CHAPTER 148

STATISTICALLY SIGNIFICANT BEACH PROFILE CHANGE WITH AND WITHOUT THE PRESENCE OF SEAWALLS.

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Abstract

The interaction of beaches and seawalls is a highly controversial subject today. Many of the arguments both "for" and "against" the construction of seawalls have been speculative. Few are based on actual field or laboratory measurements. This paper is part of a continuing study at one location, which intends to shed some light on this controversy using statistical analysis of real field data.

1. Introduction

Sandbridge, Virginia (USA) is the site for an ongoing investigation of seawall and beach interaction. The study area lies on the east coast of the United States. Sandbridge is located south of the Chesapeake Bay and north of the Virginia-North Carolina border, as depicted in Figure 1. The beach is used by local property owners, residents, and tourists as a recreational area.

The long term shoreline recession rate (Everts et al., 1983) has been shown to vary at Sandbridge from 1.1 m/yr at the north end, to 2.9 m/yr at the south end. For this reason, many beach front private property owners have acted to protect their investments by constructing timber, steel or concrete seawalls (bulkheads). The protection of septic tanks, concrete slabs, and other property at ground level are a few reasons for their construction. The majority of homes in the area are on piles above the one percent chance storm surge event.

A few wall sections were constructed as early as 1978; however, most were erected in the mid to late 1980's. Fifteen sections of wall presently exist totaling 4816 m, roughly 60 percent of the 7.7 km study length (See Figure 1, insert). In general these sections lie about 46 m seaward of our baseline, Sandfiddler Road. Some sections, particularly those south of profile 162, are located within the daily tidal range. During storm events, the beach berm, seaward of the walls, is submerged at all locations. This allows waves to break at or near the walls.

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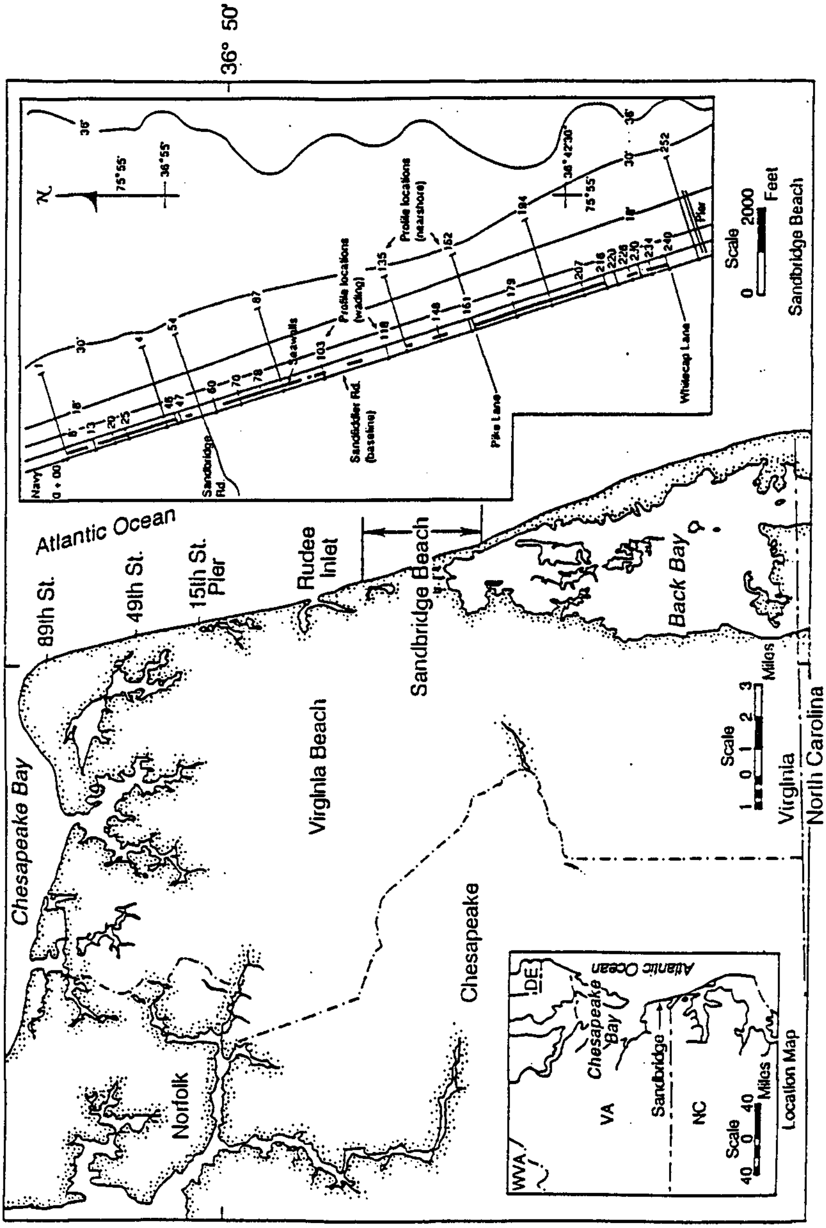

Figure 1 Location Map

The effects seawalls have on beaches, and their overall performance as a shoreline protection strategy, is the subject of much controversy today. The Journal of Coastal Research's 1988 Special Issue Number 4 entitled, "The Effects of Seawalls on the Beach", was specifically devoted to this topic (Kraus and Pilkey, 1988 Editors). Of the eight articles in this issue, none contained a rigorous statistical analysis of beach profile "change".

Profile data has been collected at Sandbridge since 1980, and continues to be collected today. Using this data, long term trends can be observed. These trends can then be used to determine statistical differences in walled and non-walled profiles. This statistically based information will help determine if the seawalls are responsible for altering the existing "natural " variations in beach profile data.

2. Field Efforts and Data Base

In August of 1990 Old Dominion University (ODU) began collecting monthly profile data at 28 locations along Sandbridge Beach. The project, sponsored by the Corps of Engineers' Coastal Engineering Research Center (CERC), has been extended through 1995. Of the 28 profile locations, 12 contain walls, 10 are across dunes, and 6 are located near wall ends, as shown in Figure 1. Profiles are taken out to low tide wading depths (-0.6 m), extending seaward about 122 m from the baseline.

The City of Virginia Beach began survey work in 1980 with profiles at roughly 305 m intervals. Most profiles extend only out to wading depths, however, some nearshore profiles (ie. to depths of -8 meters) have been taken. The time between City surveys varies over the past 12 years.

Other agencies, for instance the Corps of Engineers and the Virginia Institute of Marine Science, have also sponsored survey work at Sandbridge.

Compiling all the data from all the sources, 78 profile locations have been established. Today over 1600 separate profile lines have been taken at these 78 locations. At some locations 80 separate surveys have been taken, and by 1995 many will have over 100 surveys, spanning a 15 year period. Each profile has been archived to a common vertical and horizontal datum in CERC's Interactive Survey Reduction Program (ISRP). Using this data, statistical statements can now be made regarding the "differences" in beach profile response at walled and non-walled locations.

3. Quantification of Profile Change, Five Parameters

To quantify profile "change" we have adopted five parameters as depicted in Figure 2.

3.1 Profile Section Volumes

There are three section volume parameters, namely: landward volume (V_L), seaward volume (V_s), and total volume (V_T), each carrying units of m ^ 3/m. The

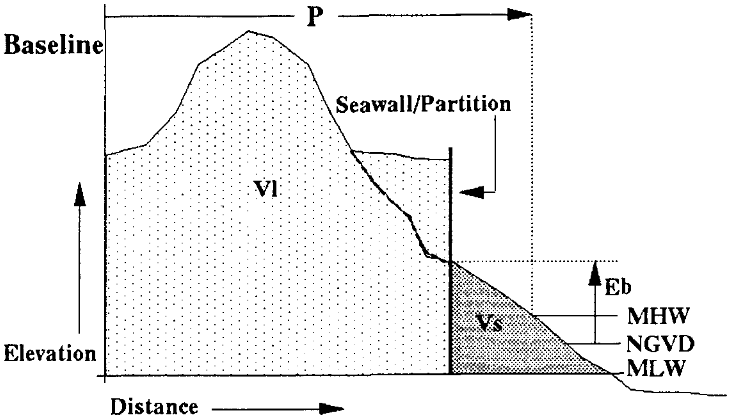

Figure 2 Definition Sketch

area between the profile and the MLW line is calculated using the trapezoidal rule. To obtain a volume, this area is then multiplied by a unit length parallel to the beach. The different volumes (landward, seaward, and total) are calculated using different right and left hand boundaries. Landward volume is bounded on the left by the survey baseline. For a walled profile, the right hand boundary for landward volume is the wall itself. However, for a dune/beach profile, an imaginary partition is used as the landward right hand boundary. This imaginary partition is located at the same distance from the baseline as the nearby seawalls. Seaward volume is bounded on the left by the imaginary partition or seawall, and on the right by the intersection of the profile and the MLW line. The total volume is simply the sum of the landward and seaward volumes. Figure 2 graphically depicts these definitions.

3.2 Berm Elevation

The berm elevation (E_B) is measured in meters above the vertical datum. It is simply defined as the elevation of the profile at the seawall or imaginary partition, as shown in Figure 2.

3.3 Shoreline Position

The shoreline position (P) is also shown in Figure 2. It is defined as the distance from the baseline, to where the profile intersects the MHW line. The MHW vertical datum has been chosen here to be consistent with map and aerial photograph data.

In Figure 3, the heavy solid line represents the shoreline position at Old Dominion University's 28 profile locations in August 1990. The heavy dotted line represents the shoreline position two years later in August 1992. The shoreline change, over that two year period, is indicated by the light solid line. Profile locations are depicted as short vertical lines at the bottom of Figure 3, and the horizontal lines represent the walled sections. Notice how close the shoreline is to the baseline (P=0) for profile numbers greater than 162. It is easily seen, that the long term receding shoreline poses an immediate threat to home and property owners.

4. Methods of Data Analysis

4.1 Jack Knife (JK) Technique

The Jack Knife (JK) technique (Dolan et al., 1991) has been used to determine a linear relationship between a given profile parameter and time. The first step in this method is to linearly regress all of the data points for one parameter versus time. This produces one slope and one intercept. Then by linear regression of all the points except the first, another slope and intercept can be calculated. Regressing all points except the second gives a third slope and intercept, ect. Given X surveys at one location, a "family" of X+1 slopes and intercepts can be generated using this method. From this "family" of slopes, the average slope, as well as the standard deviation associated with that average slope, can be computed. Two methods of data analysis have been employed using the Jack Knife technique.

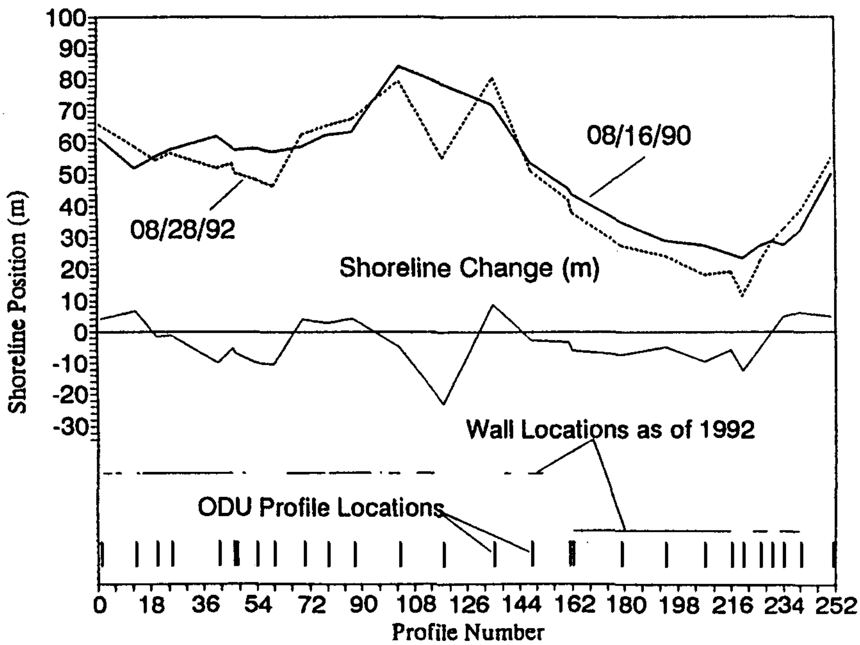

Figure 3 Shoreline Position

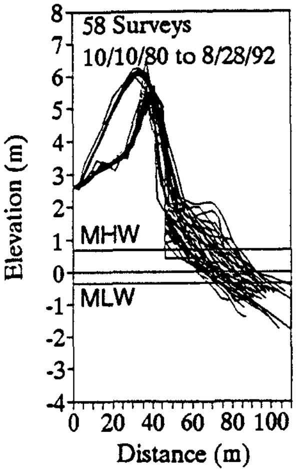

Figure 4a Profile 0

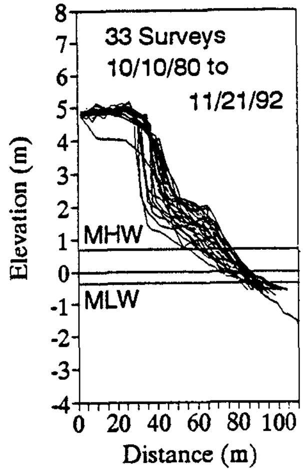

Figure 4b Profile 25

4.2 Compare Nearby Locations (CNL) Method

In this method, four profile pairs were selected at various locations along the beach. Each pair consists of a dune/beach profile and a seawall profile. Seawall profiles 25, 74, 194 and 205 were paired with dune/beach profiles 0, 60, 161, and 220, respectively. The variation in the long term shoreline recession rate along the study length, coupled with the availability of data dating far enough back in time, played a role in the selection of these pairs.

Figures 4a and 4b are envelope plots for profiles 0 and 25, respectively. Each profile line represents the beach cross section at a particular time. From each of these lines the five parameters V_L, V_s, V_T, E_B, and P can be calculated. Each parameter can then be plotted versus time. Figure 5 shows each of the three section volumes versus time for the dune/beach profile 0. Figure 6 is the same type of plot for the walled section, profile 25, 760 m south of profile 0.

In Figures 5 and 6, the data has been divided into three groups: those points prior to October 1988 (dotted), those after October 1988 (dashed), and all the points inclusive (solid). The data has been divided at October 1988 simply because this is when the nearby wall at profile 25 was constructed. The JK technique was then employed on all three data groups for each profile. Statistics for the other two parameters, E_B and P, were calculated in a similar fashion. In Figures 7 and 8, the x's represent parameter values for profile 25, and the o's represent parameter values for profile 0. The light lines are the JK lines through profile 25 data, and the darker lines are those through profile 0 data. These types of calculations were made for all four profile pairs selected (0/25, 60/74, 161/194, 205/220).

At this point, the null hypothesis test was used to determine if any statistical

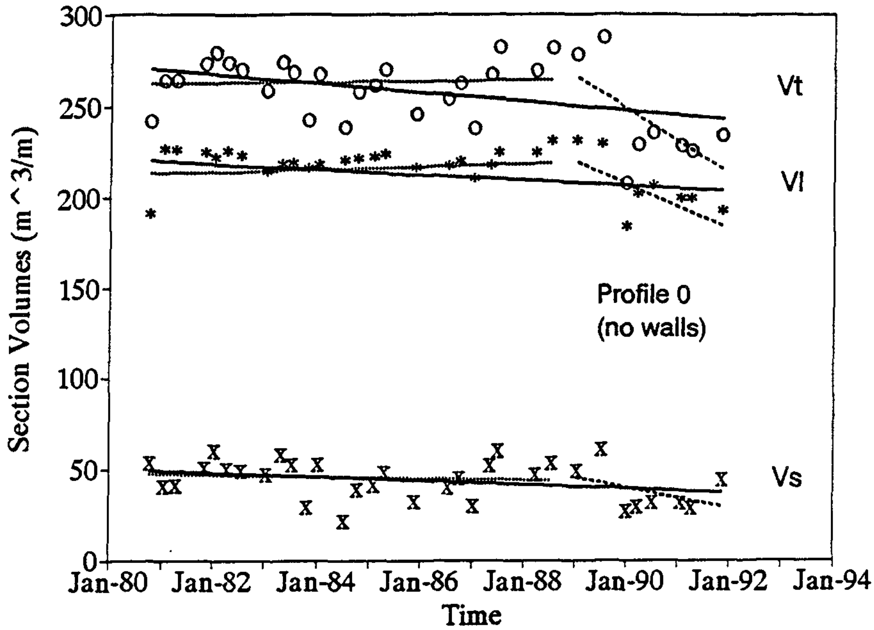

Figure 5 Section Volumes Profile 0 (dune/beach)

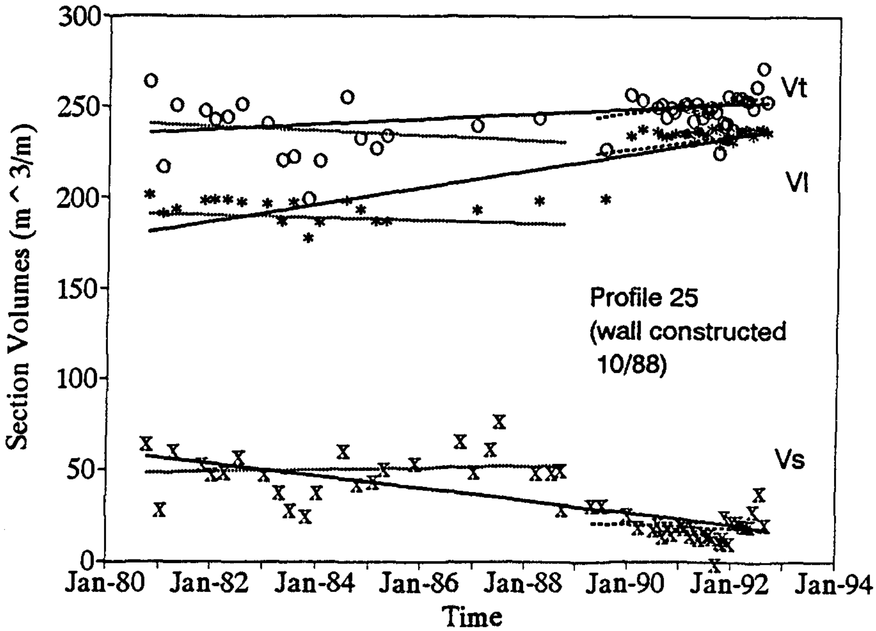

Figure 6 Section Volumes Profile 25 (seawall)

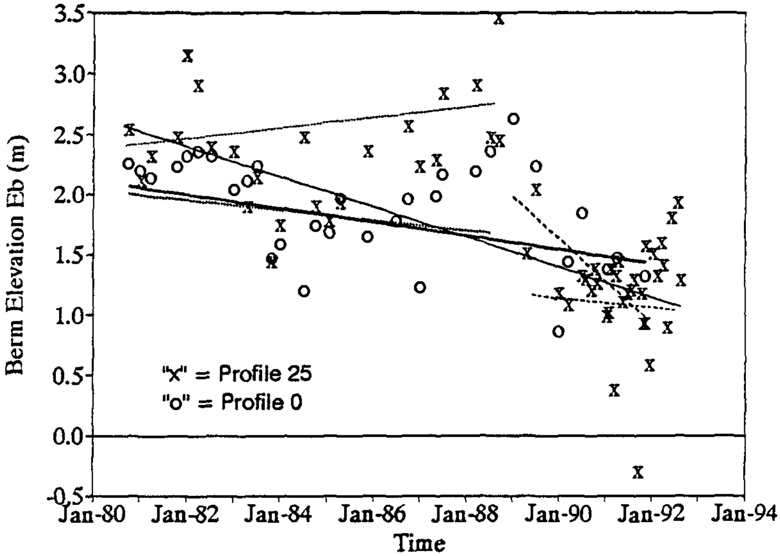

Figure 7 Berm Elevations Profile 0 and 25

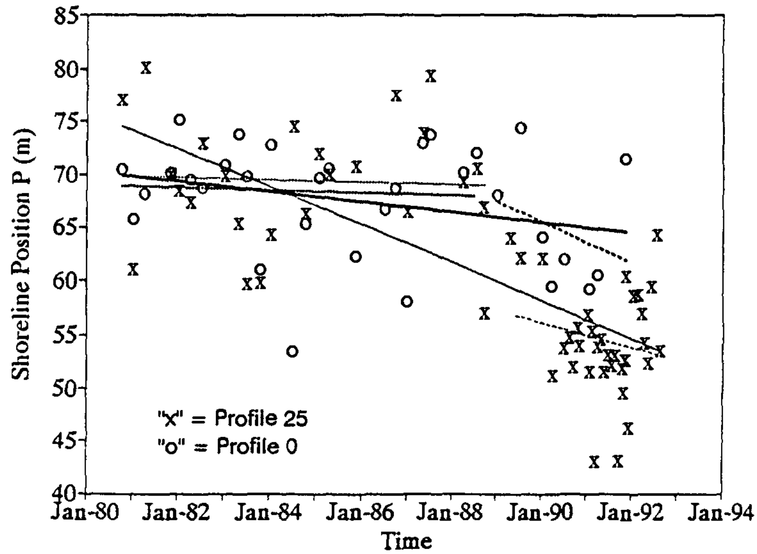

Figure 8 Shoreline Positions Profile 0 and 25

differences existed between the dune/beach and seawall line slopes generated by the JK technique. This was done for all 3 groups (prior to wall construction, after wall construction, and all data inclusive) and all four pairs. A five percent significance level or 95 percent confidence was used for the null hypothesis. Since large degrees of freedom existed (ie. more than 29 slopes generated), a standard normal curve was used (Scheaffer and McClave,1990). The results found using this technique are discussed in Section 5 and summarized in Table I.

4.3 Weighted Average (WA) Method

The second of the two data analysis techniques used is the Weighted Average (WA) method. Carefully distinguishing between walled and non-walled sections, each of the five parameters were integrated along the beach. The integrated values were then divided by a representative length, resulting in a weighted average parameter value. For example, V_L was calculated at various walled locations along the beach. These values were then used to integrate V_L along each of the fifteen walled sections. At this point an estimate of the total volume of sand in cubic meters, behind the walls was known. The weighted average V_L for the seawall sections was then calculated by dividing this total cubic volume by the entire wall length. Similar computations were made to calculate the total volume of sand behind an imaginary partition for the dunes.

To carry out this technique, data was collected monthly at 28 specific profile locations for a two year period. As mentioned earlier, Figure 3 shows the location of the 28 profiles (vertical lines), and walled sections (horizontal lines). Of the entire study length, roughly 4600 meters (60 percent) is walled and 3100 meters (40 percent) is duned. Note that not all walled sections nor duned sections have profiles running through them. These sections, however, make up only 14 percent of the study length. For this small percentage, parameter estimates were obtained using nearby profile data.

Calculating the seawall and dune/beach weighted average volumes for each of the monthly surveys, and plotting them versus time, results in Figure 9. Again we have V_L, V_s and V_T versus time as in the CNL method. The time span, however, is only 2 years in this case. In Figure 9, an "x" represents the weighted average parameter value for the seawall sections, and an "o" represents the weighted average parameter value for the dune/beach sections. The dashed and solid lines represent the Jack Knife line through the seawall and dune/beach data, respectively. Figure 10 shows the weighted average berm elevation (E_B) versus time, and Figure 11 the weighted average shoreline position (P) versus time.

Again the null hypothesis test was used to determine if any statistical differences could be found in the slopes generated by the JK technique. The results are discussed in section 5, and are summarized in Table II.

4.4 Littoral Drift Effects

One of the major concerns with this type of analysis is the independence between the two populations (seawall and dune/beach slope "families"). Two truly independent populations must exist; otherwise, it is impossible to make any valid statistical statements using the null hypothesis technique. If the sediment transport was strictly in the onshore-offshore direction, there would be no problem in

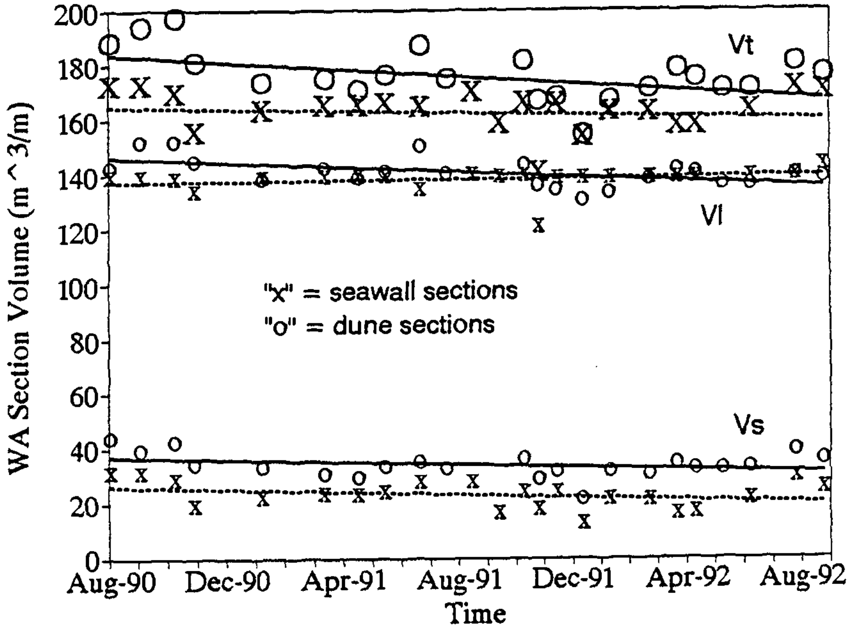

Figure 9 Section Volumes WA method

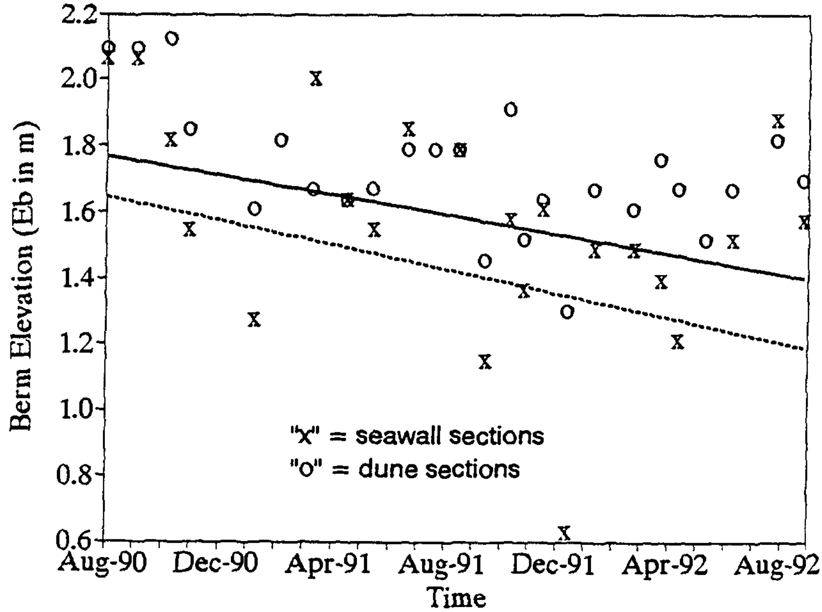

Figure 10 Berm Elevations WA method

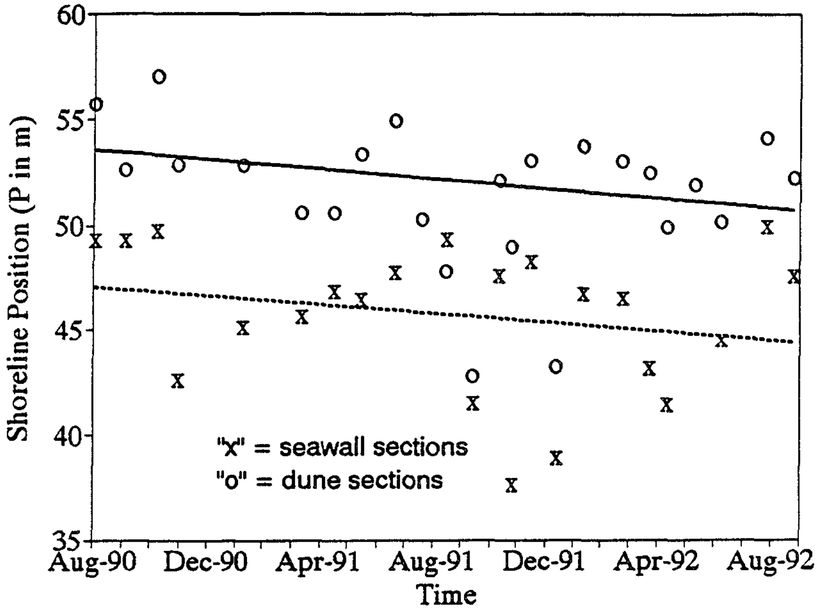

Figure 11 Shoreline Positions WA method

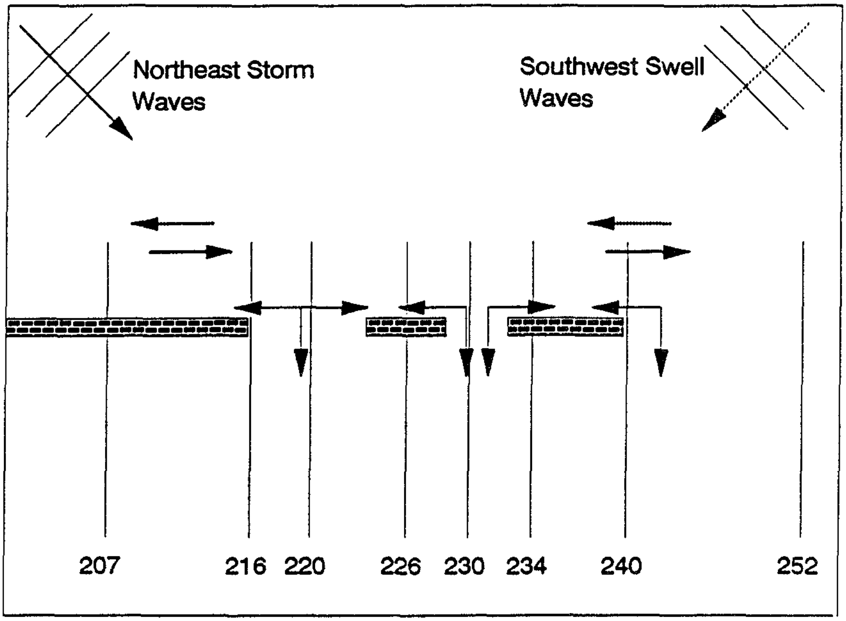

Figure 12 Littoral Drift Effects

making the independence assumption. However, this is not the case since longshore transport does exist.

In Figure 12 we depict to scale the seawall and profile locations at the southern end of the study area. Also shown are the directions for the northeast storm waves and the southwest swell waves. These produce a longshore sediment transport in the southerly (solid arrow) and northerly (dotted arrow) directions, respectively. Sand is moved from walled areas to dune/beach areas and vice-versa during the time periods corresponding to the reversals in wave direction. This is also shown schematically in Figure 12.

For the *long-term* trends analysis discussed herein, both the CNL and WA methods have tacitly assumed that the lateral transport processes **balance each other out over long periods of time**. In other words, sand moves locally from in front of walls to adjacent dune/beach areas, and in the reverse direction in approximately balanced quantities, **over the long term**. This assumption will be investigated as part of the overall project in the future, when the focus will be on end-of-wall effects on adjacent beaches, and storm induced changes over short time intervals.

5. Results

5.1 Compare Nearby Locations (CNL) Method

The five parameters V_L, V_s, V_T, E_B, and P were tested on all four profile pairs. Each profile pair consisted of six JK lines, three for the dune/beach, and three for the seawall. Recall that these three lines were generated by dividing the data at the date when the local wall in the particular area was constructed. One line used data points before wall construction, the second used points after wall construction, and the third JK line used all the data points.

The results using the null hypothesis test on the slopes generated from the JK technique are found in Table I. The first column in the table states the hypothesis being tested. Columns two, three, four, and five represent profile pairs 0/25, 60/74, 161/194, 205/220, respectively. An "x" in a column means that the pair agreed with the hypothesis (i.e., both seawall and dune/beach regression slopes came from the <u>same</u> population). If no "x" exists, the hypothesis was found to be false. Column six is the number of profile pairs out of four in agreement with the hypothesis.

The trends are clearest for Group 1 (i.e., all the data is regressed). Seawalls retain sand behind them, therefore, the higher volume loss rate for the dune/beach sections behind the imaginary partition is to be expected. This also contributes to the higher loss rate for the total volume, V_T of a dune/beach section. The volume loss rate **seaward** of the partition was shown to be **higher** for the seawall in three of the four profile pairs. Berm elevation and shoreline position comparisons were inconclusive, since two pairs exhibited one trend and two, another.

The results for Groups 1 and 2 (i.e., before and after wall construction) are

Hypothesis	Profile Pair 0 25	60 74	161 194	205 220	Number in agreement
Group 1: All Data					
Vt loss rate is higher for dune/beach.	x	x	x	x	4
Vl loss rate is higher for dune/beach.	x	x	x	x	4
Vs loss rate is higher for seawall.	x	x	x		3
Eb loss rate is higher for seawall.	x	x			2
P loss rate is higher for seawall.	x	x			2
Group 2: Data Before Wall Construction					
Vt loss rate is higher for seawall.	x	x			2
Vl loss rate is higher for seawall.	x		x		2
Vs loss rate is higher for seawall.		x			1
Eb loss rate is higher for seawall.		x	=		1
P loss rate is higher for seawall.	=	x			1
Group 3: Data After Wall Construction					
Vt loss rate is higher for dune/beach.	x	x		x	3
Vl loss rate is higher for dune/beach.	x	x		x	3
Vs loss rate is higher for seawall.		=	x		1
Eb loss rate is higher for seawall.			x		1
P loss rate is higher for seawall.			x		1

Table I Results CNL method

Profile Change Parameter	Dune/Beach Average Slope	Stdev	Seawall Average Slope	Stdev	Result
Vt	-8.20	0.650	-2.58	0.604	Dune weighted average Vt loss rate is higher.
Vl	-5.34	0.359	+0.58	0.203	Dune weighted average Vl loss rate is higher.
Vs	-2.86	0.406	-3.24	0.449	Seawall weighted average Vs loss rate is higher.
Eb	-0.17	0.014	-0.22	0.024	Seawall weighted average Eb loss rate is higher.
P	-1.40	0.174	-1.30	0.266	Weighted average P loss rates are same.

Table II Results WA method

less conclusive. We are investigating other profile pairs to expand the number used in the CNL method.

5.2 Weighted Average (WA) Method

All five parameters were tested over the 2 year period from August 1990 to August 1992. Two JK lines were calculated for each of the 5 parameters. One line was calculated using the dune/beach WA method values and the other used seawall WA method values. The results using the null hypothesis test on the slopes generated from the JK technique are found in Table II. Column one shows the profile change parameter being tested. Column two shows the average slope calculated using dune/beach WA method values, and the JK technique. Column three represents the standard deviation associated with the average slope in column two. Columns four and five are similar to two and three, only they were calculated using seawall WA method values. Column six states the result of the null hypothesis test.

The integrated, weighted average results for total and landward volume loss rates, again show that seawalls hold more sand in the profile. These are the same results a for the CNL method. Also, the volume loss rate seaward of the partition (or wall) was higher for the seawalls. The averaged seaward volume loss rate was -2.86 m^3/m (per year) for all the dune areas compared to -3.24 m^3/m (per year) for all the seawalled sections. The standard deviations of all the slopes determined by the JK technique were similar (0.406 versus 0.499) for this estimate. The WA method also shows that the berm elevation loss rate is higher for the seawalls than for the dune/beach sections.

Despite these results for weighted average seaward volumes and berm elevation at the partition (seawall), statistical evidence does not permit a similar conclusion to be drawn regarding the shoreline position change rate over the two year study period.

6. Conclusions

The seawalls were installed at Sandbridge as an effort to protect the land and other property behind them from the encroaching sea. This study has shown, that at seawalled sections, the landward loss of sediment was much lower, and the seaward loss was slightly higher. Because of the volume held behind the walls, total loss of sediment was lower. It was also shown that the berm lowering rate, is slightly larger at seawalled sections in comparison to dune/beach sections. However, no strong statistical evidence was found to support the claim that seawalls have caused higher shoreline recession rates at Sandbridge. These results include the assumption that the lateral transport rates are in balance over long time periods.

These results are based upon 12 years of data for the CNL method and 2 years for the WA method. They are reflective of one 7.7 km stretch of East Coast shoreline in the United States. At the end of the study in 1995, we should have significantly more data for the WA method to make stronger conclusions. These results are applicable to the Sandbridge site with the complicated number of short seawall segments. The extrapolation of these results to other locations should be used with caution. Future efforts to sort out the end-of-wall and short term storm effects will aid in determining the validity of the "lateral transport balance" assumption. This will also help to determine if these results can be generalized and applied to other locations.

7. References

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