Coastal Bluff Recession and Impacts on Littoral Transport: Special Reference to Montauk, NY

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Abstract

Recession of coastal bluffs supply the initial sediment to the littoral zone along the south shore of Long Island, NY. Analysis of profile data collected as part of the Atlantic Coast of New York Monitoring Program indicated volumetric recession rates vary between headlands and coves along the Montauk province ranging from 1.0 m^3/m/yr to 19.6 m^3/m/yr. Stabilization of the bluffs through vegetation, drainage control, slope reduction and toe armoring has reduced the amount of sediment supplied to the littoral drift through recession.

Introduction

A coastal bluff is a naturally formed precipitous landform. Commonly, bluffs are considered to be composed of unconsolidated rock while cliffs are consolidated rock, but the usage is flexible. The coastal bluff includes the bluff face which is all the area between the toe of the bluff and the bluff edge. Unconsolidated bluffs are a fairly rare landform found at the intersection of glacially influenced sediments and present sea level, such as around the Great Lakes, regions along the west coast of North America, the Black Sea and Long Island, NY. Along the north and south shores of Long Island, NY the coastal bluffs consist of glacial till that has been scarped through mechanical weathering. Coastal bluffs may represent significant sources of sediment to littoral transport, and in some regions control the stability of barrier beaches. Understanding the processes by which bluffs supply sediment to the littoral zone through recession, and how this potential source may be modified through stabilization techniques, is necessary for determining their contribution to the littoral budget.

Montauk Point is considered the beginning of the regional littoral transport cell for the south shore of Long Island, although it is a common misconception that these are the only source (e.g. Dean 1999 p68). Earlier estimates of the contribution of bluff erosion to the littoral sand system were based on the product of the average bluff elevation and the recession rate of the bluff crest. The bluff recession rate has been well documented due to endangerment of the historic Montauk Light House constructed in 1796. The Montauk Lighthouse commissioned by President George Washington was the fourth lighthouse constructed in the United States. The lighthouse was originally located on the landward

side of Turtle plateau, approximately 91 m inland from the edge of the bluff (Donohue 2000). By 1996 the lighthouse stood approximately 30 m from the edge of the bluff. To reduce the wave erosion at the base the U.S. Army Corps of Engineers constructed a stone revetment along most of the point.

A number of sediment budgets have been developed for the southern shore of Long Island, from Montauk Point to Fire Island Inlet to quantify the sources of sand (USACE 1958; RPI 1985; Kana 1995; Batten 2003; Rosati et al. 1999). Some of the most recent analyses indicate that net littoral transport does not increase systematically from east to west; local reversals occur in the vicinity of inlets. Transport initiated between Montauk Point and Southampton reaches a maximum rate of 354,000 m^3/yr to 460,000 m^3/yr at Democrat Point (Panuzio 1968; Kana 1995; Rosati et al. 1999). Estimates of the sediment contributed to the longshore transport derived from erosion of the Montauk bluffs range from 33,000 m^3/yr ±33,000 m^3/yr (Rosati et al. 1999) to 101,000 m^3/yr (Kana 1995). Because longshore transport increased to the west along Long Island's south shore, it was recognized that the Montauk bluffs could not account for all of the material contained within the littoral system (Fuller 1914; Panuzio 1968; McCormick and Toscano 1981). Therefore littoral transport had to be augmented by material migrating onshore from the shelf (Batten 2003; Williams and Meisberger 1987; Schwab et al. 1999), provided from cannibalization of existing beaches, or supplied through anthropogenic activity (beach nourishment from offshore or inland sources). Mapping of littoral material on the shelf indicate as much as 84,000 m^3/yr to 396,000 m^3/yr of sediment may be coming from offshore, however the mechanism for the material transport into the littoral zone has not been determined (Schwab et al. 1999).

Recent profile data collected in this region under the Atlantic Coast of New York Monitoring Program allow us now to calculate directly volume changes at the Montauk bluffs and to examine the nature and variability of erosion along this stretch of shoreline.

Background
Long Island (Figure 1) is 190 km long extending from the Narrows at the entrance to New York Harbor eastward to Montauk Point (Morang et al. 1999). It is the largest island adjoining the continental United States, even though the U.S. Supreme Court has declared recently that it is not an island (Burbidge 2004). Long Island is bound by the Long Island Sound along the north coast, on the east and south by the Atlantic Ocean, and on the west coast by New York Bay and the East River (which really isn't a river, by the way; but a tidal strait). Peconic Bay, which is about 46 km long, divides the eastern end of the island into two long narrow peninsulas locally referred to as the North and South Forks. Montauk Point is located at the eastern tip of the South Fork.

Long Island is the northern limit of the Atlantic Coastal Plain. Consolidated and semiconsolidated bedrock outcrops in the extreme west end of the island (Morang et al. 1999), composed of Cretaceous-age semiconsolidated rock and older metamorphic rocks. Long Island marks the southern boundary of the late Pleistocene glacial advancement in the eastern part of North America (Stone and Borns 1986). Surficial strata consist of morainal and outwash accumulations associated with the continental glaciers (Fuller

1914). Two end moraines run the length of Long Island. The southern moraine (Ronkonkoma) extends to Montauk Point, and the northern moraine (Harbor Hill) forms Orient Point. The moraines are superimposed along the western part of northern Long Island resulting in relatively high relief. The moraines bifurcate in eastern Long Island, where each moraine forms the core of the two "forks" north and south of Peconic Bay (Figure 1). The Ronkonkoma moraine on the southern fork extends eastward beneath the Atlantic Ocean to Nantucket, Massachusetts (Schwab et al. 1999).

Long Island exhibits greater relief on the north side and a gentler southward dipping gradient on the outwash plains, which make up much of the southern side of the island. Most of the north shore facing Long Island Sound consists of bluffs 10 m to 30 m high and, in its western half, is indented by deep bays that form good harbors for small crafts. Two physiographic provinces characterize the south shore of Long Island, a barrier island zone and a bluff zone. The barrier island zone is part of the glacial outwash plain located south of the Ronkonkoma Moraine. The outwash plain is constructed of reworked fluvioglacial sediments and stretches from 1 km to 15 km to the Atlantic Ocean (Fuller 1914; Schwab et al. 1999). It contains shallow back-barrier bays, marshes, and low-relief barrier islands (Leatherman and Allen 1985). The string of barrier islands extends from Coney Island eastward to Southampton and is dissected by six, stabilized inlets. The barrier island zone ends at the eastern extension of Shinnecock Bay in the town of Southhampton. The coast from Southampton to Montauk Point is a headland region where the Ronkonkoma moraine and associated outwash sediment are eroded directly by wave action (Williams 1976). From the east end of Shinnecock Bay to the beginning of the Montauk Bluffs, there are a series of welded barriers or bay-mouth bars that separate small freshwater ponds occasionally breached by natural and artificial mechanisms. East of Southampton the Ronkonkoma Moraine abuts the Atlantic Ocean and meanders along the coast through Montauk Point. The coastal bluffs here reach elevations greater than 24 m (Morang et al. 1999; Kana 1995). Gradual erosion of the unconsolidated glacial till has resulted in the formation of boulder reef headlands and gravely pocket beaches (Figure 2).

The Atlantic coast of Long Island can be classified as a microtidal, wave-dominated regime (Hayes 1979). The tidal range increases from east to west, averaging 0.6 m at Montauk Point to 1.4 m at New York Harbor (NOAA 1993). Similarly the width of the continental shelf increases from east to west. Average wave heights range from 1 to 2 m with periods on the order of 7 to 8 seconds. Larger waves over 4 m associated with longer period swells (period > 12 seconds) and storm events have been recorded offshore of Fire Island Inlet (National Data Buoy Center, Station 44025). The prevailing wind direction is southwesterly, but the long fetch and predominant wave and storm approach from the southeast produce a net longshore sediment transport to the west (Taney 1961; Schwab et al 1999). We have ignored the possibility of sand being transported to the east out of the south shore littoral system around Montauk Point. There is no evidence for eastward transport, but wave conditions that would drive such transport do exist. In addition there are sand shoals offshore of Montauk Point and the sand budget may be influenced by transport associated with such features. The issue deserves further study.

Two types of storms cause coastal erosion and flooding on Long Island, tropical hurricanes and extratropical northeasters (Morang 1999). Tropical storms are large-scale low-pressure cyclones that originate in tropical areas. Tropical storms typically occur between the months of July and November. Extratropical cyclones are broader weather systems associated with migratory fronts in mid to high latitude regions. Northeasters are more frequent and slower moving storms that occur from October through April. The speed at which the cyclone moves up the eastern seaboard increases the potential for flooding because the storm may span several high tides. In addition the large fetch associated with these weather systems generate high waves that erode the coast.

Wave intensity increases eastward toward Montauk Point because less energy is dissipated through shoaling of the waves as they propagate across the shelf. As a result many of the beaches within the Montauk bluff region are composed of gravel and boulders. Much of the finer material has been winnowed out by wave action. Occasionally sand deposits can be observed, but they are usually associated with a period of lower wave activity and generally do not persist. The narrower continental shelf permits more wave energy to reach the shoreline however refraction and diffraction of the waves around existing morphology can produce variable patterns of wave focusing. Waves focus around the boulder reef headlands. Wave energy is spread in the gravel pocket beaches, as a result the wave energy regime for various extents of the moraine can vary from headland to pocket beach as well as from cove to cove.

Bluff Failure
Although bluffs are continually eroded by precipitation and runoff, they deliver most sediment to the littoral zone through mass wasting processes. Bluffs may remain stable for decades then suddenly slump, receding several meters in a single event (Figure 3). Bluffs are a natural protective feature that can only be generated (for the case of Long Island) through glacial processes. Bluffs, of course, can only erode or stay stable, not accrete; and some bluff erosion must be allowed to proceed to supply sand to the beaches.

Bluff failure and episodic mass wasting events are influenced by antecedent geology, precipitation and ground water discharge, and incident wave energy. Bluffs are constantly eroded along the face by direct rainfall and surface water runoff. From a broad perspective, bluffs generally fail through undercutting and collapse of the bluff face.

Undercutting of the bluff can be caused by wave attack along the toe. Storm surge and wave setup can elevate sea level to the point where waves break at the base or toe of the bluff. Associated wave-driven currents remove the finer material from the base leaving a lag deposit of boulder and cobbles. In addition, waves undercut the bluff resulting in an unstable configuration. The undercut section of the bluff may no longer support the overlying material and the bluff face fails. The resulting fan deposit is gradually winnowed leaving only larger cobbles and gravel on the beach. The lag deposit of coarse material provides protection to dissipate wave energy, a mechanism of self-preservation for the bluff. However large storms eventually submerge the lag, and re-attack the toe.

Failure will usually occur as a slump or a debris flow. Slumping is a downward slipping of unconsolidated material with backward rotation (Easterbrook 1999). In addition, slumps generally retain much of the original geologic structure. Debris flows are moving masses of water-lubricated debris. The original geologic structure is erased during a debris flow and the material will usually be deposited as a fan or deltaic structure at the base of the bluff.

Undercutting can also occur in the face of the bluff due to ground water seepage. The bluffs on Long Island are made up of mixed sand, silt, and gravel along with clay lenses, large cobbles, and boulders. Groundwater percolating through the bluff tends to accumulate on and flow along the clay lenses. The groundwater discharges out of the face of the bluff where these clay lenses outcrop, sapping the bluff face (Figure 4). In some places along the Long Island shore a careful observer can hear the babbling of the flowing water.

Mass wasting and failure of the bluff face can also occur through slippage of overlying material along a clay lens that is dipping toward the bluff face. Groundwater percolates through the bluff material and accumulates at the top of the clay lens. As the ground water runs along the clay-surface interface it reduces friction between the clay lens and saturated overlying material. If the lens dips toward the bluff face the extra weight due to pore water and reduction in friction between the lens and overlying till can lead to instabilities, resulting in mass wasting along the face.

Methods
The headland province, which contains the majority of Montauk bluffs, ranges from Montauk Point westward approximately 8 km (Kana 1995; Rosati et al. 1999). Bluff recession rates were estimated from profile data collected as part of the Atlantic Coast of New York Monitoring Program (ACNYMP). The program was initiated to develop a coastal processes monitoring program for the Long Island south shore between Coney Island and Montauk Point (Morang 2002). The purpose of the program is to obtain and distribute data on coastal processes directed at addressing post storm actions and long-term coastal erosion control (Morang 2002). Data was collected, bi-annually, beginning in spring of 1995 through fall 2001. Cross-shore topographic-bathymetric profiles were collected up to an offshore water depth of approximately 30 m. Spacing between transects for most of the south shore ranged between 1,000 and 2,000 m.

The monitoring program subdivided the south shore into eight geographic reaches, based on geomorphology and spacing of tidal inlets. The reaches include: Coney Island, Rockaway, Long Beach, Jones Island, Fire Island, Westhampton, Ponds, and Montauk. The Ponds and Montauk reaches comprise the headland province previously discussed. For the Montauk reach eight surveys were performed between spring 1995 and spring 2001 at 43 stations. Although the Ronkonkoma Moraine runs the length of the south fork, the bluffs are not directly exposed to the coast until ACNYMP Station M35 (Figure 5).

ACNYMP stations M35 and M37 through M43 are located within coastal bluff regions. Recession rates were calculated by comparing the series of profiles. Profile volume

changes for each station were computed using the Regional Morphology Analysis Package (RMAP), developed by the US Army Corps of Engineers (Batten et al. 2004, 2005). RMAP is a collection of automated and interactive tools for analyzing morphologic and dynamic properties of shorelines and beach profiles. There is very little information about the grain size composition of the bluffs but one analysis suggests that 63 % of bluff material is suitable for down drift beaches, comprised mainly fine to medium sand (Bokuniewicz 1999). Material supplied to the littoral drift by direct erosion of the bluffs was estimated by integrating the change in profile volume between ACNYMP stations within the coastal bluff regions and proportioning that volume based on the earlier investigation of bluff composition and littoral sediments.

Results

Analysis of the profiles indicated volumetric bluff recession rates ranged from 1.0 m^3/m/year at M39 to 19.6 m^3/m/year (Table 1). The linear recession rates ranged from 0.06 m/yr to 0.6 m/yr for the six-year monitoring program. The average recession rate was 0.3 m/yr and the total annual supply of sediments when integrated along the coastal bluff region was 34,480 m^3/yr. Therefore the contribution of the bluffs to the littoral sand system of the south shore could not be more than 21,720 m^3/yr. This is comparable to more recent estimates longshore sediment transport derived from erosion of the Montauk bluffs (Rosati et al. 1999 (33,000 m^3/yr ±33,000 m^3/yr), Bokuniewicz 1999 (39,000)). Rosati et al. (1999) recognized the episodic nature of bluff erosion, which can vary both spatially and temporally.

Also illustrated in the profiles are mass wasting events triggered by unstable slopes that result from undercutting of the toe and mid face erosion (Figure 6). Profiles collected at ACNYMP Station M38 indicate the bluff crest location was stable between November 1996 and April, 1997, however the toe was undermined by wave activity and the mid face of the bluff eroded (between 4 and 7 m elevation relative to National Geodetic Vertical Datum (NGVD) 1929), steepening the profile. This unstable configuration could have stimulated a mass-wasting event, which may have been responsible for the observed 1.2 m recession of the bluff crest between April 1997 and November, 1998.

Bluff recession and contribution of material to the littoral drift is difficult to estimate because of episodic mass wasting events and partial removal of material from the bluff face and toe. Station M40 indicates recession of the toe approximately 3 m between November, 1996 and June, 2001 (Figure 7). During this period the location of the bluff crest remained stable. In addition Station M41 eroded mid face between December, 1995 and June, 2001, leaving both crest and toe positions relatively fixed (Figure 8). Erosion of these two stations resulted in steeper profiles that may eventually lead to larger mass wasting events. However for this time period these two stations exhibited the lowest overall recession rates even though their annual contribution to the littoral drift was approximately 2,150 m^3. The changes depicted at these two stations would be imperceptible from aerial photographs and therefore material contributed through erosion of these bluffs using this technique would not have been incorporated into earlier littoral budgets.

Discussion
Bluff recession rates on the east end of Long Island vary between headlands and within the individual coves. Localized bluff erosion rates were calculated for a cove within the headland province located between ACNYMP stations M40 and M41. This specific site illustrates the impacts of stabilizing techniques on bluff recession and littoral transport. In this region, vegetation, surface and subsurface drainage systems, a rock revetment and rebuilding the bluff face at a reduced slope were used to minimize mass wasting events and the continual erosion of the bluff. The revetment constructed in 1988 halted recession of the bluff associated with wave induced undercutting of the toe. In addition the stabilized bluff was vegetated with indigenous grasses and low-lying shrubs, and terraced. Groundwater and surface water runoff was collected and redirected to the base of the bluff where it exited from corrugated plastic tubing onto the gravel pocket beach. The neighboring parcels of land were not maintained and the faces of their unprotected bluffs were barren and scarred with deep runnels created by flowing surface water (Figure 10). Undercut hardpan layers were observed along the face and erosion of the unprotected bluffs periodically endangered the flanks of the revetment. By September 2003 the unprotected bluffs had eroded an additional 2.4 m to 3 m resulting in an annual recession rate of 0.15 m/yr to 0.21 m/yr.

The average annual reduction in sediment contribution during the 15 yr period due to bluff stabilization for the reveted parcel of land was calculated using the length of the revetment (57 m), the average height of the bluff in the vicinity (17 m elevation relative to NGVD 1929), and the estimated recession rates of the neighboring, unprotected properties (0.15 m/yr to 0.21 m/yr). The revetment and stabilizing efforts reduced the volumetric bluff erosion by 7,050 m^3 to 8,830 m^3 of material during the 15 yr period, or an annual rate equal to 440 m^3/yr to 620 m^3/yr. If we assume 63 % of this would be transported alongshore, then this percentage constitutes a loss of approximately 280 m^3/yr to 390 m^3/yr to the longshore transport budget. Stabilization of this small stretch of coast has potentially reduced the littoral transport associated with recession of the bluffs by 1.1 to 1.5 %.

Conclusions
Analysis of ACNYMP data for the Montauk reach indicates volumetric bluff recession rates range from 1.0 m^3/m/yr to 19.6 m^3/m/yr for the period 12/07/95 through 01/06/01. Integration of the volume change for ACNYMP profiles in the Montauk bluff province indicates that approximately 34,480 m^{3}of sediment was delivered to the shoreline every year during this six year period and an estimated 21,720 m^3 of beach-suitable sand would have been supplied to the littoral drift annually. Erosion of the bluff face and toe can supply sediment to the littoral drift without resulting in recession of the bluff crest. Bluffs can be stabilized through various combinations of slope reduction, controlled drainage, vegetation, and engineered structures, however this will reduce the volume of material supplied to the littoral system.

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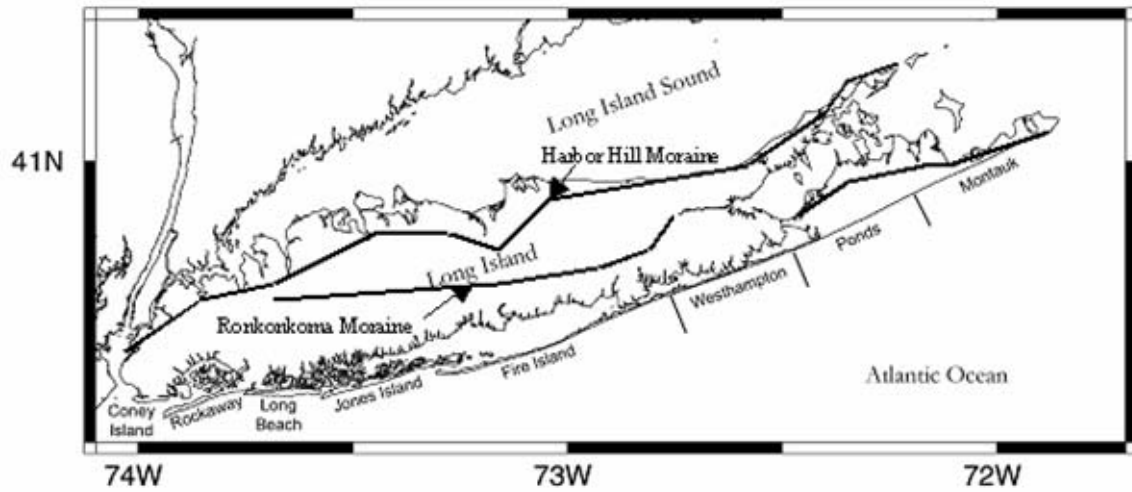
Figures

Figure 1. Map shows Long Island, NY with the solid black lines indicating the approximate location of the Harbor Hill and Ronkonkoma Moraines.

Figure 2. Erosion of the coastal bluffs along the Atlantic coast of Long Island has created boulder reefs and gravel beaches.

Figure 3. Photograph of mass wasting of the bluff face. The crest of the bluff recedes as material is transported down slope in the form of a debris slide. Remnants of terracing can be seen intertwined with boulders and gravel. Debris flows and slumps often carry vegetation as a coherent form.

Figure 4. Groundwater seeping out of the face of the bluff where hardpan layers outcrop results in concentrated streams of water incise the face, dislodge material and undercut the clay lenses.
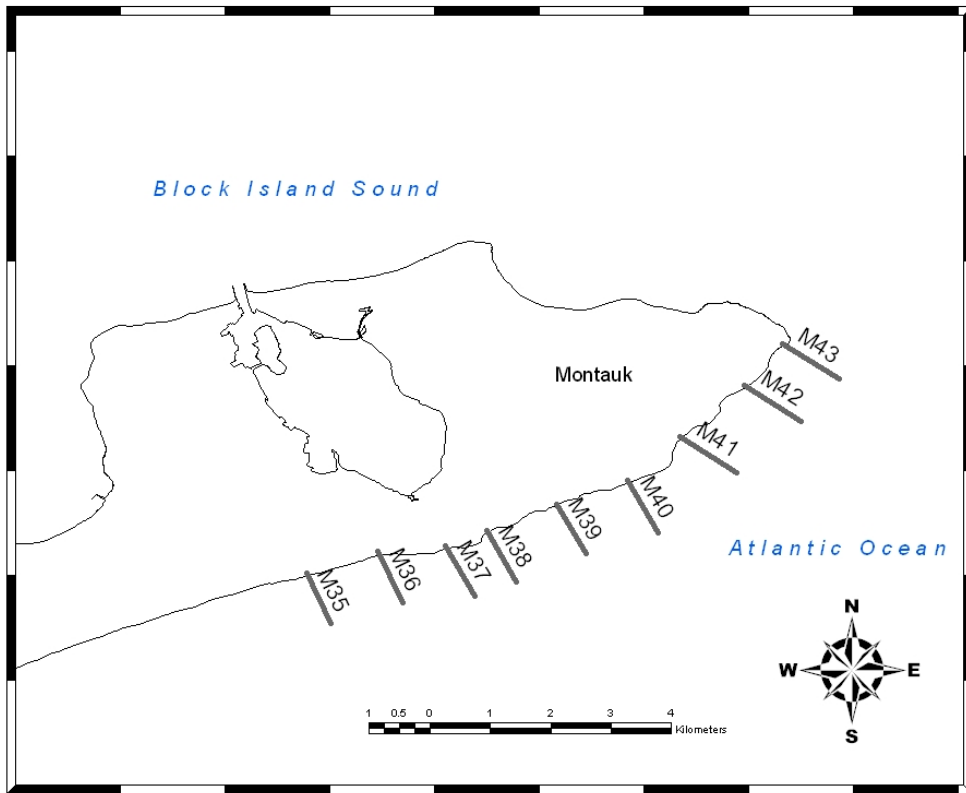
Figure 5. Atlantic Coast of New York Monitoring Program stations within the bluff region of the Montauk Reach.
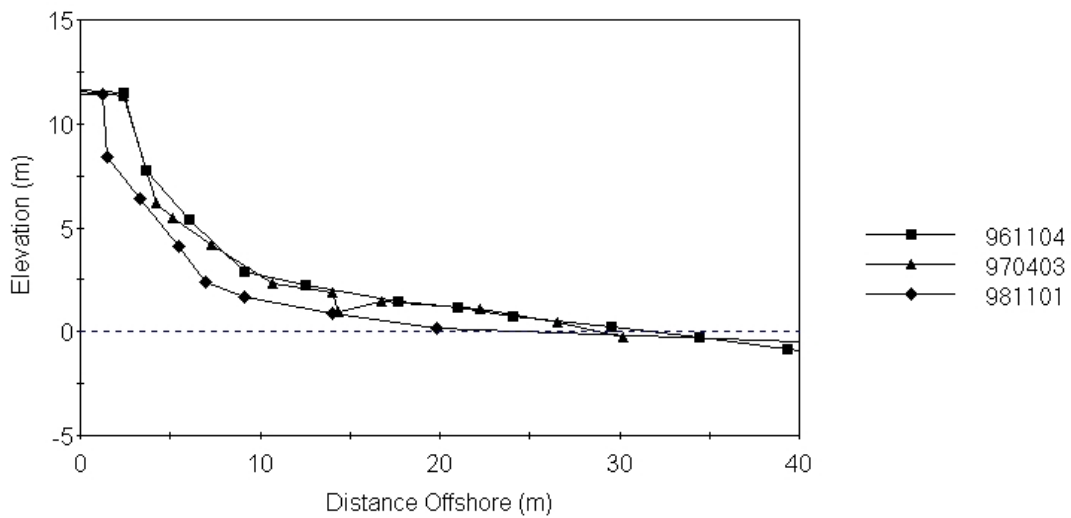

Figure 6. Station M38. Bluff elevations are relative to NGVD 1929. Undercutting of the bluff toe and mid-face erosion may have led to an unstable configuration which could have triggered a large mass wasting event resulting in the crest receding 1.2 m between 4/3/97 and 11/1/98.
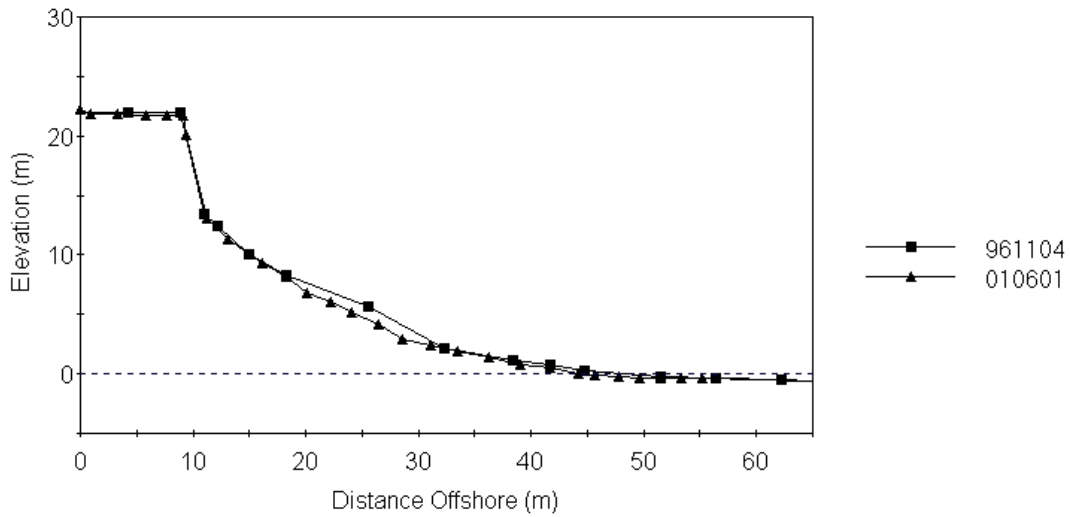
Figure 7. Station M40. Bluff elevations are relative to NGVD 1929. Profile indicates recession of the toe between 11/96 and 6/01. Bluff crest remained stable resulting in a steeper slope of the face. The rate of recession for this station was low (0.06 m/yr) however sediment was still supplied to the littoral drift at a rate of 1,450 m^3/yr.
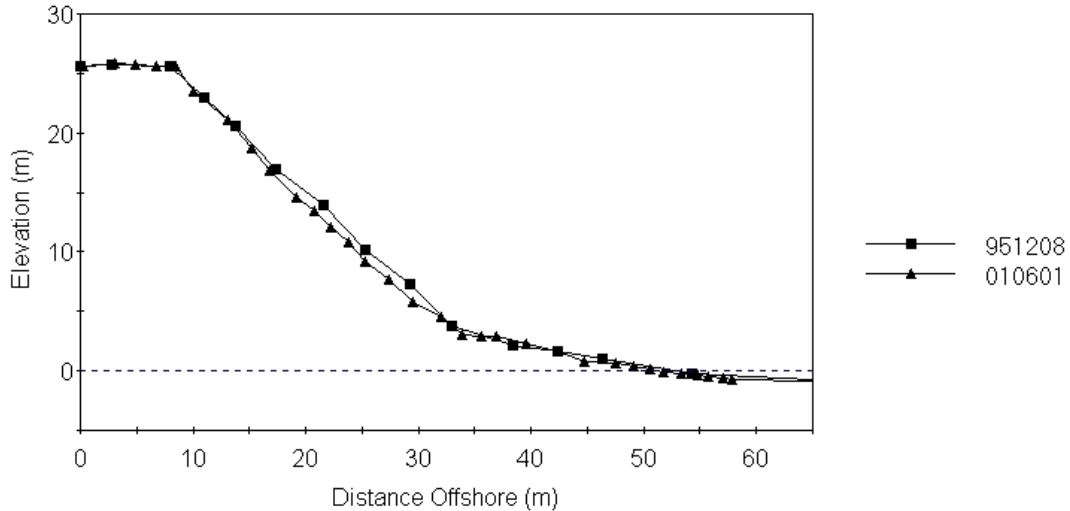

Figure 8. Station M41. Bluff elevations are relative to NGVD 1929. Sediment eroded from the middle of the bluff face between 12/95 and 6/01, preserving both crest and toe locations. Although the rate of recession for this station was higher than station M40 (0.09 m/yr) less sediment was supplied to the littoral drift (700 m^3) annually.

Figure 9. Slope reduction and vegetation appear to be the most effective stabilizing techniques. Regions of the coastal bluffs that have been stabilized with these mechanisms experience decreased recession

rates.

Figure 10. Bluff recession is intensified for non-stabilized regions. Erosion along the flanks of stabilized bluffs can undermine protective structures and often require periodic maintenance. Hardpan layers are visible in the photograph and long term incising of groundwater across the face has carved ridge structures, seen protruding form the face.

Table 1. Measured Recession Rates and Littoral Drift Contribution for Montauk Bluffs from 12/07/95 through 01/06/01

ACNYMP Station	Length of Reach m	Elevation m NGVD 1929	Recession Rate m/yr	Vol. Change m^3/m/yr	Integrated Volume m^3/yr	Littoral Volume m^3/yr
M35	930	16	0.10	8.0	7440	4690
M37	673	8	0.25	3.0	2020	1270
M38	683	12	0.58	19.6	13390	8440
M39	880	7	0.61	1.0	880	550
M40	770	22	0.06	3.0	2310	1460
M41	694	26	0.09	1.6	1110	700
M42	614	19	0.40	11.2	6880	4330
M43	222	16	0.28	2.0	450	280
Average			0.30	Total	34480	21720