

RESOURCE ASSESSMENT SERVICE  
MARYLAND GEOLOGICAL SURVEY  
Jeffrey P. Halka, Acting Director

COASTAL AND ESTUARINE GEOLOGY  
FILE REPORT NO. 09-02

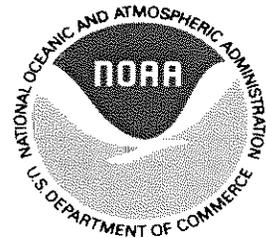
## Calvert County Shore Erosion Rate Verification

by

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Partial funding for this study was provided by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration.



April 2009

**DISCLAIMER:** This report was prepared by the Maryland Geological Survey under award number NA07NOS4190161 from the Office of Ocean and Coastal Resource Management (OCRM), National Oceanic and Atmospheric Administration (NOAA), through the Maryland Department of Natural Resources Chesapeake and Coastal Program. The statements, findings, conclusions and recommendations are those of the author and do not necessarily reflect the views of OCRM or NOAA.

**ACKNOWLEDGMENTS:** Thanks to Adam Bode at NOAA's Coastal Resources Center for providing MGS with raster images of several of the T-sheets for which digital shorelines are not yet available. He was unfailingly helpful and quick to respond to several requests and questions. Thanks also to Katie Offerman of MGS, who assisted in the GIS component of the project.

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## ABSTRACT

The Calvert County Department of Planning and Zoning is in a quandary as to which of two studies to rely on in making decisions about its coastal zone – one study by a graduate student at the University of Maryland and the other by the Maryland Geological Survey (MGS). To help resolve the problem, MGS compared the results of the two studies for two areas in Calvert County, Randle Cliff and Little Cove Point. MGS also compared a subset of its original digital shorelines for the county with either (a) shorelines derived from the same sources (T-sheets) but digitized by the National Oceanic and Atmospheric Administration (NOAA) or (b) shorelines digitized directly by MGS from original T-sheets, as opposed to derivative maps compiled from those originals.

MGS traced the inconsistencies between the two studies to two shortcomings in its own digital shoreline data set: (1) for the earliest shoreline, dating from the mid-1800s, the Survey chose to digitize, not the original T-sheets, but maps derived from them and (2) for the most recent shoreline, MGS chose to interpret the land/water interface from non-tide-coordinated orthophotography – a different shoreline change reference feature than the (mean) high water line mapped on T-sheets. Based on this study, the combined effect of those two problems was to minimize shoreline displacement and, consequently, rates of shoreline change.

MGS strongly recommends that as soon as NOAA completes digitizing the historical T-sheets and the *ca.* 2008 shoreline for the county, shoreline rates of change be recomputed. The digital shorelines will represent a consistent shoreline change reference feature, and the most recent shoreline will be based on tide-coordinated photography. Short of recompiling shorelines and recalculating rates of change, MGS recommends that Calvert County continue to use Downs's results, despite the fact that her report is based on shoreline positions that are now 40 years out of date.

## INTRODUCTION

In making decisions about development along its tidal shorelines, the Calvert County Department of Planning and Zoning has at its disposal two shoreline change studies – one by a graduate student at the University of Maryland (Downs, 1993) and the other by the Maryland Geological Survey (MGS) (Hennessee and others, 2003). (Partial results of the latter study are posted online at the Maryland Shorelines Online website (<http://shorelines.dnr.state.md.us/>). Both studies involved digitizing historical shorelines and determining shoreline rates of change. However, the two studies differed in their sources and dates of historical shorelines, their digitizing techniques, and, not surprisingly, their results. Discrepancies between the two studies have left county planners in a quandary as to which study better serves their needs. To remedy the problem, MGS reexamined its historical shorelines at two sites bordering the Chesapeake Bay in Calvert County, (1) Randle Cliff, near the Anne Arundel-Calvert County line (North Beach quadrangle) and (2) Little Cove Point, in the vicinity of Chesapeake Ranch Estates (Solomons Island quadrangle). The Survey compared its original results with those obtained by Downs and reacquired several digital shorelines for the two sites. MGS then compared three of its original shorelines with newly acquired ones to identify possible sources of error in the existing MGS shoreline position data set.

In 2008, when MGS submitted the proposal for this project, the National Oceanic and Atmospheric Administration (NOAA) was in the process of creating a new digital shoreline for the Chesapeake Bay. It still is. If that shoreline had been available during the course of the study, MGS planned to substitute it for a 1993 shoreline digitized from non-tide-coordinated orthophotography and recalculate shoreline rates of change for the two selected sites. However, as of March 5, 2008, NOAA had not yet completed the update (B. Baldwin, pers. comm.).

## BACKGROUND

Downs (1993) analyzed historical shoreline change between 1848 and 1971 along a 60-km stretch of Calvert County. As her shoreline sources, she used 16 National Ocean Service (NOS) topographic or T-sheets and two sets of vertical aerial photography (see Appendix 1). In digitizing the sources, she used a popular and tested method of the time – Metric Mapping. She identified sources of error and quantified them. The shoreline that she extracted from non-tide-coordinated aerial photos followed the wetted perimeter (wet-dry line) on the beach.

Several years later, MGS mapped shoreline change and determined erosion rates for tidal reaches of shoreline statewide. For the Chesapeake Bay shoreline bordering Calvert County, the set of historical shorelines spanned the period 1847-1993 (see Appendix 1). MGS digitized seven of the fairly recent (1942 and 1960) NOS T-sheets that Downs had digitized. However, in lieu of digitizing earlier shorelines directly from NOS T-sheets, MGS elected to digitize shorelines from an in-house set of *Historical Shorelines* maps (Conkwright, 1975) derived from those T-sheets. Shorelines depicted on *Historical*

*Shorelines* maps had been traced from the original T-sheets, projected onto USGS 7.5-minute topographic quadrangles, and redrawn by hand along the bayward edge of the shoreline. MGS subsequently digitized the bayward edge of that hand-drawn shoreline. In addition to T-sheets and maps derived from them, MGS oversaw the interpretation of the land-water interface from non-tide-coordinated digital orthophotoquads flown in 1993.

MGS rectified digitizing errors, identified by overlaying test plots of digital shorelines over the source maps, without quantifying them.

The initial impetus for acquiring digital shorelines was to produce a set of *Shoreline Changes* maps, an updated version of the Survey's *Historical Shorelines* map series. MGS subsequently used the digital data in conjunction with a computer program developed by the U.S. Geological Survey, the Digital Shoreline Analysis System (DSAS), to compute shoreline rates of change.

So, in summary, Downs utilized only original documents and digitized more shorelines, but she covered a shorter span of time. MGS utilized a mixture of original and derivative sources and digitized fewer shorelines, but it considered a broader time span, reflecting more recent changes in shoreline position. Table 1 presents a point-by-point comparison of the two original studies.

<b>Source/Technique</b>	<b>Downs (1993)</b>	<b>MGS (2003)</b>
Time span represented by historical shorelines	1848-1971	1847-1993
Shoreline years digitized	1840s, 1900s, 1930s, 1940s, 1950s, 1960s, 1970s	1840s, 1930s, 1940s, 1960s, 1990s
Shoreline sources	<ul style="list-style-type: none"> <li>o NOAA T-sheets (MHW)</li> <li>o Vertical aerial photography (corrected, non-orthogonal; non-tide-coordinated)</li> </ul>	<ul style="list-style-type: none"> <li>o Maps <u>derived</u> from NOAA T-sheets</li> <li>o NOAA T-sheets (MHW)</li> <li>o Digital orthophotography (orthogonal; non-tide-coordinated)</li> </ul>
Shoreline date used in calculating rates of change	Date of photography (recent T-sheets and aerial photography)	Date of field edit or, if not reported, date of photography
Shoreline change reference feature (T-sheets and derivative maps)	Mean high water line	Bayward edge of mean high water line
Shoreline change reference feature (aerial and orthophotography)	Wetted perimeter or wet-dry line, indicated by a change in gray tones	Land/water interface

Accuracy checks (shoreline sources)	T-sheet examined for media distortion - distortion beyond 1.0% unacceptable	T-sheet deemed unacceptable if check plots could not be corrected
Accuracy checks (digitized shoreline)	Unknown	Check plots compared to original sources – digitizing accepted if check plot shoreline lay within one pen width of the bayward edge of the shoreline plotted on the source map
Digitizing technique	Unknown	Heads-down digitizing
Shoreline rate-of-change computations	Metric Mapping	Digital Shoreline Analysis System (DSAS)
Transect spacing	46 m	20 m

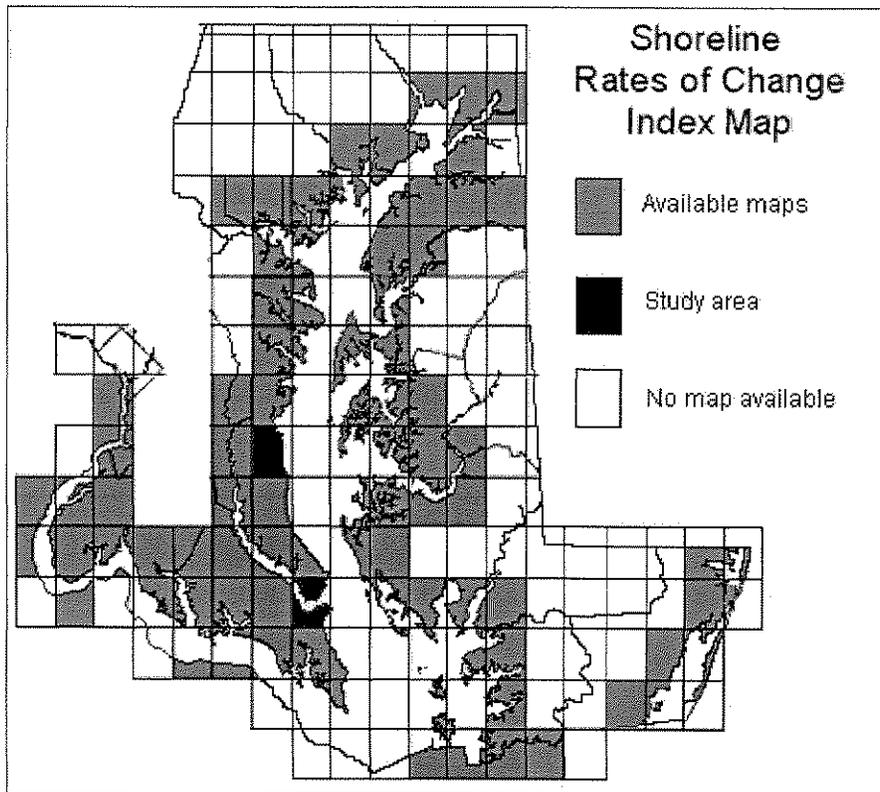
## STUDY AREA

A small group of people – Dave Brownlee, an environmental planner with the Calvert County Department of Planning and Zoning, Catherine McCall, a coastal planner with the Maryland Department of Natural Resources (DNR), Bhaskaran Subramanian, an engineer also with DNR, and the author – selected two sites in Calvert County to be included in this study: (1) Randle Cliff, near the Anne Arundel-Calvert County line (North Beach quad) and (2) Little Cove Point, in the vicinity of Chesapeake Ranch Estates (Solomons Island quad). The two sites are shown in Figure 1. Dave Brownlee was particularly concerned with (a) highly developed and eroding shorelines, represented by Randle Cliff, and (b) the discrepancy in erosion rates at Little Cove Point, as reported by Downs and MGS. Incidentally, in her thesis, Downs distinguished two littoral cells that converge at Cove Point. In the cell north of Cove Point, longshore transport is to the south; in the south cell, longshore transport is to the north. Of the two sites selected for this study, Randle Cliff lies in the northern cell, and Little Cove Point/Chesapeake Ranch Estates, in the southern cell.

## SCOPE OF WORK

The project focused on (1) a general comparison of the shoreline rates of change generated by Downs's and MGS's studies for the Randle Cliff and Little Cove Point sections of Calvert County, and (2) a detailed comparison of digital shorelines extracted from NOAA's NOS T-sheets. The latter involved comparisons between (1) two shoreline pairs (1942 and 1960) that had been independently digitized by NOAA and MGS from the same T-sheets and (2) an 1847 shoreline pair that had been digitized by MGS, initially from a *Historical Shorelines* map and then, as part of this study, from digital images of the original T-sheets. MGS visually examined the shoreline pairs to discover offsets and ran the Digital Shoreline Analysis System (DSAS) to quantify those

differences. MGS did not have access to Downs's digital shorelines, so only visual comparisons with those were possible.



**Figure 1:** Study area shown as two black quadrangles in Calvert County: the North Beach quadrangle to the north, and the Solomons Island quadrangle to the south

## METHODS

### SHORELINE SOURCES

Since Downs and MGS completed their original studies, NOAA has digitized and georeferenced many recent historical shorelines from its extensive collection of NOS T-sheets (see a map index at [http://www.ngs.noaa.gov/newsys\\_ims/shoreline/index.cfm](http://www.ngs.noaa.gov/newsys_ims/shoreline/index.cfm)). To determine which NOAA-MGS shoreline pairs to compare, MGS listed the shoreline years already in its possession, along with NOAA's digital counterparts (Table 2). For the North Beach quadrangle, MGS had previously digitized four shorelines: 1847, 1934, 1960, and 1993. The 1960 shoreline was the only one that NOAA had already digitized from the same T-sheet. Likewise, for the three shorelines (1848, 1942/1943, and 1993) that MGS had previously digitized for the Solomons Island quadrangle, the 1942/43 shoreline was the only one also available from NOAA. MGS selected those two – 1960 and 1942/43 – for direct comparisons.

For the North Beach quadrangle, MGS also compared an 1847 shoreline that it had previously digitized from an in-house *Historical Shorelines* map (CZM 28A) with a shoreline that it digitized as part of this project from digital images of T-198 and T-280. MGS intended to make a similar comparison of the 1848 shoreline for the Solomons Island quadrangle but was unable to locate a sufficient number of control points on the image of the original T-sheet (T-256) to properly georeference it.

The three shoreline pairs compared in this study are shaded in Table 2.

<b>Table 2: Study area shorelines previously digitized by MGS and sources of the comparison shorelines</b>		
<b>Shoreline year</b>	<b>Source of original MGS shoreline</b>	<b>Source of comparison shoreline</b>
<b>North Beach quad (Randle Cliff)</b>		
1847	Digitized from <i>Historical Shorelines</i> map CZM 28A	Shoreline digitized by MGS from digital images of T-198 and T-280
1934	Digitized from T-5348	No comparison; NOAA has not yet generated a shoreline vector from T-5348
1960	Digitized from T-11789 and T-11790	Shoreline digitized by NOAA for Project PH6008, which includes T-11789 and T-11790
1993	Digitized from DNR's digital orthophotography	No comparison; NOAA has no comparable shoreline for this date derived from the same or different sources
<b>Solomons Island quad (Little Cove Point/Chesapeake Ranch Estates)</b>		
1848	Digitized from Historical Shorelines map CZM 21A	MGS obtained digital image of T-256 but was unable to digitize shoreline from it due to lack of control points
1942, 1943	Digitized from T-8116 (1942)	No comparison; NOAA has not yet generated a shoreline vector from T-8116
	Digitized from: T-8542 (1942-43) T-8543 (1942) T-8544 (1942)	Shoreline digitized by NOAA for Project CS307, which includes T-8542, T-8543, T-8544
1993	Digitized from DNR's digital orthophotography	No comparison; NOAA has no comparable shoreline for this date derived from the same or different sources

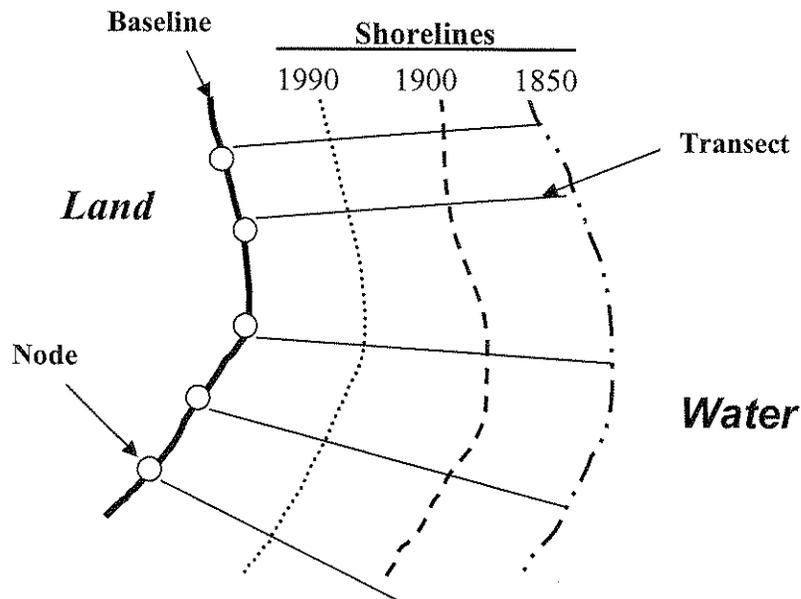
NOAA's digital shoreline vectors, in shapefile format, are available for direct download from its Shoreline Data Explorer website:

([http://www.ngs.noaa.gov/newsys\\_ims/shoreline/index.cfm](http://www.ngs.noaa.gov/newsys_ims/shoreline/index.cfm)). MGS downloaded the

1942/43 and 1960 comparison shorelines from that site. For the 1847 comparison, MGS discovered scanned images of the needed T-sheets on a website developed and maintained by the University of Alabama's Department of Geography: (<http://alabamamaps.ua.edu/historicalmaps/Coastal%20Survey%20Maps/index.html>). The Department's Cartographic Research Lab supplied MGS with digital (raster) images (.tif format) of four of the oldest T-sheets: T-198, T-280, T-281, and T-256.

**DISPLACEMENT BETWEEN SAME-YEAR SHORELINE PAIRS**

To quantify positional differences, or displacement, between same-year shoreline pairs, MGS used the Digital Shoreline Analysis System (DSAS), a computer program written and supported by researchers at the U.S. Geological Survey (Thieler, E.R. et al., 2005). DSAS is based on a commonly used measurement baseline approach to obtaining shoreline rates of change from a time series of shoreline positions (Fig. 2). As implemented in DSAS, a baseline is constructed adjacent to and landward of a series of historical shoreline positions. (As part of its original study, MGS had instructed DSAS to create a 50-meter buffer around the shorelines. The landward side of the buffer was retained as a "baseline." MGS used that same baseline in the present study.) The distance from the baseline to each shoreline in the series is measured along an orthogonal, or transect, to the baseline. Transects are spaced alongshore at user-defined intervals, in this case, 50-m intervals. For any two shorelines, DSAS computes an end-point rate of change (EPR) for a particular transect by dividing the distance between each shoreline, relative to the baseline, by the time elapsed between shoreline years. In DSAS, retreat or erosion is expressed as a negative number.



**Figure 2:** Features used or created by DSAS to calculate shoreline rates of change

MGS downloaded version 3.2 of the software from the official DSAS website (<http://woodshole.er.usgs.gov/project-pages/dsas/>) and followed the installation instructions provided. This version of the program works in conjunction with ArcGIS v. 9.2.

To facilitate computations, DSAS expects shorelines to be georeferenced to a meter-based coordinate system, like State Plane or Universal Transverse Mercator. And, of course, all shorelines must be georeferenced to the same datum and coordinate system. MGS's original shorelines were georeferenced to Maryland State Plane coordinates, (NAD 83, meters). That georeferencing system worked well in MGS's earlier iteration of erosion rates and was retained for this one.

NOAA's digital shoreline vectors are georeferenced to geographic coordinates (latitude/longitude in decimal degrees, NAD83). So, for the comparison of the 1942 and 1960 shoreline pairs, MGS converted the NOAA shorelines to Maryland State Plane coordinates (NAD83, meters).

For this study, MGS also digitized the shorelines depicted on two 1847 T-sheets. Those maps, as originally compiled, were based on a now obsolete horizontal datum. Following their production, a later generation of NOAA cartographers superimposed a map grid of geographic coordinates (latitude/longitude in degrees, minutes, and seconds, NAD27) on the originals. MGS used those tic marks and associated geographic coordinates as input during the georeferencing process, instructing the GIS software to output Maryland State Plane coordinates (NAD 83, meters). When MGS digitized shorelines from those raster images, georeferencing information was transferred automatically to the shoreline vectors.

In digitizing the 1847 shoreline, MGS had intended to employ semi-automated raster to vector conversion techniques to introduce repeatability into the shoreline delineation process. However, given the quality of the original maps, that approach was untenable. Automatic extraction works most effectively when the source raster is binary, that is, it consists entirely of black or white pixels. In those cases, the software follows the centerline of the inked line easily, requiring user input only when the moving cursor encounters gaps or branching of the line. The University of Alabama rasters had been scanned as grayscale images, which are considerably more difficult to convert automatically to vectors. So, MGS, using ArcGIS 9.2 software, extracted the shoreline from the raster images through a process of heads-up digitizing, attempting to follow the shoreline centerline, as opposed to the bayward or landward edge of the line.

Finally, before running DSAS, MGS altered the attribute tables associated with the baseline and shorelines to conform to DSAS expectations, as outlined in the *User Guide & Tutorial of the Digital Shoreline Analysis System*, also available through the DSAS website. The required shoreline fields include a 10-character Date field (mm/dd/yyyy). For each shoreline pair, MGS assigned a sometimes arbitrary date to one shoreline and a date exactly one year later to the other shoreline. For example, in its comparison of the 1960 shoreline pair, MGS used the NOAA-supplied date of 7/1/1960 for the NOAA

shoreline and assigned a date of 7/1/1961 to the MGS shoreline. In that way, DSAS was “tricked” into believing that the shorelines were collected one year apart. In its calculation of end point rate (along-transect distance between shorelines divided by time elapsed between shoreline dates, in years), DSAS divided the distance by 1 (year). The EPR, then, is the signed ( $\pm$ ) distance between the two shorelines. Positive rates indicate “accretion” and negative rates, “erosion.” More particularly, in this instance, a positive EPR indicates that, for a particular transect, the MGS shoreline lies bayward of the NOAA shoreline. Conversely, a negative EPR indicates that the MGS shoreline lies landward of its NOAA counterpart.

For outliers showing the greatest displacement, positive or negative, MGS checked the orientation of the transect with respect to the two shorelines it intersected. If the intersecting lines were not orthogonal or nearly so, MGS eliminated the transect from the dataset.

Because the results are signed, the EPR is valuable in that it allows the user to check for the degree of consistency in the direction of displacement. Does the NOAA shoreline lie consistently landward of the MGS shoreline, or vice versa? Or, is the MGS shoreline sometimes on one side of the NOAA shoreline and sometimes on the other? However, in computations of average displacement between shoreline pairs, the signed EPRs may cancel out each other. Consider, for example, two transects, one with an EPR = 3 m/yr and the other with an EPR = -3 m/yr. Averaging those two transects yields a mean EPR = 0 m/yr. But, in fact, displacement along both transects is 3 m/yr, and so should the average displacement be. To counter this problem, MGS used the absolute value of the EPR in its computations of the magnitude of displacement.

## RESULTS

### DETAILED COMPARISON OF ORIGINAL FINDINGS

MGS compared Downs’s and its own original results for the two pilot areas, Randle Cliff and Little Cove Point. The comparisons are inexact. Transect-specific results were not always available from Downs’s thesis. In those cases, MGS attempted to match shoreline reaches to those delineated by Downs and then averaged its original results for the transects that fell within the reach. In instances where Downs’s transect-specific results were available, it was difficult to establish precisely the limits of the reach to which they applied.

#### Randle Cliff

Randle Cliff lies in Downs’s Section 2 (Holland Point to Plum Point). Within that section, Downs identified three unstabilized sections of shoreline:

- Section 2-B: a low-lying, crescentic, sandy beach backed by marsh and stabilized by revetments at either end. The beach is erosional, with a maximum erosion rate of  $-2.2 \text{ m/yr} \pm 0.1 \text{ m/yr}$  at its center.
- Section 2-CC (Randle Cliff)

- Section 2-EE (Southern boundary of U.S. Naval Reservation, south to Willow Beach Colony)

Downs discusses both Sections 2-CC and 2-EE as one. Both are relatively straight stretches, oriented slightly to the northeast, backed by bluffs up to 24 m high, and with either narrow sandy beach fronting the bluffs or no beach at all. Along the eroding shoreline of these two sections, the average erosion rate is -0.5 m/yr ± 0.1 m/yr, with a maximum rate of -0.61 m/yr ± 0.1 m/yr. At the southern end of Section 2-EE, where the orientation of the cliff line changes from northeast to east, the erosional pattern changes abruptly from erosion (-0.4 m/yr ± 0.1 m/yr) to accretion (up to 0.3 m/yr ± 0.1 m/yr).

Downs provided neither transect-specific rates of change for Randle Cliff (Section 2-CC), nor the average rate of change for Section 2-CC alone. Furthermore, it was difficult, from the small-scale maps in her report, to determine the exact limits of the reach. Even so, MGS attempted to calculate roughly comparable mean rates of change from its dataset. MGS first visited the Maryland Shorelines Online website and extracted the unique identification numbers (94537-94554) of 18 transects along a stretch of shoreline extending from the southern boundary of the municipality of Chesapeake Beach to the vicinity of Summer City Blvd. (extended due eastward). Based on the Shoreline Inventory – Bank Height and Condition layer, also available on the Maryland Shorelines Online website, the transects of interest all cross a shoreline depicted as a red line of medium width, representing a highly eroding, 10-30 ft bank. None of the transects intersects stabilized shoreline.

MGS then examined the information associated with those transects in its original data set. In Table 3, erosion rates in that area, based on three shorelines, 1847, 1960, and 1993, are reported for three “eras”: 1847-1960, 1960-1993, and 1847-1993. Compared to Downs’s average rate of change of -0.5 m/yr, MGS’s average rates for all three eras, calculated, in the case of the entire time span (1847-1993), in two different ways, are considerably lower – an end point rate of -0.15 m/yr and a rate based on linear regression of -0.16 m/yr.

**Table 3:** Shoreline rates of change, Randle Cliff (Downs’s Section 2-CC), based on 18 transects in the original MGS data set

Era	Minimum (m/yr)	Maximum (m/yr)	Mean (m/yr)	
			End-point rate	Linear regression
1847-1960	-0.3	-0.09	-0.18	
1960-1993	-0.25	+0.32	-0.03	
1847-1993	-0.27	-0.01	-0.15	
	-0.28	-0.03		-0.16

MGS then calculated the same statistics for the 112 transects (94629-94684; 94457-94512) in Section 2-EE (Table 4). The stretch extends from just south of Locust Grove Beach to just north of Willow Beach Colony and is backed at both ends by 10-30 ft high banks.

**Table 4:** Shoreline rates of change, Downs's Section 2-EE, based on 112 transects in the original MGS data set

Era	Minimum (m/yr)	Maximum (m/yr)	Mean (m/yr)	
			End-point rate	Linear regression
1847-1960	-0.81	-0.26	-0.56	
1960-1993	-0.60	+0.26	-0.10	
1847-1993	-0.64	-0.28	-0.46	
	-0.69	-0.30		-0.49

Combining transects in both Sections 2-CC and 2-EE yields the results in Table 5.

If one considers the grouped results (Sections 2-CC and 2-EE) in Table 5 for the period 1847-1960, which most closely coincides with the time period of Downs's study, the results of the two studies are virtually identical: an average rate of  $-0.5 \text{ m/yr} \pm 0.1 \text{ m/yr}$  reported by Downs vs. an average rate of  $-0.51 \text{ m/yr}$  reported by MGS. (Minimum rates, that is, maximum rates of erosion, however, are slightly different:  $-0.61 \text{ m/yr} \pm 0.1 \text{ m/yr}$  (Downs) vs.  $-0.81 \text{ m/yr}$  (MGS).

**Table 5:** Shoreline rates of change, Downs's Sections 2-CC and 2-EE, based on 130 transects in the original MGS data set

Era	Minimum (m/yr)	Maximum (m/yr)	Mean (m/yr)	
			End-point rate	Linear regression
1847-1960	-0.81	-0.09	-0.51	
1960-1993	-0.60	+0.32	-0.09	
1847-1993	-0.64	-0.01	-0.41	
	-0.69	-0.03		-0.44

The most notable finding, however, is that in all three cases (Tables 3-5), the average rate of erosion for the more recent of the two eras, 1960-1993, is considerably lower than the erosion rate associated with the earlier era, 1847-1960. For example, in Table 5, the average end-point rate of erosion drops from -0.51 m/yr during the period 1847-1960 to -0.09 m/yr during the subsequent period. At a time of rising sea level, one would expect erosion rates to be increasing over time, or at least remaining steady, not decreasing.

#### Little Cove Point

In Downs's Section 7, Little Cove Point to Drum Point, Downs identifies four sub-sections defined by the presence or absence of groins:

- Section 7-A: groin field
- Section 7-B: unstabilized
- Section 7-C: groin field
- Section 7-D: unstabilized

The entire reach is highly erosional, although erosion rates diminish in the vicinity of Drum Point. The boundaries of the four sub-sections are not readily apparent, nor does Downs report average rates of change by sub-section or for the section as a whole. However, she does report that Little Cove Point is losing as much as -2.4 m/yr  $\pm$  0.1 m/yr to erosion. From Figure 28 (p. 66) in her report, erosion rates for all transects in the vicinity of Little Cove Point exceed about -1.6 m/yr. Although it is difficult to extract the transect numbers from Figure 28, the range appears to be from about 170-190. The approximate locations of those transects is apparent from Frames 33 and 34 in Appendix 1 of Downs's report (p. 146-147). Within the reach, Downs's transects intersect four or five shorelines (1847/1848, 1903/1907/1908, 1934/1944, 1952, and, except for the southernmost four or five transects, 1970/1971).

The equivalent MGS transect numbers range from 51959-51972. Erosion rates in that area, based on three shorelines, 1848, 1942 or 1943, and 1993, are reported for three "eras": 1848-1942/1943, 1942/1943-1993, and 1848-1993 (Table 6).

Era	Minimum (m/yr)	Maximum (m/yr)	Mean (m/yr)	
			End-point rate	Linear regression
1848-1942/1943	-0.41	+0.22	-0.11	
1942/1943-1993	-0.55	-0.10	-0.28	
1848-1993	-0.35	+0.11	-0.17	
	-0.36	+0.13		-0.16

MGS's results vary significantly from Downs's. None of MGS's erosion rates approaches Downs's -1.6 m/yr, much less her maximum rate of -2.4 m/yr  $\pm$  0.1 m/yr. The highest rate of erosion by MGS's calculations is -0.55 m/yr for the period 1942/1943-1993. Regarded singly, five of MGS's transects in the mid-section of the reach are slightly accretional during the earlier era (1848-1942/1943).

As shown in Appendix 2, a visual comparison of Downs's and MGS's plots of the series of historical shorelines in the area reveals that the 1848 shoreline is displaced in one study relative to the other. Whereas Downs' maps show the 1848 shoreline consistently bayward of later shorelines, MGS's maps show the mid-section of the same shoreline on the landward side of later shorelines. Clearly, the positional accuracy of that shoreline is in error in one study or the other.

MGS reexamined the source map from which it had digitized the 1848 shoreline, *Historical Shorelines* map CZM 21A, a map compiled from NOAA T-sheets. From a visual examination alone, the digitized 1848 shoreline appears to represent the source document faithfully. However, the techniques used to create CZM 21A, mentioned earlier in the Background section, were problematical in terms of faithfully representing shoreline position. In compiling the map, a Survey geologist first hand-traced the shoreline and selected map coordinates, based on a long obsolete horizontal datum, from the original T-sheet onto onion-skin paper. Using a Kargl Reflection Projector, the map compiler projected the onion-skin shoreline onto a USGS 7.5-minute quadrangle base map, simultaneously reducing the original 1:20,000 scale of the chart to 1:24,000 and adjusting the horizontal datum to the North American Datum of 1927 (NAD27). He then hand-traced the bayward edge of the projected shoreline as a dashed line onto a mylar overlay (Conkwright, pers. comm.). Two decades later, MGS hand-digitized the bayward edge of that mylar shoreline.

Errors may have been introduced at any of several points in the process: in the tracing of the shoreline onto the onion-skin paper or, later, onto the mylar overlay or, later still, in the digitizing process; in the repeated selection of the bayward edge of the shoreline, rather than the centerline, in tracing or digitizing it; in the bridging of gaps in the dashed mylar shoreline during digitizing; and in the fitting, by projector, of a shoreline generated at one particular scale and datum into a different scale and datum.

## **COMPARISON OF MGS AND NOAA SHORELINES**

### North Beach – Comparison of 1960 Shorelines Digitized by MGS and by NOAA

Both MGS and NOAA digitized T-sheet T-11789, which shares the same extents as the North Beach 7.5-minute quadrangle. For purposes of this study, MGS limited the shoreline to the Chesapeake Bay, selecting the section between Holland Point to the north and Willow Beach Colony to the south. Before inputting the two shorelines into DSAS, MGS assigned a real shoreline date of 7/1/1960 to the NOAA shoreline and a fake shoreline date of 7/1/1961 to the MGS shoreline.

Discrepancies between the two shorelines are reported in Table 7 and graphed in Figure 3, as signed (EPR) and absolute ( $|EPR|$ ) displacement, respectively. Based on 207

transects, spaced at 50-m intervals along the shoreline, absolute shoreline displacement ( $|EPR|$ ) averaged  $2.9 \text{ m} \pm 1.7 \text{ m}$ . Maximum displacement was 8.8 m. The MGS shoreline was generally displaced bayward of the NOAA shoreline. That is, for 79% of the transects, displacement was in a positive direction (as though the shoreline were “accreting” over time), as opposed to negative (as though the shoreline were “eroding”). Positive or negative shoreline displacement was not randomly distributed. The 21% of transects that showed displacement of the MGS shoreline landward of the NOAA shoreline were concentrated in the vicinity of Randle Cliff.

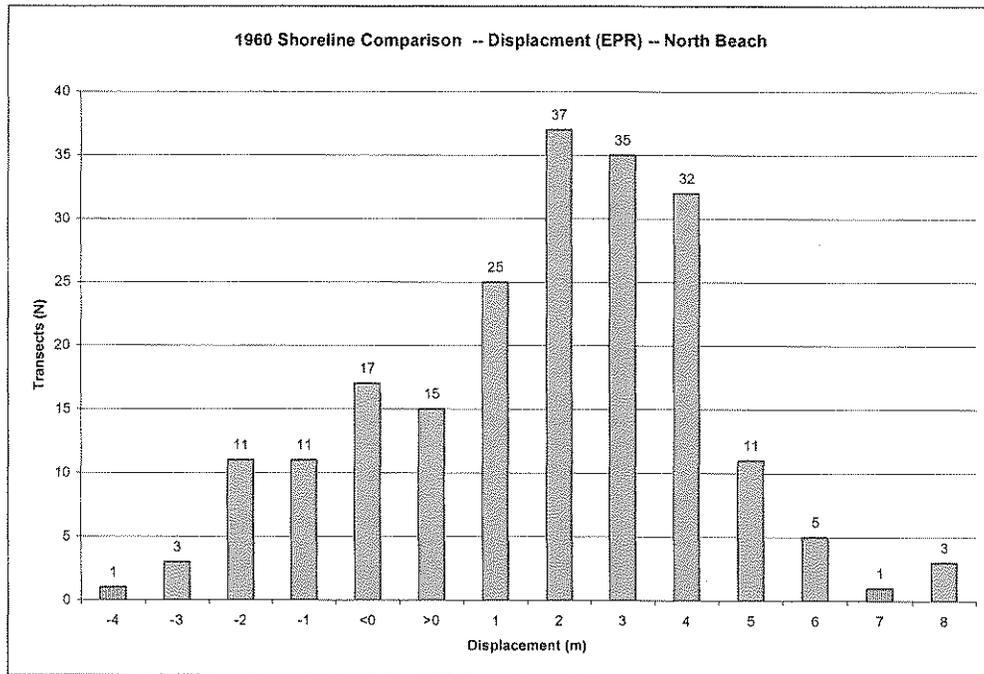
**Table 7: Signed (EPR) and absolute ( $|EPR|$ ) displacement between 1960 shorelines digitized by NOAA and by MGS from T-sheets T-11789**

<b>Transects (50-m spacing)</b>	<b>N</b>	<b>%</b>
Where $EPR < 0$	43	21
Where $EPR > 0$	164	79
Total	207	100
<b>Summary statistics (m/yr, where yr = 1)</b>		
Minimum EPR		-4.05
Maximum EPR		8.8
Mean EPR		2.23
Standard deviation		$\pm 2.52$
Minimum $ EPR $		0.04
Maximum $ EPR $		8.8
Mean $ EPR $		2.87
Standard deviation		$\pm 1.74$

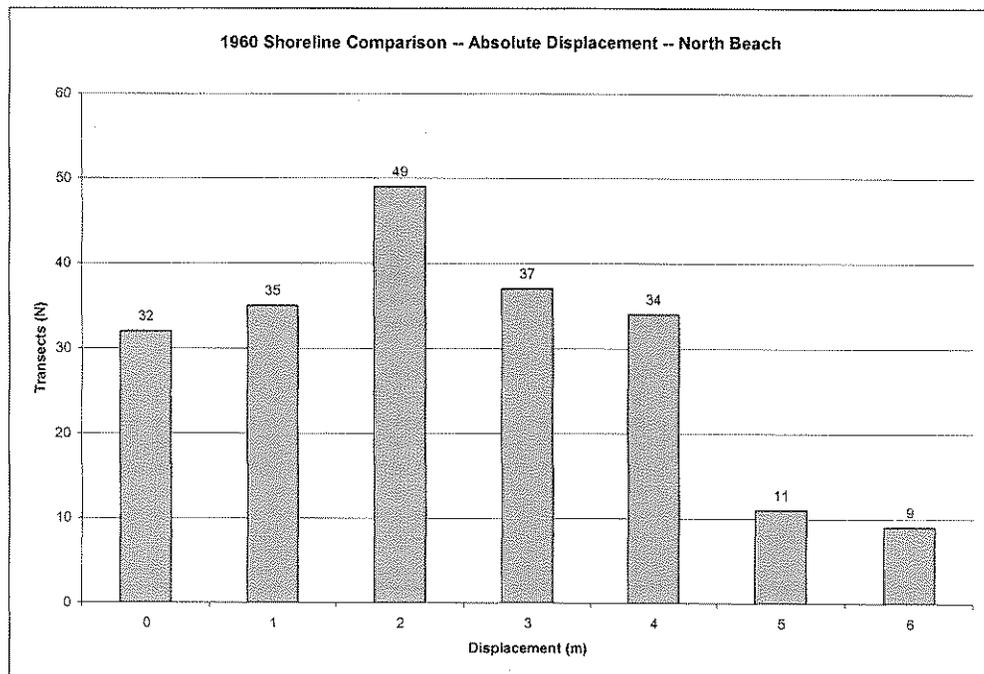
North Beach – Comparison of 1847 Shorelines Digitized by MGS from Two Sources  
 For the same area described above, MGS acquired raster images of two original T-sheets (T-198 and T-280), digitized those shorelines and compared the results with a shoreline that MGS had previously digitized from the *North Beach Historical Shorelines* map (CZM 28A). MGS assigned a shoreline date of 1/1/1846 to the shoreline digitized directed from the T-sheets and a shoreline date of 1/1/1847 to the CZM map shoreline. Results are reported in Table 8 and graphed in Figure 4.

The striking difference between the 1847 and the 1960 shoreline comparisons is the much larger discrepancy – an order of magnitude – in shoreline positions between the two 1847 sources. Based on 204 transects, spaced at 50-m intervals along the shoreline, absolute displacement ( $|EPR|$ ) averaged  $15.0 \text{ m} \pm 10.9 \text{ m}$ . Maximum displacement was 40.3 m. The CZM map shoreline was generally displaced landward of the T-sheet shoreline. That is, for 72% of the transects, displacement was in a negative direction (as though the shoreline had “eroded” over time), as opposed to positive (as though the shoreline had

(a)



(b)

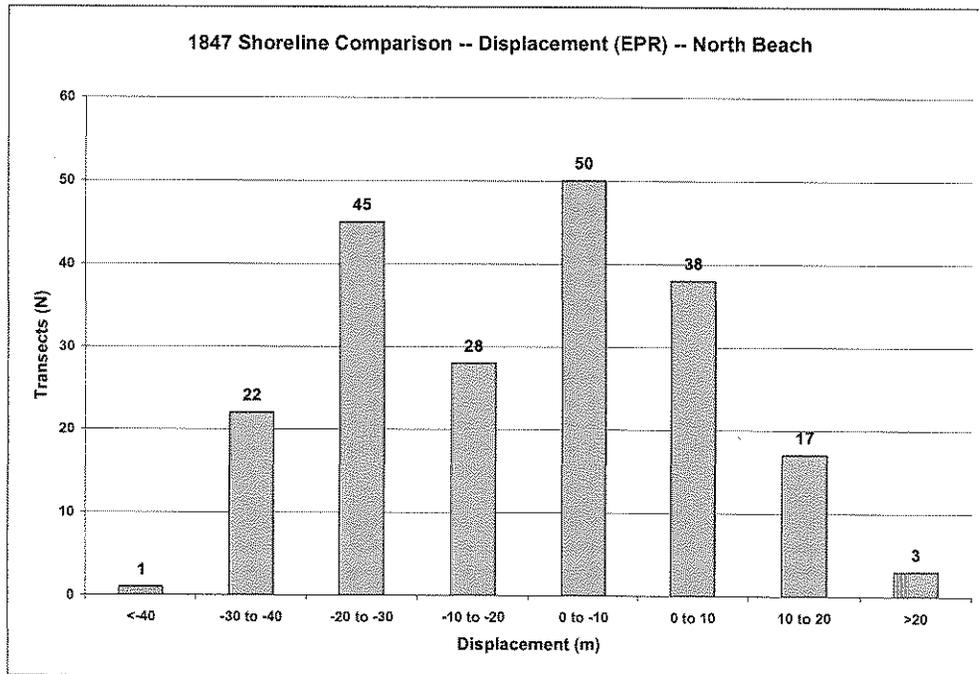


**Figure 3:** (a) Signed displacement (EPR) and (b) absolute displacement ( $|EPR|$ ) between 1960 shorelines digitized by NOAA and by MGS from T-sheet T-11789

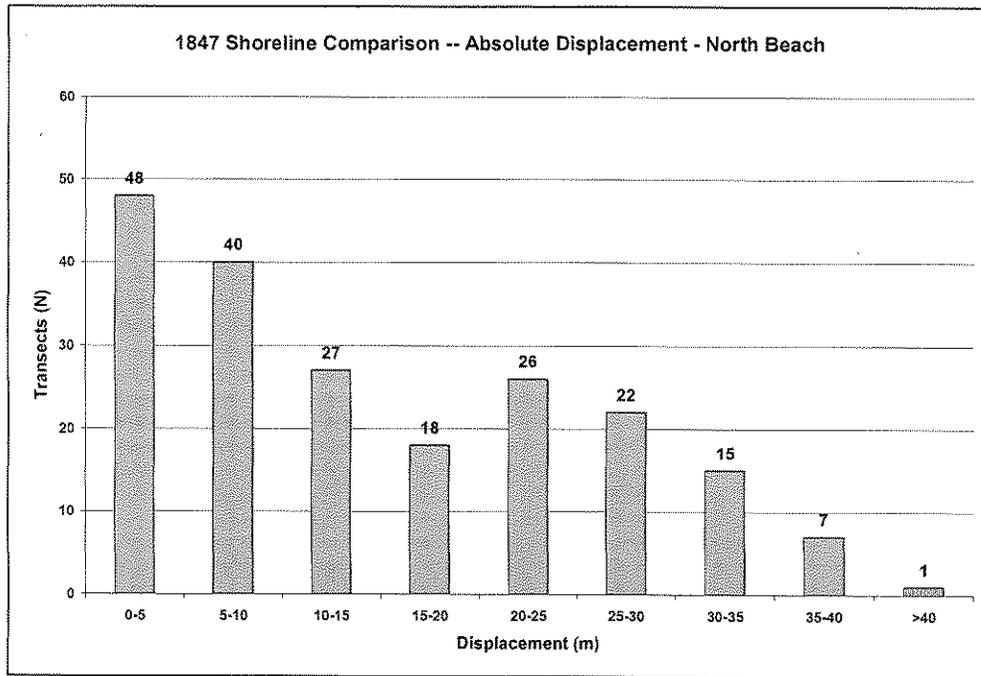
**Table 8:** Signed (EPR) and absolute (|EPR|) displacement between 1847 shorelines digitized by MGS from (a) T-sheets and (b) the *North Beach Historical Shorelines* map (CZM 28A)

Transects (50-m spacing)	N	%
Where EPR<0	146	72
Where EPR>0	58	28
Total	204	100
<b>Summary statistics (m/yr, where yr = 1)</b>		
Minimum EPR		-40.28
Maximum EPR		29.96
Mean EPR		-10.42
Standard deviation		±15.36
Minimum  EPR		0.11
Maximum  EPR		40.28
Mean  EPR		15.05
Standard deviation		±10.86

(a)



(b)



**Figure 4:** (a) Signed displacement (EPR) and (b) absolute displacement (|EPR|) between 1847 shorelines digitized by MGS from (1) T-sheets and (2) the *North Beach Historical Shorelines* map (CZM 28A)

“accreted”). Again the direction of displacement was not random. The CZM map shoreline tended to lie landward of the T-sheet shoreline in the northern end of the reach and bayward in the southern end.

#### Solomons Island – Comparison of 1942 Shorelines Digitized by MGS and by NOAA

Both MGS and NOAA digitized the T-sheets T-8542, T-8543, and T-8544, components of NOAA Project CX307. For purposes of this study, MGS restricted the shoreline to the reach extending from the northern border of the Solomons Island quadrangle, just north of Little Cove Point, to Drum Point, at the mouth of the Patuxent River. MGS assigned a real shoreline date of 01/11/1942 to the NOAA shoreline and a fake shoreline date of 01/11/1943 to the MGS shoreline.

Shoreline discrepancies are reported in Table 9 and graphed in Figure 5. Based on 112 transects, spaced at 50-m intervals along the shoreline, absolute shoreline displacement (|EPR|) averaged  $1.8 \text{ m} \pm 1.3 \text{ m}$ . Maximum displacement was 6.2 m. The MGS shoreline was generally displaced bayward of the NOAA shoreline. That is, for 67% of the transects, displacement was in a positive direction (as though the shoreline were “accreting” over time), as opposed to negative (as though the shoreline were “eroding”). Positive or negative shoreline displacement was not randomly distributed. In general, negative rates (MGS shoreline landward of NOAA shoreline) were concentrated at the

northern end of the reach, immediately south of Little Cove Point in the vicinity of Chesapeake Ranch Estates, to a point where shoreline orientation shifts from primarily east-facing to more southeast-facing, just north of Calams Run. In contrast, positive rates (MGS shoreline bayward of NOAA shoreline) prevailed at the southern end of the reach, with the largest positive discrepancies found in the vicinity of Drum Point. In between the northern and southern extremes, the two shorelines were more or less coincident.

**Table 9: Signed (EPR) and absolute (|EPR|) displacement between 1942 T-sheet shorelines digitized by NOAA and by MGS**

<b>Transects (50-m spacing)</b>	<b>N</b>	<b>%</b>
Where EPR<0	37	33
Where EPR>0	75	67
Total	112	100
<b>Summary statistics (m/yr, where yr = 1)</b>		
Minimum EPR		-6.19
Maximum EPR		5.17
Mean EPR		0.67
Standard deviation		±2.09
Minimum  EPR		0.01
Maximum  EPR		6.19
Mean  EPR		1.75
Standard deviation		±1.33

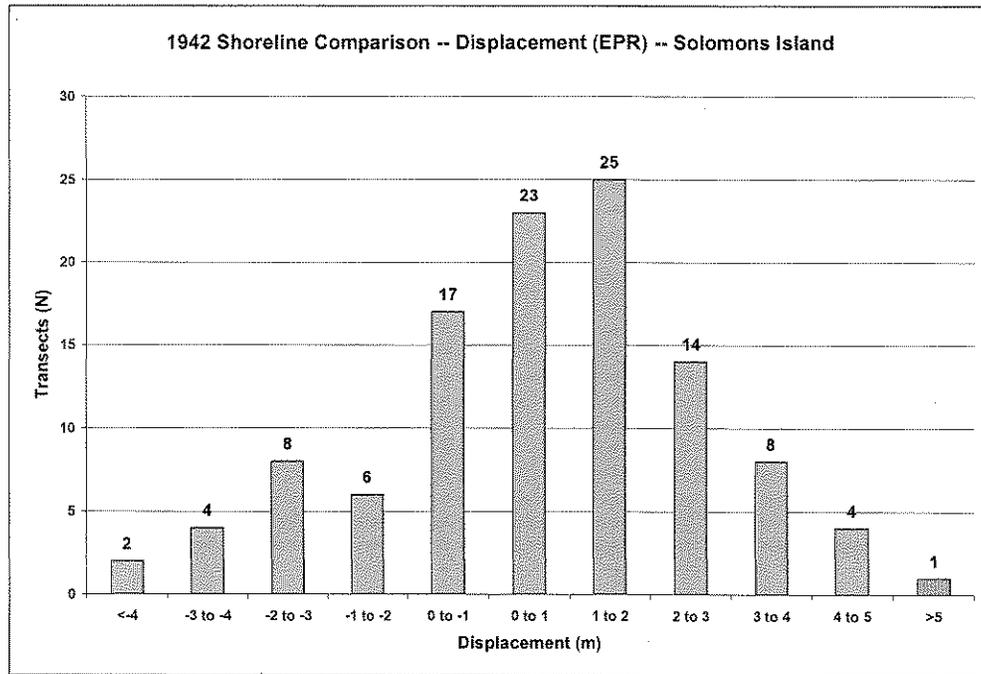
## DISCUSSION

### COMPARISON OF 1942 AND 1960 SHORELINE PAIRS

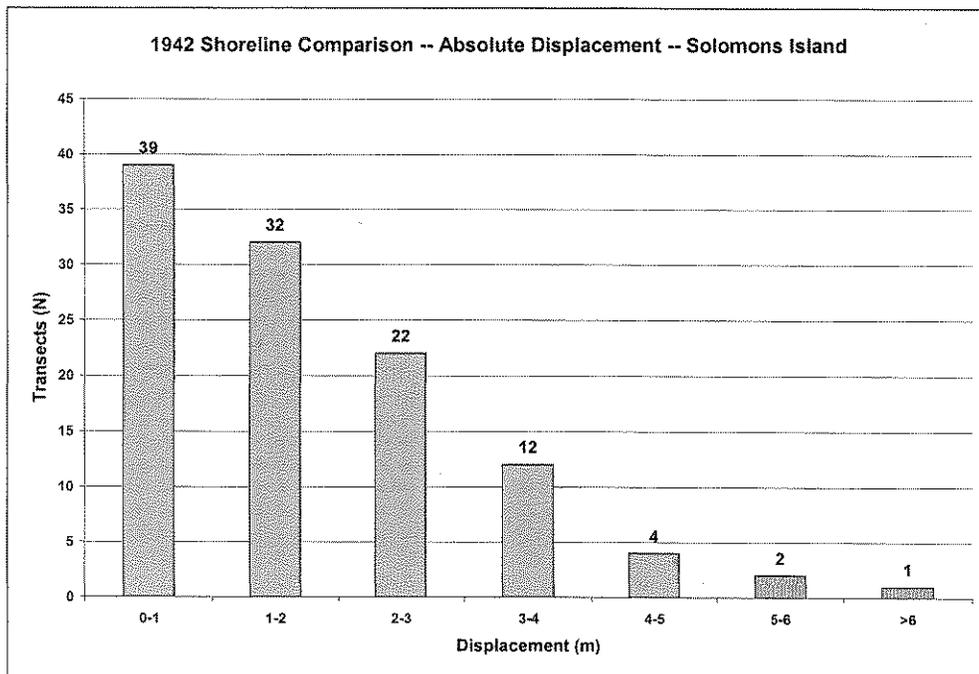
For the two relatively recent shoreline pairs (1960-North Beach and 1942-Solomons Island) digitized from 1:10,000-scale T-sheets by both MGS and NOAA, the average displacement between pairs was similar,  $2.9 \text{ m} \pm 1.7 \text{ m}$  and  $1.8 \text{ m} \pm 1.3 \text{ m}$ , respectively. In both cases, the MGS shoreline tended to be displaced bayward of the NOAA shoreline. However, displacement was not consistently in that direction. One-quarter of the 1960 transects and one-third of the 1942 transects showed displacement in the opposite direction.

The tendency of the MGS shoreline to lie bayward of the NOAA shoreline is not surprising. MGS consistently digitized the bayward edge of the inked shoreline from T-sheets. In contrast, NOAA digitized the shoreline centerline (A. Bode, pers. comm.). So, one would expect the MGS shoreline to lie slightly bayward of the NOAA shoreline. In their discussion of worst-case error estimates associated with post-1930 T-sheets

(a)



(b)



**Figure 5:** (a) Signed displacement (EPR) and (b) absolute displacement ( $|EPR|$ ) between 1942 T-sheet shorelines digitized by NOAA and by MGS

compiled from aerial photos, Crowell and others (1991) estimated the error associated with digitizing the inner to outer margin of the plotted mean high water line, assuming a line thickness of 0.40 mm, as  $\pm 4.0$  m at a scale of 1:10,000. Digitizing differences, then, largely account for the displacement between shorelines. Other possible sources of error include shrinkage of the bromide copies of the T-sheets that MGS digitized, as opposed to the originals that NOAA digitized, and digitizer/operator error.

### **COMPARISON OF 1847 SHORELINE PAIR**

Averaging 15 m and ranging up to 40 m, the large displacement between the two 1847 shorelines, both digitized by MGS but from different sources, is troubling. When MGS first began updating the *Historical Shorelines* maps in the 1990s, the project lead made a decision to digitize the oldest shoreline from that series rather than from copies of the original T-sheets. He had several compelling reasons for doing so: MGS had already expended a great deal of effort to create the maps, and they had been in use for several decades; the maps were already in MGS's possession, so no additional expense would be incurred in purchasing copies of original T-sheets; and the maps were registered to NAD27, eliminating the need to wrestle with the obsolete datums on which the older T-sheets were based. Based on the results of this study, that decision, driven largely by pragmatism, was less than ideal.

Unlike the 1942 and 1960 shorelines, MGS's 1847 shoreline, digitized from the in-house CZM map, lay landward of the original T-sheet shoreline. Although MGS was unable to digitize a comparable early shoreline directly from original T-sheets for the Solomons Island quadrangle, the visual comparison between the MGS shoreline and Downs's shoreline in the vicinity of Little Cove Point (Appendix 2), seems to indicate a gross displacement in those two shorelines, again with the MGS shoreline displaced landward of Downs's shoreline. Given those results and the fact that erosion, not accretion, is more typical of Chesapeake Bay shorelines, it seems likely that Downs's study more accurately reflects the true position of the 1840s shoreline.

## **CONCLUSIONS**

As Moore (2000) so succinctly put it, "Erosion rates can only be as accurate as the data from which they are derived and the methods by which they are calculated." However, even carefully compiled shorelines subject to similar methods of analysis may yield different results. Digitizers may use different control points to georeference a particular map or follow a plotted shoreline in slightly different ways. They may interpret the wet-dry line on an aerial photograph of a beach differently or use shoreline sources that differ in terms of number or year. With digital shorelines in hand, DSAS users may choose to construct transects at different intervals or apply different criteria in determining whether or not a transect is truly perpendicular to the shorelines it crosses.

In terms of the present study, MGS and Downs made different decisions at each of these steps. Sometimes their results were consistent despite those differences, for example, for the 1847-1960 era along sections of the North Beach quadrangle (Downs's combined

Sections 2-CC and 2-EE). At other times, the differences were striking, as in the vicinity of Little Cove Point.

Because MGS did not have access to Downs's shorelines, it was impossible to quantify or fully understand the reasons for the discrepancies between the two studies. However, the two clear shortcomings of the MGS study are that: (1) for the earliest shoreline, dating from the mid-1800s, the Survey chose to digitize, not the original T-sheets, but maps derived from them and (2) for the most recent shoreline, MGS chose to interpret the land/water interface from non-tide-coordinated orthophotography – a different shoreline change reference feature than the (mean) high water line mapped on T-sheets. Based on this study, the combined effect of those two problems was to minimize shoreline displacement and, consequently, rates of shoreline change.

The latter source of error is of particular concern along shoreline reaches characterized by broad beaches. Much of the Calvert County shoreline fronting Chesapeake Bay is lined with beaches ~15-30 m wide, on occasion ranging up to ~65 m wide. MGS consistently used the bayward limit (as opposed to the landward limit) of those beaches as its SCRF in delineating the 1993 shoreline. To the extent that the land-water interface differs from the wet-dry line, MGS used inconsistent SCRFs. The accuracy of its rate-of-change calculations suffers accordingly. Presumably, along wide, eroding beaches, calculated rates of change based on the most recent shoreline pair are skewed, indicating less erosion than might actually have occurred. This is of particular concern in the use of shoreline change rates routinely reported by the Maryland Shorelines Online website, which are based on the most recent era for which information is available, that is, on two shorelines only – a *ca.* 1990 shoreline interpreted as the land-water interface from non-tide coordinated orthophotography and the most recent NOAA shoreline available, usually dating from about 1940-1975, but sometimes as early as the 1850s.

## RECOMMENDATIONS

Although this may not be the most palatable solution for Calvert County, because of the delay involved, MGS strongly recommends that as soon as NOAA completes digitizing the historical T-sheets and the *ca.* 2008 shoreline for the county, shoreline rates of change be recomputed. The digital shorelines will represent a consistent shoreline change reference feature, and the most recent shoreline will be based on tide-coordinated photography. Furthermore, NOAA's digital shorelines will undoubtedly be regarded as the definitive historical shoreline series and will be used preferentially by other researchers. If Calvert County adopts those, its shoreline change rates will more likely be in agreement with rates produced by other government agencies at the state and national levels. Finally, new techniques of measuring rates of change take positional and measurement uncertainty into account, so that shorelines with larger estimated errors (e.g., early T-sheet shorelines) have less influence on computations than those with smaller ones (U. of Hawaii Coastal Geology Group, 2009).

In revising shoreline rates of change, Calvert County should keep in mind the following best practices, culled in part from the literature on shoreline change:

- Supplement NOAA's digital shorelines with others interpreted from high-quality, large-scale rectified vertical aerial photography (or orthophotography), in which the wetted perimeter is clearly visible. Change rates based on an evenly distributed series of shoreline positions are more likely to approximate actual rates of change. Also, by basing shoreline change analysis on multiple shorelines, the error in the spatial position of any one shoreline has less influence on the error in the rate (Dolan and others, 1991). Ideally, all of the photography will have been flown during the same season of the year, and none of it flown immediately following a major storm (Crowell and others, 1991). Avoid using photographs smaller than 1:20,000 in scale (Moore, 2000).
- For areas of particular concern, consider periodically using GPS to survey the shoreline and update rates of change more frequently than NOAA shoreline updates allow.
- Build quality control and error analysis into the compilation. Calculating erosion rates from digital shorelines always involves an element of error, particularly in discriminating between shorelines measured at short time intervals or between slowly changing shoreline positions (Anders and Byrnes, 1991).

Since the original MGS study, the DSAS program used to calculate rates of change has been upgraded and can now be readily incorporated as an application into ArcGIS. In the course of this study, successful installation and self-training in the use of the program required only a few days, compared to months several years ago (assuming some familiarity with Arc). Once DSAS is installed and digital shorelines are converted to the expected format, it is fairly easy to update rates based on the addition of new shorelines.

Short of recompiling shorelines and recalculating rates of change, MGS recommends that, for the following reasons, Calvert County continue to use Downs's results:

- Downs digitized all NOS shorelines from original T-sheets, not from maps compiled by questionable techniques from the originals.
- Downs digitized shorelines representing more years.
- In selecting a shoreline change reference feature (SCRF), Downs consistently used either the (mean) high water line depicted on NOS T-sheets or the wet-dry line visible on rectified aerial photographs. Dolan and others (1980) found the two to be roughly equivalent. In contrast, MGS used as its SCRF either the (mean) high water line on NOS T-sheets or the land-water interface on recent (1993), non-tide-coordinated digital orthophotography.

The only disadvantage of using Downs's report, the disadvantage that led MGS to recommend updating Calvert County's shoreline rates of change, is that her findings are based on data that are now 40 years old. And in the intervening years, the Chesapeake Bay and its tributaries have been subjected to shoreline-changing events, like Hurricane Isabel.

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## APPENDIX 1

### Historical Shoreline Sources Utilized by Downs (1993) or MGS (Hennessee and others, 2003) and Their Availability as Digital Shoreline Vectors from NOAA

Shoreline source	Map title	Date	Scale (1:x)	Downs	MGS	Available as shoreline vector (NOAA project)	Location
<b>NOS T-sheets</b>							
T-11789*	North Beach	19600701 (1963)	10,000	X	X	PH6008	North Beach quad
T-11790*	Randle Cliff Beach	19600701 (1963)	10,000	X	X	PH6008	Randle Cliff Beach; North Beach quad
T-11791*	Plum Point	19600701 (1963)	10,000	X	X	PH6008	Plum Pt; Prince Frederick quad
T-11792*	Dares Beach	19600701 (1963)	10,000	X	X	PH6008	Dares Beach; Prince Frederick quad
T-11793*	Kenwood Beach	19600701 (1963)	10,000	X	X	PH6008	Kenwood Beach; Broomes Is quad
T-8111*	Cove Point Quad	1944	20,000	X	X		Cove Pt quad
T-8116*	Solomons Island Quad	1944	20,000	X	X		Solomons Is quad
T-8542*	MD Chesapeake Bay Mouth of Patuxent R. and Vic.	1942, 1943	10,000		X	CS307	Mouth of Patuxent R & vicinity; Solomons Is quad
T-8543*	Solomons Island	1942	10,000		X	CS307	Solomons Is & vicinity; Solomons Is quad
T-8544*	St. Leonard Creek	1942	10,000		X	CS307	St. Leonard Cr & vicinity; Broomes Is, Cove Pt, Solomons Is quads
T-8545*	Broome Island	1942	10,000		X	CS307	Broomes Is & vicinity; Broomes Is quad
T-8546*	Battle Creek	1942	10,000		X	CS307	Battle Cr & vicinity;

Shoreline source	Map title	Date	Scale (1:x)	Downs	MGS	Available as shoreline vector (NOAA project)	Location
T-8548*	Hunting Cr.-Holland Cliff	1942	10,000		X	CS307	Broomes Is quad Hunting Cr – Holland Cliff & vicinity; Prince Frederick quad
T-5348*	Herring Bay	1934	20,000	X			Vicinity of Herring Bay; North Beach quad
T-2836	West Shore of Chesapeake Bay Vicinity of Plum Point	1907	20,000	X			Plum Pt. to Dares Beach
T-2842 (not used)	Lower Part of Patuxent River, Maryland	1908	20,000	X			Chesapeake Bay: vicinity of Cove Pt. to Drum Pt. Patuxent R: vicinity of mouth of St. Leonard Cr. to mouth of Patuxent R.
T-2868 (not used)	Maryland West Shore of Chesapeake Bay Parkers Creek to Point of Rocks	1908	20,000	X			
T-198**	From Saunders Point to Chews, including West River and Herring Bay	1846	20,000	X			
T-280**	From Chews to Parkers Creek, western shore of Chesapeake Bay	1847	20,000	X			

Shoreline source	Map title	Date	Scale (1:x)	Downs	MGS	Available as shoreline vector (NOAA project)	Location
T-281** (not used)	From Parkers Creek to Cove Point, western shore of Chesapeake Bay	1847	20,000	X			
T-388*	Cove Point, Chesapeake Bay (Cove Point only)	1848	20,000	X		EC10B02	
<b>Historical Shorelines Maps</b>							
North Beach (CZM 28A)		1847	24,000		X		North Beach quad
Cove Point (CZM 97A)		1848	24,000		X		Cove Pt quad
Prince Frederick (CZM 27A)		1848	24,000		X	EC10B02 (?)	Prince Frederick quad
Solomons Island (CZM 21A)		1848	24,000		X		Solomons Is quad
Broomes Island (CZM 23A)		1860	24,000		X		Broomes Is quad
<b>Aerial Photography</b>							
Aerial photos		Jun-Jul 1952	20,000	X			
		Aug 1970; Nov 1971	20,000	X			
Orthophotos		Apr 1993	12,000		X		

\*Obtained as georeferenced, digital vector shorelines from NOAA

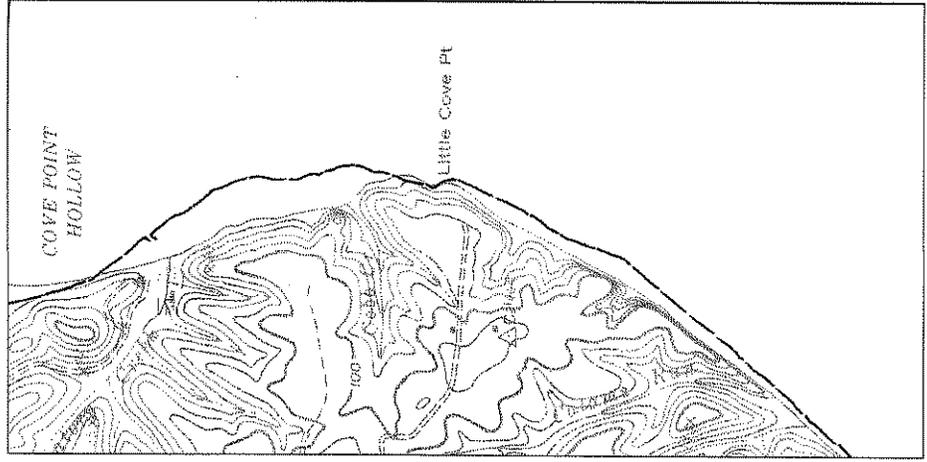
\*\*Obtained as digital raster images from Alabama Maps and georeferenced and digitized by MGS

## APPENDIX 2

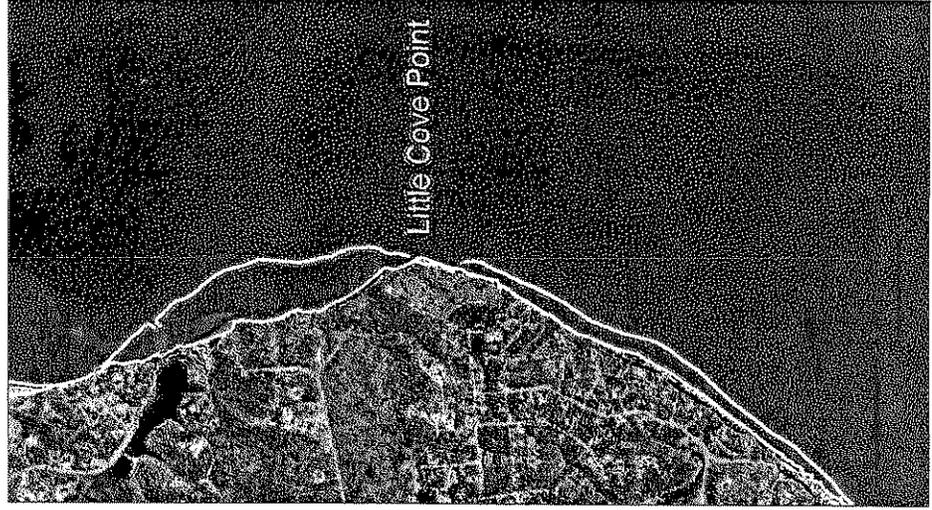
### Shorelines in the Vicinity of Little Cove Point

Shorelines in the vicinity of Little Cove Point show variation in the position of the 1848 shoreline: (a) MGS's *Historical Shorelines* map (CZM 21A) – 1848 shoreline represented by bold, black, dashed line; (b) MGS's *Shoreline Changes* map (Solomons Island) – 1848 shoreline, digitized from CZM 21A, represented by the most bayward, solid white line; (c) Downs's shorelines and transects (frames 33-34; p. 146-147) – 1848 shoreline represented by most bayward line, denoted by (\*); 1970 shoreline denoted by (>). On the MGS maps, the 1848 shoreline intersects the present landmass. On Downs's map, the 1848 shoreline is well offshore. (Map scales are only approximately the same)

(a)



(b)



(c)

