of shoreline between 1938 and 1988 as calculated by Zarillo (1989) is shown in Figure 7. This stretch of shoreline begins at Shinnecock Inlet in the west and runs for about 17 miles crossing the boundary between Southampton and East Hampton at about milepoint 12.5. There are a series of 3 groins just to the east of this boundary. Three lines are plotted on Figure 7. The center line is the difference in the shoreline position measured by Zarillo (1989) and the upper and lower lines bracket a region of plus or minus two standard deviations around that line. We can be 95%-confident that the actual difference in the mean shoreline between 1938 and 1988 is somewhere between the upper and lower lines on Figure 7. At the 95% confidence limit none of the shoreline can be said to be advancing and only 25% (which is downdrift of a groin field) can be said to have retreated during the period.

Beach surveys are available at other areas along the south shore. The range in beach positions seems to be similar to the range observed at East Hampton so it may not be unreasonable to assume that the variances would be the same. The application of a 95%-confidence interval to the long-term recession data for the entire south shore (Taney, 1961, and Leatherman and Allen, 1985) is shown in Figure 8. Figure 8a is a comparison between the earliest map in 1873/92 and aerial photographs from 1951 and 1955 west of Fire Island Inlet (Taney, 1961) and from 1979 east of Fire Island Inlet (Leatherman and Allen, 1985). Figure 8b shows the comparison for the period after 1933. Again, the central line is the reported difference in shorelines reported by the original investigators. The upper and lower lines represent the 95%-confidence interval around the reported differences. With 95% confidence, accretion can be detected over about 8% of the shoreline updrift of Shinnecock Inlet, Fire Island Inlet and at the western end of Jones Beach. Erosion can be discerned over about 18% of the shoreline that downdrift at each inlet. Over 74% of the shoreline, however, neither erosion or accretion can be documented from these sets of maps and aerial photographs.

CONCLUSION

The measurements of beach profiles at East Hampton over the past 10 years can be used to estimate the statistical confidence with which shoreline changes can be measured from sequential maps and aerial photographs. The 95% confidence interval is ±152 feet around any measured difference between two images. Reported differences exceed this value only within a few miles of groins or inlet jetties. As a result, the comparison of shorelines cannot document long term changes, either erosion or accretion over most of the south shore.

# REFERENCES

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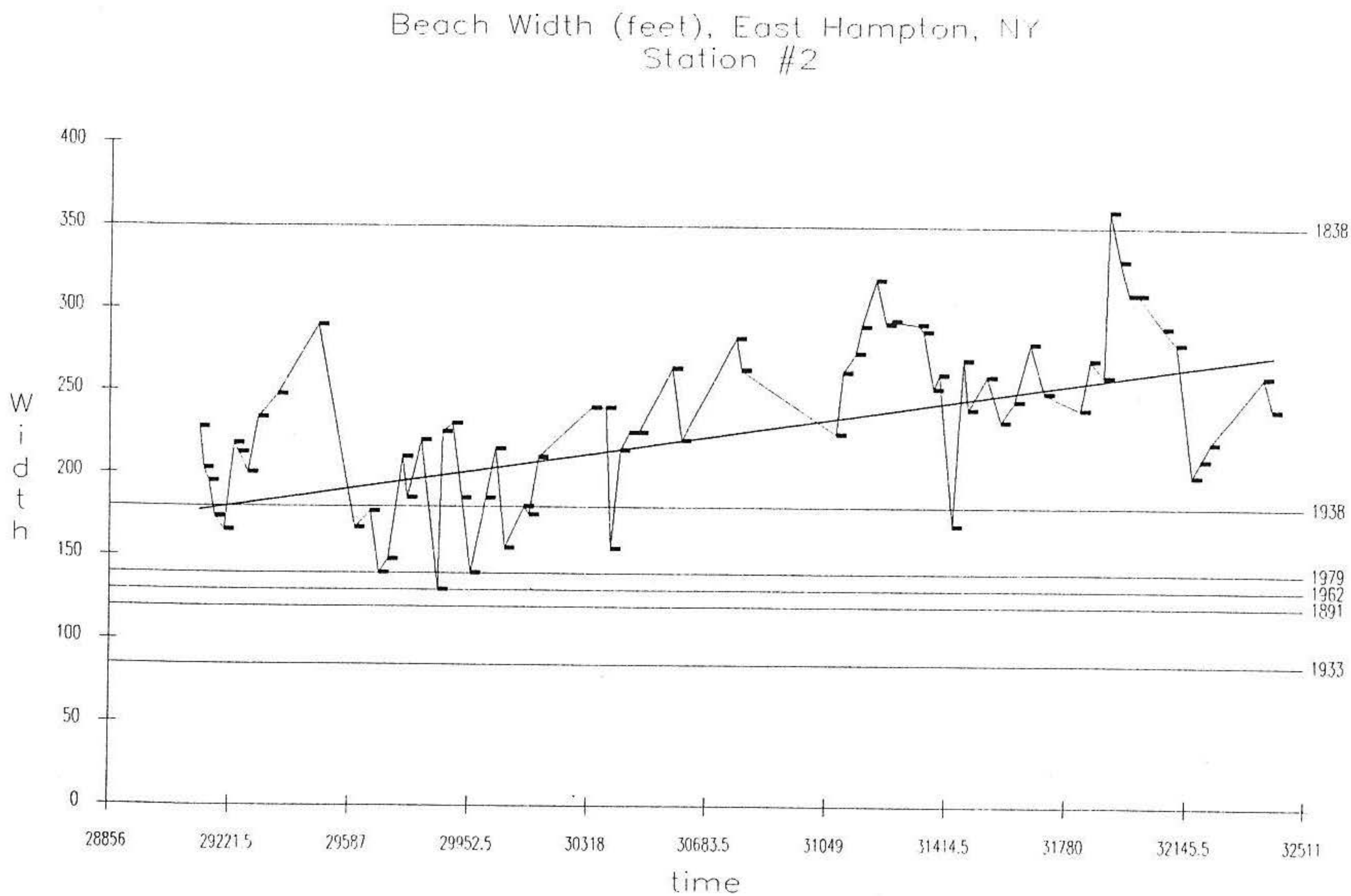

Beach Width (feet), East Hampton, NY
Station #2
W i d t h
400
350
300
250
200
150
100
50
0
28856
29221.5
29587
29952.5
30318
30683.5
31049
31414.5
31780
32145.5
32511
time
1838
1938
1979
1962
1891
1933

Figure 1

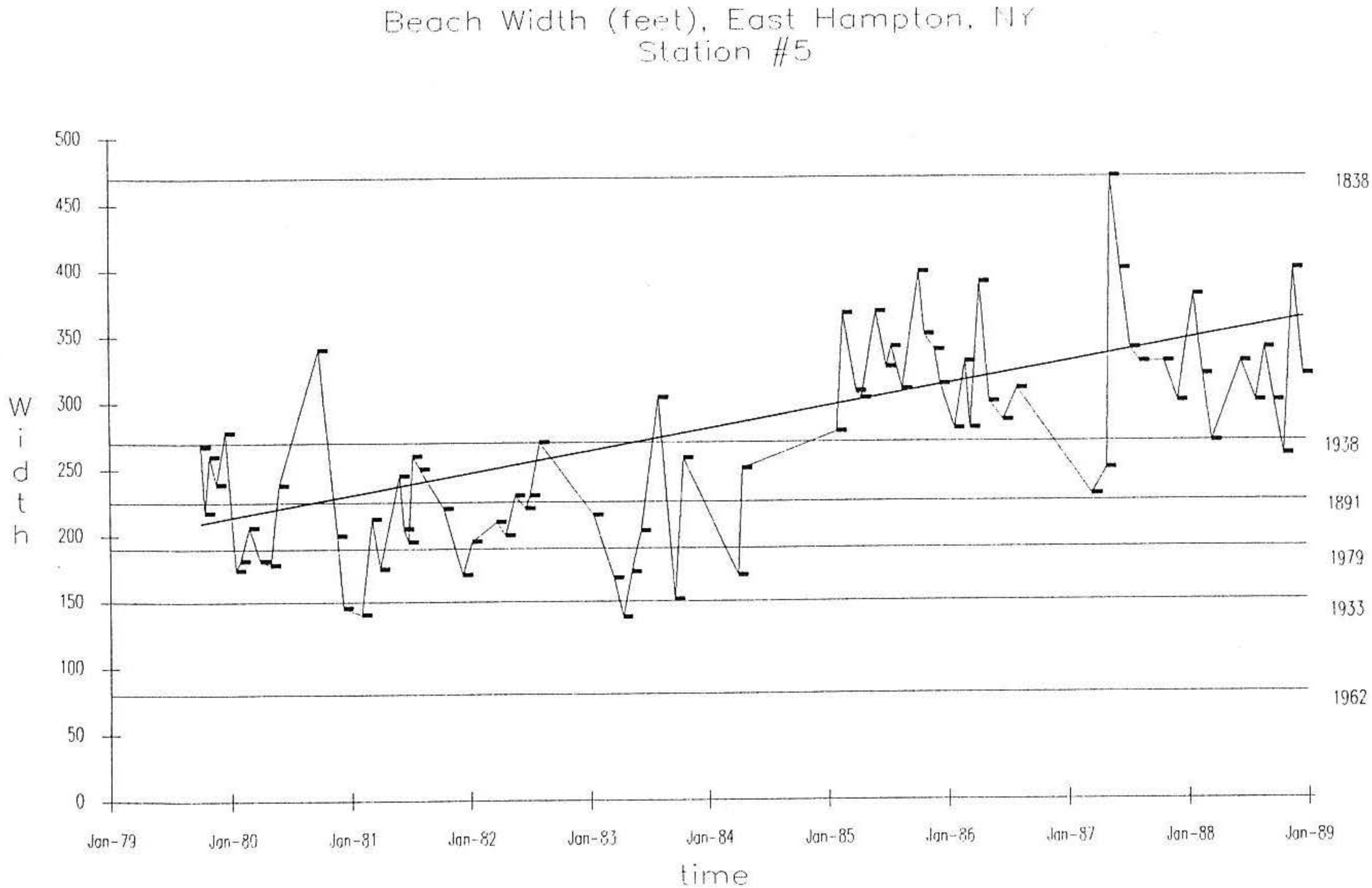

Beach Width (feet), East Hampton, NY
Station #5
Width
500
450
400
350
300
250
200
150
100
50
0
1838
1938
1891
1979
1933
1962
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
time

Figure 2

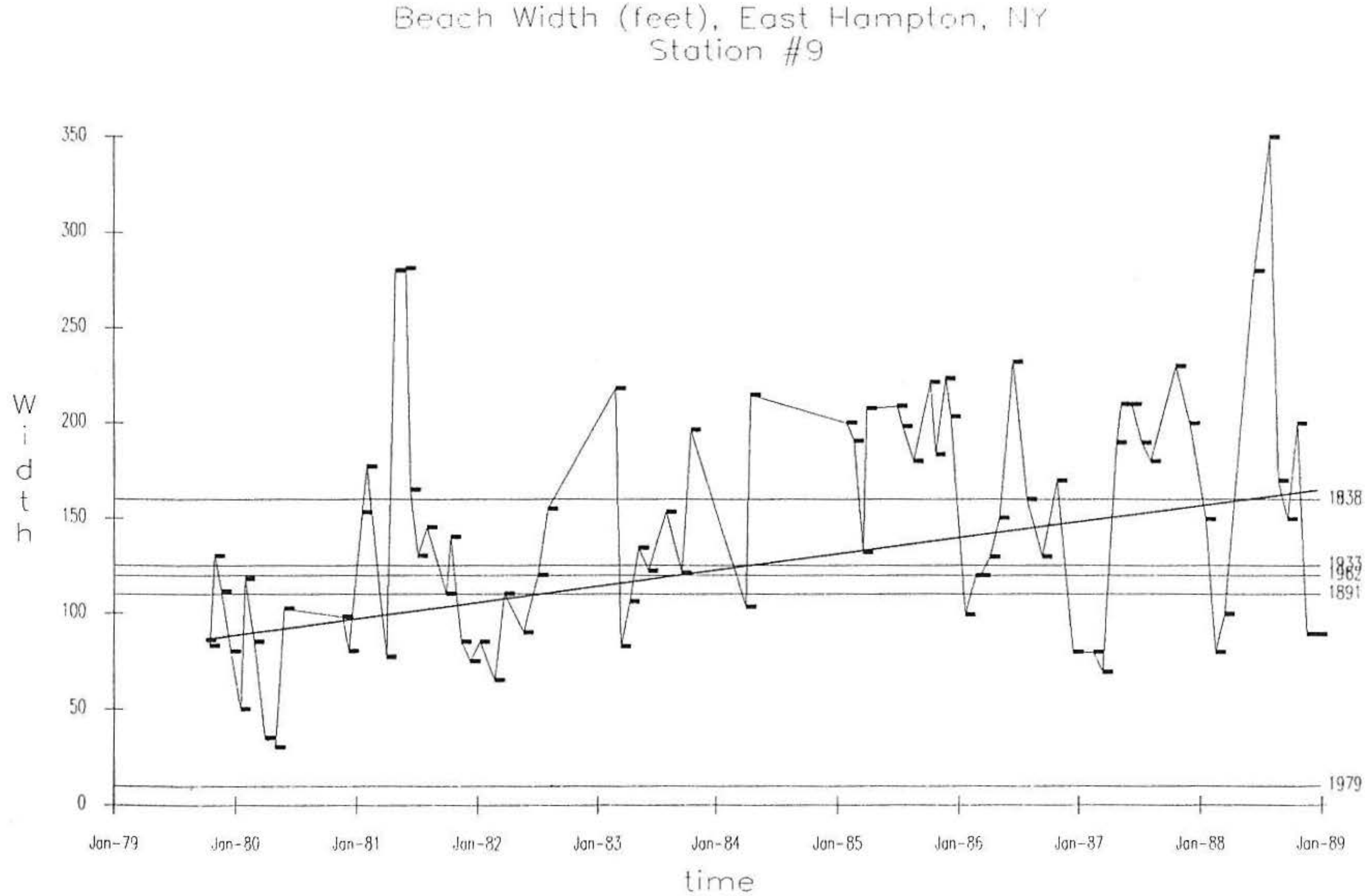

Beach Width (feet), East Hampton, NY
Station #9
W i d t h
350
300
250
200
150
100
50
0
1838
1933
1962
1891
1979
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
time

Figure 3

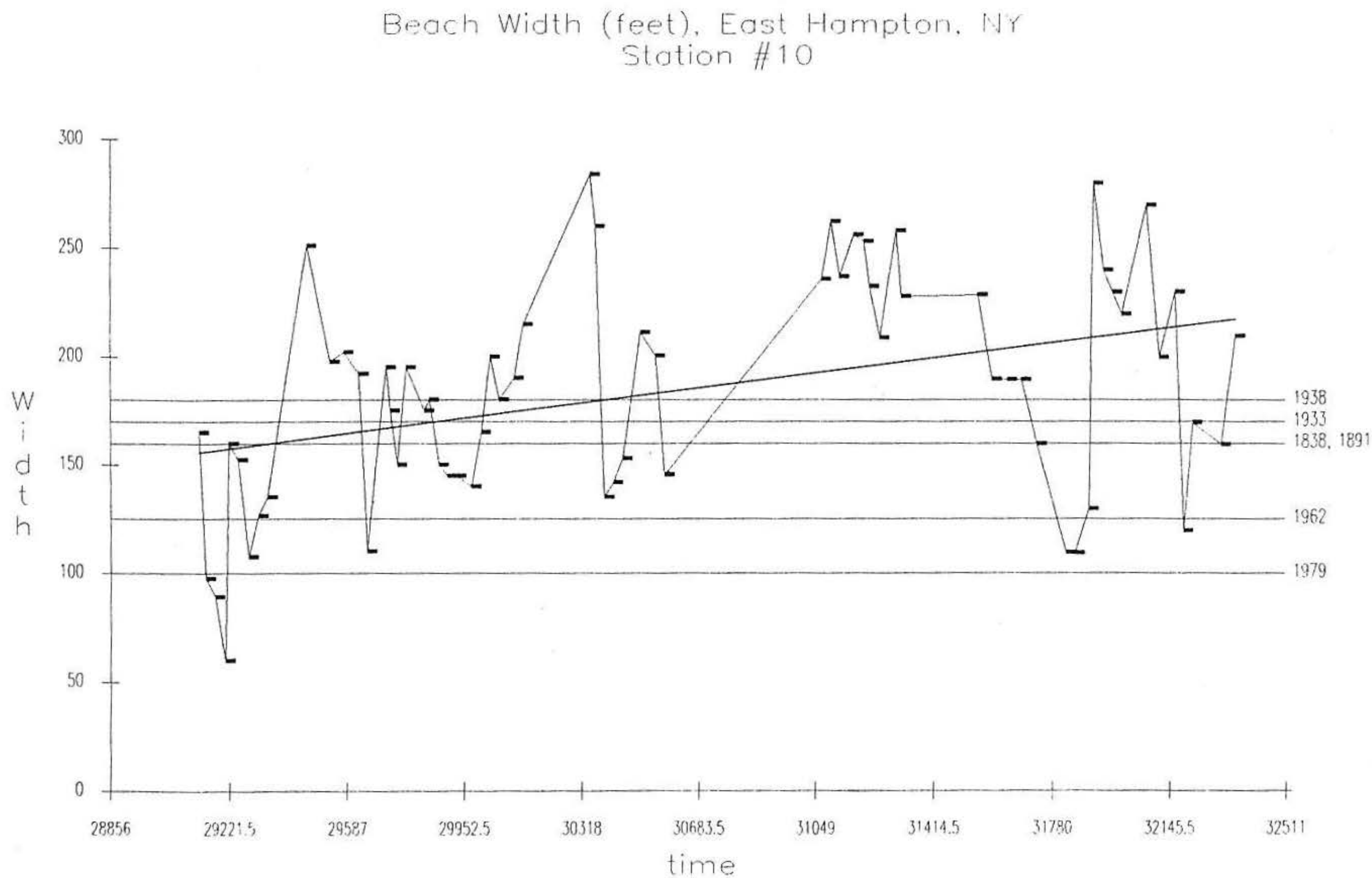
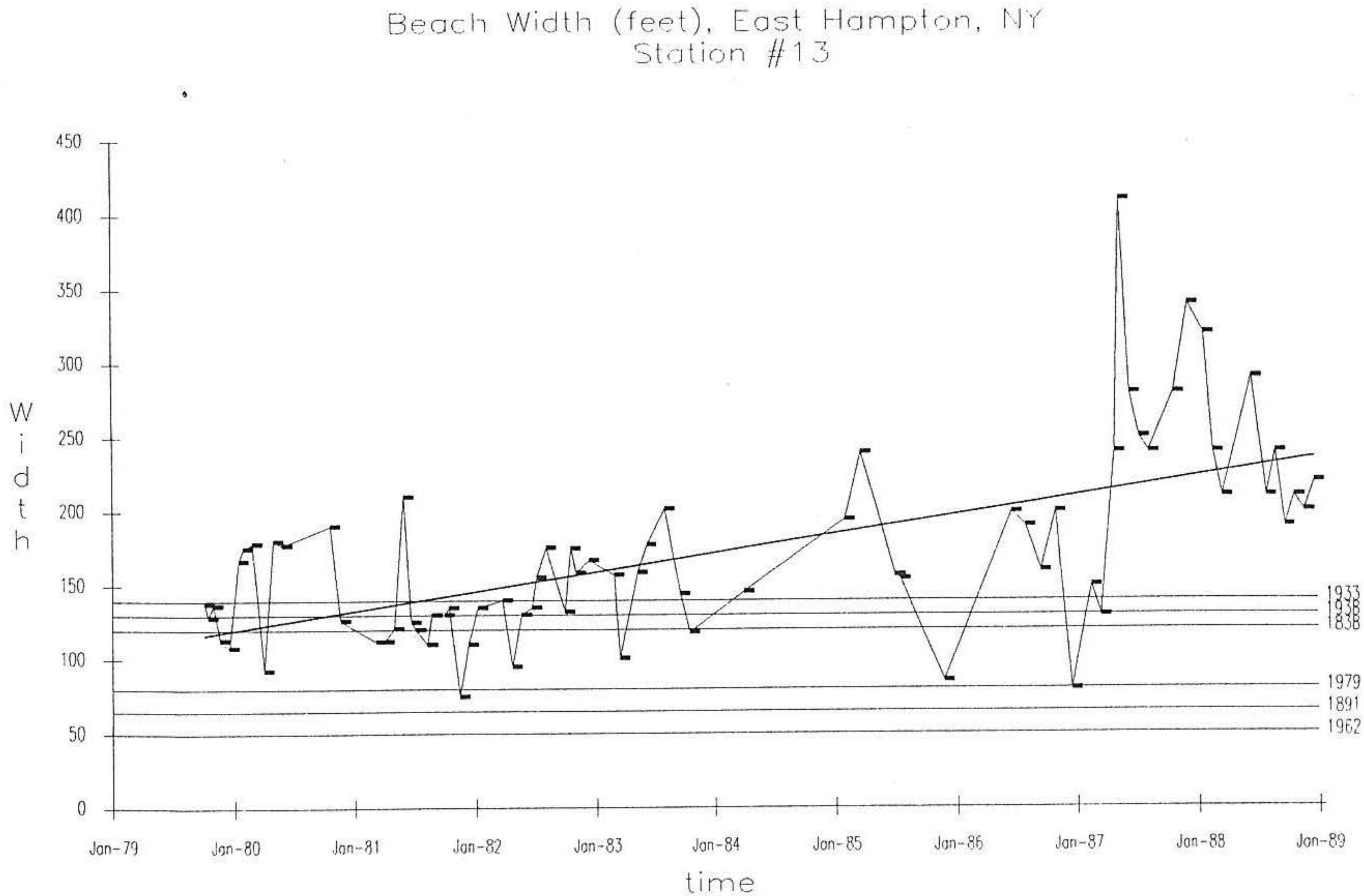

Beach Width (feet), East Hampton, NY
Station #10
300
250
200
150
100
50
0
Width
1938
1933
1838, 1891
1962
1979
28856
29221.5
29587
29952.5
30318
30683.5
31049
31414.5
31780
32145.5
32511
time

Figure 4



Beach Width (feet), East Hampton, NY
Station #13
450
400
350
300
250
200
150
100
50
0
W i d t h
1933
1938
1838
1979
1891
1962
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
time


Figure 5

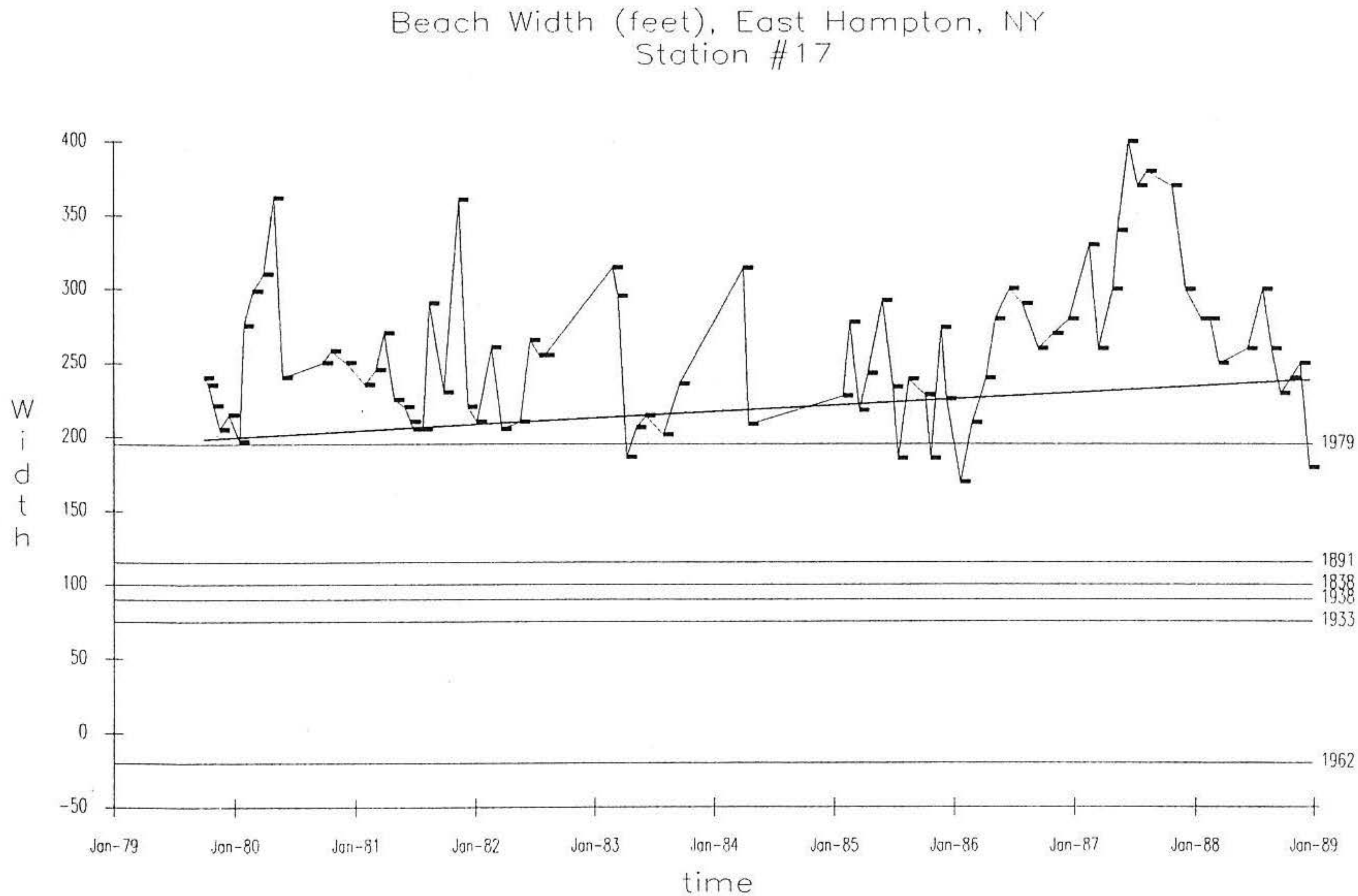
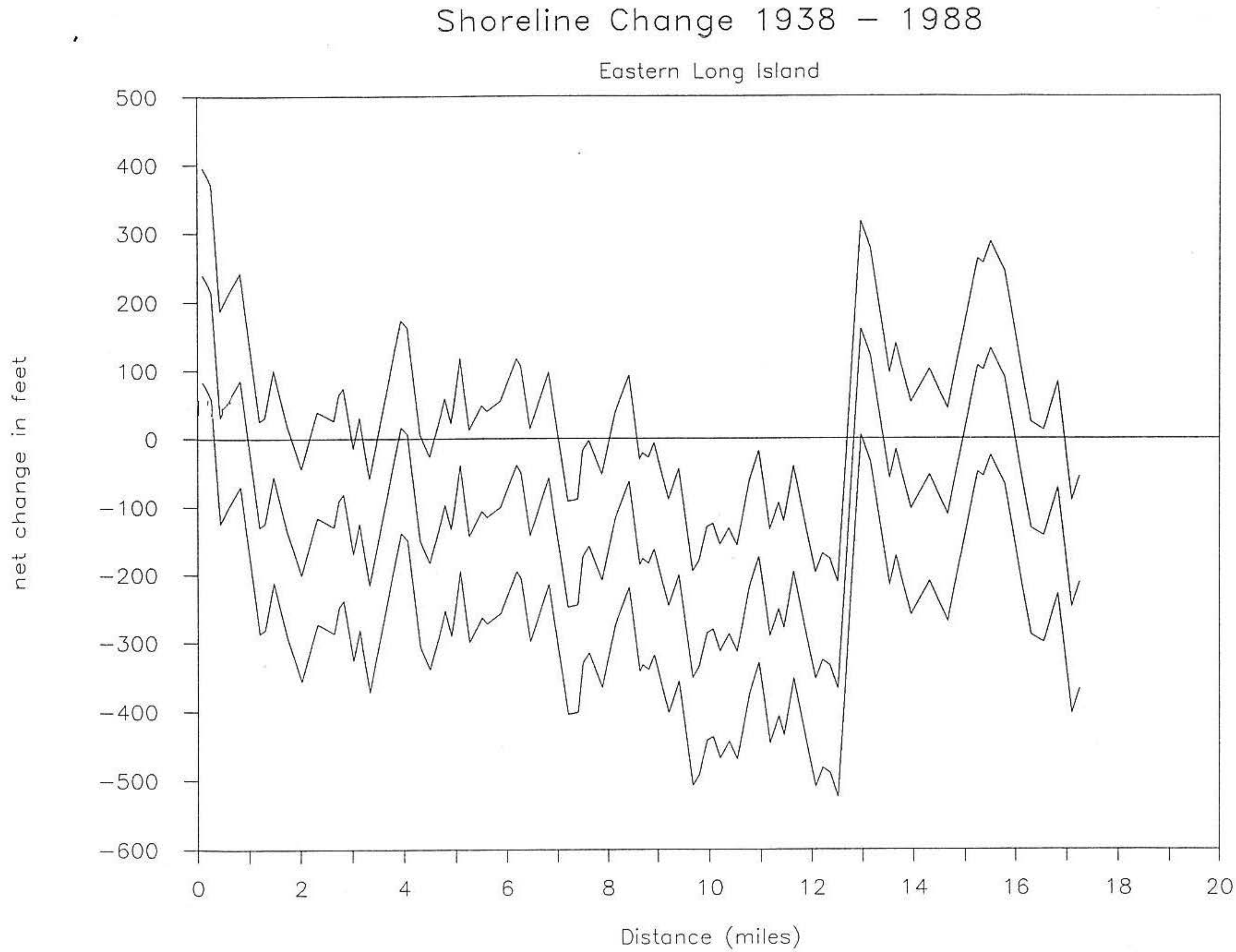
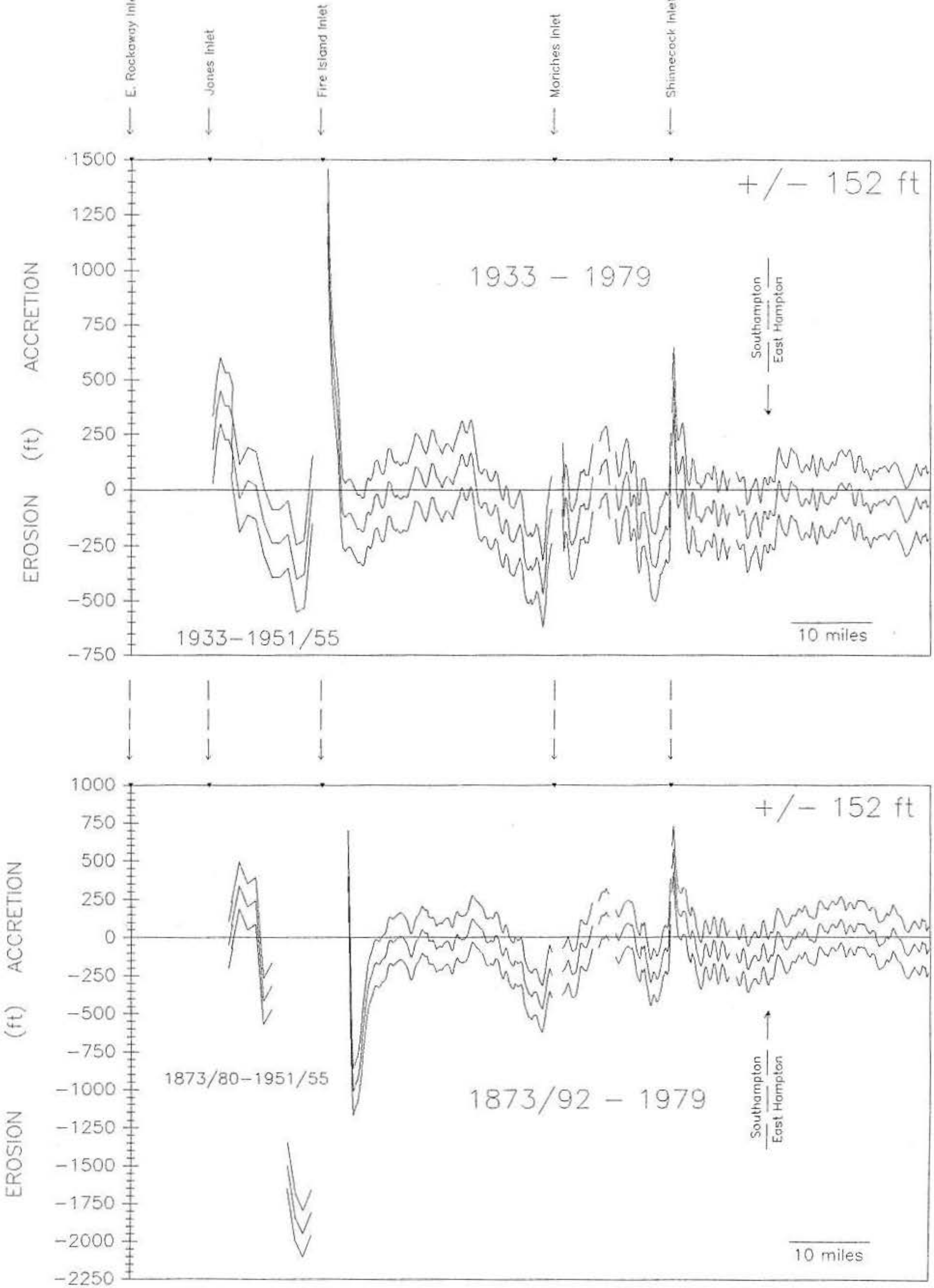

Beach Width (feet), East Hampton, NY
Station #17
Width
400
350
300
250
200
150
100
50
0
-50
1979
1891
1838
1938
1933
1962
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
time

Figure 6



Shoreline Change 1938 – 1988
Eastern Long Island
net change in feet
500
400
300
200
100
0
–100
–200
–300
–400
–500
–600
0
2
4
6
8
10
12
14
16
18
20
Distance (miles)


Figure 7



E. Rockaway Inlet
Jones Inlet
Fire Island Inlet
Moriches Inlet
Shinnecock Inlet
+/− 152 ft
1933 − 1979
Southampton
East Hampton
ACCRETION
(ft)
EROSION
1933−1951/55
10 miles
+/− 152 ft
1873/80−1951/55
1873/92 − 1979
Southampton
East Hampton
ACCRETION
(ft)
EROSION
10 miles


Figure 8