RESOURCE ASSESSMENT SERVICE
MARYLAND GEOLOGICAL SURVEY
Richard A. Ortt, Jr., Director

COASTAL AND ESTUARINE GEOLOGY
FILE REPORT NO. 2015-03

Updating Shoreline Rates of Change in Anne Arundel and Baltimore Counties, Maryland

by
Katherine A. Offerman

Maryland Geological Survey
2300 Saint Paul Street
Baltimore, Maryland 21218

This study was funded by the
Chesapeake and Coastal Service of the
Maryland Department of Natural Resources pursuant to
National Oceanic and Atmospheric Administration Award No.
NA13NOS4190143

July 30, 2015

For information or additional copies, please contact:

Maryland Department of Natural Resources
Maryland Geological Survey
2300 Saint Paul Street
Baltimore, Maryland 21218
Telephone: (410) 554-5500
Website: http://www.mgs.md.gov/

TABLE OF CONTENTS

ACKNOWLEDGEMENTS vi
ABSTRACT 1
INTRODUCTION 1
STUDY AREA 2
OBJECTIVES 3
BACKGROUND 3
Sources of Digital Shorelines 4
Maryland Geological Survey (MGS) 4
National Oceanic and Atmospheric Administration (NOAA) 8
Critical Area Commission (CAC) 9
DSAS and Quantifying Land Loss Due to Shoreline Erosion 10
DSAS Baselines and Transects 10
DSAS Statistics 11
METHODS 14
Format Shorelines for DSAS Analysis 14
Acquire, Georeference, and Clip the Shorelines 14
Delete Non-Shoreline Vectors 14
Create and Populate DSAS-Required Fields 15
Assign Shoreline Uncertainties 15
Create/Finalize the Master Shoreline Feature Class 17
Determine Rates of Shoreline Change 17
Create/Edit Baselines 17
Cast/Edit Transects 19
Generate Rate-of-Change Statistics / Join Statistics to Transect Attribute Table 19
Determine Shoreline Condition 21
Generalize Erosion Rate Categories 23
QA/QC Transect File and Rate-of-Change Statistics 24
Assign Rate-of-Change Attributes to Recent County Shorelines 25
Determine Which Recent Shoreline to Attribute 25
Attribute the Shoreline with Generalized Erosion Rate Categories 25
Final Deliverables 26
RESULTS AND DISCUSSION 28
SUMMARY AND CONCLUSIONS 33

REFERENCES 36

LIST OF FIGURES

Figure 1. Counties (shaded) for which shoreline rates of change were determined. 3

Figure 2. Illustration of offshore and onshore baseline positions. 10

Figure 3. Features used or created by DSAS to calculate shoreline rates of change. 13

LIST OF TABLES

Table 1. Final shorelines utilized in DSAS analysis for Anne Arundel and Baltimore Counties, MD, sorted by year. 5

Table 2. Definitions of available DSAS statistics. 12

Table 3. User-added, DSAS-related attribute fields in the individual shoreline files 16

Table 4. Total shoreline position uncertainties based on shoreline year, source, and measurement uncertainties. 16

Table 5. User-added baseline feature class attribute fields. 18

Table 6. DSAS-generated transect feature class attribute fields. 20

Table 7. Rate and supplemental statistic field names in final transect attribute tables. 21

Table 8. Generalized erosion rate categories utilized in transect and attributed shoreline files. . 24

Table 9. Shoreline length, in miles, by rate-of-change category, grouped by county. 29

Table 10. Shoreline length as a percentage of the length assigned numerical rate attributes (erosion, accretion, and no change). 29

Table 11. Mean rates of change by county using the 30-year End Point Rate calculation 31

Table 12. Mean rates of change by county using the 10-year End Point Rate calculation 31

Table 13. Mean rate of change by county using the method of weighted averages. 33

Table 14. Summary of mean long-term and short-term rates of change by county 33

Acronyms and Abbreviations Used in This Report	
Acronym/Abbreviation	***Description***
CAC	Critical Area Commission
CCS	Chesapeake and Coastal Service
CMP	Coastal Management Program
CTP	Coastal Training Program
CUSP	Continually Updated Shoreline Product
DOQQ	Digital Orthophoto Quarter Quadrangle
DSAS	Digital Shoreline Analysis System
ECI	Confidence of End Point Rate
EDI	Earth Data International of Maryland, LLC
EPR	End Point Rate
ESRGC	Eastern Shore Regional GIS Cooperative
ESRI	Environmental Systems Research Institute
ft	feet
GIS	Geographic Information System
HRC	Habitat Restoration and Conservation
LCI	Standard Error of the Slope with Confidence Interval for Linear Regression Rate
LMS	Least Median of Squares
LR2	R-squared statistic for Linear Regression Rate
LRR	Linear Regression Rate
LSE	Standard Error of the Estimate for Linear Regression Rate
m	meters
MD DNR	Maryland Department of Natural Resources
MGS	Maryland Geological Survey
MHW	Mean High Water
mi	miles
NAD27	North American Datum of 1927
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NSM	Net Shoreline Movement
OCS	Office of Coast Survey
SCE	Shoreline Change Envelope
USGS	United States Geological Survey
WCI	Standard Error of the Slope with Confidence Interval for Weighted Linear Regression Rate
WLR	Weighted Linear Regression
WR2	R-squared statistic for Weighted Linear Regression Rate
WSE	Standard Error of the Estimate for Weighted Linear Regression Rate
yr	year

ACKNOWLEDGEMENTS

The author wishes to thank:

Mr. Chris Cortina, Ms. Laura Younger, Mr. Bhaskar Subramanian, Mr. George Edmonds, and Ms. Catherine McCall of the Maryland Department of Natural Resources (MD DNR) Chesapeake and Coastal Service (CCS), for providing project guidance, managing project contracts, and providing thoughtful insight into this data set's integration into MD DNR's *Coastal Atlas*.

Mr. Doug Graham of the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS), for providing input on shoreline suitability for rate-of-change analysis and guiding the Maryland Geological Survey (MGS) through the various shoreline data sets available from NOAA.

Ms. Lisa Hoerger of the MD DNR Critical Area Commission (CAC), for allowing MGS to analyze recent CAC shorelines as part of this study.

Mr. Ryan Mello of the Eastern Shore Regional GIS Cooperative (ESRGC) of Salisbury University, for supplying MGS with CAC shorelines and metadata.

Ms. Lamere Hennessee (retired), Mr. Richard A. Ortt, Jr., Ms. Elizabeth Sylvia, and Ms. Heather Quinn of MGS for providing valuable technical guidance and moral support throughout this project's duration.

ABSTRACT

Since the early 1900s, the Maryland Geological Survey (MGS) has monitored, mapped, and quantified shoreline change along tidal water bodies in the State. During the 1990s, MGS, in partnership with Maryland Department of Natural Resources (MD DNR) Coastal Management Program (CMP), digitized a series of shorelines dating from 1841 – 1995. Rates of change information (erosion and accretion) for the sixteen tidewater counties in Maryland were calculated using a computer program developed by the U.S. Geological Survey (USGS), the Digital Shoreline Analysis System (DSAS). For DSAS analysis, a baseline is created parallel to the shorelines. DSAS then casts closely spaced transects perpendicular to the baseline across the shorelines, and determines rates of change along each transect. Over two decades have passed since the last data revision, and Maryland's shorelines have continued to change, particularly in response to storms. To calculate updated rates of change for Anne Arundel and Baltimore Counties, MGS compiled both historical and recent (post-2000) shorelines from various sources, including the National Oceanic and Atmospheric Administration (NOAA) and MD DNR Critical Area Commission (CAC). These "new" shorelines complemented and updated MGS's existing digital shoreline data set. Like previous efforts, the shorelines were used as input to the DSAS program to calculate updated rates of erosion and accretion. DSAS generated over 39,000 transects for Anne Arundel County and almost 21,000 transects for Baltimore County (including the Baltimore City limits). MGS generalized the DSAS results and assigned rate-of-change attributes (e.g. no change, accretion, slight erosion, low erosion, moderate erosion, high erosion) to a recent shoreline for Anne Arundel and Baltimore Counties. The attributed files provide a visually simple summary of the much larger database of shoreline rates of change. This updated rate of change data will be useful to coastal researchers and managers in need of general information about shoreline advance and retreat. This project serves as a first step in anticipation of a statewide shoreline change update for the remaining tidewater counties in Maryland.

INTRODUCTION

For well over a hundred years, the Maryland Geological Survey (MGS) has monitored, mapped, and quantified shoreline change along the tidal water bodies in the State – namely, the Chesapeake Bay and its major tributaries, the Atlantic Ocean, and the coastal bays separating the Atlantic coast barrier islands from the mainland. During the 1990s, MGS, in partnership with Maryland Department of Natural Resources (MD DNR) Coastal Management Program (CMP), (a) digitized a series of mapped historical shorelines, (b) oversaw the interpretation of a ca. 1990 shoreline from digital orthophotography, (c) published a series of more than 100 quadrangle-based *Shoreline Changes* maps, (d) determined shoreline rates of change, and (e) classified reaches of the ca. 1990 shoreline according to generalized rate-of-change categories (e.g. no change, accretion, slight erosion, low erosion, moderate erosion, high erosion).

Over two decades have passed since the last data revision, and this previous shoreline change assessment has become dated. Since the last recorded shoreline change rate was calculated, Maryland has experienced several large storms, including Hurricane Isabel and Super Storm Sandy, which have likely changed the shorelines in a number of coastal counties. To calculate updated rates of change for Anne Arundel and Baltimore Counties, MGS compiled both historical and recent (post-2000) shorelines from various sources to complement and update its existing set of digital shorelines. (For the remainder of this report, "Baltimore County" will signify Baltimore County, including the Baltimore City limits). For both Anne Arundel and Baltimore Counties, MGS acquired historical shorelines from 1) the National Oceanic and Atmospheric Administration (NOAA) Historical (T-sheets) data set; and 2) the NOAA National Shoreline data set. Recent (post-2000) shorelines were acquired from 1) the NOAA Continually Updated Shoreline Product (CUSP) data set; and 2) the MD DNR Critical Area Commission (CAC) shoreline data set. The final shoreline data sets utilized in DSAS analysis ranged in date from 1932-2010 and 1933-2011 for Anne Arundel and Baltimore Counties, respectively.

DSAS v4.3 is a free, public software application that works within the Environmental Systems Research Institute (ESRI) Geographic Information System (ArcGIS) 10.1 software platform. DSAS was developed by the U.S. Geological Survey (USGS) and computes rate-of-change statistics for a time series of shoreline vector data (Himmelstoss, 2009). In MGS's DSAS analysis, baselines were created approximately 10 meters offshore, and parallel to, the most seaward shoreline in the shoreline data set. DSAS then cast shore-normal transects from the baselines across all of the shorelines. Transects were spaced 20 meters apart. DSAS calculated a "long-term" (~ 80-year) rate of change using the linear regression rate (LRR) method and the end point rate (EPR) method. "Short-term" (~30-year and ~10-year) rates of change were calculated using the EPR method. Once DSAS computed updated rate-of-change statistics, MGS assigned generalized erosion rate categories to the recent NOAA CUSP shoreline for each county. MGS is working cooperatively with CCS to upload the results of this new analysis to MD DNR's interactive map service *Coastal Atlas*, disseminate and communicate the information to key stakeholders, and incorporate the work into shoreline management.

This project addresses Maryland's FY 2011-2015 Section 309 Strategy for Coastal Hazards and Climate Change Adaptation Planning "to integrate coastal hazard and sea level rise adaptation planning into state and local management plans, programs, and authorities." MD DNR Habitat Restoration and Conservation (HRC) group is especially interested in integrating the outcomes of this project into the services they offer and decisions they make about shoreline management. A more reliable shoreline rates-of-change data set will improve their ability to provide technical assistance to coastal communities and private landowners seeking treatment options for eroding shorelines. HRC will immediately use the rates of change data to perform site evaluations for determining suitable shoreline conservation and management strategies and detail their approach in a fact sheet and as part of a training conducted in collaboration with Maryland's Coastal Training Program (CTP). In addition to this application, the more reliable rates of change dataset will improve the CAC's project review process and improve the information available to guide decisions on coastal parcels available for acquisition through MD DNR's Stewardship Review for Maryland's Program Open Space.

STUDY AREA

The coastal region of Maryland comprises all of the tidally influenced bodies of water in the State – the Chesapeake Bay and its tributaries, the coastal bays separating Fenwick and

Assateague Islands from the mainland, and the Atlantic Ocean. There are sixteen coastal counties in Maryland – Anne Arundel, Baltimore, Calvert, Caroline, Cecil, Charles, Dorchester, Harford, Kent, Prince George's, Queen Anne's, Somerset, St. Mary's, Talbot, Wicomico, and Worcester. This project specifically focused on Anne Arundel and Baltimore Counties (including the Baltimore City limits) (Figure 1). The blue lines in Figure 1 represent shorelines in Maryland's sixteen coastal counties.

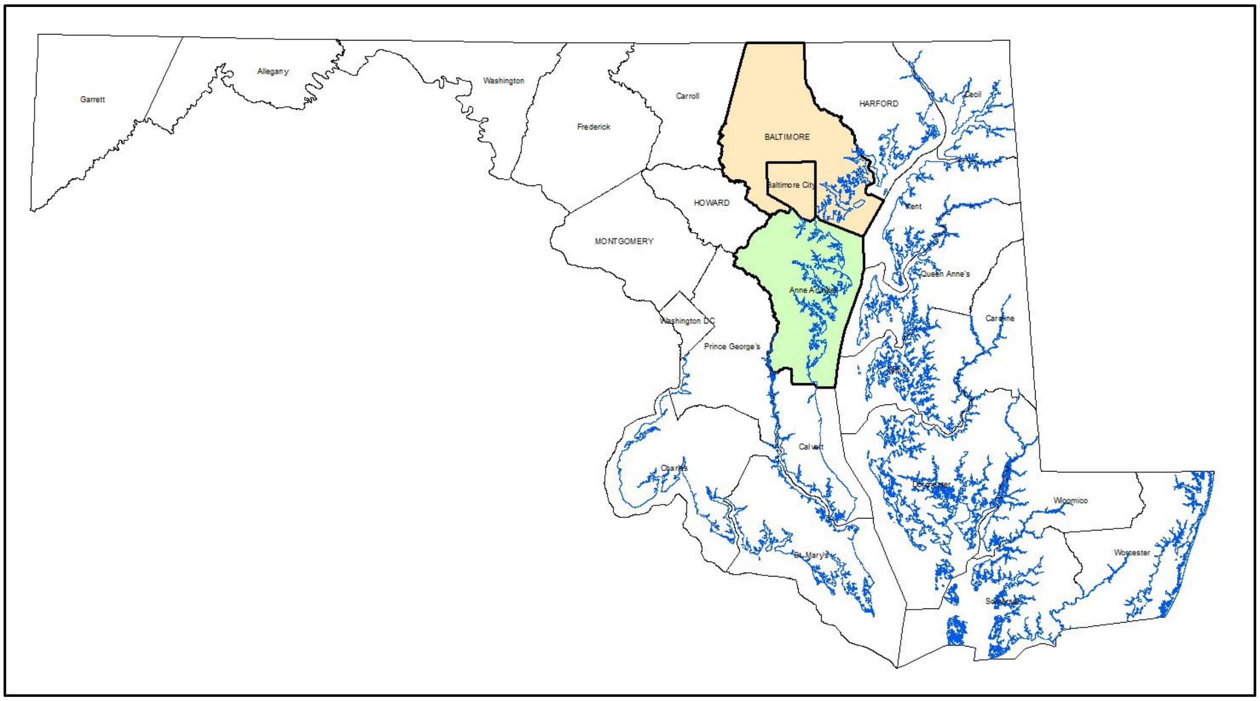


Figure 1. Counties (shaded) for which shoreline rates of change were determined.

OBJECTIVES

The objectives of this project were to:

1. Acquire new historical and recent (post-2000) shorelines for Anne Arundel and Baltimore Counties to complement and update MGS's existing digital shoreline data set;
2. Calculate updated rate-of-change statistics using DSAS v4.3; and
3. Assign generalized erosion rate categories to a recent shoreline in Anne Arundel and Baltimore Counties.

BACKGROUND

From previous shoreline change investigations completed in the 1990s, MGS already had an in-house digital shoreline data set spanning 1841-1995. Since that time, however, a number of new or recently digitized shorelines have become available for the study area. These shorelines include 1) new shorelines digitized by the Eastern Shore Regional GIS Cooperative (ESRGC) for

CAC; 2) new shorelines interpreted for NOAA's National Ocean Service (NOS) since 2000; and 3) historical shorelines interpreted and digitized by NOAA's Office of Coast Survey (OCS).

MGS included all CAC shorelines in its initial analysis. MGS also chose to use NOAA historical shorelines in place of those previously digitized by MGS wherever possible. In other words, in areas where newly acquired NOAA shorelines had similar temporal and spatial extents as the historical MGS shorelines, MGS chose to use the NOAA shorelines. The NOAA shorelines are likely to be regarded by the user community as the definitive shoreline for the year in which they were originally mapped. The mean high water (MHW) shorelines used in NOAA nautical chart production are referenced to geographic coordinates and formatted as ESRI shapefiles. Additionally, NOAA created the original nautical charts and assumed responsibility for digitizing them. MGS shorelines were utilized in DSAS analysis in areas where NOAA shorelines of similar date/location were not available. Below is a detailed description of the original MGS shoreline data set, plus a description of the newly acquired shoreline data sets from NOAA and CAC. For a tabular summary detailing which shorelines were utilized in the final DSAS analysis for each county, please reference Table 1. In Table 1, historical shorelines sourced from the NOAA National data set are shaded in green; historical shorelines sourced from MGS are shaded in tan; historical shorelines sourced from the NOAA Historical (T-sheets) data set are shaded in pink; and recent shorelines sourced from the NOAA CUSP data set are shaded in gray.

Sources of Digital Shorelines

Maryland Geological Survey (MGS)

In the early 1990s, MGS embarked on a program to revise an outdated series of *Historical Shorelines and Erosion Rates* maps. This update entailed digitizing historical and recent shorelines from a variety of sources, and displaying the shorelines over digital orthophotography to produce a *Shoreline Changes* map series (Hennessee and others, 1997, 2002a, 2003a, 2003b; Hennessee and Stott, 1999; Kerhin and others, 1994, 1997; Stott and others, 1999, 2000). Digital shorelines, representing various shoreline positions between the years 1841 and 1995, were derived from:

- *Historical Shorelines and Erosion Rates* maps compiled by MGS in 1975;
- The most recent *Coastal Survey* maps (topographic or T-sheets) produced by NOAA NOS at the time; and
- A digital wetlands delineation based on photo interpretation of 1988-1995 digital orthophoto quarter quadrangles (DOQQs) (Hennessee and others, 2003b).

Comprehensive detail about the shorelines and how they were digitized can be found in the data documentation and metadata associated with the digital data sets (Hennessee, 1999, 2000a-c).

Table 1. Final shorelines utilized in DSAS analysis for Anne Arundel and Baltimore Counties, MD, sorted by year.

County	Year	Source of Shoreline	NOAA Project ID
Anne Arundel	1932	NOAA National	MD1932B
	1932-1933	NOAA National	MD1932A1
	1933	NOAA National	MD1932A2
	1933	NOAA National	MD1932A3
	1933	NOAA National	MD1933D
	1933	NOAA National	MD1933E
	1933	NOAA National	MD1933F
	1933-1934	NOAA National	MD1934A
	1938, 1942-1943	NOAA National	CS288
	1942	NOAA National	CS307
	1944	NOAA National	MD1941A1
	1944	MGS ca. 1940	n/a
	1960	NOAA National	PH6008
	1960	NOAA National	PH6009A
	1965	NOAA National	PH6609
	1971	NOAA Historical	CM7202
	1974	NOAA National	CM7415
	1976	NOAA National	CM7601
	1993-1994	MGS ca. 1990	n/a
	2005, 2007, 2010	NOAA CUSP	CUSP
Baltimore (including Baltimore City)	1933-1934	NOAA Historical	MD1934A
	1935	NOAA National	MD1935A
	1937	NOAA National	MD1939A
	1938	NOAA National	CS288
	1960	NOAA National	PH6009B
	1960	NOAA National	PH6009C
	1972, 1974	NOAA National	CM7213
	1974-1975	NOAA National	CM7415
	1976	NOAA National	CM7601
	1994	MGS ca. 1990	n/a
	2005-2007, 2011	NOAA CUSP	CUSP

Historical Shorelines and Erosion Rates Maps (1841-1943)

In 1975, MGS Geologist Robert D. 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 an obsolete horizontal datum 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 base maps and 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 subject to similar rates of erosion (i.e. 0-2 feet/year, 2-4 feet/year, etc.) are so demarcated. Shorelines were digitized primarily from Series A maps. Although more than one shoreline is depicted on each of the *Historical Shorelines* maps, usually only the oldest was digitized. The shoreline that appears on the underlying topographic base map was never digitized (Hennessee and others, 2003b).

Although used in previous shoreline change assessments, these shorelines were not used in the final DSAS analysis for Anne Arundel or Baltimore Counties.

Coastal Survey Maps (1934-1977)

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 man-made 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; Anders and Byrnes, 1991). 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 vertical datum of “mean high water” (MHW) is used as the plane of reference for the shoreline. MGS digitized shoreline vectors from 187 *Coastal Survey* maps, at scales of 1:5,000, 1:10,000, or 1:20,000. These vectors represented shorelines for the years 1934 to 1977. T-sheet shorelines were merged and clipped to 7.5-minute quadrangle boundaries, which did not necessarily coincide with the extents of the original *Coastal Survey* maps (Hennessee and others, 2003b).

MGS utilized a portion of the ca. 1940 shoreline extracted from a *Coastal Survey* Map (T-sheets T-08255 and T-08264) in the final DSAS analysis for Anne Arundel County.

Shorelines Extracted from Wetlands Delineation (1988-1995)

Shorelines dating from 1988 to 1995 were extracted from existing wetlands vectors (Miller, 1997). The wetlands vectors were previously delineated for MD DNR over 1:1,000-scale digital orthophoto quarter quadrangles (DOQQs). The DOQQs, in turn, were derived from 1:40,000-scale CIR film (Miller, 1995).

MGS contracted the services of EarthData International (EDI) of Frederick, Maryland to interpret shorelines from DOQQs covering the coastal regions of Maryland (Hennessee, 2001). EDI extracted a subset of shoreline vectors from the existing wetlands coverage by first stripping wetlands vectors of their linear attributes (line classes). All shorelines and the DOQQ tile boundary were displayed over the DOQQ (raster) from which they had originally been interpreted and reassigned attributes. Shoreline segments were classified by shoreline type, using the following four categories: beach, structure, vegetated, and water's edge. All four categories are linear features, except for "beach," which may 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 types. The extracted vectors were then displayed to detect shoreline breaks or other inconsistencies. Errors were corrected, and shoreline vectors were re-extracted (Hennessee and others, 2003b).

After extracting the vector sets, EDI cleaned them by deleting any extraneous lines (non-shoreline vectors) that had mistakenly been 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 quadrangle) 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 (Hennessee and others, 2003b).

MGS subsequently converted beach polygons to line segments by removing the landward edge of the polygon. Beach polygons – basically, two sub-parallel lines representing the same shoreline year – would confound computer programs designed to calculate shoreline rates of change from a time series of digital shorelines. The Geographic Information Services Division of MD DNR then merged the polygon-free shorelines into a single, statewide coverage. Using the digital shorelines in conjunction with a GIS, MicroImages' TNTmips, MGS produced a series of *Shoreline Changes* maps. The maps, which depict historical shorelines over an orthophoto background, allow a qualitative assessment of shoreline erosion or accretion (Hennessee and others, 2003b).

The ca. 1990 shorelines were utilized in the final DSAS analysis for both Anne Arundel and Baltimore Counties.

National Oceanic and Atmospheric Administration (NOAA)

NOAA Historical Surveys (T-sheets)

Shorelines from the NOAA Historical Surveys (T-sheets) data set originated with NOAA's National Geodetic Survey (NGS). These shorelines were used as base maps to construct nautical charts primarily used for navigation, and current applications for these shorelines include shoreline change analysis and cartographic representation (*NOAA Historical Surveys (T-sheets)*, n.d.). These shoreline surveys, also known as coastal surveys, T-sheets, TP sheets, or shoreline manuscripts, refer to "topographic sheets compiled from maps derived in the field with a plane table, in the office from aerial photos, or using a combination of the two methods" (*NOAA Historical Surveys (T-sheets),* n.d.). Shorelines in this data set "provide the authoritative definition of the U.S. high water line", and range in scale from 1:10,000 to 1:60,000 (*NOAA Historical Surveys (T-sheets),* n.d.). MGS accessed these shorelines using the *NOAA Historical Shoreline Survey Viewer* (a Google Earth tool), which provides access to ~7,800 georeferenced historical shoreline surveys conducted by NOAA and its predecessor organizations. The earliest shoreline survey available on the *Survey Viewer* dates back to 1841 (*NOAA Historical Surveys (T-sheets),* n.d.) Additional information about the NOAA Historical Surveys (T-sheets) data set is available online here: http://shoreline.noaa.gov/data/datasheets/t-sheets.html.

MGS utilized NOAA Historical (T-sheet) CM7202 data set in its final Anne Arundel County DSAS analysis, and the MD1934A data set in its final Baltimore County DSAS analysis.

NOAA National Shoreline

According to the *NOAA National Shoreline* website, this shoreline data set was originally intended to support NOAA nautical chart production. Other applications include shoreline change analysis, boundary determination, and cartographic representation (*NOAA National Shoreline,* n.d.). Like the NOAA Historical (T-sheets) data, these shorelines originated from the NOAA NGS office. These shorelines represent a "vector conversion of NOAA National Ocean Service (NOS) raster shoreline manuscripts (T-sheets) and aerial imagery from the year 1855 to the present" (*NOAA National Shoreline,* n.d.). The shorelines used in this study range in scale from 1:5,000 to 1:20,000 and were referenced to the MHW line. Additional information about the NOAA National Shoreline data set is available here: http://shoreline.noaa.gov/data/datasheets/index.html. The shoreline may be viewed online and downloaded from the *NOAA Shoreline Data Explorer* here: http://www.ngs.noaa.gov/NSDE/.

For Anne Arundel County final DSAS analysis, MGS utilized the following 16 NOAA National Shoreline data sets: CS288, MD1932A1, MD1932A2, MD1932A3, MD1932B, MD1933D, MD1933E, MD1933F, MD1934A, CS307, MD1941A1, PH6008, PH6009A, PH6609, CM7415 and CM7601.

For Baltimore County final DSAS analysis, MGS utilized the following 8 NOAA National Shoreline data sets: CS288, MD1935A, MD1939A, PH6009B, PH6009C, CM7213, CM7415, and CM7601.

NOAA Continually Updated Shoreline Product (CUSP)

The NOAA Continually Updated Shoreline Product (CUSP) data set "was created to deliver continuous shoreline with frequent updates to support various GIS applications including coastal and marine spatial planning, tsunami and storm surge modeling, hazard delineation and mitigation, environmental studies and assist in nautical chart updates" (*NOAA Continually Updated Shoreline Product,* n.d.). This data set includes "all national shoreline that has been verified by contemporary imagery and shoreline from other non-NOAA sources" (*NOAA Continually Updated Shoreline Product,* n.d.). This shoreline data set ranges in scale from 1:1,000 to 1:24,000, and is sourced from National Shoreline data set vectors and non-NOAA sources including lidar, imagery, and shoreline vectors (*NOAA Continually Updated Shoreline Product,* n.d.). This shoreline is referenced to MHW. Additional information about the NOAA CUSP shoreline is available at: http://shoreline.noaa.gov/data/datasheets/cusp.html. The shoreline may be viewed online and downloaded from the *NOAA Shoreline Data Explorer* here: http://www.ngs.noaa.gov/NSDE/.

MGS utilized the ca. 2000/2010 NOAA CUSP shoreline in its final DSAS analysis for Anne Arundel and Baltimore Counties. Additionally, for both counties, MGS chose to attribute this recent shoreline with generalized rate-of-change categories.

Critical Area Commission (CAC)

CAC shorelines were interpreted by the Eastern Shore Regional GIS Cooperative (ESRGC) at Salisbury University as part of CAC's Critical Area map update. Funded in part through Maryland's CMP, these sets of county shorelines serve as a baseline from which to draw new Critical Area boundaries, demarcating land within 1,000 feet of the MHW line of tidal water bodies in the State.

ESRGC scanned a series of 1972 Tidal Wetlands maps flown by Air Photographics, Inc. of Martinsburg, West Virginia. Then, each set of maps was georeferenced to true-color, high-resolution orthophotography flown in Anne Arundel and Baltimore Counties between 2007 and 2008. This imagery was not tide-coordinated. Shorelines were digitized at a scale range of 1;600 to 1:1,200 based on a shoreline definition approved by ESRGC, MD DNR, CAC, and County representatives. This shoreline was defined as the "combination of the intersection of water and land as interpreted from the 2007-2008 (6-inch resolution, 100 scale) true-color orthophotography" (ESRGC, 2013). Additionally, consideration was given to the following items when estimating the high tide limit: mean high-tide, the location of water at time of image capture, and the estimation of the high tide limit based on photo interpretation and collateral data (ESRGC, 2013). More information about the CAC Critical Area re-mapping efforts may be found online here: http://www.dnr.state.md.us/criticalarea/mapupdate.asp.

MGS did not utilize the CAC shorelines in the final DSAS analysis for Anne Arundel and Baltimore Counties.

DSAS and Quantifying Land Loss Due to Shoreline Erosion

To provide a detailed and flexible quantification of shoreline change, MGS used the DSAS v4.3 computer program, written and supported by researchers at the USGS. In 1992, Danforth and Thieler recognized that coastal researchers and policy-makers, increasingly reliant on shoreline mapping as a scientific and management tool, needed a standardized method for quantifying changes in shoreline position over time. They developed DSAS in response to that need. DSAS is based on a commonly used measurement baseline approach to obtaining shoreline rates of change from a time series of shoreline positions (Hennessee and others, 2003). More information about the DSAS program is available online here: http://woodshole.er.usgs.gov/project-pages/DSAS/.

DSAS Baselines and Transects

To utilize DSAS, users first create a baseline roughly parallel to the shorelines, either seaward (offshore) or landward (onshore). Unlike previous efforts, this current project utilized an offshore baseline to calculate rates of change. Both baseline positions are equally valid, and produce the same rate-of-change calculations within DSAS. Here are examples of both an offshore and onshore baseline position, as illustrated in the “Cast Transect Settings” tab in the DSAS v4.3 “Set Default Parameters” graphical user interface (GUI):

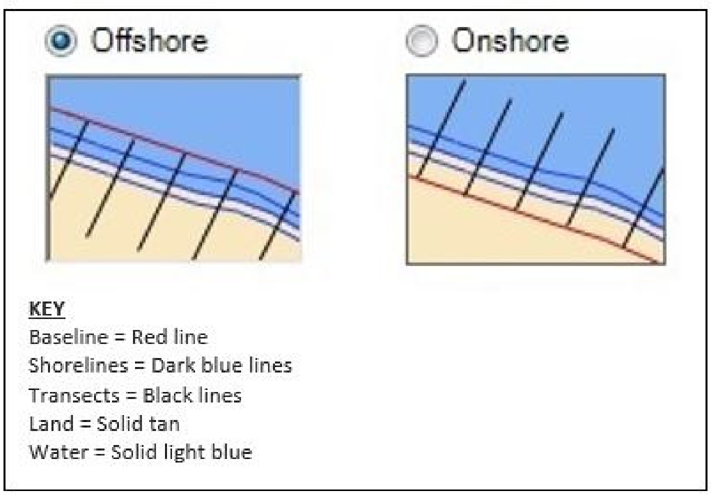


Figure 2. Illustration of offshore and onshore baseline positions.

MGS chose to create and utilize an offshore baseline in the current effort due to the following reasons:

1) Much of the shoreline in the Chesapeake Bay is eroding at various rates. As a result, many future Bay shorelines may be positioned further inshore than their current locations. Creating and editing a proper baseline for use in DSAS analysis can be a time-intensive task. By creating an offshore baseline, MGS will be able to utilize the same baseline in future studies with minimal revision. In other words, since most shorelines

are eroding, they are receding away from the offshore baseline and will not move past the baseline position.

2) Using an offshore baseline creates a more easily understood visual for the user when displaying the shorelines, baselines, and transects together. This is especially true in the narrow tributary areas where transects can be cast to either side from a single offshore baseline drawn up the centerline of the tributary. Transects cast from two onshore baselines could potentially crisscross each other, creating a confusing visual for the user.

3) Because of the reasons outlined in 2), transects cast from offshore baselines may be edited more easily.

DSAS then creates transects of a user-defined length along the baselines at user-defined intervals. Like previous efforts, MGS elected to space transects 20 meters apart for this project. Although transect lengths were often subsequently edited, MGS chose an initial transect length of 75 meters.

DSAS Statistics

The DSAS v4.3 program calculates multiple types of statistics, including distance metrics, rate calculations, and associated supplemental statistics (see Table 2). The rate calculation options include 1) the linear regression rate (LRR); 2) the end point rate (EPR); 3) the weighted linear regression (WLR) rate; and 4) the least median of squares (LMS) rate. All methods are described in detail in the "DSAS 4.0 Installation Instructions and User Guide" (Himmelstoss, 2009). MGS utilized the LRR and EPR methods during this project.

DSAS determines the LRR by "fitting a least-squares regression line to all shoreline points for a particular transect" (Himmelstoss, 2009). As such, the LRR is the slope of the line. When LRR is calculated, at least three shorelines are required for analysis. If more than three shorelines are present, all shorelines are included in the analysis.

For the EPR calculations, DSAS computes a rate of change for a particular transect by dividing the distance between each shoreline, relative to the baseline, by the elapsed time between shoreline positions. Consider, for example, two shorelines – one representing a shoreline position in 1945 and the other, a shoreline position in 1995 (Figure 3). If, during the 50-yr period, the shoreline has retreated, or moved landward, a distance of 25 meters (m), then the rate of change is 25 m/50 years = 0.50 m/year (yr). In DSAS, retreat or erosion is expressed as a negative number, yielding a rate of change for the hypothetical transect of –0.50 m/yr.

MGS initially chose to calculate both long-term and short-term rates of change for each county using the following approaches. The long-term rates were calculated using the LRR method which utilized the entire shoreline data set for each county. The long-term LRR rate calculation typically spanned a 70-80 year time period. The LRR method was chosen over the WLR method because the "LRR is a much better understood metric, and it is simpler to evaluate and communicate its underlying assumptions" (Thieler, 2014). Additionally, although the WLR

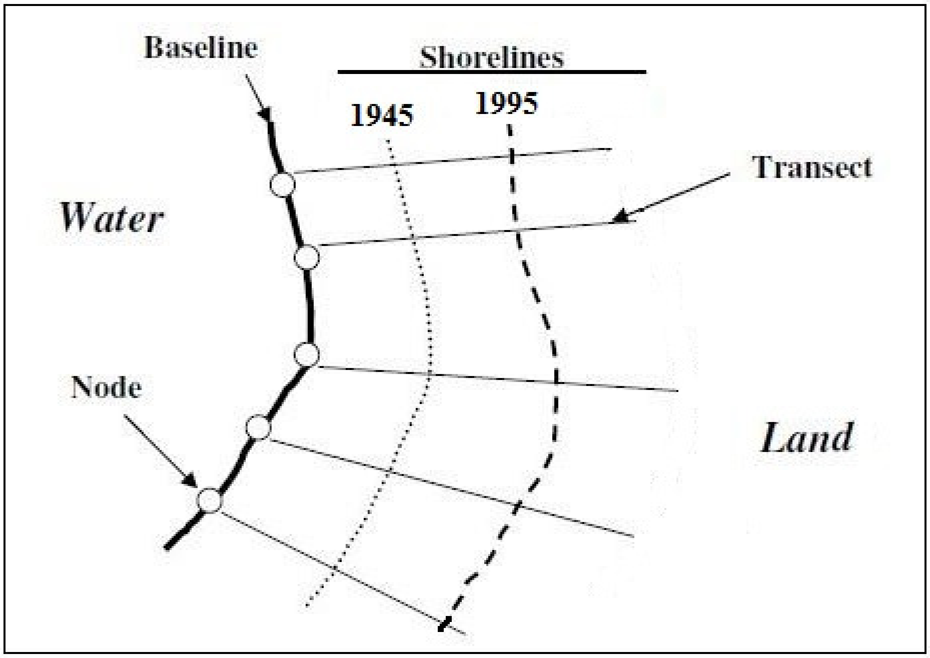
Table 2. Definitions of available DSAS statistics.

Statistic	Acronym	Type	Definition	Related Measure
Shoreline Change Envelope	SCE	Distance	Distance between the shoreline farthest from and closest to the baseline at each transect.	n/a
Net Shoreline Movement	NSM	Distance	Distance between the oldest and youngest shorelines for each transect. If this distance is divided by the number of years elapsed between the two shoreline positions, the result is the End Point Rate.	EPR
End Point Rate	EPR	Rate	Calculate by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline; requires at least 2 shorelines.	ECI, NSM
Linear Regression Rate	LRR	Rate	Determined by fitting a least-squares regression line to all shoreline points for a particular transect; the LRR is the slope of the line; requires at least 3 shorelines.	LR2, LSE, LCI
Weighted Linear Regression	WLR	Rate	Linear regression rate where more reliable data are given greater emphasis or weight towards determining a best-fit line; requires at least 3 shorelines.	WR2, WSE, WCI
Least Median of Squares	LMS	Rate	Determined by fitting a least-squares regression line to all shoreline points for a particular transect; median value of the squared residuals is used to determine the best-fit equation for the line; requires at least 3 shorelines.	n/a
Confidence of End Point Rate	ECI	Supplemental statistic	Confidence of the EPR rate; measures the shoreline uncertainties used in the end point rate calculation.	EPR
Standard Error of the Estimate	LSE, WSE	Supplemental statistic	Assesses the accuracy of the best-fit regression line in predicting the position of a shoreline for a given point in time.	LRR, WLR
Standard Error of the Slope with Confidence Interval	LCI, WCI	Supplemental statistic	Describes the uncertainty of the reported LRR or WLR rate.	LRR, WLR
R-Squared	LR2, WR2	Supplemental statistic	Percentage of the variance in the data that is explained by the regression; dimensionless index that ranges from 1.0 to 0.0.	LRR, WLR

Information reproduced from "DSAS 4.0 Installation Instructions and User Guide" (Himmelstoss, 2009).

method captures the “technological” uncertainty of the shoreline positions, “a larger source of uncertainty is the natural variability in the coastal system. This information is generally poorly known or unknown for most coastal areas” (Thieler, 2014).

The short-term rates were calculated using the EPR method, using solely the ca. 1970s shorelines and the ca. 2000/2010 shorelines as input to DSAS. The EPR method was chosen to provide consistency with MGS’s previous projects, which also utilized the EPR rate to calculate short-term rates of change. The majority of the ca. 2000/2010 NOAA CUSP shoreline spanned the



Graphic reproduced and updated from "Updating Shore Erosion Rates in Maryland" (Hennessee and others, 2003b).

Figure 3. Features used or created by DSAS to calculate shoreline rates of change.

mid-2000s, so the EPR rate calculated for this set of shorelines was named the "30-year" rate. This time period label is a rough estimate, as the time span will vary slightly based on the specific dates of the shoreline pairs used as input to DSAS at each transect.

Unfortunately, this initial approach resulted in numerous transects without rate data because of the following scenarios: 1) no long-term LRR rate could be calculated because only 2 shorelines were present at the transect and DSAS requires at least 3 shorelines to calculate the LRR; or 2) either the ca. 1970 shoreline or the ca. 2000/2010 shoreline was not available at the transect and thus the 30-year EPR could not be calculated. To generate rates of change for those transects with no long-term LRR and 30-year EPR statistics, MGS also calculated a long-term EPR (only requiring 2 shorelines) and a short-term (ca. 1990 vs. ca. 2000/2010) EPR for all transects. Again, the majority of the ca. 2000/2010 NOAA CUSP shoreline spanned the mid-2000s, so the short-term EPR rate calculated for this set of shorelines was named the "10-year" rate. Users must look at the individual transects to determine the exact time span across which the EPR rate was calculated.

In summary, MGS ultimately generated the following statistics on the shoreline data sets (associated supplemental statistics were calculated automatically by DSAS):

- Shoreline Change Envelope (SCE)
- Net Shoreline Movement (NSM)
- Long-Term End Point Rate (EPR) – Run on all available shorelines
- Long-Term Linear Regression Rate (LRR) – Run on all available shorelines
- Short-Term 30-year EPR – Run on the ca. 1970 and ca. 2000/2010 shorelines only

- Short-Term 10-year EPR – Run on the ca. 1990 and ca. 2000/2010 shorelines only

DSAS produced over 39,000 transects in Anne Arundel County and close to 21,000 transects in Baltimore County. DSAS statistics were stored in two county-specific Microsoft Access 2013 databases. All DSAS statistics were joined to county-specific transect feature class attribute tables in ArcGIS 10.1. After discussion with CCS, MGS attributed the recent NOAA CUSP shoreline in each county with the short-term 30-year EPR. For those segments of shoreline with no 30-year EPR available, MGS attributed the shoreline with the 10-year EPR where possible.

METHODS

Format Shorelines for DSAS Analysis

Acquire, Georeference, and Clip the Shorelines

MGS did not digitize any shorelines as part of this current effort; as such, the first stage of this project involved acquiring and compiling the readily available historical and recent (post-2000) shorelines from various sources. These sources included the NOAA Historical (T-sheets) data set, the NOAA National Shoreline data set, the NOAA CUSP data set, and CAC shorelines. MGS already had an in-house digital shoreline data set spanning 1841-1995 from previous work completed in the 1990s. The newly acquired shorelines were added to this shoreline data set, and in many cases, replaced the MGS shorelines. The mean high water (MHW) shorelines used in NOAA nautical chart production have been referenced to geographic coordinates and formatted as ESRI shapefiles. NOAA created the original nautical charts and assumed responsibility for digitizing them. They are, therefore, likely to be regarded by the user community as the definitive shoreline for the year in which they were originally mapped. As such, the NOAA shorelines were used in place of those previously digitized by MGS wherever possible.

NOAA Historical (T-sheets) shorelines were downloaded from the *NOAA Historical Shoreline Survey Viewer* Google Earth Tool accessed here: http://shoreline.noaa.gov/data/datasheets/t-sheets.html. NOAA National Shoreline and NOAA CUSP datasets were downloaded from the *NOAA Shoreline Data Explorer* here: http://www.ngs.noaa.gov/NSDE/. CAC shoreline data sets were acquired directly from ESRGC at Salisbury University in Salisbury, MD.
Upon acquisition, all shorelines were georeferenced to the Maryland State Plane North American Datum of 1983 (m) and clipped to county boundaries using the ArcGIS 10.1 platform. County boundaries were sourced from the MD State Highway Administration (SHA) GIS Data Download Center located here: http://www.sha.maryland.gov/Index.aspx?PageId=282.

Delete Non-Shoreline Vectors

MGS then deleted all non-shoreline vectors from the NOAA Historical (T-sheets), NOAA National, NOAA CUSP, and MGS ca. 1990 shoreline data sets. DSAS does not differentiate between a line segment representing a shoreline, and, as an example, a line segment representing a road. As such, it was necessary to delete all non-shoreline segments from the files in order for DSAS to run successfully.

Create and Populate DSAS-Required Fields

DSAS requires that the shoreline files contain two attribute fields: 1) a date field, containing the date in mm/dd/yyyy format; and 2) an uncertainty field, containing the measurement uncertainty assigned to the shoreline (Himmelstoss, 2009). To aid in file management and organization, MGS also created five additional attribute fields. These seven attribute table fields added to the individual shoreline files are explained in detail in Table 3. Subsequently, these fields were also incorporated into the master shoreline feature class file and added to the attributed shoreline feature class files. Fields are fully defined in the FGDC-compliant metadata that accompanies the final project data set.

Assign Shoreline Uncertainties

According to literature and the DSAS v4.3 manual, the calculated rates of change are only as reliable as the measurement and sampling errors when compiling each shoreline position (Anders and Byrnes, 1991; Crowell and others, 1991; Thieler and Danforth, 1994; Moore, 2000; and Himmelstoss, 2009). In DSAS, different shoreline uncertainties may be assigned to each shoreline segment. The uncertainty value should account for "positional uncertainties associated with natural influences over the shoreline position (wind, waves, tides) and measurement uncertainties (for example, digitization or global-positioning-system errors" (Himmelstoss, 2009). The rate of change calculation "may be limited by the quality and quantity of input data" (Himmelstoss, 2012).

When assigning shoreline uncertainties to its shoreline data sets, MGS referenced the USGS Open-File Report 2010-1118 titled "National Assessment of Shoreline Change: Historical Shoreline Change along the New England and Mid-Atlantic Coasts" (Hapke and others, 2010). Table 4 lists shoreline measurement uncertainties, sourced from the 2010 USGS report. For those shorelines extracted from T-sheets spanning 1800-1950s, MGS assigned an uncertainty value of 11.7 meters. For those shorelines extracted from T-sheets spanning 1960-1980s, MGS assigned an uncertainty value of 6.8 meters. For the ca. 1990 MGS shoreline, MGS assigned an uncertainty value of 7.5 meters. These shorelines were extracted from a wetlands delineation, which was based on a photo interpretation of DOQQs. As such, MGS decided to assign the more conservative value of 7.5 meters, taking into account the work of Hapke and others (2010) and Crowell and others (1991). NOAA CUSP shorelines were assigned the horizontal positional uncertainty value attributed in the native NOAA CUSP attribute field "HORR_ACC". These values ranged from 1.2 to 7.4 meters in Anne Arundel County, and 0.7 to 4.8 meters in Baltimore County.

Table 3. User-added, DSAS-related attribute fields in the individual shoreline files.

Field Name	Field Type	Field Length	Required by DSAS?	Method of Creation	Definition
DSAS_DATE	Text	10	Y	User-created	Date of shoreline segment in mm/dd/yyyy format.
DSAS_UNC	Double	n/a	Y	User-created	Estimated uncertainty assigned to the shoreline segment (m).
DSAS_SRC	Text	10	N	User-created	Identifies the source dataset from which the shoreline segment was acquired.
DSAS_DEC	Short Integer	n/a	N	User-created	Decade identifier in yyyy based on the DSAS_DATE field.
DSAS_CO	Text	25	N	User-created	County in which the shoreline segment resides.
DSAS_NPROJ	Text	10	N	User-created	Stands for "NOAA PROJect"; describes the NOAA Project ID for the NOAA Historical (T-sheets) and the NOAA National Shoreline data sets.
DSAS_SLINF	Text	25	N	User-created	Stands for "ShoreLine INFormation"; combines the DSAS_DEC, DSAS_SRC, and DSAS_NPROJ information in one field.

Table 4. Total shoreline position uncertainties based on shoreline year, source, and measurement uncertainties.

	1800-1950s	**1960-1980s**	**1970-2000s**	**1997-2000**
Measurement Uncertainty (meters)	**T-Sheets**	**T-Sheets**	**Air Photos**	**Lidar**
Georeferencing	4	4	n/a	n/a
Digitizing	1	1	1	n/a
T-sheet survey	10	3	n/a	n/a
Air photo	n/a	n/a	3	n/a
Uncertainty of High Water Line	4.5	4.5	4.5	n/a
Lidar total position uncertainty	n/a	n/a	n/a	2.3
Total shoreline position uncertainty	11.7	6.8	5.5	2.3

Table reproduced from "National Assessment of Shoreline Change: Historical Shoreline Change along the New England and Mid-Atlantic Coasts" (Hapke and others, 2010).

Create/Finalize the Master Shoreline Feature Class

DSAS requires that all shorelines reside in a single ArcGIS shoreline feature class within a personal geodatabase. First, all shorelines not already in the feature class format were converted to that format in ArcGIS 10.1. Then, all shorelines were appended into one master shoreline feature class. This master shoreline feature class contained all of the fields from the native shoreline files, plus the seven user-created fields either required for DSAS analysis or helpful in DSAS file management and analysis. The user-created fields were named DSAS_DATE, DSAS_UNC, DSAS_SRC, DSAS_DEC, DSAS_CO, DSAS_NPROJ, and DSAS_SLINF (see Table 3 for more information).

Once the master shoreline feature class was compiled, MGS carefully assessed each shoreline. For both Anne Arundel and Baltimore Counties, MGS decided to eliminate the pre-1930s shorelines from the DSAS analysis. MGS assessed positional uncertainties of up to 13 meters for these shorelines. Additionally, in some cases, particularly in the upstream reaches of tributaries and rivers, there appeared to be a significant offset in the pre-1930s shoreline position relative to the ca. 1930 and post-1930s shorelines. Even with the pre-1930s shorelines eliminated from the final DSAS analysis, MGS was still able to analyze 70-80 years of shoreline change for both counties.

Determine Rates of Shoreline Change

Create/Edit Baselines

DSAS requires a set of digital shorelines, baselines and transects in order to calculate rates of change information. Requirements for shorelines were covered in the previous section.

MGS created offshore (seaward) baselines. In ArcMap 10.1, the baseline feature class was created by 1) buffering at a distance of 10 meters around the master shoreline feature class, converting the buffer polygon to a line, and erasing the landward portion of the buffer line; and 2) manually digitizing baselines up the centerline of tributaries/rivers and other areas where baselines were needed but the buffer-created baselines did not reach. In general, baselines adjacent to only one shoreline were erased since DSAS needs at least two shorelines to calculate rates of change. Baselines were edited to increase smoothness and to ensure they ran roughly parallel to the majority of the shorelines.

In ArcMap 10.1, MGS added two fields to the final baseline feature class (Table 5). The “Group” field, not required by DSAS, aided in general baseline organization. The “ID” field, required by DSAS, assigns a unique identifier to each baseline segment.

Table 5. User-added baseline feature class attribute fields.

Field Name	Field Type	Field Length	Required by DSAS?	Method of Creation	Definition
Group	Long integer	n/a	N	User-created	MGS created this field to help organize all of the baseline segments. The baselines were generally grouped into categories based on their general physical location and method of creation.
ID	Long integer	n/a	Y	User-created	MGS created this field to assign a unique identifier to each baseline segment, based on the Group number.

The baselines were grouped into the following categories based on their general physical location and method of creation:

- Group 1 – Mainstem Baselines
  Baselines created by buffering at a distance of 10 meters around the master shoreline feature class. Typically these baselines are located along shorelines in the mainstem portions of the Chesapeake Bay and tributaries/rivers with widths greater than 20 meters.

- Group 2 – Tributary/River Baselines
  Baselines created by manually digitizing a line up the centerline of the water body to capture data in the upper extents of tributaries/rivers where the buffer-created baselines did not reach.

- Group 3 – Island Baselines
  Baselines created by both manual digitization and the buffer process around islands.

- Group 4 – Fill Area Baselines
  Baselines manually created along historical shorelines in areas that appear to have been filled in.

- Group 5 – Dredge Area Baselines
  Baselines manually created along historical shorelines in areas that appear to have been dredged.

- Group 6 – Hart-Miller Island (HMI) Baselines
  Baselines created along the historical southern shore of HMI in Baltimore County. These baselines were created by the buffer process.

- Group 7 – Pond/Inlet Baselines
  Baselines created by the buffer process around inland ponds and wide inlets.

- Group 8 – Additional Tributary/River Baselines
  Additional tributary baselines. These baselines were created by manually digitizing a line up the centerline of the water body to capture data in the upper extents of tributaries/rivers where the buffer-created baselines did not reach.

Baseline IDs were assigned according to the Group number. Baselines with a Group value of 1 were assigned ascending ID values of 101, 102, etc. Baselines with a Group value of 2 were assigned ascending ID values of 201, 202, etc.

Cast/Edit Transects

Using the DSAS program, 75-meter long, straight-line transects were cast every 20 meters along the baselines. Several attribute fields were automatically created by DSAS during this process (see Table 6). Transects were cast in one direction (to the right) along the Group 1 and Groups 3-7 baselines. Transects were cast in both directions (to the right and left) along the Group 2 and Group 8 baselines. All of these transects were cast perpendicular to the baseline and extended across the shorelines.

Transects were edited to ensure they were roughly perpendicular to the majority of the shorelines. In areas where the shorelines were highly variable, MGS edited the transects to be roughly perpendicular to the most recent shorelines. In some areas, such as narrow peninsulas, MGS shortened transects so that they did not cross over one set of shorelines, and extend over another set of shorelines. In other areas, transects were lengthened to ensure that they crossed all of the available shorelines at the particular transect location. In many cases, the transect orientation was shifted slightly so that the transect was perpendicular to the shorelines (even if this meant that the transect was not entirely perpendicular to the baseline anymore).

Generate Rate-of-Change Statistics / Join Statistics to Transect Attribute Table

For each county, the original transect files were too large to run through DSAS successfully. As such, each county transect file was separated into smaller files for DSAS analysis. In Anne Arundel County, the original transect file contained 39,069 transects. This transect file was broken down into 5 smaller files, each containing approximately 8,000 transects each. In Baltimore County, the original transect file contained 20,839 transects. This transect file was broken down into 2 smaller files, each containing approximately 10,000 transects each.

Table 6. DSAS-generated transect feature class attribute fields.

Field Name	Field Type	Field Length	Definition
BaselineID	Long integer	n/a	Values in this field are assigned by DSAS to identify the baseline segment used to generate the transect.
Group	Long integer	n/a	This field is used to aggregate shoreline data and the resulting measurement locations established by the transects into groups. Values of zero are assigned if the user did not select a baseline-group field as input.
TransOrder	Long integer	n/a	Assigned by DSAS on the basis of transect order along the baselines.
ProcTime	Text	30	Date and time each transect was processed.
Autogen	Text	1	Indicates whether a transect was automatically created by DSAS (value = 1) or added by user (value = 0).
StartX	Double	n/a	X coordinate of the beginning of the transect.
StartY	Double	n/a	Y coordinate of the beginning of the transect.
EndX	Double	n/a	X coordinate of the end of the transect.
EndY	Double	n/a	Y coordinate of the end of the transect.
Azimuth	Double	n/a	Azimuth of the transect measured in degrees clockwise from north.

Information reproduced from "DSAS 4.0 Installation Instructions and User Guide" (Himmelstoss, 2009).

MGS ran each county transect sub-file and master shoreline feature class through the following suite of DSAS statistics:

- Shoreline Change Envelope (SCE)
- Net Shoreline Movement (NSM)
- Long-Term End Point Rate (EPR) – Run on all available shorelines
- Long-Term Linear Regression Rate (LRR) – Run on all available shorelines
- Short-Term 30-year EPR – Run on the ca. 1970 and ca. 2000/2010 shorelines only
- Short-Term 10-year EPR – Run on the ca. 1990 and ca. 2000/2010 shorelines only

All rates were calculated at a 90% confidence interval. DSAS statistics were output to a Microsoft Access 2013 database. The statistical output from each individual run was joined to each individual transect feature class attribute table in ArcMap 10.1. Then, MGS merged each county's individual transect feature classes into a final, county-wide merged transect feature class. Fields containing rate and supplemental statistics were re-named to more fully describe their contents. See Table 7 for a listing and description of these fields.

Table 7. Rate and supplemental statistic field names in final transect attribute tables.

Field Name	Stands For	Description
LT_EPR	Long-Term End Point Rate	Calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and most recent shoreline; this statistic was run on ALL available shorelines to provide a long-term rate for those areas with only 2 shorelines.
LT_ECI	Confidence of the LT_EPR	Measures the shoreline uncertainties used in the end-point calculation.
LT_LRR	Long-Term Linear Regression Rate	Rate is determined by fitting a least-squares regression line to all shoreline points; requires at least 3 shorelines; this statistic was run on all available shorelines.
LT_LR2	R-squared statistic (coefficient of determination) of the LT_LRR	Percentage of variance in the data that is explained by regression; values range from 1.0 to 0.0; values close to zero indicate that the best-fit line may not be a useful model.
LT_LSE	Standard error of the estimate for the LT_LRR	Assesses the accuracy of the best-fit regression line in predicting the position of a shoreline for a given point in time; smaller numbers indicate a more accurate prediction.
LT_LCI90	Uncertainty of the LT_LRR	"90" indicates the statistics were run at a 90% confidence interval.
ST_30_EPR	Short-Term 30-Year End Point Rate	Calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and most recent shoreline; this statistic was run on the ca 1970 vs. ca 2000/2010 shorelines.
ST_30_ECI	Confidence of the ST_30_EPR	Measures the shoreline uncertainties used in the ST_30_EPR calculation.
ST_10_EPR	Short-Term 10-Year End Point Rate	Calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and most recent shoreline; this statistic was run on the ca 1990 vs. ca 2000/2010 shorelines.
ST_10_ECI	Confidence of the ST_10_EPR	Measures the shoreline uncertainties used in the ST_10_EPR calculation.

Descriptions of statistics partially reproduced from "DSAS 4.0 Installation Instructions and User Guide" (Himmelstoss, 2009).

Determine Shoreline Condition

In the final, merged transect feature class files, only transects that crossed unprotected shoreline segments were attributed with rate of change data. Rates of change calculated across protected shorelines are spurious, and, as such, are not included. For instance, if, over a 50-year period, a shoreline has eroded 50 feet (ft), the rate of erosion equals –1 ft/yr. However, if, after 25 years, a bulkhead was erected along that same reach, halting shoreline retreat, the 50 feet of erosion would have occurred over a period of 25 years, not 50. The actual rate of erosion would be –2 feet/year before bulkhead construction and 0 ft/yr afterwards. The problem in determining rates of change for protected shorelines lies in not knowing the date that a man-made structure was erected (Hennessee and others, 2003b). To ensure that rates were only delivered for transects that crossed unprotected shoreline segments, MGS first had to determine the protection status of the recent shoreline.

MGS referenced two sources to determine which shoreline segments were protected. First, MGS referenced the "ATTRIBUTE" field in the NOAA CUSP shoreline attribute table. This field describes the shoreline condition. MGS created a new field in the final transect file attribute table called "NOAA_CUSP_SL_Condition". The transect was labeled "Protected" if it crossed a shoreline segment identified in the "ATTRIBUTE" field as:

- Breakwater.Bare
- Groin.Bare
- Jetty.Bare
- Man-made.Bulkhead Or Sea Wall
- Man-made.Bulkhead Or Sea Wall.Ruins
- Man-made.Canal.Non-navigable
- Man-made.Drydock.Permanent
- Man-made.Ramp
- Man-made.Rip Rap
- Man-made.Wharf or Quay
- Man-made.Wharf Or Quay.Ruins
- Man-made.Slipway

The transect was labeled "Unprotected" if it crossed a shoreline segment identified in the "ATTRIBUTE" field as:

- Natural.Apparent.Marsh Or Swamp
- Natural.Mean High Water
- Natural.Mean High Water.Approximate
- Natural.River Or Stream

Transects that did not cross the NOAA CUSP shoreline were attributed as "No Data".

For additional shoreline condition information, MGS referenced the 2002-2005 and 2002-2003 Virginia Institute of Marine Science (VIMS) shoreline inventory data collected in Anne Arundel and Baltimore Counties, respectively (Barbosa and others, 2004; Berman and others, 2006). The VIMS shoreline condition data may be viewed and downloaded online here: http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/#md. MGS referenced the Anne Arundel County "annar_sstru.shp" and Baltimore County "balt_sstru.shp" ArcGIS shapefiles. MGS created a new field in the final transect file attribute table named "VIMS_SL_Condition". Transects were attributed as "Protected" if they crossed a shoreline labeled in the "annar_sstru.shp or "balt_sstru.shp file's "STRUCTURE" attribute table field as:

- Bulkhead
- dilapidated bulkhead
- marina
- < 50 slips, marina
- > 50 slips, marina
- Miscellaneous
- Riprap
- Wharf
- Debri
- Unconventional

If transects crossed shorelines classified in the "STRUCTURE" field as jetty, groin field, or breakwater – the transects were classified as "Unprotected". For the purposes of this analysis, MGS only considered structures located coincident with the shoreline as protective structures. Additionally, if the shoreline had no value in the "STRUCTURE" field (i.e., the record was blank) – the transect was also classified as "Unprotected". Note that the VIMS shoreline did not mirror the NOAA CUSP shoreline position exactly. Transects that did not cross the VIMS shoreline (or wouldn't, even if their lengths were extended) were attributed as "No Data".

MGS then created a field called "Sum_SL_Condition" in the final merged transect file attribute tables. If a transect crossed a shoreline designated as protected by either the NOAA CUSP or VIMS data, the transect was classified as "Protected". If a transect crossed a shoreline designated as unprotected by both sources, then the transect was classified as "Unprotected". If a transect did not cross the NOAA CUSP shoreline or the VIMS shoreline, the condition status was classified as "No data".

The rates for all transects crossing a protected shoreline, and thus attributed as "Protected" in the Sum_SL_Condition field, were made null. The SCE and NSM values (distance calculations) were left intact to provide users with a distance metric to describe the shoreline change.

Generalize Erosion Rate Categories

Once shoreline condition was determined, MGS attributed the transects in the transect feature class file with generalized erosion rate categories. Both the short-term 30-year and short-term 10-year EPR rates were generalized. First, the rates were converted to feet/year by multiplying the rate values in the "ST_30_EPR" and "ST_10_EPR" fields in the final transect feature class by 3.28084 using the Field Calculator in ArcGIS 10.1. The resultant rates were stored in two new fields in the transect file, "ST_30_EPR_ft" and "ST_10_EPR_ft".

The values in these fields were then grouped into generalized erosion rate categories using the Select by Attribute tool in ArcMap 10.1 (see Table 8). The rate categories used were similar to those employed in previous MGS projects. MGS created three additional attribute table fields to store the categorized values – represented by "Level_ID" (a numerical category ID), "Erosion_Level" (a general description of the category), and "Erosion_ft" (a detailed description of the category). In order to designate which rate was categorized in the transect file, MGS appended either "ST_30_EPR_ft_" or "ST_10_EPR_ft_" to the beginning of the field names.

The general attribute table fields – Level_ID, Erosion_Level, and Erosion_ft – were also added to the attributed shoreline files.

Table 8. Generalized erosion rate categories utilized in transect and attributed shoreline files.

Level_ID	Erosion_Level	Erosion_ft
0	No change	-0.01 to 0.01 ft/yr
1	Accretion	> 0.01 ft/yr
2	Slight	-0.01 to -2.00 ft/yr
3	Low	-2.00 to -4.00 ft/yr
4	Moderate	-4.00 to -8.00 ft/yr
5	High	> -8.00 ft/yr
6	Protected	Protected area
7	No data	Insufficient shorelines to calculate 1) desired ST_30_EPR rate 2) desired ST_10_EPR rate or 3) ST_30_EPR and ST_30_EPR*
8**	No data	No transects cast; unprotected or unknown shoreline condition
9	Rates not delivered	Calculated rates suspect

** Option 1, 2, or 3 used where appropriate.*
** * This category only used in the attributed shoreline files.*

QA/QC Transect File and Rate-of-Change Statistics

Extreme rates of erosion and accretion from each rate method (LT_LRR, LT_EPR, ST_30_EPR, and ST_10_EPR) were assessed. In many instances, these extreme rates of change were suspect. Causes of suspect rates included 1) extremely complex shorelines caused DSAS to select unintended shoreline date information; 2) the shoreline and landscape appeared to have been altered by man and filled in; 3) the shoreline and landscape appeared to have been altered by man and dredged, in many cases to make a channel or a harbor area; 4) one of the shorelines represented a man-made feature e.g. a dam; 5) the historical shoreline positions were suspect; or 6) the area appeared to be an inland pond, disconnected from the main tidal water body.

For transects with suspect change rates, all rate values stored in the LT_LRR, LT_EPR, ST_30_EPR, ST_10_EPR, ST_30_EPR_ft, ST_10_EPR_ft fields were made null. In addition, all of the associated calculation uncertainties (LT_LR2, LT_LSE, LT_LCI90, LT_ECI, ST_30_ECI, and ST_10_ECI) were made null. The distance metrics of Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM) were still delivered. An attribute table field called "Notes" was added to the final transect feature class and attributed shoreline feature class files. This field contains an explanation of why rates were considered suspect and not delivered.

Assign Rate-of-Change Attributes to Recent County Shorelines

Determine Which Recent Shoreline to Attribute

MGS chose to attribute the recent ca. 2000/2010 NOAA CUSP shoreline for Anne Arundel and Baltimore Counties with generalized erosion rate categories for several reasons. First, the majority of the historical shorelines used in this DSAS analysis were sourced from NOAA. Choosing the NOAA CUSP shoreline as the recent, post-2000 shoreline for DSAS analysis maintained consistency with regards to shoreline data source. Second, the majority of the historical shorelines used in the analysis (NOAA Historical data set shorelines, NOAA National data set shorelines) are referenced to MHW. The NOAA CUSP shoreline in Anne Arundel and Baltimore Counties is also referenced to MHW, so consistency is maintained on a tidal datum basis. Although digitized at a high resolution, the CAC shorelines were digitized from non-tide coordinated aerial photography, and thus using these shorelines (when there is a tide-coordinated option from a similar time period) is not a best practice. Lastly, the NOAA CUSP shoreline was also already attributed with shoreline condition information.

Attribute the Shoreline with Generalized Erosion Rate Categories

MGS initially attributed the ca. 2000/2010 NOAA CUSP shoreline in each county with the generalized erosion rate categories detailed in Table 8, based on the short-term 30-year EPR. These rates were calculated using the ca. 1970 shoreline and the ca. 2000/2010 NOAA CUSP shoreline.

MGS color-coded the transects according to the generalized range of rates. For example, all transects characterized by “No change” (between -0.01 and 0.01 ft/yr) were displayed in black, all transects characterized as “Accretion” (greater than 0.01 ft/yr) were displayed in green, all transects characterized by “Slight” erosion (between -0.01 and -2.00 ft/yr) were displayed in yellow, etc. Visually scanning the display, MGS generally cut the shoreline wherever the transect color changed, highlighted the newly cut segment, and assigned the appropriate Level_ID, Erosion_Level, and Erosion_ft values to those fields in the attributed shoreline table.

For those transects with no short-term 30-year EPR data, MGS attributed the NOAA CUSP shoreline with the short-term 10-year EPR (calculated from the ca. 1990 shoreline and the ca. 2000/2010 NOAA CUSP shoreline). To designate their source, the values and descriptions in the Level_ID, Erosion_Level, and Erosion_ft attribute table fields calculated from the 10-year rate are attributed with an asterisk (*).

Similar to previous projects, MGS changed attributes only after encountering a series of four or more transects of a different color. Generally, transects were spaced at 20-meter intervals. The point of the exercise was to delineate fairly long reaches of shoreline sharing similar rates of change. MGS and CCS decided that “fairly long” meant 80 meters or more. Thus, if a series of green transects was interrupted by three yellow ones, the entire stretch was classified as though it were green. If the series of green transects was interrupted by four or more yellow ones, the shoreline was cut on either side of the green transects and assigned “yellow” rate attributes. If the series of green transects was interrupted by four or more transects of varying color, MGS cut the shoreline on either side of the varying transects and attributed the stretch as the majority color. When faced with stretches containing an equal number of transects of two colors, MGS attributed the stretch with the more aggressive category (e.g. slight erosion over accretion or no change; low erosion over slight erosion, etc.). Although the goal was to maintain fairly long reaches of similar attribution, sometimes this was not possible. In many cases, small stretches of unprotected shoreline existed between long stretches of protected shoreline. These small stretches were attributed according to their rate, regardless of length, as long as a transect crossed the shoreline. If no transect crossed the shoreline segment, the shoreline was classified as Level_ID = 8 (Table 8).

Level_ID values of 0-5 contain quantitative rate categories and are self-explanatory. Level_ID values of 6 indicate a protected shoreline. Level_ID values of 7 indicate that there were insufficient shorelines to calculate the desired ST_10_EPR and the ST_30_EPR rates. No transects were cast across shoreline segments attributed with a Level_ID of 8. The shoreline condition of Level_ID 8 segments is either unprotected or unknown. Shoreline segments attributed with a Level_ID of 9 indicate that rates were calculated, but MGS determined that the rates were suspect and should not be delivered. The “Notes” attribute table field in the transect and attributed shoreline files contains an explanation of why the transect/shoreline segment was attributed as Level_ID 9.

Final Deliverables

The following deliverables are available for this project:

<u>GIS Files</u>

- "SLRoC_Final_Files.mdb"
  - Personal geodatabase; contains the master shoreline, baseline, transect, and attributed shoreline feature class files for Anne Arundel and Baltimore Counties. As specified in the SOW, all files are georeferenced to MD State Plane NAD 1983 (m).
  - Files contained within:
    - "Anne_Arundel_Co_Shorelines"
      - This line feature class contains the shoreline data sets used in the final DSAS analysis for Anne Arundel County. MGS recommends symbolizing this file by the “DSAS_SLINF” or “DSAS_DEC” attribute table fields.
    - "Baltimore_Co_Shorelines"
      - This line feature class contains the shoreline data sets used in the final DSAS analysis for Baltimore County. MGS recommends symbolizing this file by the “DSAS_SLINF” or “DSAS_DEC” attribute table fields.
    - “Anne_Arundel_Co_Baselines"
      - This line feature class contains all of the seaward (offshore) baselines utilized in the final DSAS analysis in Anne Arundel

County. The baselines were created approximately 10 meters away from the shorelines.

- "Baltimore_Co_Baselines"
  - This line feature class contains all of the seaward (offshore) baselines utilized in the final DSAS analysis in Baltimore County. The baselines were created approximately 10 meters away from the shorelines.
- “Anne_Arundel_Co_Transects"
  - This line feature class contains 39,069 transects with associated DSAS statistics. Only transects that cross unprotected shoreline segments are attributed with rate of change data.
- "Baltimore_Co_Transects"
  - This line feature class contains 20,083 transects with associated DSAS statistics. Only transects that cross unprotected shoreline segments are attributed with rate of change data.
- "Anne_Arundel_Co_Attributed_Shoreline"
  - This line feature class consists of the recent NOAA CUSP shoreline, clipped to Anne Arundel County boundaries and attributed with rate of change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields. This shoreline was attributed with the short-term 30-year EPR, unless otherwise indicated with an asterisk (*) in the Level_ID, Erosion_Level, or Erosion_ft attribute fields. The asterisk indicates that the shoreline was attributed with the short-term 10-year EPR.
- "Baltimore_Co_Attributed_Shoreline"
  - This line feature class consists of the recent NOAA CUSP shoreline, clipped to Baltimore County boundaries and attributed with rate of change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields. This shoreline was attributed with the short-term 30-year EPR, unless otherwise indicated with an asterisk (*) in the Level_ID, Erosion_Level, or Erosion_ft attribute fields. The asterisk indicates that the shoreline was attributed with the short-term 10-year EPR.

Metadata

Corresponding FGDC-compliant metadata for the above GIS files are also available:

- Anne_Arundel_Co_Shorelines_FGDC_Metadata.xml
- Anne_Arundel_Co_Baselines_FGDC_Metadata.xml
- Anne_Arundel_Co_Transects_FGDC_Metadata.xml
- Anne_Arundel_Co_Attributed_Shoreline_FGDC_Metadata.xml
- Baltimore_Co_Shorelines_FGDC_Metadata.xml

- Baltimore_Co_Baselines_FGDC_Metadata.xml
- Baltimore_Co_Transects_FGDC_Metadata.xml
- Baltimore_Co_Attributed_Shoreline_FGDC_Metadata.xml

Final Report

"Updating_Shoreline_Rates_of_Change_AA_BALT_Final_Report_v2.doc"

RESULTS AND DISCUSSION

Once rate-of-change attributes were assigned to the recent county shorelines, MGS compiled summary information about shoreline change for each county. Total shoreline miles for each county as well as a breakdown by rate-of-change category are presented in Table 9. Corresponding percentages, based only on shorelines assigned *numerical* rate attributes (erosion, accretion, or no change) are presented in Table 10.

Based on the length of the recent NOAA CUSP shoreline, Anne Arundel County's shoreline totals 532.8 miles (note that this number does not include the Anne Arundel County portion of the Patuxent River, which was not available as part of the NOAA CUSP shoreline at the time of this project). The Baltimore County NOAA CUSP shoreline (including the Baltimore City limits) totals 321.6 miles. Despite the missing Anne Arundel County Patuxent River shoreline, both county's total shoreline lengths surpass the previous lengths reported of 507.8 and 293 miles for Anne Arundel and Baltimore County (including Baltimore City), respectively (Hennessee and others, 2003). The lengths from this 2003 MGS report were extracted from the ca. 1990 MGS shoreline. The current shoreline length increase is due to the NOAA CUSP shoreline's inclusion of more headwater reaches in streams and the addition of minor tributaries. Additionally, the NOAA CUSP shoreline includes several inlets and inland ponds in both counties (for example, Big Pond, Flag Pond, Deep Creek, Deep Cove Creek, etc. in Anne Arundel County) that were not included as part of the ca. 1990 MGS shoreline.

Based on the extraction of shoreline condition (i.e. protected vs. unprotected) from the NOAA CUSP shoreline data set and the VIMS shoreline inventory data set, 255.4 miles (or 47.9%) of Anne Arundel County's shoreline is protected. In Baltimore County, 164.0 miles (or 51.0%) of the shoreline is protected. The protected statistics from the 2003 MGS report are 23.8 miles (4.69%) and 67.6 miles (23.1%) for Anne Arundel and Baltimore Counties, respectively (Hennessee and others, 2003). These apparent substantial increases in shoreline protection are due to several factors.

First, the figures in the 2003 MGS report from Hennessee and others underestimates the length of protected shoreline. Along the curvilinear shores of the Chesapeake Bay, Bay tributaries, and the coastal bays, the most obvious indication of "structure" from aerial photography is a straightened or angular shoreline, particularly along a developed reach. The resolution of the orthophotography used to extract the ca. 1990 MGS shoreline (one pixel represented 4 ft^2) is such that a short or narrow erosion control structure, such as a bulkhead, might not be obvious in the image. During the 1990s MGS projects, if the interpreter had any doubt that the shoreline

Table 9. Shoreline length, in miles, by rate-of-change category, grouped by county.

COUNTY	(1) Accretion (mi)	(0) No change (mi)	(2) Slight erosion (mi)	(3) Low erosion (mi)	(4) Moderate erosion (mi)	(5) High erosion (mi)	(6) Protected (mi)	(7) No data (insufficient shorelines) (mi)	(8) No data (no transects cast) (mi)	(9) Rates not delivered (mi)	(0-9) TOTAL (mi)	(0-5) Subtotal (mi)	(0-5) Classified with numerical rate attributes (%)
Anne Arundel	62.9	0.3	122.2	16.6	4.7	0.8	255.4	9.1	59.6	1.2	532.8	207.5	38.9
Baltimore *(incl. Baltimore City)*	37.8	0.4	71.4	4.5	0.9	0.1	164.0	0.2	38.5	3.8	321.6	115.1	35.8
TOTAL	**100.7**	**0.7**	**193.6**	**21.1**	**5.6**	**0.9**	**419.4**	**9.3**	**98.1**	**5.0**	**854.4**	**322.6**	**37.8**

Based on the length of the recent shoreline assigned rate-of-change attributes. The numbers in parentheses in the column heads correspond to the Level_ID codes in Table 8.

Table 10. Shoreline length as a percentage of the length assigned numerical rate attributes (erosion, accretion, and no change).

COUNTY	(1) Accretion (mi)	(1) Accretion (%)	(0) No change (mi)	(0) No change (%)	(2) Slight erosion (mi)	(2) Slight erosion (%)	(3) Low erosion (mi)	(3) Low erosion (%)	(4) Moderate erosion (mi)	(4) Moderate erosion (%)	(5) High erosion (mi)	(5) High erosion (%)	(0-5) TOTAL (mi)	(0-5) SUM (%)
Anne Arundel	62.9	30.3	0.3	0.2	122.2	58.9	16.6	8.0	4.7	2.3	0.8	0.4	207.5	100.0
Baltimore *(incl. Baltimore City)*	37.8	32.9	0.4	0.3	71.4	62.1	4.5	3.9	0.9	0.8	0.1	0.1	115.1	100.0
TOTAL	**100.7**	**31.2**	**0.7**	**0.2**	**193.6**	**60.0**	**21.1**	**6.5**	**5.6**	**1.7**	**0.9**	**0.3**	**322.6**	100.0

Protected shorelines, shorelines with no data, and shorelines where rates were not delivered are excluded. The numbers in parentheses in the column headings correspond to the Level_ID or rate codes in Table 8.

was "hardened," he or she assigned another shoreline type. Furthermore, a reach of shoreline stabilized by a non-structural control, such as a vegetative buffer, were classified as "vegetated" and excluded from the protection classification (Hennessee and others, 2003b).

Second, since the completion of the MGS 1990s shoreline projects, two sources of shoreline condition information have become available for Anne Arundel and Baltimore Counties – the ca. 2000/2010 NOAA CUSP shoreline data set and the ca. 2000 VIMS shoreline inventory data sets. MGS decided to utilize both of these sources in its determination of shoreline condition to take advantage of each data sets' strengths. The NOAA CUSP shoreline data set is more recent than the VIMS data set. However, the NOAA CUSP shoreline condition information was primarily interpreted from air photos. The VIMS data, although about a decade older than the NOAA CUSP data, was collected by operators in motor boats who traveled along the shoreline and manually digitized the shoreline conditions. As such, although older, this data set is likely to have a higher resolution and be more accurate in terms of the protective structures' locations at that time. For the purposes of this analysis, MGS assumed that once a shoreline was protected, it remained protected.

Of the 532.8 miles of Anne Arundel County shoreline, MGS assigned quantitative rates of change (erosion, accretion, or no change) to 207.5 miles (or 38.9%) of the total shoreline length. In Baltimore County, MGS assigned quantitative rates to 115.1 miles (or 35.8%) of the total shoreline length. Protected shorelines and shorelines with no data or suspect data were assigned qualitative attributes. Between both counties, MGS attributed a total of 9.3 miles, 98.1 miles, and 5.0 miles to the qualitative categories of No Data (insufficient shorelines to calculated desired rate), No data (no transects cast), and Rates not delivered (calculated rates suspect), respectively. In general, shoreline segments where transects were not cast consisted of the very headwater reaches of a digitized stream. Since MGS created baselines up the centerline of the streams and cast transects to either side, often times the small portion of the stream's digitized terminus ("facing" the end of the baseline) was not crossed by a transect. Additionally, if the tributary shorelines were extremely complex i.e. multiple shorelines crisscrossing each other, with no clear path upstream to draw a baseline and cast a logical transect, MGS did not create a baseline or cast transects in those areas. Another instance where a shoreline segment was classified as "No transects cast" included stretches of shoreline 80 meters or longer where MGS did not feel comfortable interpolating a rate from a transect over 80 meters away to a particular area.

Of the 207.5 miles of Anne Arundel County shoreline attributed with quantifiable change, 30.3% of the shoreline is accreting, 0.2% of the shoreline is not changing, 58.9% of the shoreline is exhibiting slight erosion, 8.0% is exhibiting low erosion, 2.3% is exhibiting moderate erosion, and 0.4% is exhibiting high erosion. Of the 115.1 miles of Baltimore County shoreline attributed with quantifiable change, 32.9% of the shoreline is accreting, 0.3% of the shoreline is not changing, 62.1% of the shoreline is exhibiting slight erosion, 3.9% is exhibiting low erosion, 0.8% is exhibiting moderate erosion, and 0.1% is exhibiting high erosion.

Tables 11 and 12 present the mean rates of change by county, broken out by the calculation method: 30-year EPR vs. 10-year EPR. Protected shorelines, shorelines with no data, and shorelines where rates were not delivered are excluded. The numbers in parentheses in the

Table 11. Mean rates of change by county using the 30-year End Point Rate calculation.

COUNTY	Mean rate of change (30-year EPR)	(1) Accretion	(0) No change	(2) Slight erosion	(3) Low erosion	(4) Moderate erosion	(5) High erosion	(0-5) SUBTOTAL	Length of shoreline attributed with 10-year EPR	(6-9) Protected / No data / Rates not delivered	Total shoreline length	Total shoreline quantified with some rate of change	Total quantified shoreline attributed with 30-year EPR
	(feet/year)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(%)
Anne Arundel	-0.28	29.6	0.3	62.5	0.0	0.5	0.0	93.9	113.6	325.3	532.8	207.5	45.3
Baltimore *(incl. Baltimore City)*	-0.40	36.8	0.4	69.9	3.7	0.9	0.1	111.9	3.2	206.5	321.6	115.1	97.2
TOTAL		**66.4**	**0.7**	**132.4**	**3.7**	**1.4**	**0.1**	**205.8**	**116.8**	**531.8**	**854.4**	**322.6**	

Table 12. Mean rates of change by county using the 10-year End Point Rate calculation.

COUNTY	Mean rate of change (10-year EPR)	(1) Accretion	(0) No change	(2) Slight erosion	(3) Low erosion	(4) Moderate erosion	(5) High erosion	(0-5) SUBTOTAL	Length of shoreline attributed with 30-year EPR	(6-9) Protected / No data / Rates not delivered	Total shoreline length	Total shoreline quantified with some rate of change	Total quantified shoreline attributed with 10-year EPR
	(feet/year)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(mi)	(%)
Anne Arundel	-0.80	33.2	0.0	59.7	15.7	4.2	0.8	113.6	93.9	325.3	532.8	207.5	54.7
Baltimore *(incl. Baltimore City)*	-0.78	1.0	0.0	1.5	0.7	0.0	0.0	3.2	111.9	206.5	321.6	115.1	2.8
TOTAL		**34.2**	**0.0**	**61.2**	**16.4**	**4.2**	**0.8**	**116.8**	**205.8**	**531.8**	**854.4**	**322.6**	

column headings correspond to the Level_ID or rate codes in Table 8. Approximately 207.5 miles of shoreline in Anne Arundel County were attributed with rate-of-change data. Of those miles, 93.9 miles (or 45.3%) were attributed with the 30-year EPR rate and 113.6 miles (or 54.7%) were attributed with the 10-year EPR rate (Tables 11 and 12). The average rate of change in Anne Arundel County for the 30-year EPR portion of the shoreline was -0.28 ft/yr, and the average rate of change for the 10-year EPR portion of the shoreline was -0.80 ft/yr. Approximately 115.1 miles of shoreline in Baltimore County (including the Baltimore City limits) were attributed with numerical rate-of-change data. Of those miles, 111.9 miles (or 97.2%) were attributed with the 30-year EPR rate and 3.2 miles (or 2.8%) were attributed with the 10-year EPR rate (Tables 11 and 12). The average rate of change in Baltimore County for the 30-year EPR portion of shoreline was -0.40 ft/yr, and the average rate of change for the 10-year EPR portion of the shoreline was -0.78 ft/yr.

Possible reasons for the higher rates of change calculated using the 10-year EPR include 1) the ca. 1990 MGS shorelines are not tide-coordinated and thus may not represent as accurate a shoreline position as the ca. 1970 NOAA shoreline data sets, which are referenced to MHW; and 2) several large storms have impacted Maryland since the 1990s and likely caused the shorelines to change in the approximate 10-year time span reflected in the 10-year EPR rate. Some of these storms included Tropical Storms Bertha and Fran (1996), Hurricanes Dennis and Floyd (1999), Hurricane Isabel (2003), and Hurricane Irene (2011). Although these storms also fall within the 30-year EPR time span, the 30-year EPR rate is tempered due to the longer time period over which the rate was calculated. As such, longer term trends of lower erosion are reflected in the 30-year rate.

Table 13 presents the weighted rate-of-change average calculated for Anne Arundel and Baltimore Counties, based on the 30-year EPR, the 10-year EPR, and the length of shoreline attributed with each of these rates. Using the method of weighted averages, the average rate of change calculated along Anne Arundel County's unprotected shoreline was -0.56 ft/yr. The average rate of change calculated along Baltimore County's unprotected shoreline was -0.41 ft/yr. Both erosion rates fall within the "Slight" erosion rate category.

Table 14 presents a summary of the long-term and short-term rates of change calculated for each county. These mean rates only apply to those segments of shoreline where quantifiable rates of change were calculated. The long-term LRR and EPR rates calculated for Anne Arundel County were -0.16 ft/yr and -0.30 ft/yr, respectively. The long-term LRR and EPR rates calculated for Baltimore County were -0.43 ft/yr and -0.39 ft/yr, respectively. The long-term rates were calculated across an approximate 70-80 year time span, depending on the shoreline data available at each transect. When looking at long-term rates, MGS recommends using the LRR rate over the EPR rate when possible. The LRR rate utilizes all available shoreline data to calculate rates of change (assuming there are three or more shorelines at the transect for analysis). MGS calculated the long-term EPR rate to ensure that long-term rates were available for those transects with only two shorelines. As previously discussed, the 10-year EPR rates for both counties are greater than the 30-year EPR rates, as well as the long-term EPR and LRR rates. In Anne Arundel County, the short-term weighted average rate (-0.56 ft/yr) is greater than both long-term rates. In Baltimore County, the short-term weighted average rate and the long-term LRR and EPR are similar at -0.41 ft/yr, -0.43 ft/yr, and -0.39 ft/yr, respectively.

Table 13. Mean rate of change by county using the method of weighted averages.

COUNTY	Mean rate of change (30-year EPR) (ft/yr)	Length of shoreline attributed with 30-year EPR (mi)	Mean rate of change (10-year EPR) (ft/yr)	Length of shoreline attributed with 10-year EPR (mi)	Mean rate of change (Weighted average of both EPR methods) (ft/yr)	Total length of shoreline attributed with EPR statistics (mi)
Anne Arundel	-0.28	93.9	-0.80	113.6	**-0.56**	207.5
Baltimore *(incl. Baltimore City)*	-0.40	111.9	-0.78	3.2	**-0.41**	115.1
TOTAL		**205.80**		**116.80**		**322.60**

Table 14. Summary of mean long-term and short-term rates of change by county.

	Long-Term Rate (ft/yr)		Short-Term Rate (ft/yr)		
COUNTY	**LRR**	**EPR**	**30-year EPR**	**10-year EPR**	**Weighted Average**
Anne Arundel	-0.16	-0.30	-0.28	-0.80	-0.56
Baltimore *(incl. Baltimore City)*	-0.43	-0.39	-0.40	-0.78	-0.41

SUMMARY AND CONCLUSIONS

For Anne Arundel and Baltimore Counties (including the Baltimore City limits), MGS acquired historical and recent (post-2000) shorelines from various sources, including NOAA and MD DNR CAC. These “new” historical and recent shorelines were added to MGS’s existing digital shorelines data set, originally assembled in the 1990s. In many cases, the newly acquired shorelines replaced the MGS shorelines.

MGS then generated updated rate of change information for Anne Arundel and Baltimore Counties using ESRI’s ArcGIS 10.1 and DSAS v4.3, a computer program developed by the USGS. DSAS used a time series of digital shorelines to generate rates of erosion and accretion for shore-normal transects spaced at 20-meter intervals along the shorelines. Shorelines used in the final Anne Arundel County DSAS analysis ranged in date from 1932-2010; shorelines used in the final Baltimore County DSAS analysis ranged in date from 1933-2011. DSAS analyzed rates of change across 39,069 transects in Anne Arundel County, and 20,839 transects in Baltimore County. DSAS calculated the long-term LRR, long-term EPR, short-term 30-year EPR, and the short-term 10-year EPR across all viable transects.

MGS then grouped the rates of change into generalized categories (i.e., accretion, 0-2 ft/yr of erosion, 2-4 ft/yr of erosion, etc.) based on the results of the short-term 30-year EPR analysis. If no rates were available from the 30-year EPR, the rates were grouped according to the short-term 10-year EPR analysis. MGS assigned the rate categories as attributes to the ca. 2000/2010 NOAA CUSP data set shoreline for each county. In addition to the numerical rate categories, three other attributes – "Protected", "No Data", and "Rates not delivered" were applied respectively to shorelines protected by man-made structures; shorelines for which insufficient data was available to calculate the desired rate, or no transects were cast; or shorelines where the calculated rates where suspect.

Based on the length of the recent NOAA CUSP shoreline, Anne Arundel County's shoreline totals 532.8 miles (note that this number does not include the Anne Arundel County portion of the Patuxent River, which was not available as part of the NOAA CUSP shoreline at the time of this project). The Baltimore County NOAA CUSP shoreline (including the Baltimore City limits) totals 321.6 miles. Despite the missing Anne Arundel County Patuxent River shoreline, both county's total shoreline lengths surpass the previous lengths reported of 507.8 and 293 miles for Anne Arundel and Baltimore County (including Baltimore City), respectively (Hennessee and others, 2003b). The lengths from the 2003 Hennessee report were extracted from the ca. 1990 MGS shoreline. The current shoreline length increase is due to the NOAA CUSP shoreline's inclusion of more headwater reaches in streams and the addition of minor tributaries. Additionally, the NOAA CUSP shoreline includes several inlets and inland ponds in both counties.

Numerical rate-of-change attributes were assigned to only 38.9 percent of the shoreline in Anne Arundel County, and 35.8 percent of the shoreline in Baltimore County. The balance of the shoreline was either protected, did not have any associated rate data, or the calculated rates were suspect.

Overall, the average annual rate of change for the quantifiable shorelines in Anne Arundel County is -0.56 ft/year; for Baltimore County, the average annual rate is -0.41 ft/year. These numbers were calculated using a weighted average of the short-term 10-year and 30-year rates, based on the length of shoreline attributed with those rates. Of the 207.5 miles of shoreline in Anne Arundel County attributed with rates, an estimated 144.3 miles (69.6%) are eroding. Of the 115.1 miles of shoreline in Baltimore County attributed with rates, an estimated 76.9 miles (66.8%) are eroding. In both counties, however, the majority of the erosion is slight – less than 2.0 ft/yr. Erosion exceeds 2.0 ft/yr along the remaining miles of retreating shoreline. Of the 207.5 miles of shoreline in Anne Arundel County attributed with rates, an estimated 62.9 miles (30.3%) are accreting. Of the 115.1 miles of shoreline in Baltimore County attributed with rates, an estimated 37.8 miles (32.8%) are accreting.

The long-term LRR and EPR rates calculated for Anne Arundel County were -0.16 ft/yr and -0.30 ft/yr, respectively. The long-term LRR and EPR rates calculated for Baltimore County were -0.43 ft/yr and -0.39 ft/yr, respectively. The 10-year EPR rates for both counties are greater than the 30-year EPR rates, as well as the long-term EPR and LRR rates. In Anne Arundel County, the short-term weighted average rate (-0.56 ft/yr) is greater than both long-term rates. In Baltimore County, the short-term weighted average rate and the long-term LRR and EPR are similar at -0.41 ft/yr, -0.43 ft/yr, and -0.39 ft/yr, respectively.

The primary impetus for the project was to enable coastal managers to identify areas subject to various rates of erosion and to incorporate that information into regional shore erosion control strategies, particularly in anticipation of sea level rise. Other coastal researchers, planners, and managers, as well as interested citizens who need general information about rates of shoreline change should also find the data set of value. To better serve these needs, this data set will be posted to MD DNR's Coastal Atlas, an interactive map service available here: http://gisapps.dnr.state.md.us/coastalatlas/iMap-master/basicviewer/index.html.

MGS does not recommend using these updated rates of change to predict future shoreline positions. According to the USGS, the DSAS rates computed at each transect only describe the historic shoreline behavior up to the date of the most recent shoreline, and "there is little agreement on the best methodology for forecasting shoreline position" (Himmelstoss, 2012).

MGS is currently in the process of calculating updated rate-of-change statistics for Calvert and Prince George's Counties in Maryland. This project is scheduled for completion by April 2016. MGS hopes to further refine its estimates of shoreline uncertainty and possibly incorporate ca. 2010 Light Detection and Ranging (LiDAR) shorelines into its DSAS analysis during this effort. These projects comprise the beginning stages of an effort to complete a statewide shoreline change update for all of the tidewater counties in Maryland.

REFERENCES

Anders, F.J., and Byrnes, M.R., 1991, Accuracy of shoreline change rates as determined from maps and aerial photographs: Shore and Beach, January 1991, pp. 17-26.

Barbosa, A., Berman, M., Berquist, H., Dewing, S., Hershner, C., Rea, H., Rudnicky, T., Schatt, D., Weiss, D., and Woods, H., 2004, Development of the Maryland Shoreline Inventory – Methods and Guidelines for Baltimore County and the City of Baltimore: Virginia Institute of Marine Science, Gloucester Point, Va., 31 p.

Berman, M., Berquist, H., Killeen, S., Nunez, K., Reay, K., Rudnicky, T., Schatt, D., and Weiss, D., 2006, Development of the Maryland Shoreline Inventory – Methods and Guidelines for Anne Arundel County: Virginia Institute of Marine Science, Gloucester Point, Va., 30 p.

Conkwright, R.D. (compiler), 1975, *Historical Shorelines and Erosion Rates Atlas*: Maryland Geological Survey, Baltimore, Md., 4 volumes.

Crowell, M., Leatherman, S.P., and Buckley, M.K., 1991, Historical shoreline change— Error analysis and mapping accuracy: Journal of Coastal Research, v. 7, pp. 839-852.

Dolan, R., Fenster, M.S., and Holme, S.J., 1991, Temporal analysis of shoreline recession and accretion: Journal of Coastal Research, v. 7, pp. 723-744.

Eastern Shore Regional GIS Cooperative (ESRGC), 2013, Critical Area Map Update Methodology: Eastern Shore Regional GIS Cooperative (ESRGC), Salisbury, Md., 2 p.

Hapke, C.J., Himmelstoss, E.A., Kratzmann, M., List, J.H., and Thieler, E.R., 2010, National assessment of shoreline change: Historical shoreline change along the New England and Mid-Atlantic coasts: U.S. Geological Survey Open-File Report 2010-1118, 57p.

Hennessee, L., 1999, Metadata: Historical shorelines, 1849-1989, northern coastal bays, Maryland (CD-ROM SCNCB_SL): Maryland Geological Survey, Baltimore, Md.

Hennessee, L., 2000a, Metadata: Historical shorelines, 1841-1976, Chesapeake Bay region of Maryland (CD-ROM SCSL_RVC): Maryland Geological Survey, Baltimore, Md.

Hennessee, L., 2000b, Metadata: Maryland digital shoreline acquisition from recent orthophotography: Recent (*ca.* 1990) shorelines, coastal regions of Maryland (CD-ROM RecentSL): Maryland Geological Survey, Baltimore, Md.

Hennessee, L., 2000c, Metadata: Historical shorelines, 1843-1989, southern coastal bays, Maryland (CD-ROM SCSCB_SL): Maryland Geological Survey, Baltimore, Md.

Hennessee, L., 2001, Acquiring a modern digital shoreline for Maryland from recent (1988-1995) orthophotography: Coastal and Estuarine Geology File Report No. 00-7, Maryland

Geological Survey, Baltimore, Md., 18 p.

Hennessee, L., Kerhin, R.T., Isoldi, J.J., Gast, R.A., and Robertson, M.S., 1997, Coastal erosion, Chesapeake Bay, Maryland: A digital approach: Proceedings of the Twelfth International Conference and Workshops on Applied Geologic Remote Sensing, Denver, Colorado, 17-19 November 1997, p. I-309 to I-314.

Hennessee, L., Miller, J., Weaver, B., Henderson, J., Pembroke, J., and Proudfoot, L., 2003a, *Shoreline Changes* maps: Coastal and Estuarine Geology File Report 03-05, Maryland Geological Survey, Baltimore, Md., 21 p.

Hennessee, L., and Stott, J., 1999, Shoreline changes and erosion rates for the northern coastal bays of Maryland: Coastal and Estuarine Geology File Report No. 99-7, Maryland Geological Survey, Baltimore, Md., 30 p.

Hennessee, L., Stott, J., and Bethke, T., 2002a, Shoreline changes and erosion rates for the southern coastal bays of Maryland: Coastal and Estuarine Geology File Report No. 00-1, Maryland Geological Survey, Baltimore, Md., 41 p.

Hennessee, L., Valentino, M., and Lesh, A., 2003, Determining Shoreline Erosion Rates for the Coastal Regions of Maryland (Part 2): Coastal and Estuarine Geology File Report No. 03-01, Maryland Geological Survey, Baltimore, Md., 57 p.

Hennessee, L., Valentino, M., and Lesh, A., 2003b, Updating Shore Erosion Rates in Maryland: Coastal and Estuarine Geology File Report No. 03-05, Maryland Geological Survey, Baltimore, Md., 31 p.

Hennessee, L., Valentino, M., Lesh, A., and Myers, L., 2002, Determining Shoreline Erosion Rates for the Coastal Regions of Maryland (Part 1): Coastal and Estuarine Geology File Report No. 02-04, Maryland Geological Survey, Baltimore, Md., 36 p.

Himmelstoss, E., 2009, DSAS 4.0 Installation Instructions and User Guide" *in:* Thieler, E.R., Himmelstoss, E. A., Zichichi, J.L., and Ergul, Ayhan, 2009. Digital Shoreline Analysis System (DSAS) version 4.0 – An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278. *updated for version 4.3.

Himmelstoss, E., 2012, August 21, Re: Shoreline future prediction/intercept WLR ! [Online forum comment]. Retrieved from https://woodshole.er.usgs.gov/discus/messages/2/702.html?1345647239.

Kerhin, R.T., Hennessee, E.L., Isoldi, J.J., and Gast, R.A., 1994, 1997, *Shoreline Changes*: Maryland Geological Survey, Baltimore, Md., 90 maps.

Miller, K.M., 1995, Digital orthophoto quarter quad metadata: Maryland Department of Natural Resources, Annapolis, Md.

Miller, K.M., 1997, Maryland DNR wetlands inventory metadata: Maryland Department of Natural Resources, Annapolis, Md.

Moore, L.J., 2000, Shoreline mapping techniques: Journal of Coastal Research, v. 16, pp. 111-124.

National Oceanic and Atmospheric Administration (NOAA), (n.d.), *NOAA Continually Updated Shoreline Product (CUSP).* http://shoreline.noaa.gov/data/datasheets/cusp.html.

National Oceanic and Atmospheric Administration (NOAA), (n.d.), *NOAA Historical Surveys (T-sheets).* http://shoreline.noaa.gov/data/datasheets/t-sheets.html.

National Oceanic and Atmospheric Administration (NOAA), (n.d.), *NOAA National Shoreline.* http://shoreline.noaa.gov/data/datasheets/index.html.

Shalowitz, A.L., 1964, *Shore and Sea Boundaries*: U.S. Government Printing Office, Washington, D.C., Publication 10-1, Vol. 2, 747 p.

Singewald, J.T., and Slaughter, T.H., 1949, *Shore Erosion in Tidewater Maryland: Bulletin 6*: Maryland Department of Geology, Mines, and Mineral Resources, Baltimore, Md., 141 p.

Stott, J.A., Hennessee, E.L., and Kerhin, R.T., 1999, 2000, *Shoreline Changes*: Maryland Geological Survey, Baltimore, Md., 9 maps.

Thieler, R., 2014, July 7, Re: WLR calculation [Online forum comment]. Retrieved from https://woodshole.er.usgs.gov/discus/messages/2/785.html?1404737665.

Thieler, E.R., and Danforth, W.W., 1994, Historical shore-line mapping (1)— Improving techniques and reducing positioning errors: Journal of Coastal Research, v. 10, p. 549-563.

Thieler, E.R., Himmelstoss, E. A., Zichichi, J.L., and Ergul, Ayhan, 2009. Digital Shoreline Analysis System (DSAS) version 4.0 – An ArcGIS extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2008-1278. *current version 4.3