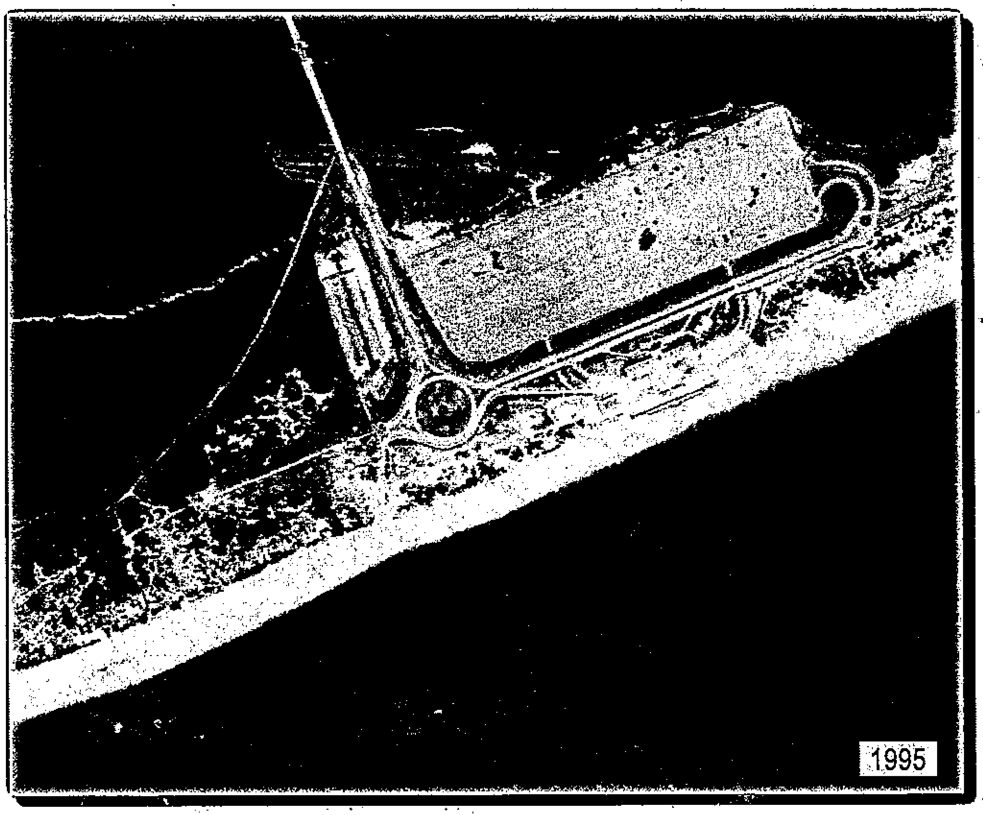
FINAL REPORT

Coastal Erosion Assessment
Smith Point County Park



Prepared for:

Suffolk County Department of Public Works
Yaphank, New York

— and —

Greenman-Pedersen Inc
Babylon, New York

CSE

COASTAL SCIENCE & ENGINEERING

FINAL REPORT

COASTAL EROSION ASSESSMENT

Smith Point County Park
New York

Prepared for:

Suffolk County Department of Public Works
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Under Subcontract to:

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COVER PHOTO: 1995 aerial view of Smith Point County Park (Source: NYS 2001)

EXECUTIVE SUMMARY

This report presents an analysis of coastal erosion along Smith Point County Park, based on historical surveys and a review of prior reports by the US Army Corps of Engineers, New York State, the National Park Service, and other institutions. The report also draws on prior studies of Fire Island by CSE.

Section 2.0 summarizes previous research related to coastal sediment transport and shoreline recession along the park. Section 3.0 describes the regional setting and large-scale coastal processes that influence the park and adjacent beaches. Section 4.0 describes the methodology used in the present study to estimate linear shoreline change rates and volumetric erosion rates. The present analyses emphasize sand volume changes and evaluate both underwater and visible beach changes over the past 40-50 years. Section 5.0 presents results of the analyses by means of tables and graphs showing trends through time and variations from one section of beach to another. Section 6.0 draws on the results and experience with similar sites to identify the primary causes of erosion along the park. Section 7.0 outlines four restoration alternatives (beach nourishment at a range of levels) including their anticipated costs and impacts over an ~10-20 year period. Section 7.1 also addresses the question of what will happen to the park's oceanfront if no action is taken to restore the beach. Section 8.0 summarizes the alternatives and discusses project maintenance.

There has been a rich history of erosion studies along Fire Island. Compared with many coastal sites, Fire Island is relatively stable with low erosion rates and few inlet/dune breaches in historic times. Between 1955 and 1979, however, underwater erosion accelerated along Smith Point County Park as well as the "Pattersquash" area immediately east of the park. At the same time, Moriches Inlet was trapping and accumulating more sand. These trends created a major sand deficit between the foredune and the outer bar along the park compared with adjacent healthy reaches (Fig A). This was less noticeable in 1979 because the visible beach remained healthy. However, by the 1990s, the foredune and dry beach zone along the park had much less sand than desirable. (See the yellow portion of the bars in the lower graph of Figure A.)

Forty-odd years of chronic erosion along the park has produced a sand deficit that, if not restored, will lead to more frequent damages in the next 10-20 years. The present study estimates the average annual erosion rate is 2.5 cubic yards per foot per year (cy/ft/yr) for the area. However, the estimated sand deficit with respect to the existing foredune is upward of 150 cy/ft in the park. CSE believes restoration of this deficit volume is the key prerequisite for a long-term erosion solution.

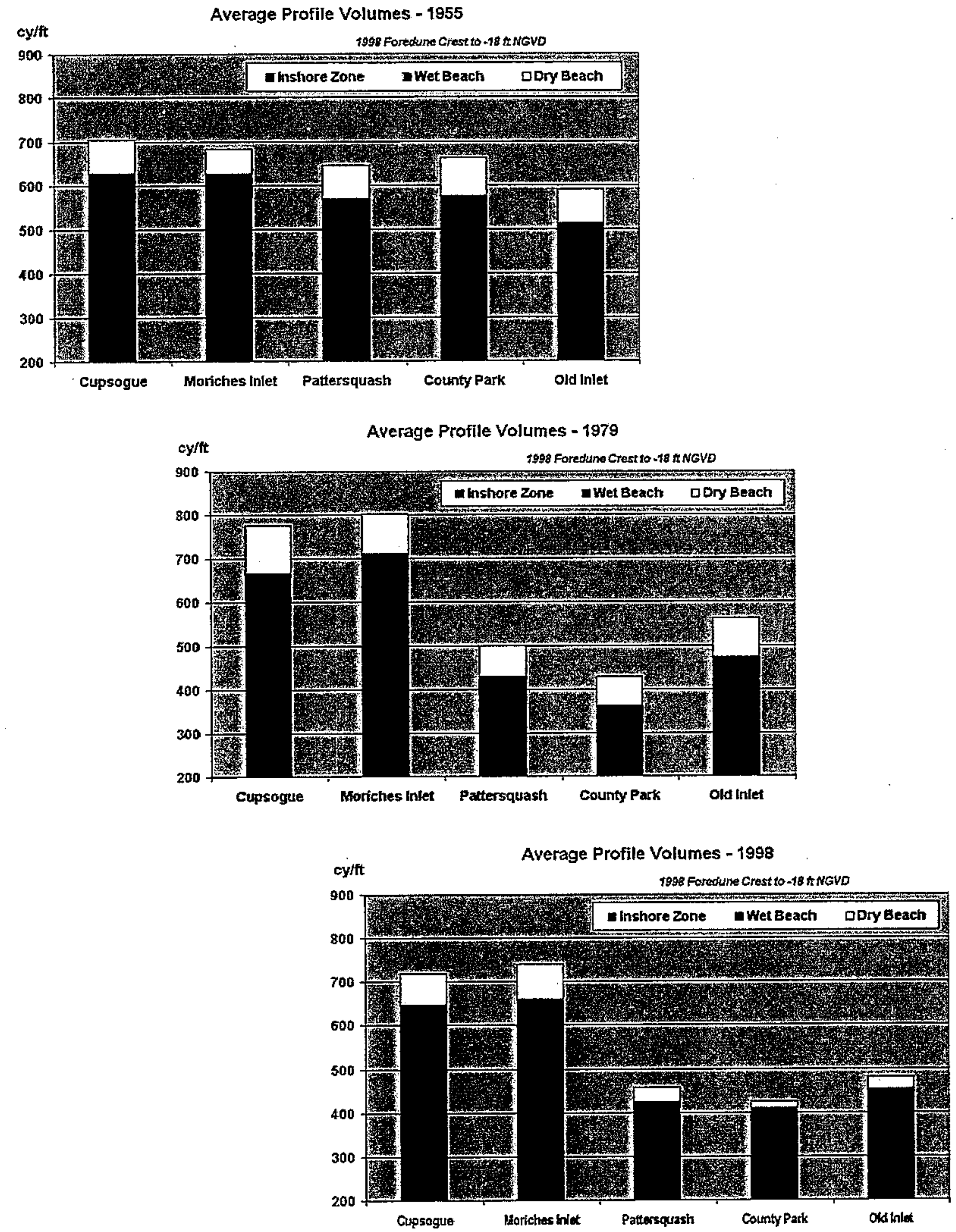


FIGURE A. Profile volumes by reach for Lenses 1, 2, and 3 (foredune to −18 ft NGVD) combined in 1955 (upper), 1979 (middle), and 1998 (lower). Note the precipitous decline in total volume and dry beach volume along the Pattersquash and county park reaches. [NOTE: Profile volume is the average volume of sand measured in cubic yards for a one-foot length of beach between the indicated features and datums. NGVD is approximate mean sea level. Dry beach is the portion of the beach above mean high water datum.]

The study identifies six primary causes of erosion along the park.

1) The opening and stabilization of Moriches Inlet (1931-1955), which has tended to trap sand and reduce the supply to the park.

2) The sheltering effect of the Moriches Inlet ebb-tidal delta (seaward shoals), which tends to act like a groin and intercepts longshore sand transport moving along the coast.

3) Erosion and loss of the foredune along the Pattersquash reach (east of the park), which leads to more frequent washovers and permanent loss of littoral sediments.

4) Reduction in nourishment sand and dredge disposal projects since 1980, which in prior decades accounted for over half the volume change along eastern Fire Island (ie, reducing the background erosion rate by more than 50 percent).

5) Sand trapping by the Westhampton groin field, which reduced the sand supply to Moriches Inlet and points further west.

6) The 1938 and 1962 storms, which had record impacts on erosion rates in the area.

All other erosion-causing factors (eg, sea-level rise, beach scraping, loss of dune vegetation, etc) are considered insignificant in this setting.

Four restoration alternatives are presented.

Alternative 1) Regional Beach Restoration – This alternative would restore the profile deficit, rebuild the dry beach, and provide ten years' worth of "advance" nourishment along 40,250 linear feet (Pattersquash reach to Old Inlet). A total of 5.7 million cubic yards would be placed by hydraulic dredge using a Corps of Engineers-designated borrow area off Long Cove and a stockpile area near Moriches Inlet. The following summarizes the estimated costs, outcome, and advantages of Alternative 1.

Volume:	5,700,000 cy
Length:	40,250 linear ft
Average Sections:	~140 cy/ft
Average increase in beach width:	~220 ft
Estimated Longevity:	>>10 years

Approximate cost:	$30,000,000 (@ ~ $5.25/cy inclusive).
Advantages:	Restores deficit along adjacent reaches as well as along the park. Likely to provide multi-decade erosion control and beach preservation given its length. Eliminates need for frequent re-nourishment and construction activities on the beach. Provides restored areas that can feed the park.
Disadvantages:	Cost; scope goes well beyond park boundaries thereby requiring multiple sponsors, particularly the National Seashore which may not be supportive of beach restoration and shore protection.

It is noted that this alternative is based on a federal beach erosion report, the future of which is unsure at this time. However, it is important that this alternative be presented, since it is a viable engineering solution to the problem of erosion at the park. Also, the need to protect the Flight 800 memorial should enhance the federal interest in an erosion control project at this location.

Alternative 2) County Park Beach Restoration –. This alternative would provide a similar improvement to the beach along the park, but would involve a much shorter length of ~12,150 ft. Because of its length, Alternative 2 would not last as long as Alternative 1. CSE estimates that fully half of the nourishment volume would erode and shift to unnourished areas away from park facilities within ten years. The cost of Alternative 2 could be reduced by upward of 33 percent if an alternate borrow area could be located directly offshore of the pavilion. The following summarizes Alternative 2.

Volume:	1,500,000 cy
Length:	12,150 linear feet
Average Sections:	175 cy/ft along primary recreation area (~4,590 ft) ~87 cy/ft along adjacent taper sections (~7,560 ft)
Average Increase in Beach Width:	~200 ft along primary recreation area ~100 ft along taper sections
Estimated Longevity:	~10 years (~50 percent remaining)
Approximate Cost:	$9,000,000 (at ~$6/cy – inclusive of engineering, permitting, dredge mobilization, and pumping from USACE Long Cove borrow area (labeled "A" on Fig 19).

Note: Alternate borrow areas "B" and "C" would involve longer pumping distances and would therefore be more costly. However, if a federal project could provide a stockpile between stations F79 and F81, the transportation distances to the park would be reduced to around 20,000 ft, making that a more economic borrow source. CSE estimates the incremental cost for trucking from stockpiles in Reach 1 to the project area would be ~$1.50/cy per mile (~$6.50-$8.25/cy). Trucking would likely become competitive with dredging if the stockpile area were moved at least as far west as station F79 (ie, ~15,000-20,000 ft from the park).

Advantages:	Restores deficit along primary recreation area of the park. Likely to provide upward of ten years of erosion relief; however, nearly 50 percent of the fill would have eroded and spread to adjacent (unnourished) reaches in that time. Would eliminate the need for frequent beach/dune scraping during the first 5-10 years.

Disadvantages:	Does not provide an updrift feeder beach to maintain the profile over a longer time. Has a limited longevity because of its relatively short length. Will require renourishment sooner.

It should be noted that this alternative differs significantly from the county's efforts to maintain a similar beach width in front of the boardwalk in the 1990s. This is due to the fact that this alternative includes restoration of the entire profile, including the underwater portion down to the −18 foot depth contour.

Alternative 3) Federal Interim Project – This alternative was formulated recently by the US Army Corps of Engineers–New York District as part of an island-wide plan. While it appears that the interim project is no longer viable according to Corps officials, there may still be a federal interest in portions of the plan, particularly at Smith Point County Park and the Flight 800 memorial. Alternative 3 calls for ~615,000 cy of nourishment over a length of ~6,000 ft. A project of this magnitude is expected to lose 50 percent of its volume within five years. The following summarizes Alternative 3.

Volume:	614,437 cy
Length:	6,000 ft
Average Sections:	~94 cy/ft (+8 cy/ft stockpiled)
Average Increase in Beach Width:	~110 feet (after fill adjustment)
Estimated Longevity:	<5 years (~50 percent remaining)
Approximate Cost:	$6,360,000 (~$10.30/cy inclusive) (~Federal~$4,125,000) (State/Local~$2,225,000)

Advantages:	Provides partial restoration of the deficit and significant restoration of the recreational beach for an estimated ~5 years. Federal cost sharing covers ~65 percent. Permitting is handled by the federal government. As a public park with excellent access, permitting and cost-share justification is usually easier.
Disadvantages:	Does not fully restore the deficit or provide significant advance nourishment. Design is controlled by the Corps of Engineers rather than the local sponsor. Time line for federal projects is often long and subject to funding appropriations by Congress. (This necessitates strong local sponsorship and political support.)

It is understood that the federal interim project received opposition from the state and federal agencies charged with environmental oversight. However, this alternative utilizes the interim project cross-section (as it is a feasible engineering solution) for only a small portion of the interim project area. The need to protect the Flight 800 memorial is a relatively recent factor which provides additional justification for a beach nourishment solution.

Alternative 4) Frequent Small-Scale Nourishment – This alternative would involve frequent beach fills, taking advantage of opportunities as they arise, such as disposal of

Moriches Inlet sediments. Under this alternative, small quantities of sand (<200,000 cy) would be trucked to the park by off-road dump trucks from stockpiles (dredge spoil areas near Moriches Inlet). Repeated nourishment would be required to restore the sand deficit while keeping pace with the background erosion rate. Fills of this order would erode rapidly, leaving about 50 percent in place after two years. The deficit along the park would be restored after 15-20 years by repeating similar projects every two years. The following summarizes Alternative 4.

Volume:	~200,000 cy
Length:	6,000 ft
Average Sections:	~33 cy/ft
Average Increase in Beach Width:	~40 ft
Estimated Longevity:	<2 years (~50 percent remaining)
Approximate Cost:	$1.3-$1.65 million*

Advantages: Partially restores the beach. Negligible mobilization costs (via trucking), relatively easy to permit. Can be performed independently of inlet dredging schedule, little lost time for weather during construction. Project scope and costs are easily scaled to the budget available.

Disadvantages: Does not fully restore the profile. Has relatively short longevity. Many repeat beach fills required to restore deficit and regain a wide recreational beach. Dependent on continuing restoration of the stockpile by the federal government.

[*Costs assume borrow material is pumped (at no cost to the county) from Moriches Inlet to a stockpile area within 4.3-5.5 miles of the park. The county would contract separately to truck material from the stockpile areas to the park at a cost of approximately $1.5/cy per mile.]

The Corps of Engineers has announced its intention to resume the maintenance dredging of Moriches Inlet on a two-year basis. The profile analysis presented in the appendix demonstrates an ample supply of sand in the inlet's ebb-tidal delta. The need to protect the Flight 800 memorial should enhance the federal interest in modifying this project to facilitate the placement of spoil in accordance with this alternative.

The average costs of the alternatives considered is summarized in Table A. These costs are primarily dependent on the transportation costs from borrow areas to the park. Because average transportation distances are upward of five miles, CSE recommends that an additional borrow area investigation be made offshore of the park. **If beach-quality sand can be located within three miles or less, the costs in Table A can be reduced by as much as 33 percent.**

TABLE A. Summary of beach restoration alternatives developed in the present study. [Alternative 3 - Source: USACE (1999). Note: All costs are given without interest and amortization for illustration purposes. Costs for Alternative 3* are the local share (excludes federal share – 65 percent).]

Alternative	Applicable Reaches	Length (ft)	Nourishment Volume (cy)	Average Fill Section (cy/ft)	Avg Increase Beach Width @ Pavilion (ft)	Beach Area Added (acres)	Estimated Half-Life (years)
1	2,3 & 4	40,000	5,700,000	142.5	220	202	20
2	Park Facilities+	12,150	1,500,000	123.5	200	37	10
3	Park Facilities	6,000	614,000	102.3	110	14	5
4	Park Facilities	6,000	200,000	33.3	40	6	2
Alternative	**Estimated Local Cost ($)**	**Avg Annual Cost ($/year)**	**Avg Unit Cost Per Beach Foot ($/ft)**	**Avg Unit Cost Per Beach Acre ($/acre)**	**Avg Unit Cost Per Acre/Year ($/acre/yr)**	**Avg Unit Cost Per Beach Foot/Year ($/ft/yr)**	
1	$ 30,000,000	$ 1,500,000	$ 750	$ 148,500	$ 7,425	$ 38	
2	$ 9,000,000	$ 900,000	$ 741	$ 240,437	$ 12,022	$ 74	
3*	$ 2,250,000	$ 450,000	$ 375	$ 163,187	$ 8,159	$ 75	
4	$ 1,500,000	$ 750,000	$ 250	$ 272,250	$ 13,613	$ 125	

No-Action Impacts – If no beach nourishment is performed, the foredune and beach will retreat by an average of at least 25 ft over the next ten years and 50 ft over the next 20 years. Such chronic erosion will expose the steel bulkhead and produce additional localized scour immediately adjacent to, and seaward of, the structure. **Flanking erosion east and west of the bulkhead will cause localized shoreline recession of up to 50 ft landward (in addition to the average recession of 25 ft over ten years).** Flanking erosion will also diminish with distance away from the exposed structure, but will directly affect upward of 1,000 ft of shoreline in either direction. Bulkhead exposure will also lead to scour along its toe and a tendency for a trough to persist. **The dry beach will be replaced by a wet beach (or will be severely diminished), thus inhibiting normal sunbathing and recreation immediately seaward of the pavilion.**

A further consequence of no-action will be a possible violation of the park's bulkhead permit from the state, which specifies that the structure be covered with sand. As erosion progresses, the need for sand scraping to cover the structure will increase, while the longevity of the covering-sand will decrease because of the narrower beach.

Present conditions of the beach and foredune are inadequate to safeguard all facilities during major storms. Chronic erosion will simply exacerbate this problem. Based on previous storm experience, **a 25- to 50-year return-period storm (which has as much chance of occurring next year as within ten years) will produce temporary dune retreat of the order 50-100 ft. This will directly impact park facilities, damage structures situated as much as 125 ft landward of the present foredune crest, and**

deposit sand in the access tunnels. Because of the presence of the steel bulkhead and other foundation structures around the pavilion and variable backshore elevations, localized flanking erosion will modify the storm damage line, shifting it further landward in some areas. A storm of this intensity could cause significant structural damage to the Flight 800 memorial if no remedial action is taken. A catastrophic storm will also trigger inlet breaches along narrow sections of Fire Island where dunes have been lost. [For a detailed description of the prerequisites and processes associated with inlet breaches along Fire Island, see Kana and Mohan (1994) – Assessment of the Vulnerability of the Great South Bay Shoreline to Tidal Flooding, prepared for New York Coastal Partnership, Babylon, New York.]

Beach Scraping – Catastrophic storm erosion differs from chronic erosion because most of the eroded sand remains nearby in the survey zone. Following major storms, the beach tends to gradually rebuild itself. The natural recovery after large storms can be accelerated by beach scraping. The success of beach scraping is directly related to the beach condition. Studies have shown that it is highly cost-effective and environmentally benign if:

1) It is performed soon after storms where large quantities of sand have been shifted from the dunes to the surf zone but not otherwise lost from the immediate vicinity.
2) The shoreline to be scraped has a relatively low background erosion rate.
3) The scraped beach does not protrude seaward of the adjacent beach strand. **and**
4) The littoral profile does not have a major sand deficit compared to a healthy profile.

Where the above-listed criteria are met, beach scraping can jump-start recovery of the dry beach and quickly reestablish a stable dune line. It may last for several years before it has to be repeated. However, where these conditions are not met, scraping after storms may provide protection for only a few weeks. **Portions of Smith Point County Park around the pavilion are considered least economic for scraping after storms because of the sand deficit and presence of the bulkhead.** As erosion continues, the longevity of scraping along the pavilion will diminish each year. If no nourishment is preferred, the probability and severity of damages to structures will increase. Widening the beach via nourishment decreases the chance and severity of damages. Sand replenishment and dune building, utilizing the maintenance practices described above, will become viable only if the beach profile deficit is addressed through a nourishment program.

The findings of this report are consistent with the Governor's Coastal Erosion Task Force findings of 1994.

DEFINITIONS

Following are definitions of some specialty terms used in the report.

Barrier island – A relatively long and narrow island of unconsolidated sediments parallel to the shore, separated from the mainland by a lagoon.

Beach – The zone of unconsolidated sediments over which waves and tides strike the shoreline and form a profile.

Beach cycle – The exchange of sand between the beach and the surf zone before and after storm events or seasonal changes in the beach profile.

Beach profile – The ground surface in a vertical plane across the beach between the dune and shallow water area.

Berm – A nearly horizontal section of the beach near the highest wave limit where unconsolidated and unvegetated sediments are dry most of the time.

Bulkhead – A vertical structure intended to retain the land at the coast, normally in sheltered areas.

Closure depth – The approximate depth of water offshore beyond which there is no measurable change in bottom elevation over a defined period of time.

Coastal processes – The principal physical processes acting at the coast including winds, waves, tides and currents.

Downdrift – The principal direction of movement of littoral material

Dry beach – The area of the beach between the base of the foredune and the high tide line.

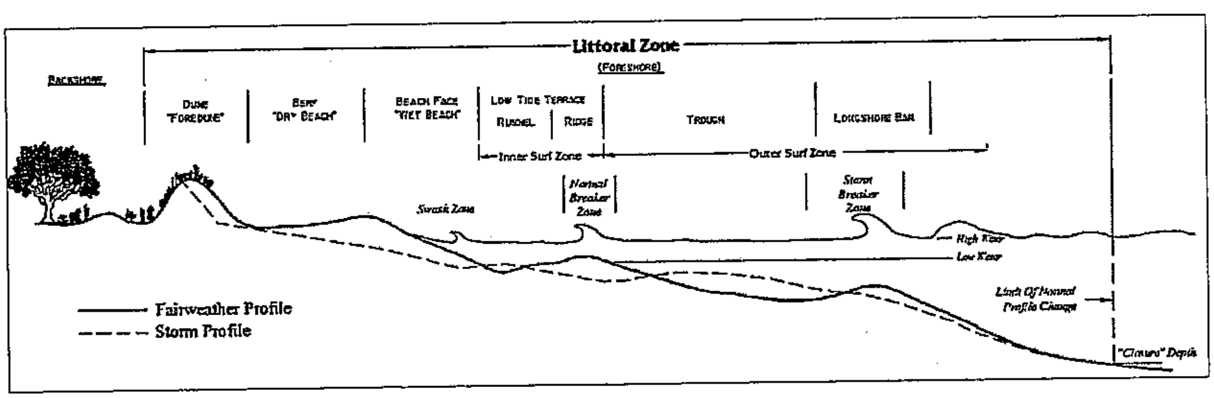
Dune – Ridges or mounds of loose, wind-blown sediment.

Foredune – The seawardmost dune.

Groin – A shore-perpendicular structure placed across the beach to trap and retain littoral sediment moving along the coast.

Jetty – A structure extending offshore designed to prevent littoral materials from entering an inlet, harbor or basin.

Littoral zone – The zone extending seaward from the beach/dune area to the outermost wave breaking zone. (See figure at bottom of page.)



Longshore – Parallel and near the coast; alongshore.

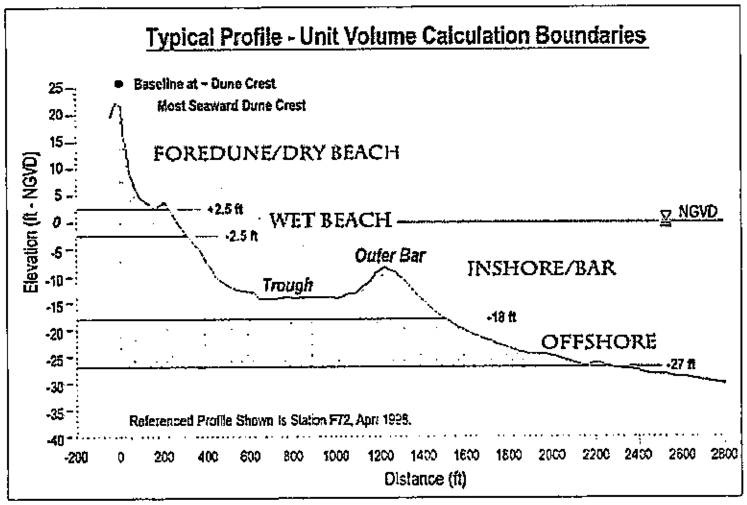
NGVD (National Geodetic Vertical Datum) – A fixed plane over the earth's surface approximating mean sea level. Used as a standard elevation reference by surveyors.

Nourishment – The process of adding unconsolidated sediments to the beach by natural or artificial means.

Outer bar – A linear mound of sediment parallel to shore beyond the normal breaker zone where only the largest waves break. (Also referred to as the **longshore bar**)

Offshore (as used in the present report) – The outer edge of the littoral zone seaward of the outer bar.

Profile volume (as used in this report) – The quantity of sediment contained in a unit length of beach (eg, one foot) between the foredune and the approximate outer bar offshore. It provides a measure of the health of one section of beach compared with another. It is subdivided arbitrarily by reference elevations and beach features (as illustrated in the figure).



Sea level – The absolute height of the sea surface in the absence of tides, waves or wind effects.

Seawall – A structure placed along a shoreline to prevent waves from inundating or damaging the land.

Setback line – A jurisdiction line generally parallel and some distance inland from the shoreline marking a seaward limit for development or other socioeconomic activities.

Shoreline – The intersection of a specified plane of water with the land. Mean high water is one example.

Shore protection – General term for alterations at the coast designed to maintain and protect upland features or the shoreline itself from the action of winds, waves, tides, currents, and storms.

Surge – A higher than normal water level along open coast resulting from the action of storms and wind.

Tidal inlet – A narrow waterway at the coast which channels the incoming (flood) or outgoing (ebb) tide into bays, lagoons, estuaries, or rivers.

Tide – The rising and falling of water in a large basin due to the gravitational attraction primarily of the moon and sun on the rotating earth.

Trough – An area between the beach and the outer bar where littoral currents flow and depths are deeper than the outer bar.

Updrift – The direction from which most littoral material originates along a particular shoreline.

Washover – A nearly horizontal deposit of beach sediments generally landward of the seawardmost dune line produced by high waves that overtop the beach and dissipate inland, carrying littoral sediment.

Wet beach – The area of the beach between the low tide mark and the high tide mark.

ACKNOWLEDGMENTS

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We thank Martin Hero (Project Manager), Robert Grover (Sr Environmental Scientist), and William Ziminiski (Sr Architect) with Greenman-Pedersen for coordinating our work and for providing timely data and information. We also obtained data from Fred Anders (New York Department of State) and Jay Tanski (New York State Sea Grant).

Much of the background data referenced herein was obtained from the New York District–US Army Corps of Engineers (in connection with previous CSE studies of the Long Island south shore), National Park Service (c/o Dr. Jim Allen and Dr. Stephen Leatherman), and New York Coastal Partnership (c/o Mr. Murray Barbash).

At CSE, Dr. Tom White (PE) and John (Trey) Hair assisted with the analysis and prepared the graphics, and Diana Sangster prepared the manuscript. The report was written by Dr. Timothy Kana.

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1.0 INTRODUCTION AND PURPOSE

This report is prepared in connection with a study of potential improvements to Smith Point County Park. Greenman-Pedersen Inc (GPI) was retained by the Suffolk County Department of Public Works (SCDPW) to review existing conditions in the park and prepare an updated master plan of improvements. One element of the review is an assessment of coastal erosion and development of alternative plans for erosion mitigation. Coastal Science & Engineering LLC (CSE) was retained by GPI to prepare the erosion analysis using historical and recent information from a variety of sources.

The report provides a brief review of previous erosion research, describes the regional setting and geomorphic history of eastern Fire Island, and summarizes local coastal processes and storm impacts. It includes detailed analysis of erosion rates and profile volumes for representative time periods. This serves as a basis for quantifying sand deficits and beach restoration requirements along the park and adjacent shoreline. The report outlines the principal causes of erosion along the park inferred from the present analysis and prior studies, and discusses alternative borrow sources for beach nourishment and periodic maintenance. The probable cost of beach improvements under several alternative nourishment scenarios is presented based on recent experience with similar projects.

2.0 PREVIOUS RESEARCH AND DATA REVIEWED

Smith Point County Park (at the eastern end of Fire Island) is situated along one of the most intensely studied coastlines in the United States. For over 80 years, the New York District– US Army Corps of Engineers (USACE) has completed studies along the southern shore in connection with inlet stabilization projects, inlet maintenance dredging, emergency beach restoration, and long-term beach/dune improvements. Surveys have been completed by the USACE following major storms such as the 1938 (unnamed) hurricane, 1962 northeaster, and the recent northeasters of December 1992 and March 1993, among others. Other surveys have been performed in connection with beach nourishment and groin construction projects at Georgica Pond and nearby Westhampton Beach.

Among the most relevant reports by the Corps for the present study are USACE 1958, 1963a, 1963b, 1967, 1980, 1994, and 1999. The 1958 report developed a comprehensive analysis of erosion and storm protection requirements for the shoreline from Montauk Point to Fire Island Inlet. As a result of changes caused by the March 1962 northeaster (northeaster of record) and construction of the Westhampton groin field (1964-1971), the USACE initiated a "Reformulation Study" (publishing parts of it in 1980). Corps subcontractors, including CSE's parent company (Research Planning Institute Inc), assisted with the reformulation study (eg, RPI 1985), developing a sediment budget analysis. Other contractors (eg, URS 1985) evaluated structural damages and the economic impacts of storms along the south shore.

A second "Reformulation Study" was initiated in the early 1990s after damaging northeasters of December 1992 and March 1993. USACE (1999) is an interim plan for south shore beach restoration, preliminary to completion of the present reformulation study scheduled for 2006 (L Bocamazo, NY District, pers comm, May 2001).

Another series of important studies were prepared by the National Park Service and its subcontractors, notably Dr. Steve Leatherman and Dr. Jim Allen. Leatherman and Joneja (1980) prepared a "geomorphic analysis of south shore barriers" which includes an excellent annotated bibliography on the evolution of barrier islands (with specific reference to Fire Island), a compilation of historical maps, charts, and aerial photographs; and an analysis of historic shorelines (Leatherman and Allen 1985), inlets, and washovers. Other linear shoreline change analyses of Long Island's south shore have been prepared by the US Geological Survey (Dolan et al 1985).

The Federal Emergency Management Agency (FEMA 1987) has prepared flood insurance studies and maps of predicted flood zones and flood elevations for the Town of Brookhaven as well as other south shore reaches. These reports provide official estimates of extreme open coast tide levels for various return-period storms. Data from FEMA studies have also been combined with land-use plans developed by the Long Island Regional Planning Board (eg, LIRPB 1984, 1989).

Other relevant reports are from the New York State Governor's Coastal Erosion Task Force (eg, NYDOS 1994) which were prepared by a broad panel of state experts in response to extensive erosion in the early 1990s. Also in response to the 1992 breach at Westhampton, the New York Coastal Partnership commissioned a study of potential impacts to the Great South Bay shoreline of a breach of Fire Island (Kana and KrishnaMohan 1994, Kana 1995, Koppelman 1995). These documents synthesize much of the erosion and sediment budget data developed in earlier studies.

An important data source for earlier sediment budgets (eg, RPI 1985, Kana 1995, Kana 1999) are dredging and beach fill records compiled by Suffolk County Planning Department (SCPD 1985). For many years, SCDP maintained a fleet of dredges and performed periodic maintenance dredging in Moriches Inlet, the Intracoastal Waterway, and numerous bay channels to Fire Island. Between the 1950s and 1970s, millions of yards of sediment were disposed along Westhampton Beach and Fire Island in conjunction with county maintenance dredging.

A complete listing of other relevant articles about shore erosion, coastal processes, sediments, and geologic history is beyond the scope of the present study. However, a number of articles are mentioned here because CSE regards them as classic studies for the area:

Colony (1932)	on the source and texture of south shore sand
DeWall (1979)	on Westhampton Beach changes (1962-1973) along the visible beach
Duane et al (1972)	on linear shoals (potential nourishment sources) off the south shore
Krinsley et al (1964)	on tracing the movement of sand grains along the coast
McBride and Moslow (1991)	on the origin and evolution of offshore sand ridges, particularly off Fire Island Inlet
McCormick (1973)	on shoreline changes along the south shore of eastern Long Island
Nersessian et al (1993)	on the functioning of groins at Westhampton Beach
Panuzio (1969)	providing an early synthesis of studies, particularly those of the USACE–New York District

Sanders and Kumar (1975)	on the quaternary history of the inner shelf off Fire Island
Taney (1961)	a comprehensive early study of coastal processes and sediments along the south shore
Williams and Meisburger (1987)	on the potential contribution of inner shelf sediments to the long-term stability of Fire Island

During the past decade, the State of New York (in collaboration with New York State Sea Grant and the USACE) began a detailed shoreline monitoring program which includes Westhampton Beach and Fire Island. A network of profiles (established in 1995) have been surveyed up to eight times to wading depth or out to about 30-foot (ft) depths. Data have been compiled in a GIS database along with controlled vertical aerial photographs and other relevant shoreline data (NYS 2001). These data are available from New York State Department of State (NYDOS) on CD-ROMs (including software to read the files; c/o Mr. Fred Anders at 518-474-6000). The data are accessed using Coastal View (Version 1.2.0) by Science Application International Corporation (SAIC). This database offers an unparalleled compilation of historical information, although some recent data on the disk have not been fully verified for quality control (J Tanski, pers comm, Feb 2002). The most recent set of beach surveys available in the NYDOS program are from spring 2001. The majority of new work in the present study involved merging recent New York State surveys with historical surveys by the USACE and developing updated erosion rates. A later section of this report discusses in detail which specific data sets were merged and how they were used in this analysis.

A final set of relevant articles were published recently in the proceedings of Coastal Sediments '99 [Kraus and McDougal (eds) 1999], a specialty conference in Hauppage, New York (21-23 June 1999). Rosati et al (1999) provide an updated regional sediment budget for Fire Island to Montauk Point (part of the current reformulation study). Kana (1999) provides a "century" estimate of all nourishment volumes along the south shore. Schwab et al (1999) discuss the evolution and contribution of offshore shoals to central Fire Island's stability. Gravens (1999) analyzes rhythmic beach morphology and its relation to the longshore bar. Headland et al (1999) review tidal inlet stability at Moriches Inlet.

The above-listed references provide a rich history of the area and serve as a basis for the present study. Many have been reviewed in previous studies by CSE and are listed here to facilitate future studies of physical and geologic processes along the south shore. Biological studies have been omitted as less relevant to the problem of coastal erosion. However, the botany of barrier islands is very important and relevant for evaluating dune stabilization alternatives. In keeping with CSE's primary charge, we reference generic vegetative stabilization options, but leave it to other experts (including our colleagues at GPI) to develop specific landscaping plans.

3.0 SHORELINE SETTING AND HISTORY

3.1 GEOLOGY AND GEOMORPHOLOGY

Long Island marks the southern terminus of the Wisconsin glacier and owes its existence to moraines deposited as the glacier receded (Flint 1971). The south shore is the outwash plain fronting the Ronkonkoma moraine. Outwash deposits are typically mixtures of silts, sands, and fine gravel fanning out as deltas from the terminal moraine. As sea level rose between 15,000 and 5,000 years ago, waves reshaped the outer lobes of the deltas and built the barrier islands of today. Swales landward of the barriers became Moriches Bay and Great South Bay. The outwash channels were drowned and became tidal tributaries such as Carmen's River and Connetquot River.

In settings like the south shore, littoral processes rather than riverine processes dominate at the coast. Sediments become sorted by waves and tidal currents, winnowing out fine-grained material and leaving medium to coarse sand along beaches (Colony 1932). Littoral transport moves sands along shore, forming spits and bars parallel to shore.

Tidal Inlets

Inlets provide periodic breaks in the barrier beach and serve as conduits for tides into the bays. Where tide range is relatively low and wave energies high, natural inlets are widely spaced (Hayes 1980). They tend to be ephemeral and migrate in the predominant drift direction. Their channels are usually shallow and are not directly linked to the position of paleochannels of the outwash plain.

South shore inlets are maintained by tidal flows in and out of the bays. Similar to rivers, inlets also have associated deltas. In contrast to rivers, however, tidal deltas form on the bay side as well as on the ocean side of the inlet. Flood tides generate deltas into the bays; hence, the term "flood tidal" deltas for these deposits. Ebb tides generate "ebb tidal" deltas on the ocean side.

The extent to which waves or tides dominate at the coast is reflected in the shoreline morphology. Where tides dominate, such as along the Georgia shore, the coastline will be highly irregular. Where waves dominate, the coast will tend to be straight with few interruptions by tidal inlets. This, of course, is the case along the south shore of Long Island.

Barrier Island Evolution

There are several theories on the formation of barrier islands which are discussed in detail by Leatherman and Joneja (1980) and Davis (1994), among others. The earliest theory (by de Beaumont 1845) suggested that barrier islands formed as a result of emergence and upward shoaling of shallow sand bars near the coast. Another famous geologist (GK Gilbert 1885) theorized that barrier islands form by way of spit growth under the influence of longshore drift. The third theory (proposed by McGee 1890) suggested that barrier islands formed by drowning of coastal ridges. As sea level rises, according to this last theory, high dune ridges along a mainland shore become isolated as the lower portions of the coastal plain are flooded and become lagoons.

In recent years, geologists have found evidence to support all three theories (Davis 1994). In all likelihood, barrier islands like those of Long Island's south shore probably formed by a combination of processes, particularly via emergent bars and spit growth. Regardless of the primary mode of formation, the result and persistence of barrier islands is what is important for development planning.

Smith Point County Park is located near the eastern end of Fire Island, the south shore's premier barrier island (Fig 1). Fire Island is characteristic of "microtidal" barriers which tend to be long (32 miles in this case) and narrow with a dominant foredune ridge. Fire Island is bounded on the east by Moriches Inlet and Westhampton Beach. The two barrier islands have been linked in historic times as well as subdivided by inlets (Fig 2).

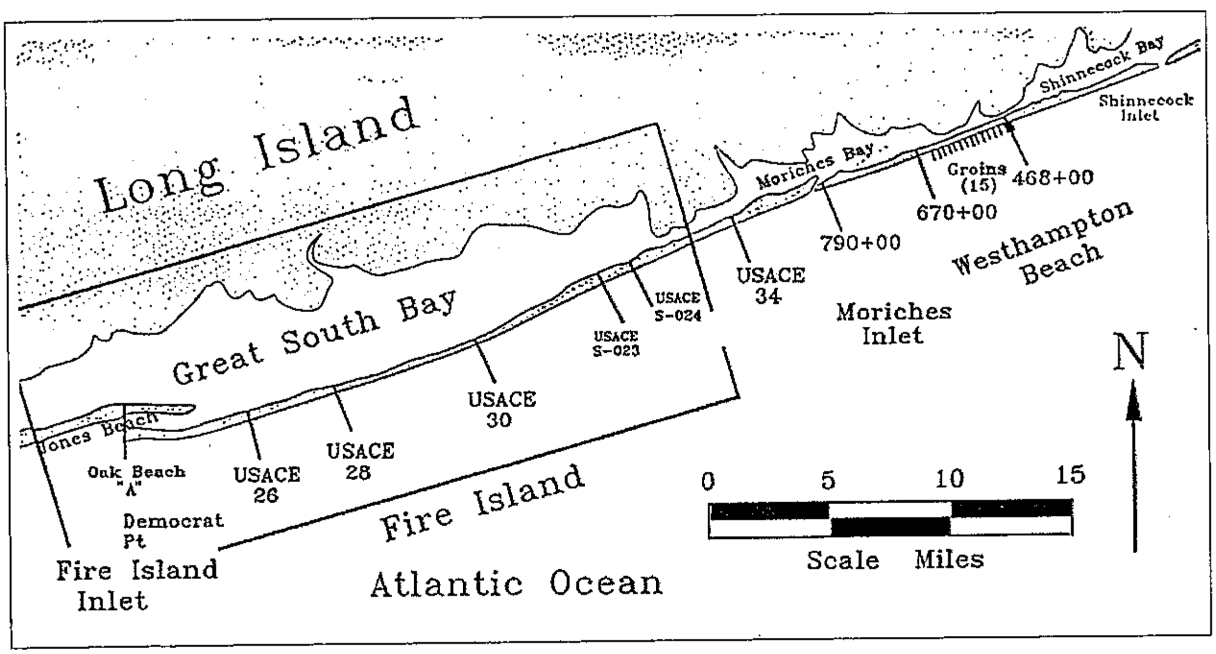


FIGURE 1. General location map of Fire Island and Westhampton Beach cross-sections referenced herein. The county park is situated between USACE 34 and USACE S-024.

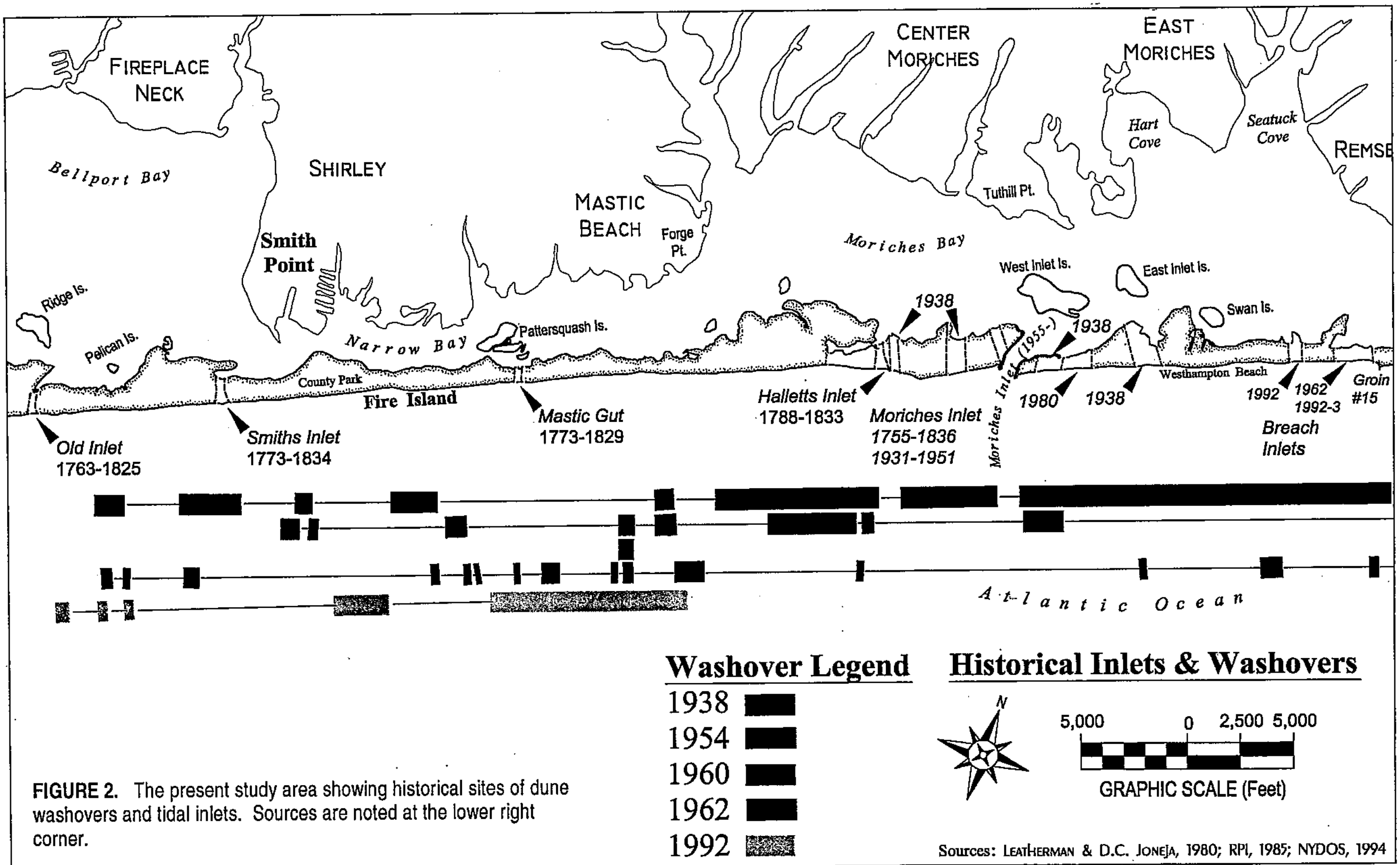


FIGURE 2. The present study area showing historical sites of dune washovers and tidal inlets. Sources are noted at the lower right corner.

Leatherman and Joneja (1980) reported 26 inlet sites between Shinnecock Inlet and Fire Island Inlet over the past 300 years. Two more can be added since the December 1992 northeaster. Most historic inlets (21) occurred along Westhampton Beach. By contrast, Fire Island has had relatively few inlets west of Moriches Inlet. As Figure 2 shows, three inlets existed near the county park between the late 1700s and early 1800s: Mastic Cut near Pattersquash Island (east of the park), Smith's Inlet about 3,000 ft west of the park, and Old Inlet off Bellport. By 1835, all three had closed and none have formed since then in this area.

For the next 100 years, Fire Island and much of Westhampton Beach were linked as one barrier island. Moriches Inlet breached the barrier in the vicinity of an earlier inlet in 1931 and persisted in a natural state until 1951 when it shoaled and closed. During this period, the hurricane of record in September 1938 produced over a dozen major breaches and left multiple inlets that eventually shoaled and closed along Westhampton Beach.

No inlets formed through Fire Island during the 1938 hurricane, but washovers (precursors to inlets) broke through the foredune in several places and deposited littoral sand along the back side of the island (Fig 2). One small washover occurred in the vicinity of today's park pavilion and another large one along today's campground. Leatherman (1985) found that few washovers have managed to reach Great South Bay or Moriches Bay. Instead, washovers build up the back-barrier elevation, sometimes burying emergent salt marsh vegetation. Full breaches of the barrier islands are thought to account for most of the sand deposited in the bays during storms.

3.2 LARGE-SCALE EROSION PROCESSES

In historic times, eastern Fire Island's response to storms has been quite different from that of Westhampton Beach. It has not breached; fewer washovers have formed; and less sand has been lost to the bay. This has made Fire Island positionally stable over the past 300 years. Differences between Westhampton Beach and Fire Island are reflected in their cross-sections.

Kana and KrishnaMohan (1994) analyzed the condition of south shore barrier islands and their vulnerability to breaches using profile geometry and volumes. Barrier islands develop a profile under the combined force of waves and currents. It has been shown that a certain minimum profile cross-section is required to maintain stable dunes seaward of a fixed point on the barrier. As long as sufficient sand is supplied to the littoral system, the barrier island is self-maintained. If the supply is insufficient, profile volumes decline and the shoreline recedes. If extra sand is added, the shoreline advances. Excess sand in the visible beach is a fundamental prerequisite for dune building.

During the early 20th century, Westhampton Beach and eastern Fire Island were linked and free of inlets or structures that interrupt littoral drift. Since the 1930s, inlets, tidal deltas, the Moriches Inlet jetties (1956) and the Westhampton groin field (1964-1971) have modified littoral processes such that some areas have gained sand and others have lost sand relative to a minimum, healthy barrier cross-section. Figures 3-5 illustrate these large-scale trends.

The Westhampton Beach groin field consists of 15 large quarrystone groins, built in response to erosion and barrier breaches. It extends for four miles, beginning about 3.1 miles east of Moriches Inlet. After construction of the groins (plus some nourishment), the shoreline within the groin cells built over 200 ft seaward. The wider beach allowed development of a new foredune and effectively doubled the volume of sand in the barrier island profile above mean sea level (Fig 3, upper, USACE 468+00). In contrast, downcoast profiles outside the groin field eroded, and the foredune receded. By 1979 (15 years after the initial groin construction), some barrier island sections had no dune protection and less than half of the volume required for stability (Fig 3, lower, USACE 670+00). Throughout the 1980s, continued erosion left this downcoast reach vulnerable to breaching. The December 1992 northeaster breached Westhampton Beach at this vulnerable spot.

Another breach occurred in January 1980 just east of Moriches Inlet. This section, along Cupsogue Beach, was narrow because of encroachment of the bay channel. During a minor storm, the isthmus breached, leaving a low sill in place of the barrier beach (Fig 4, USACE 790+00). The 1980 breach produced extensive deposition of littoral sand in the bay channel and recession of the inshore profile seaward of the breach. This is one of the few breach events documented by profile surveys. About one year after the breach formed, the USACE closed the channel by dredge and trucks using sand from the bay channel and mainland (Vogel and Kana 1985).

During the same period represented in Figures 3 and 4, eastern Fire Island lost sand in the inshore zone (Fig 5). Profiles near Pattersquash Island show persistence of the dunes between 1967 and 1979, but upward of 200 ft recession of the shoreline and loss of sand between the dune and outer bar (Fig 5, upper, USACE34). At Old Inlet, the December 1992 and March 1993 northeasters breached the foredune and left a low washover at USACE station S-024 (Fig 5, lower).

Before quantifying erosion along the park, it is useful to note that eastern Fire Island has been relatively stable compared to Westhampton Beach. While narrow, its foredune has tended to maintain sufficient size and reduce the frequency of breaches and washovers. And, in contrast to some barrier islands like Core Banks (NC) (Moslow and Heron 1979) and Westhampton Beach before the groin field, Fire Island has not tended to "roll over" from the ocean side into the bay during the past few centuries.

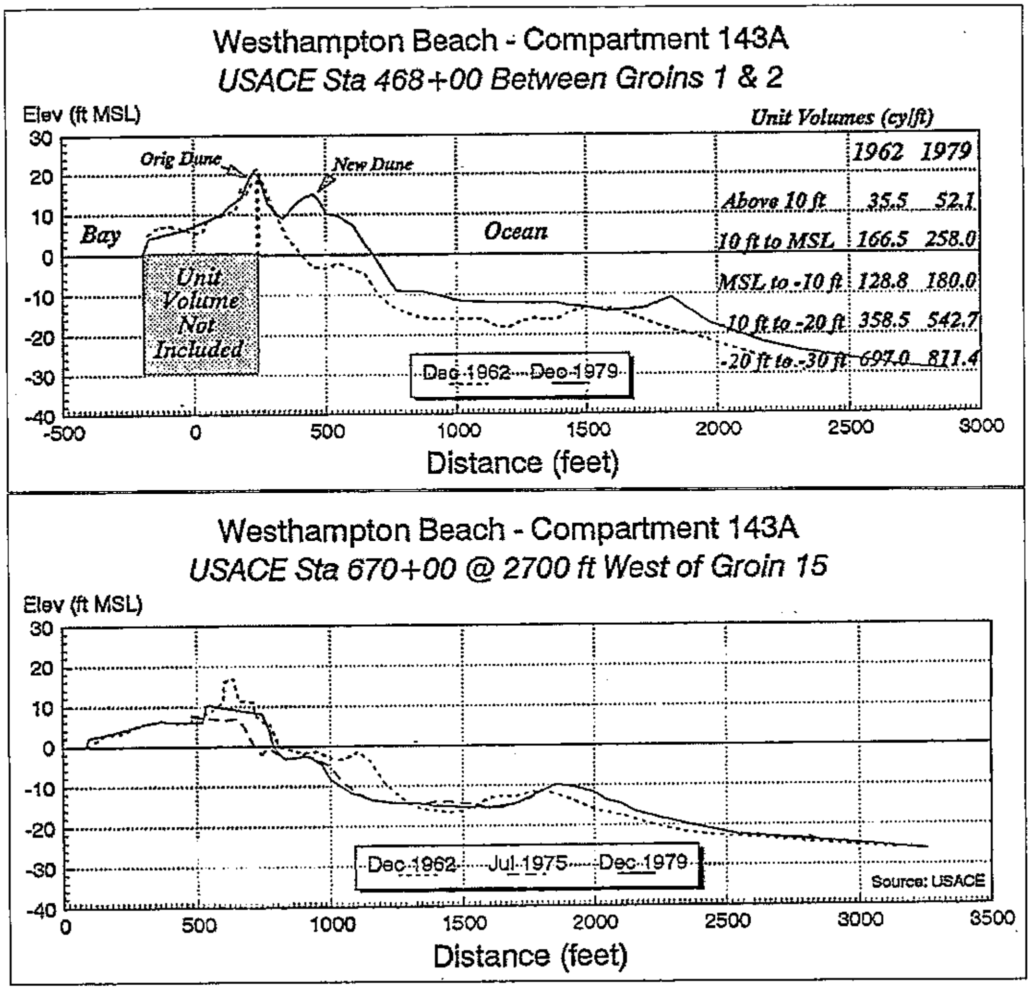


FIGURE 3. Representative, barrier-island cross-sections from the eastern end of the Westhampton groin field (upper) and Pikes Beach (lower), illustrating opposite trends in shoreline change between 1962 and 1979. Unit volumes are the quantity of sand contained in a one-foot length of beach between the indicated contours. The profile volume provides a quantitative measure of beach conditions. [After Kana and KrishnaMohan 1994]

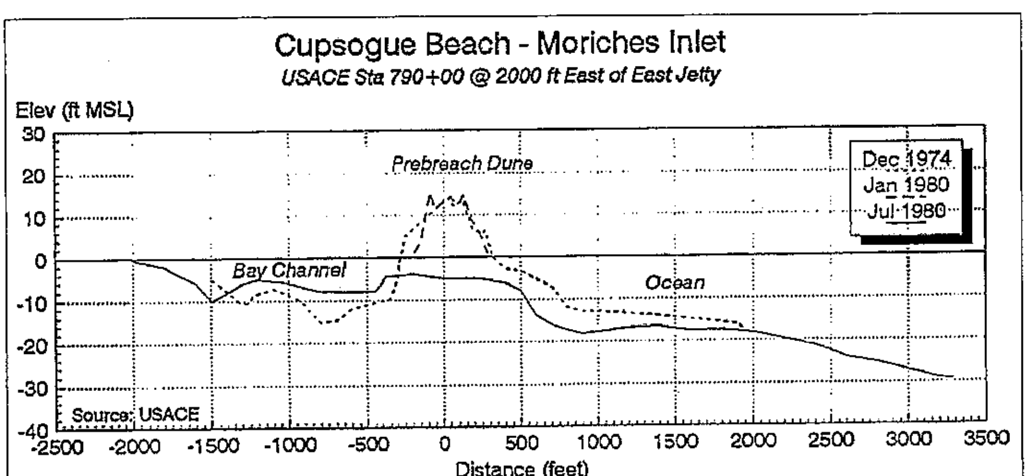


FIGURE 4. USACE station 790+00 situated ~2,000 ft east of Moriches Inlet. Erosion in 1980 occurred after the January 1980 breach to the east migrated through this section. Note the complete loss of beach and dunes by July 1980. [After Kana and KrishnaMohan 1994]

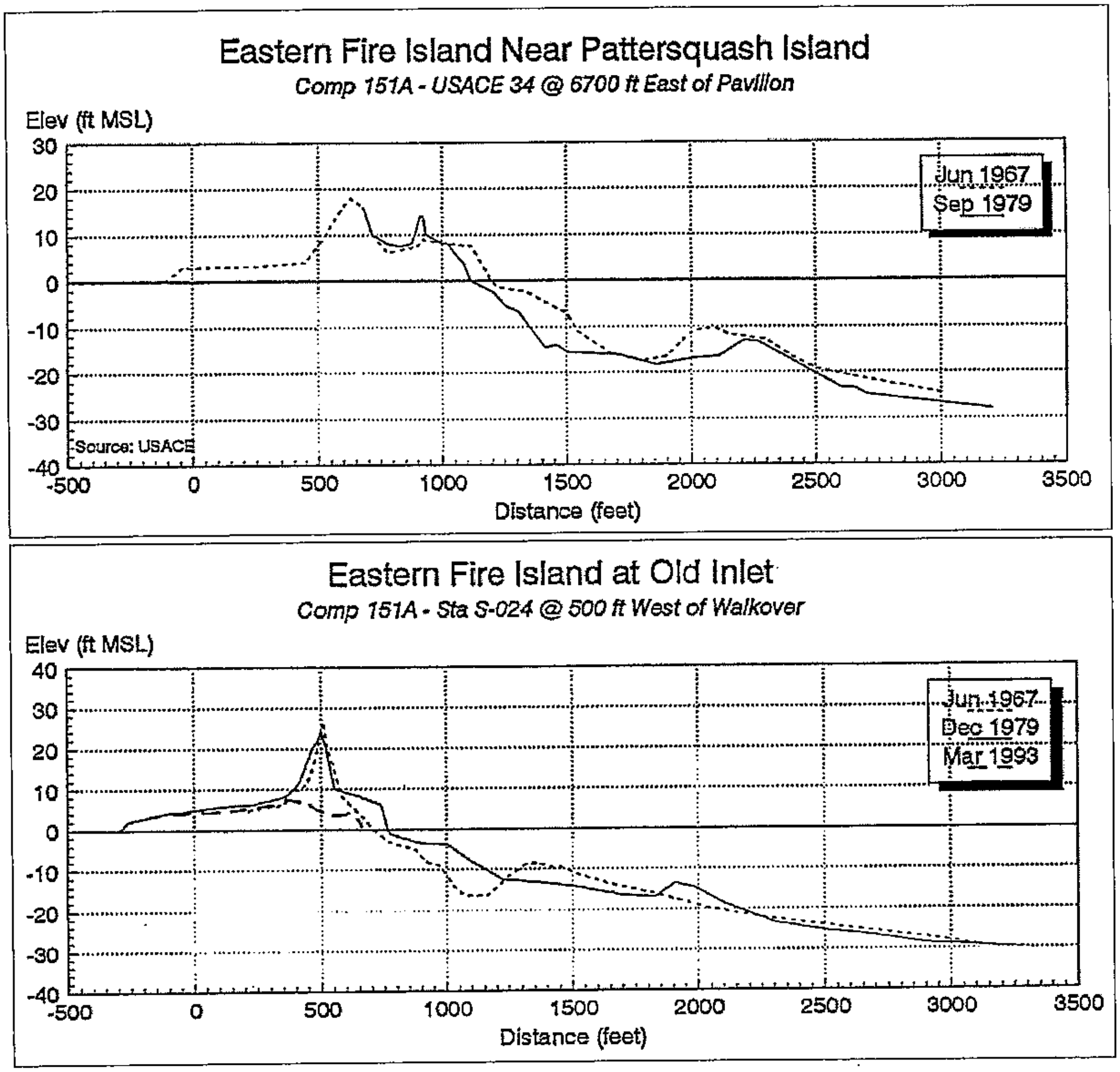


FIGURE 5. Representative, barrier-island cross-sections from (upper) Pattersquash Island area east of Smith Point County Park (locality for numerous washovers in the past 20 years) and (lower) Old Inlet off Bellport (site of a washover during the December 1992 storm). [After Kana and KrishnaMohan 1994]

3.3 COASTAL PROCESSES AND STORMS

The controlling processes along the Long Island coast are winds, waves, currents, and tides. Winds generate waves which do most of the beach reshaping work. Tides control the level at which waves interact with the shoreline and generate strong currents around inlets. Waves breaking over the longshore bar and on the beach impart motion to exposed sediment particles, causing movement across and along the shoreline. The degree and direction of sediment motion are related to the approach angle of the waves and the height of the waves.

Tides

Mean tide range increases from 2.0 ft at Montauk Point to 4.6 ft at New York Harbor. Moriches Inlet's mean tide range is 3.3 ft, and spring tide is 4.0 ft (NOAA 1996). Surveyors use National Geodetic Vertical Datum of 1929 (NGVD) as a common vertical reference. At Moriches Inlet, NGVD is 1.8 ft below mean high water (MHW) and 1.5 ft above mean low water (MLW) (USACE 1999).

Tidal Currents

Tidal currents produce strong flow fields in the immediate vicinity of inlets, but are generally negligible several thousand feet away. Typical maximum inlet velocities are 4-6 feet per second (ft/s) in Moriches Inlet between the jetties (USACE 1999). Tidal currents deflect sediment into tidal deltas and help maintain major sediment deposition zones at the inlets (Militello and Kraus 2001).

Winds

Prevailing winds are from the southwest. Northeast winds tend to be less frequent but stronger and tend to dominate during most storms. Highest winds are in hurricanes. Typical wind speeds are 10-15 miles per hour (mph). Northeaster storms in Long Island tend to be more intense than those of southern states with typical wind speeds of 30-45 mph (versus 20-30 mph in the south). Highest recorded wind speeds in the area have approached 100 mph (USACE 1999).

Waves

The predominant wave direction is from the southeast (longest fetch). This accounts for wave breaking and net sediment transport toward the west. Prevailing winds produce "fair weather" waves that tend to break toward the east. USACE (Hubertz et al 1993) has hindcasted waves for various, return-period wind conditions using offshore stations (USACE 78 is closest to Smith Point County Park). In 30-ft water depths, the predicted highest significant wave is 18.5 ft (period equal to 11 seconds) for a five-year return period wind and 23.5 ft (period equal to 14 seconds) for a 50-year wind (Table 1). Waves of these heights will break on the longshore bar upward of 1,000 ft offshore. Therefore, incident waves on the beach are typically much lower, even in storms. The mean wave height for the area is typically about 3-3.5 ft.

Storm Surges

Data on open-coast surge levels are rare for the area because of lack of tide recordings or fixed objects to which high watermarks can be obtained. Flood levels in Mastic Beach were reported as high as 15 ft during the 1938 hurricane. This estimate may include local wind setup over shallow water in the bay and, therefore, possibly overestimates open-coast surge levels during that storm.

TABLE 1. Predicted maximum significant wave heights in 30-ft depths off Fire Island by hindcasting from wind records. Station 78 is closest to Smith Point County Park. (1) Using CERC stage-frequency curve for Westhampton Beach. (2) Value used in analysis: 30-ft depth. [After USACE 1999]

	WIS Hurricane		WIS	(1) Water Level (ft NGVD)	(2) Significant Wave Height Hs (ft)	Peak Wave Period (sec)
Return Period (Years)	Station 24 Hs (ft)	Station 25 Hs (ft)	Station 78 Hs (ft)			
2			16.6	5.0	15.2	10
5	16.4	19.7	18.5	5.2	15.3	11
10	20.0	24.9	19.9	5.9	15.6	12
20	24.3	31.8	21.4	6.7	15.9	13
44	32.7	46.8	23.2	8.0	16.5	14
50	34.1	49.2	23.5	8.2	16.6	14
100				9.4	17.1	14
200				10.7	17.6	14

FEMA (1987) has applied uniform surge models to the area and predicts a 100-year surge elevation (with wave action) of 12.0 ft at Smith Point and 14.0 ft at East Moriches, several miles to the east of the park. The 50-year and 10-year predicted flood elevations are 10.0 ft and 8.0 ft (respectively) at Smith Point (Fig 6).

Storms

Hurricanes and northeasters occur at frequencies typical for the eastern United States (Ho et al 1975). Leatherman and Joneja (1980) list 17 hurricanes and about 26 extra-tropical (northeasters) for the period 1788-1980. The number of extratropical storms increases dramatically after 1950, suggesting that early records tended to ignore these frequent events. The most notable storms of record for the area are:

Great Blizzard of 1888 (March 11-14)
Hurricane of 1938 (September 21, storm of record)
Hurricane *Carol* (31 August 1954)
Hurricane *Donna* (1960)
Northeaster of 1962 ("Five High") (6-8 March, record dune recession over five tidal cycles)
Hurricane *Belle* (August 1976)
Northeaster of 1992 (December 11) (produced breach at Westhampton Beach)
Northeaster of 1993 (March 13-14)
Hurricanes *Felix* and *Luis* (1995)
Northeaster of 1995 (November 14-15)
Northeaster of 1996 (January) (reportedly caused 200 ft of beach erosion at the park, USACE 1999)

The above listing suggests that the largest storm-induced changes over the past century occurred in connection with the 1938 hurricane, 1962 northeaster, and the rash of storms in the early 1990s. Between these 25-30 year periods, the frequency or intensity of storms was less. Beaches often respond to storm cycles by eroding rapidly, then recovering slowly (Hayes 1967). The systematic variation in wave energy between stormy and normal periods controls the "cross-shore" movement of sediment and development of the littoral profile.

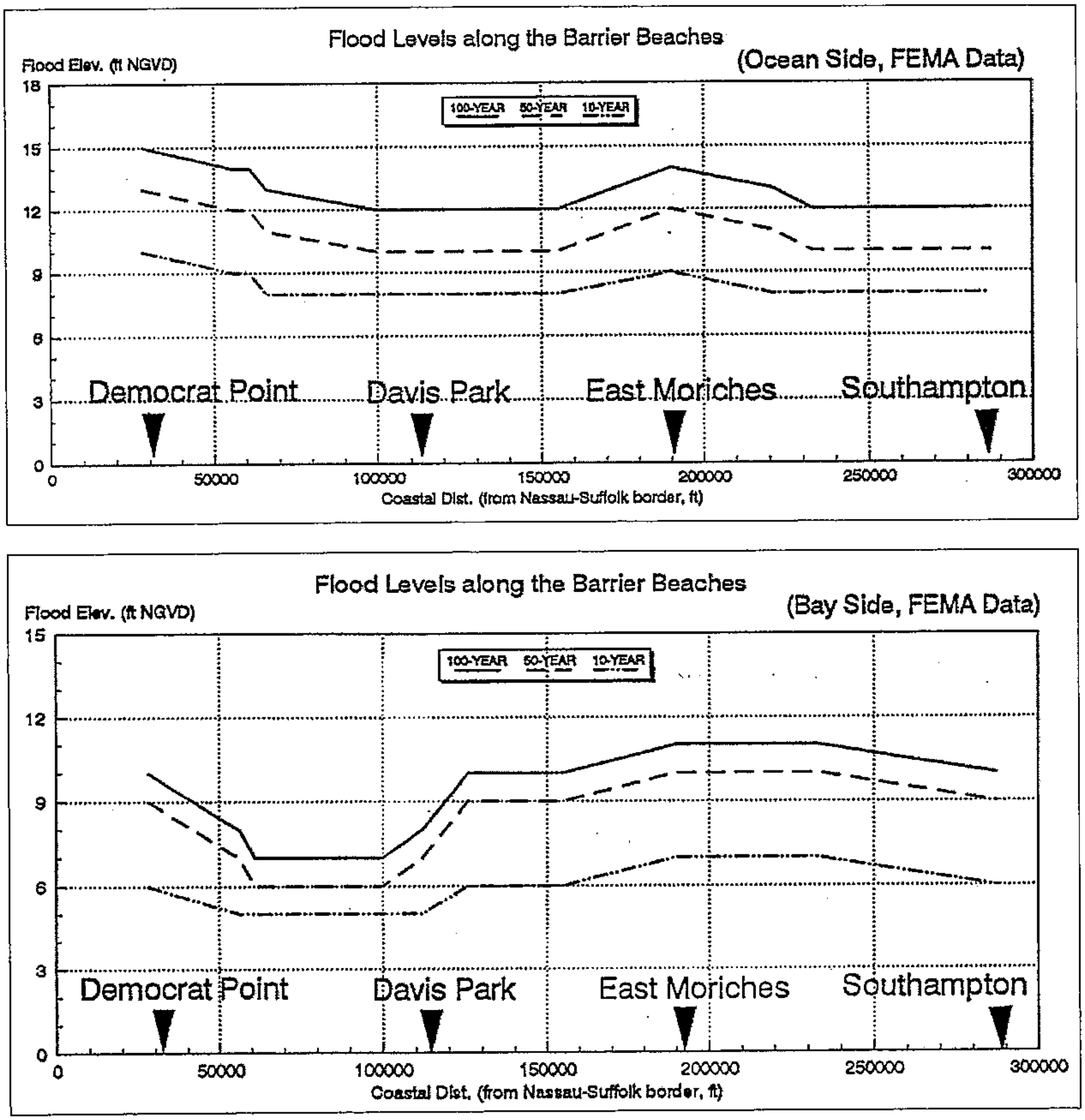


FIGURE 6. FEMA predicted flood elevations (with wave action) along south shore barrier beaches — ocean side (upper) and bay side (lower). [After Kana and KrishnaMohan 1994]

Longshore Transport

Estimates of net longshore transport along Fire Island span a wide range from ~100,000 cubic yards per year (cy/yr) to over 600,000 cy/yr (USACE 1958, RPI 1985, Kana 1995, USACE 1999, Rosati et al 1999). All estimates are to the west. The earliest reliable rates were based on sand trapping at Democrat Point (Fire Island Inlet jetty). Between 1940 (when the jetty was built) and 1954, sand accumulated updrift of the jetty at rates of about 460,000 cy/yr (USACE 1958) to 600,000 cy/yr (Panuzio 1969). RPI (1985) estimated the rate of fillet growth at ~550,000 cy/yr. These often-quoted rates were frequently referenced as characteristic for all of Fire Island.

Rates determined for Moriches Inlet have tended to be much lower than Fire Island Inlet, ranging from 84,000 cy/yr (Kana 1995) to 350,000 cy/yr (Panuzio 1969). Kana's rate was imputed from a regional sediment budget (RPI 1985) and surveyed volume changes updrift and downdrift of Moriches Inlet during the time period 1955 to 1979. During this period, profiles in Westhampton Beach indicated the groin field was a total littoral barrier. Kana (1995) theorized that as the groin cells were filling, they captured sand from east **and west**, producing a local drift reversal. Transport to the west resumed somewhere along Cupsogue Beach and was necessarily low at Moriches Inlet.

The USACE (1999) has reevaluated the RPI (1985) and Kana (1995) sediment budgets and believes that the net transport rate off the Westhampton groin field is zero, rather than some net quantity to the **east**. By assuming zero at the groin field, the imputed rate at Moriches Inlet rises to 194,000 cy/yr (westerly) for the 1955-1979 period. The Corps used 1989 surveys to estimate the net rate at 143,300 cy/yr (westerly) for 1979-1989 (USACE 1999). The Corps has speculated that even these rates are low because of "an apparent ongoing westerly drift at the Westhampton groins" (USACE 1999, p C-17). Based on this unquantified observation, the Corps adopted (for planning purposes) the USACE (1958) rate of 300,000 cy/yr (westerly) at Moriches Inlet for the period 1979 to 1998.

Longshore transport rates closer to the county park have been estimated to be ~84,000 cy/yr (west) at a point ~14,000 ft east of the park pavilion (Kana 1995). Rosati et al (1999) (also working on the reformulation project) estimate net longshore transport ~2 miles west of Moriches Inlet to be 183,000 cy/yr. At an equal distance west of the pavilion, Kana (1995) estimated longshore transport at 287,000 cy/yr for the 1955-1979 period. The large difference in the rates east and west of the pavilion reflects the large net losses of sand along the park during the period. If the Corps' (1999) higher transport rate for Moriches Inlet is assumed, longshore transport around Old Inlet would be greater than 400,000 cy/yr. The long-term stability of central Fire Island suggests the net transport rate must be lower than this recent Corps estimate. CSE recommends the Kana (1995) and Rosati et al (1999) rates as the most reliable range for planning purposes.

Littoral Boundaries and Closure Depth

Beach erosion is complicated by the fact that the shoreline erodes across a dynamic boundary. While the most noticeable erosion occurs at the foredune, sand can be lost below low water as well. During storms, the upper part of the profile usually erodes while the lower part gains sand and builds seaward. Rapid profile adjustment during storms is generally followed by a slow recovery of sand along the visible beach. Thus, it is important to distinguish cyclical events (which may balance out and yield no net sand volume losses) from permanent losses.

The active littoral zone is generally considered to extend from the foredune to the seaward limit of **measurable change in bottom elevation** (ie, "closure depth"). From day to day, the seaward limit of detectable change is close to shore in shallow water. But over several years or decades, measurable sand movement can be seen much further offshore.

The profiles shown in Figures 3-5 provide an indication of the scale of the littoral zone. The limit of detectable change for eastern Fire Island is considered to fall between 24 ft and 30 ft. Researchers have assumed closure at 24 ft (eg, RPI 1985), 27 ft (eg, USACE 1999), and 30 ft (eg, Kana 1995) for purposes of computing profile changes and erosion rates. Until a substantially larger profile database is available, all of these estimates are reasonable but not precise. For purposes of the present study, CSE assumes that profile closure is 27 ft. This means that the typical littoral boundaries of interest extend about 2,500 ft offshore and encompass a broad zone between the beach and the outer bar. In theory, surveys that encompass the entire littoral zone will account for nearly all sediment moving into or out of the system.

The landward littoral boundary is also imprecise. Where a stable, high foredune exists over time, it is reasonable to use the seaward face of the dune or the crest as a boundary. Where dunes are low and frequently overtopped, the landward limit of sand movement may be inland. Washover deposits define the landward limit. However, it is generally recognized that once sediment is pushed by waves landward of the adjacent foredune, it is "lost" from the active littoral zone. While washovers can be large in some settings, they usually comprise only a small fraction of the littoral volume (RPI 1985).

Similar to the exposed portions of icebergs, the visible beach makes up a small part of the barrier island profile. Most of the sediment that forms the core of the barrier island is below the mid-tide mark. To the extent that the underwater profile maintains a large volume of sediment, the recreational beach and dune system will remain healthy.

4.0 EROSION ANALYSIS METHODOLOGY

Analyses of coastal erosion are primarily dependent on the quality and extent of historical data. Most erosion rate data are derived from historical maps, vertical aerial photographs, and nautical charts. CSE has found these useful for depicting trends and developing estimates of **linear** shoreline change rates, but unsuitable (or unreliable) for determining volumetric changes. Carefully surveyed profiles across the beach and inshore zone are generally considered much better measures of change because they depict a broader littoral zone (CERC 1984). By repeatedly surveying profiles along the same lines, it is possible to determine how much sediment is in the littoral zone compared to other beaches and to calculate volumetric changes between surveys. Some very recent surveys provide the equivalent of continuous profiles alongshore such that a three-dimensional picture of the littoral zone is obtained. However, such density of coverage is generally unavailable for more than one date at any site; therefore, they are of less use until comparative surveys become available.

CSE used two forms of data for the present erosion analysis:

1) **Historical shorelines** (Source: NYS 2001) – Coastal View v.1.2 – Digitized "shorelines" along Fire Island from 1830 to 1995. This is believed to be the most up-to-date interpretation of "shorelines" and is geo-referenced on planimetric maps. CSE established a reference baseline and selected representative points for purposes of measuring distances between the fixed baseline and a particular shoreline of interest.

2) **Surveyed littoral profiles** (Sources: USACE 1958, USACE (Strock) 1980, RPI 1985, NYS 2001) – The USACE (1958) established and surveyed widely spaced profiles out to ~30-ft depths along Fire Island and Westhampton Beach in 1933, 1940, and 1955. Profiles along Fire Island are numbered 20-36. Closest profiles to the county park are 33 at Old Inlet and 34 near Pattersquash Island. The Corps (1980) commissioned Strock & Associates to obtain a more closely spaced set of profiles in 1979. These profiles are S-022 through S-032 along eastern Fire Island, with S-026 located close to the park pavilion. RPI (1985) (CSE's predecessor company) merged the 1979 data and 1933-1955 data to develop a sediment budget for Montauk Point to Fire Island Inlet. New York State (in collaboration with the USACE) initiated a more frequent shoreline monitoring program in 1995. A new set of profile lines was defined (F-series along Fire Island and W-series along Westhampton Beach). The new lines were surveyed up to eight times between spring 1995 and spring 2001. Profiles F64 to F84 span the area from around Old Inlet to Moriches Inlet.

For purposes of the present study, CSE selected an 11.5-mile section of shoreline extending from Cupsogue (Westhampton Beach) to Old Inlet (Fig 7). The area chosen incorporates the western end of Westhampton Beach downdrift of the groin field, Moriches Inlet, the wilderness section of eastern Fire Island, the county park, and the Old Inlet area off Bellport. The majority of the study area extends updrift from the park under the assumption that this area constitutes the primary sand supply to the park. Five analysis reaches (0-4) were defined using available historical profiles as boundaries:

Reach 0 – Cupsogue – Westhampton Beach — A 9,850-ft reach between profile W6 (new Village of Westhampton Dunes) to profile F84 (west jetty of Moriches Inlet). This reach is downdrift of the groin field. The updrift portion of the reach was nourished in 1997 and 2001 as part of the court settlement between the Village of Westhampton Dunes and the federal government in response to excess sand trapping by the groins. The reach also encompasses the area of the 1980 breach channel east of the jetties and portions of the Moriches Inlet ebb-tidal delta.

Reach 1 – Moriches Inlet Bypass Zone — A 10,390-ft reach between profiles F84 and F79. This reach receives sand that "bypasses" across Moriches Inlet. It is directly influenced by the ebb-tidal delta and tends to receive sand episodically as shoals break free of the delta and migrate onto the beach; hence, the term "shoal bypassing" (Sexton and Hayes 1983, Gaudiano and Kana 2001).

Reach 2 – Pattersquash Washover Zone — A 14,215-ft reach in the National Seashore east of the park between profiles F79 and F74. In recent years, this area has lost much of its protective foredune. Washover fans nearly reach Moriches Bay, and near-breaches occurred during the storms of the early 1990s.

Reach 3 – Smith Point County Park — A 12,150-ft reach actually extending several thousand feet updrift and downdrift of the park facilities between profiles F74 and F70. The major facilities of the park are situated between F73 and F71. A federal memorial site for victims of TWA Flight 800 is established about 150 ft east of the pavilion.

Reach 4 – Old Inlet — A 13,885-ft reach between profiles F70 and F64. This reach in the National Seashore wilderness area encompasses sites of historic inlets off Bellport. During the December 1992 northeaster, the dune breached near profile F68, producing a small washover, the first significant breach in the area in the past century.

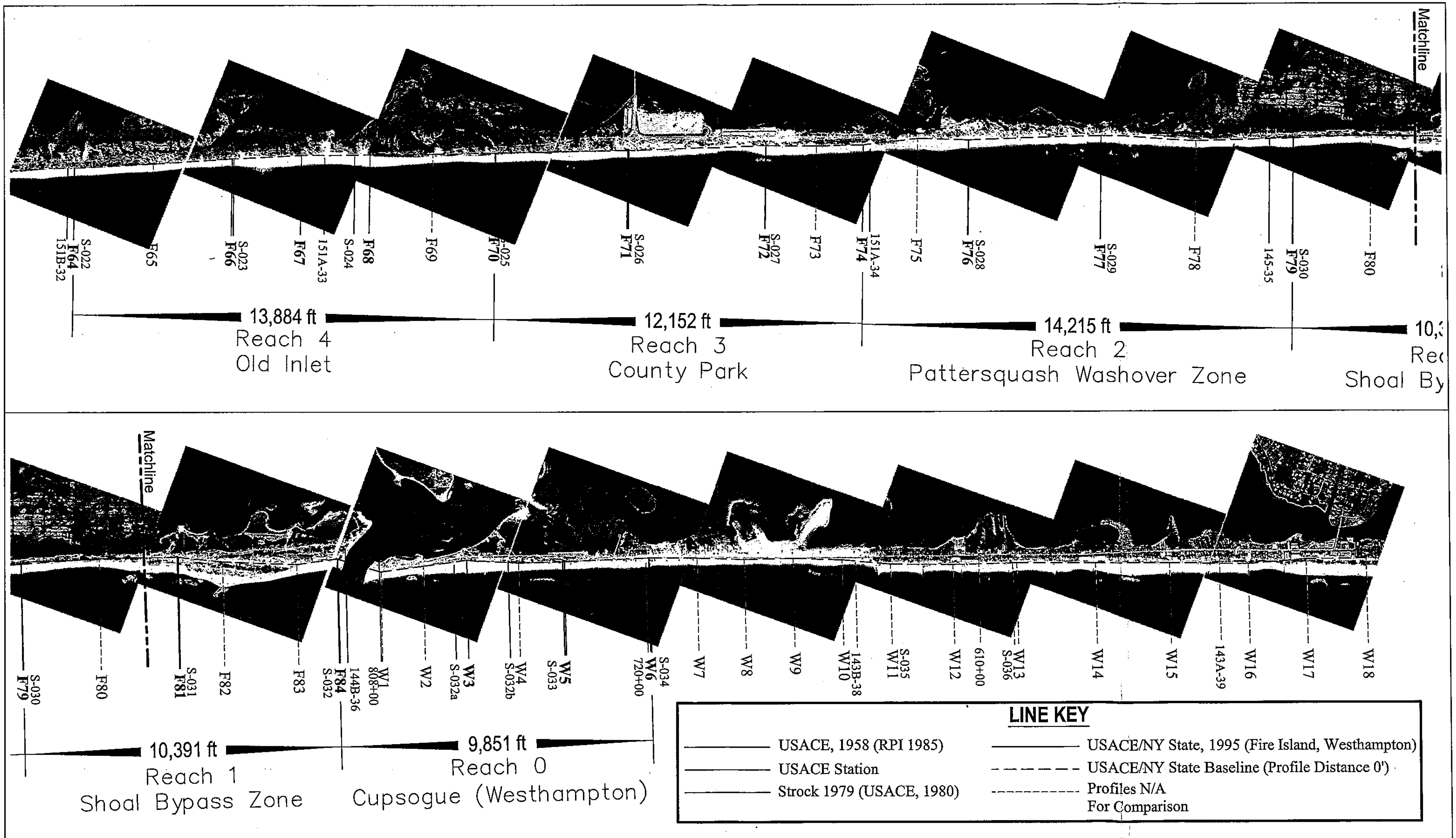


FIGURE 7. General location of available beach profiles and five reaches evaluated in the present study. Base map developed from data and photos in Coastal View (Version 1.2) (Atlantic Coast of New York Monitoring Program).

Each of the above-listed reaches contains several historic profile lines for which comparative data exist. CSE selected F-series and W-series profiles having nearby comparative data for 1979 and 1955. Raw profile data (post-1995) were downloaded from Coastal View 1.2 and converted to CSE's Beach Profile Analysis System (BPAS) format to create unique data sets for each line. Historical data sets from 1933 to 1979 were merged with the post-1995 data by juxtaposition following standard practice. To facilitate the juxtaposition, CSE prepared a base map in AutoCAD™ format and downloaded a set of spring 1995 rectified aerial images onto the state plane grid (NAD'83 coordinates) for general reference (Fig 7). Published profile coordinates were converted to NAD'83 and highlighted on the map. The relationship between historical control monuments for early profiles and recent profiles was determined on the base map. Historical profiles were then shifted to the recent profile lines, and their cross-shore distances were corrected to match the orientation of recent data. This standard technique is performed by making the profile shift **parallel** to the littoral contours. While not precise, this is the only method which allows direct comparison of recent profiles from one point with historical profiles originating from a nearby point.

The profiles selected for analysis are given in Appendix I. Appendix I-A lists the profile coordinates; Appendix I-B shows the general locations of available profiles; Appendix I-C shows the geographic relationship between adjacent historical and recent profiles and the applicable offset distances (cross-shore and alongshore); Appendix I-D contains F-series and W-series profiles for representative survey dates. Table 2 shows the dates and surveys, indicating which stations have coverage to ~30-ft depths (ie, long) or just to low-tide wading depth (ie, short). For the present study, CSE favored data encompassing the entire littoral zone to the estimated depth of closure. As Table 2 indicates, the most comprehensive data sets were obtained in June 1955, December 1979, April 1995, and April 1998. Other survey dates are missing lines or contain a mix of long and short profiles.

CSE's BPAS software facilitates file preparation, data plotting, data correction and quality control, calculations of distances to contours of interest, and calculation of profile geometry (widths and slopes between contours, distance to closure depth, etc). Profile cross-sections ("areas") between selected contours or beach features are computed and extrapolated over one unit shoreline length to yield "unit-width" volumes [typically measured in cubic yards per linear foot (cy/ft) of beach]. Changes in "area" of a profile between selected survey dates yield a volumetric measure of erosion. Appendix II (CD-ROM) contains profile data and output files used in the analysis.

TABLE 2. Profile coverage for the present study area. L = long ranges to approximately −30 ft NGVD (unless otherwise indicated). S = short ranges to approximate mean low water (MLW). *Dates with most comprehensive coverage [S = spring (~ April) | F = fall (~ November)]. **Except 1955.

PROFILE (quality of closure)	SURVEY DATE Quality of Juxtaposition: (E) = excellent | (G) = good | (F) = fair | (P) = poor														
	1933	1940	1955*	1967	1979*	S-1995*	F-1995	S-1996	F-1996	S-1997	F-1997	S-1998*	F-1998	S-2000	S-2001
F64 (P)	L (E)	L (E)	L (E)	—	L (E)	ND	S	S	S	S		L			S
66 (E)					L (E)	L	L	L	L	L		L	L		S
67 (G)	L (P)	L (P)	L (P)		L (P)	—	S	S	S	S		L			S
68 (F)			L (P)		L (F)	L	S	S	S	S		L			S
70 (E)					L (E)	L	L	L	L	L		L	L		S
71 (G)					L (E)	L	S	S	S	S		L			S
72 (G)**			L (P)		L (E)	L	L	L	L	L		L	L		L
74 (F)	L (F)	L (F)	L (F)		L (P)		S	S	S	L		L			S
76 (P)			L (F)		L (E)	L	S	S	S	L		L			S
77 (E)					L (E)	L	L	L	L	L		L	L		L
79 (F)	L (P)	L (F)	L (F)		L (E)	L	L	L	L	L		L	L		L
81 (E)					L (E)	L	L	L	L	L		L	L		L
84 (P)	L (F)	L (F)	L (F)		L (E)	L	L	S	L	L		L	L (-18)		L
W3 (P)			L	L	L (F)	M (-11)	S	S	S	S		L		L	L
5 (P)					L (E)	L	L	L	L	L			L	L	L
6 (P)**			L		L (E)		S	L	L	L			L		L

For the present study, CSE divided the profiles into volume "lenses" of particular interest (Fig 8). While the division is arbitrary, CSE has found certain divisions across the beach to be useful for evaluating and interpreting the causes of erosion. Based on previous experience at Fire Island, CSE selected the following lenses/boundaries for analysis:

Lens 1 – Foredune/dry beach — Extends from the NY State (1995) baseline along the crest of the foredune to the +2.5-ft NGVD contour (near approximate mean high tide). This is the visible part of the beach of most concern for recreation and storm protection.

Lens 2 – Wet beach — Extends between the +2.5-ft and the −2.5-ft NGVD contours. This is the primary zone of wave breaking each day between low water and high water. Its slope is an indicator of whether the beach has recently eroded or accreted.

Lens 3 – Inshore/bar — Extends from −2.5-ft to −18-ft NGVD contours. The lower depth was selected based on the maximum depth of the trough between the longshore bar and the beach. Most of the profile movement occurs above this contour from the bar to the shore.

Lens 4 – Offshore — Extends from −18-ft to −27-ft NGVD contours. For the present study, CSE assumes −27 ft as the closure depth based on previous studies and examination of recent profiles. This is also consistent with USACE (1999). This implies that Lens 4 captures the remainder of sand volume changes in the time periods of interest and that negligible profile change has occurred seaward of −27 ft.

The utility of profile volume analysis will be seen in the next section. FEMA (Dewberry and Davis 1989) uses profile volumes above storm-surge elevations as a means of assessing poststorm emergency protection (Fig 9). Kana and KrishnaMohan (1994) evaluated barrier island volumes as a way of estimating the likelihood of breaches through Fire Island (cf, Figs 3-5).

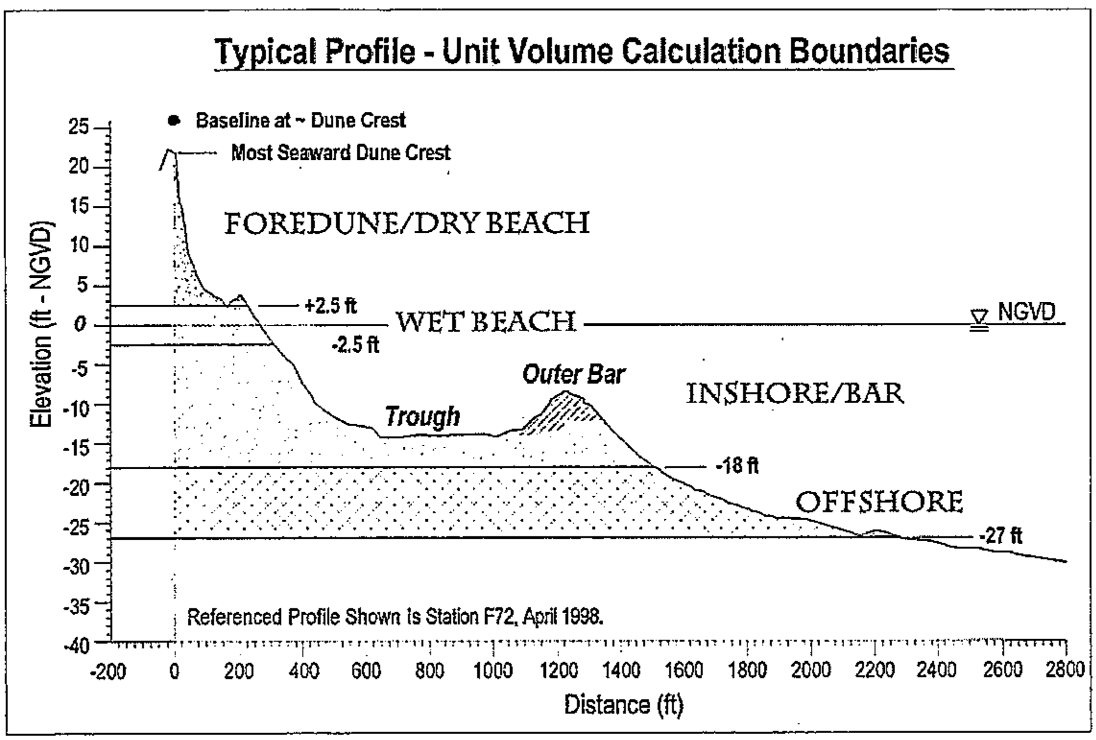
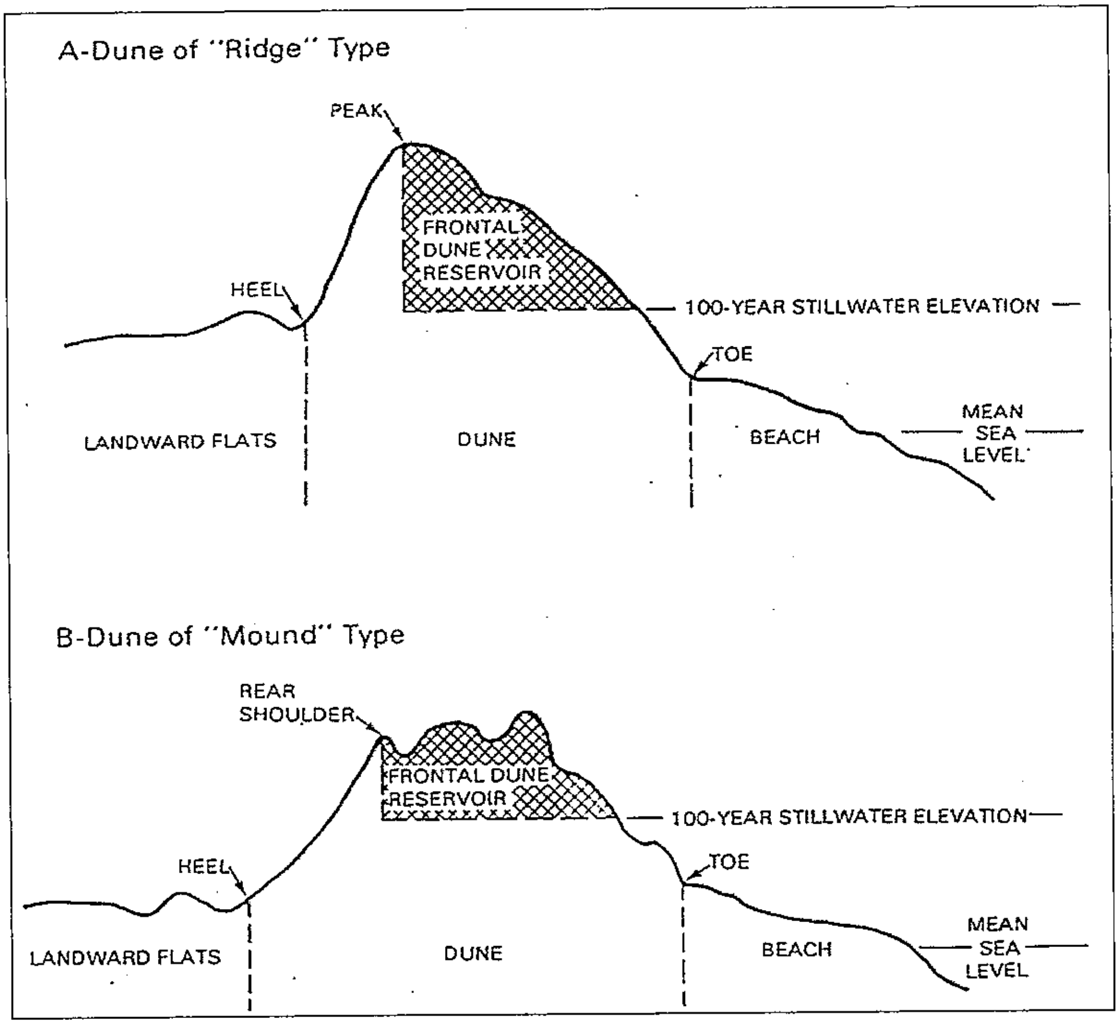


FIGURE 8. Schematic profile showing the calculation boundaries for four "lenses" representing key portions of the littoral zone. The lens limits are based on site-specific morphology and experience with previous erosion surveys.



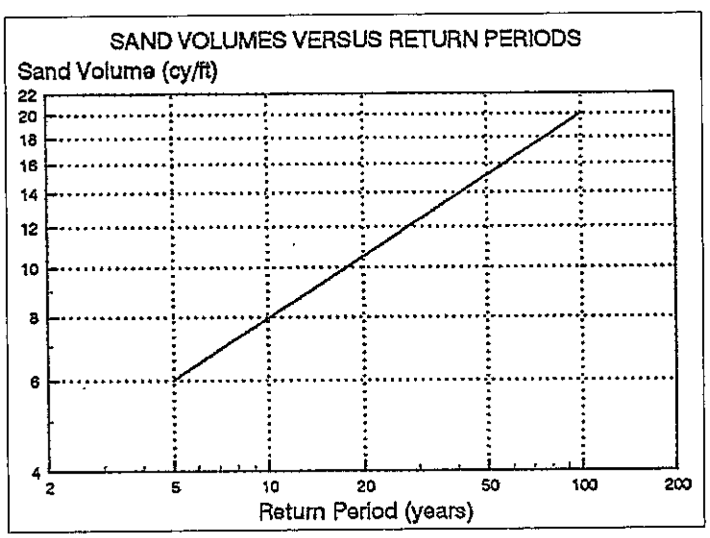


FIGURE 9.

[UPPER] Frontal dune reservoirs considered by FEMA in flood insurance study erosion assessments.

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

5.0 EROSION ANALYSIS

5.1 LINEAR SHORELINE CHANGE TRENDS

CSE calculated linear shoreline changes for various periods between 1830 and 1995 using digital shorelines available from the Atlantic Coast of New York Monitoring Program (NYS 2001). The distance from an arbitrary baseline to the digitized shoreline was determined electronically (using AutoCAD™) at six representative stations (F70 to F79). The available dates for comparison are 1830, 1870, 1933, 1938 (poststorm), 1962 (poststorm), 1979, 1983, 1988, and 1995. The results are shown in Table 3 and Figure 10.

The general trend for all stations is recession averaging ~1.9 ft/yr between 1830 and 1995. The highest "decadal" rate is ~10 ft/yr between 1938 and 1962, the period marked by the 1938 hurricane of record and the March 1962 storm. Before 1938 and after 1962, the average annual rates were consistently around −0.6 ft/yr according to the New York State data.

The specific rates near the park pavilion (F71) were −0.2 ft/yr (1830-1938), −7.9 ft/yr (1938-1962), and −0.4 ft/yr (1962-1995). The early rate reflects conditions when Moriches Inlet was closed for most of the period. The latest rate reflects a period when the inlet was open and stabilized, as well as a period when beach nourishment was performed. The middle rate encompassing the two great storms was also a period when nourishment was added to the beach. Kana (1995) reports a total of ~405,000 cy placed along the county park between 1955 and 1960. About 400,000 cy were added between 1960 and 1974. These beach fills had the effect of lowering the observed rate of shoreline change during the later two periods. However, it is not possible to determine the magnitude of the effect from movement of one contour.

Station F79 (boundary between Reach 1 and Reach 2) shows the highest rate of change overall (−3.6 ft/yr for 1830-1995) and the highest rate since 1979 (−1.6 ft/yr). This station is situated in the washover area where picking "shorelines" off vertical aerial photography is problematic. As New York State officials advise, the digitized shoreline data in Coastal View v.1.2 may have errors. However, as a first-cut approximation, they are useful for illustrating trends.

Assuming what was digitized in NYS (2001) represents the upper limit of wave action (typical base of foredune) or the seaward edge of vegetation (near crest of dune), the results suggest:

- Long-term shoreline recession rates for the area are low (<2 ft/yr).
- Two major storms, particularly the March 1962 northeaster, account for most of the shoreline recession.
- The rate of change since 1962 has averaged <1 ft/yr.

Table 3. Trends in linear shoreline change with respect to an arbitrary baseline parallel to the beach based on analysis of "shorelines" digitized by New York State as part of the Atlantic Coast of New York Monitoring Program (SAIC 2001). Rates for key time periods are highlighted.

Distance From Baseline (feet)									
Station	**1830**	**1870**	**1933**	**1938**	**1962**	**1979**	**1983**	**1988**	**1995**
F70	*606*	*456*	*526*	*551*	*316*	*371*	*270*	*304*	*383*
F71	*524*	*457*	*545*	*502*	*312*	*337*	*394*	*289*	*324*
F72	*479*	*462*	*572*	*508*	*306*	*299*	*296*	*274*	*266*
F74	*396*	*557*	*507*	*384*	*310*	*312*	*298*	*271*	*229*
F77	*667*	*652*	*582*	*464*	*207*	*223*	*114*	*81*	*80*
F79	*822*	*737*	*703*	*676*	*289*	*362*	*360*	*270*	*336*
Mean	***582***	***554***	***572***	***514***	***290***	***317***	***289***	***248***	***270***

Average Annual Change (ft/year)									
Rates	1830	1870	1933	1938	1962	1979	1983	1988	1995
1830	N/A	-0.72	-0.10	**-0.63**	-2.21	-1.78	-1.92	-2.11	**-1.89**
1870		N/A	0.30	-0.58	-2.86	-2.17	-2.34	-2.59	-2.27
1933			N/A	**-11.67**	-9.74	-5.55	-5.68	-5.90	-4.88
1938				N/A	**-9.34**	-4.80	-5.01	-5.32	-4.29
1962					N/A	1.61	-0.06	-1.61	**-0.62**
1979						N/A	-7.17	-7.69	-2.98
1983							N/A	-8.10	-1.58
1988								N/A	3.07
1995									N/A

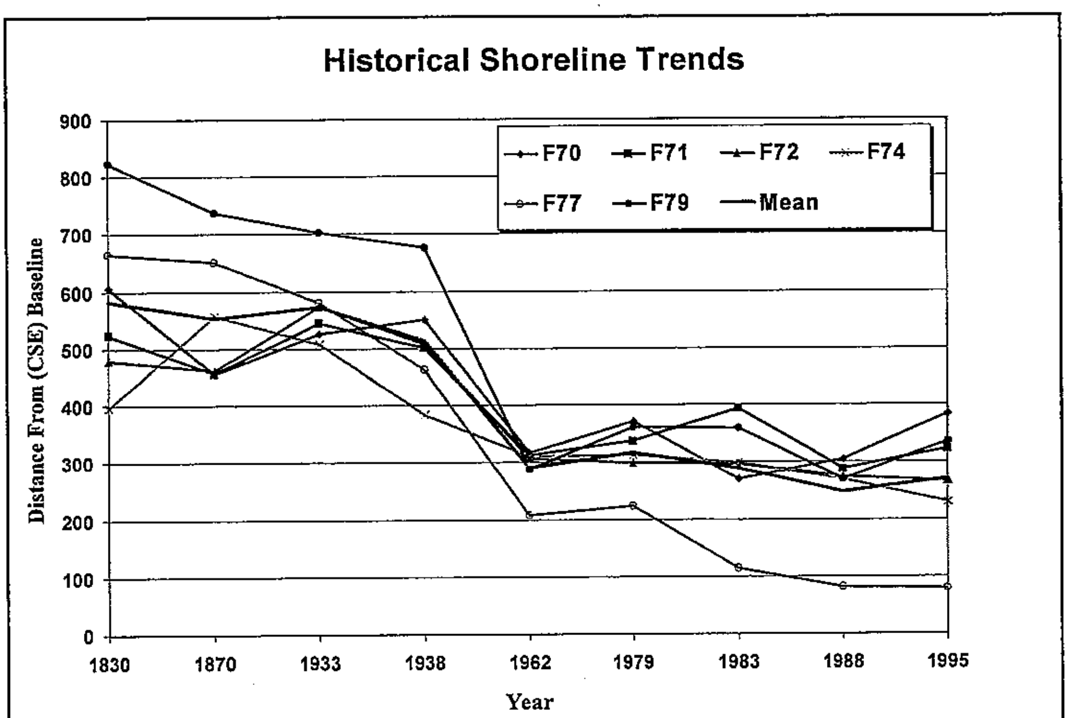


FIGURE 10. Trend in shoreline position based on the data in Table 3. Station F71 is situated close to the park pavilion. Station F77 is situated in the washover section east of Pattersquash Island.

The low rates during the past three decades possibly reflect the positive impact of nourishment as well as emergency dune scraping along the park (which tends to maintain a more constant line of vegetation along the dune).

5.2 VOLUMETRIC CHANGES

The profiles used in the present analysis are shown in Appendix I. These were analyzed two ways. First, unit volumes for each of four lenses (see Fig 8) were computed. Then volume changes by lens between selected dates were computed.

The first computation provides a measure of how much sediment volume exists at a station. By comparing these quantities among stations, it is possible to identify areas that have sand deficits relative to other sections of the beach. Also, by tracking unit volumes at a station, or along a reach over time, developing trends can be spotted, even if erosion along the visible beach is not apparent. In the following graphs, data are ordered from updrift (Reach 0) to downdrift (Reach 4) in conformance with the net sediment transport direction. Individual profiles, however, are numbered from west to east and are so listed in certain data tables.

Profile Volumes

Unit volume data by lens are given in Appendix III. The graphs of Figure 11 (a-e) show the results for individual stations along with the average for all 16 stations used in the analysis. The graphs include intermittent data because many profiles do not extend beyond low-tide wading depth. Each page of graphs shows results for the upper three lenses (dry beach, wet beach, and inshore), with the fourth graph of each set incorporating all four lenses. Results for individual stations and lenses tend to be highly variable. However, when all four lenses are combined, much of the variation is eliminated because the total volume in the profile tends to average out differences among discrete lenses.

It is useful to compare results for a particular station with the average for all 16 data sets (line labeled "all"). If an individual result falls below the average, it indicates there is less sediment (or a deficit) in that particular profile (cf, Fig 11d). If the unit volumes are consistently higher than the average, the station has more sediment (or a surplus) in the profile (cf, Fig 11c). Following are some trends illustrated by these graphs.

- Lenses 1 and 2 (foredune/dry beach and wet beach) each typically contain 50-80 cy/ft seaward of the baseline (foredune crest).

- Lens 3 (inshore/bar) contains around 500 cy/ft.

- Lenses 1-4 combined contain around 1,250 cy/ft.

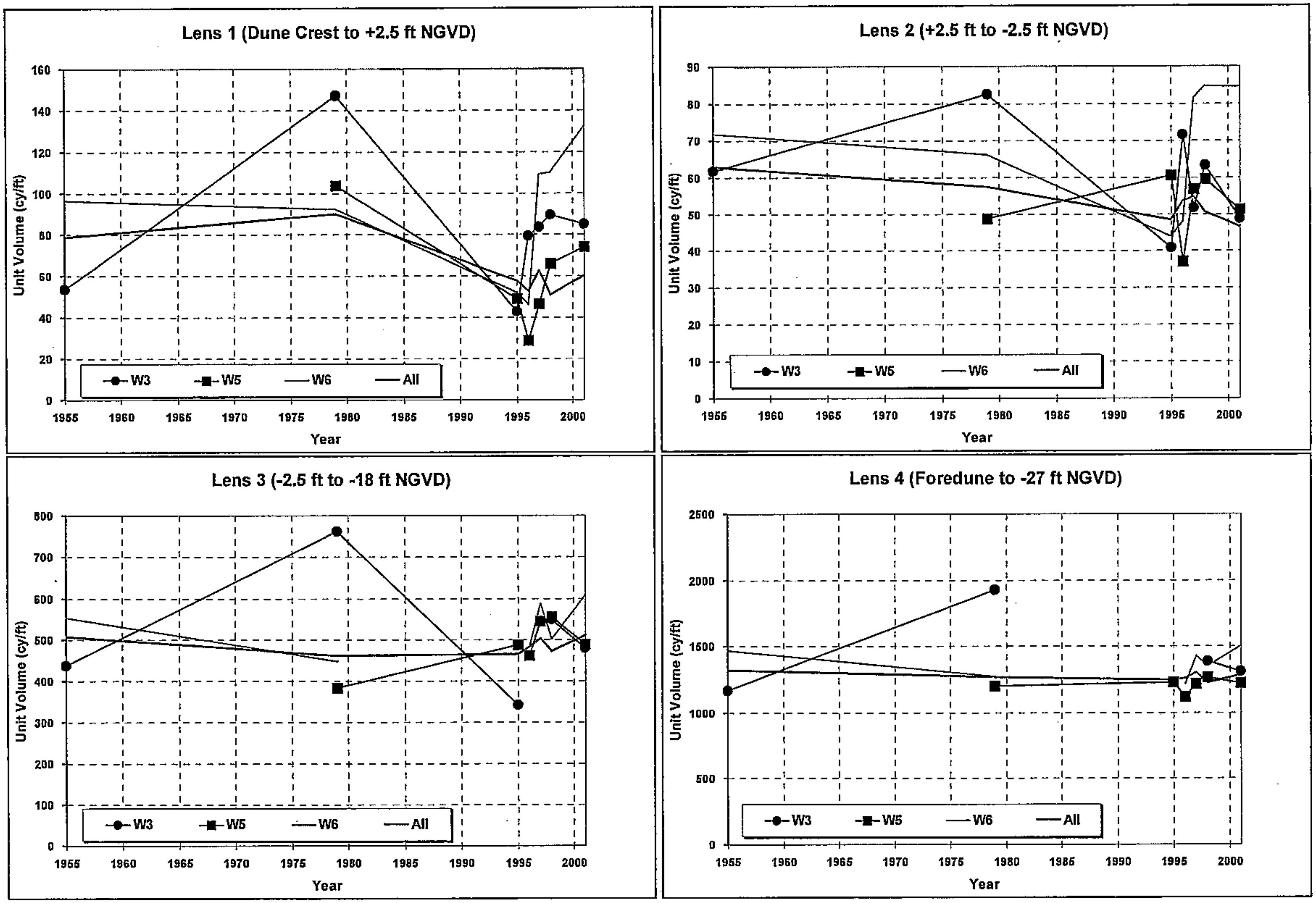


Figure 11a. Unit-width volumes by lens for representative profiles in ***Reach 0 – Cupsogue Beach***. See Figure 8 for definition of computation boundaries. "All" is the average result for all 16 stations used in the present analysis.

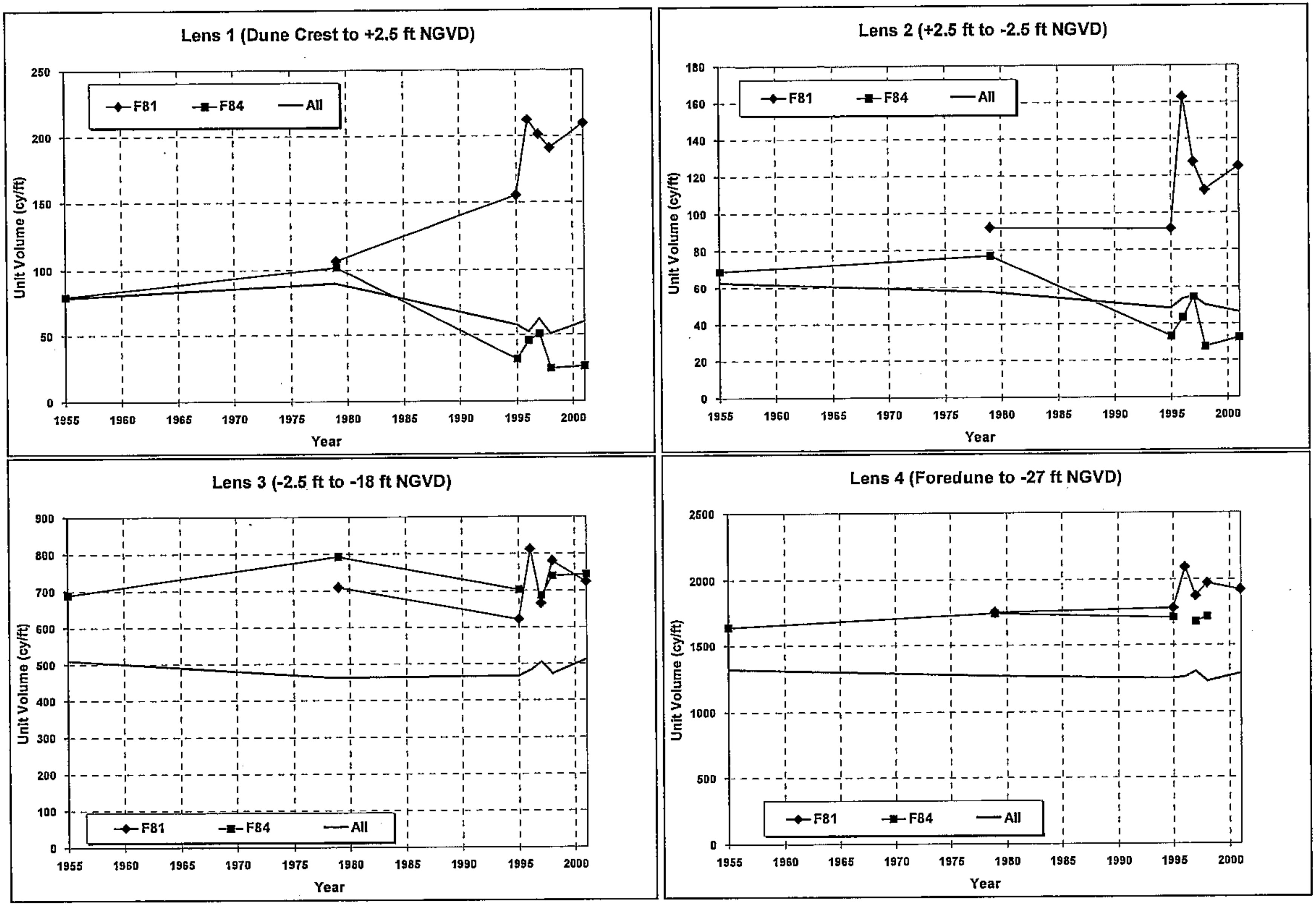


Figure 11b. Unit-width volumes by lens for representative profiles in ***Reach 1 – Moriches Inlet bypass zone.*** See Figure 8 for definition of computation boundaries. "All" is the average result for all 16 stations used in the present analysis.

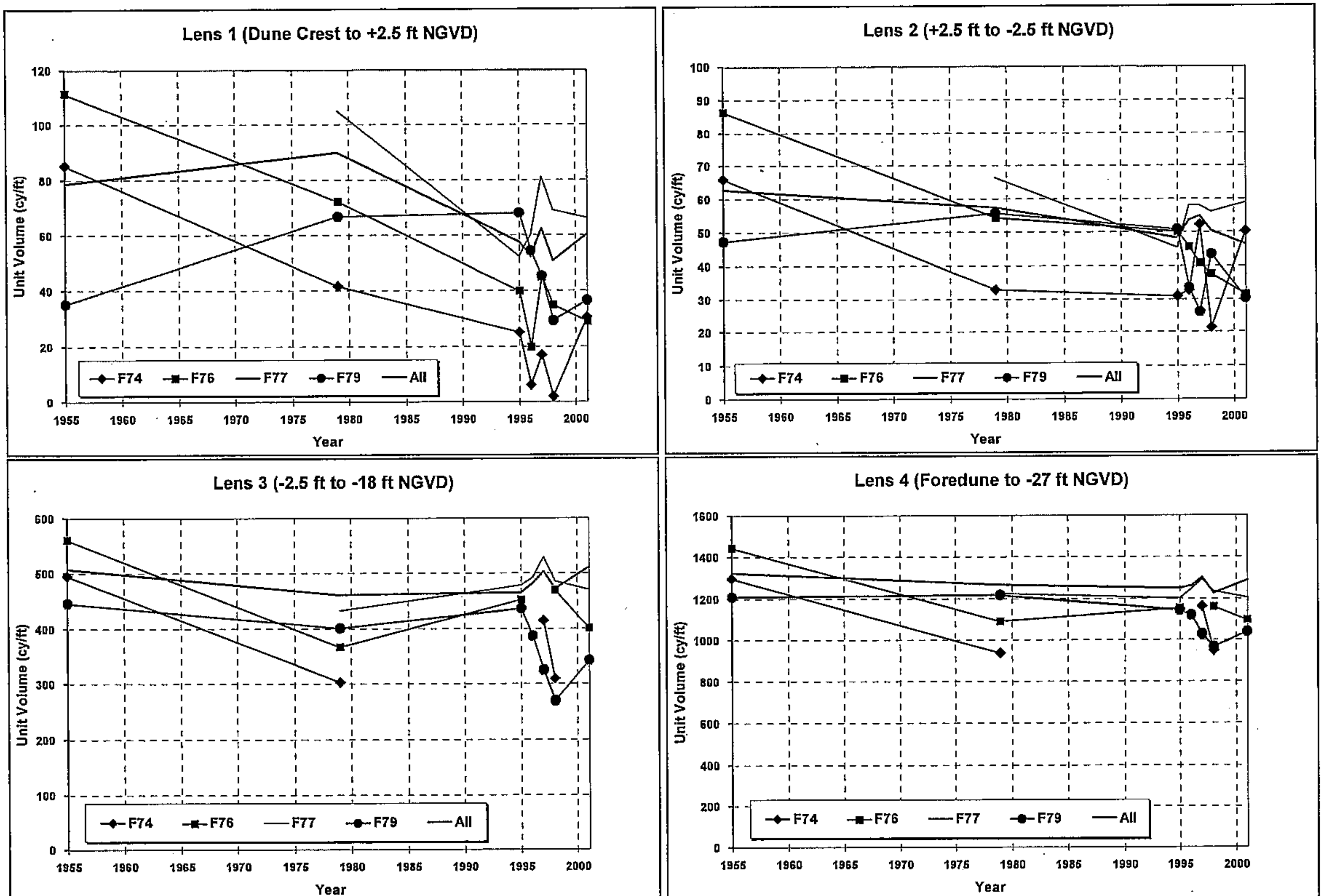


Figure 11c. Unit-width volumes by lens for representative profiles in ***Reach 2 – Pattersquash washover zone***. See Figure 8 for definition of computation boundaries. "All" is the average result for all 16 stations used in the present analysis.

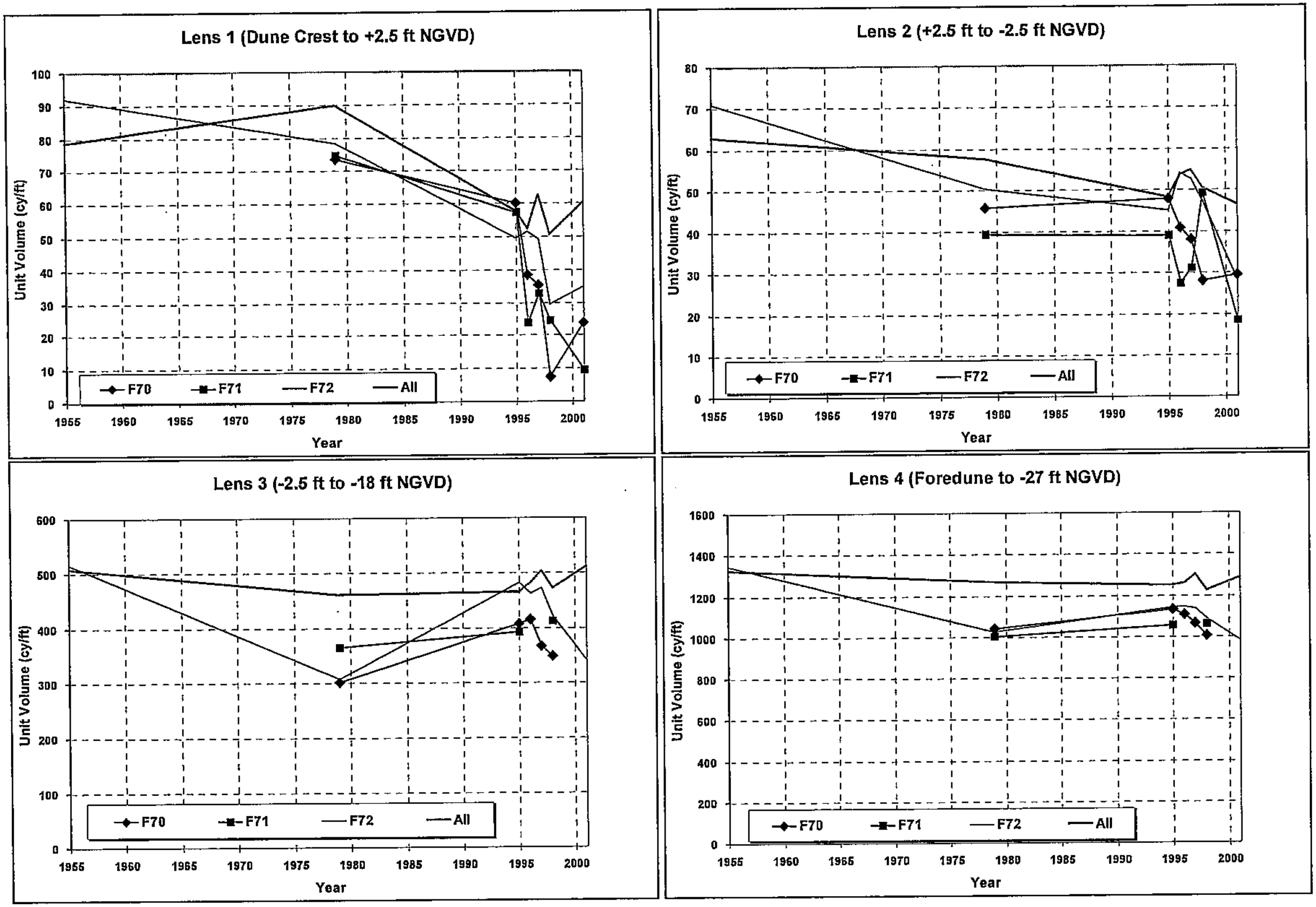


Figure 11d. Unit-width volumes by lens for representative profiles in ***Reach 3 – Smith Point County Park.*** See Figure 8 for definition of computation boundaries. "All" is the average result for all 16 stations used in the present analysis.

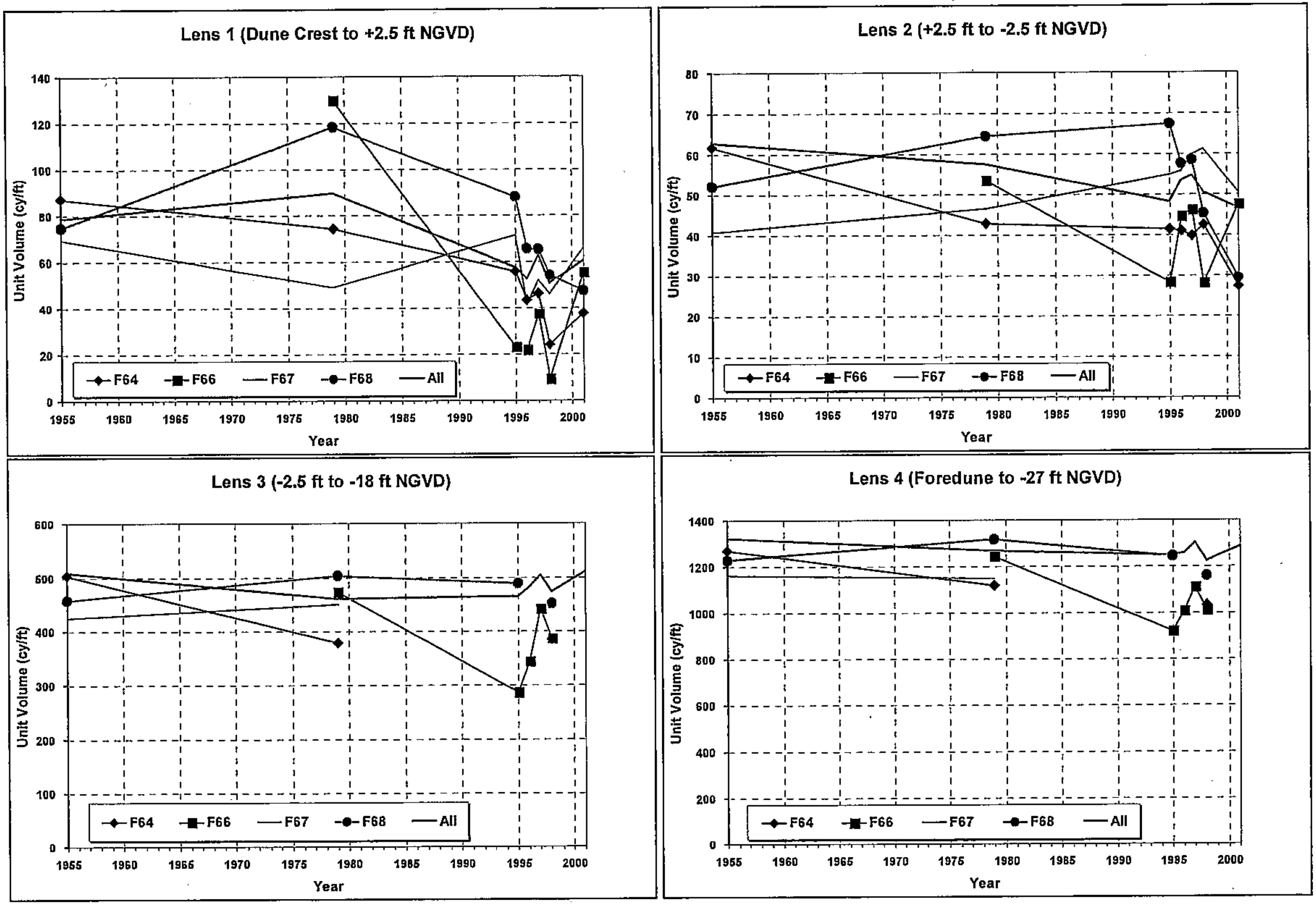


Figure 11e. Unit-width volumes by lens for representative profiles in ***Reach 4 – Old Inlet***. See Figure 8 for definition of computation boundaries. "All" is the average result for all 16 stations used in the present analysis.

- Reach 0 (Fig 11a) shows a decline in Lenses 1 and 2 (dune to low water) between 1979 and 1995. Then volumes rise suddenly, reflecting the impact of nourishment along Westhampton Dunes in 1997.

- Reach 1 has much higher volumes than average, reflecting the accumulation of sand in the inlet bypass zone downdrift of Moriches Inlet.

- Reach 2 has consistently lower volumes than average with marked declines in the visible beach (Lens 1) seaward of the baseline.

- Reach 3 (**county park**) shows a precipitous drop in volumes for Lens 1 and Lens 2 after 1995.

- Reach 4 shows a precipitous drop in volume at station F66 after 1980 followed by a partial recovery over the past six years.

Figure 12(a-c) averages the lens results by reach. (Averages include the boundary profile in adjacent compartments.) These graphs are easier to track because some of the variability of individual profiles is eliminated. Trends shown by these graphs include the following:

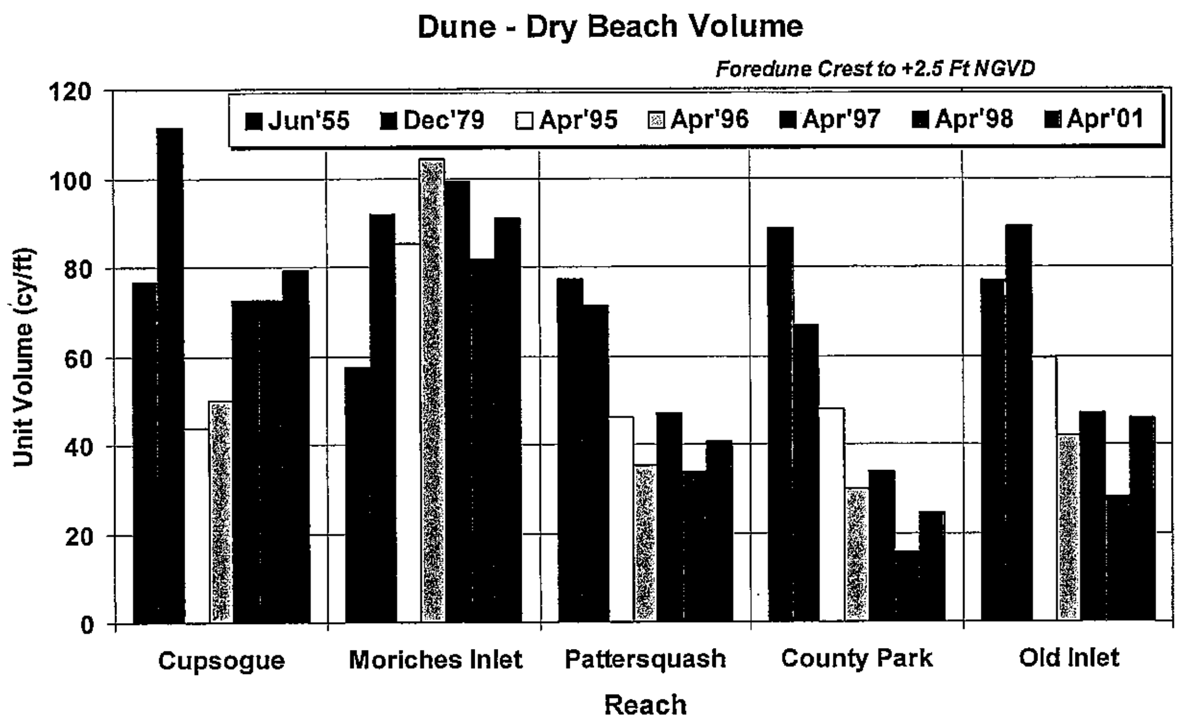
- Substantial decline in profile volumes along the county park reach in Lenses 1, 2, and 3. The drop is particularly large for the dune-dry beach lens (Fig 12a, upper). A similar, but smaller decline also occurred along the Pattersquash reach.

- The Moriches Inlet bypass zone has gained sand since 1955 and now has the "healthiest" profile volumes in the study area.

- The Cupsogue reach experienced a dramatic loss of volume in Lenses 1 and 2 between 1979 and 1995. Since then, the reach has regained volume (via nourishment) and is close to its condition of 1955.

- Lens 4 (−18 ft to −27 ft NGVD, Fig 12b, lower) typically shows the least variation in profile volume. This suggests that the zone seaward of −18 ft accounts for relatively little profile volume change. (Note: A perfect data set in an area where profiles close **shallower** than −18 ft would show no variation for this lens. Small variations in the graph for Lens 4 also tend to reflect imprecision of surveys, particularly older data collected by less accurate methods.)

Of particular concern, **the data in Figure 12 indicate that the dry-beach volume in the park has declined to one-third of its 1979 volume.** This means much less area is available for recreation, and the degree of protection during storms is severely diminished.



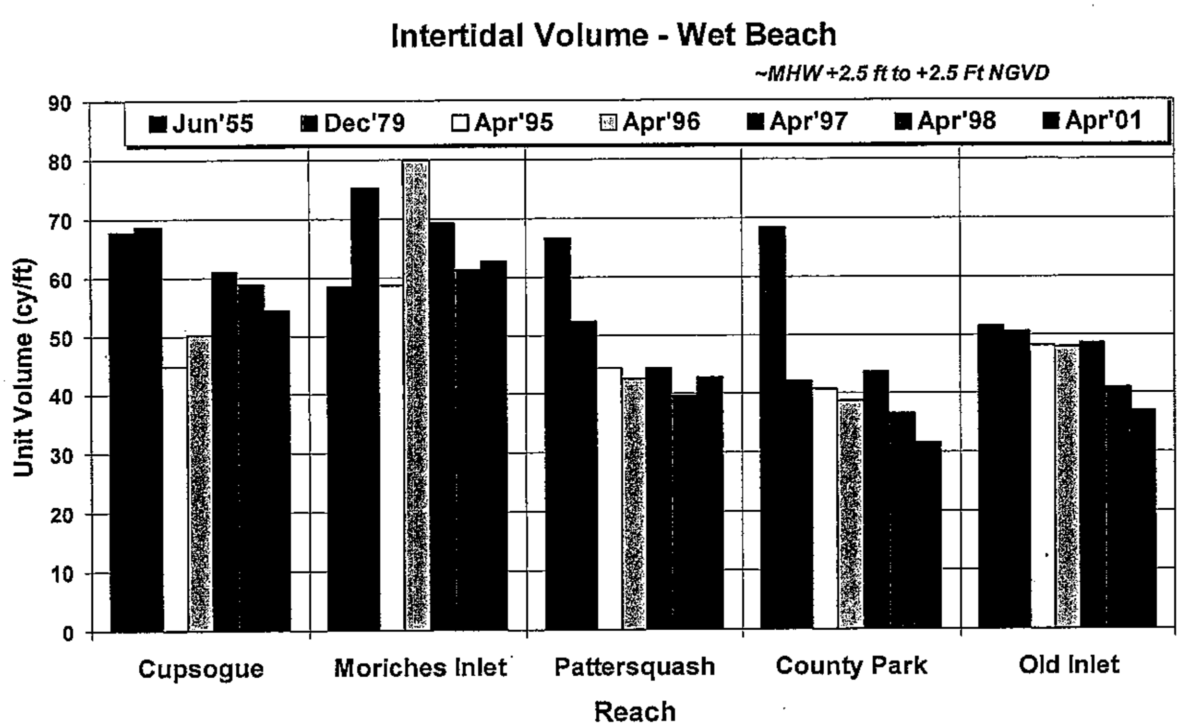
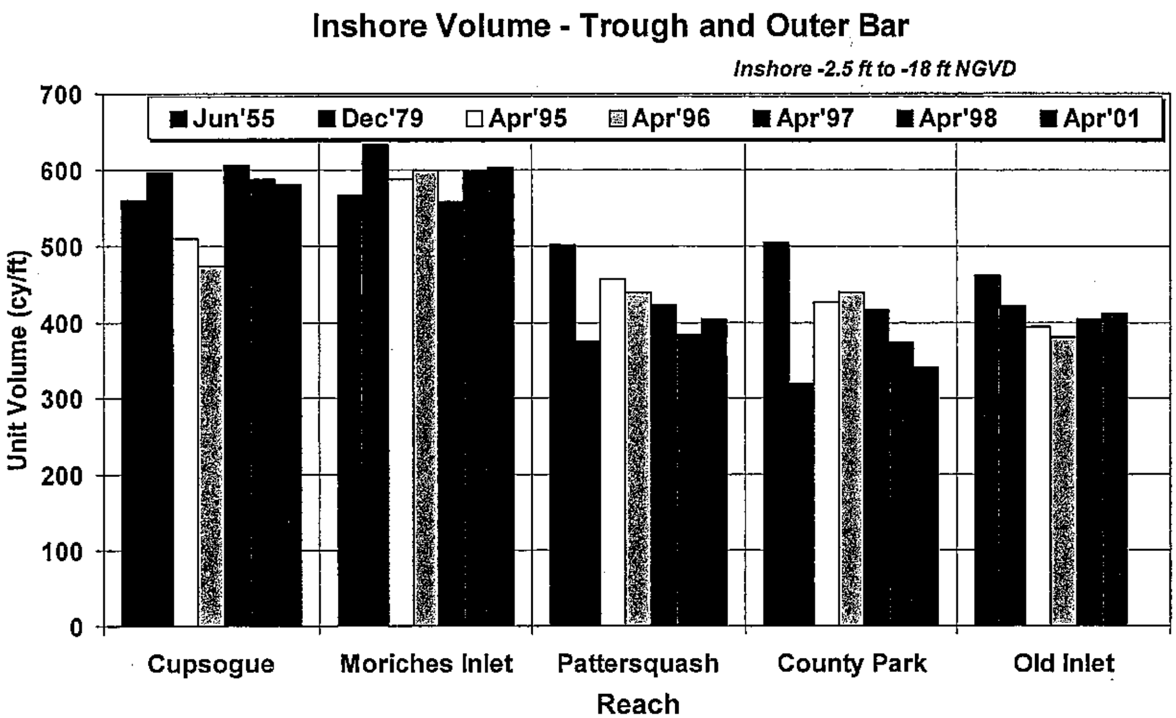


FIGURE 12a. Average profile volumes for Lens 1 (upper) and Lens 2 (lower) by reach and date based on the results for individual profiles (see Fig 11).



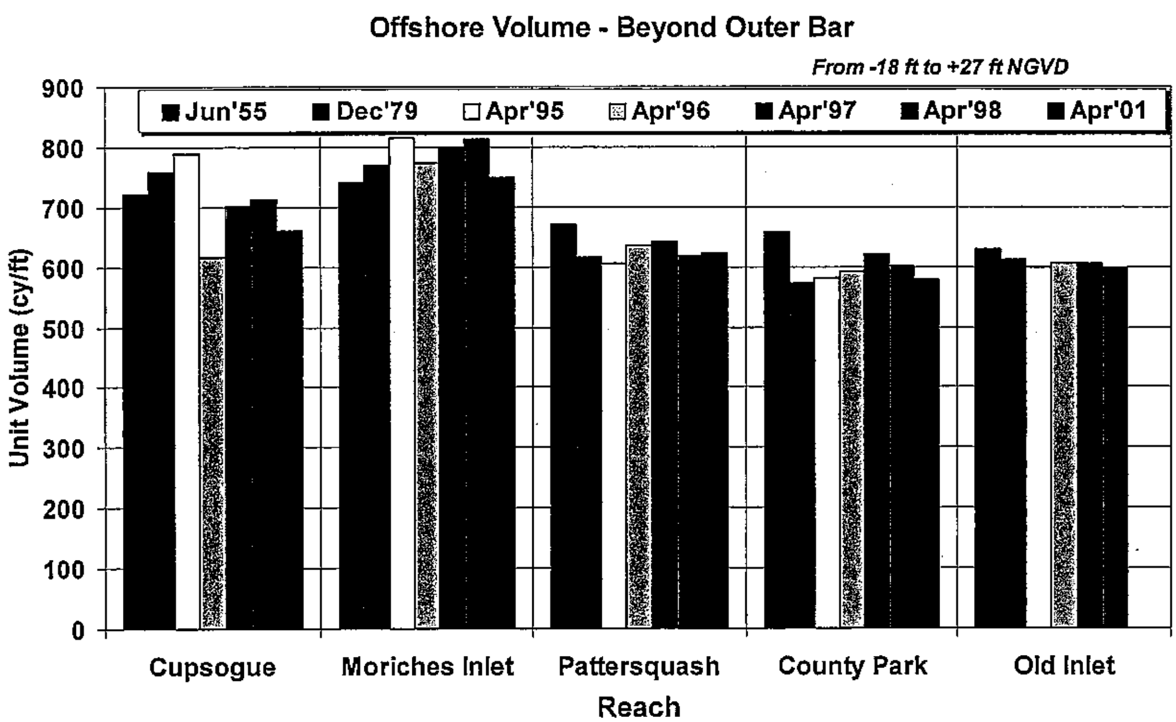


FIGURE 12b. Average profile volumes for Lens 3 (upper) and Lens 4 (lower) by reach and date based on the results for individual profiles (see Fig 11).

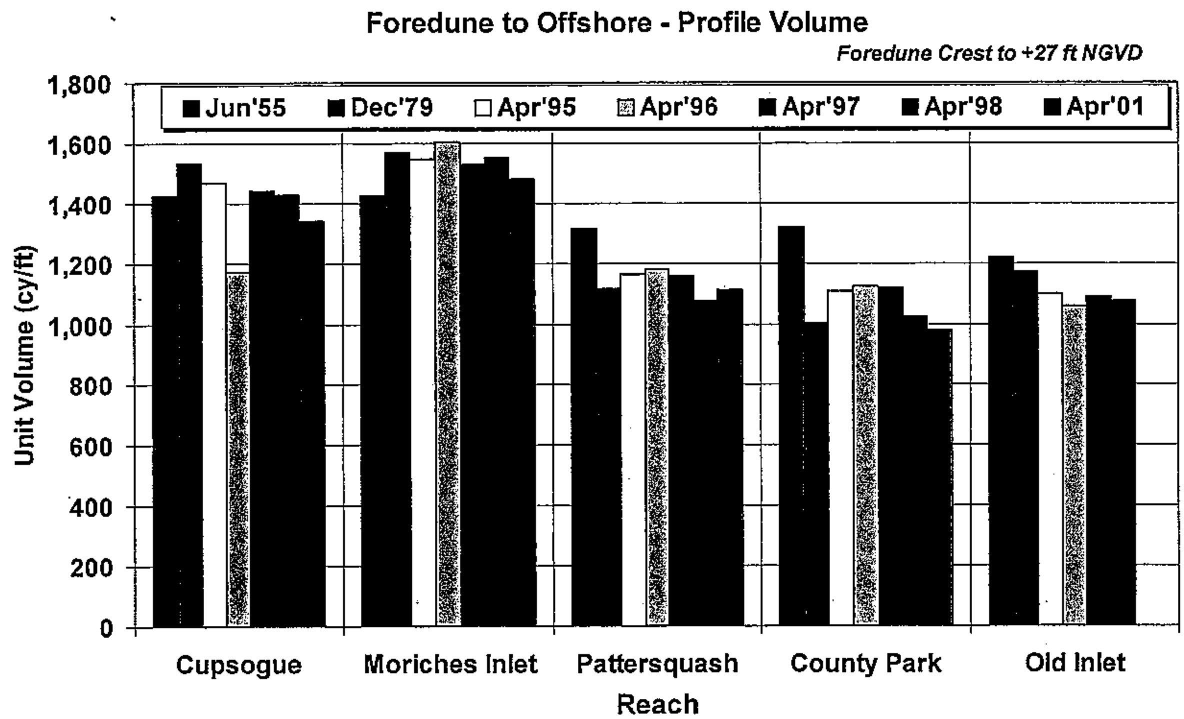


FIGURE 12c. Average profile volumes for all lenses combined by reach and date based on the results for individual profiles (see Fig 11).

The final unit-volume comparison is shown in Figures 13 and 14. These graphics combine the results for Lenses 1, 2, and 3 (foredune to −18 ft NGVD) and average them by reach for three primary survey dates: 1955, 1979, and 1998. The stacked graphs (Fig 13) show the dry beach volume in yellow, the wet beach volume in red, and the inshore volume in blue. The striking feature of these graphs is the dramatic decline in profile volumes west of Moriches Inlet between 1955 and 1979. Since then, there has been a lesser decline in total volumes for Reaches 2, 3, and 4, but a large drop in the volume of the visible beach (Lens 1). This latter decline was worst in the county park reach. In 1955, all five reaches had similar total volumes to −18 ft and relatively large volumes in the foredune/visible beach. By 1979, volumes in the Cupsogue and Moriches Inlet reaches increased by about 100 cy/ft, whereas volumes in the Pattersquash and county park reaches dropped by 150-200 cy/ft.

The county park's beach health is directly linked to the profile volumes beyond wading depth. Its future health is also dependent on the condition of the Pattersquash reach. Where sand deficits occur, there is a much higher probability of storm damage to the foredune and oceanfront facilities. If the updrift reach has a deficit, there is less sand available to feed the park's beach. Profile volumes since 1955 confirm both of these negative trends.

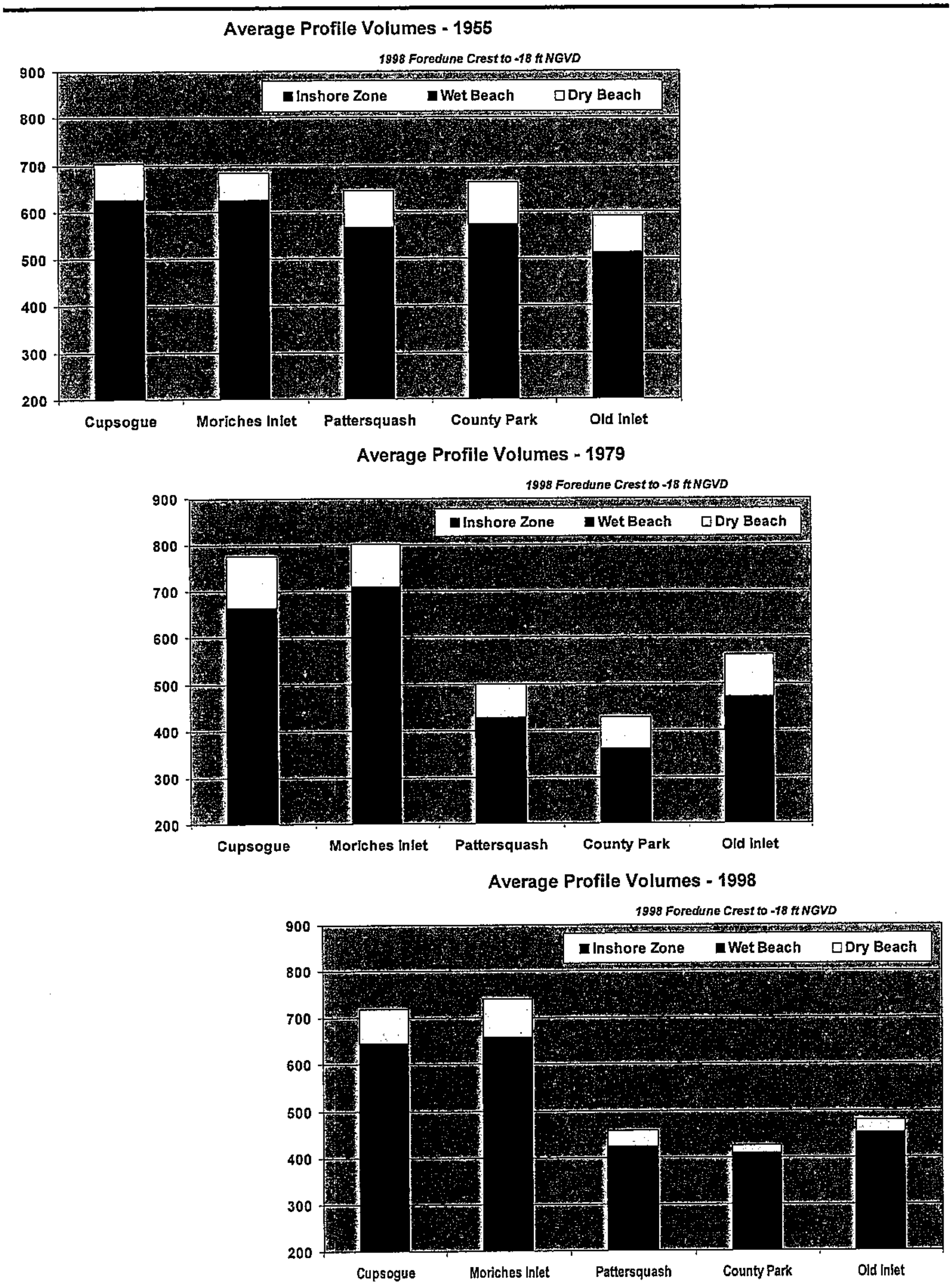
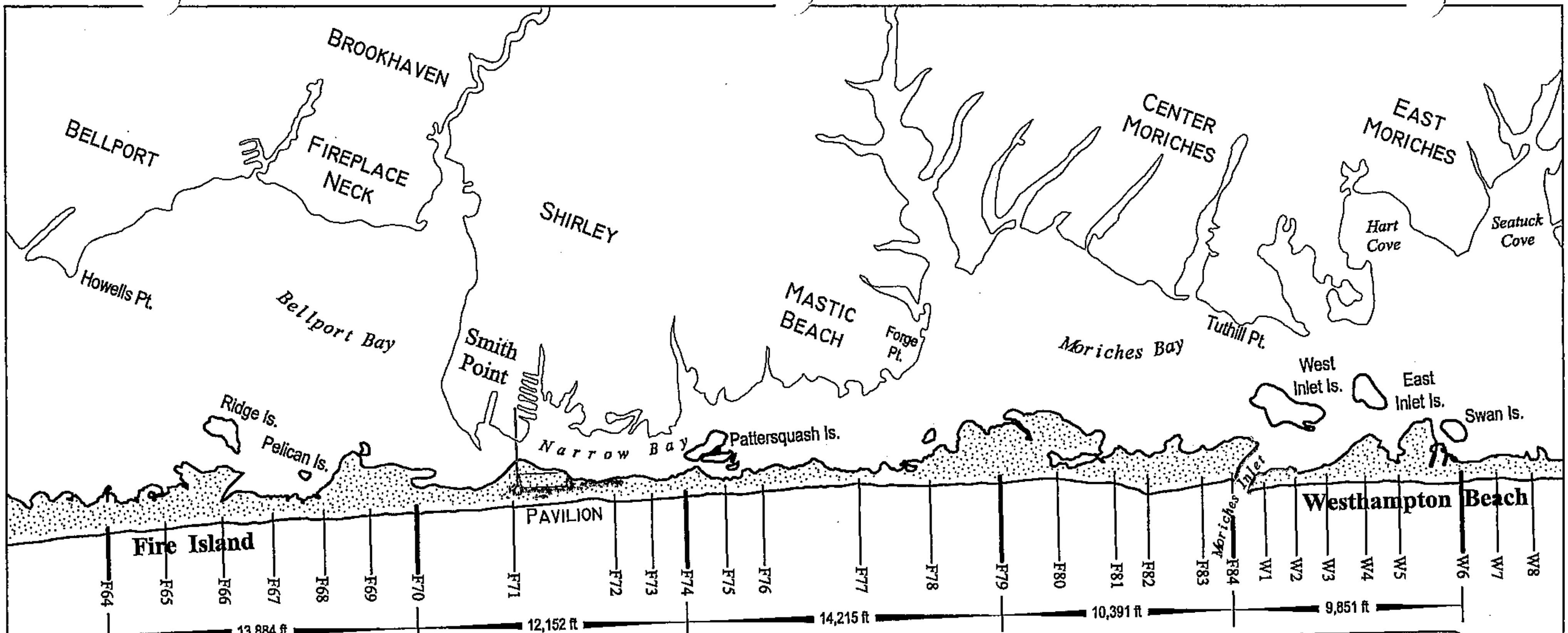


FIGURE 13. Profile volumes by reach for Lenses 1, 2, and 3 (foredune to −18 ft NGVD) combined in 1955 (upper), 1979 (middle), and 1998 (lower). Note the precipitous decline in total volume and dry beach volume along the Pattersquash and county park reaches.



	Reach 4 Old Inlet	Reach 3 County Park	Reach 2 Pattersquash Washover Zone	Reach 1 Moriches Inlet Bypass Zone	Reach 0 Cupsogue (Westhampton)
1955	591	663	645	684	704
1979	561	428	500	802	776
1998	481	425	457	740	718
Surplus/ Deficit *	-94	-150	-118	+165	+143

Atlantic Ocean

Unit Profile Volumes (cy/ft)

Foredune to -18ft NGVD

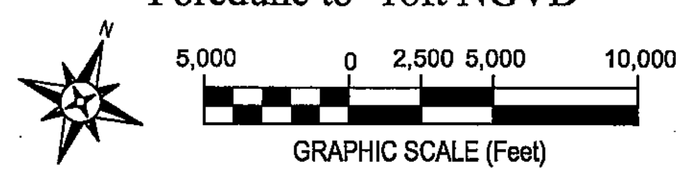


FIGURE 14. Average, unit profile volumes to – 18 ft NGVD by reach for three key dates. The deficit and surplus are based on a recommended minimum profile volume of 575 cy/ft. Profiles with a deficit have narrower beaches and are more likely to sustain damage to dunes and upland structures during storms.

* 1998 with respect to minimum target beach volume =575 cy/ft.

Based on examination of profiles in the study area, CSE believes profile volumes to −18 ft must be at least 575 cy/ft to provide for a healthy dry beach that can accommodate the normal range of profile changes from year to year. All reaches met this criteria (on average) in 1955. By 1979, however, Reach 2 and Reach 3 dropped significantly below this value.

Figure 14 shows the profile volumes (to −18 ft) by reach and year along with the average deficit or surplus volume with respect to the target value of 575 cy/ft. It is apparent that the surplus volumes in Cupsogue and Moriches Inlet reaches nearly equal the deficit volumes along the Pattersquash, county park, and Old Inlet reaches.

Volumetric Erosion Rates

The slopes of the graphs shown in Figure 11 provide a measure of the rate of erosion (or accretion). Similar to the linear shoreline change rates (see Fig 10), there is a high degree of variation in erosion rates, particularly over short time periods. For planning purposes, it is generally more useful to establish a range of "decadal" change rates, which are indicative of the "background" erosion volume. This provides a more realistic measure of how much sediment is lost over time.

Short-term erosion rates during storms can be many times greater than the long-term erosion rate. These larger scale, but temporary, changes provide a measure of how much volume is needed to accommodate storms without damage to oceanfront development.

Based on the available data, CSE selected two **20-year** periods (1955-1979 and 1979-1998) having the most comprehensive coverage and computed volumetric change rates for each period. Rates given in Appendix III are weighted averages by reach based on extrapolating the results of individual profiles over the applicable shoreline length between profiles using the average-end-area method. By this method, CSE calculated total volume changes by reach and lens, then unitized them to obtain a weighted average. The computed changes were annualized by dividing net rates by the applicable years in each period. Rates computed by this method will differ slightly from rates derived by comparing the unit volumes previously shown in Figures 11 and 12 because the latter are based on linear averages. Minor differences also accrue because of missing data from 1955. For example, there were no surveys at stations F70 and F71 (pavilion) in 1955. Therefore, the results for 1955-1979 are based on interpolation of profiles from stations F68 and F72.

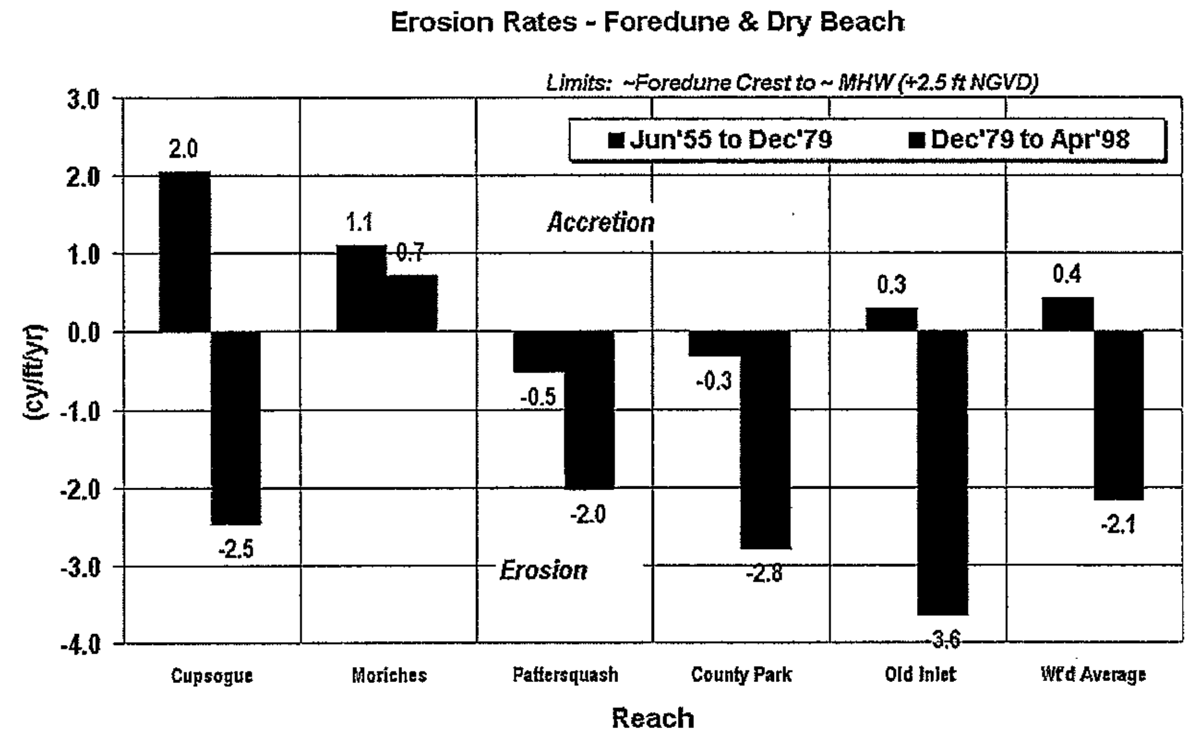
Figure 15 (a-c) shows the average annual erosion rates by reach, period, and lens. Rates are given in cubic yards per foot (cy/ft) with negative values indicating erosion and positive values indicating accretion. The following trends are indicated by the data.

- Along the dry beach (Lens 1), erosion rates generally increase from east to west, and the rates are much higher for the 1979 to 1998 period compared to 1955-1979.

- The change along the wet beach is relatively minor, indicating a general uniformity of that portion of the profile. (A value of zero means the wet beach is not becoming flatter or steeper over time.)

- Highly variable rates for Lenses 3 and 4 with alternating periods of erosion and accretion for most reaches. For example, erosion occurred along the county park in Lenses 3 and 4 between 1955 and 1979, whereas accretion has been the trend since 1979.

- The overall average annual change (foredune to −27 ft NGVD) was erosion of 1.4 cy/ft/yr for 1955-1979 and a loss of 2.6 cy/ft/yr for 1979-1998.



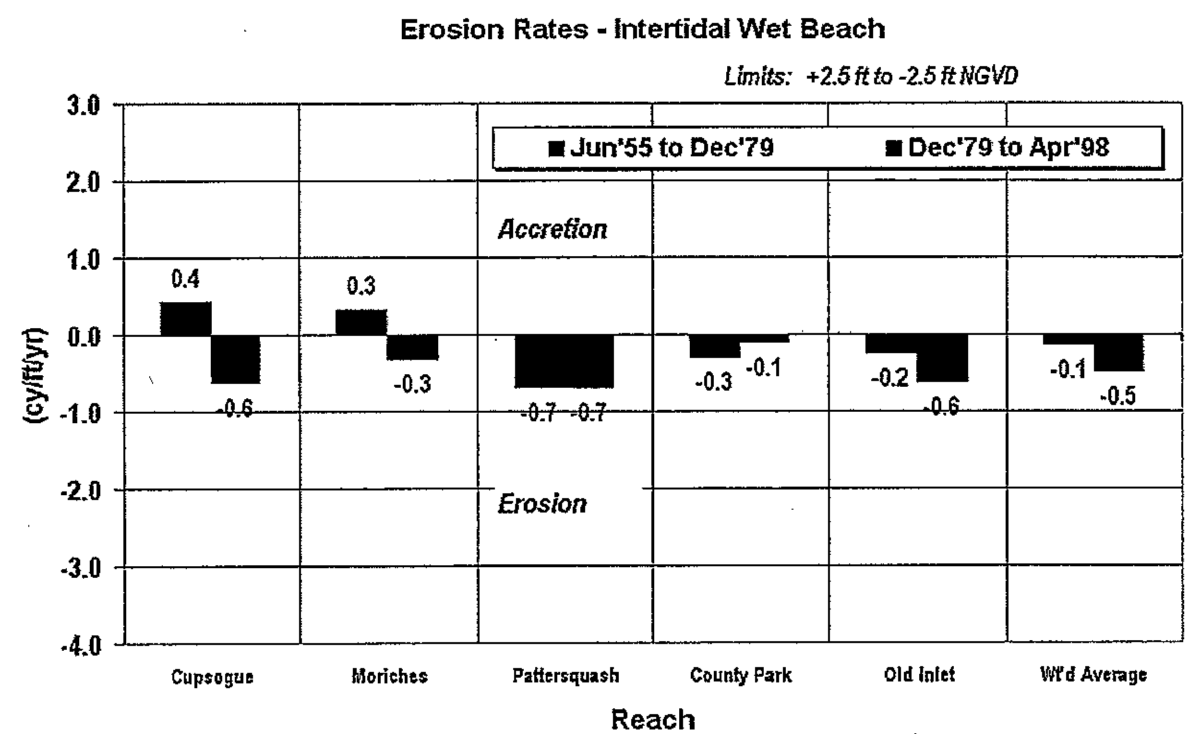


FIGURE 15a. Average annual volume changes by reach and lens for two primary time periods (1955 to 1979 and 1979 to 1998).

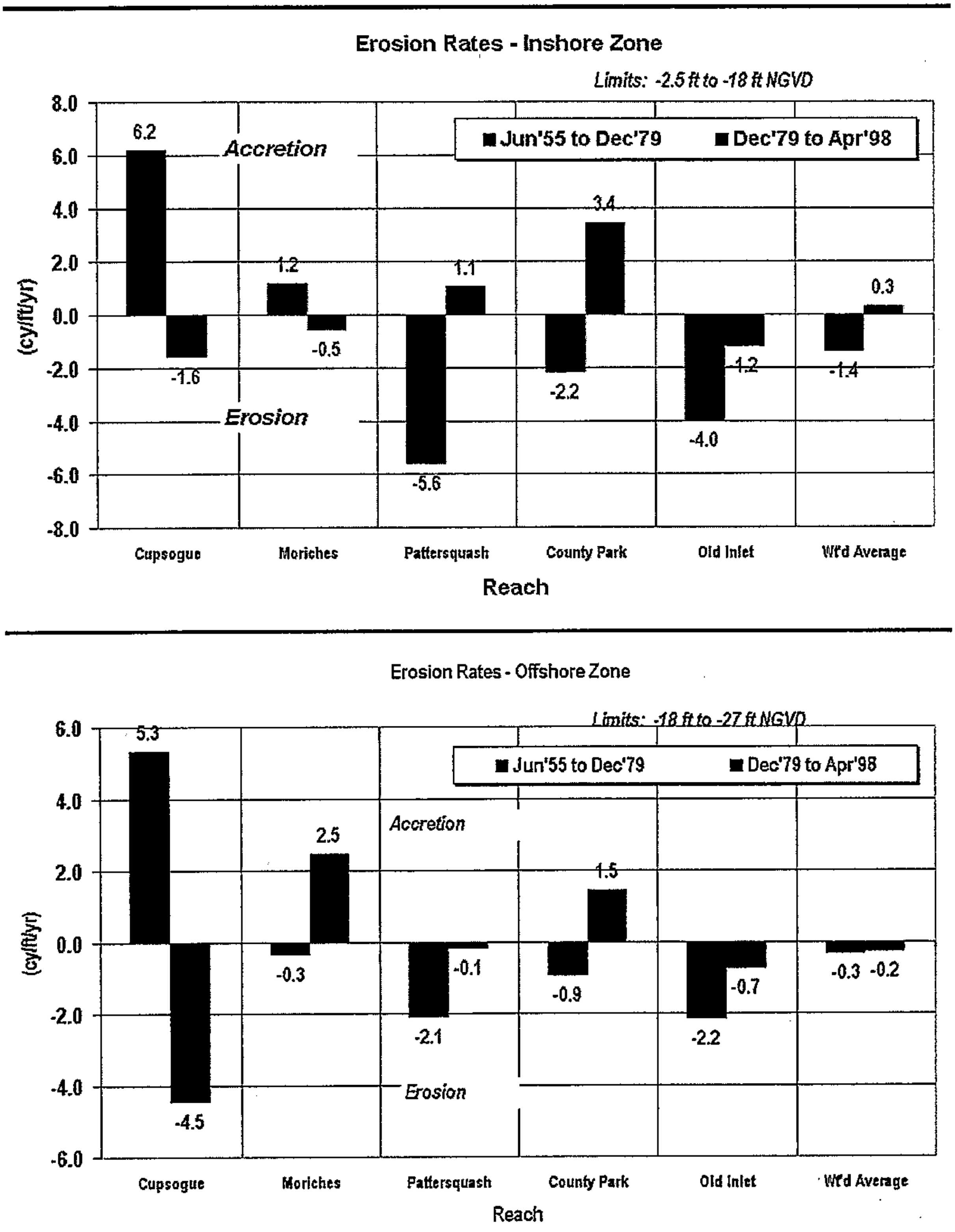


FIGURE 15b. Average annual volume changes by reach and lens for two primary time periods (1955 to 1979 and 1979 to 1998).

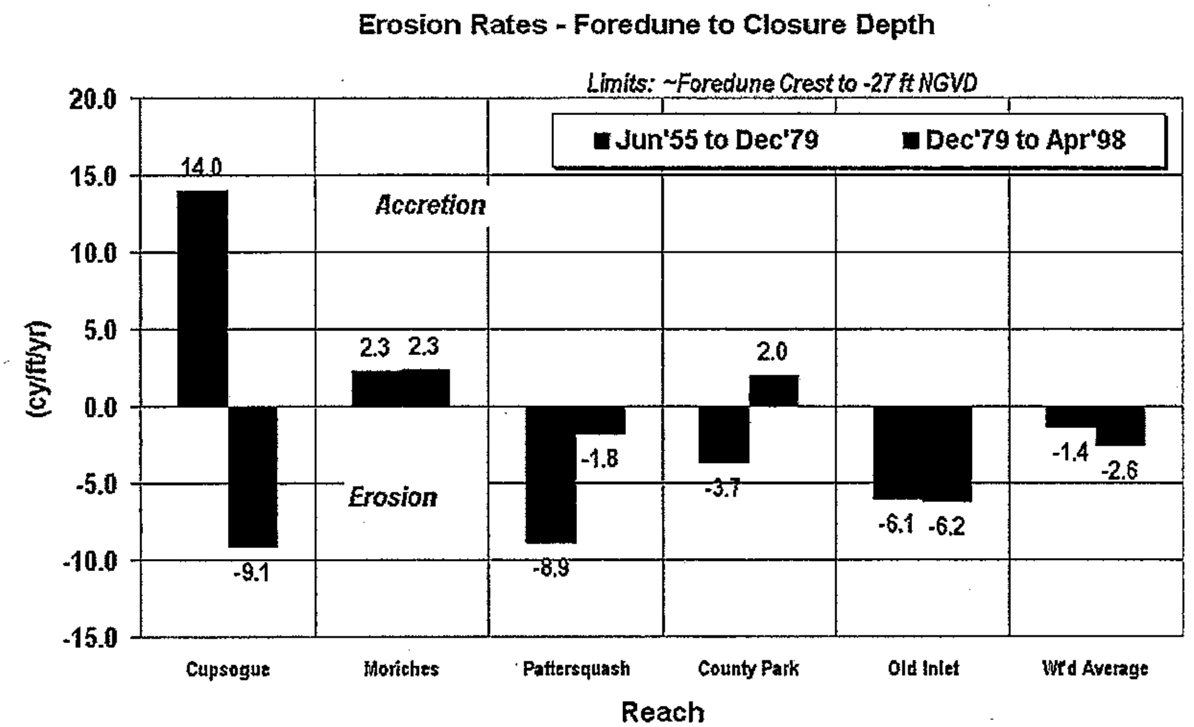
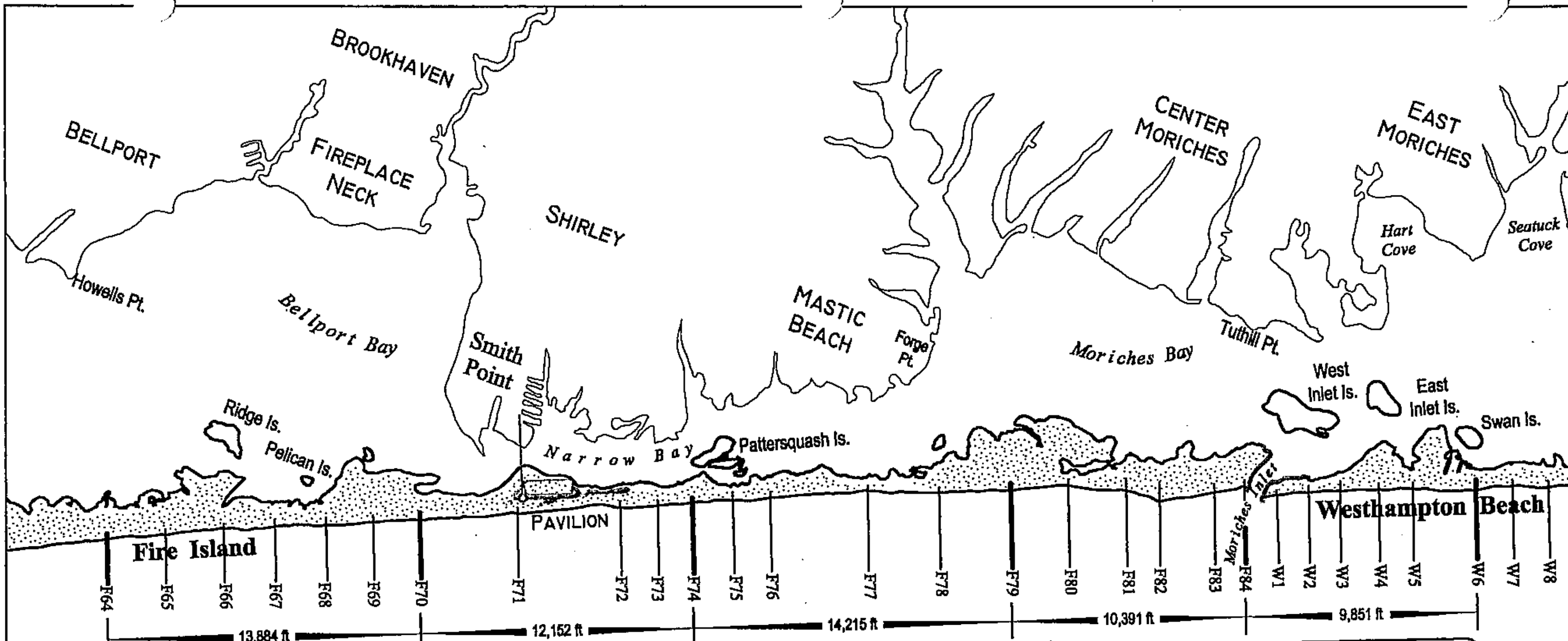


FIGURE 15c. Average annual volume changes by reach and all lenses combined for two primary time periods (1955 to 1979 and 1979 to 1998).

Figures 16a and 16b summarize the annual volume changes by reach based on the data in Appendix III. The results for the period 1955 to 1979 (Fig 16a) show the striking accumulation in Reaches 0 and 1, counterbalanced by large losses in Reaches 2, 3, and 4. Approximately 75 percent of the net volume loss or gain occurred in Lens 3 (inshore zone from MLW to −18 ft). Losses along the dry beach at the park represent only 10 percent of the average annual loss for the reach. However, this low volume may reflect the positive impact of nourishment during the period. By the 1980s and 1990s, losses along the dry beach in the park increased dramatically (Fig 16b). Further, it appears that erosion of Lens 1 between 1979 and 1998 in Reaches 2 and 3 accounts for much of the buildup underwater in Lens 3 during the period. **These data indicate that a total of 100,000-180,000 cy/yr have eroded from Reaches 2, 3, and 4 (combined) over the past 45 years. This provides a measure of the quantities that must be replaced each year to keep pace with erosion.**



	Reach 4 Old Inlet	Reach 3 County Park	Reach 2 Pattersquash Washover Zone	Reach 1 Moriches Inlet Bypass Zone	Reach 0 Cupsogue (Westhampton)	
Foredune/ Dry beach	+4,100	-3,750	-7,200	+11,450	+21,000	Foredune/ Dry beach
Wet beach	-3,350	-3,500	-9,550	+3,450	+4,350	Wet beach
Inshore	-55,100	-26,250	-78,400	+12,400	+63,650	Inshore
Totals Foredune to -18	**-54,350**	**-33,500**	**-95,150**	**+27,300**	**+89,000**	**Totals Foredune to -18**

Atlantic Ocean

Annual Volume Changes (cy/ft)

June 1955 to December 1979 (24.5yrs)

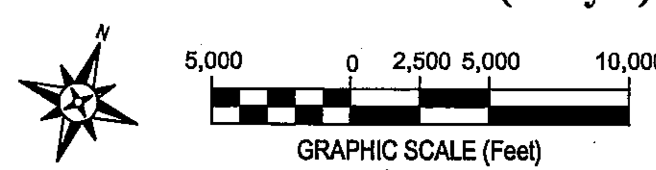
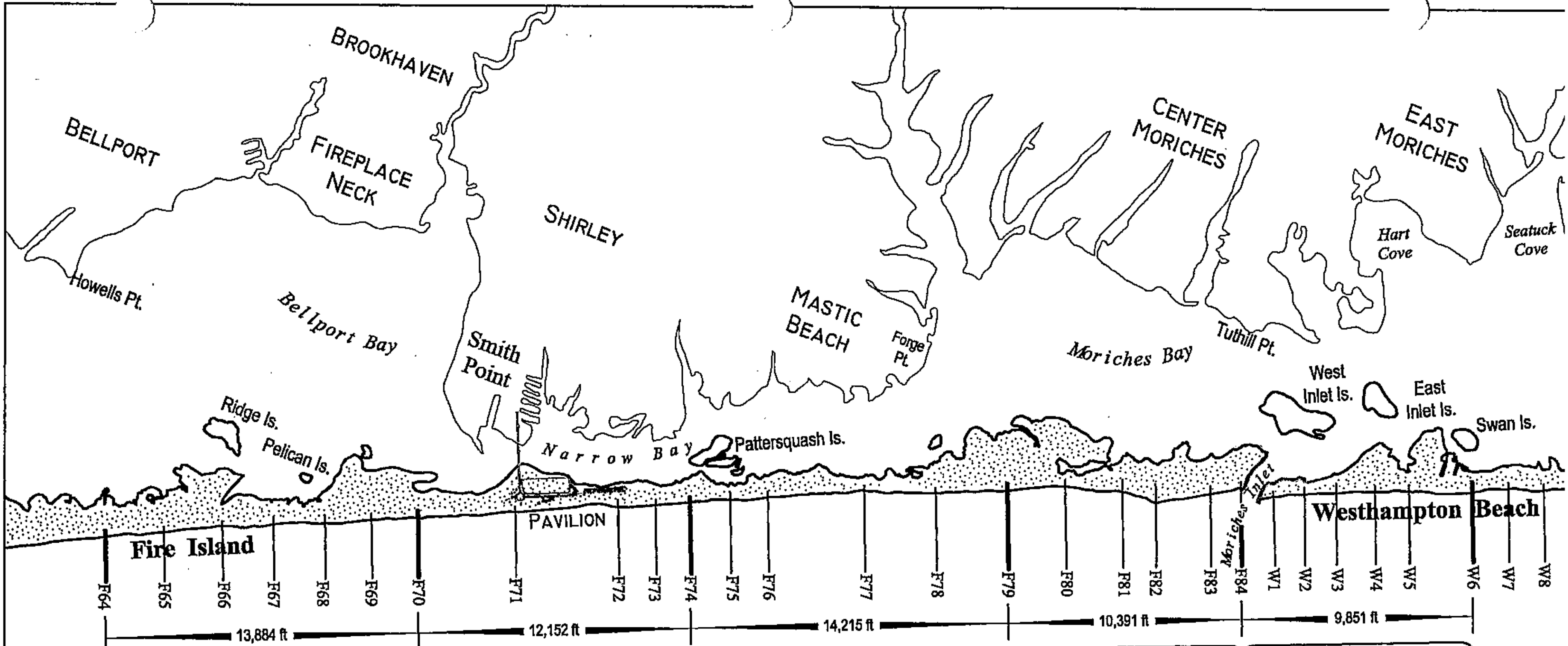


FIGURE 16a. Average annual volume changes by reach and lens (to -18 ft NGVD) for the period 1955 to 1979.



	Reach 4 Old Inlet	Reach 3 County Park	Reach 2 Pattersquash Washover Zone	Reach 1 Moriches Inlet Bypass Zone	Reach 0 Cupsogue (Westhampton)	
Foredune/ Dry beach	-50,550	-33,850	-28,150	+7,450	-25,250	Foredune/ Dry beach
Wet beach	-8,700	-1,350	-9,600	-3,250	-6,400	Wet beach
Inshore	-16,350	+41,600	+14,900	-5,700	-16,350	Inshore
Totals Foredune to -18	**-75,600**	**+6,400**	**-22,850**	**-1,500**	**-48,000**	**Totals Foredune to -18**

Atlantic Ocean

Annual Volume Changes (cy/ft)

December 1979 to April 1998 (18.4yrs)

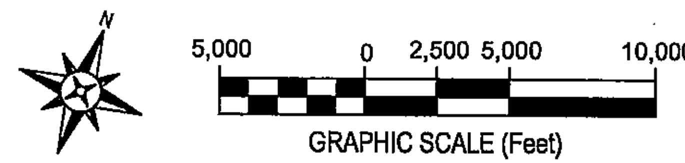


FIGURE 16b. Average annual volume changes by reach and lens (to −18 ft NGVD) for the period 1979 to 1998.

Estimated Impact of Nourishment

Table 4 summarizes the volume of beach fills placed within the study area since 1955. The data regarding beach nourishment volumes are somewhat sketchy because many early fills in the 1950s and 1960s consisted of marginal beach-quality material from disposal projects. For example, bay channels in Moriches Inlet were dredged by the county and others, with deposits made east and west of the inlet. Some of this material was undoubtedly very fine grained and unsuitable for nourishment in the littoral zone. Suffolk County DPW (1985) compiled the dredge volumes and provided the New York Coastal Partnership with estimates of what portion consisted of littoral sand and an approximation of what portion of certain fills was placed in the various study reaches (J. Hunter, pers comm, Aug 1994). The totals in Table 4 take this into account, eliminating nonbeach-quality material.

Since 1990, there have been several small beach fills along the county park using inland sand and other sources. The estimate of 150,000 cy is based on communication with county officials. The 1979-1998 estimate for Cupsogue assumes a pro-rata share (approximately 500,000 cy) of nourishment was placed in the reach in connection with the Westhampton Dunes beach fill of ~4 million-cubic-yards.

TABLE 4. Summary of beach nourishment volumes placed in the study area since 1955. Data Sources: USACE, New York State, Suffolk County, RPI (1985), Kana (1995). [Note: Estimate for Cupsogue includes ~500,000 cy in 1997. Estimate for County Park includes ~150,000 in 1993-1998.]

		1955-1979			1979-1998		
Reach	Length (ft)	Total (cy)	Average Annual (cy/yr)	Unit Width Avg Annual (cy/ft/yr)	Total (cy)	Average Annual (cy/yr)	Unit Width Avg Annual (cy/ft/yr)
Cupsogue	10,255	1,644,600	67,127	6.55	1,050,000	57,065	5.56
Moriches Inlet	10,391	1,012,000	41,306	3.98	0	0	0.00
Pattersquash	13,975	712,700	29,090	2.08	0	0	0.00
County Park	12,152	804,200	32,824	2.70	150,000	8,152	0.67
Old Inlet	13,884	0	0	0.00	0	0	0.00
Totals	**60,657**	**4,173,500**	**170,347**	**2.81**	**1,200,000**	**65,217**	**1.08**

Background Erosion Rate (cy/ft/yr)

		1955-1979 (Foredune to −18 ft)			1979-1998 (Foredune to -18 ft)		
Reach	Length (ft)	Nourishment	Surveyed Change	Without Nourish	Nourishment	Surveyed Change	Without Nourish
Cupsogue	10,255	6.55	8.6	8.6	5.56	−4.7	−10.26
Moriches Inlet	10,391	3.98	2.6	−1.38	0	−0.1	−0.1
Pattersquash	13,975	2.08	−6.8	−8.88	0	−1.6	−1.6
County Park	12,152	2.7	−2.8	−5.5	0.67	0.5	−0.17
Old Inlet	13,884	0	−3.9	−3.9	0	−1.2	−1.2
Totals	**60,657**	**2.81**	**−1.1**	**−3.91**	**1.08**	**−2.3**	**−3.38**

The effect of nourishment is to decrease the observed rate of erosion. Therefore, a more realistic background erosion rate is obtained if the nourishment volumes are subtracted from the surveyed volumes. Figure 17 shows the results. Although the fill quantities are imprecise, the results indicate that nourishment has had a significant impact in the study area:

- Cupsogue accumulated sand between 1955 and 1979 by way of natural accretion (~2 cy/ft/yr) and nourishment (~6.5 cy/ft/yr) upcoast of the Moriches Inlet jetty. Between 1979 and 1998, this reach lost a very large volume because of sand trapping by the Westhampton groin field and the 1980 breach channel. Nourishment reduced the rate of loss from about 10 cy/ft/yr (background erosion rate for the period) to ~5 cy/ft/yr.

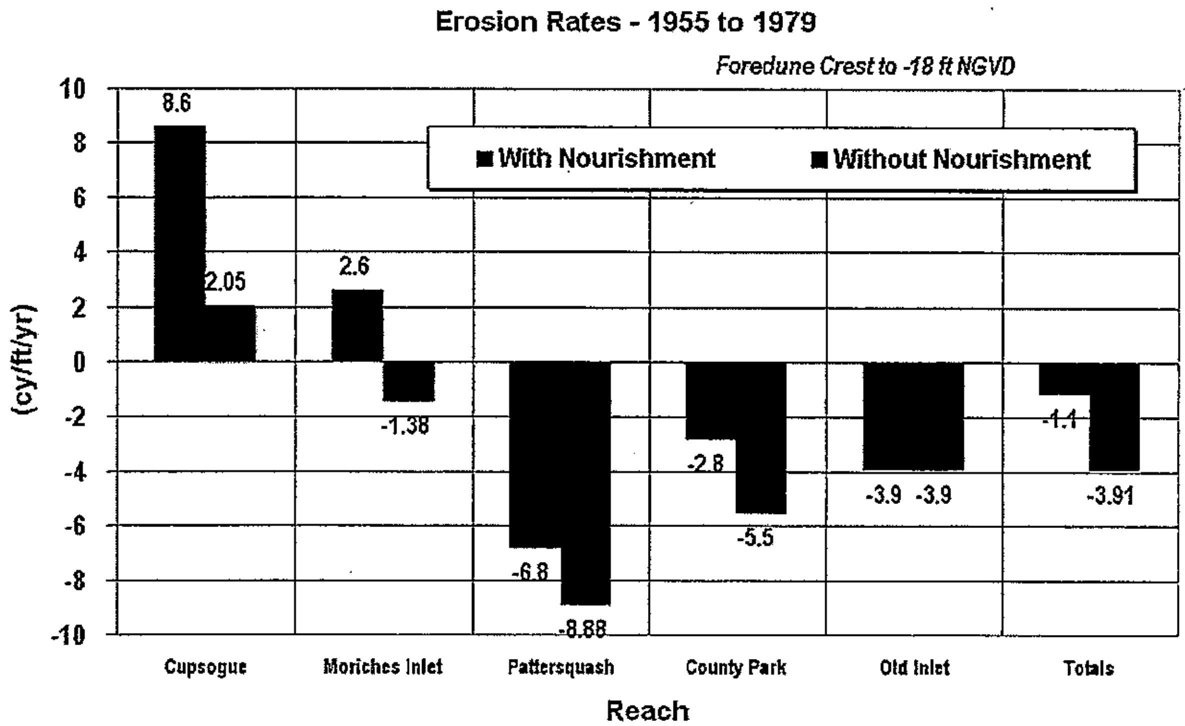
- The Moriches Inlet bypass zone would have had a background erosion rate of ~1.5 cy/ft/yr (1955-1979) without nourishment. Nourishment offset the natural trend and accounts for a net gain of ~2.5 cy/ft/yr in the reach prior to 1980. Since then, there has been little change.

- The Pattersquash reach sustained the most erosion of any reach in 1955-1979, losing nearly 7 cy/ft/yr (with nourishment) and almost 9 cy/ft/yr without nourishment. Erosion has continued during the past 20 years in this reach, but at a much lower rate (~1.6 cy/ft/yr).

- The county park reach eroded at ~3 cy/ft/yr (with nourishment) and ~5.5 cy/ft/yr without nourishment prior to 1980. Since then, the average annual changes to −18 ft have been very small. Remember that the change along the visible beach (rapid erosion) has been offset by gains seaward of low water in this reach.

- Overall, the average rate of sand loss has been remarkably consistent between the two periods analyzed. When nourishment is factored out, the average annual erosion rate to −18 ft for all reaches is ~3.9 cy/ft/yr for 1955-1979 and ~3.4 cy/ft/yr for 1979-1998.

Based on the above-listed results, CSE concludes that the underlying rate of sand loss for the entire study area is ~3.5 cy/ft/yr. The county park lost sand faster than this in the 1950s-1970s, but much lower than this rate in the 1980s and 1990s. For planning purposes, CSE recommends **adoption of a minimum 2.5 cy/ft/yr erosion rate along the county park.**



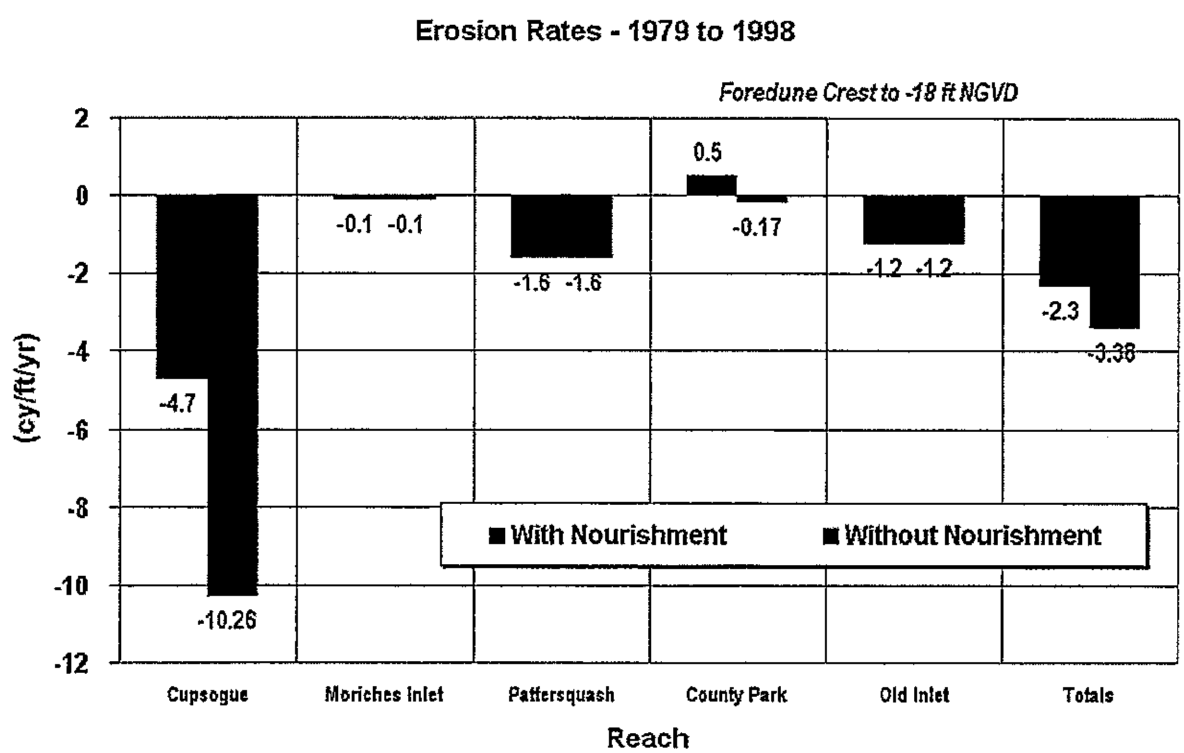


FIGURE 17. Average annual erosion rates with and without nourishment by reach for two primary time periods (1955 to 1979 and 1979 to 1998).

6.0 CAUSES OF EROSION

Based on the present analysis and review of prior studies of the area, CSE believes the following factors constitute the primary causes of erosion along Smith Point County Park during the past 50 years.

1) **The opening and stabilization of Moriches Inlet.** Prior to 1931, Moriches Inlet had been closed for nearly 100 years. The uninterrupted and relatively straight shoreline from Westhampton Beach to Fire Island allowed for a steady supply of sand and relatively uniform profile volumes. With the opening of the new inlet, sand was captured, drawing off a portion of the littoral volume. After inlet stabilization by jetties in 1955 through 1979, the updrift and downdrift reaches (0 and 1) accumulated over 4.1 million cubic yards (Appendix III, foredune to −27 ft NGVD). Approximately 60 percent of this volume gain was by way of nourishment. A breach of Cupsogue spit near Moriches Inlet in 1980 captured more sand, with upward of 750,000 cy lost from the beach into the bay channels (Vogel and Kana 1985). This single event accounts for a large portion of lost sand in Reach 0 for the period 1979 to 1998. Sand has bypassed Moriches Inlet during the past 40 years, but much of it has been trapped and held in Reach 1 within two miles of the inlet. For example, the dry beach and foredune area in Reach 1 has gained over 400,000 cy since 1955. While a significant part of this volume is the result of nourishment, natural accumulation in the shoal-bypass zone is continuing, leaving less volume to propagate toward the park.

2) **Sheltering effect of the Moriches Inlet ebb-tidal delta.** While related to the opening of Moriches Inlet, this is listed as a separate cause of erosion because the process is common around tidal inlets. As the ebb-tidal delta grows, it creates a shadow zone downcoast. The effect increases in relation to the size of the ebb-tidal delta. Vogel and Kana (1985) reported significant growth of the Moriches Inlet ebb-tidal delta between 1955 and 1979. This is reconfirmed in the present study by sediment volume results. It is believed that some of the early growth of the Moriches Inlet delta can be accounted for by erosion in the inshore zone of Reach 2 (Pattersquash). The presence and growth of the ebb delta in essence matched with localized erosion downcoast, much like the accretion and erosion associated with groins, but on a much larger scale. While the sheltering effect has lessened since 1979 (based on a lesser volume loss in Reach 2), the effect is still apparent. Also contributing to the sheltering effect are channel maintenance activities. When jettied inlets and their outer bars are dredged, the discharge into the bay increases. A higher tidal prism through the channel with each tide increases the potential size (and sheltering effect) of the ebb-tidal delta (Walton and Adams 1976). Czerniak (1976) documented an increase in the Moriches Bay tide between the 1950s and 1975.

3) **Erosion of dunes and frequent overwash in Reach 2**. Major loss of sand in the inshore zone (low water to the outer bar) due to reduced longshore transport inputs and increased sheltering downcoast of Moriches Inlet left the beach and dunes vulnerable to breaching. The beach narrowed to the point where there was insufficient volume to sustain seasonal profile changes. Erosion rates increased locally and caused complete breaches of the foredune. Once the profile goes into washover mode, erosion rates accelerate in the vicinity, for the simple reason that a small part of the littoral volume is removed from the active system with each overwash. In the aggregate, washover volumes are small. However, in the Pattersquash reach, they probably represent upward of 250,000 cy and account for ~1 cy/ft/yr erosion during the past 30 years. This is roughly one third the average background erosion rate for the study area. Significantly for Smith Point County Park, any loss of sand from the active littoral zone immediately upcoast means that much less sand available. The indirect result is cannibalization of the profile to accommodate losses to washovers. Beaches free of washovers with high dunes tend to recede at a lower rate. The natural barrier created by the dune preserves the littoral sand supply along the beach. Eroded dunes lose sand offshore. However, it remains in the active system and tends to return to the beach or shift to downcoast areas.

4) **Reduction in nourishment and dredge disposal projects since 1980**. Kana and KrishnaMohan (1994) reported that nourishment volumes along the south shore declined by nearly 80 percent between the 1950s-1960s and the 1970s-1980s. Until the Westhampton Dunes restoration in 1997, there was negligible nourishment in the study area for about 20 years. As the erosion analyses show, nourishment has had a major effect in reducing the background erosion rate. During the 1950s through the 1970s, nourishment reduced the average erosion rate for the study area by about 70 percent. Since 1980, nourishment has only reduced the rate by about 30 percent. In the park, nourishment has reduced the rate by 50 percent.

5) **Sand trapping by the Westhampton groin field**. During 1964-1971, 15 large groins were constructed 3-7 miles east of Moriches Inlet. They have had a proven impact along Pikes Beach and the Cupsogue reach, acting as total littoral barriers for portions of the time periods 1955-1979 and 1979-1998 (RPI 1985, USACE 1999, Rosati et al 1999). The reduction in longshore transport led to downcoast erosion, loss of dunes, and at least two complete breaches of the barrier (1980 and 1992). Each event removed sand from the littoral system. The impact of the groin field on the county park cannot be quantified. However, it has had at least an indirect impact of some magnitude because it dramatically reduced the supply of sand to Moriches Inlet, thus reducing the quantity available for bypassing. Higher longshore transport rates at Moriches

inlet would tend to "over-extend" the channel toward the west and lead to more frequent shoal bypassing to Fire Island. The groin field has inhibited this process.

6) **The 1938 and 1962 storms**. Of all the storm events in the past two centuries, the 1938 hurricane and the 1962 northeaster had the most impact on erosion rates. Historical shoreline changes for the 1938-1962 period account for the majority of the observed change over the century. While dramatic in event, the impact of these two storms is considered a lesser factor than the above-listed causes. Further, the evidence suggests that the majority of south-shore storms have produced little net sand losses. Fire Island beaches tend to recover efficiently in the succeeding weeks or months after each storm.

The above-listed erosion factors constitute what CSE believes to be the basic, underlying causes of erosion along Smith Point County Park. CSE has targeted the factors that account for major quantities at century time scales, purposely eliminating popular erosion causes that involve small quantities (eg, sea-level rise, dune scraping, loss of dune vegetation, vehicles on the beach, etc).

The next section discusses needs and alternatives for beach restoration along the park as well as within the entire study area.

7.0 BEACH RESTORATION ALTERNATIVES

The foregoing analysis of erosion along Smith Point County Park and adjacent reaches indicates:

1) There is a major volume deficit in profiles along the park in comparison with a minimum healthy beach and inshore zone.
2) The park loses sand at an average rate of at least 2.5 cy/ft/yr.
3) The adjacent updrift reach (Pattersquash) also has a substantial sand deficit, meaning less sediment is available to feed the park reach.
4) The Moriches Inlet bypass reach has a large surplus of sand well above the minimum volume of a healthy beach.

These trends in volume gains and losses have generally continued since 1998 (Table 5).

Profile data (see Fig 11 and Appendix 1) indicate Reaches 0 and 1 have 3-5 times more sand on the dry beach than the park and nearly twice as much sand in the profile out to −18 ft. Table 5 gives the average unit volumes by reach for Lenses 1, 2, and 3 for spring 1998 and spring 2001. Along the park, all lenses have deficits. In the past four years, the park has lost another 30 cy/ft in the profile. Fortunately, because of moderate storm conditions since 1998 and the addition of a small quantity of nourishment in connection with construction of the steel seawall, profile volumes in the dry beach have increased by ~10 cy/ft. At the pavilion seawall (station F71), they have declined.

TABLE 5. Deficit volumes by reach/lens (cy/ft) with respect to the recommended minimum profile volume for the study area.

	Dry Beach		Wet Beach		Inshore		Totals - Foredune to -18 Ft NGVD	
Target Volume	***75***		***50***		***450***		***575***	
Existing Volume	Apr'98	Apr'01	Apr'98	Apr'01	Apr'98	Apr'01	Apr'98	Apr'01
Cupsogue	72.6	79.5	58.8	54.3	587.0	580.2	718.4	714.0
Moriches Inlet	81.7	90.8	61.2	62.7	597.3	602.9	740.2	756.4
Pattersquash	33.8	40.6	39.6	42.7	383.8	404.4	457.2	487.7
Park	**15.8**	**24.7**	**36.5**	**31.6**	**372.9**	**340.3**	**425.2**	**396.6**
Old Inlet	28.2	45.9	41.1	36.9	411.3	ND	480.6	ND
Profile F72	29.4	35.0	47.3	28.2	421.3	340.3	498	403.5
Profile F71	24.6	9.7	49.3	18.5	412.7	ND	486.6	ND
Deficit								
Cupsogue	-2.4	4.5	8.8	4.3	137	130.2	143.4	139
Moriches Inlet	6.7	15.8	11.2	12.7	147.3	152.9	165.2	181.4
Pattersquash	-41.2	-34.4	-10.4	-7.3	-66.2	-45.6	-117.8	-87.3
Park	**-59.2**	**-50.3**	**-13.5**	**-18.4**	**-77.1**	**-109.7**	**-149.8**	**-178.4**
Old Inlet	-46.8	-29.1	-8.9	-13.1	-38.7	ND	-94.4	ND

CSE evaluated beach restoration alternatives at several levels:

1) Complete restoration of the eastern Fire Island beach to 1955 conditions.
2) Restoration of the county park reach to 1955 levels.
3) Ongoing restoration by way of small scale but frequent nourishment.

CSE also reviewed the USACE (1999) interim plan for the park.

Regional Beach Restoration — Alternative 1

Using the profile deficits to −18 ft, CSE estimates that full restoration of Reaches 2, 3, and 4 will require addition of ~5.7 million cubic yards (Fig 18). Restoration would include the deficit volumes (90-150 cy/ft depending on the reach) and advance nourishment to accommodate average annual erosion losses. In the scenario presented, CSE assumes ten years' worth of advance nourishment (~25 cy/ft). Under this alternative, ~4 million cubic yards would be placed along the Pattersquash and county park reaches. The balance would be placed along Reach 4.

Five potential sand sources are identified:

1) USACE offshore borrow area "3-Long Cove" situated between 2,500-10,000 ft offshore (OSS 1983, USACE 1999).
2) Accreted shoals in Reach 1 (Moriches Inlet bypass zone).
3) Moriches Inlet channel maintenance (or stockpiled dredge spoil from such projects in Reach 1).
4) Nearby bay maintenance dredging.
5) Inland sand pits via trucking to the park.

For quantities approaching 5 million cubic yards, the latter two sources can probably be eliminated for economic and environmental reasons. Trucking from inland sources is generally much more costly than nourishment by dredging sources near the site. Bay dredging of large quantities will introduce potential environmental concerns related to excavations of organic-rich sediments as well as potential creation of deep holes where water quality may become an issue. Of the remaining borrow sources, all could be used for portions of the project, subject to appropriate confirmation of sediment quality.

The USACE offshore borrow area near Long Cove is situated about 5 miles west of the park. If sufficient beach-compatible material is confirmed by the USACE, this area could serve to restore Reach 4 and portions of Reach 3 (county park). For the remainder of the park and Reach 2, Moriches Inlet or the bypass zone (Reach 1) would provide more economic borrow areas, given their proximity. In general, nourishment pumping distances become much more expensive after about 5 miles.

The following summarizes the estimated costs, outcome and advantages of Alternative 1.

Alternative 1 Summary

Volume:	5,700,000 cy
Length:	40,250 linear ft
Average Sections:	~140 cy/ft
Average increase in beach width:	~220 ft
Estimated Longevity:	>>10 years
Approximate cost:	$30,000,000 (@ ~ $5.25/cy inclusive).
Advantages:	Restores deficit along adjacent reaches as well as along the park. Likely to provide multi-decade erosion control and beach preservation given its length. Eliminates need for frequent re-nourishment and construction activities on the beach. Provides restored areas that can feed the park.
Disadvantages:	Cost; scope goes well beyond park boundaries thereby requiring multiple sponsors, particularly the National Seashore which may not be supportive of beach restoration and shore protection.

While Alternative 1 is not considered a viable alternative for Suffolk County because of its length and cost, it is presented as a target plan. Nourishment of this magnitude would feed the rest of Fire Island for many years and provide several decades of benefits. Figure 18 implies it is a "10-year" plan. However, ten years simply applies to the advance nourishment quantities. After a decade, most of the deficit volume would remain in the system, leaving the beach in much better condition than at present. Benefits of a wider beach therefore continue for many years longer. When considered over a 20-30 year period, the cost per year for regional beach restoration becomes quite favorable.

County Park Beach Restoration — Alternative 2

CSE used the same profile deficits to develop Alternative 2 (beach restoration along the county park). The primary beach facilities exist between stations F71 and F72 (an ~4,590 ft reach). Figure 19 shows the schematic plan. In this case, CSE assumes that the primary recreation area will be fully restored to approximate 1955 conditions, and the adjacent reaches will provide gradual tapers for transition to unnourished areas. Under this alternative, 1,500,000 cy would be placed along the ~12,150-ft reach between stations F70 and F74. Figure 20 shows the effect of nourishment at ~175 cy/ft along the park. The upcoast and downcoast sections (~3,200 ft and ~4,350 ft, respectively) would average about 85 cy/ft. Nourishment at this quantity would initially provide an ~200-ft wider dry beach in the main recreation area. Its width would taper to existing conditions outside Reach 3. Figure 20 (lower) shows the impact of ~150 cy/ft fill at station F71 (pavilion) compared with the April 1998 profile. There are no comparative data for 2001 beyond low-tide wading depth. CSE assumes the full nourishment section (~175 cy/ft) would be required to make up for volume losses between 1998 and 2001.

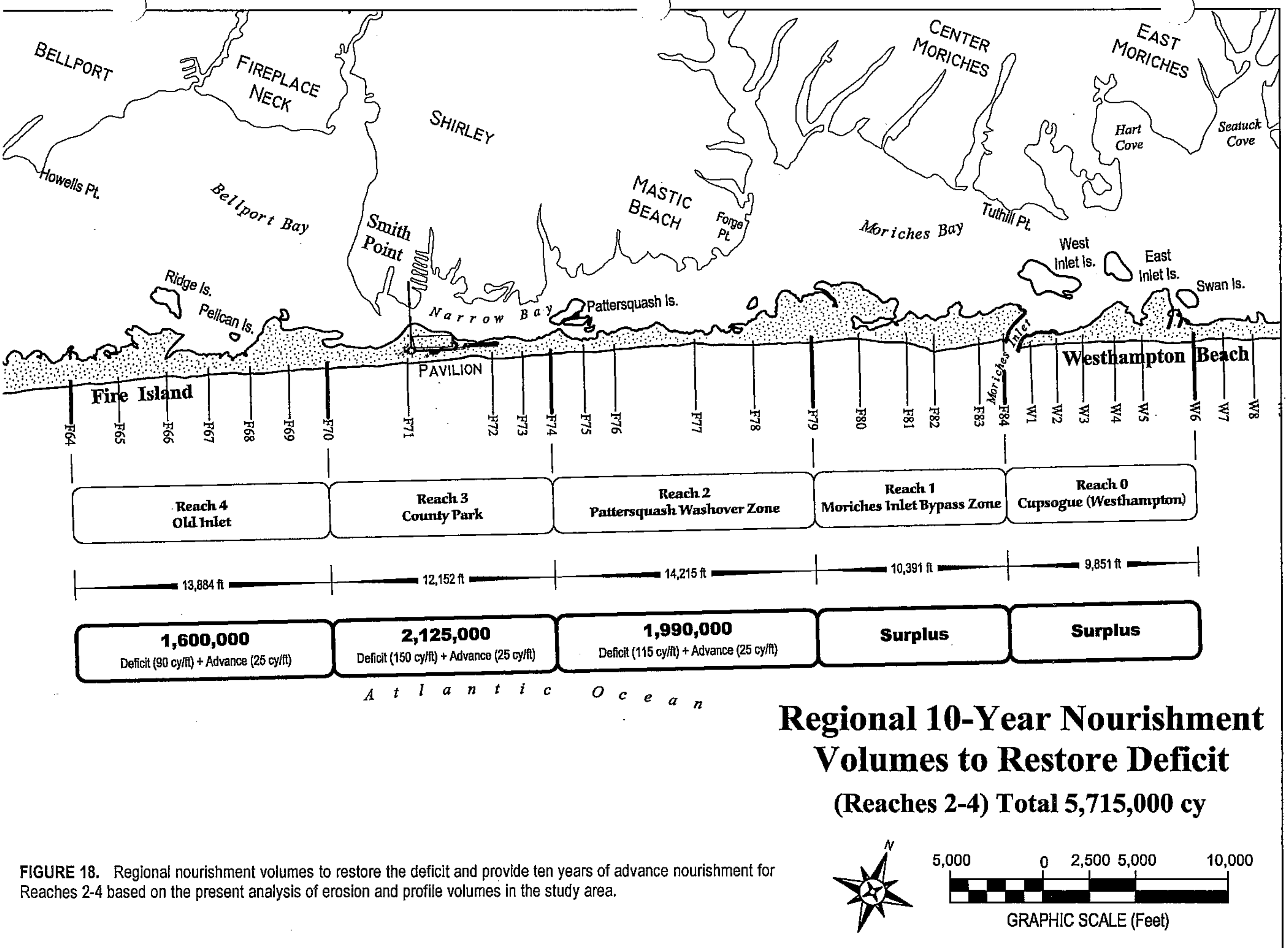


FIGURE 18. Regional nourishment volumes to restore the deficit and provide ten years of advance nourishment for Reaches 2-4 based on the present analysis of erosion and profile volumes in the study area.

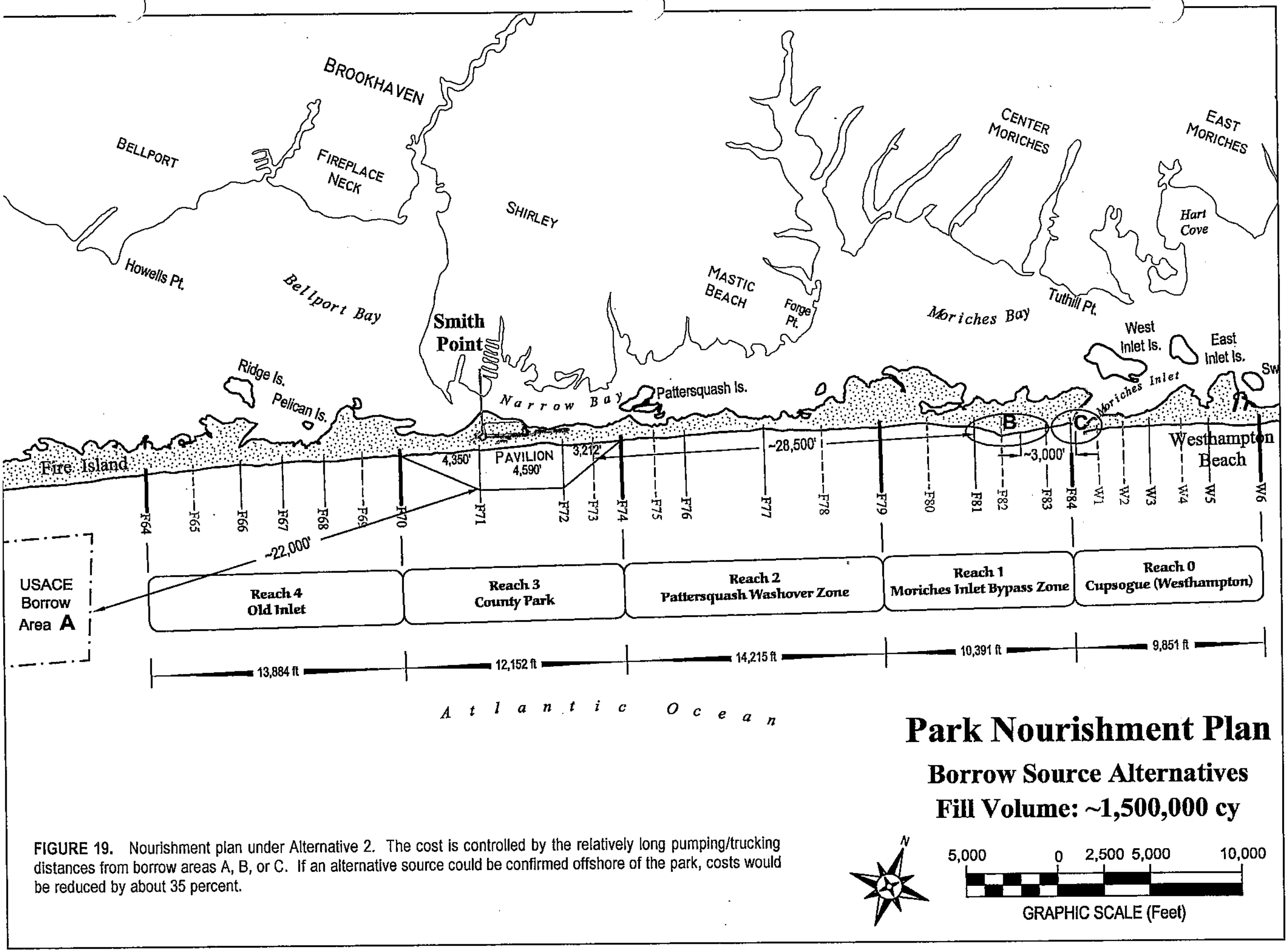
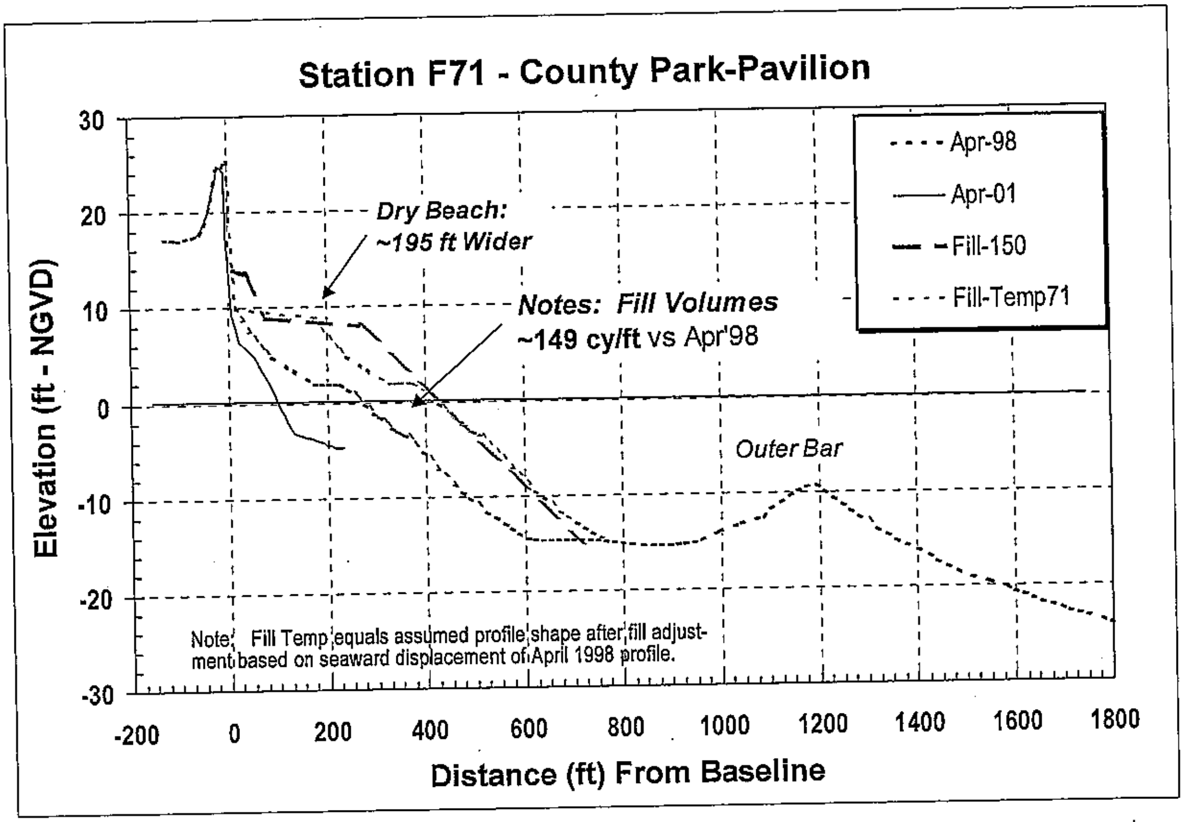


FIGURE 19. Nourishment plan under Alternative 2. The cost is controlled by the relatively long pumping/trucking distances from borrow areas A, B, or C. If an alternative source could be confirmed offshore of the park, costs would be reduced by about 35 percent.



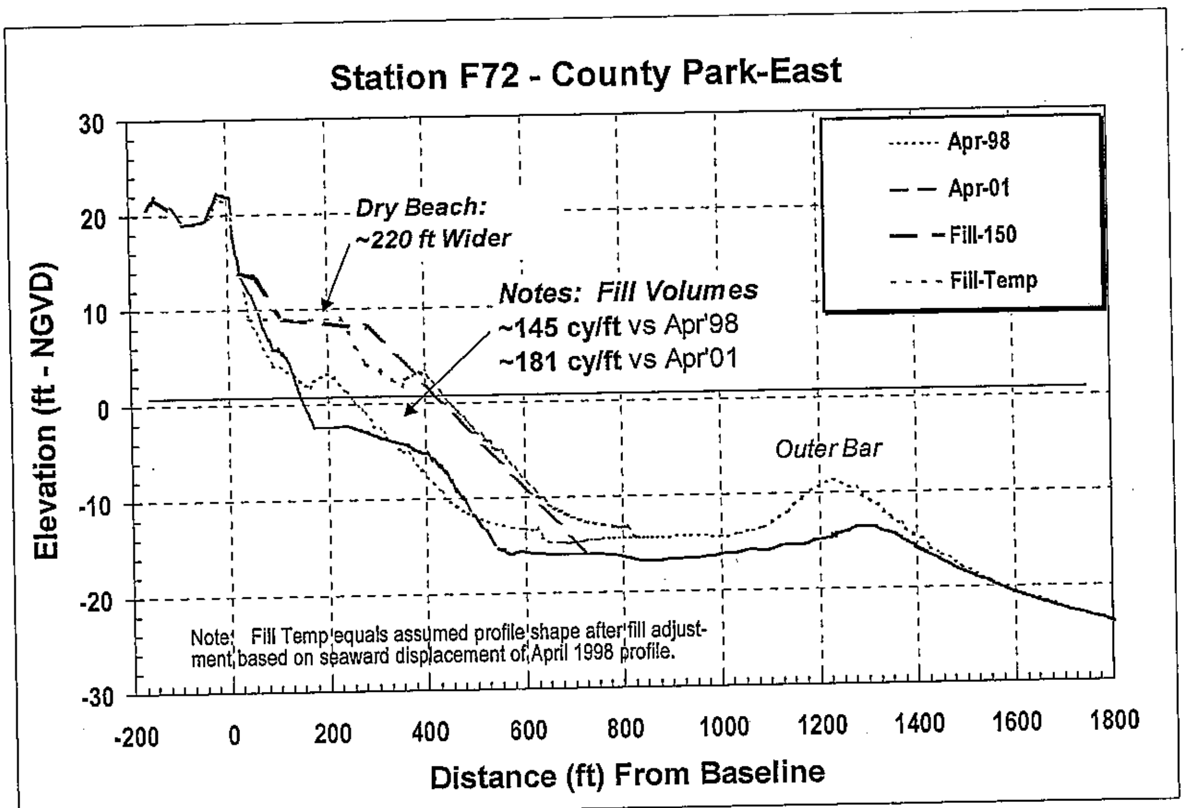


FIGURE 20. Projected fill sections along the county park under Alternatives 1 and 2, based on restoration of the profile deficit and approximately ten years of advance nourishment.

Alternative 2 would involve a much shorter project length and would leave adjacent reaches unnourished. As a result, it would tend to erode much faster than Alternative 1. The USACE (1995) provides a methodology for estimating the longevity of beach fills as a function of their lengths. The recommended method is a modification of earlier work by Dean and Yoo (1992). [For information on the methodology, the reader should consult both references.] CSE applied the USACE method (based on EM Eq 4-9 in USACE, 1995) assuming a project length of 8,000 ft (same section volumes without tapers) and an estimated closure depth of approximately -20 ft.

Table 6 lists the predicted percentage remaining near the center of the project. This methodology only assumes diffusion of the fill at either end. In the presence of strong longshore transport, the rate of spreading will increase. As Table 6 shows, the approximate half-life of the fill would be ~15 years. In the first two years of the project almost 25 percent would be lost to the unnourished reaches. Other methods (eg, Dean and Yoo 1992) predict lower loss rates, but CSE does not recommend them over the more conservative USACE (1995) method. Also, the loss rates beyond 20 years are not reliable, given the general lack of data to verify diffusion rates over this length of time. **For planning purposes, CSE recommends assumption of a ten-year half-life to allow for advection of the fill by longshore transport.**

TABLE 6. Estimated longevity of a short nourishment project comparable in length and volume to Alternative 2. (Based on method in USACE 1995, EM1110-2-3301 Eq 4-9.) Diffusion rate excludes the effect of longshore advection.

Time	% Remaining	Time	% Remaining
1 year	85	~15 years	~50 (half-life)
2 years	78	20 years	45
5 years	65	30 years	40
10 years	57	50 years	30

Alternative 2 Summary

Volume:	1,500,000 cy
Length:	12,150 linear feet
Average Sections:	175 cy/ft along primary recreation area (~4,590 ft) ~87 cy/ft along adjacent taper sections (~7,560 ft)
Average Increase in Beach Width:	~200 ft along primary recreation area ~100 ft along taper sections
Estimated Longevity:	~10 years (~50 percent remaining)
Approximate Cost:	$9,000,000 (at ~$6/cy – inclusive of engineering, permitting, dredge mobilization, and pumping from USACE Long Cove borrow area (labeled "A" on Fig 19).

Note: Alternate borrow areas "B" and "C" would involve longer pumping distances and would therefore be more costly. However, if a federal project could provide a stockpile between stations F79 and F81, the transportation distances to the park would be reduced to around 20,000 ft, making that a more economic borrow source. CSE estimates the incremental cost for trucking from stockpiles in Reach 1 to the project area would be ~$1.50/cy per mile (~$6.50-$8.25/cy). Trucking would likely become competitive with dredging if the stockpile area were moved at least as far west as station F79 (ie, ~15,000-20,000 ft from the park).

Advantages: Restores deficit along primary recreation area of the park. Likely to provide upward of ten years of erosion relief; however, nearly 50 percent of the fill would have eroded and spread to adjacent (unnourished) reaches in that time. Would eliminate the need for frequent beach/dune scraping during the first 5-10 years.

Disadvantages: Does not provide an updrift feeder beach to maintain the profile over a longer time. Has a limited longevity because of its relatively short length. Will require renourishment sooner.

The cost of Alternative 2 is sensitive to the proximity of nourishment sources. CSE assumes dredging of Narrow Bay will not provide sufficient beach-quality volumes (or require much larger volumes to account for differences in grain sizes and stability to yield comparable performance). In our experience, bay sediments typically are finer and yield overfill ratios (RAs – CERC 1984) that are >3. This means more than three times as much material must be pumped from the bay to provide the performance of quality littoral sediments. If a suitable sand source with low RAs could be found directly offshore of the park, dredging costs could be reduced by upward of $2/cy, and the overall budget could be brought down to approximately $6 million. This suggests additional borrow source studies would be worthwhile.

Federal Interim Project — Alternative 3

The USACE (1999) recently formulated an "interim project" for Fire Island, which includes a separate fill along the county park. The total interim project would involve ~7.75 million cubic yards, nearly all of which are designated for western and central Fire Island. The county park reach (USACE 1999, Reach 4) calls for placement of 490,815 cy plus 15 percent tolerance volume and a 50,000 cy stockpile volume along a 6,000-ft reach spanning stations F71 to F72 (plus small tapers at either end).

A fill of this magnitude (excluding the stockpile volume) would provide an average of ~94 cy/ft along a 6,000-ft reach. This would widen the beach by ~110 ft. Applying similar fill erosion methods as Alternative 2, an estimated 30 percent of the fill would be eroded within two years, leaving the dry beach about 75 ft wider than prenourishment conditions around the center of the project. The assumed borrow area is USACE area "A" shown on Figure 19.

The federal cost estimates for Alternative 3 is ~$5,077,000 (pumping cost via hopper dredge at $8.26/cy) plus a pro-rata share of mobilization, engineering, and administration. Because these numbers are difficult to back out of USACE (1999), CSE assumes 25 percent based on experience, yielding a **total cost of about $6,350,000**. Because this would be a federal project, it will be cost-shared with local sponsors. Based on present cost-share formulas, an estimated 65 percent would be paid by the federal government and 35 percent by the local sponsor (and possibly, the State of New York). **The local share under this scenario would be ~$2.25 million.**

The unit pumping costs assumed by the Corps are considerably higher than CSE's estimate for Alternatives 1 and 2. In our experience, locally funded projects involve less complicated oversight and administration by engineering and dredging firms. Also, the time for permitting and project review tends to be shorter with private projects. This is reflected in the costs. CSE believes the unit cost estimates under Alternatives 1 and 2 are realistic based on recent pumping costs at Fire Island Inlet and Westhampton Beach as well as comparable projects in North and South Carolina (Great Lakes Dredge & Dock Co, Mr. D. Hussin, pers comm, May 2002). Presumably, reduced bid prices under Alternative 3 would pass back savings to the local sponsors.

Alternative 3 Summary

Volume:	614,437 cy
Length:	6,000 ft
Average Sections:	~94 cy/ft (+8 cy/ft stockpiled)
Average Increase in Beach Width:	~110 feet (after fill adjustment)
Estimated Longevity:	<5 years (~50 percent remaining)
Approximate Cost:	$6,360,000 (~$10.30/cy inclusive) (~Federal~$4,125,000) (State/Local~$2,225,000)

Advantages: Provides partial restoration of the deficit and significant restoration of the recreational beach for an estimated ~5 years. Federal cost sharing covers ~65 percent. Permitting is handled by the federal government. As a public park with excellent access, permitting and cost-share justification is usually easier.

Disadvantages: Does not fully restore the deficit or provide significant advance nourishment. Design is controlled by the Corps of Engineers rather than the local sponsor. Time line for federal projects is often long and subject to funding appropriations by Congress. (This necessitates strong local sponsorship and political support.)

Alternative 3 is approximately 40 percent of the level of nourishment under Alternative 2. Comparing the local cost-share in Alternative 3 (~$2.25 million) with a pro-rata equivalent cost under Alternative 2 (~$3.6 million) indicates the federal project would be less costly to the county, given the large subsidy. Alternative 3 would require renourishment sooner and would not provide as wide a recreational beach as the park may need to accommodate the number of daily users in the summer.

Based on informal communications between USACE officials and the GPI project team, it now appears the interim project is unlikely to move forward (J Vietri, USACE-New York District, pers comm, April 2002). However, CSE includes it as an alternative herein because it provides a federally sanctioned formulation for the park area. While the entire interim project may be problematic, the portion addressing the park may remain viable. There is now an apparent federal interest in maintaining and protecting the memorial to the Flight 800 victims, as well as maintaining public access to Fire Island. CSE recommends that county officials use the formulation of the interim project as a target minimum solution to the erosion problem along the park.

Frequent Small-Scale Nourishment — Alternative 4

The final alternative considered would involve frequent, small-scale beach fills taking advantage of opportunities as they arise. Recently, for example, the federal government has authorized bi-annual dredging of Moriches Inlet at a level of the order 200,000 cy/yr (R. Grover, pers comm, April 2002). For the park to benefit from this, the spoil should be placed in Reach 2 (Pattersquash) so that it will migrate to the park. If it is placed in Reach 1 or stockpiled above the dunes, it will not provide a direct benefit over the next decade.

As Figure 19 illustrates, the pumping distance from the inlet to the park is well beyond economic range. Based on similar federal projects, it is unlikely that the Corps would be authorized to pump over 30,000 ft to the park. However, they may be able to provide a stockpile upward of 5,000-10,000 ft from the inlet. Such a scenario could provide a renewable source for the park that can be transferred by off-road vehicles along the beach.

Fills of the order 200,000 cy would provide ~33 cy/ft along a 6,000-ft reach in the prime recreation area. This would have the effect of widening the beach by ~40 ft (Fig 21). Assuming fills of this magnitude are repeated bi-annually with the Moriches Inlet dredging cycle, the deficit along the park would be restored slowly over a period of about 15-20 years.

Alternative 4 Summary

Volume:	~200,000 cy
Length:	6,000 ft
Average Sections:	~33 cy/ft
Average Increase in Beach Width:	~40 ft
Estimated Longevity:	<2 years (~50 percent remaining)
Approximate Cost:	$1.3-$1.65 million*

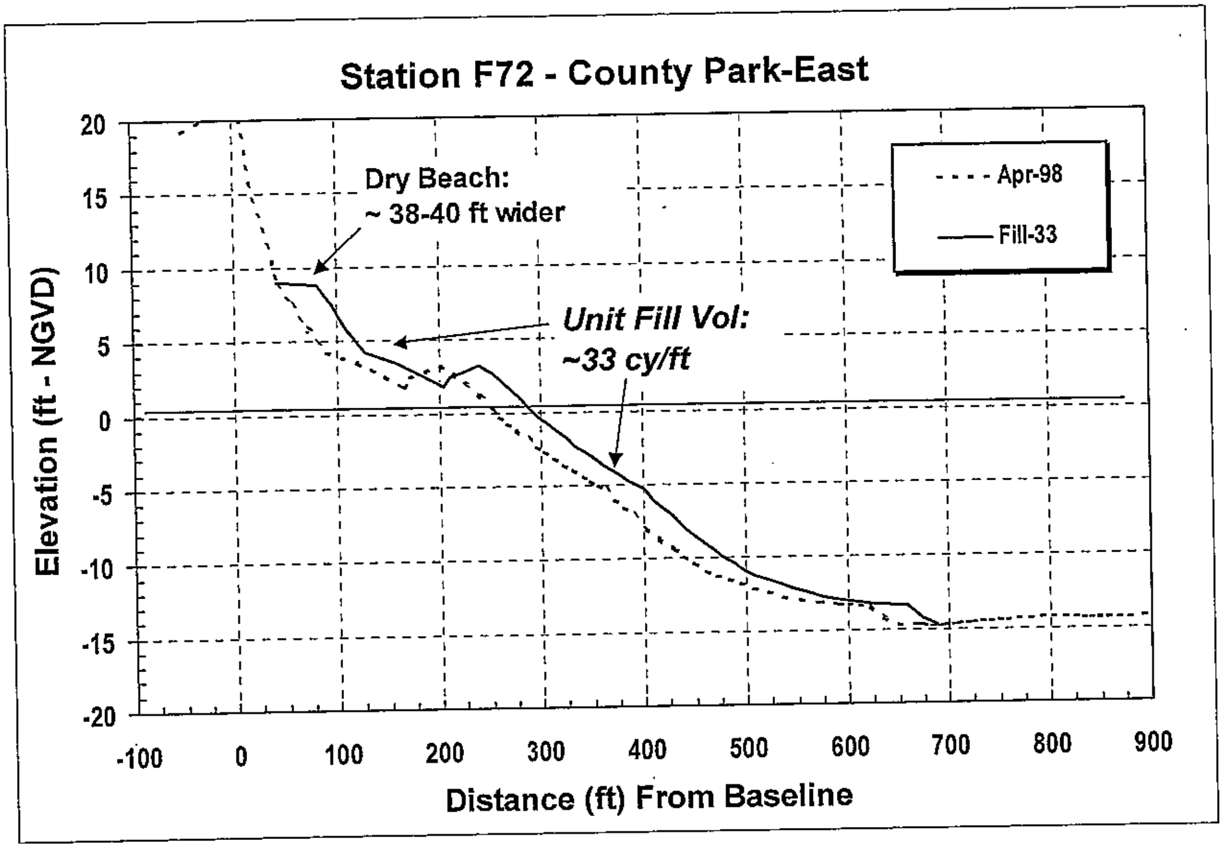


FIGURE 21. The anticipated impact of a 200,000 cy fill along 6,000 ft of park shoreline.

Advantages: Partially restores the beach. Negligible mobilization costs (via trucking), relatively easy to permit. Can be performed independently of inlet dredging schedule, little lost time for weather during construction. Project scope and costs are easily scaled to the budget available.

Disadvantages: Does not fully restore the profile. Has relatively short longevity. Many repeat beach fills required to restore deficit and regain a wide recreational beach. Dependent on continuing restoration of the stockpile by the federal government.

[*Costs assume borrow material is pumped (at no cost to the county) from Moriches Inlet to a stockpile area within 4.3-5.5 miles of the park. The county would contract separately to truck material from the stockpile areas to the park at a cost of approximately $1.5/cy per mile.]

Alternative 4 offers opportunities for efficient mobilization after storms and a "pay-as-you-go" source of sand. A key requirement for the park is to place the stockpile as far west as practicable so that transportation costs are reduced. CSE does not recommend pumping via boosters from the inlet because of the distance. Further, it is unlikely that the dredging can be performed via ocean-certified hopper dredges and transferred via hoppers to the park. Such hopper dredges generally require operational depths of at least 25 ft.

7.1 EROSION SCENARIO IF NO NOURISHMENT IS PERFORMED

Smith Point County Park will continue to erode over the next decade if no action is taken to renourish the beach. The rate of erosion is likely to remain low relative to many beaches around the world and will probably average less than 2.5 cy/ft/yr. CSE predicts low rates because:

1) Park profiles have a large deficit compared to adjacent reaches. In simple terms, when a site has less sand than its neighbors, it has less sand to lose each year.

2) The federal nourishment program along Reach 0 (Westhampton Beach) and the anticipated Moriches Inlet dredging is likely to increase the volume of sand in Reach 1. Some of this excess sand will migrate west.

3) The Pattersquash reach has a large profile deficit that must be restored before the park reach experiences significant gains.

After a decade or two of nourishment along Westhampton Beach, profile volumes along the park are likely to stabilize and begin to recover. However, over the next 10-20 years, they will be insufficient to accommodate storms and provide a broad dry beach for recreation.

No-Action Impacts

If no beach nourishment is performed, the foredune and beach will retreat by an average of at least 25 ft over the next ten years and 50 ft over the next 20 years. Such chronic erosion will expose the steel bulkhead and produce additional localized scour immediately adjacent to, and seaward of, the structure. **Flanking erosion east and west of the bulkhead will cause localized shoreline recession of up to 50 ft landward (in addition to the average recession of 25 ft over ten years).** Flanking erosion will also diminish with distance away from the exposed structure, but will directly affect upward of 1,000 ft of shoreline in either direction. Bulkhead exposure will also lead to scour along its toe and a tendency for a trough to persist along the upper beach. **The dry beach will be replaced by a wet beach (or will be severely diminished), thus inhibiting normal sunbathing and recreation immediately seaward of the pavilion.**

A further consequence of no-action will be a possible violation of the park's bulkhead permit from the state, which specifies that the structure be covered with sand. As erosion progresses, the need for sand scraping to cover the structure will increase, while the longevity of the covering-sand will decrease because of the narrower beach.

Present conditions of the beach and foredune are inadequate to safeguard all facilities during major storms. Chronic erosion will simply exacerbate this problem. Based on previous storm experience, **a 25-year to 50-year return-period storm (which has as much chance of occurring next year as within ten years) will produce temporary dune retreat of the order 50-100 ft. This will directly impact park facilities, damage structures situated as much as 125 ft landward of the present foredune crest, and deposit sand in the access tunnels.** Because of the presence of the steel bulkhead and other foundation structures around the pavilion and variable backshore elevations, localized flanking erosion will modify the storm damage line, shifting it further landward in some areas. The impact areas of chronic shoreline recession and major storm erosion are illustrated in Figure 22. A catastrophic storm will also trigger inlet breaches along narrow sections of Fire Island where dunes have been lost. [For a detailed description of the prerequisites and processes associated with inlet breaches along Fire Island, see Kana and Mohan (1994) – Assessment of the Vulnerability of the Great South Bay Shoreline to Tidal Flooding, prepared for New York Coastal Partnership, Babylon, New York.]

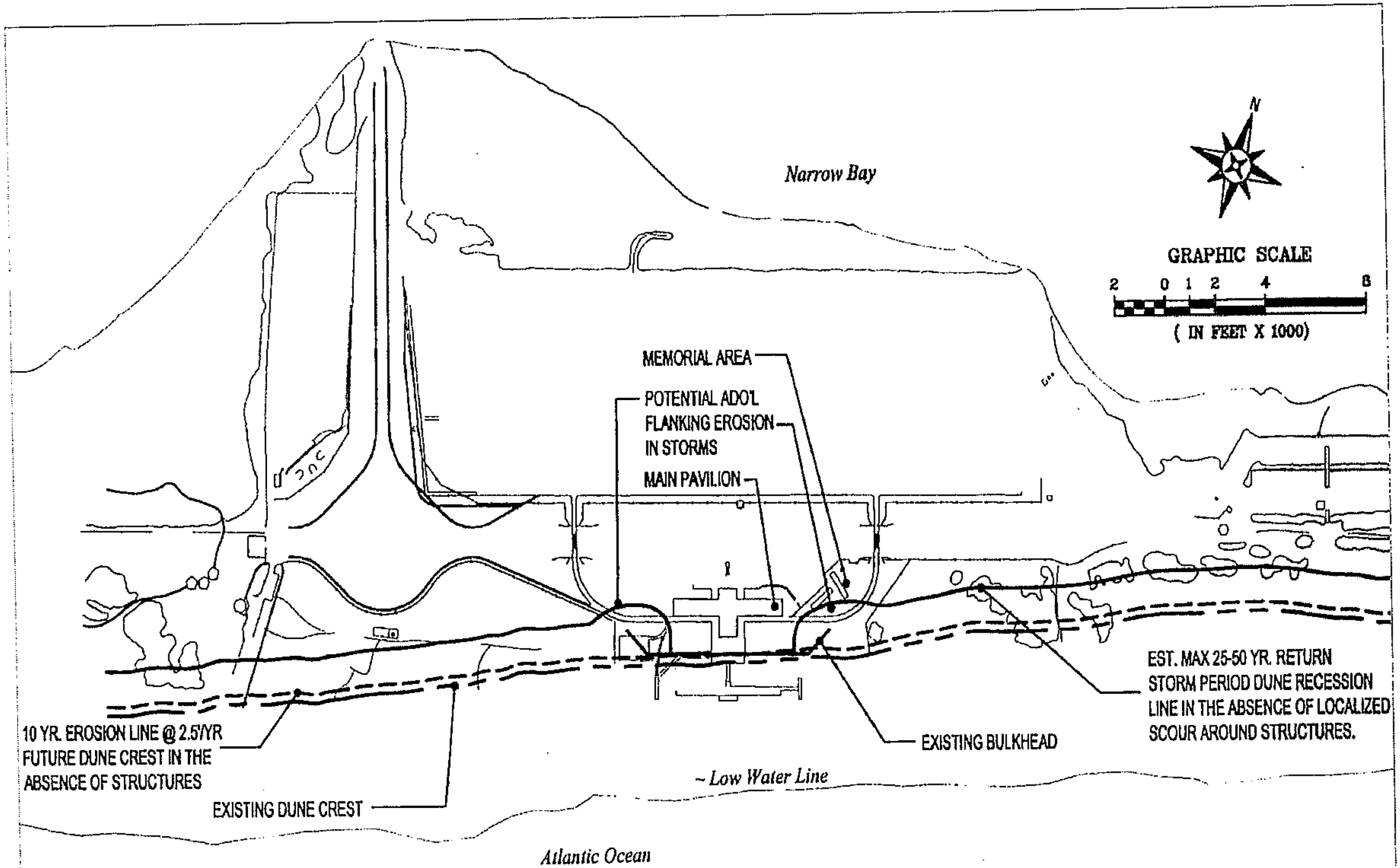


FIGURE 22. Projected ten-year erosion line (future dune crest) with respect to the existing dune crest. The solid line depicts the anticipated dune recession line during a 25-year to 50-year return-period storm. The existing bulkhead will produce additional "flanking" erosion as along as it remains exposed to wave action. [Base map courtesy of GPI, after Cashin Associates 1999]

Beach Scraping

Catastrophic storm erosion differs from chronic erosion because most of the eroded sand remains nearby in the survey zone. Following major storms, the beach tends to gradually rebuild itself. The natural recovery after large storms can be accelerated by beach scraping. The success of beach scraping is directly related to the beach condition. Studies have shown that it is highly cost-effective and environmentally benign if:

1) It is performed soon after storms where large quantities of sand have been shifted from the dunes to the surf zone but not otherwise lost from the immediate vicinity.

2) The shoreline to be scraped has a relatively low background erosion rate.

3) The scraped beach does not protrude seaward of the adjacent beach strand.
   and
4) The littoral profile does not have a major sand deficit compared to a healthy profile.

Where the above-listed criteria are met, beach scraping can jump-start recovery of the dry beach and quickly reestablish a stable dune line. It may last for several years before it has to be repeated. However, where these conditions are not met, scraping after storms may provide protection for only a few weeks. Portions of Smith Point County Park around the pavilion are considered least economic for scraping after storms because of the sand deficit and presence of the bulkhead. As erosion continues, the longevity of scraping along the pavilion will diminish each year. If no nourishment is performed, the probability and severity of damages to structures will increase. Widening the beach via nourishment decreases the chance and severity of damages. A complete analysis of potential damages to park facilities if no action is taken is beyond the scope of the present study. However, relevant economic analyses are available for Fire Island (cf, URS 1985, Koppelman 1995, USACE 1999).

8.0 SUMMARY AND MAINTENANCE RECOMMENDATIONS

CSE has presented four alternatives for beach restoration along the county park. Alternatives 1 and 2 restore the profile deficit and provide for the equivalent of about ten years of advance nourishment. Alternative 1 encompasses 40,000 ft (Reaches 2, 3, 4) extending well beyond the boundary of the park, whereas Alternative 2 would only provide nourishment around the primary park facilities (Reach 3). Alternatives 3 and 4 provide lesser nourishment quantities along an ~6,000-ft reach centered at the pavilion and campground. Alternative 3 is the USACE (1999) "interim project," representing about 40 percent of the nourishment volume of Alternative 2. Alternative 4 is the smallest nourishment based on opportunities for obtaining sand after each channel maintenance project at Moriches Inlet. The latter two alternatives would only partially restore the profile deficit.

Potential borrow sources include a USACE designated offshore borrow area off Long Cove about 4.5-5.5 miles from the park, an accretion zone in Reach 1 downcoast of Moriches Inlet (which may also be the site for stockpiling inlet spoil), and Moriches Inlet shoals (which are upward of 6 miles from the park). Given the distance of all borrow sources (including trucking from inland deposits), **CSE recommends additional offshore investigations of borrow sources closer to the park. This could potentially reduce the cost of Alternatives 2, 3, and 4 by 35 percent.**

Table 7 summarizes the major parameters and costs of each alternative. Costs have been annualized and unitized without interest and amortization for illustrative purposes.

Based on the scale and estimated half-life of each scenario, Alternative 3 is the most cost-effective for the county. This is not surprising, given the fact that it assumes a cost share of 65 percent paid by the federal government under the Corps of Engineers' present funding formulas. The second lowest cost per year is Alternative 4 because of its small scale. However, this alternative results in the highest cost per beach-foot or beach-acre per year. Alternative 1 yields the lowest unit beach cost per year because of its long half-life and other economies of scale.

Maintenance of the Project

Maintenance of beach nourishment projects is linked to the scale of the project and frequency of damaging storms. To the extent that a project restores the profile deficit and incorporates some quantity of sand that can be sacrificed each year, maintenance will be significantly reduced.

TABLE 7. Summary of Beach Restoration Alternatives Developed in the Present Study. [Alternative 3 - Source: USACE (1999). Note: All costs are given without interest and amortization for illustration purposes. Costs for Alternative 3* are the Local Share (excludes federal share – 65 percent).]

Alternative	Applicable Reaches	Length (ft)	Nourishment Volume (cy)	Average Fill Section (cy/ft)	Avg Increase Beach Width @ Pavilion (ft)	Beach Area Added (acres)	Estimated Half-Life (years)
1	2,3 & 4	40,000	5,700,000	142.5	220	202	20
2	Park Facilities+	12,150	1,500,000	123.5	200	37	10
3	Park Facilities	6,000	614,000	102.3	110	14	5
4	Park Facilities	6,000	200,000	33.3	40	6	2
Alternative	**Estimated Local Cost ($)**	**Avg Annual Cost ($/year)**	**Avg Unit Cost Per Beach Foot ($/ft)**	**Avg Unit Cost Per Beach Acre ($/acre)**	**Avg Unit Cost Per Acre/Year ($/acre/yr)**	**Avg Unit Cost Per Beach Foot/Year ($/ft/yr)**	
1	$ 30,000,000	$1,500,000	$ 750	$ 148,500	$ 7,425	$ 38	
2	$ 9,000,000	$ 900,000	$ 741	$ 240,437	$ 12,022	$ 74	
3*	$ 2,250,000	$ 450,000	$ 375	$ 163,187	$ 8,159	$ 75	
4	$ 1,500,000	$ 750,000	$ 250	$ 272,250	$ 13,613	$ 125	

Alternates 1 and 2 are formulated at a level intended to restore the profile deficit and provide some advance nourishment. Both alternatives will provide a much wider recreational beach that can adjust to seasonal changes in the profile with little adverse impact to the foredune. The resulting dry beach will naturally feed the dunes. Dunes may be enhanced and stabilized by scraping (a rapid means of replacing missing dunes or raising the elevations of existing dunes above storm-surge levels) and by sand fencing or vegetation.

CSE recommends dune enhancement sufficient to provide at least 50-year storm-surge protection. This means a sufficient volume of sand should be maintained in the foredune above the 50-year surge level. Approximating FEMA criteria (Dewberry and Davis 1989; cf, Fig 9), there should be at least 15 cy/ft above the +10-ft NGVD contour. This criteria is met at present along large portions of the park and some portions of the Pattersquash reach. Maintenance of dune volumes above surge elevations is critical for preserving the littoral sand budget or minimizing the threat of breaches of the barrier. This is consistent with recommendations of the Governor's Coastal Erosion Task Force (NYDOS 1994), which recommends immediate closure of breaches should they occur. Alternative 1 provides nourishment along the Pattersquash reach such that dune volumes can be maintained. Alternative 2 does not provide sufficient nourishment to fully restore the dunes along the Pattersquash reach.

CSE anticipates that under Alternatives 1 and 2, minimal dune maintenance will be required during the first five years of the project. After five years, Alternative 2 will experience a significant decline in profile volumes along the ends of the project. This will increase the likelihood of dune scarping and backshore erosion in some sections. Small-scale dune restoration should be performed using stockpiled sand quantities as needed. Sand fencing and vegetation should be maintained along the foredune following state guidelines.

Alternatives 3 and 4 are much smaller scale projects with shorter half-lifes. Maintenance requirements will therefore be greater. The federal (interim) project anticipates maintenance in the form of renourishment at approximate five-year intervals. [Note: Because it is an interim project, implicit in the plan is an assumption that a certain larger scale nourishment would be implemented based on the reformulation study.] The scope and cost of maintenance would be comparable to the initial cost of Alternative 3 (USACE 1999). This cost can be roughly approximated on an annual basis using Table 7.

Alternative 4 would have the shortest longevity and would have to be repeated on an ongoing basis every 2-3 years to keep pace with erosion **and** restore a portion of the deficit. While this gradual restoration takes place, the dunes/backshore area will remain vulnerable to storm damage. This is likely to result in higher dune maintenance costs during the first 10-15 years of the project under Alternative 4.

As the Governor's Coastal Erosion Task Force found (NYDOS 1994):

> *Beach erosion during severe storms is a recurring long-term problem for the south shores of Long Island. It is a precursor of dune erosion, dune overwash, failure of shoreline protection structures, and destruction of shoreline development. Dune erosion . . . must be addressed by long-term public policy. In some areas, dune overwash has been identified as a matter for immediate attention because of the potential for breaches to be opened by subsequent . . . storm events. Overwash sites in Fire Island National Seashore and Smith Point County Park are examples of areas believed to be vulnerable to breaching. Critical erosion of this type must be addressed.* (Excerpted from pp 6-7)

CSE believes that the conditions described above have not fundamentally changed since the task force made its finding in 1994.

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APPENDIX I

Historical and Recent Beach/Inshore Profiles Used in the Present Analyses

A. Profile listing.

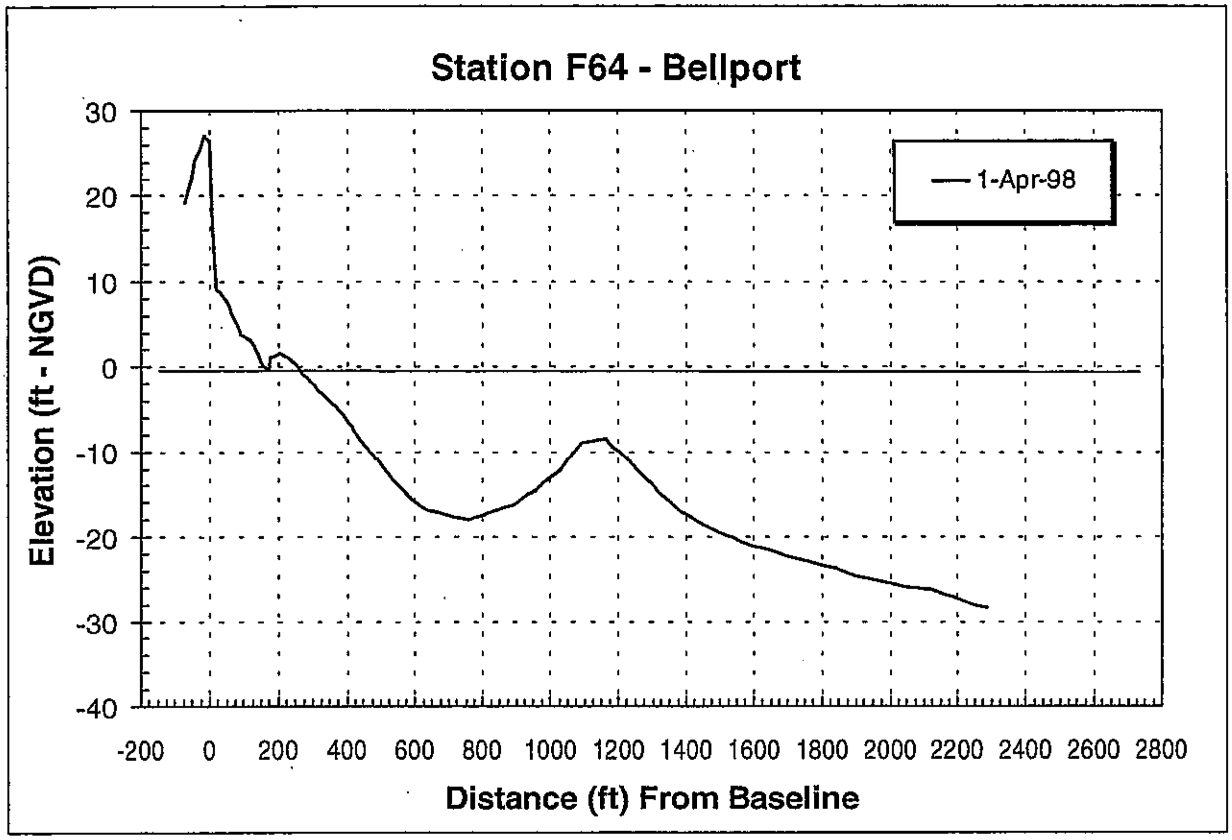
B. Map showing general profile locations.

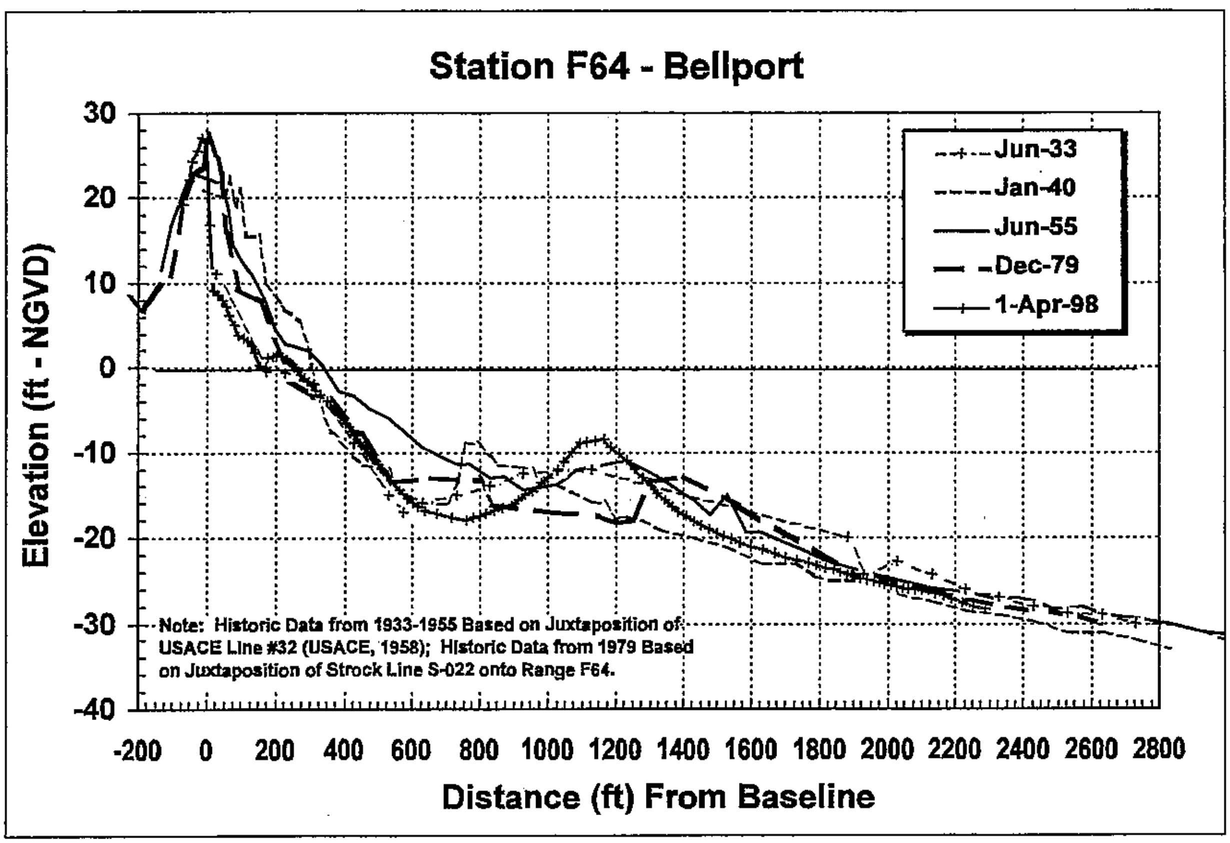
C. Geographic relationship of profile stations with respect to a shore-parallel baseline for purposes of juxtaposing historical and recent data

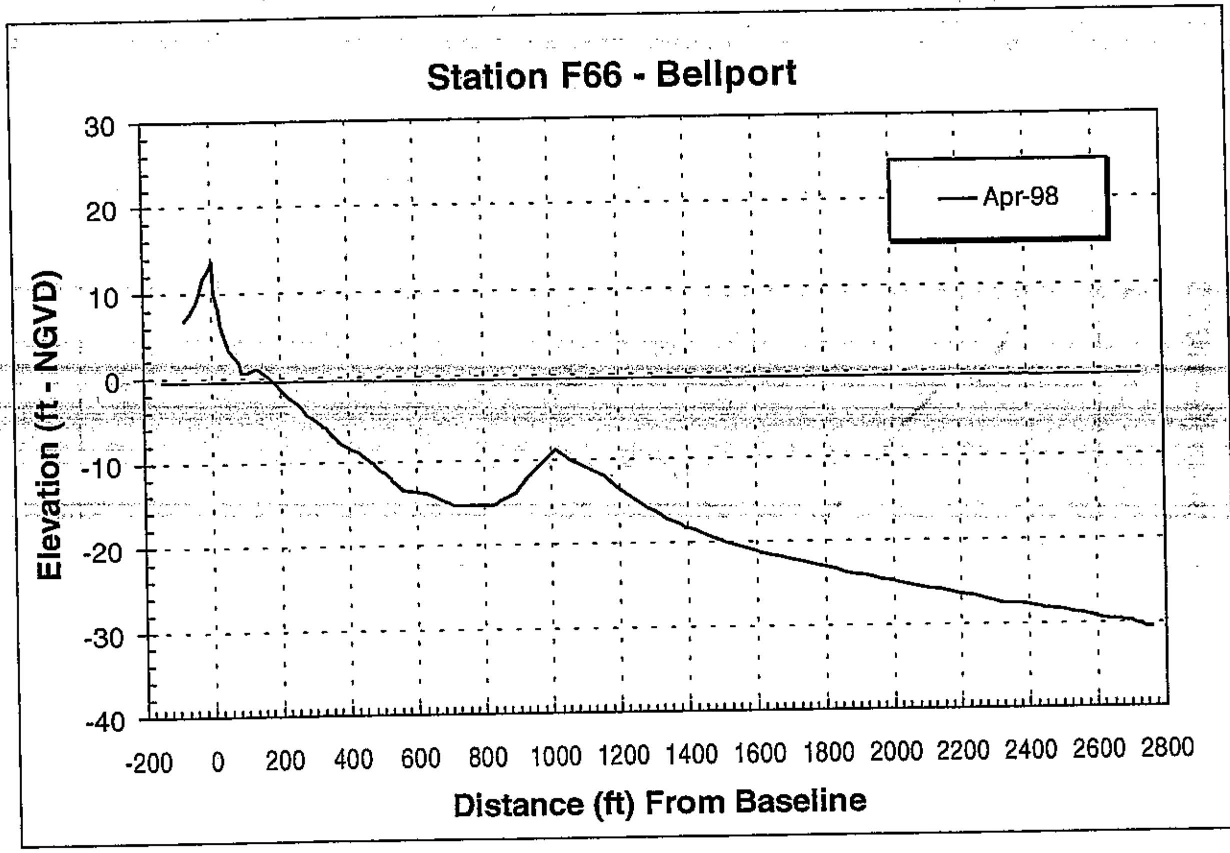
D. Profiles for "F" and "W" series stations showing representative dates. Table D-1 lists the applicable coverage for the present study area.

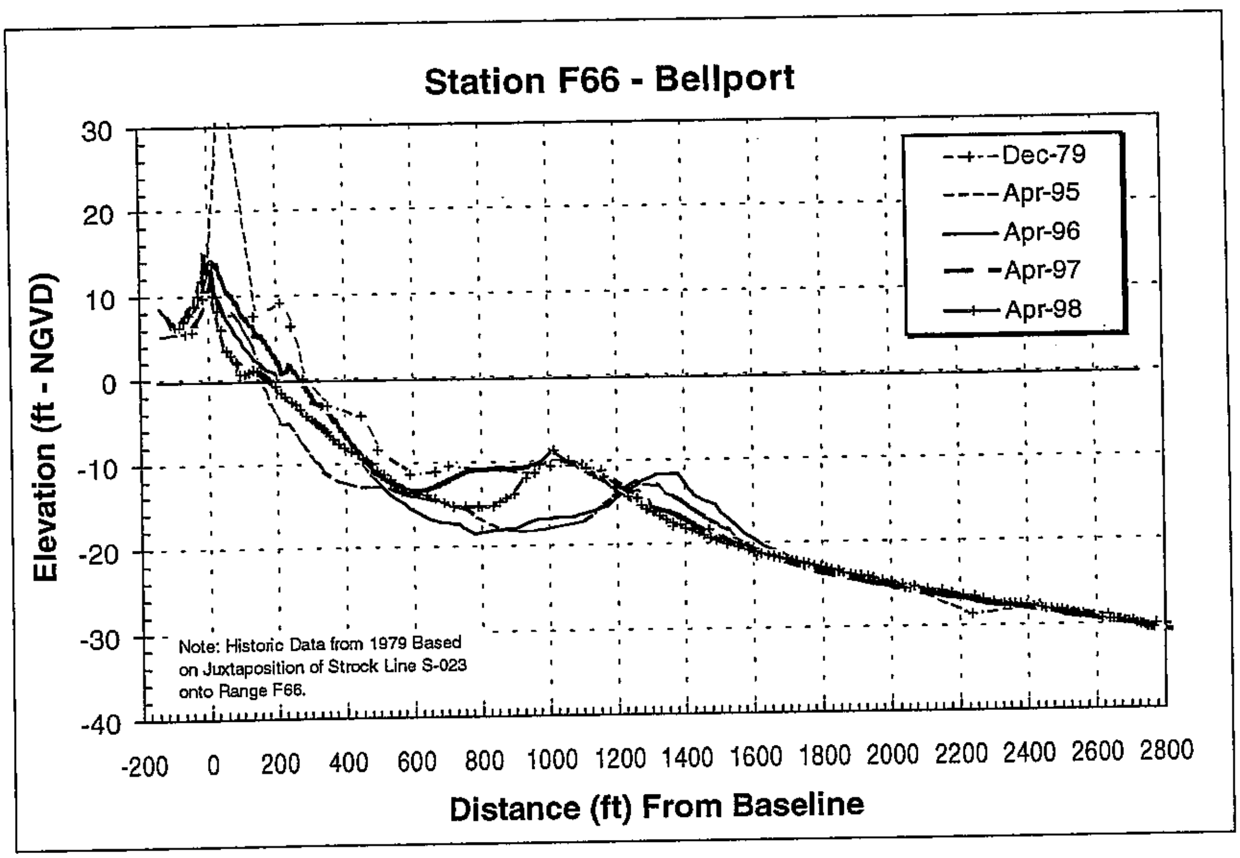
APPENDIX I-A. Profile listing with coordinates and benchmark elevations. Datum: US State Plane NAD 1983 Zone: New York – Long Island 3104

	Station	Northing	Easting	Elevation @ BM / 0 ft Distance (ft NGVD)
USACE (1958) Series	143B-720+00	*223654.743*	*1338156.503*	NA
	143B-808+00	*220679.623*	*1329876.446*	NA
	144B-36	*220721.612*	*1328696.441*	13.0
	145A-35	*216279.456*	*1318126.416*	10.0
	151A-34	*211062.292*	*1306006.365*	14.5
	151A-33	*204054.086*	*1289396.285*	25.0
	151B-32	*200561.993*	*1281676.245*	22.0
Strock (1979) Series	S-022	*200662.995*	*1281856.246*	27.5
	S-023	*202870.990*	*1286626.325*	37.5
	S-024	*204460.097*	*1290286.290*	32.0
	S-025	*206299.631*	*1294552.340*	24.0
	S-026	*208031.775*	*1298610.636*	28.0
	S-027	*209826.252*	*1302776.350*	23.5
	S-028	*212408.330*	*1308976.379*	12.3
	S-029	*214156.996*	*1312945.429*	27.0
	S-030	*216603.468*	*1318846.419*	24.5
	S-031	*218587.870*	*1323560.402*	NA
	S-032	*220277.606*	*1328586.444*	18.5
	S-032A	*221432.655*	*1332226.459*	21.0
	S-033	*222733.173*	*1335567.923*	27.0
	S-034	*223692.744*	*1338266.504*	23.0
NYDOS (F/W) Series	F-64	200666.715	1281864.127	NA
	F-66	202883.790	1286564.159	NA
	F-67	203842.489	1288631.993	NA
	F-68	204706.354	1290734.739	NA
	F-70	206325.866	1294560.512	NA
	F-71	208023.747	1298570.774	NA
	F-72	209885.984	1302770.276	NA
	F-74	211106.094	1305734.001	NA
	F-76	212558.760	1308910.642	NA
	F-77	214320.562	1312891.357	NA
	F-79	216603.776	1318843.108	NA
	F-81	218571.597	1323601.422	NA
	F-84	220310.012	1328556.441	NA
	W-3	221724.848	1332571.128	NA
	W-5	222779.053	1335613.294	NA
	W-6	223842.740	1338181.859	NA


Station F64 - Bellport
1-Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline


Station F64 - Bellport
Jun-33
Jan-40
Jun-55
Dec-79
1-Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #32 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-022 onto Range F64.
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline


Station F66 - Bellport
Apr-98
Elevation (ft - NGVD)
Distance (ft) From Baseline
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800


Station F66 - Bellport
Dec-79
Apr-95
Apr-96
Apr-97
Apr-98
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-023 onto Range F66.
Elevation (ft - NGVD)
Distance (ft) From Baseline
30
20
10
0
-10
-20
-30
-40
-200
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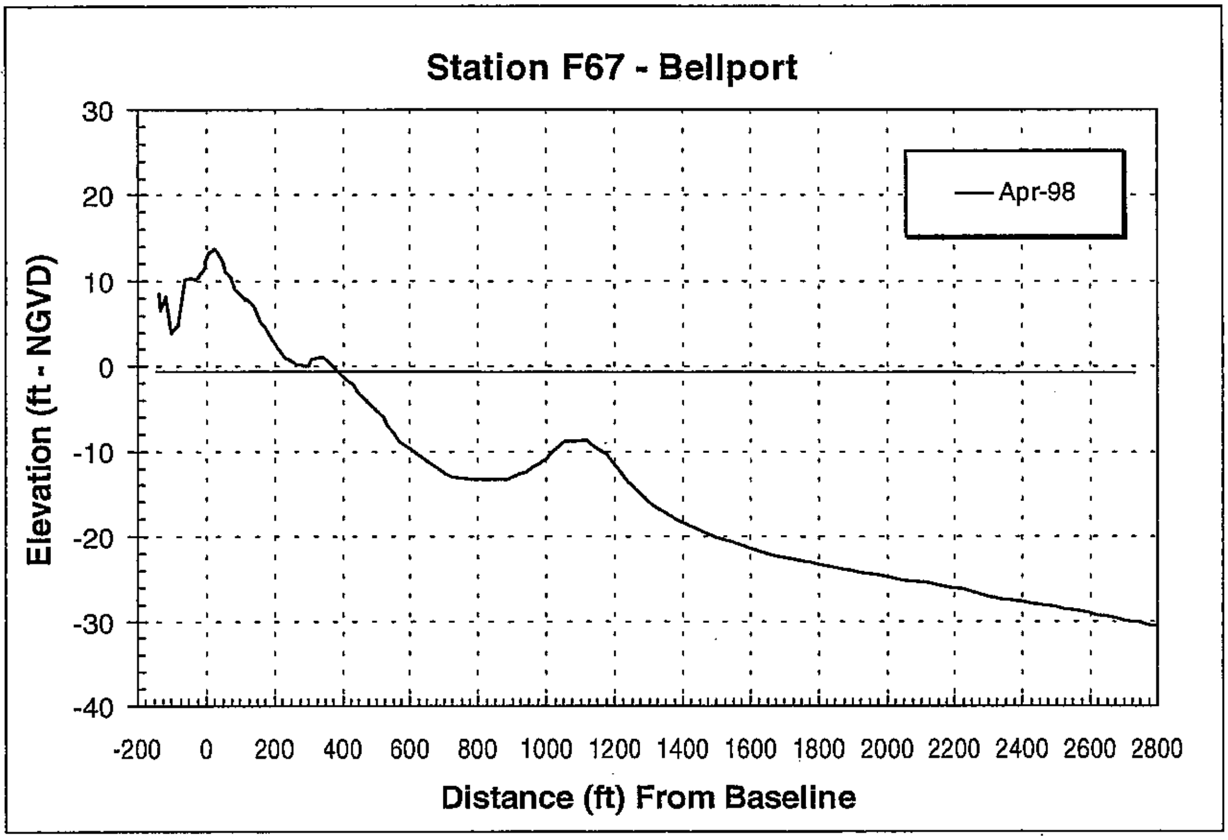
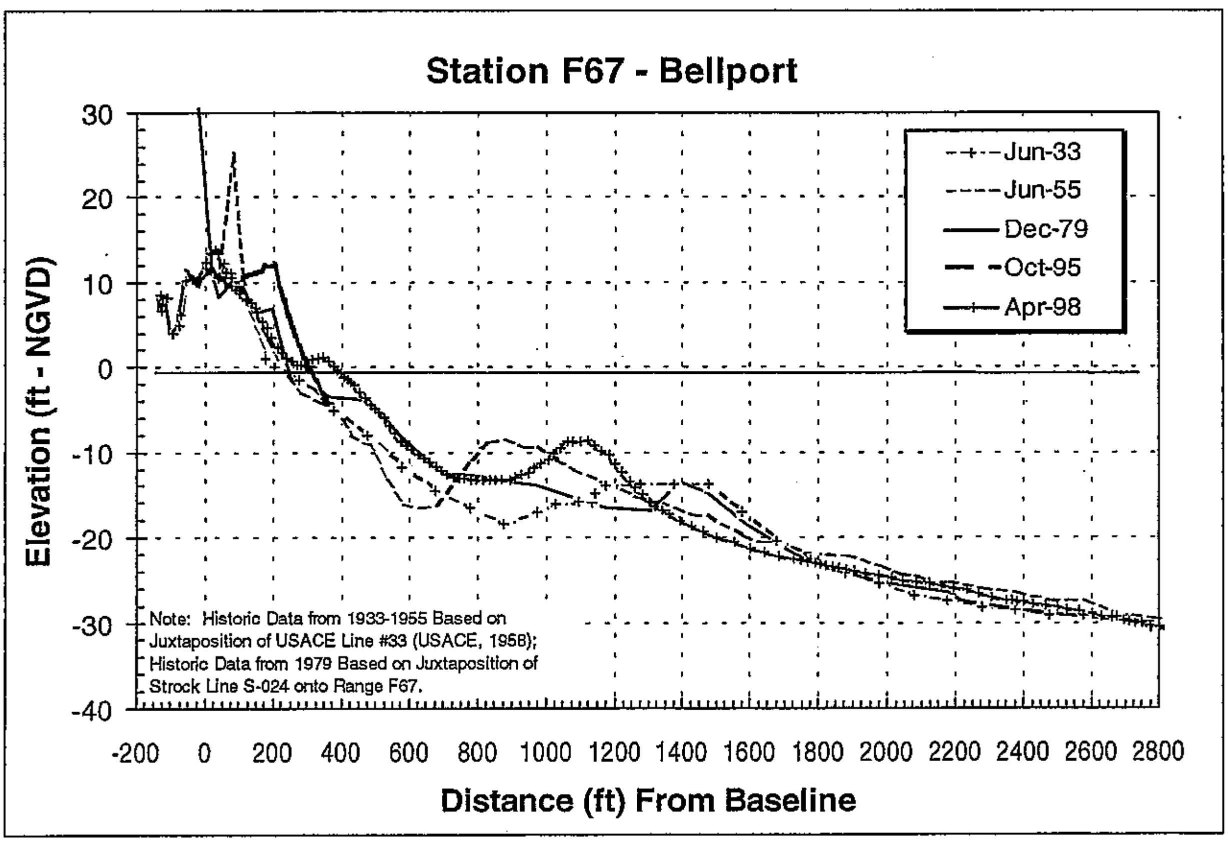
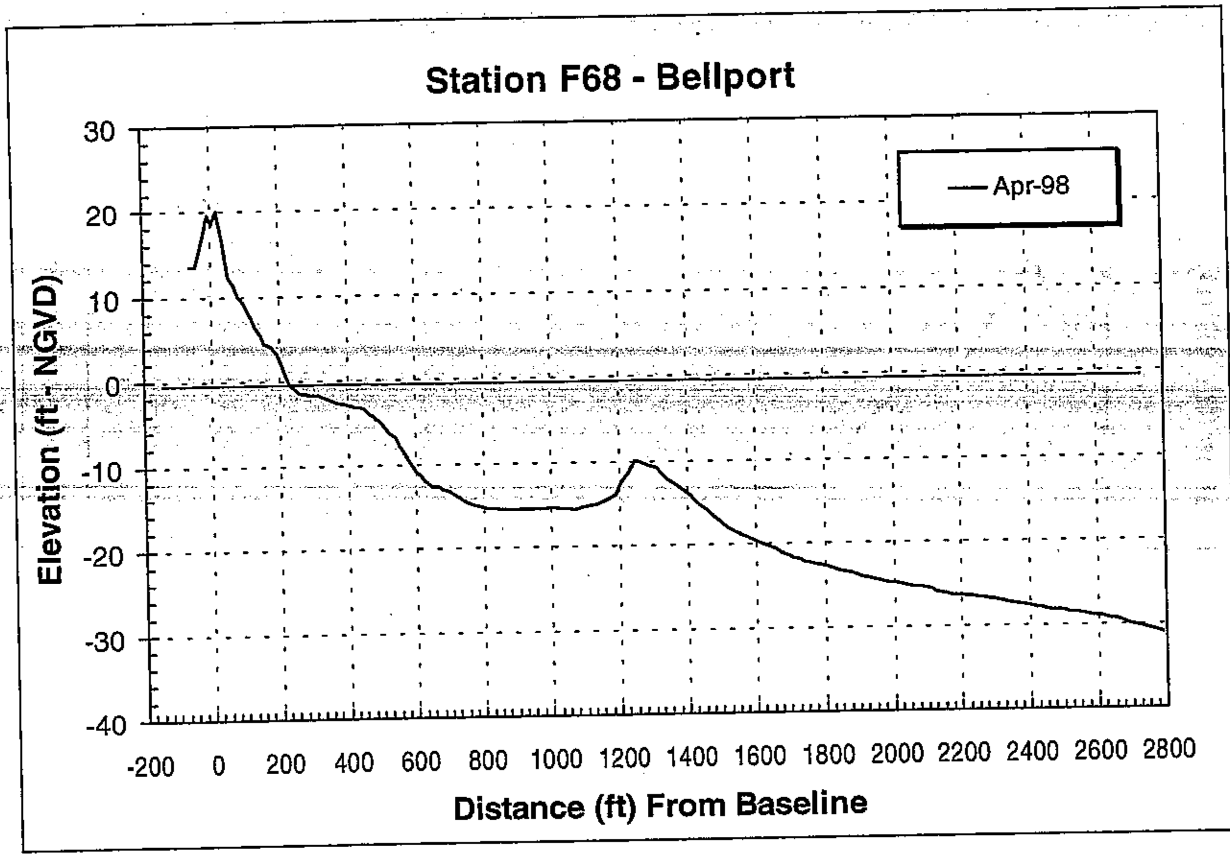
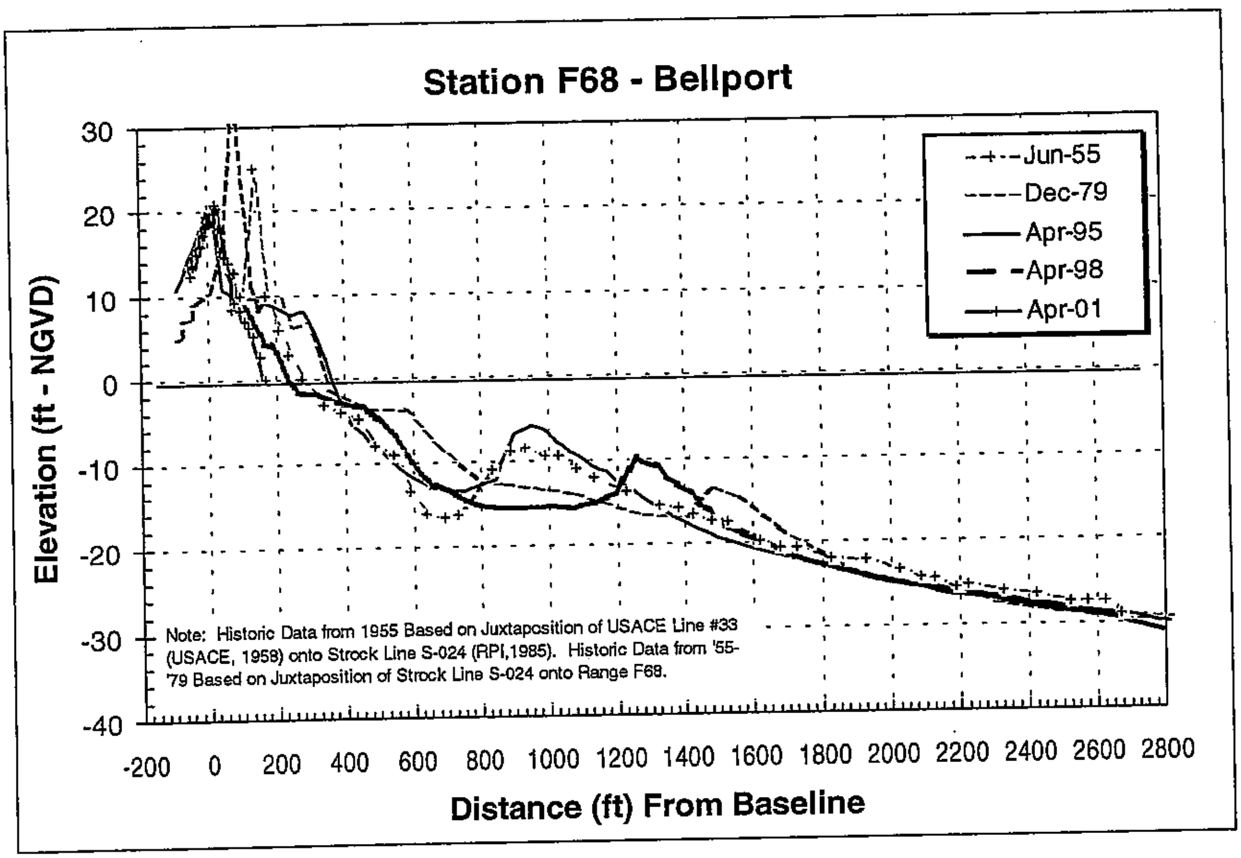
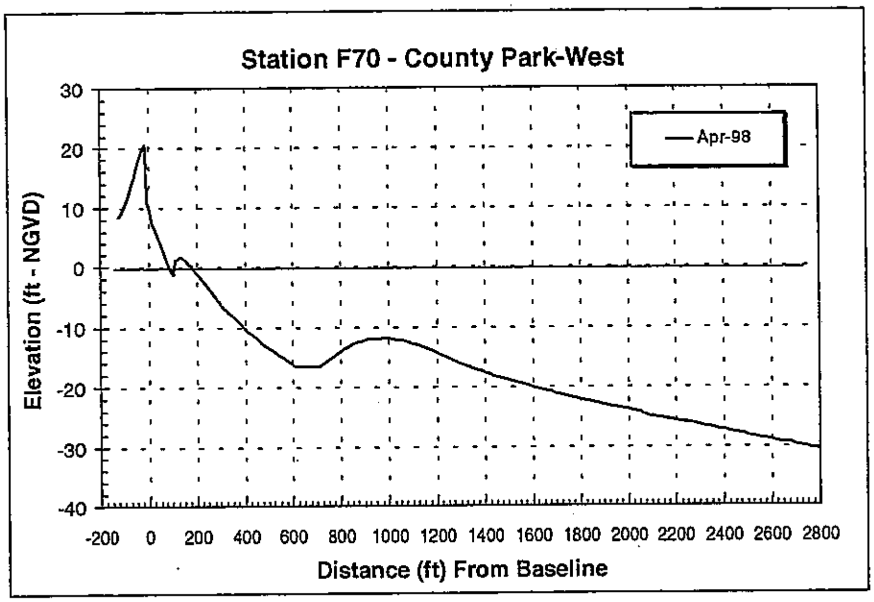
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800

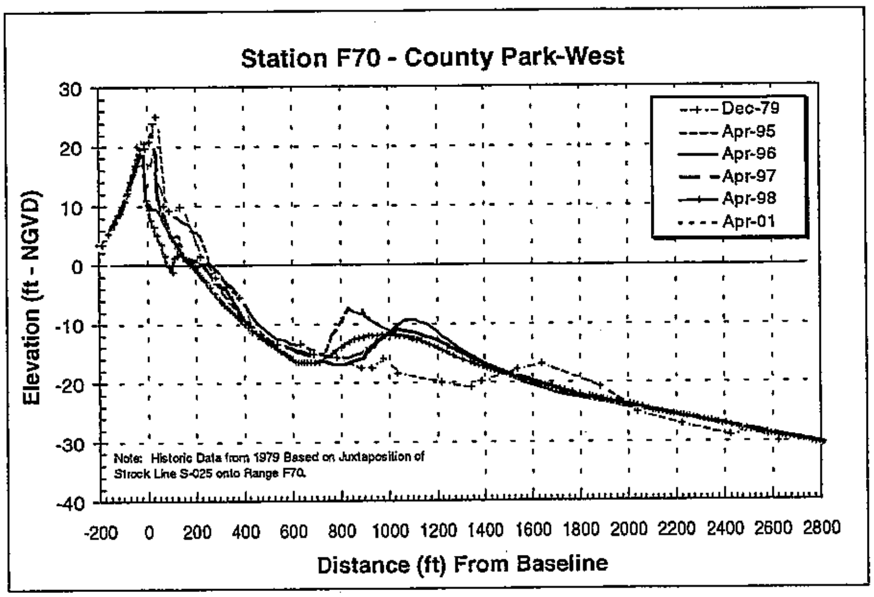

Station F67 - Bellport
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

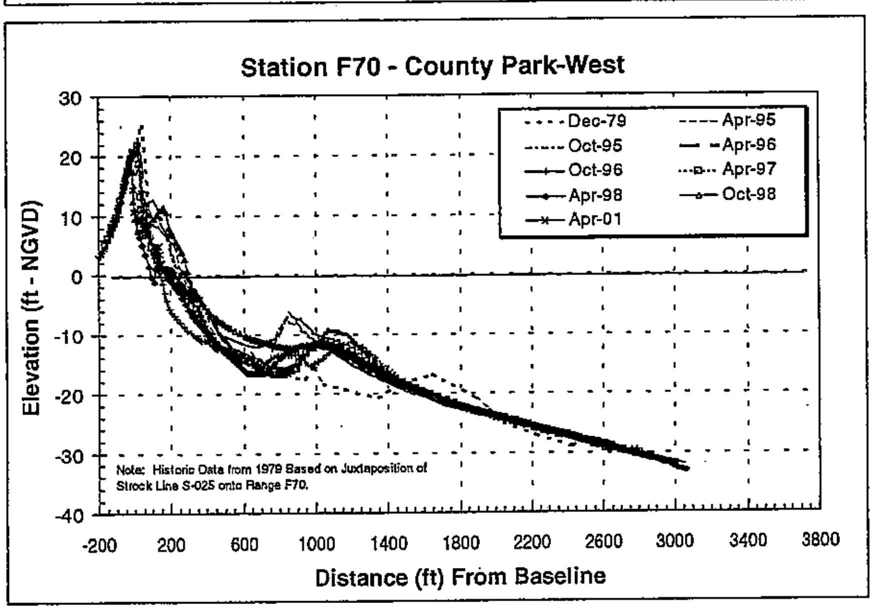

Station F67 - Bellport
Jun-33
Jun-55
Dec-79
Oct-95
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #33 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-024 onto Range F67.
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

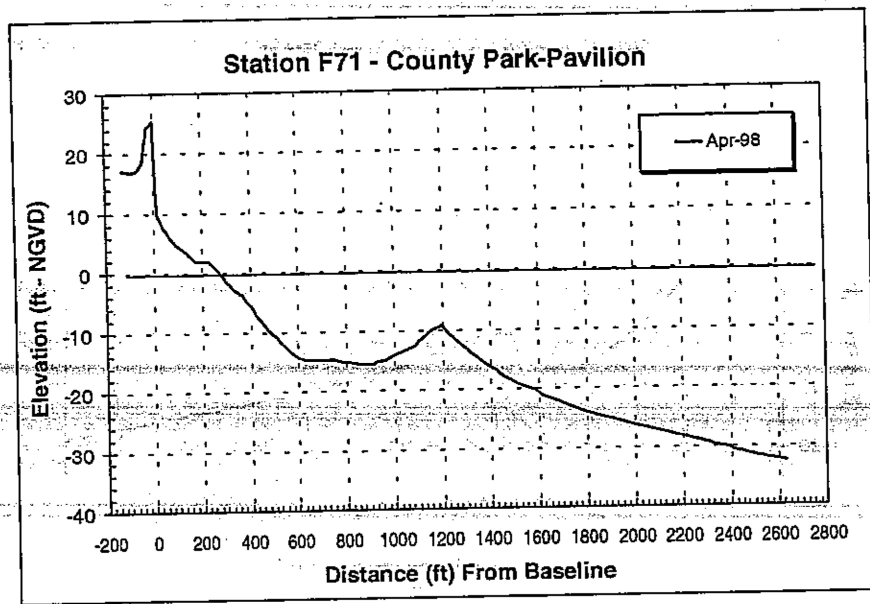

Station F68 - Bellport
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline


Station F68 - Bellport
Jun-55
Dec-79
Apr-95
Apr-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1955 Based on Juxtaposition of USACE Line #33 (USACE, 1959) onto Strock Line S-024 (RPI,1985). Historic Data from '55-'79 Based on Juxtaposition of Strock Line S-024 onto Range F68.
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

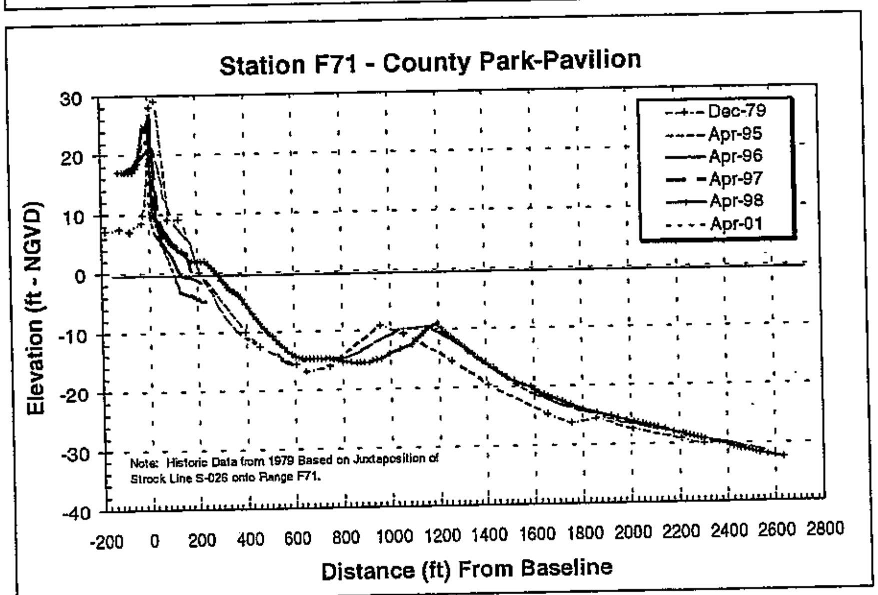

Station F70 - County Park-West
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline


Station F70 - County Park-West
Dec-79
Apr-95
Apr-96
Apr-97
Apr-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-025 onto Range F70.
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline

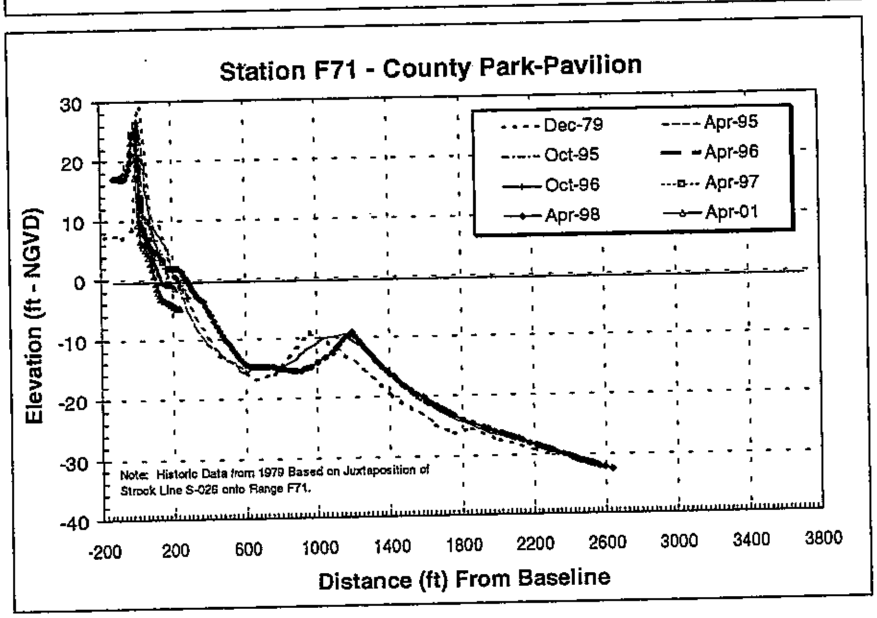

Station F70 - County Park-West
Dec-79
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Oct-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-025 onto Range F70.
-200 200 600 1000 1400 1800 2200 2600 3000 3400 3800
Distance (ft) From Baseline



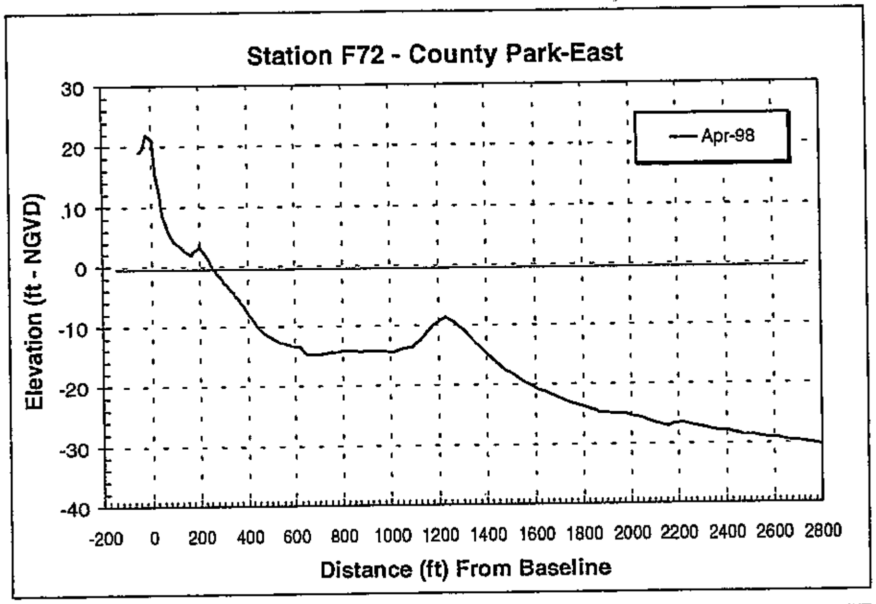
Station F71 - County Park-Pavilion
Apr-98
Elevation (ft - NGVD)
Distance (ft) From Baseline

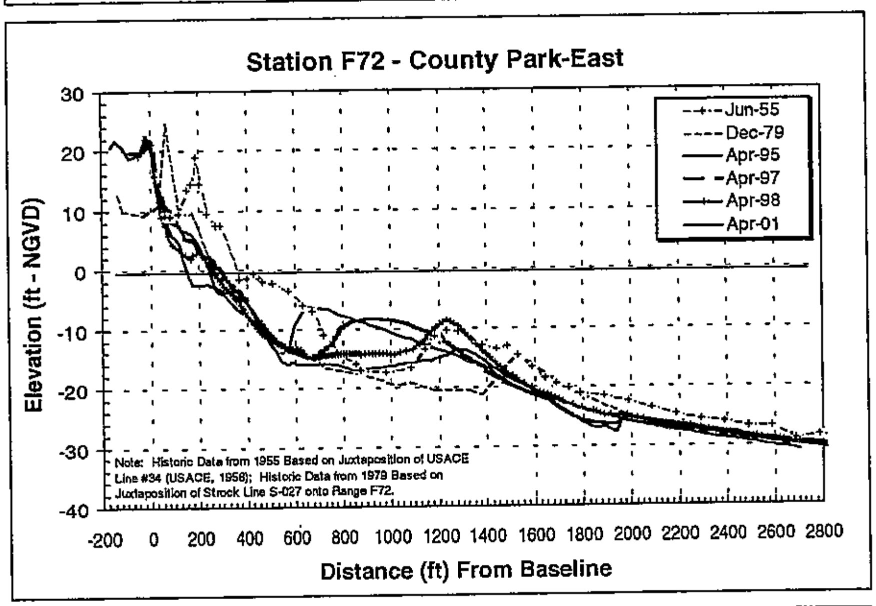


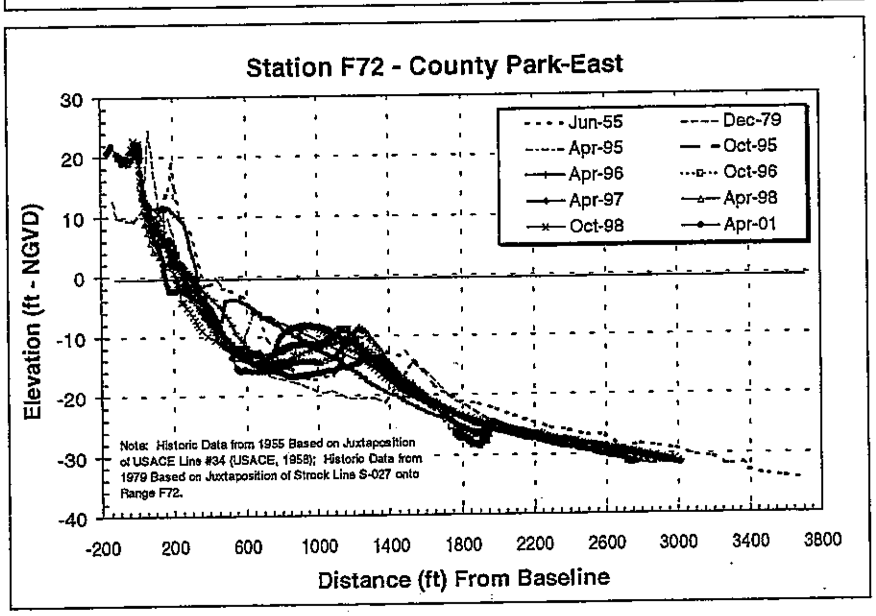
Station F71 - County Park-Pavilion
Dec-79
Apr-95
Apr-96
Apr-97
Apr-98
Apr-01
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-026 onto Range F71.
Elevation (ft - NGVD)
Distance (ft) From Baseline

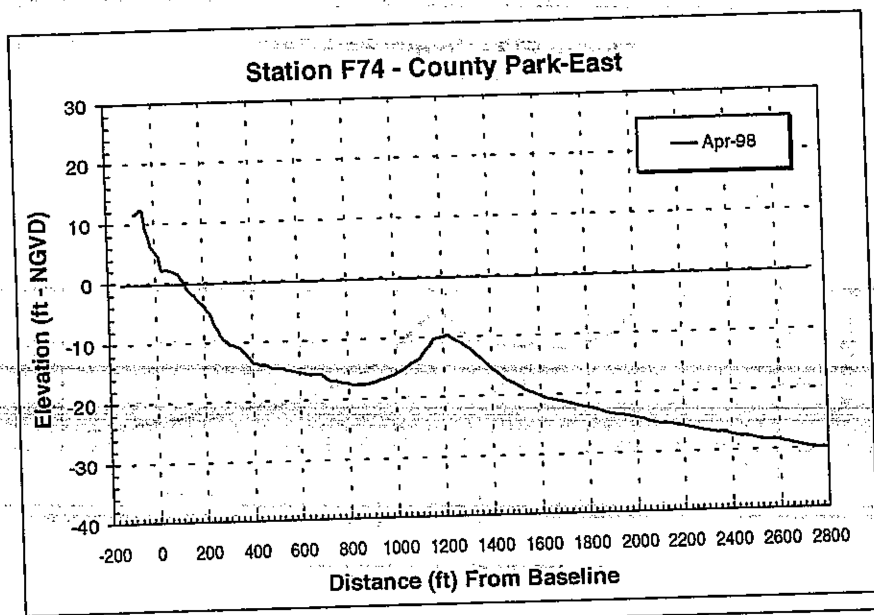


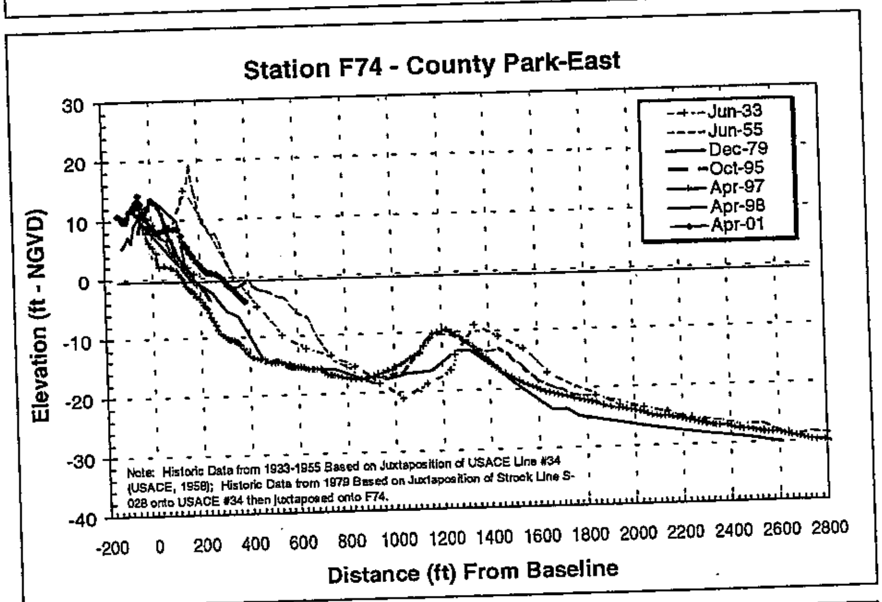
Station F71 - County Park-Pavilion
Dec-79
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Apr-01
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-026 onto Range F71.
Elevation (ft - NGVD)
Distance (ft) From Baseline

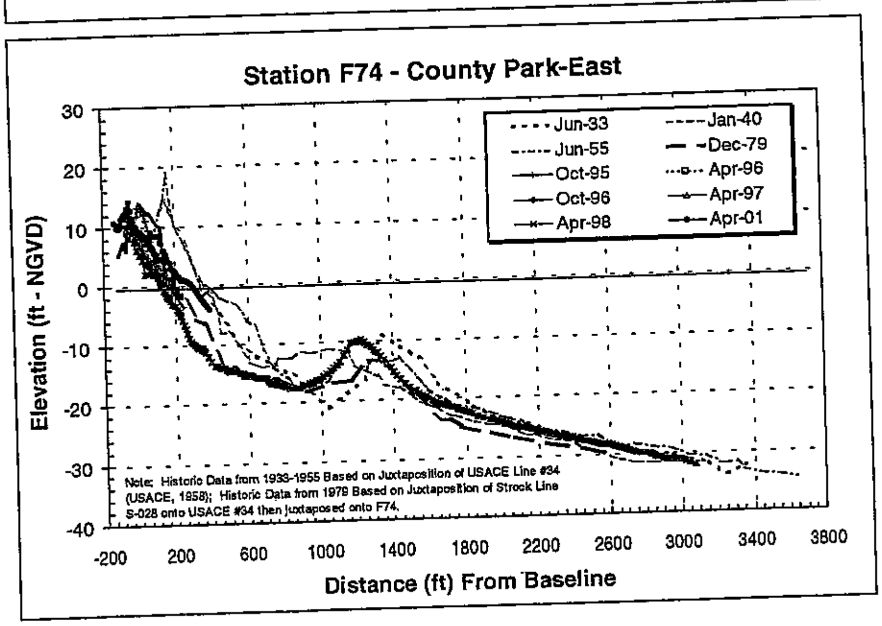

Station F72 - County Park-East
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

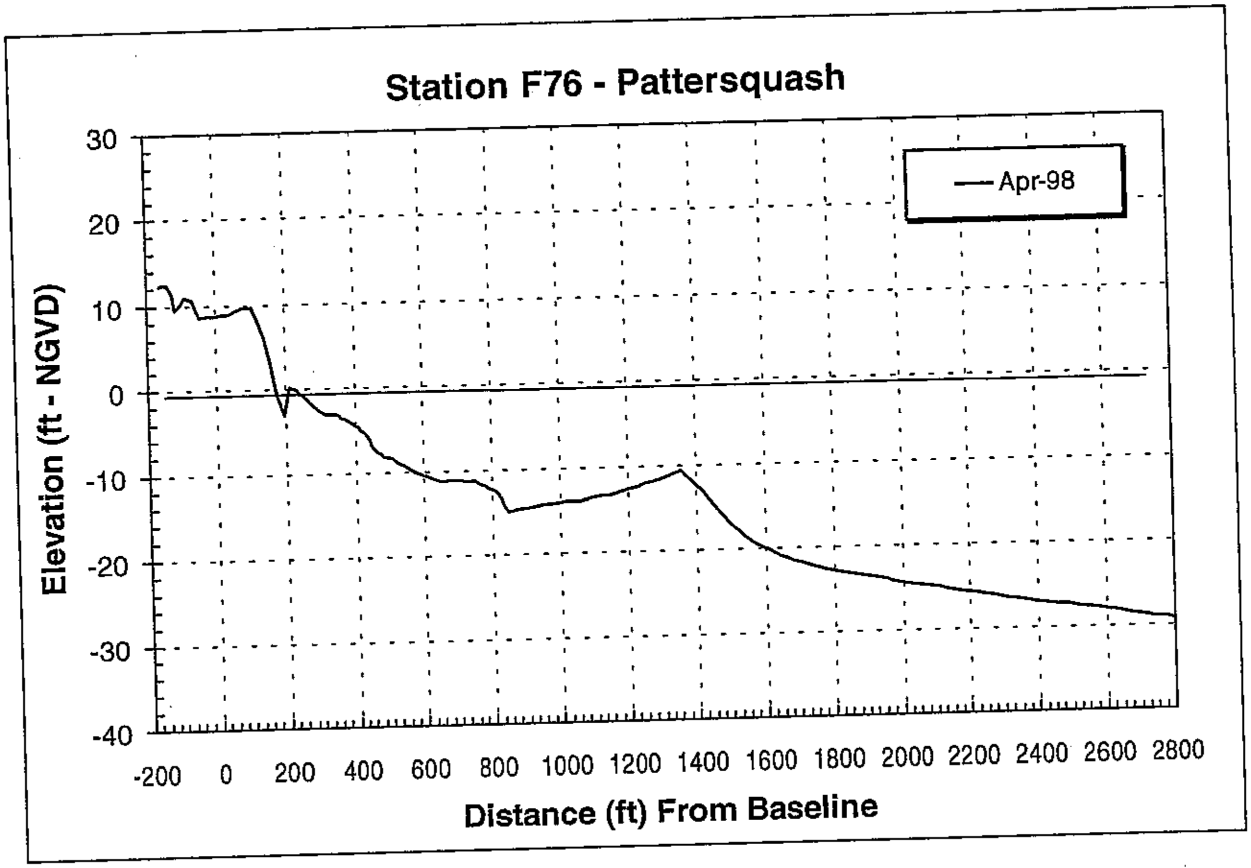

Station F72 - County Park-East
Jun-55
Dec-79
Apr-95
Apr-97
Apr-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1955 Based on Juxtaposition of USACE Line #34 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-027 onto Range F72.
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

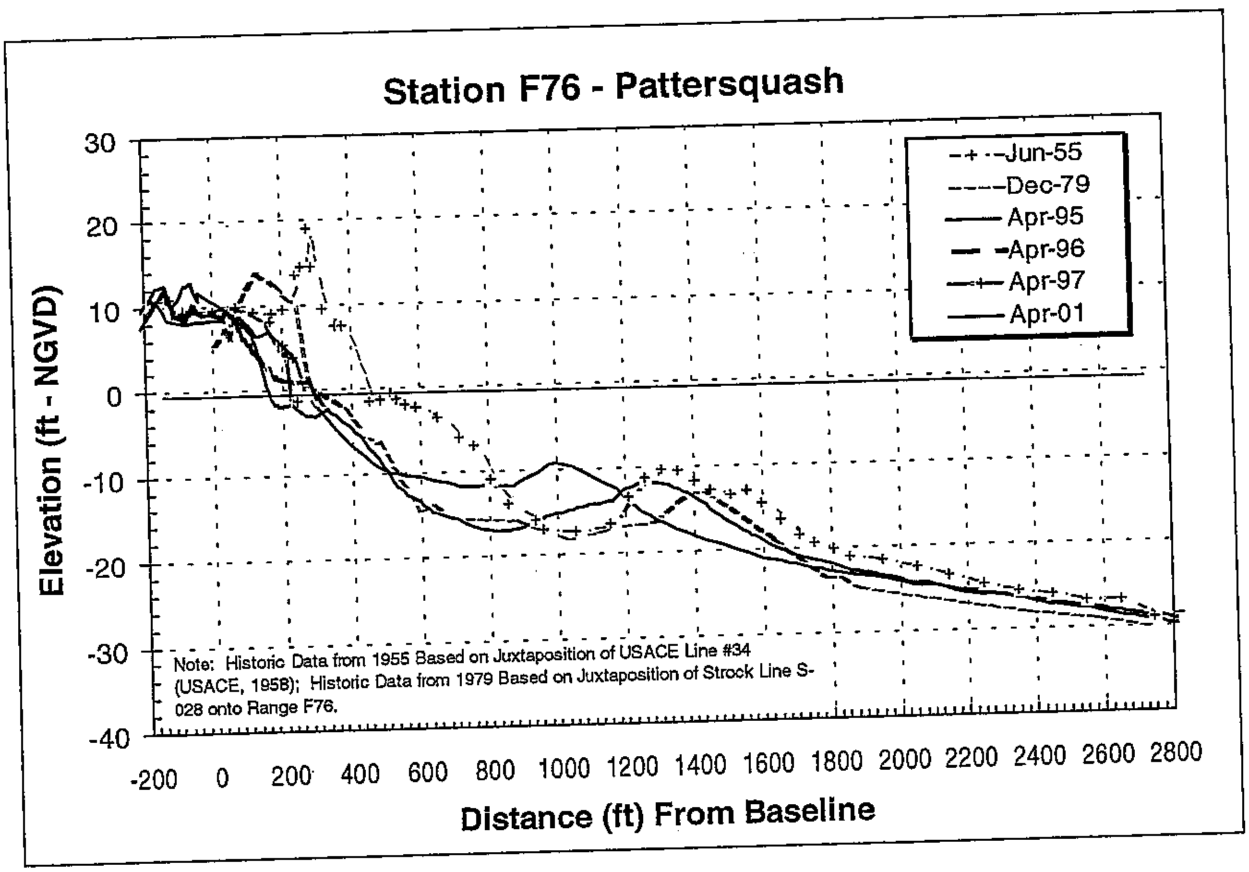

Station F72 - County Park-East
Jun-55
Dec-79
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Oct-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1955 Based on Juxtaposition of USACE Line #34 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-027 onto Range F72.
-200
200
600
1000
1400
1800
2200
2600
3000
3400
3800
Distance (ft) From Baseline

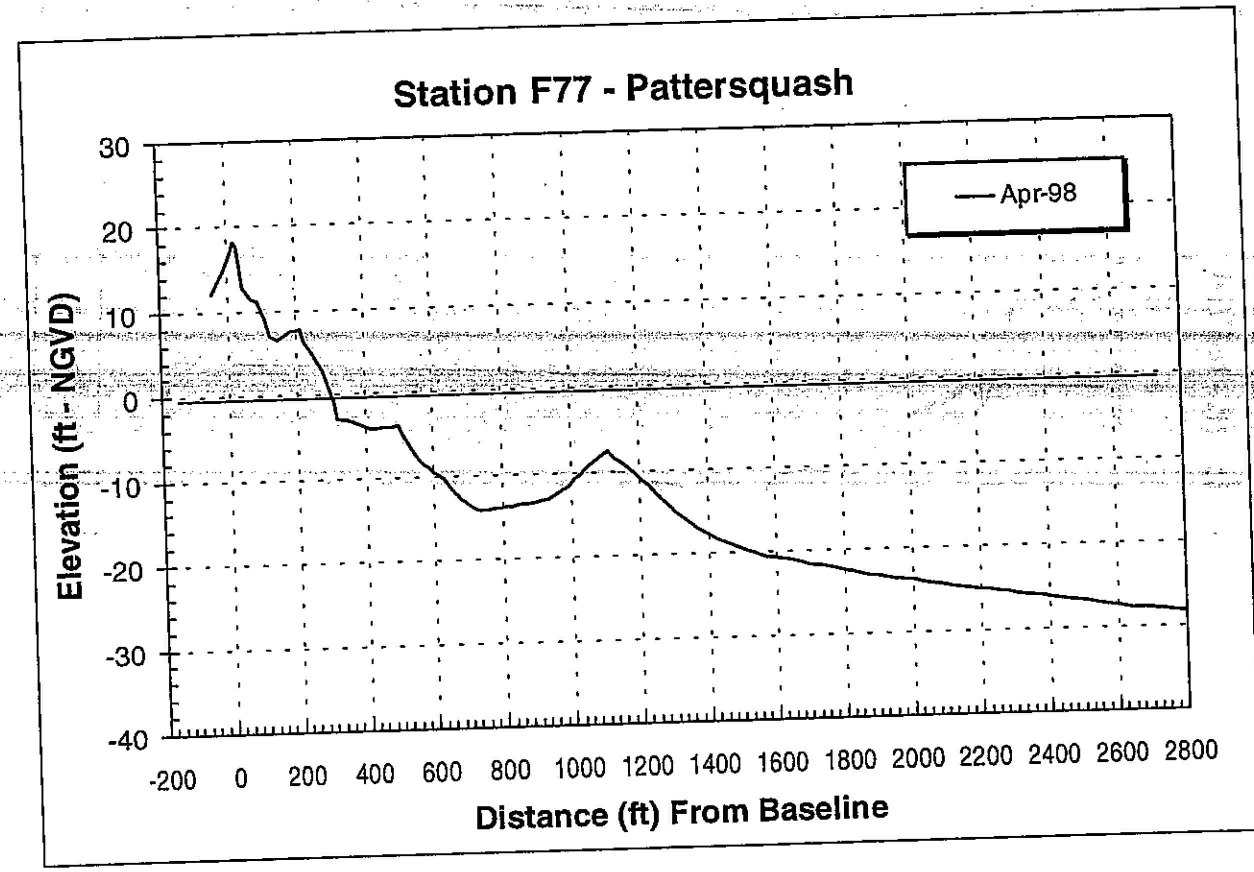

Station F74 - County Park-East
Apr-98
Elevation (ft - NGVD)
Distance (ft) From Baseline


Station F74 - County Park-East
Jun-33
Jun-55
Dec-79
Oct-95
Apr-97
Apr-98
Apr-01
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #34 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-028 onto USACE #34 then juxtaposed onto F74.
Elevation (ft - NGVD)
Distance (ft) From Baseline

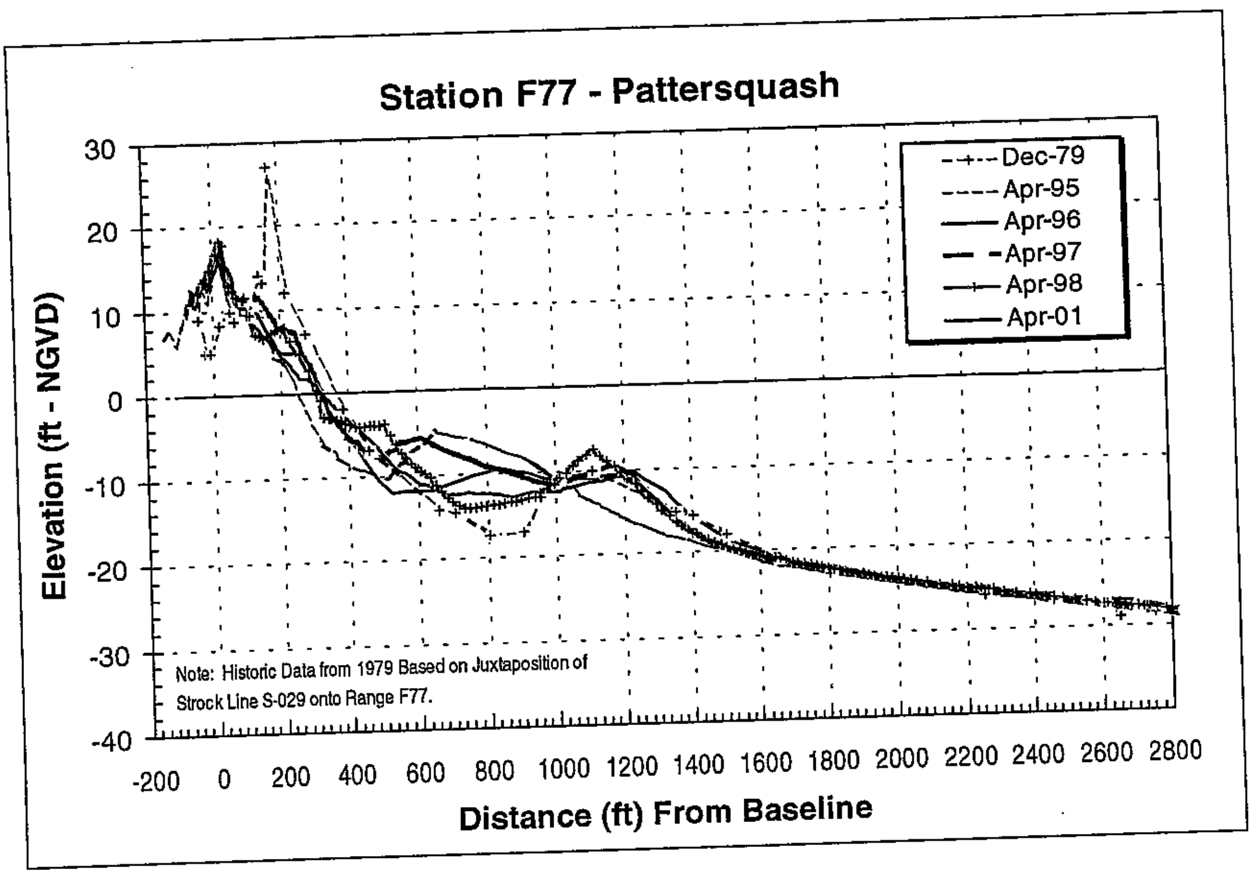

Station F74 - County Park-East
Jun-33
Jan-40
Jun-55
Dec-79
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Apr-01
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #34 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-028 onto USACE #34 then juxtaposed onto F74.
Elevation (ft - NGVD)
Distance (ft) From Baseline


Station F76 - Pattersquash
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline

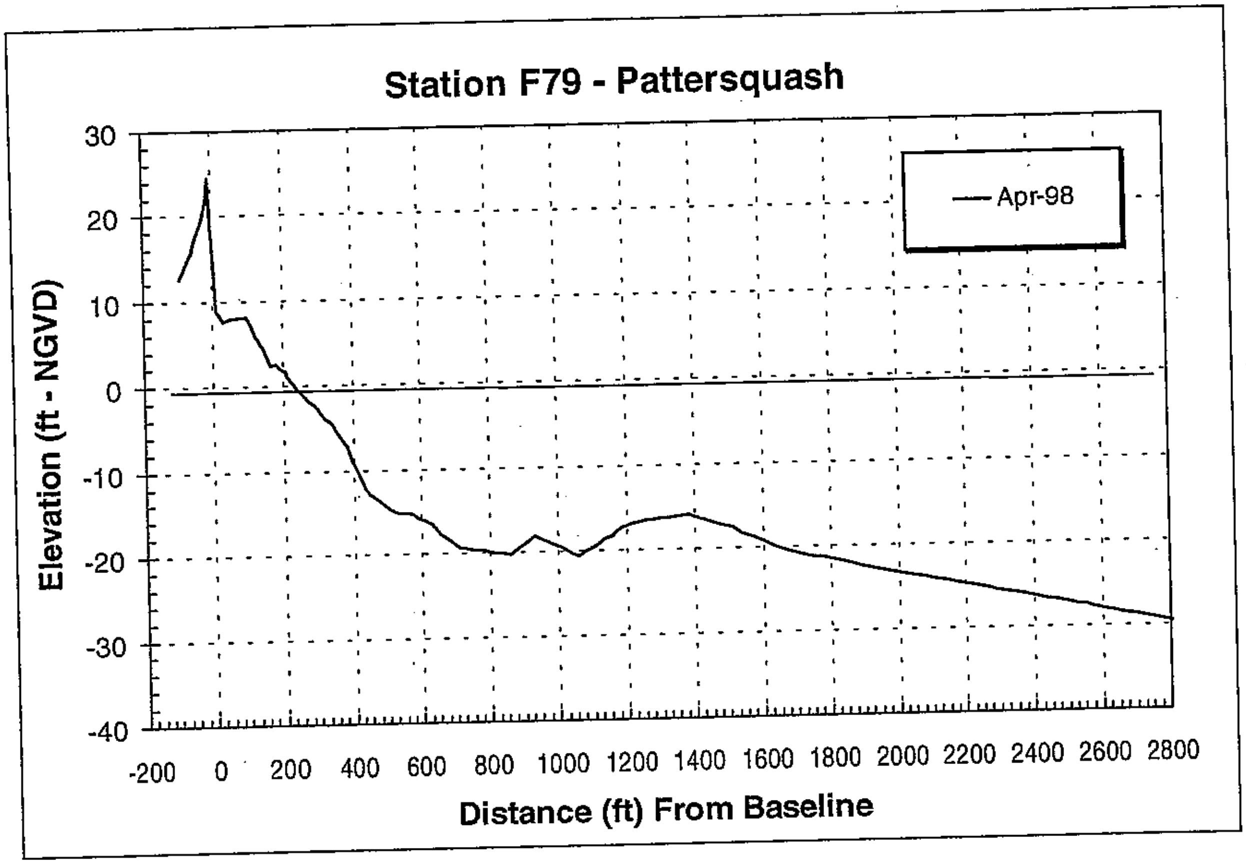

Station F76 - Pattersquash
Jun-55
Dec-79
Apr-95
Apr-96
Apr-97
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1955 Based on Juxtaposition of USACE Line #34 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-028 onto Range F76.
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline



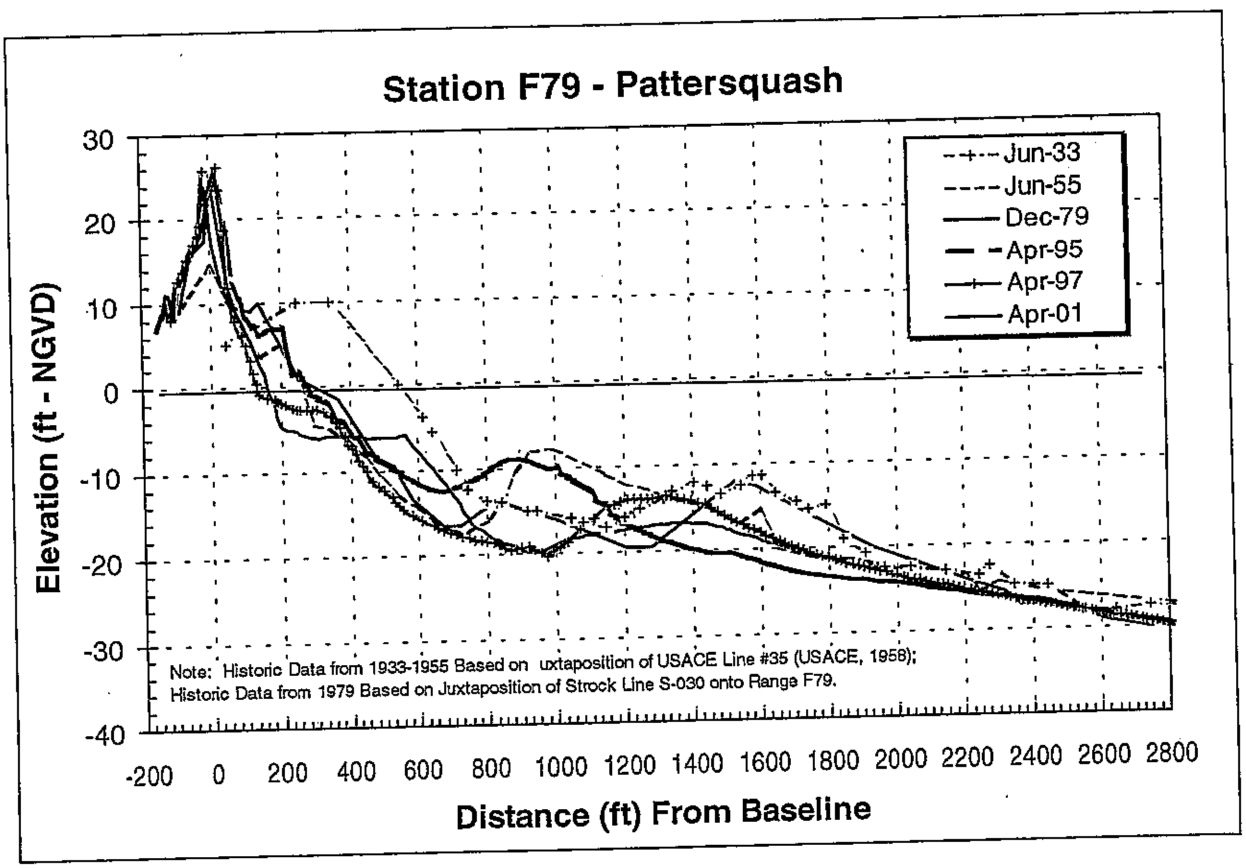
Station F77 - Pattersquash
Apr-98
Elevation (ft - NGVD)
Distance (ft) From Baseline
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800



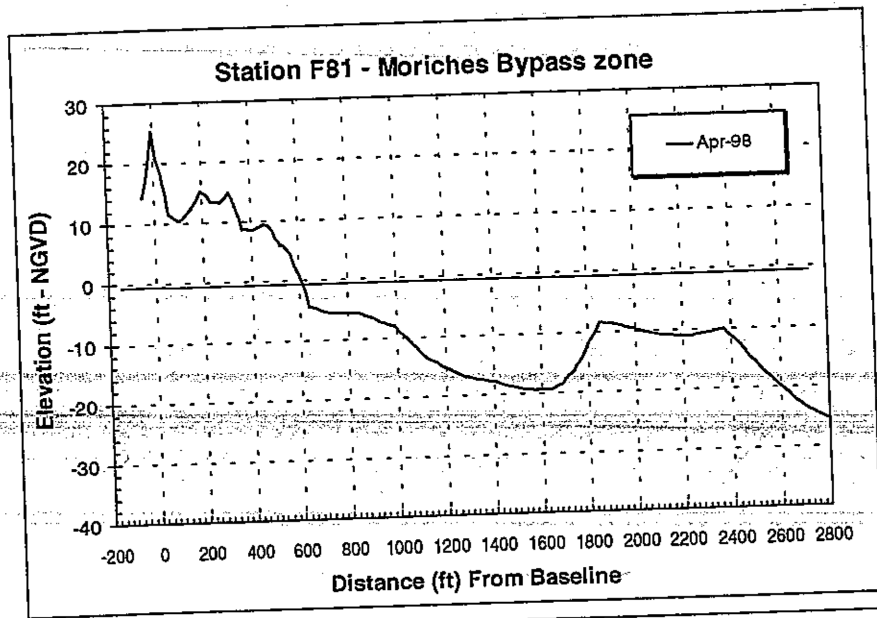
Station F77 - Pattersquash
Dec-79
Apr-95
Apr-96
Apr-97
Apr-98
Apr-01
Elevation (ft - NGVD)
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-029 onto Range F77.
Distance (ft) From Baseline
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800



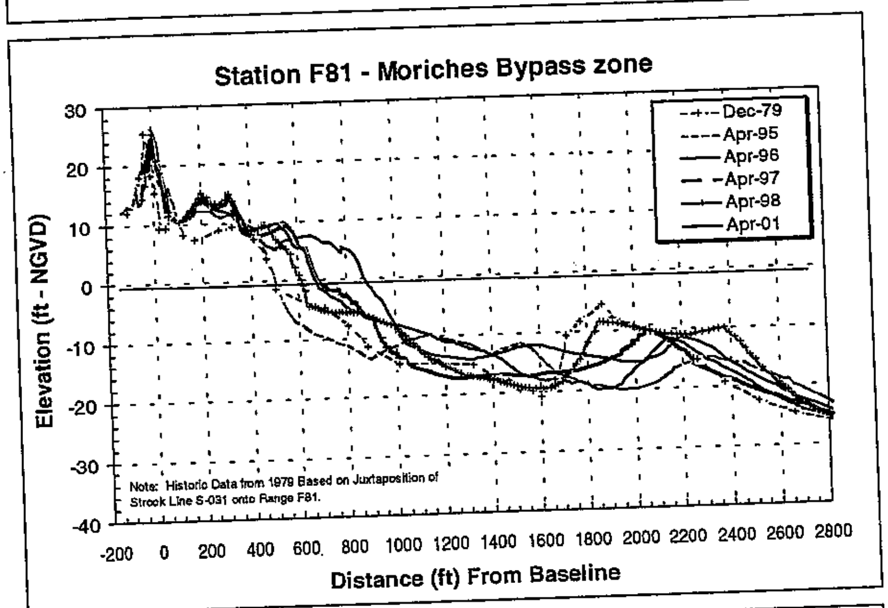
Station F79 - Pattersquash
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline



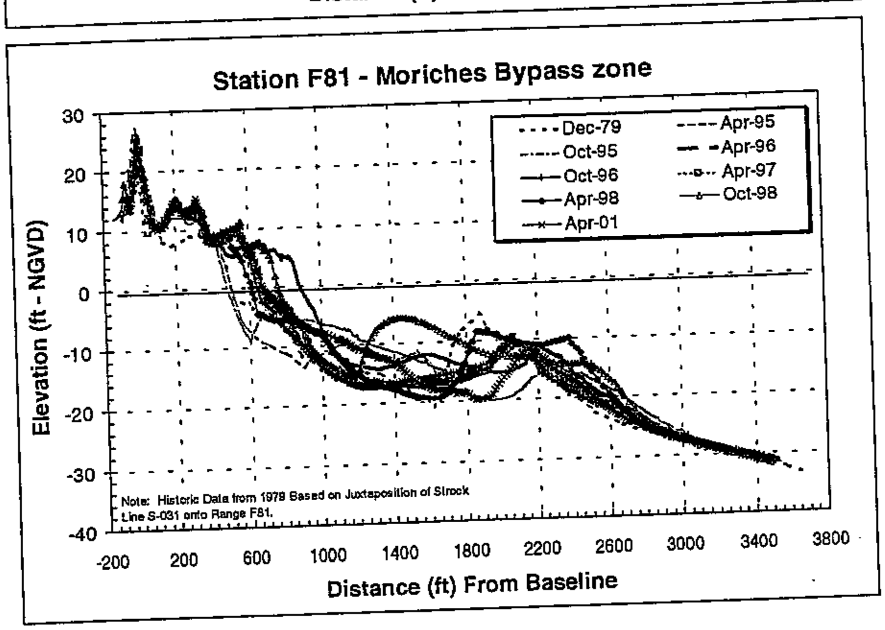
Station F79 - Pattersquash
Jun-33
Jun-55
Dec-79
Apr-95
Apr-97
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1933-1955 Based on uxtaposition of USACE Line #35 (USACE, 1958);
Historic Data from 1979 Based on Juxtaposition of Strock Line S-030 onto Range F79.
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline



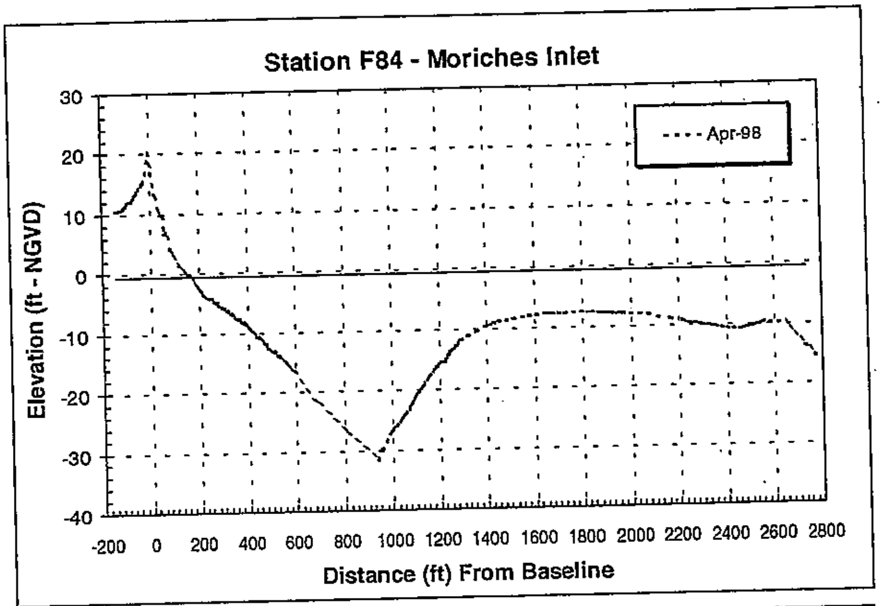
Station F81 - Moriches Bypass zone
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

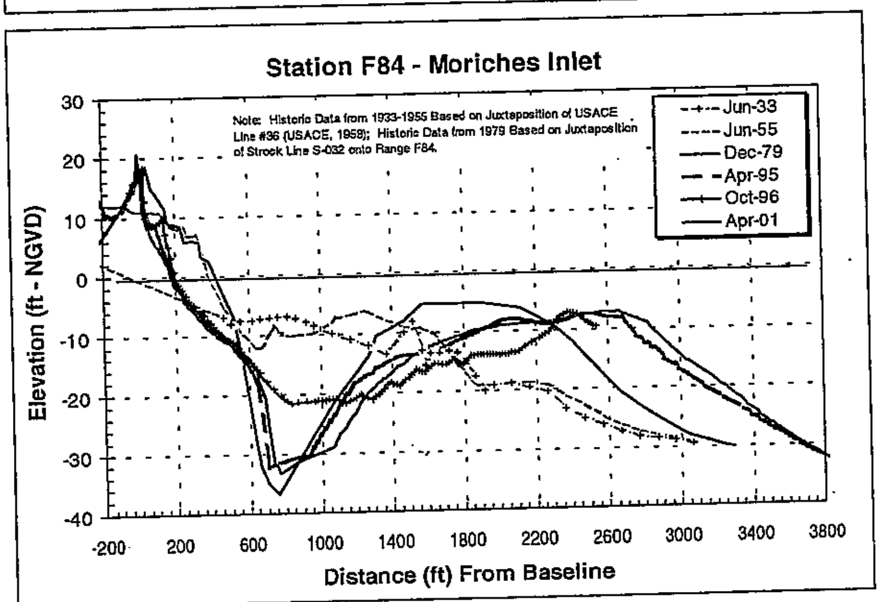


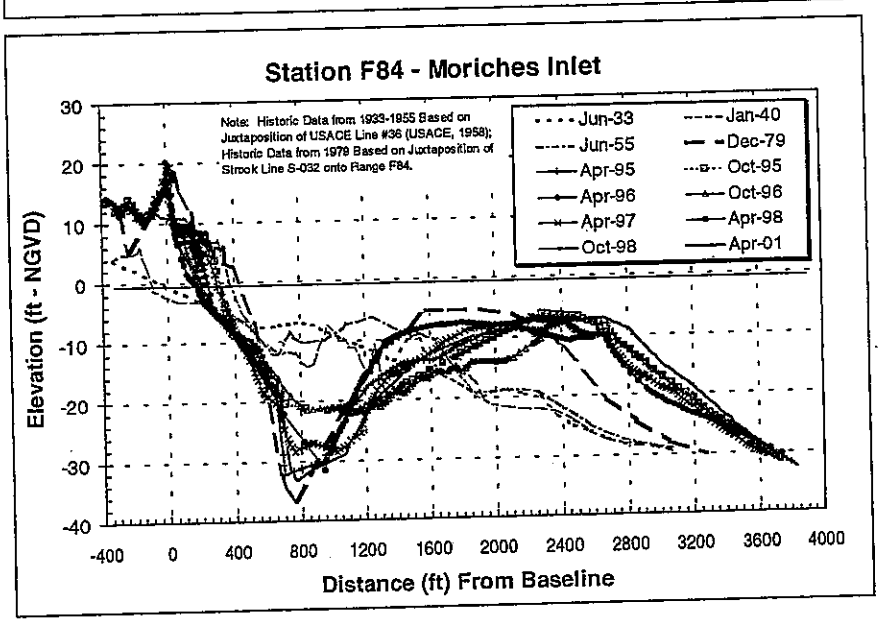
Station F81 - Moriches Bypass zone
Dec-79
Apr-95
Apr-96
Apr-97
Apr-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1979 Based on Juxtaposition of
Strook Line S-031 onto Range F81.
-200
0
200
400
600.
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

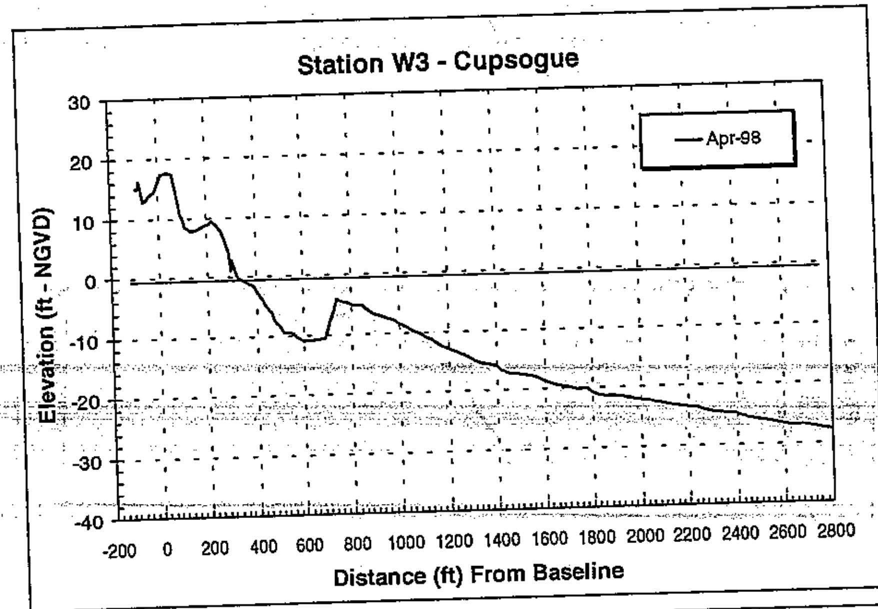


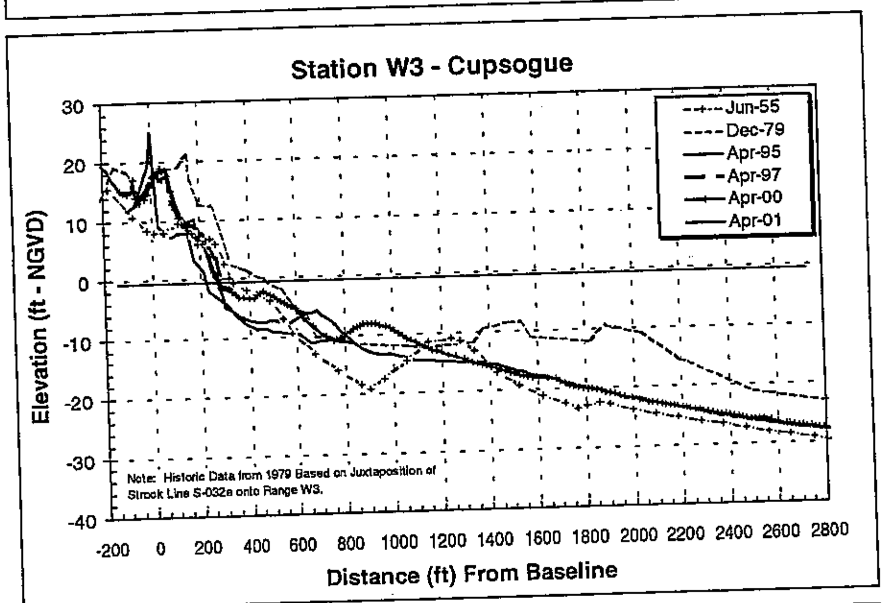
Station F81 - Moriches Bypass zone
Dec-79
Oct-95
Oct-96
Apr-98
Apr-01
Apr-95
Apr-96
Apr-97
Oct-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1979 Based on Juxtaposition of Strock
Line S-031 onto Range F81.
-200
200
600
1000
1400
1800
2200
2600
3000
3400
3800
Distance (ft) From Baseline

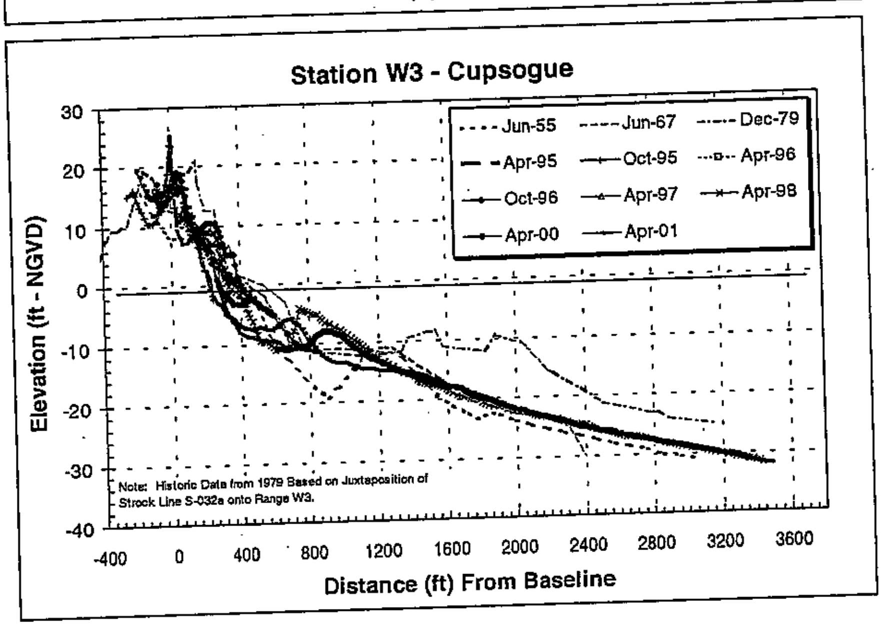

Station F84 - Moriches Inlet
Apr-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

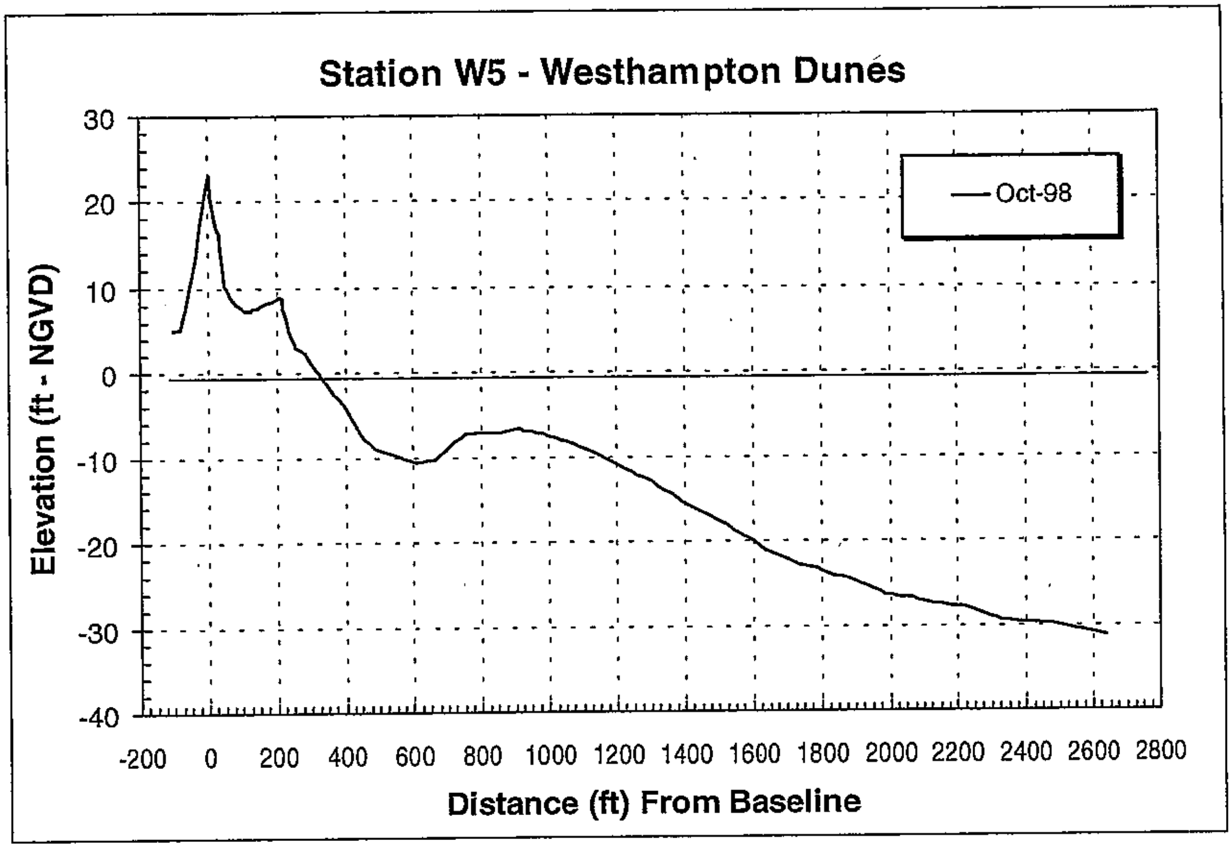

Station F84 - Moriches Inlet
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #36 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strock Line S-032 onto Range F84.
Jun-33
Jun-55
Dec-79
Apr-95
Oct-96
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
200
600
1000
1400
1800
2200
2600
3000
3400
3800
Distance (ft) From Baseline

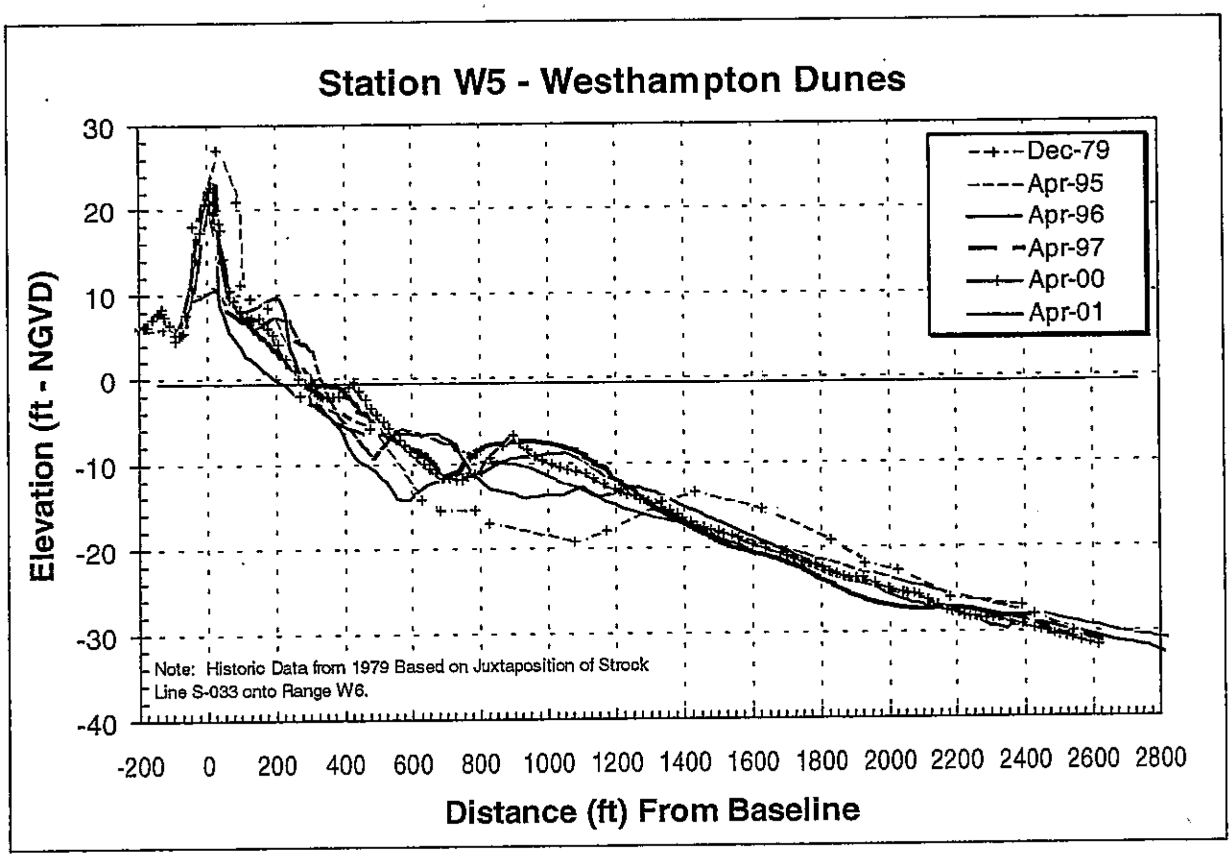

Station F84 - Moriches Inlet
Note: Historic Data from 1933-1955 Based on Juxtaposition of USACE Line #36 (USACE, 1958); Historic Data from 1979 Based on Juxtaposition of Strook Line S-032 onto Range F84.
Jun-33
Jan-40
Jun-55
Dec-79
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Oct-98
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-400
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
Distance (ft) From Baseline

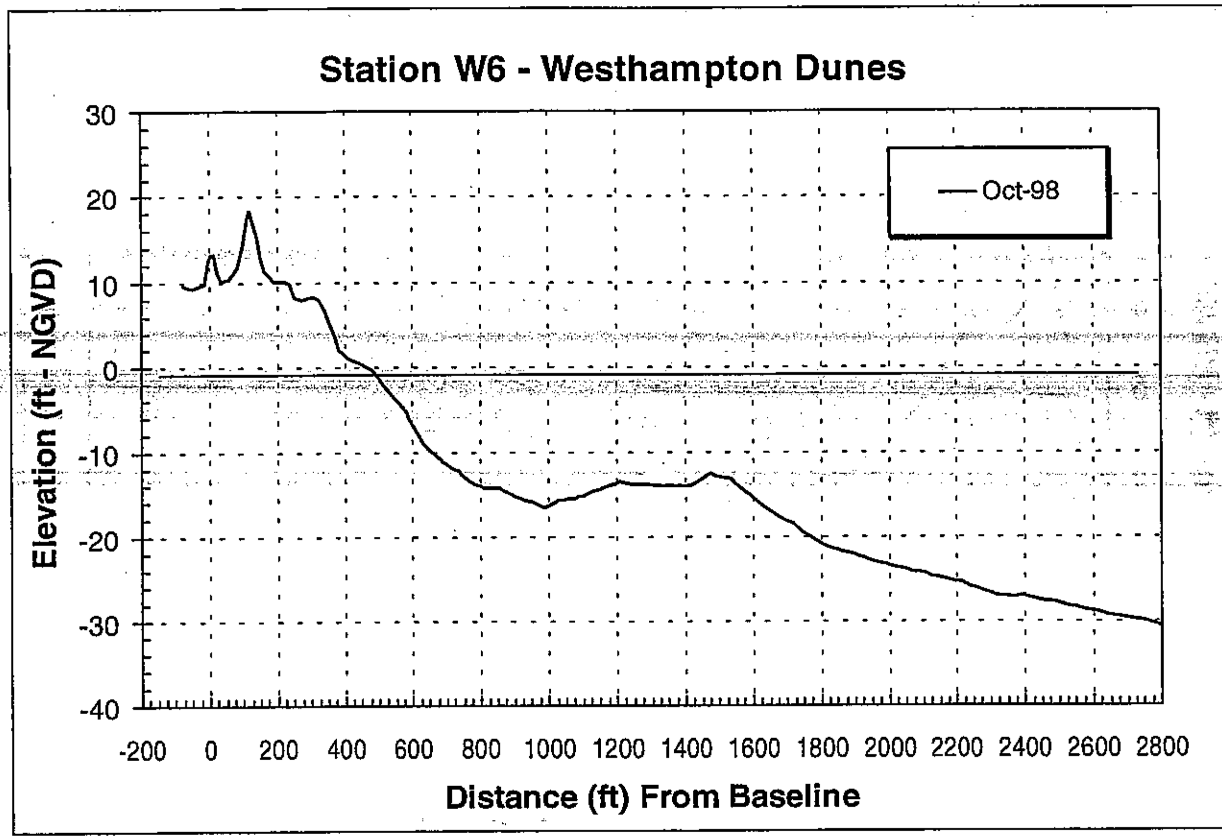

Station W3 - Cupsogue
Apr-98
Elevation (ft - NGVD)
Distance (ft) From Baseline


Station W3 - Cupsogue
Jun-55
Dec-79
Apr-95
Apr-97
Apr-00
Apr-01
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-032a onto Range W3.
Elevation (ft - NGVD)
Distance (ft) From Baseline

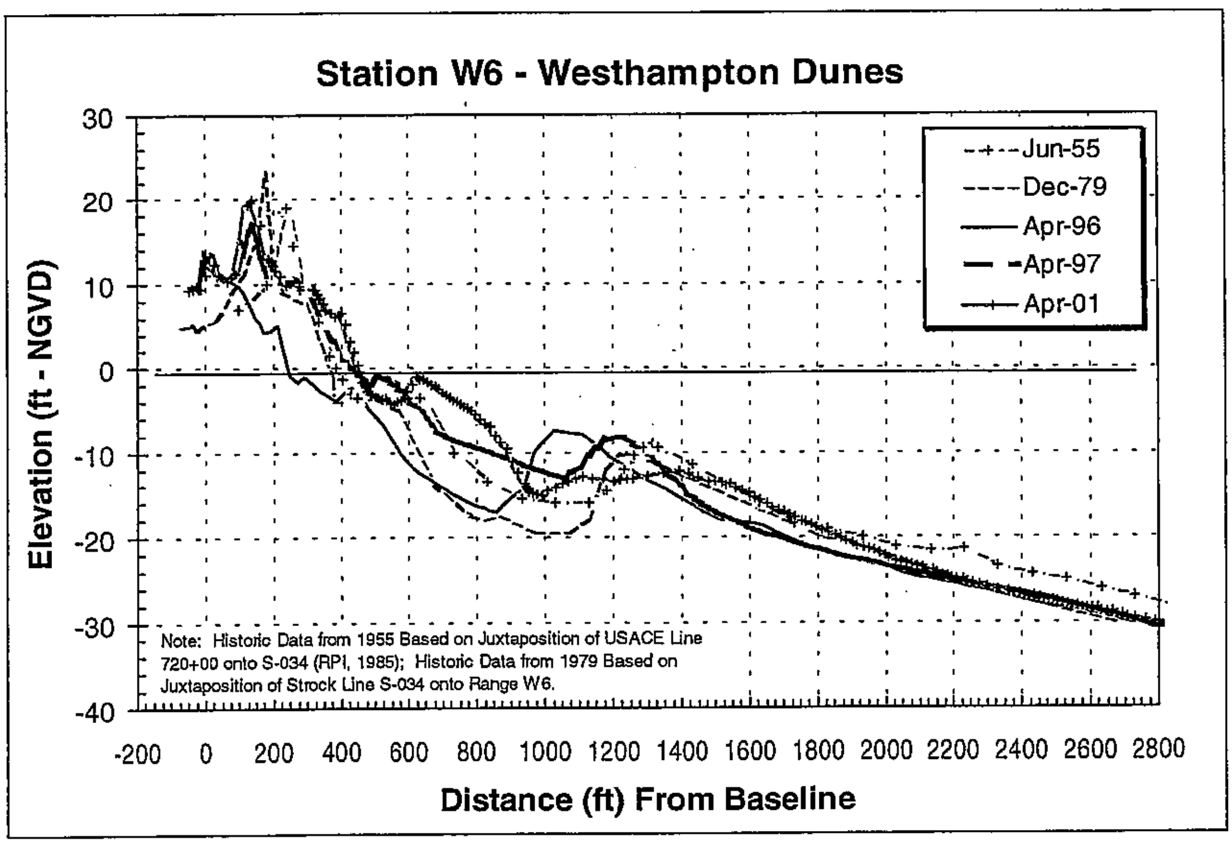

Station W3 - Cupsogue
Jun-55
Jun-67
Dec-79
Apr-95
Oct-95
Apr-96
Oct-96
Apr-97
Apr-98
Apr-00
Apr-01
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-032a onto Range W3.
Elevation (ft - NGVD)
Distance (ft) From Baseline


Station W5 - Westhampton Dunes
Oct-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline

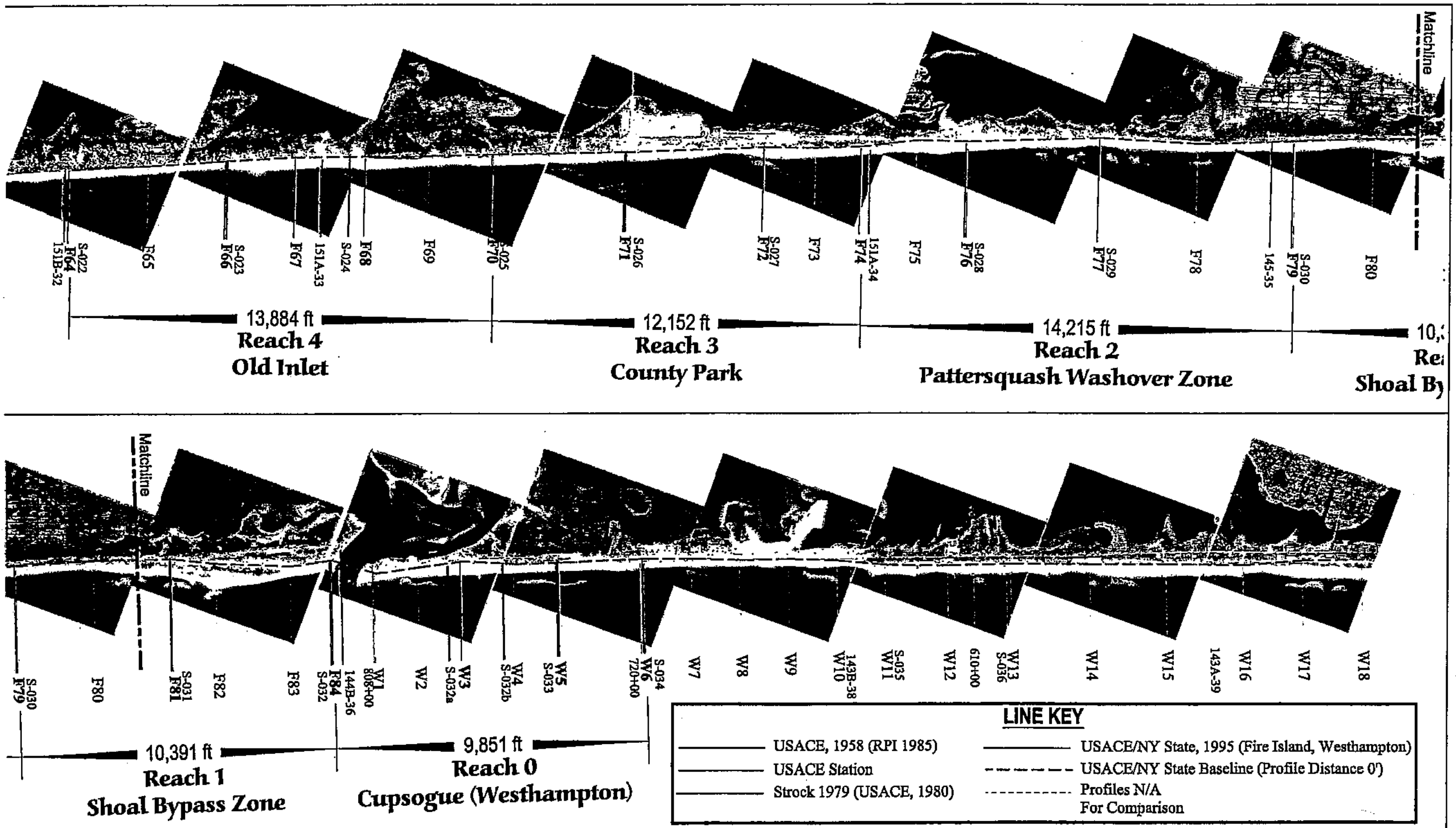

Station W5 - Westhampton Dunes
Dec-79
Apr-95
Apr-96
Apr-97
Apr-00
Apr-01
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
Note: Historic Data from 1979 Based on Juxtaposition of Strock Line S-033 onto Range W6.
-200 0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Distance (ft) From Baseline



Station W6 - Westhampton Dunes
Oct-98
Elevation (ft - NGVD)
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

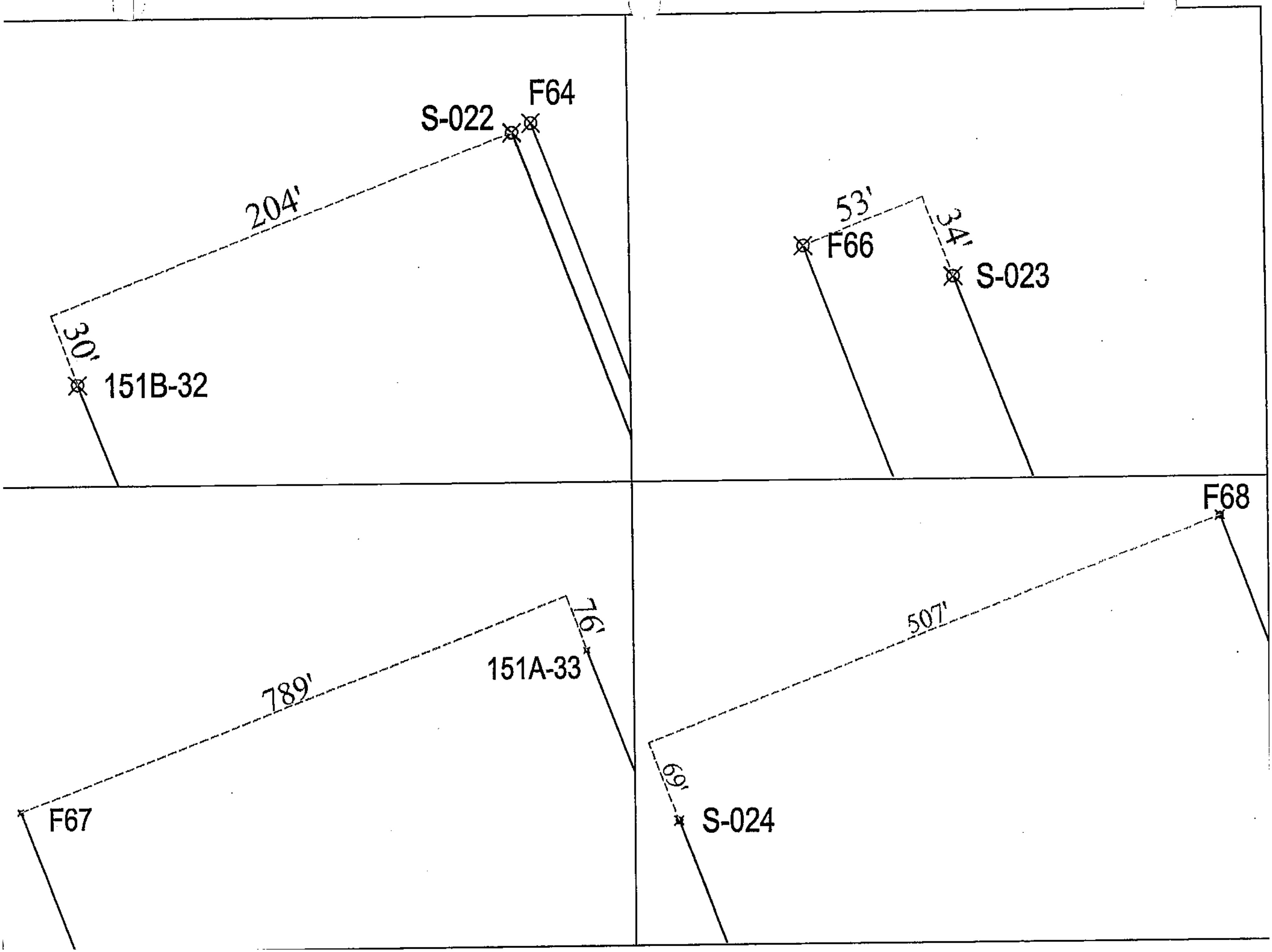


Station W6 - Westhampton Dunes
Jun-55
Dec-79
Apr-96
Apr-97
Apr-01
Elevation (ft - NGVD)
Note: Historic Data from 1955 Based on Juxtaposition of USACE Line 720+00 onto S-034 (RPI, 1985); Historic Data from 1979 Based on Juxtaposition of Strock Line S-034 onto Range W6.
30
20
10
0
-10
-20
-30
-40
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Distance (ft) From Baseline

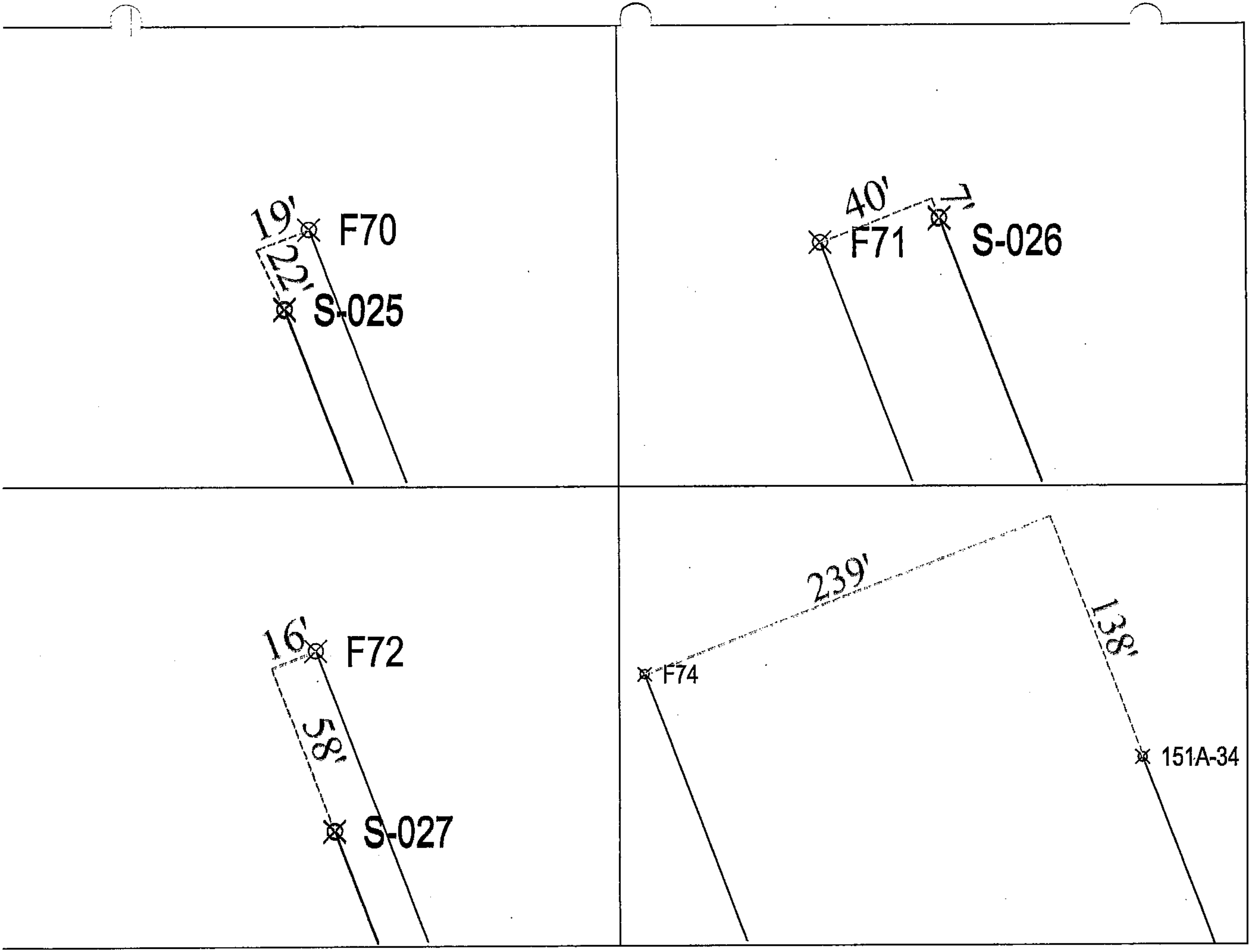


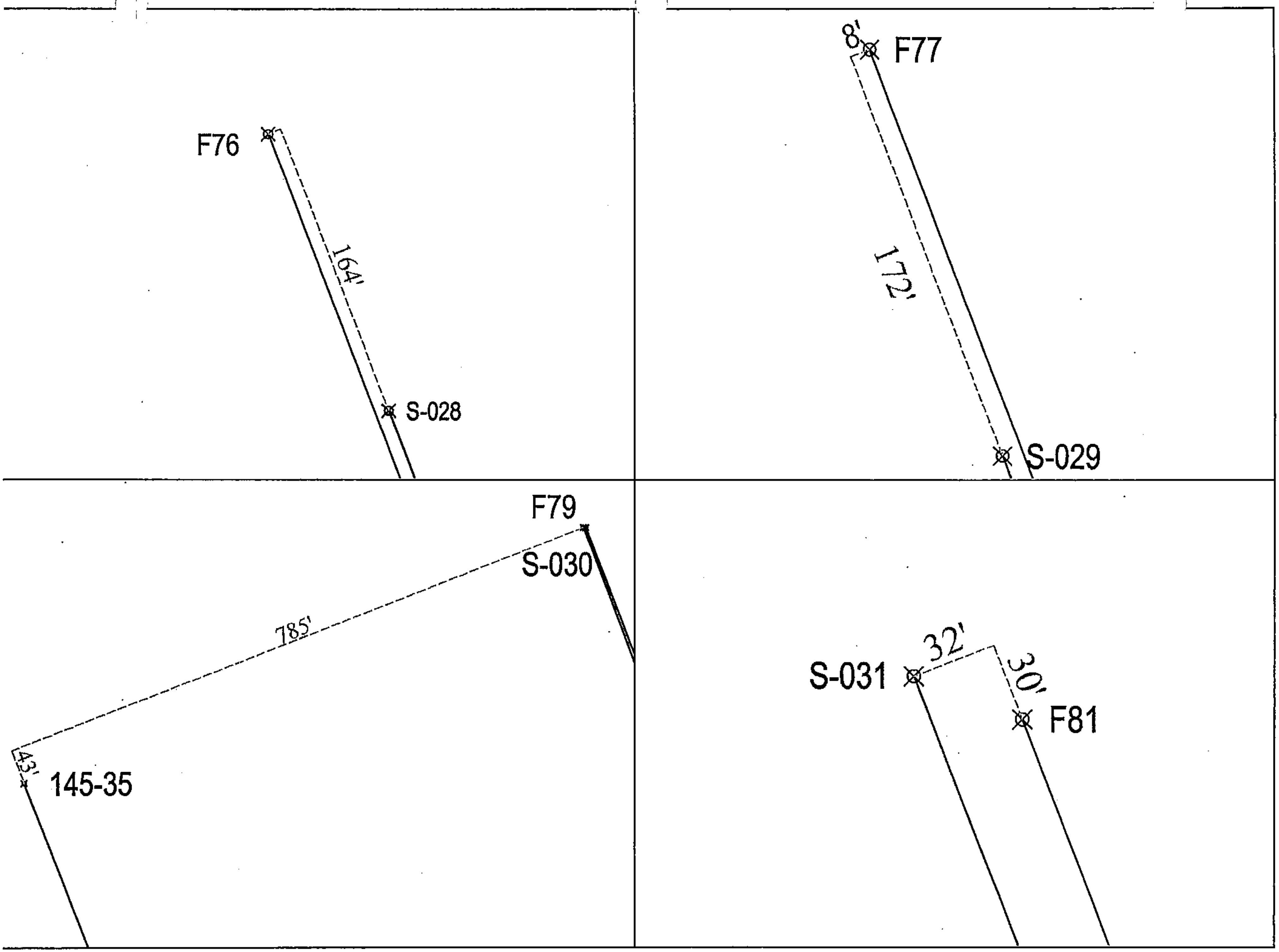
Date of Photographs: Spring 1995
Source: SAIC - Coastal View version 1.2.0

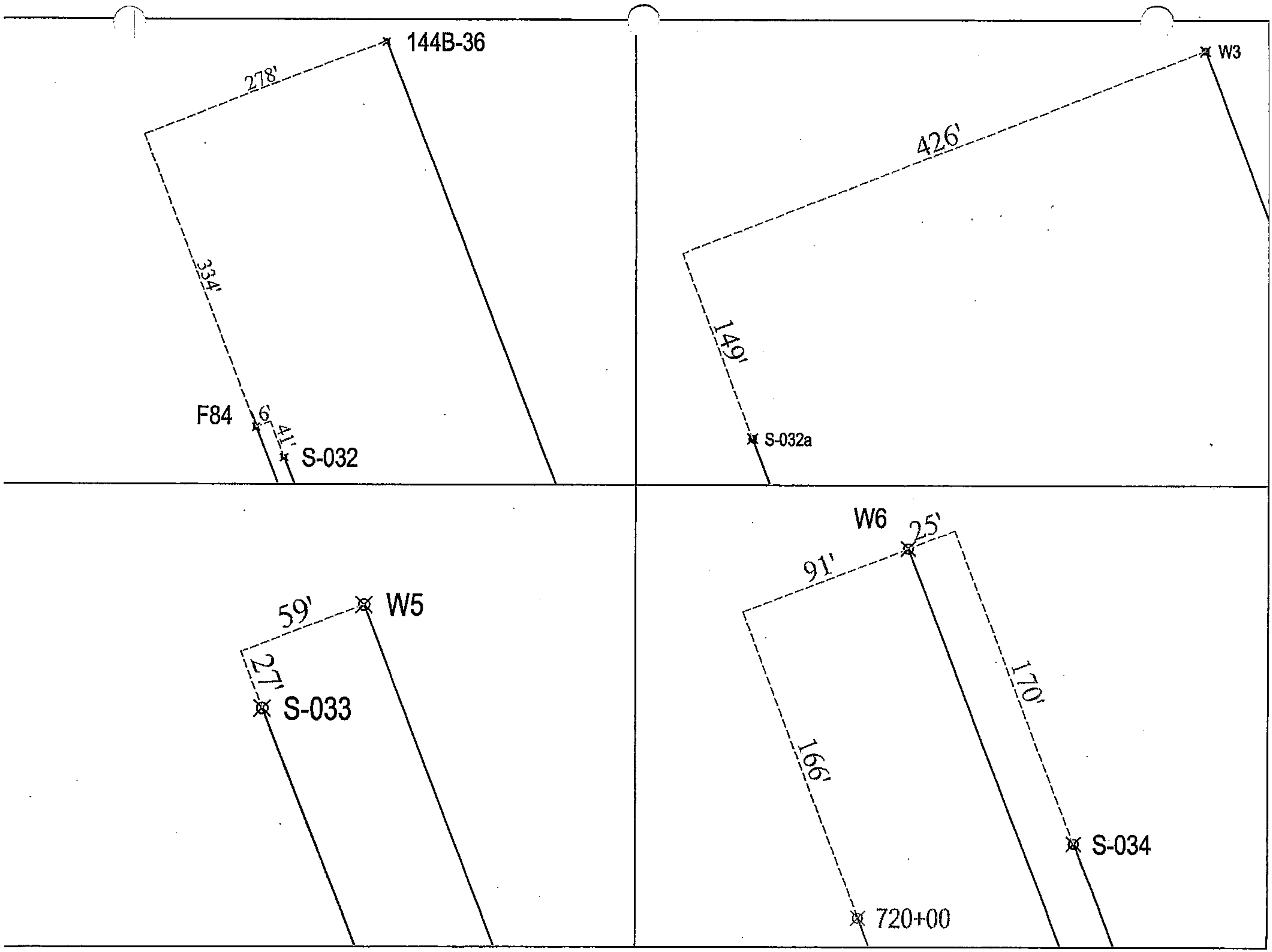
APPENDIX 1B. General profile locations.



S-022
F64
204'
30'
151B-32
53'
34'
F66
S-023
F68
507'
69'
S-024
76'
151A-33
789'
F67


19'
F70
22'
S-025
40'
7'
F71
S-026
16'
F72
58'
S-027
239'
138'
F74
151A-34


F76
164'
S-028
8'
F77
172'
S-029
F79
S-030
785'
43'
145-35
S-031
32'
30'
F81


144B-36
278'
334'
F84
6'
41'
S-032
W3
426'
149'
S-032a
59'
W5
27'
S-033
W6
25'
91'
170'
166'
S-034
720+00

APPENDIX 1-D. Profile coverage for the present study area. L = long ranges to approximately −30 ft NGVD (unless otherwise indicated). S = short ranges to approximate mean low water (MLW). *Dates with most comprehensive coverage [S = spring (~ April) | F = fall (~ November)]. **Except 1955.

QUALITY OF CLOSURE	QUALITY OF JUXTAPOSITION (E) = EXCELLENT | (G) = GOOD | (F) = FAIR | (P) = POOR														
	1933	1940	<u>1955*</u>	1967	<u>1979*</u>	<u>S-1995*</u>	F-1995	S-1996	F-1996	S-1997	F-1997	<u>S-1998*</u>	F-1998	S-2000	S-2001
F64 (P)	L (E)	L (E)	L (E)	—	L (E)	ND	S	S	S	S		L			S
66 (E)					L (E)	L	L	L	L	L		L	L		S
67 (G)	L (P)	L (P)	L (P)		L (P)	—	S	S	S	S		L			S
68 (F)			L (P)		L (F)	L	S	S	S	S		L			S
70 (E)					L (E)	L	L	L	L	L		L	L		S
71 (G)					L (E)	L	S	S	S	S		L			S
72 (G)**			L (P)		L (E)	L	L	L	L	L		L	L		L
74 (F)	L (F)	L (F)	L (F)		L (P)		S	S	S	L		L			S
76 (P)			L (F)		L (E)	L	S	S	S	L		L			S
77 (E)					L (E)	L	L	L	L	L		L	L		L
79 (F)	L (P)	L (F)	L (F)		L (E)	L	L	L	L	L		L	L		L
81 (E)					L (E)	L	L	L	L	L		L	L		L
84 (P)	L (F)	L (F)	L (F)		L (E)	L	L	S	L	L		L	L (-18)		L
W3 (P)			L	L	L (F)	M (-11)	S	S	S	S		L		L	L
5 (P)					L (E)	L	L	L	L	L			L	L	L
6 (P)**			L		L (E)		S	L	L	L			L		L

APPENDIX II

(under separate cover on CD-ROM)

Profile data, distances to selected contours ("excursion"), and unit-width volumes for selected lenses ("area") for F- and W-series stations (historical data juxtaposed)

Note: Profile data area given in x-y format using the NY State (1995) benchmark as zero ("0") starting point. These data sets were derived from several sources as outlined in the report including NY State, Department of State on CD-ROM (Coastal View – Atlantic Coast of New York Monitoring Program, Version 1.2).

APPENDIX III

Profile Volumes and Volume Changes
for Selected Dates and Reaches
Developed for the Present Analysis

APPENDIX 3a. Profile volumes and volume changes - Top to +2.5 ft NGVD

											Unit (cy/ft) and Net (cy) Volume Changes: Dune Crest to 2.5 ft NGVD									
	Limits		Distance	Unit Volumes (cy/ft): Baseline (~Dune Crest) to 2.5 ft NGVD							06/55 - 12/79		12/79 - 04/95		04/95 - 04/98		04/98 - 04/01		12/79 - 04/98	
Station	Distance	Depth	To Next	06/55	12/79	04/95	04/96	04/97	04/98	04/01	Unit	Net	Unit	Net	Unit	Net	Unit	Net	Unit	Net
F64	0-end	-27.0	5,181	87.29	74.48	56.03	43.53	46.16	23.99	37.58	-12.81	-123,467	-18.45	-324,952	-32.04	-118,515	13.59	154,938	-50.49	-443,468
F66	0-end	-27.0	2,274		130.04	23.05	22.01	37.36	9.34	55.56	ND	ND	-106.99	-96,202	-13.71	-44,434	46.22	74,712	-120.7	-140,636
F67	0-end	-27.0	2,277	69.32	49.02	71.40	41.28	51.72	46.03	65.52	-20.30	26,789	22.38	-9,279	-25.37	-67,331	19.49	14,334	-2.99	-76,610
F68	0-end	-27.0	4,152	74.74	118.57	88.04	65.60	65.35	54.27	47.37	43.83	197,166	-30.53	-91,489	-33.77	-179,055	-6.9	19,328	-64.3	-270,544
F70	0-end	-27.0	4,350		73.50	59.96	38.53	35.34	7.48	23.69	ND	ND	-13.54	-67,273	-5[illegible].48	-185,723	16.21	2,893	-66.02	-252,996
F71	0-end	-27.0	4,590		74.87	57.48	24.12	32.98	24.57	9.69	ND	ND	-17.39	-106,006	-32.91	-121,727	-14.88	-21,344	-50.3	-227,733
F72	0-end	-27.0	3,212	92.01	78.30	49.50	51.47	49.42	29.37	34.95	-13.71	-92,056	-28.8	-73,153	-20.13	-69,460	5.58	55,086	-48.93	-142,613
F74	0-end	-27.0	3,248	85.19	41.58	24.83	5.99	16.81	1.71	30.43	-43.61	-134,581	-16.75	-79,787	-23.12	-45,569	28.72	36,865	-39.87	-125,357
F76	0-end	-27.0	4,339	111.65	72.39	40.01	19.88	45.12	35.07	29.05	-39.26	-41,567	-32.38	-184,711	-4.94	25,795	-6.02	-19,265	-37.32	-158,916
F77	0-end	-27.0	6,388		105.05	52.29	60.20	81.01	69.12	66.26	ND	ND	-52.76	-164,140	16.83	-70,204	-2.86	13,894	-35.93	-234,344
F79	0-end	-27.0	5,113	35.37	66.88	68.25	54.39	45.63	29.44	36.65	31.51	280,609	1.37	127,825	-38.81	-8,385	7.21	64,884	-37.44	119,440
F81	0-end	-27.0	5,278		106.56	155.19	211.99	200.97	190.72	208.89	ND	ND	48.63	-56,369	35.53	74,367	18.17	53,334	84.16	17,998
F84	0-end	-27.0	4,234	79.80	102.30	32.31	46.31	51.37	24.96	27.00	22.5	245,403	-69.99	-369,332	-7.35	83,791	2.04	-5,314	-77.34	-285,541
W3	0-end	-27.0	3,181	53.58	147.00	42.53	79.16	83.35	89.46	84.91	93.42	268,808	-104.47	-253,255	46.93	101,903	-4.55	5,726	-57.54	-151,352
W5	0-end	-27.0	2,840		103.61	48.85	28.81	46.47	65.99	74.14	ND	ND	-54.76	-135,397	17.14	107,082	8.15	42,941	-37.62	-28,315
W6	0-end	-27.0	0	96.50	92.37	51.78	46.20	109.10	110.05	132.14	-4.13		-40.59		58.27		22.09		17.68	
All	Totals/Linear Averages		60,657	78.55	89.78	57.59	52.47	62.39	50.72	60.24	3.59	627,102	-32.19	-1,883,520	-6.87	-517,465	9.52	493,011	-39.06	-2,400,985
By Reach - Unit and Net Change for Period										*# years*	*24.5*		*15.42*		*3*		*3*		*18.42*	
Reach 0	Cupsogue		10,255	76.6	111.3	43.9	50.1	72.6	72.6	79.5	50.1	514,210	-73.9	-757,984	28.5	292,776	4.2	43,353	-45.4	-465,208
Reach 1	Moriches Inlet		10,391	57.6	91.9	85.3	104.2	99.3	81.7	90.8	27.0	280,609	6.9	71,456	6.3	65,982	11.4	118,218	13.2	137,438
Reach 2	Pattersquash		13,975	77.4	71.5	46.3	35.1	47.1	33.8	40.6	-12.6	-176,148	-30.7	-428,638	-6.4	-89,978	2.3	31,494	-37.1	-518,616
Reach 3	County Park		12,152	88.6	67.1	47.9	30.0	33.6	15.8	24.7	-7.6	-92,056	-20.3	-246,432	-31.0	-376,910	3.0	36,635	-51.3	-623,342
Reach 4	Old Inlet		13,884	77.1	89.1	59.7	42.2	47.2	28.2	45.9	7.2	100,487	-37.6	-521,922	-29.5	-409,335	19.0	263,311	-67.1	-931,257
			60,657					Totals/Weighted Averages			10.3	627,102	-31.1	-1,883,520	-8.5	-517,465	8.1	493,011	-39.6	-2,400,985
By Reach - Average Annual Unit and Net Change																				
Reach 0	Cupsogue										2.0	20,988	-4.8	-49,156	9.5	97,592	1.4	14,451	-2.5	-25,256
Reach 1	Moriches										1.1	11,453	0.4	4,634	2.1	21,994	3.8	39,406	0.7	7,461
Reach 2	Pattersquash										-0.5	-7,190	-2.0	-27,798	-2.1	-29,993	0.8	10,498	-2.0	-28,155
Reach 3	County Park										-0.3	-3,757	-1.3	-15,981	-10.3	-125,637	1.0	12,212	-2.8	-33,840
Reach 4	Old Inlet										0.3	4,102	-2.4	-33,847	-9.8	-136,445	6.3	87,770	-3.6	-50,557
			60657					Totals/Weighted Averages			0.4	25,596	-2.0	-122,148	-2.8	-172,488	2.7	164,337	-2.1	-130,347

APPENDIX 3b. Profile volumes and volume changes - +2.5 ft to -2.5 ft NGVD

									Unit (cy/ft) and Net (cy) Volume Changes: 2.5 ft to -2.5 ft NGVD										
	Distance	Unit Volumes (cy/ft): Baseline 2.5 to -2.5 ft NGVD							06/55 - 12/79		12/79 - 04/95		04/95 - 04/98		04/98 - 04/01		12/79 - 04/98	
Station	To Next	06/55	12/79	04/95	04/96	04/97	04/98	04/01	Unit	Net	Unit	Net	Unit	Net	Unit	Net	Unit	Net
F64	5,181	61.71	42.94	41.46	40.99	39.78	42.45	27.41	-18.77	-49,111	-1.48	-68,830	0.99	1,813	-15.04	11,839	-0.49	-67,016
F66	2,274		53.51	28.42	44.69	46.18	28.13	47.74	ND	ND	-25.09	-18,874	-0.29	6,867	19.61	10,165	-25.38	-12,007
F67	2,277	40.77	46.37	54.86	55.75	59.85	61.19	50.52	5.60	20,436	8.49	13,104	6.33	-17,909	-10.67	-30,273	14.82	-4,804
F68	4,152	52.07	64.42	67.44	57.75	58.63	45.38	29.46	12.35	25,639	3.02	10,650	-22.06	-86,673	-15.92	-30,351	-19.04	-76,023
F70	4,350		45.75	47.86	40.79	38.13	28.17	29.47	ND	ND	2.11	3,719	-19.69	-20,641	1.3	-64,076	-17.58	-16,922
F71	4,590		39.50	39.10	27.52	31.34	49.30	18.54	ND	ND	-0.4	-12,783	10.2	28,320	-30.76	-114,314	9.8	15,537
F72	3,212	70.87	50.32	45.15	54.05	52.56	47.29	28.24	-20.55	-86,242	-5.17	-11,419	2.14	-11,820	-19.05	15,867	-3.03	-23,239
F74	3,248	65.96	32.81	30.87	32.64	52.18	21.37	50.30	-33.15	-105,885	-1.94	-9,858	-9.5	-36,020	28.93	36,897	-11.44	-45,878
F76	4,339	86.45	54.40	50.27	45.62	40.92	37.59	31.38	-32.05	-69,532	-4.13	-54,628	-12.68	-4,469	-6.21	-7,268	-16.81	-59,097
F77	6,388		66.44	45.39	58.10	57.99	56.01	58.87	ND	ND	-21.05	-82,661	10.62	10,444	2.86	-33,218	-10.43	-72,216
F79	5,113	47.43	55.71	50.88	33.41	26.27	43.53	30.27	8.28	84,843	-4.83	-14,853	-7.35	33,950	-13.26	-869	-12.18	19,097
F81	5,278		92.48	91.50	162.65	127.46	112.13	125.05	ND	ND	-0.98	-118,280	20.63	39,268	12.92	47,106	19.65	-79,012
F84	4,234	69.36	77.41	33.57	43.81	54.45	27.82	32.75	8.05	61,160	-43.84	-181,321	-5.75	35,227	4.93	-20,027	-49.59	-146,094
W3	3,181	61.77	82.61	40.80	71.46	51.64	63.19	48.80	20.84	33,146	-41.81	-47,826	22.39	34,212	-14.39	-36,088	-19.42	-13,615
W5	2,840		48.75	60.49	37.10	56.79	59.61	51.31	ND	ND	11.74	-14,654	-0.88	56,601	-8.3	-11,999	10.86	41,947
W6	0	71.78	65.94	43.88	47.96	81.41	84.62	84.47	-5.84		-22.06		40.74		-0.15		18.68	
All	60,657	62.82	57.46	48.25	53.39	54.72	50.49	46.54	-3.45	-85,547	-9.21	-608,514	2.24	69,172	-3.95	-226,608	-6.97	-33708.87
By Reach - Unit and Net Change for Period								# years	24.5		15.42		3		3		18.42	
Reach 0	10,255	67.6	68.7	44.7	50.1	61.1	58.8	54.3	9.2	94,306	-23.8	-243,802	12.3	126,040	-6.6	-68,114	-11.5	-117,762
Reach 1	10,391	58.4	75.2	58.7	80.0	69.4	61.2	62.7	8.2	84,843	-12.8	-133,133	7.0	73,219	4.4	46,237	-5.8	-59,915
Reach 2	13,975	66.6	52.3	44.4	42.4	44.3	39.6	42.7	-12.6	-175,417	-10.5	-147,146	-2.1	-30,045	-0.3	-3,588	-12.7	-177,192
Reach 3	12,152	68.4	42.1	40.7	38.8	43.6	36.5	31.6	-7.1	-86,242	-1.7	-20,483	-0.3	-4,141	-13.4	-162,522	-2.0	-24,623
Reach 4	13,884	51.5	50.6	48.0	48.0	48.5	41.1	36.9	-0.2	-3,036	-4.6	-63,950	-6.9	-95,901	-2.8	-38,620	-11.5	-159,851
						Totals/Weighted Averages			-1.4	-85,547	-10.0	-608,514	1.1	69,172	-3.7	-226,608	-8.9	-539,342
By Reach - Average Annual Unit and Net Change																		
Reach 0	Cupsogue								0.4	3,849	-1.5	-15,811	4.1	42,013	-2.2	-22,705	-0.6	-6,393
Reach 1	Moriches								0.3	3,463	-0.8	-8,634	2.3	24,406	1.5	15,412	-0.3	-3,253
Reach 2	Pattersquash								-0.5	-7,160	-0.7	-9,543	-0.7	-10,015	-0.1	-1,196	-0.7	-9,620
Reach 3	County Park								-0.3	-3,520	-0.1	-1,328	-0.1	-1,380	-4.5	-54,174	-0.1	-1,337
Reach 4	Old Inlet								0.0	-124	-0.3	-4,147	-2.3	-31,967	-0.9	-12,873	-0.6	-8,678
						Totals/Weighted Averages			-0.1	-3,492	-0.7	-39,463	0.4	23,057	-1.2	-75,536	-0.5	-29,280

APPENDIX 3c. Profile Volumes and volume changes - -2.5 ft to -18 ft NGVD

									Unit (cy/ft) and Net (cy) Volume Changes: -2.5 ft to -18 ft NGVD									
	Distance	Unit Volumes (cy/ft): -2.5 to -18 ft NGVD							06/55 - 12/79		12/79 - 04/95		04/95 - 04/98		04/98 - 04/01		12/79 - 04/98	
Station	To Next	06/55	12/79	04/95	04/96	04/97	04/98	04/01	Unit	Net	Unit	Net	Unit	Net	Unit	Net	Unit	Net
F64	5,181	503.76	379.28				385.87		-124.48	-368,687	ND	ND	ND	ND	ND	ND	6.59	-208,950
F66	2,274		473.92	286.69	343.83	442.06	386.67		ND	ND	-187.23	-982,348	99.98	301,449	ND	ND	-87.25	-59,795
F67	2,277	424.35	449.92				484.58		25.57	81,118	ND	ND	ND	ND	ND	ND	34.66	-20,516
F68	4,152	458.21	503.89	489.24			451.21		45.68	-1,061,827	-14.65	189,663	-38.03	-201,372	ND	ND	-52.68	-11,709
F70	4,350		300.95	406.96	415.81	366.28	347.99		ND	ND	106.01	291,863	-58.97	-86,478	ND	ND	47.04	205,385
F71	4,590		365.33	393.51			412.72		ND	ND	28.18	463,842	19.21	-95,908	ND	ND	47.39	367,934
F72	3,212	516.24	308.35	482.28	462.13	471.88	421.28	340.26	-207.89	-643,091	173.93	842,319	-61	-141,765	-81.02	-984,555	112.93	192,929
F74	3,248	494.80	302.26			413.91	309.46		-192.54	-629,560	ND	ND	ND	ND	ND	ND	7.2	180,524
F76	4,339	561.70	366.58	453.43			470.54	400.38	-195.12	-1,291,424	86.85	287,871	17.11	53,782	-70.16	-184,386	103.96	341,653
F77	6,388		431.87	477.71	492.62	529.82	485.39	470.56	ND	ND	45.84	260,024	7.68	-508,070	-14.83	183,687	53.52	-248,046
F79	5,113	446.68	401.02	436.59	387.06	324.83	269.84	342.18	-45.66	303,937	35.57	-135,597	-166.75	-19,429	72.34	36,686	-131.18	-155,026
F81	5,278		710.05	621.44	811.08	663.72	780.59	722.60	ND	ND	-88.61	-471,642	159.15	521,915	-57.99	-146,333	70.54	50,273
F84	4,234	688.84	793.00	702.89		688.54	741.51	744.05	104.16	905,864	-90.11	-1,078,082	38.62	519,956	2.54	-144,570	-51.49	-558,126
W3	3,181	437.44	761.18	342.04			549.03	478.20	323.74	653,248	-419.14	-503,839	206.99	439,503	-70.83	-218,201	-212.15	-64,336
W5	2,840		384.43	486.79	461.84	544.14	556.13	489.77	ND	ND	102.36	290,702	69.34	196,926	-66.36	58,248	171.7	321,744
W6	0	553.17	446.42		483.65	586.49	501.30	608.68	-106.75		ND		ND		107.38	ND	54.88	
All	60,657	508.52	461.15	464.96	482.25	503.17	472.13	510.74	-23.33	-2,050,420	-13.81	-545,222	18.33	980,509	-11.18	-1,399,423	10.98	20,871
By Reach - Unit and Net Change for Period								# years	24.5		15.42		3		3		18.42	
Reach 0	10,255	559.8	596.3	510.6	472.7	606.4	587.0	580.2	152.0	1,559,113	-125.9	-1,291,218	112.8	1,156,385	-29.7	-304,522	-29.3	-300,718
Reach 1	10,391	567.8	634.7	587.0	599.1	559.0	597.3	602.9	29.3	303,937	-58.4	-607,239	48.4	502,486	-10.6	-109,647	-10.1	-104,753
Reach 2	13,975	501.1	375.4	455.9	439.8	422.9	383.8	404.4	-137.5	-1,920,983	39.2	547,894	-32.5	-454,288	-0.1	-699	19.6	274,131
Reach 3	12,152	505.5	319.2	427.6	439.0	417.4	372.9	340.3	-52.9	-643,091	131.5	1,598,025	-26.7	-324,151	-81.0	-984,555	63.1	766,248
Reach 4	13,884	462.1	421.6	394.3	379.8	404.2	411.3	ND	-97.2	-1,349,396	-57.1	-792,685	7.2	100,077	ND	ND	-21.7	-300,969
						Totals/Weighted Averages			-33.8	-2,050,420	-9.0	-545,222	16.2	980,509	-23.1	-1,399,423	5.5	333,939
By Reach - Average Annual Unit and Net Change																		
Reach 0	Cupsogue								6.2	63,637	-8.2	-83,737	37.6	385,462	-9.9	-101,507	-1.6	-16,326
Reach 1	Moriches								1.2	12,406	-3.8	-39,380	16.1	167,495	-3.5	-36,549	-0.5	-5,687
Reach 2	Pattersquash								-5.6	-78,407	2.5	35,531	-10.8	-151,429	0.0	-233	1.1	14,882
Reach 3	County Park								-2.2	-26,249	8.5	103,633	-8.9	-108,050	-27.0	-328,185	3.4	41,599
Reach 4	Old Inlet								-4.0	-55,077	-3.7	-51,406	2.4	33,359	ND	ND	-1.2	-16,339
						Totals/Weighted Averages			-1.4	-83,691	-0.6	-35,358	5.4	326,836	-7.7	-466,474	0.3	18,129

APPENDIX 3d. Profile volumes and volume changes - -18 ft to -27 ft NGVD

									Unit (cy/ft) and Net (cy) Volume Changes: -18 ft to -27 ft NGVD									
	Distance	Unit Volumes (cy/ft): -18 to -27 ft NGVD							06/55 - 12/79		12/79 - 04/95		04/95 - 04/98		04/98 - 04/01		12/79 - 04/98	
Station	To Next	06/55	12/79	04/95	04/96	04/97	04/98	04/01	Unit	Net	Unit	Net	Unit	Net	Unit	Net	Unit	Net
F64	5,181	617.21	620.61				582.18		3.4	-84,167	ND	ND	ND	ND	ND	ND	-38.43	-92,144
F66	2,274		586.14	583.51	599.29	586.62	589.00		ND	ND	-2.63	-155,858	5.49	64,426	ND	ND	2.86	-12,552
F67	2,277	628.20	602.22				588.32		-25.98	-45,642	ND	ND	ND	ND	ND	ND	-13.9	-40,474
F68	4,152	643.91	629.80	600.40			608.15		-14.11	-604,392	-29.4	-71,041	7.75	29,583	ND	ND	-21.65	-41,458
F70	4,350		620.58	615.76	611.69	625.74	622.26		ND	ND	-4.82	82,737	6.5	34,604	ND	ND	1.68	117,341
F71	4,590		523.49	566.35			575.76		ND	ND	42.86	36,766	9.41	82,459	ND	ND	52.27	119,225
F72	3,212	666.56	588.34	561.50	574.66	562.82	588.02	579.15	-78.22	-270,675	-26.84	-43,411	26.52	109,303	-8.87	-107,788	-0.32	88,780
F74	3,248	650.15	559.83			676.08	615.43		-90.32	-295,747	ND	ND	ND	ND	ND	ND	55.6	123,944
F76	4,339	686.78	594.99	608.39			615.71	634.57	-91.79	-415,510	13.4	36,404	7.32	18,701	18.86	4,144	20.72	55,105
F77	6,388		618.28	621.66	632.13	618.55	622.96	606.01	ND	ND	3.38	-327,193	1.3	110,225	-16.95	-23,668	4.68	-216,968
F79	5,113	678.79	693.11	587.29	641.58	631.39	620.50	630.04	14.32	-88,479	-105.82	-86,282	33.21	24,466	9.54	-30,985	-72.61	-61,816
F81	5,278		840.69	912.76	903.80	880.70	889.12	867.46	ND	ND	72.07	645,473	-23.64	-113,371	-21.66	-57,161	48.43	532,102
F84	4,234	804.03	772.68	945.20		887.66	925.88	ND	-31.35	612,977	172.52	525,464	-19.32	-244,584	ND	ND	153.2	-200,162
W3	3,181	613.38	934.28	ND			686.53	696.07	320.9	726,163	ND	ND	ND	ND	9.54	51,230	-247.75	-517,215
W5	2,840		661.49	630.70	593.88	571.29	584.05	606.72	ND	ND	-30.79	-87,444	-46.65	-132,486	22.67	64,127	-77.44	-125,940
W6	0	745.16	665.47		641.07	645.62	654.22	676.71	-79.69		ND		ND		22.49	ND	-11.25	
							*Oct'98											
All	60,657	673.42	657.00	602.79	649.76	668.65	648.01	588.53	-4.55	-465,473	6.50	555,615	0.49	-16,674	2.23	-100,100	-8.99	-17,015
By Reach - Unit and Net Change for Period								*# years*	*24.5*		*15.42*		*3*		*3*		*18.42*	
Reach 0	10,255	720.9	758.5	788.0	617.5	701.5	712.7	659.8	130.6	1,339,140	42.7	438,020	-36.8	-377,070	11.2	115,357	-82.2	-843,317
Reach 1	10,391	741.4	768.8	815.1	772.7	799.9	811.8	748.8	-8.5	-88,479	53.8	559,191	-8.6	-88,906	-8.5	-88,146	45.3	470,285
Reach 2	13,975	671.9	616.6	605.8	636.9	642.0	618.7	623.5	-50.9	-711,257	-20.8	-290,789	9.2	128,926	-1.4	-19,524	-2.7	-37,919
Reach 3	12,152	658.4	573.1	581.2	593.2	621.5	600.4	579.2	-22.3	-270,675	6.3	76,092	18.6	226,367	-8.9	-107,788	26.8	325,346
Reach 4	13,884	629.8	611.9	599.9	605.5	606.2	598.0	ND	-52.9	-734,202	-16.3	-226,899	6.8	94,009	ND	ND	-13.4	-186,628
						Totals/Weighted Averages			-7.7	-465,473	9.2	555,615	-0.3	-16,674	-1.7	-100,100	-4.5	-272,233
By Reach - Average Annual Unit and Net Change																		
Reach 0	Cupsogue								5.3	54,659	2.8	28,406	-12.3	-125,690	3.7	38,452	-4.5	-45,783
Reach 1	Moriches								-0.3	-3,611	3.5	36,264	-2.9	-29,635	-2.8	-29,382	2.5	25,531
Reach 2	Pattersquash								-2.1	-29,031	-1.3	-18,858	3.1	42,975	-0.5	-6,508	-0.1	-2,059
Reach 3	County Park								-0.9	-11,048	0.4	4,935	6.2	75,456	-3.0	-35,929	1.5	17,663
Reach 4	Old Inlet								-2.2	-29,967	-1.1	-14,715	2.3	31,336	ND	ND	-0.7	-10,132
						Totals/Weighted Averages			-0.3	-18,999	0.6	36,032	-0.1	-5,558	-0.6	-33,367	-0.2	-14,779

APPENDIX 3e. Profile volumes and volume changes - Foredune Crest to -27 ft NGVD.

	Distance	Unit Volumes (cy/ft): Foredune to -27 ft NGVD							Unit (cy/ft) and Net (cy) Volume Changes: Foredune to -27 ft NGVD									
									6'55 - 12'79		12'79 - 4'95		4'95 - 4'98		4'98 - 4'01		12'79 - 4'98	
Station	To Next	6'55	12'79	4'95	4'96	4'97	4'98	4'01	Unit	Net	Unit	Net	Unit	Net	Unit	Net	Unit	Net
F64	5,181	1269.97	1117.31				1034.49		-152.66	-625,325	ND	ND	ND	ND	ND	ND	-82.82	-811,604
F66	2,274		1243.61	921.68	1009.82	1112.21	1013.13		ND	ND	-321.93	-1,914,771	91.45	26,033	ND	ND	-230.48	-225,012
F67	2,277	1162.64	1147.54				1180.12		-15.10	82,712	ND	ND	ND	ND	ND	ND	32.58	-142,415
F68	4,152	1228.93	1316.68	1245.11			1159.01		87.75	-1,522,796	-71.57	37,783	-86.1	-437,496	ND	ND	-157.67	-399,713
F70	4,350		1040.77	1130.54	1106.82	1065.49	1005.90		ND	ND	89.77	311,025	-124.64	-258,238	ND	ND	-34.87	52,787
F71	4,590		1003.20	1056.43			1062.34		ND	ND	53.23	381,796	5.91	-106,832	ND	ND	59.14	274,964
F72	3,212	1345.68	1025.30	1138.43	1142.31	1136.68	1085.97	982.60	-320.38	-1,092,096	113.13	571,226	-52.46	-147,385	-103.37	-1,256,152	60.67	115,921
F74	3,248	1296.10	936.47			1158.97	947.98		-359.63	-1,165,772	ND	ND	ND	ND	ND	ND	11.51	133,265
F76	4,339	1446.58	1088.37	1152.09			1158.92	1095.38	-358.21	-1,875,938	63.72	84,936	6.83	93,809	-63.54	-206,797	70.55	178,745
F77	6,388		1221.63	1197.06	1243.04	1287.37	1233.47	1201.69	ND	ND	-24.57	-313,906	36.41	-457,668	-31.78	140,664	11.84	-771,575
F79	5,113	1208.27	1216.72	1143.01	1116.44	1028.12	963.31	1039.13	8.45	580,857	-73.71	-108,907	-179.7	30,601	75.82	69,690	-253.41	-78,306
F81	5,278		1749.78	1780.89	2089.52	1872.85	1972.56	1924.00	ND	ND	31.11	-818	191.67	522,179	-48.56	-612,478	222.78	521,361
F84	4,234	1642.04	1745.39	1713.97		1682.02	1720.17		103.35	1,825,362	-31.42	-10,641	6.2	167,357	ND	ND	-25.22	-1,189,945
W3	3,181	1166.18	1925.07				1388.20	1307.98	758.89	1,693,346	ND	ND	ND	ND	-80.22	-197,286	-536.87	-746,549
W5	2,840		1198.28	1226.83	1121.62	1218.69	1265.77	1221.95	ND	ND	28.55	81,082	38.94	110,590	-43.82	153,346	67.49	209,422
W6	0	1466.61	1270.20		1218.88	1422.61	1350.19	1502.00	-196.41		ND		ND		151.81		79.99	
All	60,657	1323.30	1265.40	1246.00	1256.06	1298.50	1221.35	1284.34	-27.75	-2,099,650	-8.98	-881,195	-4.09	-457,051	-8.98	-1,909,013	-44.05	-179,916
By Reach - Unit and Net Change for Period								# years	24.5		15.42		3		3		18.42	
Reach 0	10,255	1,424.9	1,534.7	1,470.4	1,170.3	1,441.1	1,431.1	1,344.0	343.1	3,518,708	6.9	70,441	27.1	277,946	-4.3	-43,940	-168.4	-1,727,072
Reach 1	10,391	1,425.2	1,570.6	1,546.0	1,603.0	1,527.7	1,552.0	1,481.6	55.9	580,857	-10.6	-109,725	53.2	552,780	-52.2	-542,787	42.6	443,055
Reach 2	13,975	1,317.0	1,115.8	1,164.1	1,179.7	1,158.2	1,075.9	1,112.1	-217.7	-3,041,710	-16.4	-228,970	-26.0	-363,859	-4.7	-66,133	-32.9	-459,564
Reach 3	12,152	1,320.9	1,001.4	1,108.5	1,124.6	1,120.4	1,025.5	982.6	-89.9	-1,092,096	104.0	1,264,047	-42.2	-512,455	-103.4	-1,256,152	36.5	443,672
Reach 4	13,884	1,220.5	1,173.2	1,099.1	1,058.3	1,088.9	1,078.5	ND	-148.8	-2,065,409	-135.2	-1,876,988	-29.6	-411,463	ND	ND	-113.7	-1,578,744
						Totals/Weighted Averages			-34.6	-2,099,650	-14.5	-881,195	-7.5	-457,051	-31.5	-1,909,013	-47.5	-2,878,652
By Reach - Average Annual Unit and Net Change																		
Reach 0	Cupsogue								14.0	143,621	0.4	4,568	9.0	92,649	-1.4	-14,647	-9.1	-93,761
Reach 1	Moriches								2.3	23,708	-0.7	-7,116	17.7	184,260	-17.4	-180,929	2.3	24,053
Reach 2	Pattersquash								-8.9	-124,151	-1.1	-14,849	-8.7	-121,286	-1.6	-22,044	-1.8	-24,949
Reach 3	County Park								-3.7	-44,575	6.7	81,974	-14.1	-170,818	-34.5	-418,717	2.0	24,086
Reach 4	Old Inlet								-6.1	-84,302	-8.8	-121,724	-9.9	-137,154	ND	ND	-6.2	-85,708
						Totals/Weighted Averages			-1.4	-85,700	-0.9	-57,146	-2.5	-152,350	-10.5	-636,338	-2.6	-156,279