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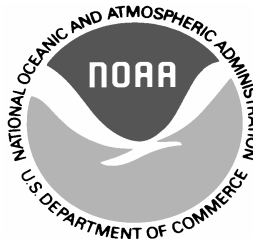
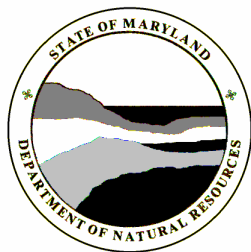
COASTAL AND ESTUARINE GEOLOGY
FILE REPORT NO. 00-1

**Shoreline Changes and Erosion Rates for the
Southern Coastal Bays of Maryland**

by

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ABSTRACT

For the southern coastal bays of Maryland, the Maryland Geological Survey (MGS) digitally mapped historic shorelines dating from 1843 to 1989 and, based on changes in shoreline position, calculated coastal land loss. MGS compiled digital shorelines from existing maps and a digital wetlands delineation, displayed the shorelines over recent orthophotography, and plotted *Shoreline Changes* maps for three 7.5-minute quadrangles, Boxiron, Girdletree, and Whittington Point. Shoreline vectors were saved to CD-ROM in the proprietary format (.rvc) of a geographic information system (GIS), MicroImages' TNTmips. The information provides a historical perspective in planning for the effects of global warming and sea level rise on local coastal communities. To the extent that past conditions are a key to the future, examining previous shoreline positions reveals the reaches of shoreline most susceptible to erosion. The digital data will facilitate future shoreline updates and comparisons, as well as GIS-based research and decision-making regarding the coastal bays.

To estimate coastal land loss in Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River, MGS used a GIS to measure and compare the area occupied by water at four points in time, 1850, 1942, 1962, and 1989. Increases in water area correspond exactly to decreases in land area, and vice versa. In total, MGS quantified change along 332 miles of predominantly vegetated (86%) shoreline. Between 1850 and 1989, net loss of land in the study area amounted to -1,634 acres. Erosion outpaced accretion, except in eastern Sinepuxent Bay. Chincoteague Bay lost -1,662 acres; Newport Bay lost -452 acres; western Sinepuxent Bay lost -283 acres; the St. Martin River lost -254 acres. The losses were partially offset by a gain of +1,017 acres in eastern Sinepuxent Bay. Erosion was greatest along the western shore of Chincoteague Bay, which lost -9.8 acres annually, at a rate of loss of -0.17 acres/mile/yr. Elsewhere, annual losses ranged from -1.8 to -3.3 acres/yr, and rates of loss, from -0.02 to -0.10 acres/mile/yr. The exception, eastern Sinepuxent Bay, gained +7.3 acres/yr at a rate of +0.18 acres/mile/yr.

Juxtaposing shorelines from different years reveals the pattern of erosion in a particular place. In the study area, erosion occurs primarily through parallel retreat. All points lying along a stretch of shoreline retreat at about the same rate. Consequently, the more recent shoreline lies parallel to and landward of a previous one. Other patterns of erosion are apparent. Points of land, particularly marshy points, tend to erode at faster rates than do coves. Peninsulas are sometimes breached, leaving remnant islands. Islands subsequently diminish in size through further breaching and/or erosion of their peripheries. In marshes, ditching appears to contribute to shoreline erosion; erosion at the mouths of ditches is commonly more pronounced than erosion of the intervening shorelines.

The present study indicates the two-dimensional area lost to erosion. It does not take into account the volume of sediment lost, nor does it differentiate between sediment types – sand and silt/clay. When eroded, sands are more likely to be deposited near shore, whereas finer sediments are more likely to remain suspended in the water column. Suspended sediments affect water quality (e.g., turbidity and nutrient loading). By clouding the water, for example, they

reduce the ability of sunlight to reach the bay floor and interfere with the growth of bay grasses. The next avenue of research, then, is to couple area losses with bank height and grain size information to calculate one of the major components of a sediment budget for the coastal bays.

INTRODUCTION

For any coastal area, knowledge of the history of shoreline change is fundamental to understanding the possible effects of sea level rise in the region. To the extent that past conditions are a key to the future, examining previous shoreline positions reveals the reaches of shoreline most susceptible to erosion. Erosion studies, coupled with information about sea level rise, enable managers to plan more effectively for the effects of global warming on coastal communities and the infrastructure on which they depend. Detailed information about shorelines and their changing positions may also be used to address a variety of other coastal issues:

- Determining set-backs for flood insurance or other purposes, particularly in areas at high risk of erosion or in areas vulnerable to sea level rise;
- Determining the volume of sediment lost by erosion, a critical component in calculating a sediment budget for the coastal bays. Shoreline erosion may be the source for as much as half of the sediment deposited in Maryland's coastal bays (Wells, pers. comm.).
- Assessing the effects of shoreline erosion on bay water quality (e.g., turbidity, nutrient loading) and subaqueous habitats; and
- Understanding the processes responsible for shoreline erosion. These processes include anthropogenic activities (e.g., boating and dredging), as well as natural phenomenon, (e.g., weather events and tide changes).

This study is a continuation of an effort to map and assess shoreline changes in Maryland's coastal bays. It focuses primarily on shoreline changes in the southern coastal bays, Chincoteague, Newport, and Sinepuxent Bays.

PREVIOUS WORK

MGS recently completed a project similar to this one for the northern coastal bays (Hennessee and Stott, 1999). For that project, MGS digitally mapped historic shorelines dating from 1849 to 1989 and, based on changes in shoreline position, calculated coastal land loss (acreage) for Assawoman and Isle of Wight Bays. Digital shorelines were compiled from existing maps and a digital wetlands delineation, displayed over recent orthophotography, and plotted as *Shoreline Changes* maps for six 7.5-minute quadrangles (Assawoman Bay, Berlin, Ocean City, Public Landing, Selbyville, and Tingles Island). As the shoreline bordering a body of water erodes, water area increases at the expense of land area. Given that, MGS estimated coastal land loss in the two northern bays by determining and comparing total water area at four points in time.

MGS has also completed a detailed characterization of surficial sediments in the coastal bays (Wells *et al.*, 1994a, 1994b, 1996, 1997, 1998). The distribution pattern of sediments, based on texture, indicates that shore erosion is the source of most of the sediments found in the western half of the bays.

Generally, the most recent, comprehensive shoreline change information available for the coastal bays, excluding the upstream reaches of some of the tributaries, comes from a 1949 study of coastal erosion in tidewater Maryland by Singewald and Slaughter. MGS calculated rates of erosion by comparing two sets of shorelines, dating from 1849-1850 and 1942. They measured net loss (deposition minus erosion), in acres, for shoreline segments of known length:

- Chincoteague Bay
For the 92-year period, net loss along 23.6 miles of the western shore of Chincoteague Bay was -261 acres and from islands in the bay, -36 acres. Along 19.7 miles of the eastern shore, however, there was a net gain of +333 acres due to the closure of a former inlet to the bay. The average annual rate of erosion for the western shore was -0.12 acres per mile of shoreline, compared to an average annual accretion rate of +0.18 acres/mile for the eastern shore.
- Newport Bay
Net loss along 7.7 miles of the Newport Bay shoreline was -133 acres over 92 years, with an average annual rate of erosion of -0.18 acres/mile.
- Sinepuxent Bay
Sinepuxent Bay, like Chincoteague Bay, lost land along 13.6 miles of the western shore (-106 acres, net) and gained land along 31.8 miles of the eastern shore (+758 acres, net) during the period studied. Respective annual average rates of loss and gain were -0.08 acres/mile and +0.26 acres/mile.
- St. Martin River
Along 11.8 miles bordering the St. Martin River, net loss amounted to -202 acres; average annual rate of loss during the 93-year period was -0.18 acres/mile.

A summary of the authors' findings for the study area is presented in Appendix 1.

Conkwright (1975) compiled and updated the maps on which Singewald and Slaughter (1949) had based their findings. He produced a series of historical shorelines maps, depicting the 1849-50 and 1942 shorelines on a U.S. Geological Survey (USGS) 7.5-minute quadrangle topographic base. In addition to mapping shoreline position, Conkwright delineated reaches of shoreline subject to similar rates of erosion or accretion.

Recent studies of coastal erosion in the region have generally been limited in area. Volonté and Leatherman (1992), for example, predicted future wetlands and upland losses for the mainland (western) shores of Assawoman and Isle of Wight Bays and their main tributaries. As part of that study, they measured linear rates of shoreline change along 41 miles of shoreline (at 215 sites located approximately 1000 ft apart) for the period 1850 to 1989. The findings for three reaches of shoreline in their study area, Zones 5, 6, and 7 (corresponding to St. Martin River, Shingle Landing Prong, and Bishopville Prong, respectively) are relevant to this study. In those zones, linear rates of change ranged from +1.4 to -3.3 ft/yr. Overall average rates of erosion were:

- St Martin River (Zone 5): -1.1 ft/yr
- Shingle Landing Prong (Zone 6): -0.2 ft/yr
- Bishopville Prong (Zone 7): -0.3 ft/yr.

Other results pertaining to the three zones are summarized in Appendix 2.

STUDY AREA

The southern coastal bays of Maryland are located on the Atlantic coast of the Delmarva Peninsula, between latitude 38° 7' 30" N to the north and the Maryland-Virginia line to the south. The area covers three 7.5-minute USGS topographic quadrangles (Boxiron, Girdletree and Whittington Point), which include northern Chincoteague Bay (Fig. 1). MGS produced *Shoreline Changes* maps for each of these three quadrangles. In addition to measuring land loss in the Maryland section of Chincoteague Bay, MGS also determined coastal land loss in Newport, and Sinepuxent Bays and the St. Martin River.

OBJECTIVES

This study focuses on changes in the shorelines that form the boundaries of Maryland's southern coastal bays. In addition to mapping shoreline positions in the southern coastal bays, MGS also quantified shoreline rates of change (i.e., erosion and accretion) for Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River. Specifically, the project objectives were to:

1. Establish within a GIS a series of historical shoreline position vectors; overlay these vectors on merged digital orthophoto quarter quads (DOQQs) to produce updated *Shoreline Changes* maps for three 7.5-minute quadrangles (Boxiron, Girdletree, and Whittington Point); and
2. Quantify linear rates of shore erosion within Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River. During the course of the project, this objective was modified. Rather than quantifying linear rates of change, MGS determined area of coastal land loss for the four bodies of water.

METHODS

This section of the report explains the methods that MGS used in meeting the two project objectives. It describes the hardware and software utilized, the source documents that were digitized in the production of the *Shoreline Changes* maps and related digital data sets, and the techniques used to determine coastal land loss.

HARDWARE AND SOFTWARE

For this project, MGS used a Pentium II computer (400MHz; 256 MB RAM; 10 GB Ultra Wide SCSI-III Hard Drive) running Microsoft Windows NT 4.0. The GIS, MicroImages' TNTmips, (versions 6.1 - 6.2), was used to digitize shoreline vectors, merge base maps, and create layouts of the *Shoreline Changes* maps. Except for print files of the *Shoreline Changes* maps, all digital files were saved in TNTmips proprietary .rvc format. Print files were formatted for a Hewlett-Packard DesignJet 755CM printer. Permanent files were written to CD-ROMs formatted according to ISO 9660, using Adaptec DirectCD software (version 2.5c).

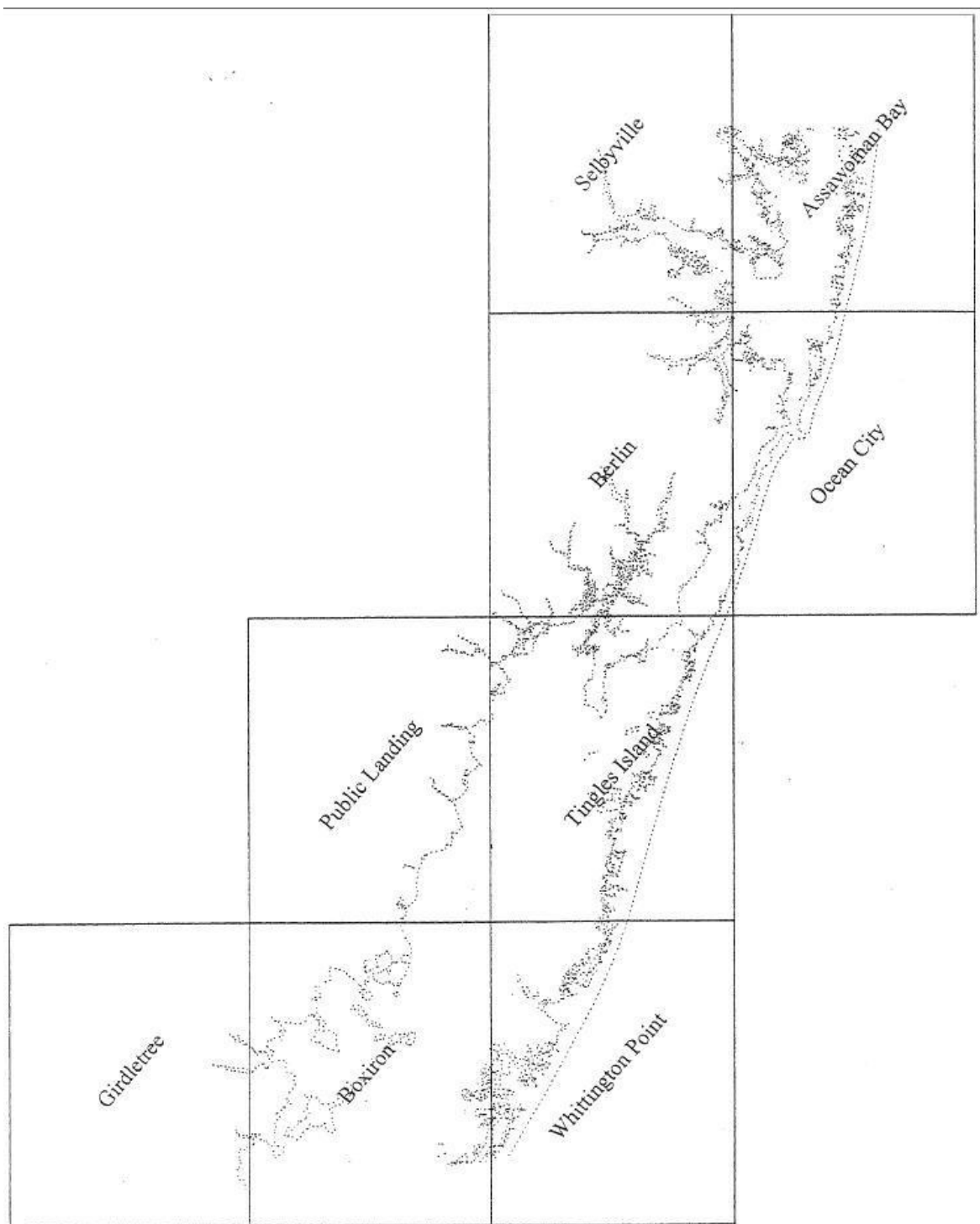


Figure 1: The 7.5-minute quadrangles covering the coastal bays of Maryland

SHORELINE CHANGES MAPS

To produce *Shoreline Changes* maps for the three 7.5-minute quadrangles that cover the southern coastal bays, MGS acquired and processed digital data from several sources. Digital shorelines, representing various shoreline positions between the years 1843 and 1989, were derived from:

- *Historical Shorelines and Erosion Rates* maps (Conkwright, 1975),
- *Coastal Survey* maps (topographic or T-sheets) produced by the National Ocean Service (NOS), a branch of the National Oceanic and Atmospheric Administration (NOAA), and
- A digital wetlands delineation based on 1989 digital orthophoto quarter quads (DOQQs).

To orient the map reader, MGS displayed the shorelines over a photographic base or background – orthophotographs produced by resampling and merging 3.75-minute orthophotoquads flown in 1988 and 1989. The digital wetlands delineation from which the 1989 shoreline was extracted was based on photo interpretation of the same orthophotography.

Data Sources and Processing

Shoreline Vectors

Historical Shorelines and Erosion Rates Maps

In 1975, Conkwright produced a map series, *Historical Shorelines and Erosion Rates*, depicting the data published in *Shore Erosion in Tidewater Maryland* (Singewald and Slaughter, 1949). Historical shorelines were compiled from U.S. Coast and Geodetic Survey charts dating from 1841 to 1943. As part of the compilation, charts based on obsolete horizontal datums were adjusted to the North American Datum of 1927 (NAD27). The original scale of the charts – 1:10,000 or 1:20,000 – was reduced to 1:24,000 using a Kargl Reflection Projector. The smaller scale shorelines were superimposed on USGS 7.5-minute quadrangle topographic base maps, then hand-traced as dashed lines on mylar overlays. For “thick” shorelines, the seaward edge of the charted shoreline was traced onto the overlay (Conkwright, pers. comm.). Shoreline position at one, two, or three different points in time, excluding the base map shoreline, is depicted on each of the 90 quadrangles in the series.

Two maps were compiled for each quadrangle. Series A, *Historical Shorelines*, shows former shoreline positions only. Series B, *Historical Shorelines and Erosion Rates*, shows the same shoreline positions as Series A. However, in Series B, shorelines are also categorized by erosion rate; reaches of shoreline that have experienced approximately the same rates of erosion are demarcated. Shorelines were digitized from Series A maps. Although more than one shoreline is depicted on each of the *Historical Shorelines*, only the oldest (1843 or 1850) was digitized. See Appendix 3 for the map ID and shoreline dates of the three maps in the *Historical Shorelines* series that were digitized as part of this project.

MGS used an on-screen (heads-up) digitizing technique to convert shorelines from the three *Historical Shorelines* maps to digital format. The steps in the process were as follows:

- **Scanning** – Under contract to MGS, CADDScan Engineering, Inc. (Columbia, Md.) scanned the three maps as grayscale images at 300 dots per inch (dpi) using an Ideal FSC

5010 scanner.

- Georeferencing – After importing the three files as rasters into TNTmips, MGS used the neatline corners to manually register the images to latitude/longitude (NAD27). Initially, a raster's registration was transferred to the shoreline vector. After the vector was edited and checked (see next step), shoreline registration was converted to the Maryland State Plane Coordinate System (SPCS) (NAD83, meters) by an internal TNTmips warping routine.
- Digitizing – Using the object editor function in TNTmips, the GIS operator zoomed the raster to a scale of 1:5,000. She then traced the seaward edge of the shoreline, capturing the shoreline digitally as a series of connected points. After digitizing the entire document, she edited her work, deleting overshoots, closing gaps, and removing extraneous nodes. As a quality assurance measure, she plotted the digitized shoreline to the scale of the source document and compared the check plot to the original. The plot was examined primarily for accurate line placement and omissions. (The digitizing technique minimizes the creation of unwanted overshoots, undershoots, and additions, such as double-digitized lines.) If the plotted shoreline was within one line width of the original, its accuracy was accepted. Omitted lines were added to the vector file, and the vector was reregistered to the Maryland SPCS.
- Classification – The final step in preparing the vector was to assign a concatenated year-source attribute to the lines.

Coastal Survey Maps

The NOS (formerly the U.S. Coast and Geodetic Survey) is charged with surveying the coastline of the United States. NOS *Coastal Survey* maps, also known as topographic or T-sheets, are special use, planimetric maps that define the shoreline and alongshore natural and manmade features, including rocks, bulkheads, jetties, piers, and ramps. *Coastal Survey* maps are generally acknowledged to be the most accurate source of historical shoreline data (Shalowitz, 1964). They are often used in litigation to determine property ownership, to enforce regulatory mandates, and to estimate rates of shoreline change. Prior to 1927, *Coastal Survey* maps were based on plane table surveys, and after 1927, on aerial photography. The datum of “mean high water (MHW)” is used as the plane of reference for the shoreline.

MGS digitized shoreline vectors from ten *Coastal Survey* maps, at scales of 1:10,000 or 1:20,000. These represented shorelines for the years 1942-1963 (a 1942 and a 1961-1963 shoreline for all three quadrangles). (See Appendices 3 and 4 for additional information about the ten maps.) T-sheet shorelines were merged and clipped to 7.5-minute quadrangle boundaries, which do not necessarily coincide with the original *Coastal Survey* map boundaries.

MGS used an on-screen (heads-up) digitizing technique to convert shorelines from the ten *Coastal Survey* maps to digital format. The steps in the process were as follows.

- Scanning – At the start of the project, MGS possessed bromide copies of all ten of the *Coastal Survey* maps. Under contract to MGS, CADDScan Engineering, Inc. (Columbia, Md.) scanned the maps as grayscale images at 300 dpi using an Ideal FSC 5010 scanner.
- Georeferencing – After importing the scans as rasters into TNTmips, MGS used neatline

corners and/or grid intersections to manually register the images to latitude/longitude (NAD27) or Maryland State Plane coordinates (NAD27). Initially, a raster's registration was transferred to the shoreline vector. After the vector was edited and checked (see next step), shoreline registration was converted to the Maryland SPCS (NAD83, meters) by an internal TNTmips warping routine.

- Digitizing – This step was identical to that used in digitizing *Historical Shorelines* maps.
- Classification – Vectors were assigned a concatenated year-source attribute.
- Merging and clipping – After all of the *Coastal Survey* maps for a 7.5-minute quadrangle were digitized, same-year shorelines were merged and files were clipped to quadrangle boundaries.

Shorelines Extracted from Wetlands Delineation

In addition to shorelines derived from printed maps, a 1989 shoreline was extracted from existing wetlands vectors, previously delineated for the Maryland Department of Natural Resources (DNR) over 1:1,000-scale DOQQs. The DOQQs, in turn, were derived from 1:40,000-scale CIR film (Miller, 1997). The same DOQQs, resampled and merged, serve as the base of the *Shoreline Changes* maps. (See next section for a description of the digital orthophotography.) MGS contracted the services of EarthData International (EDI) of Gaithersburg, Md., to interpret shorelines from nine of DNR's digital orthophoto quarter quads (Appendix 3).

EDI extracted a subset of shoreline vectors from the existing wetlands coverage as follows. Wetlands vectors were stripped of their linear attributes (line classes). All shorelines and the DOQQ tile boundary were displayed over the DOQQ (raster) from which they were originally interpreted and reassigned attributes. Shoreline segments were classified using the following four categories: beach, structure, vegetated, and water's edge. All four categories are linear features, except for "beach," which can be both linear and polygonal. The DOQQ tile boundary was arbitrarily assigned one of the four categories so that it could be extracted with the shoreline vectors. Shoreline vectors were extracted from the original vector set by line class, using only the four shoreline categories. The extracted vectors were then displayed to detect shoreline breaks or other inconsistencies. Errors were corrected, and shoreline vectors were re-extracted. After extraction, vector sets were cleaned by any deleting extraneous lines (non-shoreline vectors) that had been mistakenly assigned one of the four categories before extraction. Beach polygons were assigned attributes at this time, and the DOQQ tile boundary was reassigned to a fifth category, unclassified. The final quality control check consisted of two steps. First, each tile (quarter quad) was displayed individually to check for unclassified shoreline vectors. Second, vectors from adjacent tiles were merged into a single, 7.5-minute quadrangle vector set. The merged vector set was then displayed to check for class consistency (proper edge-matching) between adjacent tiles. Any necessary corrections were made before the finished vector sets were saved as TNTmips .rvc files.

MGS saved the original data set, then modified it. Including beach polygons on the *Shoreline Changes* maps created unnecessary confusion for the map reader. Polygons also confound computer programs designed to calculate erosion rates from a series of shoreline

vectors. So, before adding the 1989 shoreline to the maps, MGS converted beach polygons to line segments by removing the landward edge of the polygons.

Digital Orthophoto Quarter Quads (DOQQs)

The base of a *Shoreline Changes* map is a composite of (usually) four digital orthophoto quarter quads (DOQQs), originally produced by DNR (Appendix 3). Orthophotos are mosaics of aerial photographs in which displacements caused by the camera and the terrain have been removed. They combine the image characteristics of a photograph with the geometric qualities of a map. A quarter quad (3.75-minute format) consists of one quarter (NW, SW, NE, or SE) of the area covered by a 7.5-minute quadrangle. The DOQQs used as backdrops for the *Shoreline Changes* maps were compiled from color infrared aerial photography flown on March 30, 1988, or April 12, 1989. Based on methods developed by the American Society for Photogrammetry and Remote Sensing, the original digital images, with a ground resolution of 4 ft/pixel, meet National Map Accuracy Standards at the production scale of 1:12,000 (Miller, 1995).

The original quarter quad files were quite large – on the order of 30 megabytes each. Therefore, before merging, or mosaicking, the files, MGS used the TNTmips manual resampling process to systematically decrease the size of the original (input) rasters. Manual resampling, based on the nearest neighbor resampling method, reduces the dimensions of the output raster without changing its internal geometry. The process determines how much smaller the output raster will be based on the ratio of column and line widths between the input and the output rasters. The computer operator set the relative cell size of the input raster to 1 and the relative cell size of the output raster to 2, for a relative cell size ratio of 1:2. Thus, the cell size of the output raster was twice as large as the cell size of the input raster (8 ft as opposed to 4 ft). Because the line and column cell size scaling factors were both the same, no aspect distortion was introduced. As part of the process, MGS also specified that TNTmips create pyramid tiers to speed up the time required to display the resampled raster.

The resampled quarter quad files were merged using a mosaicking technique in TNTmips. Using the original registration information (Maryland Coordinate System, NAD83) to determine how the input pieces fit together, the mosaicking process merged the individual quarter quads into a single 7.5-minute quadrangle at a selected scale, in this case, 1:24,000. None of the optional features, which allow the user to adjust the appearance of the mosaic, was utilized.

Map Layout and Production

MGS used the map and poster layout tools in MicroImages' TNTmips to compose the three *Shoreline Changes* maps. Map layout files are precursors of print files – they specify page setup, including printer make/model, as well as the path and filenames of the component files. (Layout files point to the locations where the component objects are stored, rather than incorporating the objects themselves into the file.) They also contain instructions for the placement and size of the various objects on the page. Laying out a *Shoreline Changes* map entailed assembling and arranging about 30 different digital objects – orthophoto backdrop, shorelines, text blocks, logos,

north arrow, etc. Once the various objects were satisfactorily arranged, TNTmips created print files for plotting on an HP DesignJet 755CM printer.

CD-ROM Production

In addition to the paper maps, MGS produced several related CD-ROMs:

- 1988-1989 7.5' Orthophotoquads – CD-ROM – SCSCB_OQ
This CD-ROM contains resampled digital orthophoto quarter quads, merged into 7.5-minute rasters. The images, in TNTmips (.rvc) format, serve as backdrops for the *Shoreline Changes* maps.
- Historical Shorelines, 1843-1989 – CD-ROM – SCSCB_SL
This CD-ROM contains all of the historical shoreline vectors depicted on the *Shoreline Changes* maps,. Shorelines are grouped by quadrangle and by region (southern coastal bays). The original 1989 shoreline, with beaches delineated as polygons, is also included.
- Map layout files for the *Shoreline Changes* maps – CD-ROM – SCSCB_ML
Map layouts, in TNTmips (.rvc) format, are created for a specific printer, in this case, a Hewlett-Packard (HP) DesignJet 755CM printer. Except for the orthophotoquads and shoreline vectors, this CD-ROM contains all of the components of the *Shoreline Changes* maps and instructions for placing them on the printed page.
- Print files for the *Shoreline Changes* maps – CD-ROM – SCSCB_PF
As the final step in the map layout process, TNTmips created print files in an HP DesignJet 755CM-compatible format. This CD-ROM contains two sets of print files per quadrangle. One file can be printed to a 36-roll of paper, and the other, to an E-sized sheet of paper.

Each CD contains a Readme.txt file, in ASCII format, which describes the contents of the CD. The orthophotoquads and historical shorelines CDs also contain data documentation files (metadata) in both ASCII and WordPerfect 6/7/8 format. The metadata complies with the Federal Geographic Data Committee standard, "Content Standards for Digital Geospatial Metadata," dated June 8, 1994.

COASTAL LAND LOSS MEASUREMENTS

Initially, MGS intended to quantify linear rates of erosion by applying a computer program, Digital Shoreline Analysis System (DSAS), written by Danforth and Theiler (1992) and incorporated by MicroImages into TNTmips. However, DSAS was originally designed to measure rates of change along fairly straight shorelines, namely those along barrier islands of the Atlantic coast. Applying DSAS to the convoluted shorelines of the coastal bays was problematic. The program requires drawing a baseline composed of straight line segments parallel to and inland of the most landward shoreline. The TNTmips module then automatically constructs transects perpendicular to the baseline, across a series of historical shorelines, and calculates linear rates of change along each transect. With convoluted shorelines, it is impossible

to create straight-line baselines parallel to the shoreline. Transects, then, are not strictly perpendicular to any of the shorelines. The resulting statistics are inaccurate to some degree, depending on the deviation of the transect from normal. Furthermore, the program is confounded by certain coastal features common in the coastal bays (e.g., islands that are relicts of peninsulas, areas developed on fill).

In lieu of running DSAS, MGS decided to provide regional rate of change statistics. Shorelines for each of four time periods, (1) 1843/1850, (2) 1942, (3) 1961-1963, and (4) 1988/1989, were merged into separate files. All polygons within a file were classified as either land or water. The 1843/1850 shoreline, the most limited in extent of the four, defined the study area (Fig. 2). By comparing the areas occupied by water for each of the four points in time, MGS was able to calculate rates of coastal land loss for Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River.

After merging, edge-matching, and classifying same-year shoreline vectors, MGS estimated coastal land loss in the four bodies of water by determining, then comparing, total water area in 1850, 1942, 1962, and 1989. A change in water area indicates an equivalent change in land area. The steps in the process are described in detail below.

- For the quadrangles covering the study area, merge and edge-match same-year shorelines.
In the first phase of the process, digital shorelines were clipped to 7.5-minute quadrangle boundaries and stored, by year, as “objects” in .rvc files named for the quadrangles. In this step, same-year shorelines from the .rvc files were merged into individual bay or river coverages. To edge-match shorelines at the joins between quadrangles, the operator zoomed in on all of the nodes in the vicinity of a join. (Nodes mark the ends of lines and points of line intersection.) For the most part, edge-matching entailed (1) drawing short, straight lines to close the narrow gaps between shorelines of adjacent quadrangles and (2) erasing overlapping lines (overshoots).
- For the 1989 coverage, convert all beach polygons to lines, using the bayward edge of the polygon as the shoreline.
Line segments comprising the 1989 shoreline were originally assigned one of four attributes: beach, structure, vegetated, or water’s edge. Beaches wide enough to be outlined as polygons were represented as such. For this exercise, the landward edge of each beach polygon was erased, leaving the land/water boundary as the shoreline.
- Eliminate interior ponds.
When digitizing shorelines from 1942 and 1962 source documents, the computer operator routinely included interior ponds, which lack a direct connection to the river or bay of interest. These occurred primarily in marshy areas. All such interior ponds were deleted, that is, classified as land.
- Add identical boundaries to all shoreline coverages (Fig. 2).
For each same-year shoreline vector file, the operator created a boundary around the entire

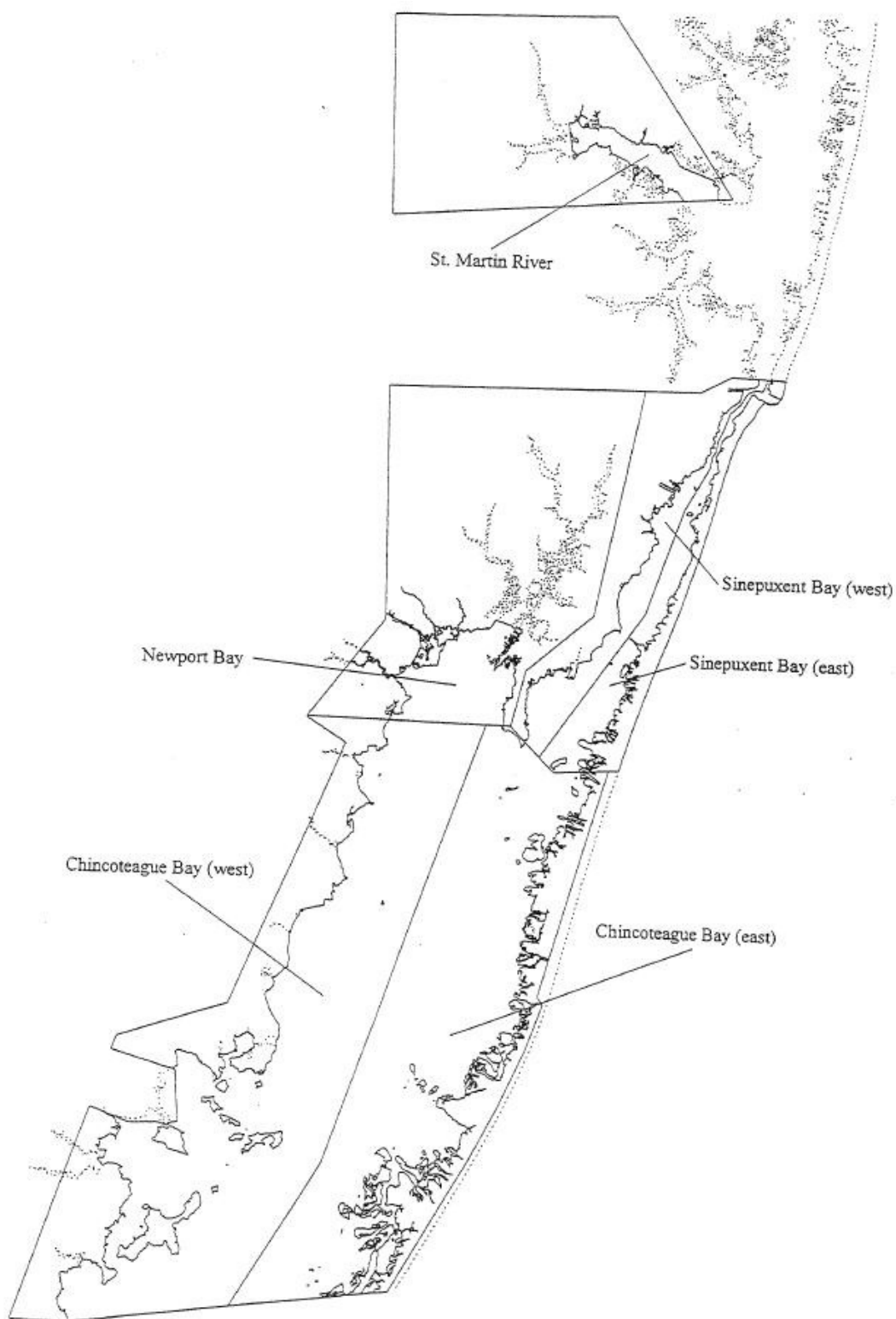


Figure 2: Areas included in coastal bay land loss calculations (excludes dotted shorelines)

study area, using the outermost lines of latitude and longitude of the quadrangles covering the coastal bays. She then added the Maryland-Virginia State line and coastal bay boundaries to the files. Coastal bay boundaries are usually straight line segments drawn across the mouths of tributaries and, in some places, at the headward extent of the 1843/1850 shoreline. The 1843/1850 shoreline does not always extend as far upstream as the more recent shorelines. To ensure that land loss determinations for the four time periods were comparable, only areas for which there was complete shoreline coverage were included in the calculations. All same-year shorelines were clipped to the same extents.

- Close the gaps in all shorelines, so that each file consists entirely of water or land polygons. Boundary-shoreline intersections were checked for closure and connected, if necessary.
- Assign attributes (“water” or “land”) to all of the polygons. Polygons were assigned one of two classifications – water or land. Whenever the operator was in doubt as to the appropriate category, she displayed the shoreline over the corresponding orthophotoquad to observe and assign the correct attribute.
- For the four time periods, calculate land loss by measuring and comparing areas occupied by land and water. Using measurement tools available in TNTmips, MGS determined coastal land loss in the study area by measuring the area occupied by water within each body of water. For any two time periods (e.g., 1850 and 1942), the difference in area usually represents the change due to shoreline retreat. (The difference in water area is equivalent to the difference in land area; water covers the area previously occupied by land.)
- For each year, determine shoreline length. Using measurement tools available in TNTmips, MGS measured the length of shoreline in the four bodies of water for each of the four shoreline years. (For the 1988/1989 shoreline, the length of each of the four types of shoreline is also reported.) Dividing the area of land lost by the shoreline length permits a comparison of different study areas. For this study, the 1988/1989 shoreline length was used as the divisor.
- Calculate average annual rates of change. For each time interval, dividing land loss by time elapsed produces average acreage lost from a particular river or bay each year. Dividing land loss/shoreline length by time elapsed produces the average lost from each mile of shoreline annually.

RESULTS

The area occupied by water at four different points in time is shown in Table 1 for the measured sections of four of Maryland’s coastal bays, Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River. (Comparable figures for Assawoman and Isle of Wight Bays are reported in Hennessee and Stott (1999).) Except for the eastern shores of Chincoteague and

Sinepuxent Bays, water area tends to increase at the expense of land at each successive point in time.

Table 1: Area occupied by water (acres) over time – Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River

	1850	1942	1962	1989
Chincoteague Bay				
East shore	21,204	20,982	21,473	21,508
West shore	24,393	25,395	25,729	25,751
Total	45,597	46,377	47,202	47,259
Newport Bay				
Total	2,581	2,952	3,027	3,033
Sinepuxent Bay				
East shore	3,970	3,334	3,242	2,953
West shore	2,733	2,888	2,987	3,016
Total	6,704	6,222	6,228	5,969
St. Martin River				
Total	1,073	1,288	1,329	1,327

Table 2 shows land area:water area ratios over time for most of the study area. Differences among water bodies are meaningless, depending as they do on the arbitrary boundaries drawn around the bay or river. Within a particular water body or section, however, the ratios permit a quick comparison of gross change over time. For example, in St. Martin River, land loss occurred between 1850-1942, but not in subsequent years, as indicated by identical ratios in 1942, 1962, and 1989. Ratios are not presented for eastern Sinepuxent Bay or Sinepuxent Bay as a whole, because the boundary of the study area changed in response to the migration of Assateague Island.

Table 2: Land:water ratios over time – Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River

	1850	1942	1962	1989
Chincoteague Bay				
East shore	22:78	23:77	21:79	21:79
West shore	33:67	31:69	30:70	30:70
Total	29:71	27:73	26:74	26:74
Newport Bay				
Total	89:11	88:12	88:12	88:12
Sinepuxent Bay				
East shore				
West shore	67:33	65:35	64:36	63:37
Total				
St. Martin River				
Total	94:6	93:7	93:7	93:7

Table 3 presents shoreline length for the same four points in time. The figures in the table represent only the length of shoreline included in the area for which land loss was calculated, not necessarily the length of shoreline of the entire water body. For example, St. Martin River was truncated just upstream of the confluence of the Bishopville and Shingle Landing Prongs, and the headward extent of Newport Bay was located just south of latitude 38°15'. Usually, the extent of the 1850 shoreline determined the limits of each area.

In general, the 1850 shoreline is shorter than the others, and the 1962 shoreline is longer. The 1850 shoreline was commonly restricted to the truck of the main bay or river; minor tributaries were excluded. To some extent, though, these differences in shoreline length reflect the scale of the source documents and the varying level of detail portrayed on the maps. The 1850 shoreline was digitized from 1:24,000-scale maps, and the 1962 shoreline, from 1:10,000-scale maps. The 1942 and 1989 shorelines were derived from sources at intermediate scales,

Table 3: Shoreline length (miles) – Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River

	1850	1942	1962	1989
Chincoteague Bay				
East shore	62.4	128.1	167.7	139.7
West shore	67.7	65.9	69.7	58.6
Total	130.1	194.0	237.4	198.3
Newport Bay				
Total	12.2	49.6	64.2	48.9
Sinepuxent Bay				
East shore	18.9	40.1	48.3	39.7
West shore	17.1	24.2	31.9	26.0
Total	35.9	64.3	80.3	65.7
St. Martin River				
Total	17.6	17.4	20.5	18.7

1:20,000 and 1:12,000, respectively. These two shorelines are most nearly alike in length. The length of the 1989 shoreline is used in subsequent calculations.

Tables 4 through 7 show the differences in area and shoreline rates of change between various years for Chincoteague Bay, Newport Bay, the St. Martin River, and Sinepuxent Bay, respectively. The first three rows of each table show long-term changes, beginning in 1850, for increasingly longer periods of time (1850-1942; 1850-1962; 1850-1989). The next two rows show changes beginning in 1942 (1942-1962; 1942-1989), and the last row, changes for the period 1962-1989. The tables contain:

- Column A – Time interval – beginning and ending dates of the time interval,
- Column B – Years elapsed – the length of the time interval,
- Column C – 1989 shoreline length – 1989 shoreline length included in land loss determinations, in miles

- Column D – Total land loss or gain – the difference in water area, in acres, between the two bracketing dates of the time interval,
- Column E – Annual land loss or gain – the average number of acres lost (-) or gained (+) each year during the time interval,
- Column F – Total land loss or gain per shoreline mile – the number of acres lost (-) or gained (+) per mile of shoreline during the time interval, and
- Column G – Annual land loss or gain per shoreline mile – the average number of acres lost (-) or gained (+) per mile of shoreline each year during the time interval.

During the 139 years that elapsed between 1850 and 1989, shoreline erosion outweighed accretion throughout the study area, except for eastern Sinepuxent Bay. Chincoteague Bay lost -1,662 acres; Newport Bay lost -452 acres; western Sinepuxent Bay lost -283 acres; the St. Martin River lost -254 acres. The losses were partially offset by a gain of +1,017 acres in eastern Sinepuxent Bay. Thus, taken together, the 332 miles of shoreline in the study area underwent a net loss of -1,634 acres of land. Erosion was greatest along the western shore of Chincoteague Bay, which lost -9.8 acres annually, at a rate of loss of -0.17 acres/mile/yr. Elsewhere, annual losses ranged from -1.8 to -3.3 acres/yr, and rates of loss, from -0.02 to -0.10 acres/mile/yr. The exception, eastern Sinepuxent Bay, gained +7.3 acres/yr at a rate of +0.18 acres/mile/yr.

Land losses and gains were distributed unevenly over time. The pattern of erosion was similar for the western shores of both Chincoteague and Sinepuxent Bays – an initial period of erosion (1850-1942), followed by a period of more severe erosion, and, then, most recently, by comparatively minor losses. The same pattern – an intermediate period of severe erosion, moderated during recent years – is also evident along the eastern shore of Chincoteague Bay. For Newport Bay and the St. Martin River, annual rates of loss remained consistent through 1962 (-0.08 and -0.11 to -0.12 acres/mile/yr, respectively). Virtually no change in total land area occurred over the next 27 years. Accretion along eastern Sinepuxent Bay occurred throughout the 139-year period, but at varying rates – lowest (+0.12 acres/mile/yr) between 1942-1962 and highest (+0.27 acres/mile/yr) since 1962.

For the truncated areas included in the land loss determinations, Table 8 shows the percentages of the various shoreline types, by bay or river, as interpreted from 1989 orthophotography. Throughout the study area, vegetated shorelines predominate. They account for over 90% of the Newport Bay and eastern Chincoteague Bay shorelines and over 50% of all others. Structural erosion control is largely limited to western Sinepuxent Bay and the St. Martin River. In 1989, slightly less than 10 miles of shoreline throughout the study area were protected. Beaches are rare, except along western Chincoteague Bay, where they occur along 21% of the shoreline.

Table 4: Shoreline changes – Chincoteague Bay

A Time interval	B Years elapsed	C 1989 shoreline length (miles)	D Total land loss (-) or gain (+) (acres)	E Annual land loss (-) or gain (+) (acres/yr) (D/B)	F Total land loss (-) or gain (+) per shoreline mile (acres/mile) (D/C)	G Annual land loss(-) or gain (+) per shoreline mile (acres/mi/yr) (D/C/B)
Eastern shore						
1850-1942	92	139.7	+222	+2.4	+1.6	+0.02
1850-1962	112	139.7	-269	-2.4	-1.9	-0.02
1850-1989	139	139.7	-304	-2.2	-2.2	-0.02
1942-1962	20	139.7	-491	-24.6	-3.5	-0.18
1942-1989	47	139.7	-526	-11.2	-3.8	-0.08
1962-1989	27	139.7	-35	-1.3	-0.3	-0.01
Western shore						
1850-1942	92	58.6	-1,002	-10.9	-17.1	-0.19
1850-1962	112	58.6	-1,336	-11.9	-22.8	-0.20
1850-1989	139	58.6	-1,358	-9.8	-23.2	-0.17
1942-1962	20	58.6	-334	-16.7	-5.7	-0.28
1942-1989	47	58.6	-356	-7.6	-6.1	-0.13
1962-1989	27	58.6	-22	-0.8	-0.4	-0.01
Entire bay						
1850-1942	92	198.3	-780	-8.5	-3.9	-0.04
1850-1962	112	198.3	-1,605	-14.3	-8.1	-0.07
1850-1989	139	198.3	-1,662	-12.0	-8.4	-0.06
1942-1962	20	198.3	-825	-41.2	-4.2	-0.21
1942-1989	47	198.3	-882	-18.8	-4.4	-0.09
1962-1989	27	198.3	-57	-2.1	-0.3	-0.01

Table 5: Shoreline changes – Newport Bay

A Time interval	B Years elapsed	C 1989 shoreline length (miles)	D Total land loss (-) or gain (+) (acres)	E Annual land loss (-) or gain (+) (acres/yr) (D/B)	F Total land loss (-) or gain (+) per shoreline mile (acres/mile) (D/C)	G Annual land loss(-) or gain (+) per shoreline mile (acres/mi/yr) (D/C/B)
1850-1942	92	48.9	-371	-4.0	-7.6	-0.08
1850-1962	112	48.9	-446	-4.0	-9.1	-0.08
1850-1989	139	48.9	-452	-3.3	-9.2	-0.07
1942-1962	20	48.9	-75	-3.8	-1.5	-0.08
1942-1989	47	48.9	-81	-1.7	-1.7	-0.04
1962-1989	27	48.9	-6	-0.2	-0.1	0.00

Table 6: Shoreline changes – St. Martin River

A Time interval	B Years elapsed	C 1989 shoreline length (miles)	D Total land loss (-) or gain (+) (acres)	E Annual land loss (-) or gain (+) (acres/yr) (D/B)	F Total land loss (-) or gain (+) per shoreline mile (acres/mile) (D/C)	G Annual land loss(-) or gain (+) per shoreline mile (acres/mi/yr) (D/C/B)
1850-1942	92	18.7	-215	-2.3	-11.5	-0.12
1850-1962	112	18.7	-256	-2.3	-13.7	-0.12
1850-1989	139	18.7	-254	-1.8	-13.6	-0.10
1942-1962	20	18.7	-41	-2.0	-2.2	-0.11
1942-1989	47	18.7	-39	-0.8	-2.1	-0.04
1962-1989	27	18.7	+2	+0.1	+0.1	0.00

Table 7: Shoreline changes – Sinepuxent Bay

A Time interval	B Years elapsed	C 1989 shoreline length (miles)	D Total land loss (-) or gain (+) (acres)	E Annual land loss (-) or gain (+) (acres/yr) (D/B)	F Total land loss (-) or gain (+) per shoreline mile (acres/mile) (D/C)	G Annual land loss(-) or gain (+) per shoreline mile (acres/mi/yr) (D/C/B)
Eastern shore						
1850-1942	92	39.7	+636	+6.9	+16.0	+0.17
1850-1962	112	39.7	+728	+6.5	+18.3	+0.16
1850-1989	139	39.7	+1,017	+7.3	+25.6	+0.18
1942-1962	20	39.7	+92	+4.6	+2.3	+0.12
1942-1989	47	39.7	+381	+8.1	+9.6	+0.20
1962-1989	27	39.7	+289	+10.7	+7.3	+0.27
Western shore						
1850-1942	92	26.0	-155	-1.7	-6.0	-0.06
1850-1962	112	26.0	-254	-2.3	-9.8	-0.09
1850-1989	139	26.0	-283	-2.0	-10.9	-0.08
1942-1962	20	26.0	-99	-5.0	-3.8	-0.19
1942-1989	47	26.0	-128	-2.7	-4.9	-0.10
1962-1989	27	26.0	-29	-1.1	-1.1	-0.04
Entire bay						
1850-1942	92	65.7	+482	+5.2	+7.3	+0.08
1850-1962	112	65.7	+476	+4.2	+7.2	+0.06
1850-1989	139	65.7	+735	+5.3	+11.2	+0.08
1942-1962	20	65.7	-6	-0.3	-0.1	0.00
1942-1989	47	65.7	+253	+5.4	+3.9	+0.08
1962-1989	27	65.7	+259	+9.6	+3.9	+0.15

Table 8: Shoreline type (%), based on photo interpretation of the 1989 shoreline

Study area	Shoreline type				
	Beach	Structure	Vegetated	Water's edge	Total
Chincoteague Bay					
East shore	1	0	99	<1	100
West shore	21	2	74	3	100
Total	7	1	91	1	100
Newport Bay					
Total	2	0	94	4	100
Sinepuxent Bay					
East shore	5	0	84	11	100
West shore	7	16	61	16	100
Total	6	6	75	13	100
St. Martin River					
Total	0	23	52	25	100

DISCUSSION

CHINCOTEAGUE BAY

Chincoteague Bay, or the part of Chincoteague Bay within Maryland, extends south from the mouths of Newport, and Sinepuxent Bays (see below) to the Maryland-Virginia line. All of the tributaries along western Chincoteague Bay were truncated at their confluence with the bay proper. Rowley Cove and western Brockatonorton Bay were omitted due to the absence of an 1850 shoreline. In eastern Chincoteague Bay, the 1942 and 1962 shorelines included numerous interior ponds, particularly in marshes. All of these ponds were deleted before land losses were determined. That is, inland ponds were treated as “land,” as were islands throughout the bay.

Based on the 1989 shoreline classification, 74% of the western bay shoreline is vegetated. Beaches make up most of the remainder. These are found mainly to the south, rimming the edges of Johnson and Parker Bays and Mills, Tizzard, and Assacorkin Islands. To the north, beaches also border parts of the two coves flanking Handys Hammock. Virtually all (99%) of the eastern Chincoteague Bay shoreline is vegetated.

Although marshes fringe much of the western Chincoteague Bay shoreline, they are distributed somewhat differently to the north and south. To the north, marshes are relatively narrow and are interrupted by stretches of upland. Their outline forms a distinctive series of points (e.g., Ricks Point, Kelly Point, Handys Hammock) and shallow coves. Islands are absent. To the south, marshes are broader and more ragged in outline. Large marshy islands and island archipelagos lie offshore, forming a number of small bays (i.e., Purnell, Parker, Johnson, Brockatonorton, and Martin Bays).

To some degree, rates of erosion in the two areas differ. Overall, rates are somewhat higher to the south, in the minor bays, than they are to the north, in western Chincoteague Bay proper. Erosion in both areas proceeds primarily by shoreline retreat. Marshes tend to erode more quickly than upland, and marshy points tend to erode more quickly than marshy coves. Less commonly, peninsulas are breached, forming islands. Islands subsequently diminish in size, through further breaching and/or erosion of their peripheries. Sometimes, after a peninsula is breached, a spit forms in the gap between mainland and island (e.g., Martin Pt.).

Some of the largest islands in the coastal bays are located in western Chincoteague Bay. They are fast disappearing. For the four time periods, acreage of the larger islands in the bay is shown in Table 9. Between 1850 and 1989, island area diminished by 35%, from a total of 1,491 acres to 973 acres. Individual islands lost a considerably larger proportion of land. About 80% of Assacorkin Island, for example, disappeared. The island, which covered 42 acres in 1850, covered only 9 acres in 1989.

Eastern Chincoteague Bay is situated on the bay side of Assateague Island, an Atlantic coast barrier island. Here, shoreline changes are primarily accretional, dominated by dynamic processes that continually reshape the island. Storms can change the barrier island rapidly and dramatically, forming inlets between the Atlantic and the coastal bays and washing sediment from the ocean to the bay side of the island. Gradually filled by sediment, inlets eventually revert to island. In 1850, such an inlet existed in the vicinity of Middlemoor, about halfway between the Maryland-Virginia state line and Green Run Bay. By 1942, that inlet had closed. Overwash delivers sediment to the bay side of a barrier island. Periods of quiescence lead to the development of drainage systems. Over time, the headward lengthening and gradual coalescence of these drainage systems create offshore islands. Examples of all of these changes are evident in the series of shorelines.

Table 9: Western Chincoteague Bay -- Island area (acres)

Island	1850	1942	1962	1989
Mills Island	761.4	626.3	584.7	561.4
Tizzard Island	228.9	187.8	181.5	175.6
Assacorkin Island	41.9	17.1	11.5	8.7
Big Bay Marsh	303.3	144.2	127.9	106.7
Ready Cove Tump		39.3	34.0	28.6
Islands connecting Big Bay Marsh & Ready Cove Tump		1.8 (1 island)	1.1 (3 islands)	0.3 (1 island)
Big Bay Marsh + Ready Cove Tump + Connecting islands	303.3	185.3	163.0	135.6
Robbins Tump	42.7	31.7	26.8	23.3
Shelldrake Island	71.1	48.2	43.4	38.6
Rattlesnake Island	41.8	35.1	32.1	30.1
Martin Point	connected to mainland	13.2	10.2	8.3
TOTAL ACRES (except Martin Pt.)	1,491.1	1,131.5	1,043.0	973.3

NEWPORT BAY

For purposes of calculating land loss, the main body of Newport Bay was truncated at about 38°15', near the northern border of the Tingles Island quadrangle. The study area extends southward to an east-west trending line drawn between Lower Sinepuxent Neck on the eastern shore and a point midway between Handys Hammock and Log Point on the western shore. South Point, on Lower Sinepuxent Neck, is included in Chincoteague Bay. Where they are delineated (all years except 1850), Marshall, Porter, Bassett, and Catbird Creeks, draining the western shore of the Bay, are also included in the study area.

Low-lying marshes fringe much of Newport Bay. Based on the 1989 shoreline classification, 94% of the shoreline is vegetated. Marshes are criss-crossed by drainage ditches constructed to control mosquitoes. In sets of straight, parallel lines, the ditches are spaced at 150-ft intervals. Marshes are more extensive and less fragmented along the western shore than they are on the

eastern shore. Along Newport Neck, at the north end of the eastern shore, much of the marsh is a cluster of innumerable small islands. South of Newport Neck, along Lower Sinepuxent Neck, the physiography changes once again. There, minor fringing marshes are interrupted by sandy pocket beaches that lie immediately adjacent to fastland.

Throughout the 139-year period, the western shore of Newport Bay and Lower Sinepuxent Neck lost land through parallel retreat of the shoreline. Along the western shore, total linear retreat exceeded -300 ft. at Log Point and Out Point. Between those two points of land and between Marshall and Cropper Creeks, ditching of the marshes appears to contribute to shoreline erosion. Shoreline indentation or crenulation due to differential erosion at the mouths of ditches had begun to develop by 1962 and was quite pronounced by 1989. In an area north of Marshall Creek, the shoreline retreated about 15-20 ft between 1962 and 1989, except at the mouths of ditches, where erosion totaled 40 ft, double the erosion rate of the adjoining shoreline. Along Newport Neck, marsh segmentation and subsequent reduction in the size of remnant islands was common.

SINEPUXENT BAY

The Sinepuxent Bay study area extends from the Rt. 50 bridge in the north to a bent line drawn from a point on Lower Sinepuxent Neck just north of South Point, across the bay to a point on Assateague Island due east of Great Egging Beach. It includes Great Egging Beach. The only tributary excluded from the study area is a small, unnamed creek on Lower Sinepuxent Neck just west of Green Point. It was truncated just above its mouth because of the limited extent of the 1850 shoreline.

Creating a single, unchanging boundary around the bay was impossible because of the migration of Assateague Island. For the eastern shore, boundaries were drawn in such a way as to ensure the inclusion of the entire bay shoreline and the exclusion of the Atlantic shore of Assateague Island. Consequently, the area of land plus water for the eastern shore (and for the entire bay) changes from one time period to the next. Although land area over time cannot be compared, water area can be.

Based on the 1989 shoreline classification, about 75% of the Sinepuxent Bay shoreline is vegetated – more of the eastern shore (84%) and less of the western shore (61%). Beaches, representing less than 10% of the total shoreline, are distributed about equally between the eastern and western shores. In eastern Sinepuxent Bay, interrupted beaches occur along the reach of shoreline extending 1-2 miles south of the Ocean City Inlet. The beaches have formed along the margins of lobes, which project into the bay, and extend southward from the lobes as spits. In western Sinepuxent Bay, beaches line the shore from just north of Sandy Point almost continuously to just south of Rum Point. Structural shoreline protection, for the most part fortifying canal banks in developed areas, occurs intermittently along 4 miles (16%) of the western shore.

Like Chincoteague Bay, the eastern shore of Sinepuxent Bay is dominated by processes associated with barrier island migration, particularly inlet formation and overwash. In 1850,

Assateague Island formed an unbroken border along the eastern shore of the bay. By 1942, the Ocean City Inlet had opened, establishing a direct connection between Sinepuxent Bay and the Atlantic Ocean. Between 1942 and 1962, Assateague Island was again breached, and a second inlet opened about 1.5 miles south of Ocean City Inlet. By 1989, the second inlet had closed. From a point on the eastern shore of Sinepuxent Bay, opposite the reach of the western shore of the bay between Grays Point and Fassett Point, Assateague Island appears to have rotated landward. In the vicinity of the second inlet, the island migrated about 3,000 ft between 1850 and 1989, constricting Sinepuxent Bay in the process.

Although accretion is usually regarded favorably, as being preferable to erosion, the deposition of sediment at one site presupposes its removal from another. In eastern Sinepuxent Bay, accretion occurs at the expense of the Atlantic side of Assateague Island. Furthermore, the constriction of the bay due to barrier island migration necessitates dredging to maintain a navigable channel.

Great Egging Beach, the largest island in eastern Sinepuxent Bay steadily decreased in size over the period of study. In 1850, the island covered 47 acres; in 1989, only 27 acres. The measured loss is a conservative figure, attributable entirely to the shrinking perimeter of the island. It does not take into account the development and expansion of interior ponds. If those were considered, the actual land area would be even less.

Generally, the shoreline of western Sinepuxent Bay is eroding, through parallel retreat of the shoreline and the disappearance of islands. Linear recession ranges from 100-400 ft over the 139-year period. Erosion has not occurred steadily over time, however, particularly in the northern part of the bay. Crossing shorelines indicate numerous small areas of erosion and deposition, alternating alongshore. Accretion and the formation of south-trending spits have occurred at a few points, namely Sandy Point and Salt Point.

ST. MARTIN RIVER

For purposes of determining land loss, the St. Martin River study area extends from the confluence of the river's two main tributaries, Bishopville and Shingle Landing Prongs, to the Rt. 90 bridge at the mouth of the river. It includes the western shore of Isle of Wight. The limited headward extent of the 1850 shoreline resulted in the exclusion of the two prongs. In addition, most of the marsh behind Saltgrass Point, bordering Buck Island Pond and Smokehouse Cove, was excluded, because a section of the 1962 shoreline was missing. Finally, most of the canals constructed since 1942 were omitted. To reiterate, excluding features means classifying them as "land" rather than "water."

Prior to 1962, the St. Martin River, particularly its southern shore, steadily lost land; annual land loss ranged narrowly from 2.0-2.3 acres/yr. The area covered by water increased through:

- Parallel retreat of comparatively straight stretches of shoreline,
- Segmentation of marshy points of land that extended into the river, forming remnant islands (e.g., Hasty and Shell Gut Points on the southern shore and Woods Point and Saltgrass Point on the northern shore),

- Subsequent reduction in size or complete disappearance of islands (e.g., Saltgrass Point); and
- Widening of the mouths of tributaries, as well as possible headward lengthening (e.g., the mouth of Shell Gut increased in width from about 130 ft. in 1850 to nearly 300 ft. in 1942).

Since 1962, erosion appears to have reversed itself; for the period 1962-1989, the St. Martin River study area gained +0.1 acres/yr. The seeming net gain in land, however, is confounded by man's modifications to the shoreline. Particularly along the southern shore in the vicinity of Ocean Pines, structural protection entailed straightening the shoreline and, commonly, filling areas that had previously been classified as "water". If one considers specific reaches of unprotected shoreline, however, certain stretches clearly underwent erosion between 1962 and 1989. For example, Saltgrass Point virtually disappeared from the study area, and a section of marsh between Harry Creek and Buck Island Creek on the northern shore of the river retreated more than 100 ft. For much of the remaining shoreline, the 1962 and 1989 shorelines are intertwined, indicating minor erosion or accretion and no net change.

Table 10 presents the findings of this study, along with those of Singewald and Slaughter (1949), for the period 1850-1942. In general, the direction of change – erosion or deposition – is the same in both studies. However, Singewald and Slaughter reported greater gains in areas of accretion and greater losses in areas of erosion. Annual rates differ between the two studies in part because rates are based on shoreline length. In general, the miles of shoreline measured by Singewald and Slaughter were less than the length of the 1989 shoreline used in the present study. Another difference between the two studies is methodology. Singewald and Slaughter's study predates computer technology. Presumably, the use of a GIS provides more accurate results than did the measurement techniques available to those authors. These measurements include not only area, but shoreline length as well.

CONCLUSIONS

Spanning the period 1843-1989, historical shorelines for the southern coastal bays of Maryland have been converted to digital format. The availability of these vectors will facilitate future updates of shoreline changes maps and GIS-based research and decision-making regarding the coastal bays. The classification of the most recent (1988/1989) shoreline by shoreline type (beach, structure, vegetated, water's edge) provides a baseline against which future shoreline changes can be compared. In particular, that classification provides an indication of the minimum length of shoreline that was protected by erosion control structures in 1988/1989. (The figure probably underestimates the length of protected shoreline, because it depends on the photo interpreter's being able to distinguish man-modified from natural shoreline.)

Table 10: Net land lost (-) or gained (+) between 1849-1850 and 1942, comparison of studies

	Singewald & Slaughter		Hennessee et al.	
	Acres	Annual rate	Acres	Annual rate
Chincoteague Bay				
East shore	+333	+0.18	+222	+0.02
West shore	-261	-0.12	-1,002	-0.19
Total	+36	+0.01	-780	-0.04
Newport Bay				
Total	-133	-0.18	-371	-0.08
Sinepuxent Bay				
East shore	+758	+0.26	+636	+0.17
West shore	-106	-0.08	-155	-0.06
Total	+652	+0.15	+482	+0.08
St. Martin River				
Total	-202	-0.18	-215	-0.12

To estimate coastal land loss in Chincoteague, Newport, and Sinepuxent Bays and the St. Martin River, MGS measured and compared the area occupied by water at four points in time. Increases in water area correspond to decreases in land area, and vice versa. In total, MGS quantified change along 332 miles of predominantly vegetated (86%) shoreline. Between 1850 and 1989, net loss of land in the study area amounted to -1,634 acres. Erosion outpaced accretion, except in eastern Sinepuxent Bay. Chincoteague Bay lost -1,662 acres; Newport Bay lost -452 acres; western Sinepuxent Bay lost -283 acres; the St. Martin River lost -254 acres. The losses were partially offset by a gain of +1,017 acres in eastern Sinepuxent Bay. Erosion was greatest along the western shore of Chincoteague Bay, which lost -9.8 acres annually, at a rate of loss of -0.17 acres/mile/yr. Elsewhere, annual losses ranged from -1.8 to -3.3 acres/yr, and rates of loss, from -0.02 to -0.10 acres/mile/yr. The exception, eastern Sinepuxent Bay, gained +7.3 acres/yr at a rate of +0.18 acres/mile/yr.

Juxtaposing shorelines from different years reveals the pattern of erosion in a particular place. In the study area, erosion occurs primarily through parallel retreat. That is, all points lying along a stretch of shoreline retreat at about the same rate. Consequently, the more recent shoreline lies parallel to and landward of a previous one. Other patterns of erosion are also apparent. Points of land, particularly marshy points, tend to erode at faster rates than coves. Peninsulas are sometimes breached, leaving remnant islands. Islands subsequently diminish in size through further breaching and/or erosion of their peripheries. In marshes, ditching appears to contribute to shoreline erosion; erosion at the mouths of ditches is commonly more pronounced than erosion of the intervening shorelines.

Shoreline accretion, largely restricted to eastern Sinepuxent and Chincoteague Bays, is associated with the landward migration of Assateague Island, an Atlantic coast barrier island. Overwash, which transports sediment from the ocean side to the coastal bay side of the island, and the formation and evolution of inlets account for many of the accretionary features along these shorelines.

The method used in this study to determine land loss differs from a common approach of estimating linear rates of shoreline change – constructing shore-normal transects at approximately equal intervals along the shoreline, measuring erosion along each transect, and aggregating the rates. Both methods have their strengths. For a well-defined study area, comparing land or water area over time provides an easy, accurate measurement of total land loss. The technique, implemented in a GIS, is particularly well suited to areas characterized by irregular shorelines, such as the coastal bays. It may also be more forgiving of slight offsets (errors) in shoreline position, depending on the direction of the shift.

In measuring linear shoreline retreat along closely spaced, shore-normal transects, shoreline reaches are seldom excluded because of a few missing historical shorelines. Rather, rates of change are based on the available shorelines. Compared to determining gross changes along predetermined reaches, the method also affords greater flexibility in defining reaches of interest. Once a reach is identified, its average rate of change can be obtained simply by aggregating rates for all transects within the reach.

As for future research suggested by this study, one immediate possibility is to couple coastal rates of change with knowledge of the height and grain size composition of shoreline banks – to assess the contribution of shoreline erosion to sediment load. Shoreline erosion has a vertical aspect; imagine the retreat of a bluff or bank. Converting area losses (ft^2) to volume losses (ft^3) requires knowledge of bank height along the eroding shoreline. If the relative proportions of sand and of silt/clay comprising the eroding banks are also known, then it is possible to estimate the mass of sediment entering the coastal bays. Differentiating sand and silt/clay components is useful, because sands are more likely to be deposited near shore, whereas finer sediments are more likely to remain suspended in the water column. Suspended sediments affect water quality (turbidity and nutrient loading) and underwater habitats. For example, by clouding the water, they reduce the ability of sunlight to reach the bay floor and thereby interfere with the growth of bay grasses.

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APPENDIX 1
Shore Erosion in Chincoteague, Newport, and
Sinepuxent Bays and the St. Martin River, Maryland
(from Singewald and Slaughter, 1949)

Chincoteague Bay

East shore

Latitude 38° 07' 30" N to the Maryland-Virginia boundary

Area of erosion:

The north shore of Green Run Bay shows a maximum linear recession of 400 ft.

Areas of deposition:

Southward from Sugar Point for a distance of 4400 ft., maximum linear building out is 900 ft. The area of Middlemoor shows the greatest amount of deposition. Some points of marsh have built out a maximum of 2700 ft.

West shore

Handys Hammock to Tanhouse Creek

Areas of greatest erosion:

1. Between Handys Creek and Waterworks Creek, there is a maximum linear recession of 250 ft.
2. Between Kelly Point and Turpin Cove, the maximum linear recession is 250 ft.
3. From Robins Creek to Scarboro Creek, maximum linear recession is 350 ft. Ricks Point has receded 500 ft.
4. From Scarboro Creek to Tanhouse Creek, the maximum linear recession is 500 ft.

Areas of deposition are small but numerous.

Tanhouse Creek to Martin Bay

The entire shore line has undergone erosion, with a maximum linear recession of 450 ft. between Figgs Landing and Watermelon Point. Watermelon Point has receded 400 ft.

A spit at the east shore entrance of Martin Bay has built out 500 ft. west.

Martin Bay to the Maryland-Virginia boundary, including the tributary bays

From the entrance of Scarboro Creek to Shell Point in Johnson Bay, there is a maximum linear recession of 300 ft. Shell Point has receded 800 ft. and Hunting Point 240 ft. At the entrance to Purnell Bay, Purnell Point has receded 400 ft. and Goose Point 450 ft.

Areas of deposition are numerous but small and scattered.

Newport Bay

East shore

Between South Point and Spence Cove, there is a maximum linear recession of 460 ft. South Point has receded 400 ft., Island Point 460 ft., and Knox Point 200 ft.

West shore

From latitude 38° 15' N to latitude 38° 14' N the maximum linear recession is 260 ft. Out Point has receded 200 ft.

Sinepuxent Bay

East shore

The shore from the Ocean City Inlet to 2000 ft. north of latitude 38°16' N, shows a maximum linear building out of 2500 ft. A large spit on the south shore of the Ocean City Inlet has built out 2200 ft. to the northeast and has advanced 1000 ft. southward.

West shore

From the dredged harbor slip at Ocean City to Sandy Point

From Fassett Point to Sandy Point, there is a maximum linear recession of 200 ft. Other areas of erosion are numerous but small.

Areas of deposition are numerous but small.

Sandy Point to South Point

Between Salt Point and Green Point, maximum linear recession is 400 ft. and maximum building out 240 ft. Other areas of erosion and deposition are small.

Sinepuxent and Chincoteague Bays

East shore

Latitude 38° 15' N to Latitude 38° 07' 30" N

Areas of deposition are numerous. Maximum linear building out is 700 ft.

St. Martin River

From Poplar Point on the north shore and Cedar Point on the south shore 3 miles upstream

Both shore lines are very ragged and deeply indented with a complex system of marshy inlets, coves and creeks. Erosional areas are small but numerous. Jenkins Point has receded 200 ft. and Cedar Point 500 ft.

Areas of deposition are small.

Islands

Mills Island

Mills Island is at the south end of Chincoteague Bay, separated from the mainland by Parker Bay. Its north shore is on Johnson Bay. Mills Island is predominantly marsh with three small areas of low land. One in the northeast part of the island reaches a height of 20 ft.

The north shore has a maximum linear recession of 320 ft., the east shore 400 ft., the south shore 380 ft., and the west shore 150 ft. The southeast end of the island has receded 80 ft.

Tizzard Island

The north shore of Tizzard Island is on Brockatonorton Bay, the east and south shores on Johnson Bay, and the west shore on Rowley Cove. A narrow strip of lowland runs north and south through the center of the island, which is predominantly marsh.

The north shore has a maximum linear recession of 300 ft., the east shore 250 ft., the south shore 200 ft., and the west shore 200 ft.

Locality	A Time interval (years)	B Miles measured	C Erosion (acres)	D Deposition (acres)	E Net loss (-) or gain (+) (acres) (C-D)	F Rate of loss (-) or gain (+) (acres/mile) (E/B)	G Annual rate of loss (-) or gain (+) (acres) (F/A)
Chincoteague Bay							
East shore <i>Latitude 38° 07' 30" N to the Maryland- Virginia boundary</i>	92	19.7	-102	+435	+333	+16.9	+0.18
West shore <i>Handys Hammock to Tanhouse Creek</i>	92	8.3	-148	+4	-144	-17.3	-0.18
West shore <i>Tanhouse Creek to Martin Bay</i>	92	2.4	-45	+6	-39	-16.2*	-0.18*
West shore <i>Martin Bay to the Maryland-Virginia boundary</i>	92	12.9	-111	+33	-78	-6.0	-0.06
West shore subtotal	92	23.6	-304	+43	-261	-11.1	-0.12
Mainland subtotal	92	43.3	-406	+478	+72	+1.7	+0.02
Islands	92	0.7	-36	0	-36		
Total	92	44.0	-442	+478	+36	+0.8	+0.01

Locality	A Time interval (years)	B Miles measured	C Erosion (acres)	D Deposition (acres)	E Net loss (-) or gain (+) (acres) (C-D)	F Rate of loss (-) or gain (+) (acres/mile) (E/B)	G Annual rate of loss (-) or gain (+) (acres) (F/A)
Newport Bay							
Total	92	7.7	-135	+2	-133	-17.2	-0.18
Sinepuxent Bay							
<u>East shore</u> <i>To latitude 38° 15' N</i>	92	8.5	-22	+472	+450	+52.9	+0.57
<u>East shore</u> <i>Latitude 38° 15' N to 38° 07' 30" N</i>	93	23.3	-37	+345	+308	+13.2	+0.16
East shore subtotal	93	31.8	-59	+817	+758	+23.8	+0.26
<u>West shore</u> <i>Ocean City dredged harbor slip to Sandy Pt.</i>	93	8.5	-68	+6	-62	-7.2	-0.07
<u>West shore</u> <i>Sandy Pt. to South Pt.</i>	93	5.1	-50	+6	-44	-8.6	-0.09
West shore subtotal	93	13.6	-118	+12	-106	-7.8	-0.08
Mainland subtotal	93	45.4	-177	+829	+652	+14.4	+0.15
Islands	93	0	-3	0	-3		

Locality	A Time interval (years)	B Miles measured	C Erosion (acres)	D Deposition (acres)	E Net loss (-) or gain (+) (acres) (C-D)	F Rate of loss (-) or gain (+) (acres/mile) (E/B)	G Annual rate of loss (-) or gain (+) (acres) (F/A)
Total	93	45.4	-177	+829	+652	+14.4	+0.15
St. Martin River							
<i>From Poplar Point on the north and Cedar Point on the south, upstream 3 miles</i>	93	11.8	-205	+3	-202	-17.1	-0.18

* Singewald and Slaughter report Rate of loss/gain = -12.0 and Annual rate of loss/gain = -0.13. If "Miles measured" is correct, then their calculations are in error.

APPENDIX 2
Historical Erosion Rates in St. Martin River,
Shingle Landing Prong and Bishopville Prong, Maryland
(from Volonté and Leatherman, 1992)

Zone	Location	Shoreline length (miles)	Number of transects	Range of rates of erosion (ft/yr)	Overall average rate of erosion (ft/yr)	Marsh average rate of erosion (ft/yr)
5	St. Martin River					
	South bank		11	+0.9 to -1	+0.03	-0.06
	North bank		17	-0.5 to -3.3	-1.8	-1.8
	Total	7.17	28	+0.9 to -3.3	-1.1	-1.3
6	Shingle Landing Prong					
	South bank		8	+1.4 to -1	+0.02	-0.7
	North bank		6	+0.3 to -1.3	-0.5	-0.8
	Total	3.52	14	+1.4 to -1.3	-0.2	-0.8
7	Bishopville Prong					
	West bank		5	stable	0	0
	East bank		8	stable to -1.5	-0.4	-0.3
	Total	2.66	13	stable to -1.5	-0.3	-0.3

Zone 5

- The south bank of the St. Martin River is relatively stable, though some areas are accreting (transects 101-107, 125-126, 132-133).
- Only a small portion of the south bank contains marshy shores; the rest has been developed into residential marinas with hard shoreline stabilization structures (Ocean Pines, between transects 103 and 104).
- The marshy shores at the source of the river have been accreting or are stable (transects 106-107, 125-126, 132-133).
- The north bank of the St. Martin River has less development and more marshy shoreline (than the south bank).
- All north bank transects (from 150-165) indicate erosion at rates higher than -1 ft/yr, except for three transects (150, 151, and 164) that show erosion rates of -0.5 ft/yr.

Zone 6

- The banks of Shingle Landing Prong, located on the upper part of the St. Martin River, are relatively steep.
- Transects at the mouth of the south bank of the prong (transects 108-111) indicate erosional trends of about -0.5 ft/yr.
- At the upper part of the prong (transects 112, 116-118), accretional trends vary between +1.4 and +0.4 ft/yr.
- The north bank of the prong (transects 119-124) has steep slopes and small areas of marshes that are presently eroding at an average rate of -0.5 ft/yr.

Zone 7

- The banks of Bishopville Prong, part of the St. Martin River basin, consist of steep slopes and a small, marshy shoreline at the mouth of the prong.
- Transects on the west bank indicate a stable shoreline since 1934 (transects 134-139).
- The east bank of the prong has been slightly eroding north of Daye Road, but, in general, this bank is stable (transects 140-147).

APPENDIX 3

Sources of Shoreline Data, by Quad

In the following table, dates are reported in the format YYYYMMDD, where YYYY = year, MM = month, and DD = day. For some dates, only year (YYYY) or month and year (YYYYMM) are known. Dates of the shorelines drawn on the *Historical Shorelines* maps are given. For *Coastal Survey* maps, “Date(s)” is the date(s) on which the aerial photography was flown. Digital orthophoto quarter quads (DOQQs) were the ultimate source of both the 1989 shoreline and the *Shoreline Changes* base map.

Quad	<i>Historical Shorelines map</i>		<i>Coastal Survey map</i>		DOQQ	
	ID	Date	ID	Date(s)	ID	Date
Boxiron	89A	1850	T-8155	194204	NE, NW, SE, SW	19890412
			T-12088	196105		
			T-12089	196105		
				196303		
			T-12092	196105		
				196303		
			T-12093	196203		
				196204		
Girdletree	88A	1843	T-8154	194204	NW*	19880330
			T-12091	196105	NE, SE, SW*	19890412
				196303		
Whittington Point	90A	1850	T-8156	194204	NE, NW, SW	19890412
			T-12090	196203		
				196204		
			T-12094	196203		
				196204		

*Used only in compiling base map; no associated shoreline vectors interpreted from quarter quad

APPENDIX 4
Coastal Survey Maps
Citation Details

ID	Title	Scale (1:)	Quads	Source media
T-8154	Girdletree Quadrangle – Maryland and Virginia	20,000	Girdletree	bromide
T-8155	Boxiron Quadrangle – Maryland and Virginia	20,000	Boxiron	bromide
T-8156	Whittington Point Quadrangle – Maryland and Virginia	20,000	Whittington Point	bromide
T-12088	Maryland – Worcester County – Boxiron Bay	10,000	Boxiron	bromide
T-12089	Maryland – Worcester County – Big Bay Point to Figgs Landing	10,000	Boxiron	bromide
T-12090	Maryland – Worcester County – Pope Bay to Sugar Point	10,000	Whittington Point	bromide
T-12091	Maryland-Virginia – Chincoteague Bay – Powell Creek to Riley Creek	10,000	Girdletree	bromide
T-12092	Maryland-Virginia – Chincoteague Bay – Purnell Bay to Assacorkin Island	10,000	Boxiron	bromide
T-12093	Maryland-Virginia – Chincoteague Bay – Calfpen Bay to Rum Harbor Cove	10,000	Boxiron	bromide
T-12094	Maryland-Virginia – Chincoteague Bay – Pope Bay	10,000	Whittington Point	bromide