VDEM - Lancaster County- Westland Beach - Windmill Point Shoreline

BENEFIT COST ANALYSIS REPORT

BRIC 2022

Contents

BCA SUMMARY

SUB APPLICANT
Lancaster County

LAT/LON
37.6158609, -76.2919770

PROPERTY TYPE
Roads and Bridges

HAZARD TYPE
Coastal V Flood

MITIGATION TYPE
Floodplain and Stream Restoration

DAMAGE AND FREQUENCY
Professional Expected Damages

The Westland Beach-Windmill Point Shoreline Stabilization project will use a multi-faceted approach of armor stone breakwaters, armor spurs and nature-based solutions, including beach nourishment and beach and dune vegetation planting to stabilize 1,324 feet or eroding shoreline along the Rappahannock River.

The project will include the construction of five armor stone breakwaters (180', 240', 220', 90', and 110'), two armor spurs (60' and 50'), and the installation of 18,000 cubic yards of beach nourishment with 42,000 square feet of beach and dune vegetation plantings. All existing concrete debris and stone groins (located channel ward of breakwaters) will be removed to allow for restoration of the beach and a more comprehensive approach to stabilization of the shoreline. The vegetation plantings will include salt meadow cordgrass (spartina patens), American beach grass and Atlantic coastal panic grass. The cost of this stabilization project is estimated to be ~~$2,178,000.00.~~ $2,319,000.00.

Estimated Benefits (B) = $ 7,458,373
Estimated Costs (C) = $ ~~2,178,000.00~~ Estimated Costs updated on November 7, 2023 = $2,319,119.00
BCR (B/C) = ~~3.40~~ Updated BCR (C/C) = 3.22

Benefit-Cost Analysis

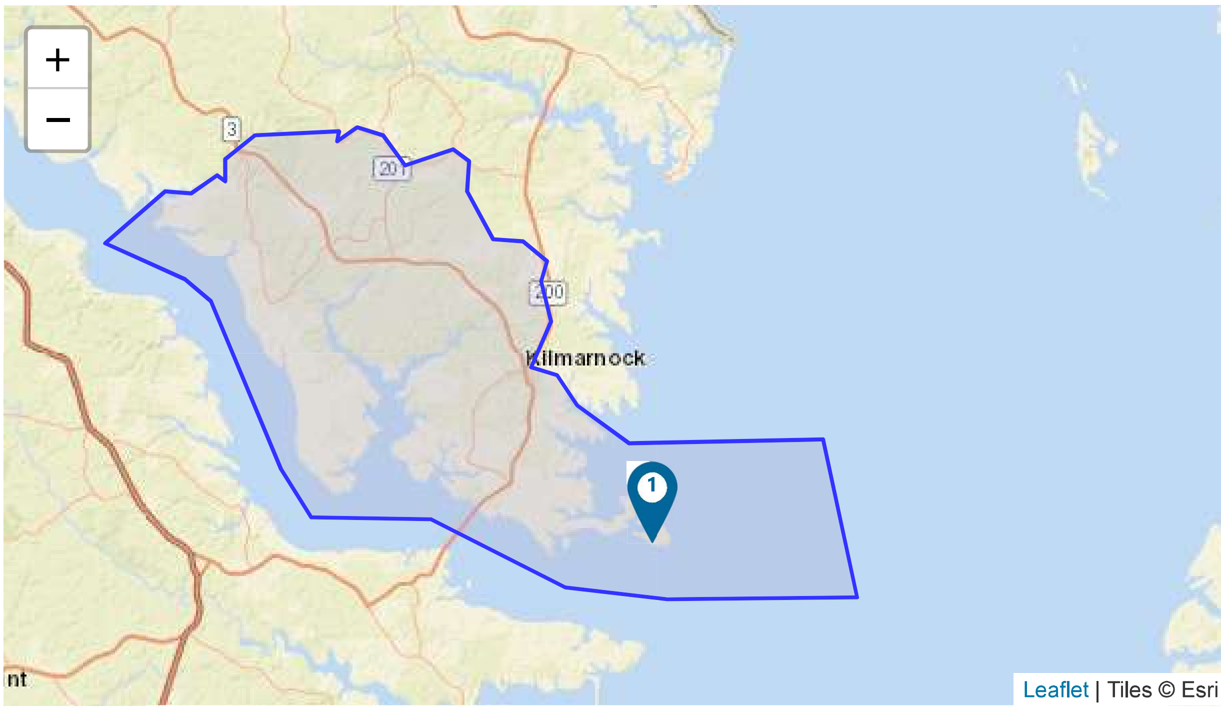
FEMA

Benefit-Cost Calculator

V.6.0 (Build 20221028.1600 | Release Notes)

Benefit-Cost Analysis

Project Name: Lancaster County - Westland Beach - Windmill Point Shoreline



				Using 7% Discount Rate			Using 3% Discount Rate (For FY22 BRIC and FMA only)		
Map Marker ▲	Mitigation Title	Property Type	Hazard	Benefits (B)	Costs (C)	BCR (B/C)	Benefits (B)	Costs (C)	BCR (B/C)
1	Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578		DFA - Coastal V Flood	$ 7,458,373	$2,319,119.00 ~~$ 2,195,299~~	3.22 ~~3.40~~	~~$ 9,347,049~~	~~$ 2,199,680~~	~~4.25~~
TOTAL (SELECTED)				$ 7,458,373	~~$ 2,195,299~~	~~3.40~~	~~$ 9,347,049~~	~~$ 2,199,680~~	~~4.25~~
TOTAL				$ 7,458,373	~~$ 2,195,299~~	~~3.40~~	~~$ 9,347,049~~	~~$ 2,199,680~~	~~4.25~~

Property Configuration

Property Title:	Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578
Property Location:	22578, Lancaster, Virginia
Property Coordinates:	37.61586099752033, -76.291977007078
Hazard Type:	Coastal V Flood
Mitigation Action Type:	Floodplain and Stream Restoration
Property Type:	Roads & Bridges
Analysis Method Type:	Professional Expected Damages

Cost Estimation

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Project Useful Life (years):	12
Project Cost:	$2,178,000
Number of Maintenance Years:	12 Use Default:Yes
Annual Maintenance Cost:	$2,178

Comments

-

Project Useful Life:

Project-specific, the PUL and event RI should be the same to show the complete loss of the asset being protected by the project.

-

Mitigation Project Cost:

Construction costs for the shoreline stabilization project. Design and construction costs for pier. Floodplain and Stream Restoration (FSR) projects are used primarily to reduce flood risk and erosion by providing stable reaches but can also be used to help mitigate drought. These projects restore and enhance the floodplain, stream channel and riparian ecosystem's natural function. They provide baseflow recharge, water supply augmentation, floodwater storage, water quality renovation, terrestrial and aquatic wildlife habitat, and recreation opportunities, by restoring the site's soil, hydrology and vegetation conditions that mimic the pre-development, or pre-alteration natural channel/floodplain connectivity.

-

Annual Maintenance Cost:

Based on 1% of the project costs.

Damage Analysis Parameters - Damage Frequency Assessment

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Year of Analysis was Conducted:	2022
Year Property was Built:	1961
Analysis Duration:	62 Use Default:Yes

Roads and Bridges Properties

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Estimated Number of One-Way Traffic Detour Trips per Day:	1,000
Additional Time per One-Way Detour Trip (minutes):	60
Number of Additional Miles:	1
Federal Rate ($):	0.625 Use Default:Yes
Economic Loss Per Day of Loss of Function ($):	36,225

Comments

-

Number of Trips:

A minimum of 1,000 cars were assumed as this location is a tourist-attraction.

-

Time per Trip:

Dead End Road: 60-minute input was used.

-

Number of Miles:

Assumed additional 1 mile of detour since this is a dead end road.

Professional Expected Damages Before Mitigation

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

	ROADS AND BRIDGES	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Impact (days)	Facility and Revenue Loss	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
12.75	365	500,000	0	0	0	0	13,722,125

Comments

-

Damages Before Mitigation:

This 56-year event was used as the baseline for damages before mitigation for this site. This baseline was developed assuming a constant erosion rate based on the 2019-2022 erosion rate estimate, which could reach the roadway shoulder/bridge in 12.75 years (102-ft divided by 8 ft/year = 12.75 years), or about a 7.8-percent annual chance event (1 event or 100% divided by 12.75 years = 7.8%). While this assumption was used for the BCA, field conditions demonstrate that the erosion risk and impacts can change quickly due to one flood. These changes to the river alignment due to a single high flow event highlight the erosion susceptibility of this coast, in proximity to the subject roads and facilities. Optional Damages for potential revenue loss, road damages and total loss to the World Marina structure, and contents.

Annualized Damages Before Mitigation

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
12.75	13,722,125	1,076,244
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	13,722,125	1,076,244

Professional Expected Damages After Mitigation

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

	ROADS AND BRIDGES	OPTIONAL DAMAGES			VOLUNTEER COSTS		TOTAL
Recurrence Interval (years)	Impact (days)	Facility and Revenue Loss	Category 2 ($)	Category 3 ($)	Number of Volunteers	Number of Days	Damages ($)
100	365	500,000	0	0	0	0	13,722,125

Comments

-

Damages After Mitigation:

Design of the improvements is intended to provide stream stability and flood damage reduction up to the 100-year recurrence interval event (1-percent annual chance) without significant damage to the improvements.

Annualized Damages After Mitigation

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Annualized Recurrence Interval (years)	Damages and Losses ($)	Annualized Damages and Losses ($)
100	13,722,125	137,220
	Sum Damages and Losses ($)	Sum Annualized Damages and Losses ($)
	13,722,125	137,220

Standard Benefits - Ecosystem Services

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

Total Project Area (acres):	0
Percentage of Urban Green Open Space:	0.00%
Percentage of Rural Green Open Space:	0.00%
Percentage of Riparian:	0.00%
Percentage of Coastal Wetlands:	0.00%
Percentage of Inland Wetlands:	0.00%
Percentage of Forests:	0.00%
Percentage of Coral Reefs:	0.00%
Percentage of Shellfish Reefs:	0.00%
Percentage of Beaches and Dunes:	0.00%
Expected Annual Ecosystem Services Benefits:	$0

Benefits-Costs Summary

Floodplain and Stream Restoration @ 40 Windjammer Ln, White Stone, Virginia, 22578

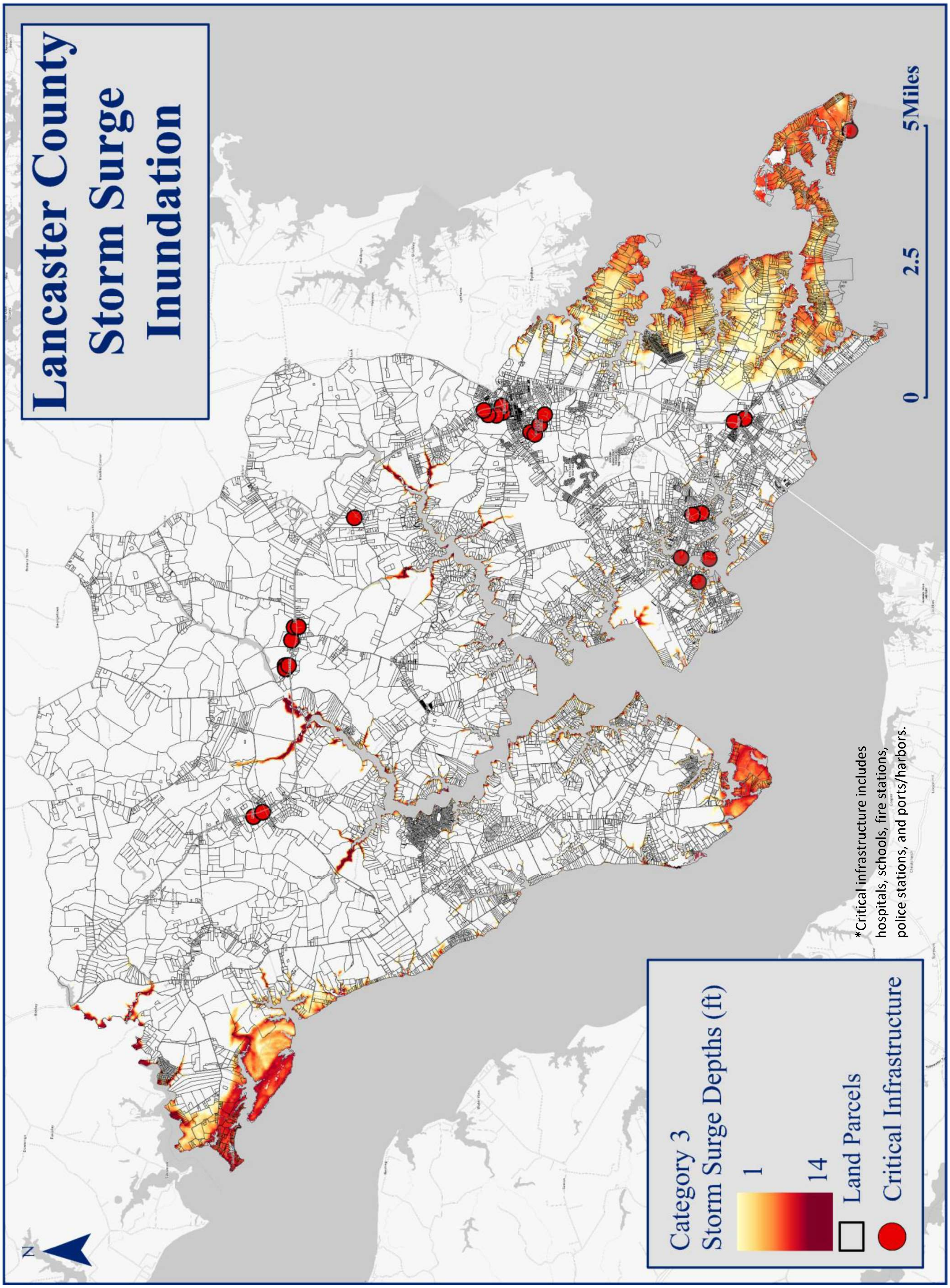
Total Standard Mitigation Benefits:	$7,458,373
Total Social Benefits:	$0
Total Mitigation Project Benefits:	$7,458,373
Total Mitigation Project Cost:	~~$2,195,299~~ $2,319,119.00
Benefit Cost Ratio - Standard:	~~3.40~~ 3.22
Benefit Cost Ratio - Standard + Social:	~~3.40~~ 3.22

Appendix A - Storm Surge

OLD DOMINION UNIVERSITY
Resilience Collaborative

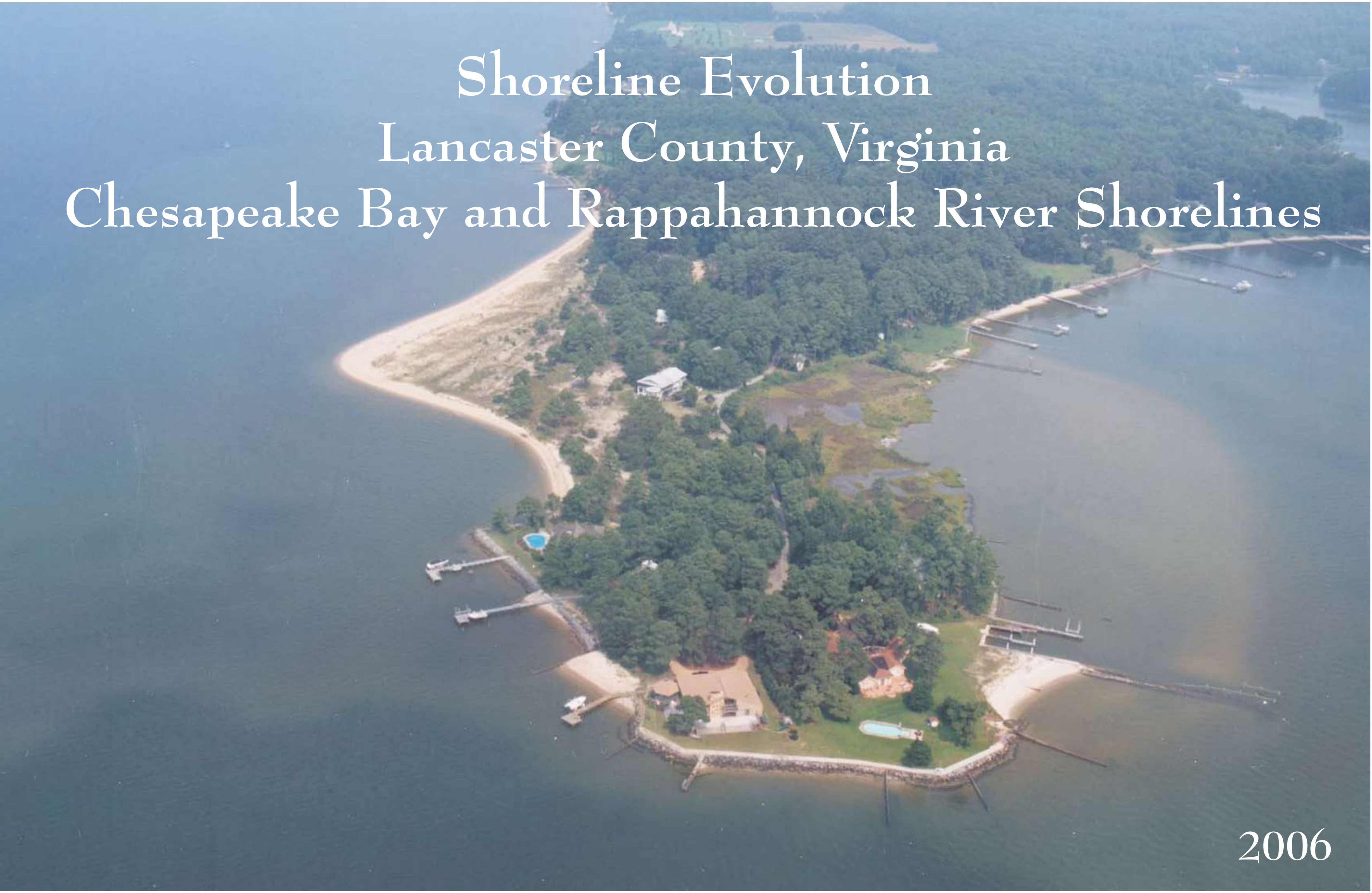
WILLIAM & MARY
LAW SCHOOL
VIRGINIA COASTAL
POLICY CENTER

UNIVERSITY of VIRGINIA
INSTITUTE for
ENGAGEMENT & NEGOTIATION
Shaping Our World Together



For more information visit: https://raft.ien.virginia.edu/

Appendix B - Shoreline Evolution


Shoreline Evolution
Lancaster County, Virginia
Chesapeake Bay and Rappahannock River Shorelines
2006

Shoreline Evolution
Lancaster County, Virginia
Chesapeake Bay and Rappahannock River Shorelines

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Gloucester Point, Virginia

2006

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Cover Photo: Photograph of Mosquito Point in Lancaster County. Photo taken by Shoreline Studies Program on 15 August 2003.

I. INTRODUCTION

A. General Information

Shoreline evolution is the change in shore position through time. In fact, it is the material resistance of the coastal geologic underpinnings against the impinging hydrodynamic (and aerodynamic) forces. Along the shores of Chesapeake Bay and Rappahannock River, it is a process-response system. The processes at work include winds, waves, tides and currents, which shape and modify coastlines by eroding, transporting and depositing sediments. The shore line is commonly plotted and measured to provide a rate of change but it is as important to understand the geomorphic patterns of change. Shore analysis provides the basis to know how a particular coast has changed through time and how it might proceed in the future.

The purpose of this report is to document how the dunes along the Bay and river shores of Lancaster (Figure 1) have evolved since 1937. Aerial imagery was taken for most of the Bay region beginning that year, and it is this imagery that allows one to assess the geomorphic nature of shore change. Aerial imagery shows how the coast has changed, how beaches, dunes, bars, and spits have grown or decayed, how barriers have breached, how inlets have changed course, and how one shore type has displaced another or has not changed at all. Shore change is a natural process but, quite often, the impacts of man through shore hardening or inlet stabilization come to dominate a given shore reach. Most of the change in shore positions will be quantified in this report. Others, particularly very irregular coasts, around inlets, and other complicated areas will be subject to interpretation.

B. Chesapeake Bay Dunes

The primary reason for developing this Shoreline Evolution report is to be able to determine how dunes and beaches along the Bay and river coast of Lancaster have and will evolve through time. The premise is that, in order to determine future trends of these important shore features, one must understand how they got to their present state. Beaches and dunes are protected by the Coastal Primary Sand Dune Protection Act of 1980 (Act)[1]. Research by Hardaway *et al.* (2001) located, classified and enumerated jurisdictional dunes and dune fields within the eight localities listed in the Act. These include the counties of Accomack, Lancaster, Mathews, Northampton and Northumberland and the cities of Hampton, Norfolk and Virginia Beach (Figure 2). Only Chesapeake Bay and river sites were considered in that study.

In 2004, Hardaway *et al*. created the Lancaster County Dune Inventory. That report detailed the location and nature of the jurisdictional primary dunes along the Bay shore of Lancaster County and those results appear in Appendix B. For this study, the positions of the dune sites are presented using the latest imagery in order to see how the sites sit in the context of past shoreline positions. The dune location information has not been field verified since the original visits in 2000. This information is not intended to be used for jurisdictional determinations regarding dunes.

[1]The General Assembly of Virginia enacted the Coastal Primary Sand Dune Protection Act (the Dune Act) in 1980. The Dune Act was originally codified in § 62.1-13.21 to -13.28. The Dune Act is now recodified as Coastal Primary Sand Dunes and Beaches in § 28.2-1400 to -1420.

II. SHORE SETTING

A. Physical Setting

The Bay shoreline of the Lancaster includes about 12 miles of shoreline from Windmill Point to Indian Creek which is the border with Northumberland County. The Rappahannock River shoreline extends from Windmill Point to Morattico Creek which is the border with Richmond County. This includes about 40 miles of tidal shoreline on the Rappahannock River and Corrotoman River. The shorelines along Chesapeake Bay are mostly low sandy banks and marsh. Historic shore change rates vary from 0 ft/yr (inside Little Bay) to -8 ft/yr (Windmill Point) for shore recession along the Bay coast (Byrne and Anderson, 1978). The open Bay coasts have the highest erosion rates. Up the Rappahannock River, shore erosion and accretion rates are highly variable. The point at Morrattico Creek had an erosion rate of -3.1 ft/yr. The shore along the Corrotoman River has erosion and accretion rates between -5 ft/yr and +2 ft/yr. Between the Corrotoman River and Mosquito Point, erosion and accretion occurred between +2.4 ft/yr (Mosquito Point) and -1.6 ft/yr (farther upriver). Some areas showed no change (Byrne and Anderson, 1978). The shore along the Rappahannock River includes high and low sandy banks and occasional marshes.

The coastal geomorphology of the County is a function of the underlying geology and the hydrodynamic forces operating across the land/water interface, the shoreline. The Chesapeake Bay coast of Lancaster County varies between Holocene marsh and Holocene beach sands (Figure 3). Both sediment types overlie the Lynnhaven Member of the Tabb Formation (Late Pleistocene). Along the Rappahannock River, the Sedgefield Member, Shirley Formation and Lynnhaven Member outcrop along the shoreline. In addition, Quaternary alluvium was deposited at Towles Point. The Atlantic Ocean has come and gone numerous times over the Virginia coastal plain over the past million years or so. The effect has been to rework older deposits into beach and lagoonal deposits at the time of the transgressions. The last low stand found the ocean coast about 60 miles to the east when sea level about 300 feet lower than today and the coastal plain was broad and low. The current estuarine system was a meandering series of rivers working their way to the coast. About 15,000 years ago, sea level began to rise and the coastal plain watersheds began to flood. Shorelines began to recede. The slow rise in sea level is one of two primary long-term processes which cause the shoreline to recede; the other is wave action, particularly during storms. As shorelines recede or erode the bank material provides the sands for the offshore bars, beaches and dunes.

Sea level is continuing to rise in the Chesapeake Bay Region. Tide data collected at Gloucester Point on the York River showed that sea level has risen 3.95 mm/yr or 1.3 ft/century (http://www.co-ops.nos.noaa.gov/). Lewisetta on the Potomac River rose 4.85 mm/yr or 1.59 ft/century. Windmill Point and the Rappahannock River are between these two guages. The amount of sea level rise directly effects the reach of storms and their impact on shorelines. Anecdotal evidence of storm surge during Hurricane Isabel, which impacted North Carolina and Virginia on September 18, 2003, put it on par with the storm surge from the "storm of the century" which impacted the lower Chesapeake Bay in August 1933. Boon (2003) showed that even though the tides during the storms were very similar, the difference being only 4 cm or about an inch and a half, the amount of surge was different. The 1933 storm produced a storm surge that was greater than Isabel's by slightly more than a foot. However, analysis of the mean water levels for the months of both August 1933 and September 2003 showed that sea level has risen by 41 cm (1.35 ft) at Hampton Roads in the seventy years between these two storms (Boon, 2003). This is the approximate time span between our earliest aerial imagery (1937) and our most recent (2002), which means the impact of sea level rise to shore change is significant. The beaches, dunes, and nearshore sand bars try to keep pace with the rising sea levels. Five shore reaches are described along the coast of Lancaster County (Figure 4). Reaches I, III, and IV are on the north shore of the Rappahannock River. Reach II is on the Corrotoman River, and Reach V is on the open Chesapeake Bay.

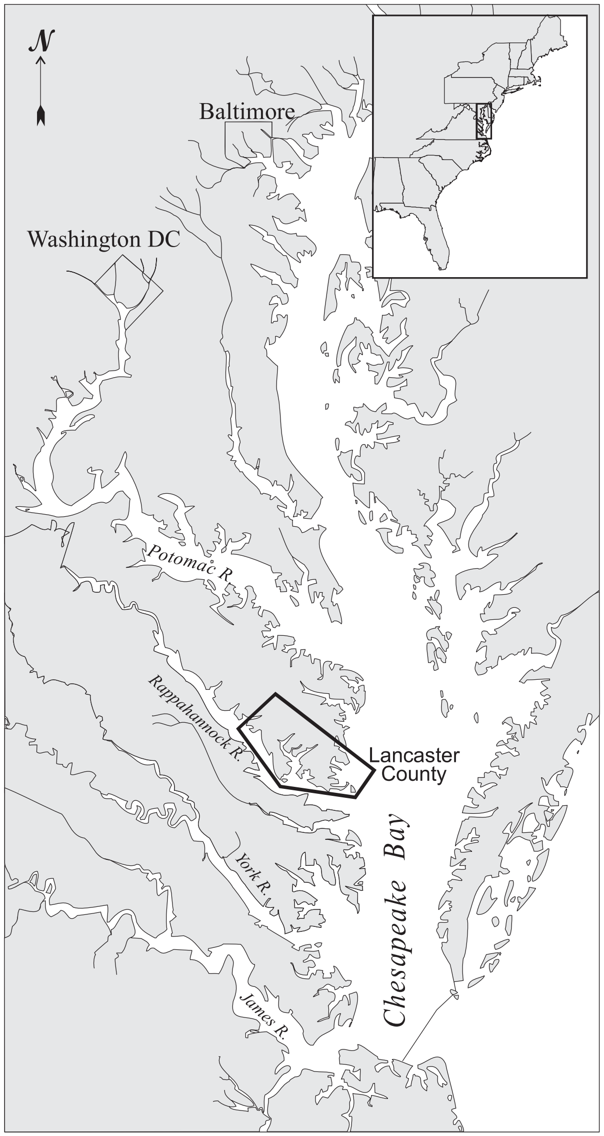


Figure 1. Location of Lancester County within the Chesapeake Bay estuarine system.

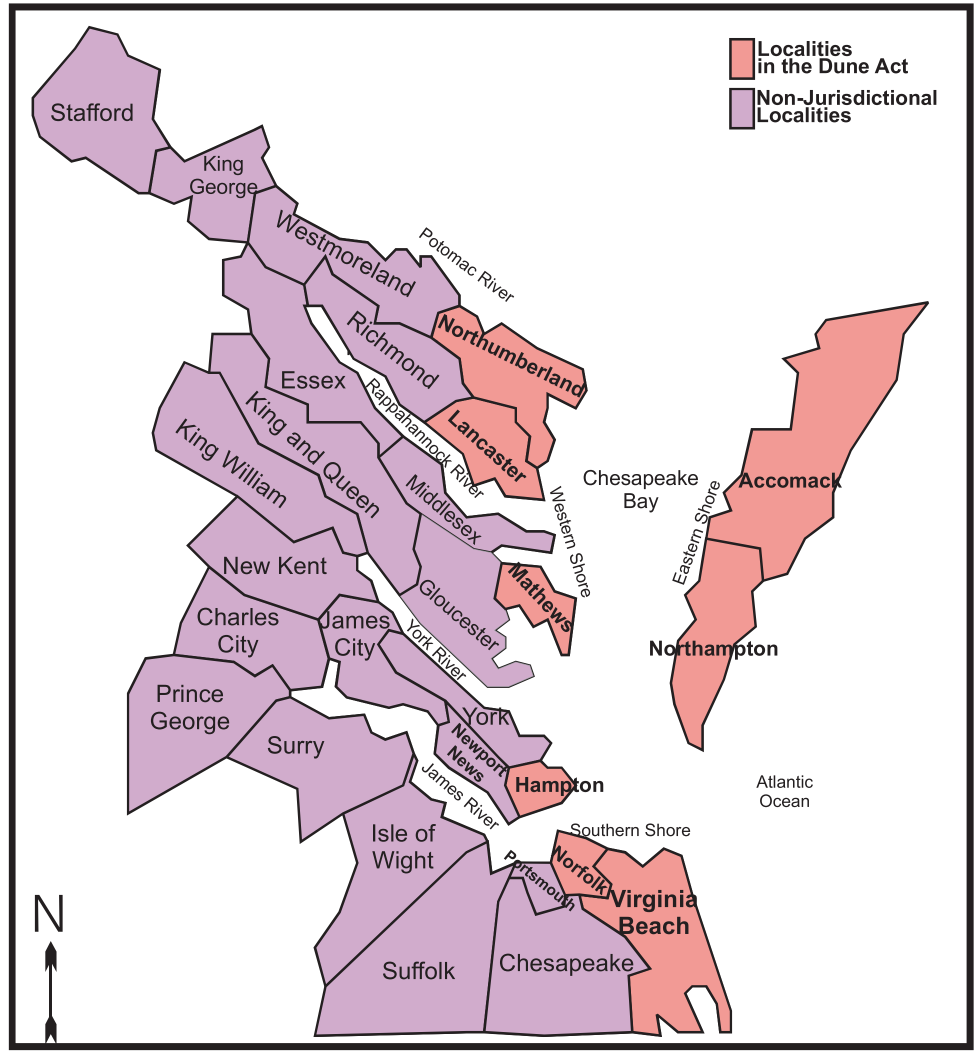
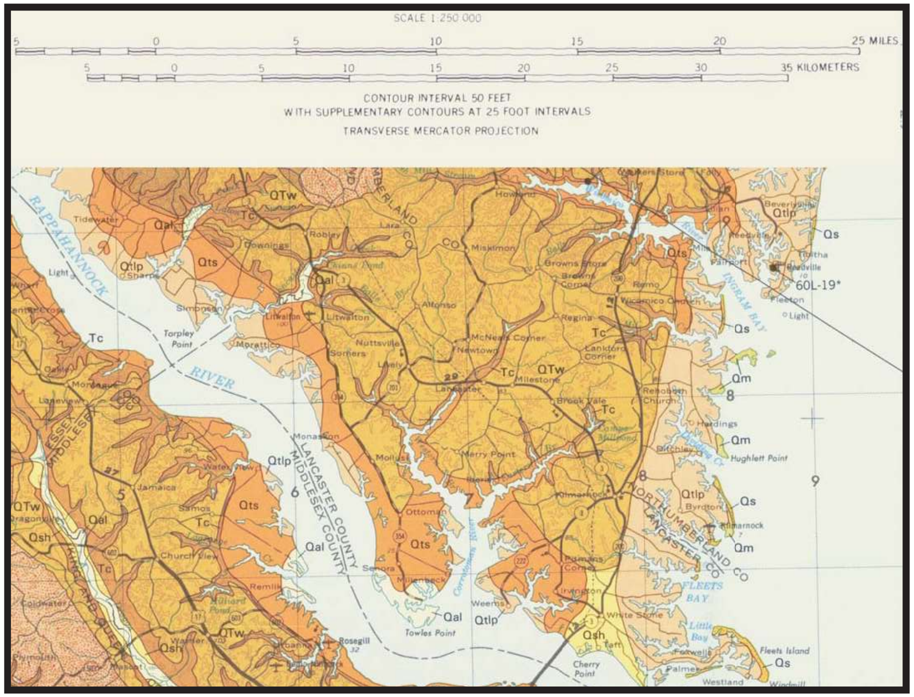


Figure 2. Location of localities in the Dune Act with jurisdictional and non-jurisdictional localities noted.



Qm **Holocene Soft Mud** - Medium to dark-gray, and peat, grayish brown. Comprises sediment of marshes in coastal areas and Chesapeake Bay. Thickness is 0-10 ft.

Qs **Holocene Sand** - Pale gray to light-yellowish gray, fine to coarse, poorly sorted to well sorted, shelly in part; contains angular to rounded fragments and whole valves of mollusks. Comprises deposits of coastal barrier islands and narrow beach-dune ridges bordering brackish-water marshes of Chesapeake Bay. As much as 40 ft in thickness.

Qtlp **Lynnhaven and Poquoson Members, undifferentiated.**

Qts **Sedgefield Member** - Pebbly to bouldery, clayey sand and fine to medium, shelly sand grading upward to sandy and clayey silt; locally, channel fill at base of unit includes as much as 50 ft of fine to coarse, crossbedded sand and clayey silt and peat containing in situ tree stumps. Sandy bay facies commonly contains Crassostrea biostromes, Mercenaria, Anadara, Polynices, Ensis, and other mollusks. Specimes of the coral Astrangia have yielded estimated uranium-series ages averaging 71,000 +/- 7,000 yrs B.P. (Mixon and others, 1982). Unit constitutes surficial deposit of river- and coast-parallel plains (alt. 20-30 ft) bounded on landward side by Suffolk and Harpersville scarps. Thickness is 0-50 ft.

Qal **Alluvium** - Fine to coarse gravelly sand and sandy gravel, silt, and clay, light- to medium- gray and yellowish-gray. Deposited mainly in channel, point-bar, and flood-plain environments; includes sandy deposits of narrow estuarine beaches, and mud, muddy sand, and peat in swamps and in fresh- and brackish-water marshes bordering tide-water rivers. Grades into colluvium along steeper valley walls at margins of unit. Mostly Holocene but, locally, includes low-lying Pleistocene(?) Terrace deposits. As much as 80 ft thick along major streams.

QTw **Windsor Formation (lower Pleistocene or upper Pliocene)** - Gray and yellow to reddish-brown sand, gravel, silt, and clay. Constitutes surficial deposits if extensive plain (alt. 85-95 ft) seaward of Surry scarp and coeval, fluvial-estuarine terrace west of scarp. Fining-upward sequence beneath plain consists of basal pebbly sand grading upward into crossbedded, quartzose Sand and massive, clayey silt and silty clay; lower and upper parts of sequence were deposited, repectively, in shallow-marine or open-bay and restricted-bay or lagoonal environments. In terraces west of Surry scarp, fluvial-estuarine deposit comprise muddy, coarse, trough-crossbedded sand and gravel grading upward to sandy silt and clay. Unit is 0-40 ft thick.

Qsh **Shirley Formation (middle Pleistocene)** - Light-to dark-gray and brown sand, gravel, silt, clay, and peat. Constitutes surficial deposits of riverine terraces and relict baymouth barriers and bay-floor plains (alt. 35-45 ft) inset below depositional surfaces of the Chuckatuck Formation (Johnson and Peebles, 1984). Upper part of unit is truncated on the east by the Suffolk and Harpersville scarps; locally, lower part extends east of scarps. Fluvial-estuarine facies comprises (1) a lower pebble to boulder sand overlain by (2) fine to coarse sand interbedded with peat and clayey silt rich in organic material, including in situ tree stumps and leaves and seeds of cypress, oak, and hickory, which grades upward to (3) medium- to thick-bedded, clayey and sandy silt and silty clay. Marginal-marine facies in lower James River and lowermost Rappahannock River areas is silty fine sand and sandy silt containing *Crassostrea virginica*, *Mulinia*, *Noetia*, *Mercenaria*, and other mollusks. *Astrangia* from lower Rappahannock River area has yielded a uranium-series age of 184,000 +/- 20,000 years B.P. (Mixon and other, 1982). Thickness is 0-80 ft.

Tc **Chesapeake Group (upper Pliocene to lower Miocene)** - Fine to coarse, quartzose sand, silt, and clay; variably shelly and diatomaceous, deposited mainly in shallow, inner- and middle-shelf waters. Ages of units based in studies of foraminiferal, nannofossil, diatom, and molluscan assemblages in Virginia and adjacent states (Andrews, 1988; Gibson, 1983; Gibson and others, 1980; Poag, 1989; Ward and Blackwelder, 1980; Ward and Krafft, 1984), Includes the following formations (see also sheet 2, figure 1), from youngest to oldest; Chowan River Formation (upper Pliocene), Yorktown Formation (lower upper and lower Pliocene), Eastover Formation (upper Miocene), St. Mary's Formation (upper and middle Miocene), Choptank Formation (middle Miocene), and Calvert Formation (middle and lower Miocene).

Figure 3. Geologic map of Lancaster County (from Mixon *et al*., 1989).

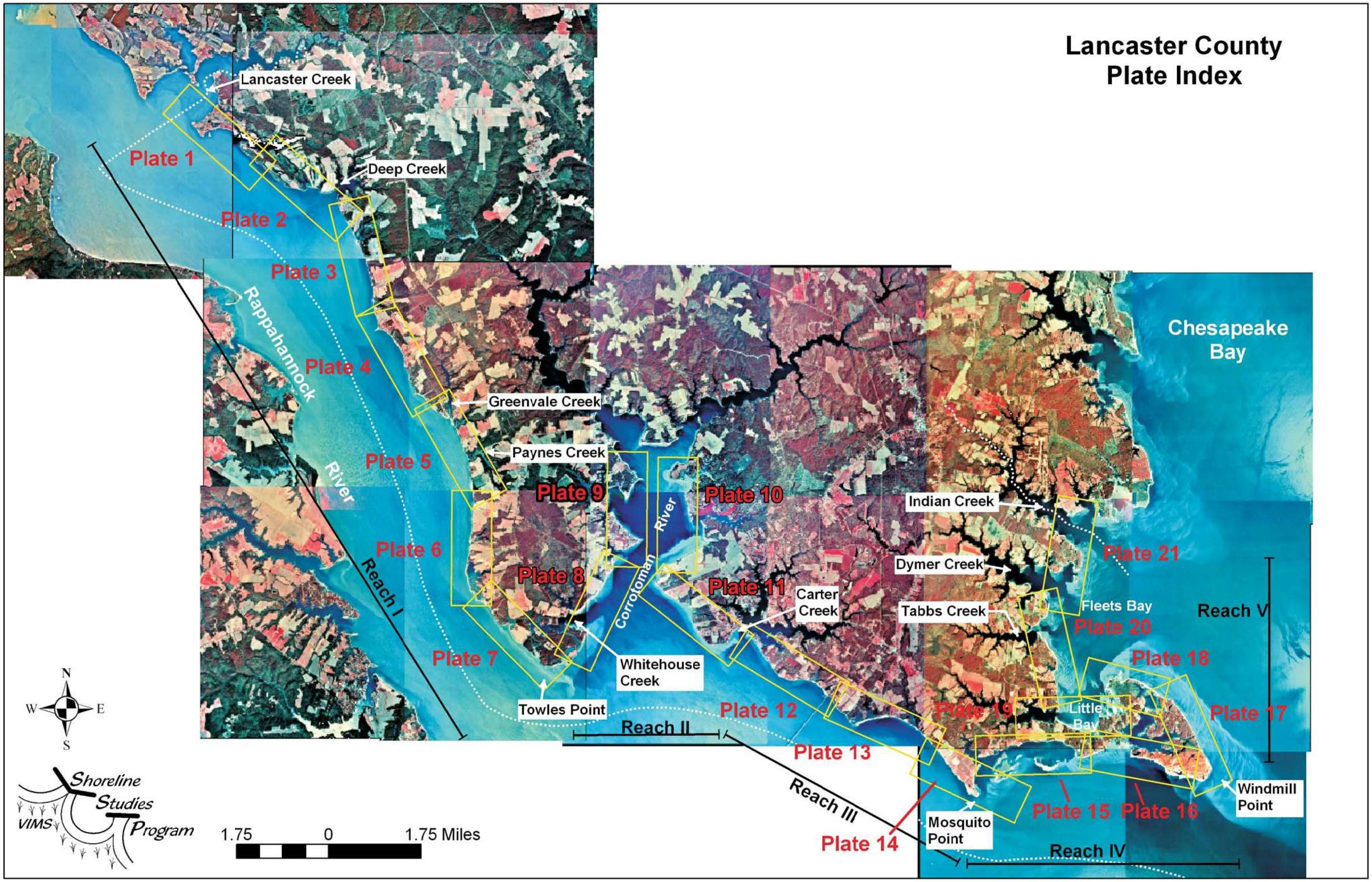


Figure 4. Index of shoreline plates.

B. Hydrodynamic Setting

Mean tide range at Windmill Point in Lancaster County is 1.2 ft (1983-2001). Up the Rappahannock River, mean tide range is 1.3 ft on the Corrotoman River, and 1.6 ft at Bayport which is across the river from Morattico Creek. The wind/wave climate impacting the Bay coast is defined by large fetch exposures to the northeast, east and southeast across Chesapeake Bay. Wind data from Norfolk International Airport reflect the frequency and speeds of wind occurrences from 1960 to 1990 (Table 1). Northeasters can be particularly significant in terms of the impacts of storm surge and waves on beach and dune erosion. The Rappahannock River is more fetch-limited. With the exception of the shore between Mosquito Point and Windmill Point, the coast is impacted by waves from the southwest, south, and southeast across limited open water.

Hurricanes, depending on their proximity and path can also have an impact to the Lancaster County Bay coast. On September 18, 2003, Hurricane Isabel passed through the Virginia coastal plain. The main damaging winds began from the north and shifted to the east then south. Beach and dune erosion were significant. Storm surge and wave action combined to create wrack lines measuring up to 8 ft above MLW around much of the Bay and up the rivers.

Table 1. Summary wind conditions at Norfolk International Airport from 1960-1990.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**South**	**South west**	**West**	**North west**	**North**	**North east**	**East**	**South east**	**Total**
< 5	3	5497* 2.12+	3316 1.28	2156 0.83	1221 0.47	35748 13.78	2050 0.79	3611 1.39	2995 1.15	56594 21.81
5-11	8	21083 8.13	15229 5.87	9260 3.57	6432 2.48	11019 4.25	13139 5.06	9957 3.84	9195 3.54	95314 36.74
11-21	16	14790 5.70	17834 6.87	10966 4.23	8404 3.24	21816 8.41	16736 6.45	5720 2.20	4306 1.66	100572 38.77
21-31	26	594 0.23	994 0.38	896 0.35	751 0.29	1941 0.75	1103 0.43	148 0.06	60 0.02	6487 2.5
31-41	36	25 0.01	73 0.03	46 0.02	25 0.01	162 0.06	101 0.04	10 0.00	8 0.00	450 0.17
41-51	46	0 0.00	0 0.00	0 0.00	1 0.00	4 0.00	4 0.00	1 0.00	0 0.00	10 0.00
Total		41989 16.19	37446 14.43	23324 8.99	16834 6.49	70690 27.25	33133 12.77	19447 7.50	16564 6.38	259427 100.00

*Number of occurrences +Percent

III. METHODS

A. Photo Rectification and Shoreline Digitizing

Recent and historic aerial photography was used to estimate, observe, and analyze past shoreline positions and trends involving shore evolution for Lancaster County. Some of the photographs were available in fully geographically referenced (georeferenced) digital form, but most were scanned and orthorectified for this project.

Aerial photos from VIMS Shoreline Studies and Submerged Aquatic Vegetation (SAV) Programs, as well as from United States Geological Survey (USGS) archives were acquired. The years used for the shoreline change analysis included 1937, 1959, 1982, 1994, and 2002. Color aerials were obtained for 1982 and 1994. The 1994 imagery was processed and mosaicked by USGS, while the imagery from 2002 was mosaicked by the Submerged Aquatic Vegetation Program. The aerial photography for the remaining years were mosaicked by the VIMS Shoreline Study Program.

The images were scanned as tiffs at 600 dpi and converted to ERDAS IMAGINE (.img) format. They were orthorectified to a reference mosaic, the 1994 Digital Orthophoto Quarterquadrangles (DOQQ) from USGS. The original DOQQs were in MrSid format but were converted into .img format as well. ERDAS Orthobase image processing software was used to orthographically correct the individual flightlines using a bundle block solution. Camera lens calibration data was matched to the image location of fiducial points to define the interior camera model. Control points from 1994 USGS DOQQ images provide the exterior control, which is enhanced by a large number of image-matching tie points produced automatically by the software. A minimum of four ground control points were used per image, allowing two points per overlap area. The exterior and interior models were combined with a 30-meter resolution digital elevation model (DEM) from the USGS National Elevation Dataset (NED) to produce an orthophoto for each aerial photograph. The orthophotographs that cover each USGS 7.5 minute quadrangle area were adjusted to approximately uniform brightness and contrast and were mosaicked together using the ERDAS Imagine mosaic tool to produce a one-meter resolution mosaic also in an .img format.

To maintain an accurate match with the reference images, it was necessary to distribute the control points evenly. This can be challenging in areas with little development. Good examples of control points are permanent features such as manmade features and stable natural landmarks. The maximum root mean square (RMS) error allowed is 3 for each block.

Once the aerial photos were orthorectified and mosaicked, the shorelines were digitized in ArcMap with the mosaics in the background to help delineate and locate the shoreline. For Lancaster' coast, an approximation to mean low water (MLW) was digitized. This often was defined as the "wetted perimeter" on the beach sand as the last high water location. In areas where the shoreline was not clearly delineated on the aerial photography, the location was estimated based on the experience of the digitizer. Digitizing the shoreline brings in, perhaps, the greatest amount of potential error because of the problems of image clarity and definition of shore features. A series of Lancaster dune site profiles are displayed in Figure 5 which shows beach/dune variability. Figure 6 shows the relationship of MHW, MLW and beach/dune system components.

B. Rate of Change Analysis

A custom Arcview extension called "shoreline" was used to analyze shoreline rate of change. A straight, approximately shore parallel baseline is drawn landward of the shoreline. The extension creates equally-spaced transects along the baseline and calculates distance from the baseline at that location to each year's shoreline. The output from the extension are perpendicular transects of a length and interval specified by the user. The extension provides the transect number, the distance from beginning baseline to each transect, and the distance from the baseline to each digitized shoreline in an attribute table. The attribute table is exported to a spreadsheet, and the distances of the digitized shoreline from the baseline are used to determine the rates of change. The rates of change are summarized as mean or average rates and standard deviations for each Plate.

It is very important to note that this extension is only useful on relatively straight shorelines. In areas that have unique shoreline morphology, such as creek mouths and spits, the data collected by this extension may not provide an accurate representation of true shoreline change. The shore change data was manually checked for accuracy. However, where the shoreline and baseline are not parallel, the rates may not give a true indication of the rate of shoreline change.

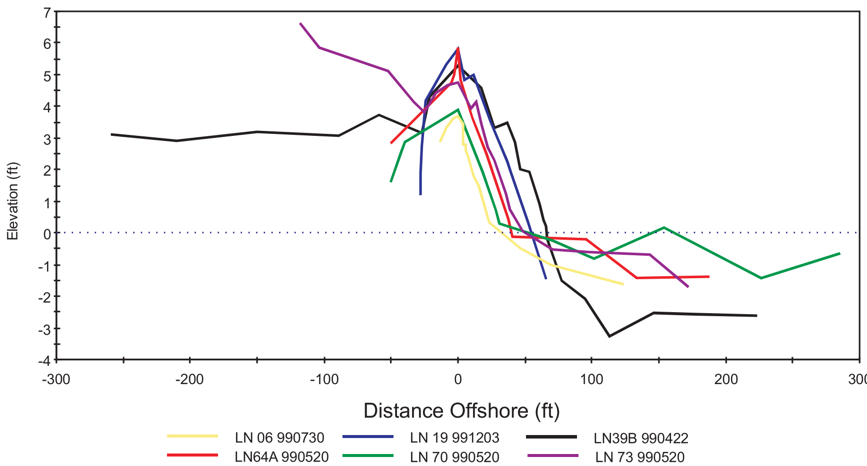


Figure 5. Variability of dune and beach profiles in Lancaster County.

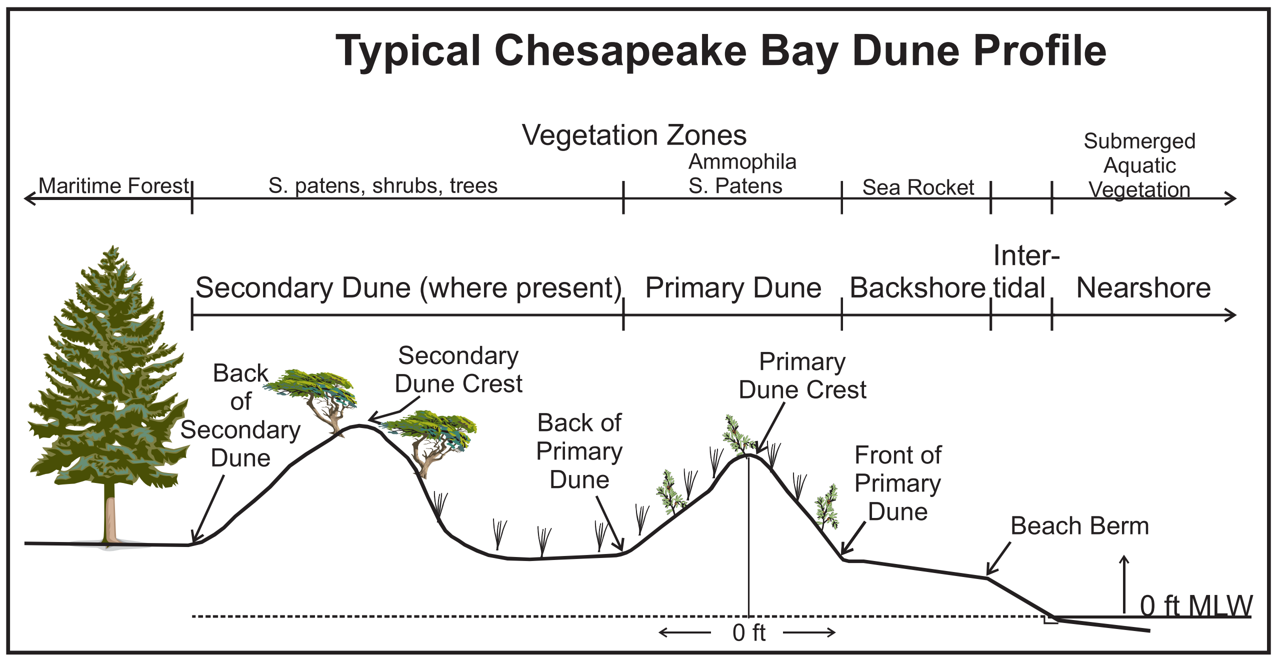


Figure 6. Typical profile of a Chesapeake Bay dune system (from Hardaway *et al.*, 2001).

IV. RESULTS

The Plates referenced in the following sections are in Appendix A. Dune locations are shown on all photo dates for reference only. Dune sites and lengths are positioned accurately on the 2002 photo. Because of changes in coastal morphology, the actual dune site might not have existed earlier. Site information tables are in Appendix B. More detailed information about Chesapeake Bay dunes and individual dune sites in Lancaster County can be found in Hardaway *et al.* (2001) and Hardaway *et al.* (2004). Since much of the dune data were collected several years ago and the beach and dune systems may have changed, this report is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits. Some Plates did not have dunes identified on them, but the shore change information can still be valuable from a shoreline management perspective.

A. Reach I

Reach I occurs along the Rappahanock River and extends from the upriver county line at Lancaster Creek down to Towles Point and includes Plates 1 thru 7. The dune sites along Reach I are riverine dunes and generally face southwest. Plates 1 and 2 have no identified dune sites. The long-term trend for shore change (1937-2002) is negative on all three baselines on Plate 1. Baseline 1C has the highest due to its open exposure along the Rappahannock River. Shore trend is erosional along the single baseline on Plate 2.

Plate 3 contains dune sites LN3, LN4 and LN5. Site LN3 came into its present day form by 1994 and is maintained by a series of low groins. Sites LN4 and LN5 have evolved around respective small creek inlets since 1937 and are likely to continue change as the inlet spits and shoals do but stay in the same geomorphic setting. The overall shore change for Plate 3 is slightly erosional.

Plate 4 contains dune sites LN6, LN7, LN8, LN10 and LN11. Sites LN6, LN7 and LN8 reside along a relatively stable curvilinear coast protected on the upriver end by an unnamed point at Monaskon where the remains of an old pier help hold the headland. The sites are separated by breaks in the semi-continuos beach/dune system. Site LN10 and LN11 sit on either side of a man-made point (fill) that has eroded back over the years. Site LN11 has a secondary dune. The advance of these points can be seen in the shore change rates from 1937 to 1959. The long-term shore change trend along Plate 4 is slightly erosional.

Dune sites LN12, LN13, LN15 and LN16 are shown on Plate 5. Site LN12 is very small and developed as an overwash into a small tidal pond. Site LN 13 has been some type of beach feature since 1937 as it resides just upriver of Greenvale Creek. Dredging of Greenvale Creek was first performed in 1965 and sporadically since. Much of the material was placed just downstream of the entrance where it formed a large sandy headland. This headland has eroded away, but it has provided material for a small spit dune site, LN15, at its distal end. Dune site LN16 is a small dune on a spit across the mouth of Payne's Creek. The shoreline along Plate 5 has been relatively stable over time except for an advance and subsequent recession spike at the mouth of Greenvale Creek associated with dredge material disposal.

Plate 6 is the home of nine isolated dune sites labeled LN17 thru LN25. Sites LN17 and LN18 sit on either side of Bulls Creek as creek mouth dunes. Dune sites LN19 to LN24 are erosional remnants of a once more continuous beach/dune shoreline that fronts a marsh spit separating Beach Creek from the Rappahannock River. Most likely this is why this creek got its name. Dune site LN25 was formed as the distal end of the spit as it continued to lengthen. Channel dredging can be seen at the distal end of the spit since 1937 just downriver of LN24. The material was placed downriver which sealed up the natural channel. Site LN25 is attached to land on its downriver end. Grass became established, and a riverine dune developed. The shoreline rates of change are quite variable but show a long-term erosional trend for the baseline shown. The high variability of shore change along the Beach Creek spit is not quantified but can be seen pictorially.

Dune sites LN24 and LN25 also are shown on Plate 7, but no other sites occur. Shoreline change is minimal but slightly erosional. The shore attachment of the Beach Creek spit and its subsequent accretion is reflected between stations 0 and 1000.

B. Reach II

Reach II includes Plates 8, 9 and 10; no identified dune sites exist along this reach. These plates cover the main trunk of the Corrotoman River. Plate 8 has two baselines both showing erosional trends. Baseline 9A on Plate 9 shows a stable coast while baseline 9B is slightly erosional. The short single baseline on Plate 10 is also erosional.

C. Reach III

Reach III extends from the downstream side of the entrance to the Corrotoman River to Mosquito Point. This coast is a series of headland and embayments where the subreaches alternate riverine fetch exposures from the southwest then south. Reach III includes Plates 11 thru 14.

Plate 11 had dune site LN28 and LN29 (discussed in next plate). Site LN28 is a small isolated dune that resides in a small coastal embayment. This embayment can be seen in the imagery as early as 1937. The overall long-term shore trend from Corrotoman Point to Orchard Point has been stable.

Plate 12 has dune sites LN29 and LN32. Site LN29 has resided against the jetty at Crab Point since at least 1959. Site LN32 has developed on the upstream side of the Norris Bridge approach abutment since it was installed in the 1950s. It has developed a series of secondary dune ridges. Long-term shoreline trends along the Plate 12 coast are erosional becoming stable to accretional toward the Norris Bridge, then erosional on the downriver side.

Two dune sites occur along the Plate 13 shoreline, LN34 and LN36. They are the dune segments of a long curvilinear sandy embayment on the downstream side of Cherry Point. Portions of the beach are known locally as White Stone Beach. This is a relatively stable coast as reflected in the near zero net shore change rate for that shore segment. The Plate 13 shoreline is the upsteam, spiral bay section of a larger embayment that extends from Cherry Point downriver to Mosquito Point. Site LN34 is the longer site on Plate 13 and has had a tidal creek near its center breach intermittently over the years. This would cause an ebb shoal to form at its exit. The inlet's position can be seen in 1937 and 1959 imagery, but then the shoal moves downriver forcing the channel alongshore where it exits again and shoals as seen in 1982, 1994 and 2002.

The Plate 14 shoreline is the dowriver extension of the Plate 13 shoreline; it is the tangential section of the embayed shoreline from Cherry Point to Mosquito Point. It has one continuous dune site but with two wind/wave fetch exposures. Site LN39A faces west-southwest up the Rappahannock River while LN39B faces the open Bay. The dune crests vary accordingly with the higher one on LN39B (Bay Influenced) and the lower one along LN39A (Riverine). Mosquito Point dunes are also a VIMS monitoring site (http://www.vims.edu/physical/research/shoreline). They have evolved over time as Mosquito Point has moved upriver. Most of the Plate 14 shoreline on the Rappahannock River has been slightly erosional over time.

D. Reach IV

Reach IV includes Plate 15 and 16 and extends from Mosquito Point to Windmill Point. The coast includes several island complexes and faces generally southerly. Plate 15 includes the small isolated dune site LN40A along the sheltered mainland coast. LN40A resides against a protruding bulkhead and has been there since 1937. A long spit ending at Deep Hole Point with dune signature existed until 1982. This spit was actually an island in 1937 which became shore connected in 1959 and 1982. The spit was significantly breached by 1994 leaving the distal end an island that has advanced upriver into Deep Hole. Shoreline change rates are for the sheltered embayed coast showing it to be very stable.

The Deep Hole Island spit extended to Windmill Point Creek in 1937 and was an island (Plate 16). The island attached by 1959 creating two spits with one going to Deep Hole Point and the other ending at Windmill Point Creek. This spit receded landward and connected to the mainland by 1982 creating the foundation for site LN43 and has persisted since. Other dune sites along the Plate 16 coast include LN47, LN50, LN51 and LN52. These are all isolated erosional remnants that were once part of a continuous beach/dune system along the south side of Fleet's Island from Windmill Point Creek to Windmill Point (Plate 17). Numerous groins, large and small have been installed over the years, and each of the dune sites resides within a groin field.

E. Reach V

From Windmill Point north to the county line is designated Reach V and includes Plates 17, 18, 19, 20 and 21. This is mostly open bay shoreline that is broken by four smaller tidal creeks including Little Bay, Tabbs Creek, Dymer Creek and Indian Creek. Plate 17 includes Fleets Island with no identified dune sites. Historical erosion is significant at an average of 7 ft/yr. In order to abate erosion, a series of breakwaters were placed along the shoreline between 1994 and 2002. Plate 18 has no dune sites identified either and is also very erosive at about 5 ft/yr. The erosion of Fleets Island has provided sediments to upriver shorelines, particularly the Rappahannock River coast, where spits, islands, beach and dune have evolved and decayed over time. Plate 19 has no dune sites identified and was too irregular to apply the straight line shore change model.

Plate 20 contains dune sites LN64A, LN65, LN66 LN67 and LN68 which all occur along the distal end of Poplar Neck between Dymer Creek and Poplar Creek. These sites evolved and were created as the Bay-exposed end of Poplar Neck eroded. Dune sites LN64A and LN65 were not in existence in 1937. Site LN64 evolved by 1982 between two groins. A pond existed in 1937 and 1959, but it had completely breached by 1982. By 1959, LN65 had found a niche at a small washover into the pond and stabilized. Dune sites LN66 and LN67 evolved as isolated dunes on the mainland side of the old pond shoreline after the pond was breached as seen in 1982 imagery. Site LN68 resides as a small pocket beach bounded by a marsh headland and stone revetment.

Plate 21 shows the end of Fleets Neck which lies between Rones Bay and Indian Creek. Five dune sites occur on Fleets Neck including LN69, LN70, LN71, LN72 and LN73. They were all part of more extensive dune/beach coast in 1937. Over time, shore recession and development fragmented the coast. Each site settled into its own isolated geomorphic setting. Erosion has been most severe on the distal end on the Neck, and Grogg Island has been reduced to almost non-existence.

V. DISCUSSION: NEAR FUTURE TRENDS OF DUNE SITES

The following discussion is a delineation of shoreline trends based on past performance. Ongoing shore development, shore stabilization and/or beach fill, and storms will have local impacts on the near term. "Near Future" is quite subjective and only implies a reasonable expectation for a given shore reach to continue on its historic course for the next 10 to 20 years. In addition, the basis for the predictions are the shorelines digitized on geo-rectified aerial photography which have an error associated with them (see Methods, Section III). Each site's long-term and recent stability as well as a near future prediction are shown in a table in Appendix B. **This data is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.**

A. Reach I

Dune site LN3 has been stable for the last 30 years or so and should remain so for the near term (Figure 7). Site LN4 that occurs across a creek mouth has advanced and receded over time and will most likely continue that trend so it might be deemed erosional in that regard. Site LN5 appears stable as long as the bounding marsh headlands remain intact.

Site LN6 has lost much of its beach and the *Spartina patens* is eroding. The upriver headland also is eroding so this site will continue to recede. Site LN7 resides in a relatively stable coastal setting (Figure 7), and LN8 is reasonably secure within its groinfield. Site LN10 is in an erosional trend, and LN11 appears stable as it resides on the "sheltered" side of the adjacent upriver headland.

Dune site LN12 appears to be in a stable setting with the potential to advance and recede as the creek mouth opens and closes (Figure 7). Site LN13 is fairly stable within the existing groinfield. Although relatively stable now, LN15 may face potential long-term impacts as the bounding marsh headland recede. Site LN16 will most likely continue to recede.

Dune sites LN17 and LN18 are generally receding while LN19 resides in a relatively stable groinfield. Dune sites LN20, LN21, LN22 and LN23 are isolated dune features along a decaying shoreline while LN24 might be stable against the old jetty for the near term. Dune site LN25 will probably maintain its existence as the spit recedes to the mainland.

B. Reach II

No dune sites exist along this reach.

C. Reach III

Site LN28 and LN29 appear stable for the near term in their isolated geomorphic settings.
The Norris bridge has provided a stable coastal setting for LN32 (Figure 8). Dune sites LN34 and LN36 also occur along a stable beach planform though their vegetative extent may transition alongshore (Figure 8). The Mosquito Point dunes, LN39A and LN39B will continue to exist as mobile features an the point migrates upriver (Figure 8).

D. Reach IV

Site LN40A is in a stable setting. Dune site LN43 is transgressing landward while LN47 is stable within its groinfield (Figure 9). Site LN50 is stable to accretionary, and LN51 and LN52 appear stable on either side of the old wharf/groin (Figure 9).

E. Reach V

Along the end of Poplar Neck, LN64A and LN65 appear to be in an erosional/transgressive state while LN66 is stable if not advancing. Site LN67 is presently in a stable configuration but will recede as the adjacent headland erodes, and LN68 appears stable to accretionary for the near term (Figure 9).

Site LN69 is stable between groins, and LN70 is still mobile between a revetment and breakwater but might become stable over time as it evolves between these man-made headlands. A groinfield helps maintain the stability of LN71 and LN72 in a stable embayment. Site LN73 also appears stable between a jetty and groin (Figure 9).

Figure 7. Selected dune site ground photos in Reach I.

Figure 8. Selected dune site ground photos in Reach III.

Figure 9. Selected dune site ground photos in Reach IV and V.

VI. SUMMARY

Shoreline change rates are based on aerial imagery taken at a particular point in time. We have attempted to portray the same shoreline feature for each date along the coast of Lancaster County. Every 500 feet along each baseline on each plate, the rate of change was calculated. The mean or average rate for each plate is shown in Table 2 for five time periods with the long-term rate determined between 1937 and 2002. The total average and standard deviation (Std Dev) for the entire data set of individual rates is also given. The standard deviation shows the relative spread of values about the mean or average. Larger standard deviation values relative to the mean indicates a wider scatter of erosion rates about the mean while lower standard deviation values indicates erosion rates are concentrated near the mean (*i.e.* all the rates calculated for the entire plate were similar).

The largest variability in mean shore change rates and standard deviations were recorded for the shoreline described by baseline 16A. For instance, between 1982 and 1994, the standard deviation was larger than the average rate of change indicating that the overall rate is probably not indicative of the change which occurred on this section of shore. However, not all of the dates for this section of shore had mean shore change rates with large standard deviations. In fact, many standard deviations were equal to or significantly less than the average rate of change, indicating that the shore change rates were relatively consistent for those time periods. In general, the plates influenced by the Chesapeake Bay wave climate (Plates 16-21) had the largest rates of change.

When short time frames are used to determine rates of shoreline change, shore alterations may seem amplified. The rates based on short-time frames can modify the overall net rates of change. Hopefully, the shore change patterns shown in this report along with the aerial imagery will indicate how the coast will evolve based on past trends and can be used to provide the basis for appropriate shoreline management plans and strategies. Dunes and beaches are a valuable resource that should be either maintained, enhanced or created in order to abate shoreline erosion and provide sandy habitat.

Table 2. Summary average shoreline rates of change and their standard deviation for Lancaster County.

	Plate 1A		Plate 1B		Plate 1C		Plate 2		Plate 3		Plate 4		Plate 5		Plate 6	
Imagery Dates	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**
1937-1959	-0.3	0.7	0.3	0.7	-0.5	1.4	-0.4	0.9	-0.2	2.8	0.2	4.4	-0.8	1.9	-0.5	1.6
1959-1982	-1.0	0.7	-0.4	0.6	-2.6	1.3	-2.3	1.3	-1.0	1.4	0.1	2.3	1.2	5.9	0.0	1.4
1982-1994	-0.1	0.7	-0.6	0.8	-5.0	3.7	-2.8	1.2	-1.5	2.6	-0.7	2.7	-1.6	2.1	-0.4	2.2
1994-2002	-3.8	1.3	-0.4	0.8	-4.3	4.8	-3.3	2.8	-0.6	3.7	-1.9	4.8	-1.8	4.9	-3.3	1.9
1937-2002	**-0.9**	**0.4**	**-0.2**	**0.3**	**-2.6**	**0.8**	**-1.9**	**0.8**	**-0.8**	**1.0**	**-0.7**	**2.0**	**-0.3**	**1.3**	**-0.9**	**1.4**

	Plate 7		Plate 8A		Plate 8B		Plate 9A		Plate 9B		Plate 10		Plate 11		Plate 12	
Imagery Dates	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**
1937-1959	0.3	1.7	-3.4	3.4	-3.0	2.2	0.9	0.6	4.5	1.1	-0.7	1.5	-1.2	1.7	0.0	2.4
1959-1982	-1.8	1.6	-0.7	0.9	-0.7	1.1	-1.9	0.7	-5.9	2.3	-1.3	0.4	-0.4	0.9	-1.2	2.1
1982-1994	1.2	9.7	-1.3	1.5	0.0	1.6	0.1	0.3	3.3	2.6	-0.4	0.7	-0.8	1.4	-0.6	3.5
1994-2002	-3.7	5.6	-1.7	0.9	-1.6	1.7	-0.5	0.6	-4.8	3.1	-1.6	2.6	-0.6	2.4	0.1	1.7
1937-2002	**-0.7**	**1.7**	**-1.9**	**1.3**	**-1.4**	**1.0**	**-0.4**	**0.3**	**-0.6**	**0.5**	**-1.0**	**0.5**	**-0.8**	**0.6**	**-0.5**	**1.0**

	Plate 13		Plate 14		Plate 15		Plate 16A		Plate 16B		Plate 17		Plate 18		Plate 20	
Imagery Dates	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**	**Rate of Change (ft/yr)**	**Std. Dev.**
1937-1959	-0.7	1.0	-0.2	5.5	0.5	0.9	-5.7	8.6	-2.1	5.0	-9.6	1.3	-3.3	4.3	-2.9	2.8
1959-1982	-1.2	1.6	-0.4	3.5	-0.6	0.9	-14.4	7.4	-0.7	3.4	-6.8	3.6	-4.3	3.6	-3.0	2.4
1982-1994	-1.8	2.4	-2.0	4.8	-0.9	1.7	-20.1	27.7	-1.0	2.1	-4.3	7.1	-9.3	11.7	-1.4	3.9
1994-2002	0.9	2.6	2.7	4.1	1.1	3.4	-3.0	1.8	-0.4	2.3	-1.8	5.2	-1.6	9.9	-1.8	2.5
1937-2002	**-0.9**	**1.0**	**-0.3**	**1.7**	**-0.1**	**0.6**	**-11.1**	**4.5**	**-1.2**	**1.5**	**-6.7**	**2.0**	**-4.6**	**2.4**	**-2.5**	**1.8**

VII. REFERENCES

Boone, J., 2003. The Three Faces of Isabel: Storm Surge, Storm Tide, and Sea Level Rise. Informal Paper. http://www.vims.edu/physical/research/isabel.

Byrne, R. J. and G. L. Anderson, 1978. Shoreline Erosion in Tidewater Virginia. SRAMSOE Number 111. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 102 pp.

Hardaway, C. S., Jr., D. A. Milligan, L. M. Varnell, G. R. Thomas, W. I. Priest, L. M. Meneghini, T. A. Barnard, and C.A. Wilcox, 2004. Lancaster County Dune Inventory. Technical Report, Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

Hardaway, C.S., Jr., L.M. Varnell, D.A. Milligan, G.R. Thomas, and C.H. Hobbs, III, 2001. Chesapeake Bay Dune Systems: Evolution and Status. Technical Report. Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia.

Mixon, R.B., C.R. Berquist, Jr., W.L. Newell, and G.H. Johnson, 1989. Geologic Map and Generalized Cross Sections of the Coastal Plain and Adjacent Parts of the Piedmont, Virginia. U.S. Geological Survey Map I-2033 (Sheet 1 of 2).

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APPENDIX A

For each Plate shown on Figure 4 (Page 4), Appendix A contains orthorectified aerial photography flown in 1937, 1959, 1982, 1994, and 2002. Also shown are the digitized shorelines, identified dune sites, and an arbitrarily created baseline. A plot shows only the relative locations of the shorelines while another one depicts the rate of shore change between dates. A summary of the average Plate rate of change in ft/yr as well as the standard deviation for each rate is also shown.

This data is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.

APPENDIX B

The data shown in the following tables were primarily collected as part of the Chesapeake Bay Dune: Evolution and Status report and presented in Hardaway *et al.* (2001) and Hardaway *et al.* (2004). Individual site characteristics may now be different due to natural or man-induced shoreline change.

An additional table presents the results of this analysis and describes each dune site's relative long-term, recent, and near-future predicted stability. This data results from the position of the digitized shorelines which have an error associated with them (see Methods, Section III).

Since much of the dune data were collected several years ago and the beach and dune systems may have changed, this report is intended as a resource for coastal zone managers and homeowners; it is not intended for use in determining legal jurisdictional limits.

These data were collected as part of the Chesapeake Bay Dune: Evolution and Status Report (Hardaway *et al.*, 2001). Site characteristics may now be different due to natural or man-influenced shoreline change.

Identified dune sites in Lancaster County as of 2000.

Dune Site No.	Location^ Easting (Feet)	Northing (Feet)	Date Visited	Dune Shore Length (feet)	Primary Dune Site?	Secondary Dune Site?	*Public Ownership?
3	2,555,400	525,350	30-Jul-1999	250	Yes	No	No
4	2,555,750	524,600	30-Jul-1999	210	Yes	No	No
5	2,557,700	518,400	30-Jul-1999	130	Yes	No	No
6	2,558,750	515,750	30-Jul-1999	670	Yes	No	No
7	2,559,900	514,900	30-Jul-1999	1,025	Yes	No	No
8	2,560,450	514,150	30-Jul-1999	580	Yes	No	No
10	2,562,200	509,650	30-Jul-1999	110	Yes	No	No
11	2,562,800	509,450	30-Jul-1999	990	Yes	Yes	No
12	2,564,500	507,800	30-Jul-1999	190	Yes	No	No
13	2,565,400	507,250	30-Jul-1999	300	Yes	No	No
15	2,566,000	507,200	30-Jul-1999	150	Yes	No	No
16	2,567,750	503,350	30-Jul-1999	125	Yes	No	No
17'	2,568,300	495,050	30-Jul-1999	120	Yes	No	No
18	2,568,350	494,750	30-Jul-1999	310	Yes	No	No
19	2,568,050	492,350	30-Jul-1999	200	Yes	No	No
20'	2,568,150	491,450	03-Dec-1999	140	Yes	No	No
21'	2,568,200	491,200	03-Dec-1999	160	Yes	No	No
22'	2,568,550	490,250	03-Dec-1999	100	Yes	No	No
23'	2,568,950	489,800	03-Dec-1999	170	Yes	No	No
24'	2,569,200	489,150	03-Dec-1999	240	Yes	No	No
25	2,570,000	488,750	03-Dec-1999	420	Yes	No	No
28'	2,593,600	485,650	03-Dec-1999	120	Yes	No	No
29'	2,596,400	486,600	03-Dec-1999	150	Yes	No	No
32	2,604,050	481,450	22-Apr-1999	900	Yes	Yes	No
34	2,608,900	478,650	22-Apr-1999	1,200	Yes	No	No
36	2,610,700	479,100	22-Apr-1999	140	Yes	No	No
39A	2,619,050	471,800	22-Apr-1999	850	Yes	Yes	No
39B	2,619,050	471,800	22-Apr-1999	600	Yes	No	No
40A	2,623,930	476,750	22-Apr-1999	320	Yes	No	No
43	2,631,650	476,200	22-Apr-1999	820	Yes	No	No
47	2,636,250	475,750	22-Apr-1999	360	Yes	No	No
50	2,638,500	474,850	22-Apr-1999	580	Yes	No	No
51	2,638,750	747,350	22-Apr-1999	250	Yes	No	No
52	2,639,000	474,150	22-Apr-1999	100	Yes	No	No
64A	2,626,220	489,950	20-May-1999	200	Yes	No	No
65	2,626,300	490,350	20-May-1999	150	Yes	No	No
66	2,626,100	490,600	20-May-1999	170	Yes	No	No
67	2,625,750	491,250	20-May-1999	140	Yes	No	No
68	2,625,350	491,900	20-May-1999	250	Yes	Yes	No
69	2,628,800	494,300	20-May-1999	100	Yes	No	No
70	2,628,550	496,450	20-May-1999	100	Yes	No	No
71	2,628,250	496,850	20-May-1999	300	Yes	No	No
72	2,627,400	497,650	20-May-1999	570	Yes	Yes	No
73	2,626,700	498,050	20-May-1999	300	Yes	Yes	No

*Public ownership includes governmental entities including local, state, and federal; otherwise ownership is by the private individual.
^Location is in Virginia State Plane South, NAD 1927
'Sites were noted as dunes but were not photographed or surveyed

Dune site measurements in Lancaster County as of 2000.

Dune Site Measurements									
	Dune Shore Length	Primary Dune			Secondary Dunes				
		Crest Elev	Distance from Crest				Distance From		
Site No.	(feet)	(ftMLW)	landward to back base (feet)	To MLW (feet)	2nd Dune Site	Crest Elev (ftMLW)	Primary Crest to 2nd Crest (feet)	2ndCrest landward (feet)	2nd Crest seaward to 1st back base (feet)
3	250	5	18	35					
4	210	3.94	21	44					
5	130	3.44	32	45					
6	670	3.67	14	33					
7	1025	5	6	53					
8	580	4.81	39	40					
10	110	4.06	12	32					
11	990	3.53	3	28	Yes	3.27	29	3	26
12	190	3.87	9	47					
13	300	4.58	23	28					
15	150	3.75	19	35					
16	125	2.77	13	23					
17'	120								
18	310	5.09	18	27					
19	200	5.83	24	54					
20'	140								
21'	160								
22'	100								
23'	170								
24'	240								
25	420	4.59	15	50					
26	240								
27'	360								
28'	120								
29	150								
32	900	4.52	18	45	Yes	4.41	61	29	43
34	1200	5.54	28	60					
36	140								
39A	850	3.7	32	61	Yes	3.44	143	86	25
39B	600	5.28	27	65					
40A	320	5.5	20	45					
43	820	5	20	30					
47	360	5	50	41					
50	580	4.34	15	60					
51	250	5	40	28					
52	100	7.15	32	63					
64A	200	5.84	50	40					
65	150	4.86	44	48					
66	170	3.74	7	42					
67	140	5.13	63	50					
68	250	3.63	18	79	Yes	3.42	60	13	42
69	100	5.41	25	65					
70	100	3.91	50	52					
71	300	5.25	4	44					
72	570	3.39	18	29	Yes	3.03	40	18	4
73	300	4.74	25	50	Yes	5.11	104	52	27

These data were collected as part of the Chesapeake Bay Dune: Evolution and Status Report (Hardaway *et al*., 2001). Site characteristics may now be different due to natural or man-influenced shoreline change.

Dune site parameters in Lancaster County as of 2000.

Site No.	Type	Fetch Exposure A	Shoreline Direction of Face B	Nearshore Gradient C		Morphologic Setting D	Relative Stability E	Underlying Substrate F	Structure or Fill G
3	Man Inf	Riverine	Southwest	Medium	No Bars	Isolated, Pocket	Stable	Upland	Groin
4	Natural	Riverine	Southwest	Medium	No Bars	Ck Mouth Barrier/Spit	Erosional	Marsh	
5	Natural	Riverine	West	Medium	No Bars	Ck Mouth Barrier/Spit	Stable	Marsh	
6	Natural	Riverine	South	Steep	No Bars	Isolated, Shallow Bay	Erosional	Upland	
7	Natural	Riverine	Southwest	Steep	No Bars	Dune Field, Linear	Stable	Upland	
8	Man Inf	Riverine	Southwest	Steep	No Bars	Isolated, Linear	Stable	Upland	Groin
10	Natural	Riverine	West	Steep	No Bars	Isolated, Linear	Erosional	Upland	
11	Natural	Riverine	Southwest	Medium	No Bars	Dune Field, Shallow Bay	Stable	Upland	
12	Man Inf	Riverine	Southwest	Medium	No Bars	Ck Mouth Barrier/Spit	Accretionary	Marsh	Revet/Bulkhead
13	Man Inf	Riverine	Southwest	Steep	No Bars	Isolated, Linear	Stable	Upland	Groin
15	Man Inf	Riverine	Southwest	Medium	No Bars	Isolated, Linear	Erosional	Marsh	Beach Fill
16	Man Inf	Riverine	West	Medium	No Bars	Ck Mouth Barrier/Spit	Erosional	Marsh	Revet/Bulkhead
17	Man Inf	Riverine	West	Medium	No Bars	Ck Mouth Barrier/Spit	Erosional	Marsh	Revet/Bulkhead
18	Man Inf	Riverine	West	Medium	No Bars	Ck Mouth Barrier/Spit	Erosional	Marsh	Revet/Bulkhead
19	Man Inf	Riverine	West	Medium	No Bars	Isolated, Linear	Stable	Upland	Groin
20	Man Inf	Riverine	West	Medium	No Bars	Isolated, Linear	Erosional	Marsh	Groin
21	Natural	Riverine	West	Medium	No Bars	Isolated, Linear	Erosional	Marsh	
22	Natural	Riverine	Southwest	Steep	No Bars	Isolated, Pocket	Erosional	Marsh	
23	Natural	Riverine	Southwest	Steep	No Bars	Isolated, Linear	Erosional	Marsh	
24	Man Inf	Riverine	West	Steep	No Bars	Ck Mouth Barrier/Spit	Accretionary	Marsh	Jetty
25	Man Inf	Riverine	Southwest	Medium	No Bars	Isolated, Linear	Stable	Marsh	Beach Fill
26	Natural	Riverine	Southwest	Steep	No Bars	Ck Mouth Barrier/Spit	Stable	Marsh	
27	Man Inf	Riverine	Southeast	Steep	No Bars	Isolated, Linear	Stable	Upland	Groin
28	Natural	Riverine	South	Steep	No Bars	Isolated, Pocket	Stable	Marsh	
29	Man Inf	Riverine	Southwest	Steep	No Bars	Ck Mouth Barrier/Spit	Stable	Upland	Jetty
32	Man Inf	Riverine	Southwest	Steep	No Bars	Dune Field, Linear	Stable	Upland	Jetty
34	Man Inf	Riverine	South	Steep	No Bars	Ck Mouth Barrier/Spit	Stable	Marsh	Groin
36	Man Inf	Riverine	South	Steep	No Bars	Isolated, Shallow Bay	Stable	Upland	Groin
39A	Natural	Riverine	West	Steep	No Bars	Dune Field, Salient	Accretionary	Upland	
39B	Natural	River, Bay Inf	South	Steep	No Bars	Dune Field, Salient	Erosional	Upland	
40A	Man Inf	River, Bay Inf	Southeast	Shallow	No Bars	Isolated, Shallow Bay	Stable	Upland	Revet/Bulkhead
43	Natural	River, Bay Inf	Southeast	Medium	Bars	Dune Field, Linear	Erosional	Upland	
47	Man Inf	River, Bay Inf	South	Medium	Bars	Isolated, Linear	Stable	Upland	Groin
50	Man Inf	River, Bay Inf	Southwest	Medium	No Bars	Dune Field, Shallow Bay	Stable	Upland	Groin
51	Man Inf	River, Bay Inf	Southwest	Steep	No Bars	Isolated, Linear	Stable	Upland	Groin
52	Man Inf	River, Bay Inf	South	Steep	No Bars	Isolated, Linear	Stable	Upland	Groin
64A	Man Inf	Open Bay	East	Medium	Bars	Isolated, Linear	Erosional	Upland	Beach Fill
65	Man Inf	Open Bay	East	Medium	Bars	Isolated, Pocket	Erosional	Upland	Revet/Bulkhead
66	Natural	Riverine	Northeast	Shallow	No Bars	Isolated, Salient	Accretionary	Upland	
67	Natural	River, Bay Inf	East	Medium	Bars	Isolated, Pocket	Erosional	Marsh	
68	Natural	River, Bay Inf	North	Steep	No Bars	Isolated, Salient	Accretionary	Upland	
69	Man Inf	River, Bay Inf	South	Steep	Bars	Isolated, Pocket	Erosional	Upland	Groin
70	Man Inf	River, Bay Inf	Northeast	Steep	Bars	Isolated, Linear	Erosional	Marsh	Breakwaters
71	Man Inf	River, Bay Inf	Northeast	Steep	Bars	Isolated, Linear	Stable	Upland	Groin
72	Natural	River, Bay Inf	North	Steep	No Bars	Dune Field, Shallow Bay	Stable	Upland	
73	Man Inf	River, Bay Inf	Northeast	Steep	No Bars	Isolated, Salient	Stable	Upland	Jetty

Long-term, recent stability and future predictions of shore erosion and accretion rates for dune sites in Lancaster County.

	Site No.	Long-Term Stability 1937-2002	Recent Stability 1994-2002	Near Future Prediction
LN	3	Erosional	Stable	Stable
LN	4	Stable	Erosional	Erosional
LN	5	Erosional	Erosional	Stable
LN	6	Erosional	Erosional	Erosional
LN	7	Accretionary	Erosional	Stable
LN	8	Accretionary	Stable	Stable
LN	10	Accretionary	Erosional	Erosional
LN	11	Accretionary	Stable	Stable
LN	12	Erosional	Accretionary	Stable
LN	13	Stable	Stable	Stable
LN	15	Erosional	Stable	Erosional
LN	16	Erosional	Erosional	Erosional
LN	17	Erosional	Erosional	Erosional
LN	18	Accretionary	Erosional	Erosional
LN	19	Accretionary	Stable	Stable
LN	20	Erosional	Erosional	Erosional
LN	21	Erosional	Erosional	Erosional
LN	22	Erosional	Erosional	Erosional
LN	23	Erosional	Erosional	Erosional
LN	24	Accretionary	Erosional	Stable
LN	25	Accretionary	Erosional	Erosional
LN	28	Erosional	Stable	Stable
LN	29	Stable	Stable	Stable
LN	32	Accretionary	Stable	Stable
LN	34	Erosional	Stable	Stable
LN	36	Erosional	stable	Stable
LN	39A	Accretionary	Accretionary	Accretionary
LN	39B	Accretionary	Erosional	Erosional
LN	40A	Accretionary	Accretionary	Stable
LN	43	Accretionary	Erosional	Erosional
LN	47	Erosional	Stable	Stable
LN	50	stable	Stable	Stable
LN	51	Erosional	stable	Stable
LN	52	Erosional	Stable	Stable
LN	64A	Erosional	Erosional	Erosional
LN	65	Erosional	Erosional	Erosional
LN	66	Erosional	stable	Accretionary
LN	67	Erosional	Accretionary	Stable
LN	68	Accretionary	Stable	Stable
LN	69	Stable	Stable	Stable
LN	70	Erosional	Erosional	Erosional
LN	71	Erosional	Stable	Stable
LN	72	Accretionary	Stable	Stable
LN	73	Accretionary	Stable	Stable