CHAPTER 211

Profile Volumes as a Measure of Erosion Vulnerability

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ABSTRACT

Profile volumes provide an indication of the condition of barrier islands and beaches. While site specific, they can be used along any littoral shoreline as a measure of the relative "health" of one section compared with another. Assuming shorelines develop an equilibrium profile around which the beach cycle and cross shore changes occur, profile volumes integrate small scale perturbations and provide a target sediment volume for the site between reference contours. Profile volumes may be considered for various parts of the profile as follows:

- *Dune volume above storm surge levels* (after FEMA) as a measure of the reservoir of sand required to prevent over topping.

- *Mean sea level (MSL) barrier cross-section* — the section that must be fully scoured to produce a full breach channel.

- *Inner beach profile* — the section that represents the condition of the recreational beach.

- *Inshore profile* — the section that represents the core "base" of the barrier island.

By comparing versions of these sections from site to site, especially where there have been known breaches and variations in beach erosion rates it is possible to develop systematic eriteria for the health of the shoreline in question. Profile volumes provide a straight-forward technique for diagnosing barrier erosion problems. A case study from Westhampton Beach and Fire Island (New York) illustrate the application.

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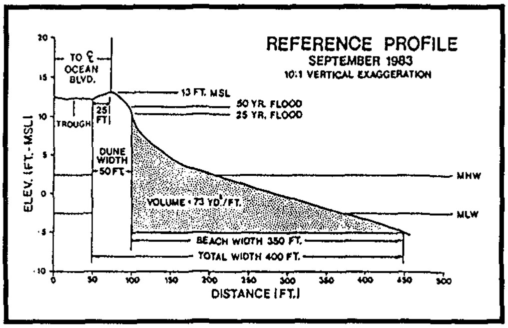
INTRODUCTION

Profile volumes, that is, the unit quantity of sediment contained between defined contour limits in the littoral zone, can be used as predictors of erosion vulnerability, breach vulnerability, and nourishment requirements. They are especially useful for analyzing sites with few data or sites where surveys are spaced widely in time. The profile volume for a site, ideally, should incorporate the foredune (or the entire backshore seaward of buildings where development is a concern), berm, intertidal beach, and lower foreshore to closure depth.

Multiple transacts surveyed between common boundaries along shorelines having similar orientations and exposures provide a set of profile volumes that can be normalized and compared statistically by simple means (Fig. 1) (Kana et al., 1984; Kana, 1993). The unit volume of any one profile to closure integrates all small-scale perturbations in slope and bar formation, and becomes a reasonably pure measure of the littoral condition. Seasonal or beach-cycle-related variations are accounted for in the volume. Therefore, the phasing of surveys with storms or seasons is less critical. Where the setting is a narrow barrier beach, the profile volume method also provides a measure of vulnerability to breaches.

FIGURE 1.

The reference profile illustrates how average unit-width profile volumes can be developed on a site-specific basis for analyses of the condition of the beach from one section to another, as well as from one survey to the next (after Kana et al., 1984).



Barrier Sediment Volumes

There are no universally accepted criteria defining the eondition of a barrier beach to withstand erosion and storm surges without breaching. In the United States, FEMA (Dewberry & Davis, 1989) has developed rough guidelines relating to dune preservation during storms. FEMA considers a particular volume of sand above the still-water flood level and seaward of the dune crest as being the minimum necessary to prevent overtopping and washovers for a particular return-period storm. Dutch coastal engineers (TAW, 1985; Van de Graaff, 1986) further consider the amount of freeboard above the still-water surge level needed to absorb wave runup without overtopping and breaching. These criteria are based on probabilities and are poorly documented because there are so few sites where all necessary data are available to quantify the relationship. In most cases, dunes either remain standing with considerable excess sediment landward of poststorm scarps, or they are washed out. Thus, establishing threshold minimum quantities to sustain surges without (dune) breaching is difficult.

The present criteria of FEMA are given in a rating curve (Fig. 2). The minimum cross-sectional areas recommended above the still-water surge elevation (for a particular return period) equate to unit volumes of sand (cubic yards per fool) as given on the graph. In simple terms, the 100-year storm would require about 20 cy/ft (50 m^3/m) above its still-water surge level, whereas a 5-year storm would require about 6 cy/ft (15 m^3/m) for protection. FEMA representatives emphasize these criteria are for guidance only and may not apply for certain dune configurations (R. Hallermeier, Dewberry & Davis, pers. comm., March 1994). In other words, the absolute quantity of sand above the surge level must be configured to absorb wave runup effectively; otherwise, breaching may still occur.

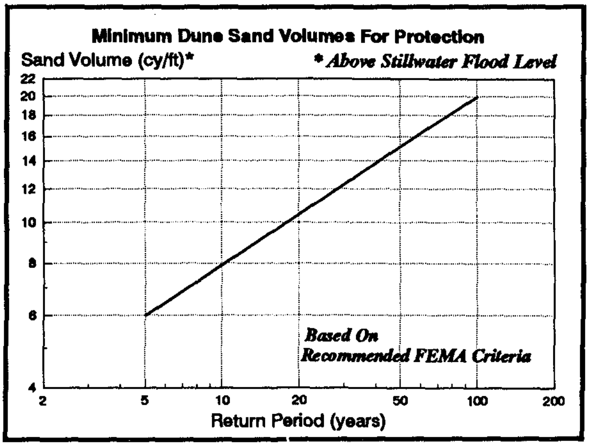


FIGURE 2.

FEMA minimum criteria for dune unit volumes above flood still-water level as a function of storm-return period (based on guidelines in Dewberry & Davis, 1989). Standard deviation for the 100-year storm is ± 10 cy/ft, confirming a wide range of "safe" values based on experience.

In the following example application, the authors have computed reference sand volumes above particular datums to relate the condition of a barrier to FEMA criteria. Unit-volume analysis is also useful for comparing the overall condition of the barrier island, including the underwater portion of the profile. By comparing barrier sections that have experienced breaches with unbreached sections, it is possible to develop site-specific criteria relating to the potential vulnerability of future breaches along nearby sites.

EXAMPLE APPLICATION

Winter storms (northeasters) on 11 December 1992 and 13 March 1993 caused widespread damage along the south shore of Long Island, New York (Fig. 3). In terms of beach erosion, structural damage, and mainland flooding, these two storms were the worst for this part of the coast since the well-known 4-6 March 1962 northeaster (USACE, 1963). Over 100 houses were lost along Pikes Beach (Westhampton, immediately downdrift of the groin field) as a result of continued erosion and a breach through the barrier in December. The 1992 breach was left open for over ten months and contributed to locally higher tides in Moriches Bay (J. Tanski, unpubl. data, SUNY, Stony Brook, March, 1993) before it was closed by the U.S. Army Corps of Engineers by hydraulic dredge (contractor: Great Lakes Dredge & Dock Co.).

The breach at Westhampton demonstrated the problem of unstable inlets near development and the potential for increased flooding around the lagoon shoreline. Concerns over the possibility of a similar breach through Fire Island, the next barrier island downdrift of Westhampton Beach, and a possible increase in the tide range within Great South Bay led to a study funded by the New York Coastal Partnership (Kana and Krishnamohan, 1994). The purpose of the study was to assess the vulnerability of Fire Island to storm breaches and determine the likely physical impacts along Great South Bay (Fig. 3). The study was multidisciplinary and drew on historical shoreline data, developed an updated sediment budget for Westhampton and Fire Island, and used available predictive models of storm surges to evaluate flooding potential. One analysis (the subject of the present paper) evaluated profile volumes in an attempt to develop site-specific criteria for barrier sections that had breached in the past and to identify other potential sites for breaches.

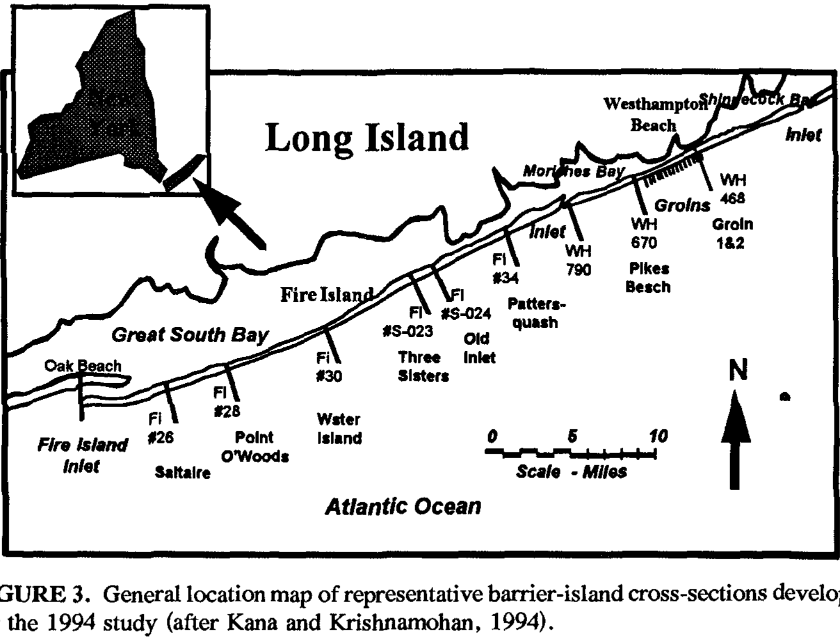


FIGURE 3. General location map of representative barrier-island cross-sections developed for the 1994 study (after Kana and Krishnamohan, 1994).

Methodology

Representative cross-sections through Westhampton Beach and Fire Island were developed from USACE profiles (RPI, 1985), unpublished surveys, and planimetric maps (see Fig. 3). These were selected to represent the range of conditions including physical dimensions of the barriers and historical erosion trends. The profiles extend from the bay shoreline across the barrier and out to approximately -30 ft below MSL. Table 1 describes some of the cross-sections, localities, and significant features [see Kana and Krishnamohan (1994) for details].

TABLE 1. Representative barrier island cross-sections, relevant physical dimensions, and key distinguishing features. [*(1) Width at mean sea level. (2) Highest dune elevation. (3) Distance from MSL to -20 ft contour.]

USACE Transect ID	Locality	1979 Dimensions (ft) (1)*	(2)*	(3)*	Key Features
WESTHAMPTON BEACH					
468+00	Between groins 1 and 2, east end of groin field	825	21	1,400	Rapid accretion and growth of a new foredune to 15 ft MSL between 1962 and 1979; continued accretion through 1993.
670+00	2,700 ft west of groin 15, compartment 143B	700	10	1,600	Rapid erosion between 1962 and 1979, loss of an 18-ft-high foredune within 1,000 ft of 1962 and 1992 breaches.
790+00	2,000 ft east of east jetty, Moriches Inlet	450	15	1,950	Situated btwn 1980 breach and east jetty; breach widening and easterly migration eroded the section btwn January and July 1980.
FIRE ISLAND					
34	6,700 ft east of Smith Point Park Pavilion, eastern Fire Island	1,225	18	1,350	Zone of washovers west of Moriches Inlet; high erosion rates; artificial dune (spoil area from bay dredging) constructed 400 ft landward of the shoreline.
~26	West walk at Saltaire, western Fire Island	2,050	15	1,375	Wide barrier section; highly erosional; first row of houses lost between 1967 and 1979; area of concentrated damage in 1992-93.

Westhampton Profiles

In 1962, Westhampton had sustained its worst storm since the 1938 hurricane (storm of record). The March northeaster breached the barrier along Pikes Beach and caused extensive structural damage. Prior to the storm, erosion had reduced the width of the barrier and chronic problems of overwash forced periodic sand scraping to clear Dune Road. The USACE (1958) had been developing a shore protection plan which proposed construction of 21 groins and concomitant nourishment. By December 1962, emergency repairs had closed the storm breach and had added almost one million cubic yards of additional sand to Westhampton Beach (USACE, 1963). Construction of a portion of the groin field was initiated in 1964 and the final four of 15 groins were completed around 1969.

Two transects illustrate dramatically different results along Westhampton Beach between 1962 and 1979--USACE station 468+00 (Fig. 4a) situated at the updrift end of the groin field between groins 1 and 2, and USACE station 670+00 (Fig. 4b) situated 2,700 ft downdrift of groin 15. In 1962, both transacts represented narrow sections of the barrier island. In fact, the updrift station (468+00) was barely 600 ft wide from the ocean to the bay shoreline and contained a single, well-developed foredune to 20 ft above sea level. The downdrift station (670+00) was slightly wider at about 725 ft with a smaller foredune reaching about 17 ft.

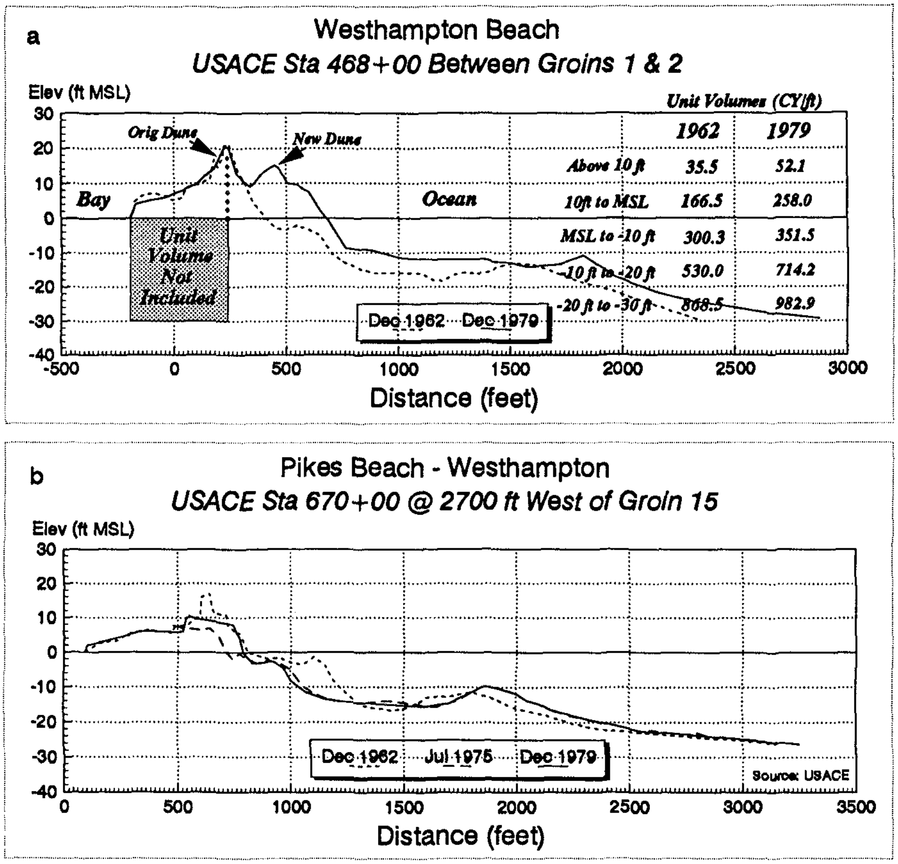


FIGURE 4. Representative, barrier-island cross-sections from the east end of the Westhampton groin field (a) and Pikes Beach (b), illustrating opposite trends in shoreline change between 1962 and 1979. Unit volumes refer to the profile areas between the indicated contours.

By 1979, station 468+00 had gained a second foredune and the shoreline built seaward, increasing the barrier width to about 825 ft (Fig. 4a). Associated with the dune and upper beach building was a large increase in sand volume below MSL. This trend of large-scale accretion has continued through 1993 as shown in nearby profile 461+25 at groin 1 (Fig. 5). By January 1994, groins 1 and 2 (500-ft-long structures when built) were completely buried.

In contrast, transect 670+00 lost dune elevation and width between 1962 and 1979. The trends shown in Figure 4b actually incorporate several beaeh fills during the period. By July 1975, the barrier had narrowed to about 600 ft and the maximum elevation at the transect was only 7 ft above sea level. Nourishment is believed to have restored part of the beach between 1975 and 1979, but the dune elevation remained no higher than 10 ft MSL. An aerial photo from August 1981 (Fig. 6) in the vicinity of station 670+00 shows the recession of the shoreline downdrift of the groin field and a number of houses left standing on the active beach.

The 1992 northeaster caused at least two breaches between transect 670+00 and groin 15. The easternmost breach immediately downdrift of groin 15 became the dominant and only channel and expanded from several hundred feet wide after the storm to over 2,000 ft wide by the summer of 1993 (Westhampton Fire Marshall's Office, unpubl. reports). Field observations by the authors in March 1993 and January 1994 confirmed deposition of a flood delta in Moriches Bay in connection with the breach channel. Around November 1993, the breach was closed by hydraulic dredge using a USACE-approved offshore borrow source ~1.5 miles south of the breach.

A third Westhampton Beach transect considered here is from USACE 790+00, ~2,000 ft east of the east jetty of Moriches Inlet. This undeveloped section of Cupsogue spit consists of a narrow barrier segment flanked on the landward side by the navigation channel to Moriches Inlet. During the 1960s, the bay channel meandered closer to Cupsogue spit and contributed to scour along the bay shoreline.

By 1979, portions of the spit about 0.5 mile north of the jetties had been reduced in width to 300 ft from ocean to bay. In January 1980, continued narrowing of the spit combined with higher-than-normal wave action breached the barrier (Kana et al., 1981). Between January and July, the breach channel widened and migrated west until it removed the last part of the spit and coalesced with the navigation channel between the jetties.

Transect 790+00 is situated between the January breach point and east jetty. At the time of the breach, section 790+00 had a width of about 450 ft and a dune elevation of 15 ft (Fig. 7). Much of this section was artificial, having been filled several times in connection with dredging projects in the bay. As the breach widened, it migrated through section 790+00, washing out the beach and depositing a large volume in the bay channel.

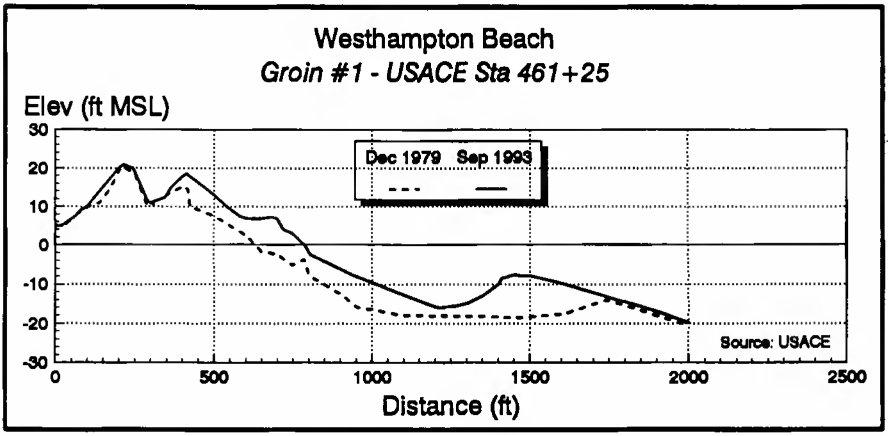


FIGURE 5. Comparative profiles at groin 1 (easternmost) for December 1979 and September 1993. Data courtesy of U.S. Army Corps of Engineers.

FIGURE 6. Pike's Beach and Westhampton Beach in August 1981, looking east. Groin field is at top of photo.

As Figure 7 shows, by July 1980, the elevation across 790+00 was about 4 ft below sea level. The breach was closed in January 1981 by hydraulic dredge, using barrier and littoral sediments that had accumulated in the bay channel, and by trucks using sand from an inland source.

Unit volumes were computed through each barrier cross-section by 10 ft contour intervals (example values given on Fig. 4a). Conveniently, the predicted 100-year still-water surge elevation along this microtidal coast nearly equals +10.0 ft MSL (FEMA, 1987).

Unit volumes above the +10 ft contour generally reflect the condition of the dunes. At Westhampton, the volumes above 10 ft are much greater at section 468+00 (groin field) than the sections near recent breaches. If 468+00 is typical of the groin field, dune unit volumes approached 50 cy/ft by 1979 and are higher today (see Fig. 5). In contrast, stations 670+00 and 790+00 yield an average volume of about 10 cy/ft with zero volume occurring in three of the six surveys used in the analysis.

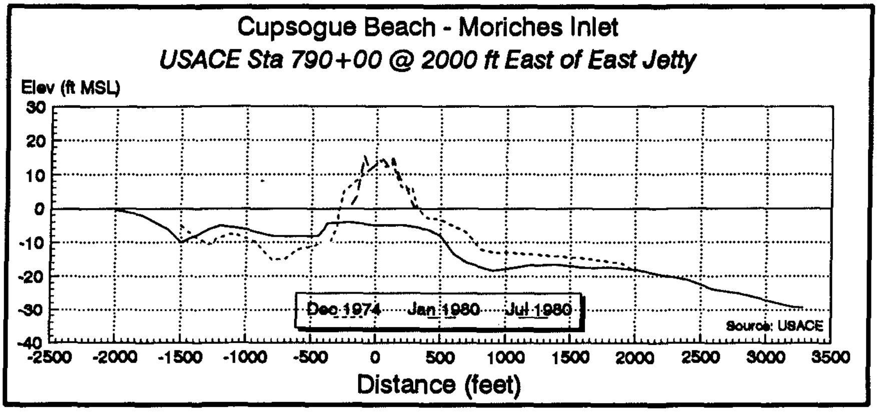


FIGURE 7. USACE station 790+00 situated ~2,000 ft east of Moriches Inlet. Erosion in 1980 occurred after the January 1980 breach to the east migrated through this section.

Between +10 ft and mean sea level, the barrier cross-section volume is largely a function of barrier width. Of the few surveys used for Westhampton, a typical section volume is about 160 cy/ft.

Relative to the total section volumes above MSL, the net changes for the three Westhampton stations generally represent a high percentage of the maximum section volume. For example, station 468+00 gained 108 cy/ft between 1962 and 1979, a volume which is 35 percent of the 1979 section volume (i.e., a gain of over 50 percent of the original unit volume). Station 790+00 lost 100 percent of its 1974 section volume due to the January 1980 breach; station 670+00 lost more than reflected (see Fig. 4) because of remedial nourishment between surveys.

Underwater sand volumes for Westhampton Beach stations similarly reflect the trends above sea level. Typical unit volumes from MSL to -10 ft seaward of the foredune are about 125 cy/ft and from -10 ft to -20 ft are about 425 cy/ft. The net change for 468+00 (groins) between MSL and -20 ft was 235 cy/ft, nearly 50 percent more sand than the 1962 volume. Assuming 461+25 (see Fig. 5) is similar, 468+00 has probably gained an additional 240 cy/ft in these lenses between 1979 and 1993.

Station 670+00 actually contained almost 20 percent more sand than 468+00 between MSL and -20 ft in 1962 before the groins were built. By 1979, this section contained about 75 percent of the unit volume at 468+00 (between MSL and -20 ft); a greater loss occurred between MSL and -10 ft; unit volumes between -10 ft and -20 ft increased by about 5 percent. Most likely, the change would have been much greater if there had been no beach fills.

Station 790+00 had a healthy underwater profile prior to the 1980 breach. As the breach widened and eroded the section, unit-volume losses between MSL and -20 ft were 260 cy/ft, an exceedingly rapid loss over the five-year survey interval. The upper lens from MSL to -10 ft was reduced to a section of about 50 cy/ft by July 1980, a volume representing the underwater sill through the breach. The lower shoreface (-10 ft to -20 ft) eroded severely, reducing the section volume to 330 cy/ft (about 80 percent of the same lens at station 670+00).

Based on the sand volume results in Table 2, typical Westhampton Beach values (rounded) are as follows:

Dune Volume	Mean (cy/ft)	Std. Dev. (cy/ft)	(No. of Surveys)
Above +10 ft MSL	20	±20	(8)
+10 ft to MSL	150	±77	(8)
MSL to -10 ft*	125	±45	(7)
-10 ft to -20 ft*	425	±75	(7)

[*Seaward of dune crest of earliest survey]

The results show high standard deviation because one station built up rapidly and one incorporated breach conditions. Thus, the "healthy" profiles reflect volumes incorporating the additional volume indicated by the plus standard deviation. Unhealthy profiles vulnerable to breaching reflect mean volumes minus the standard deviation. These results provide benchmarks for comparison with Fire Island profiles.

TABLE 2. Barrier-island unit-profile volumes (cy/ft) from the bay to -30 ft NGVD (above MSL encompasses entire barrier width; below MSL extends from foredune seaward). [Numbers in parentheses represent number of surveys.]

	Above 10 ft	10 ft to MSL	MSL to -10 ft	-10 ft to -20 ft	-20 ft to -30 ft
WESTHAMPTON					
468+00 (avg)	43.8 (2)	212.2 (2)	154.4 (2)	450.6 (2)	754.2 (2)
Breach sections (avg)	12.6 (6)	139.6 (6)	115.6 (5)	420.6 (5)	811.2 (4)
FIRE ISLAND					
Minimum	3.1	210.0	90.7	310.9	665.5
Maximum	90.0	475.1	176.3	459.2	786.8
Mean	32.3 (11)	343.3 (11)	134.3 (10)	407.7 (10)	739.6 (9)

Fire Island Profiles

Six transacts across Fire Island (two of which are shown in Figure 8) illustrate the typical range of conditions (see Table 1). Unit volumes have been computed for the same contour intervals and boundaries as Westhampton (Table 2). Some differences are immediately apparent. Above mean sea level, Fire Island profiles typically contain more sediment. The average unit volume above +10 ft is 32 cy/ft (±27.7 cy/ft standard deviation) for 11 surveys. Point O'Woods (USACE-28) and Saltaire (near USACE-26) had the lowest dune volumes, ranging from 3.1 cy/ft for the 1993 Saltaire profile to 7.1 cy/ft for the 1967 Point O'Woods profile. Three Sisters dunes off Bellport represented the maximum with 90 cy/ft above +10 ft (1979). Between +10 ft and MSL, Fire Island sections averaged about 345 cy/ft (±98.6 cy/ft standard deviation), much of which is due to the wider backshore. In fact, volumes in this lens

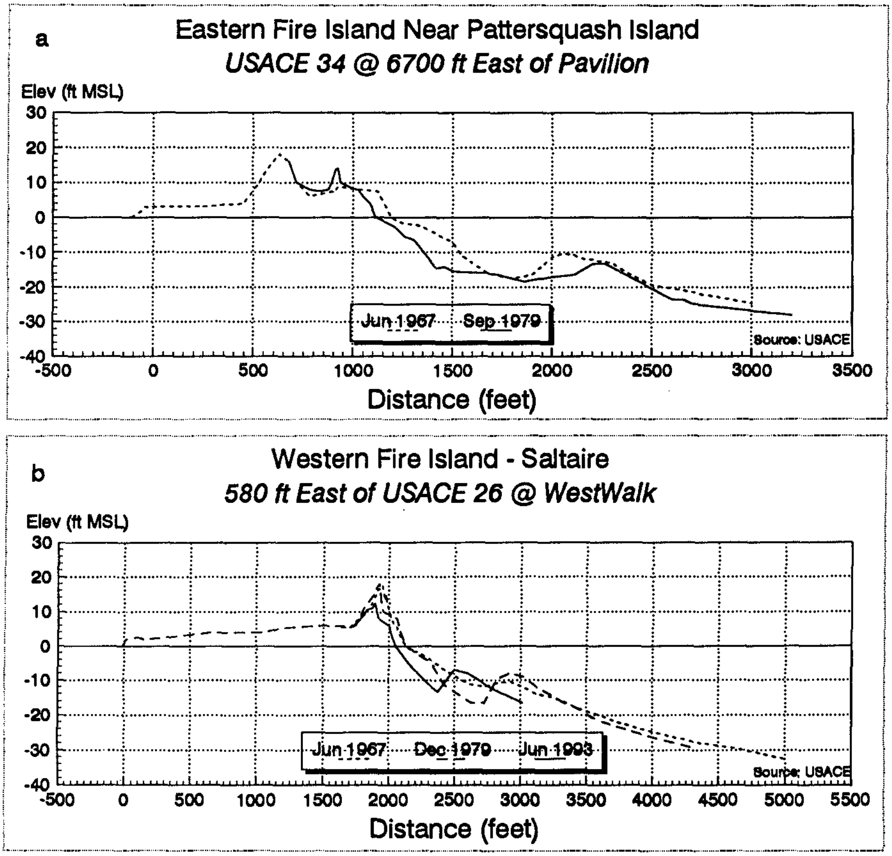


FIGURE 8. Representative, barrier-island cross-sections from (a) Pattersquash Island area east of Smith Point Park (locality for numerous washovers) and (b) west end of Saltaire, where major erosion of the underwater profile has accelerated erosion of the foredune.

are roughly double those of Westhampton (Table 2). Below mean sea level, unit volumes were very similar to Westhampton's, averaging -135 cy/ft between MSL and -10 ft, and ~400 cy/ft between -10 and -20 ft. This is expected because the landward computation boundary in each case is the dune crest.

Highest erosion rates were at the Pattersquash section (near USACE-34) and at Saltaire (near USACE-26) (see Fig. 8). The net change for these stations, respectively, ranged from about 10 cy/ft to 50 cy/ft above MSL and from 200 cy/ft to 150 cy/ft below MSL. In 1979, station USACE-34 was reduced to a volume of 415 cy/ft below MSL (to -20 ft) compared to an average of -550 cy/ft for other stations.

Aerial overflights by the authors and reports from officials of Suffolk County Department of Public Works (SCDPW) indicate the area around the Pattersquash Island transect continued to overwash through January 1994. But at this station, the setback of the artificial dune appears to have prevented a more landward shift of sediment. The artificial dune ends less than 1,000 ft to the east of transect 34, suggesting that more easterly areas are likely to experience deeper penetration of overwash along the back barrier. The authors observed a number of large washovers in that area during a January 1994 overflight. Officials at SCDPW confirmed these trends along eastern Fire Island over the past ten years. The results of the profile volume analysis suggest washovers will be more likely along Fire Island when the profile volumes between MSL and -20 ft go below 500 cy/ft relative to the foredune and when the foredune has negligible volume above +10 ft MSL.

The Saltaire section (near USACE-26) bears some similarities to USACE-34 because of its rapid erosion since 1967. While the barrier is much wider at Saltaire, its backshore elevations are low, averaging less than 5 ft above sea level (Fig. 8b). A single foredune has existed along the oceanfront. In 1967, the dune contained about 24 cy/ft above the +10 ft contour, about 75 percent of the average for the selected Fire Island transacts. By June 1993, dune volume above +10 ft was reduced to only 3 cy/ft. This low volume is offset by over 450 cy/ft between +10 ft and MSL (a total approximately three times that of Westhampton sections). Below mean sea level, station 26 lost about 155 cy/ft between 1967 and 1993, reducing its volume seaward of the 1967 dune crest to 450 cy/ft. As discussed in a regional sediment budget analysis (Kana, 1995), rapid erosion in the western Fire Island area is believed the result of depletion of offshore shoals associated with an earlier position of Fire Island Inlet. This has left the foredune much more vulnerable to erosion. An ~80 ft recession of the foredune since 1967 has destroyed (or caused to be removed) the oceanfront structures at this site, leaving the second row buildings on the oceanfront in 1993.

On the basis of backshore volumes above mean sea level, the Saltaire section is less likely to breach than Pattersquash because it contains almost twice the volume. But the Saltaire foredune is more likely to recede than Pattersquash's artificial dune because of the low unit volumes seaward of it and the lesser setback. Pattersquash's artificial dune profile could be created at Saltaire, but to be stable under present offshore conditions, it would have to be set back at least 150 ft from the 1993 dune crest. Planimetric maps indicate there are at least three rows of houses within 150 ft of the present dune crest at that locality.

SUMMARY — CASE STUDY

The remaining four sections along Fire Island represent intermediate conditions and are not discussed in this paper (see Kana and Krishnamohan, 1994, for details). By the measure of profile volumes through 1979, Fire Island cross-sections generally contain much more sand above MSL than Westhampton Beach sections. The difference in dune volumes between the two islands represents only a fraction of the total lens of sand comprising the barrier. The bulk of the subareal barrier is contained between MSL and +10 ft. Westhampton profiles contain roughly half the volume of Fire Island profiles above mean sea level. Transects that are breached along Westhampton typically contained less than 150 cy/ft above MSL before breaching.

While absolute volumes above mean sea level are not the only parameters to rank the condition of the barrier and establish vulnerability to breaching, they provide one quantitative measure to compare with historical breach areas.

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