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

COASTAL AND ENVIRONMENTAL GEOLOGY
FILE REPORT NO. 2016-04

Updating Shoreline Rates of Change in Calvert and Prince George's Counties, Maryland

by
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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.
NA13NOS4190136

April 28, 2016

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This report was prepared by Maryland Geological Survey under award number NA13NOS4190136 from the Office of Ocean and Coastal Resource Management (OCRM), National Oceanic and Atmospheric Administration (NOAA), through the Maryland Department of Natural Resources Chesapeake and Coastal Service. The statements, findings, conclusions and recommendations are those of the author(s) and do not necessarily reflect the view of NOAA or the U.S. Department of Commerce.

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Acronyms and Abbreviations Used in This Report	
Acronym/Abbreviation	***Description***
CAC	Critical Area Commission
CCS	Chesapeake and Coastal Service
CIR	Color Infrared
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
LT	Long-Term
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
ST	Short-Term
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 authors wish to thank:

Ms. Catherine McCall, Mr. Chris Cortina, Ms. Laura Younger, Mr. Bhaskar Subramanian, Mr. George Edmonds, and Ms. Marion Clement 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., Mr. Stephen Van Ryswick, and Ms. Heather Quinn of MGS for providing valuable technical guidance and 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 total data revision, and Maryland's shorelines have continued to change, particularly in response to storms. To calculate updated rates of change for Calvert and Prince George's 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 newly acquired shorelines complemented and updated MGS's existing digital shoreline data set. DSAS generated almost 16,300 transects in Calvert County and almost 8,200 transects in Prince George's County. These updated shoreline data sets and transect files were used as input to the DSAS program to calculate long-term and short-term rates of erosion and accretion. Using DSAS, MGS calculated rates of long-term change (typically spanning 70-80 years) using the linear regression rate (LRR) and end point rate (EPR) method. Short-term rates of change – typically spanning about 10, 30, and 40 years – were calculated using the EPR method. Negative rates indicate erosion; positive rates indicate accretion. The mean long-term LRR and EPR rates calculated for Calvert County were -0.30 feet/year and -0.20 feet/year, respectively. The mean long-term LRR and EPR rates calculated for Prince George's County were -0.44 feet/year and -0.58 feet/year, respectively. In Calvert County, the mean short-term 10-year EPR (-0.51 feet/year) is less erosional than the mean short-term 40-year EPR (-0.63 feet/year). In Prince George's County, the mean short-term 10-year EPR (-1.27 feet/year) is more erosional than the mean short-term 30-year EPR (accreting at a very low 0.01 feet/year; essentially no change). The mean short-term 10-year EPR rates calculated for both counties are more erosional than the long-term mean LRR and EPR rates. MGS generalized the short-term DSAS results and assigned rate-of-change attributes (e.g. no change, accretion, slight erosion, low erosion, moderate erosion, high erosion) to recent shorelines in Calvert and Prince George's Counties. These attributed shoreline files provide a visually simple summary of the much larger database of shoreline rates of change data. This updated rate of change data set will be useful to coastal researchers and managers in need of general information about shoreline advance and retreat. This project is the second project in an overall effort to update the shoreline rates of change data for all 16 tidewater counties in Maryland. To date, the completed counties include Anne Arundel, Baltimore, Calvert, and Prince George's Counties. MGS does not recommend using these updated rates of change to predict future shoreline positions or future rates of change. The DSAS rates computed at each transect (and used to attribute the recent shorelines) only describe the historic shoreline behavior up to the date of the most recent shoreline used in the particular DSAS rate analysis.

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 Calvert and Prince George's Counties, MGS compiled both historical and recent (post-2000) shorelines from various sources to complement and update its existing digital shoreline data set. For both 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 1933-2007 and 1937-2010 for Calvert and Prince George's 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 digital shoreline data set. DSAS then cast shore-normal transects from the baselines across all of the shorelines. Transects were spaced 20 meters apart. Using DSAS, MGS calculated a "long-term" (~70-80-year) rate of change using the linear regression rate (LRR) method and the end point rate (EPR) method, and a "short-term" ~10-year rate of change using the EPR method in both counties. Additionally, MGS calculated a short-term ~40-year EPR in Calvert County and a short-term ~30-year EPR in Prince George's County. Once DSAS computed updated rate-of-change statistics, MGS assigned generalized short-term erosion rate categories to a recent shoreline for each county. This recent shoreline consisted of the NOAA CUSP shoreline, supplemented with the CAC shoreline in areas of missing NOAA CUSP coverage. 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. Additionally, 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 Calvert and Prince George's Counties, shaded in green and tan, respectively (Figure 1). In Figure 1, counties completed in previous projects are shaded in gray, and the blue lines represent shorelines in Maryland's sixteen tidewater counties.

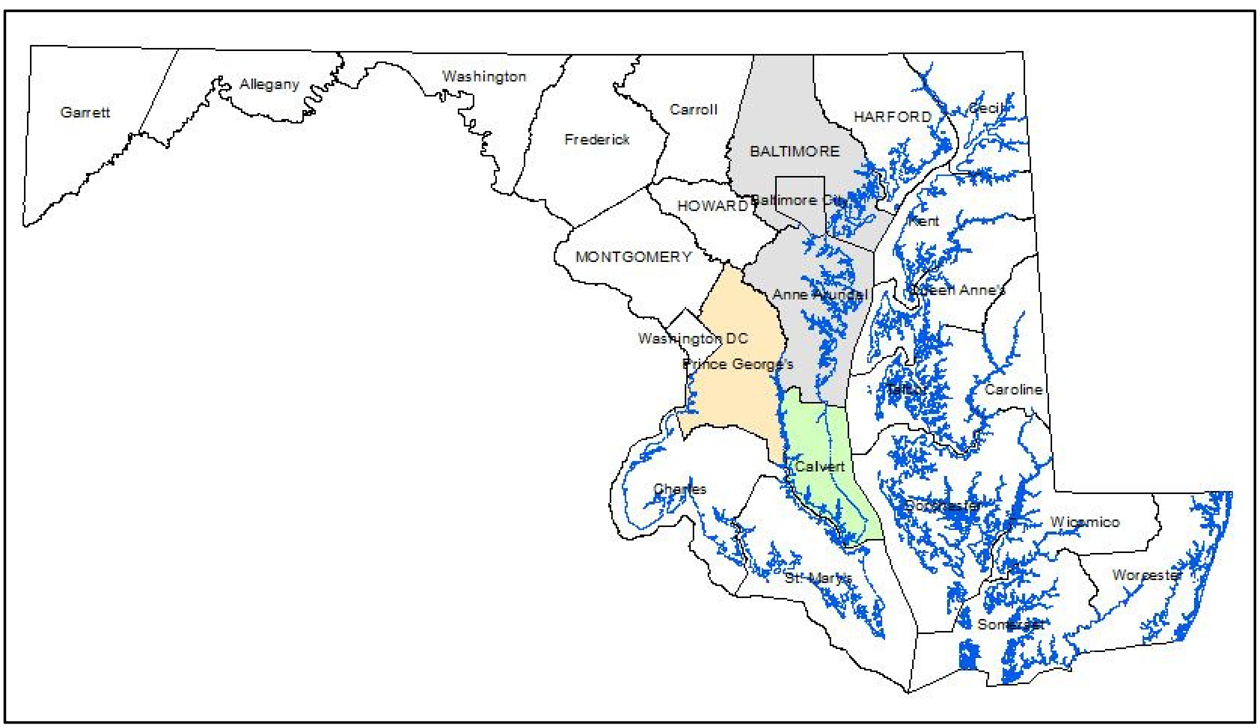


Figure 1. Maryland Counties (shaded) for which shoreline rates of change have been determined.

OBJECTIVES

The objectives of this project were to:

1. Acquire newly available historical and recent (post-2000) shorelines for Calvert and Prince George's 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 short-term erosion rate categories to recent shorelines in Calvert and Prince George's Counties.

BACKGROUND

From previous shoreline change investigations completed in the 1990s, MGS already had an in-house digital shoreline data set for Maryland 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 chose to use NOAA 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 (e.g. both agencies had digitized the same historical NOAA topographic sheets, or "T-sheets"), MGS chose to utilize the NOAA data sets in its analysis. 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. Additionally, in areas where a NOAA CUSP shoreline was not available, the CAC shoreline was utilized in DSAS analysis.

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 the shorelines 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; recent shorelines sourced from the NOAA CUSP data set are shaded in gray; and recent shorelines sourced from CAC are shaded in pink.

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 (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; Hennessee, 2000a; Hennessee, 2000b; Hennessee, 2000c).

Table 1. Final shorelines utilized in DSAS analysis for Calvert and Prince George's Counties, Maryland, sorted by year.

County	Year	Source of Shoreline	NOAA Project ID
Calvert	1933	NOAA National	MD1942A3
	1934	NOAA National	MD1934A
	1938	NOAA National	CS288
	1938, 1942	NOAA National	CS278A
	1942	NOAA National	CS307
	1943	NOAA National	MD1941A2
	1941, 1944	NOAA National	MD1941A1
	1960	NOAA National	PH6008
	1993-1994	MGS ca. 1990	n/a
	2005-2006	NOAA CUSP	CUSP
	2007	CAC	n/a
Prince George's	1937	NOAA National	DC38A
	1937	NOAA National	PH12
	1942	NOAA National	CS307
	1938, 1943	NOAA National	CS288
	1958	NOAA National	MD133F02
	1972	NOAA National	PH7012
	1993-1994	MGS ca. 1990	n/a
	2007	CAC	n/a
	2005-2006, 2008-2010	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 this 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 (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).

These digital shorelines were not used in the final DSAS analysis for Calvert and Prince George’s Counties. MGS sourced digital shorelines for this time period from the NOAA National shoreline data set.

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 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).

These digital shorelines were not used in the final DSAS analysis for Calvert and Prince George’s Counties. MGS sourced digital shorelines for this time period from the NOAA National shoreline data set.

Shorelines Extracted from Wetlands Delineation (1988-1995)

Shorelines dating from 1988 to 1995 (ca. 1990) 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). These digital shorelines are not referenced to a tidal datum.

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 boundaries 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 Geographic Information System (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 MGS digital shorelines were utilized in the final DSAS analysis for both Calvert and Prince George's Counties. MGS was unable to source a ca. 1990 shoreline from the available NOAA shoreline data sets suitable for shoreline rates of change analysis.

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", range in scale from 1:10,000 to 1:60,000, and are referenced either to MHW or mean lower low water (MLLW) (*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 approximately 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 did not utilize NOAA Historical (T-sheet) shorelines in its final Calvert or Prince George's Counties DSAS analysis since identical data sets were available from the NOAA National shoreline data set.

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 1:4,800 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 final DSAS analysis in Calvert County, MGS utilized the following eight NOAA National Shoreline data sets: CS278A, CS288, MD1932A3, MD1934A, CS307, MD1941A1, MD1941A2, and PH6008.

In Prince George's County final DSAS analysis, MGS utilized the following six NOAA National Shoreline data sets: CS288, DC38A, PH12, CS307, MD133F02, and PH7012.

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 this recent NOAA CUSP shoreline in its final DSAS analysis for Calvert and Prince George's Counties. Since NOAA CUSP coverage was not comprehensive in both counties, MGS decided to supplement the NOAA CUSP coverage with CAC shorelines in areas where NOAA CUSP shorelines were not available. As such, the NOAA CUSP and CAC shorelines comprised the "recent" shoreline utilized in DSAS analysis.

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 Calvert and Prince George's Counties in 2007. 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.

At the time MGS acquired the CAC shorelines (May 2015), the Calvert County CAC shoreline position was still "proposed" i.e. not completely through review by Calvert County and thus not yet formally adopted as part of their Critical Area maps. However, ESRGC did not expect any more changes to be made to the Calvert County CAC shoreline position. The Prince George's County CAC shoreline was already formally adopted by Prince George's County and approved as part of their Critical Area Maps at the time that MGS acquired the shoreline.

In the final DSAS analysis, MGS utilized portions of this recent CAC shorelines in areas of Calvert and Prince George's Counties where NOAA CUSP shoreline coverage was not available. As such, the NOAA CUSP and CAC shorelines comprised the "recent" shoreline utilized in DSAS analysis.

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):

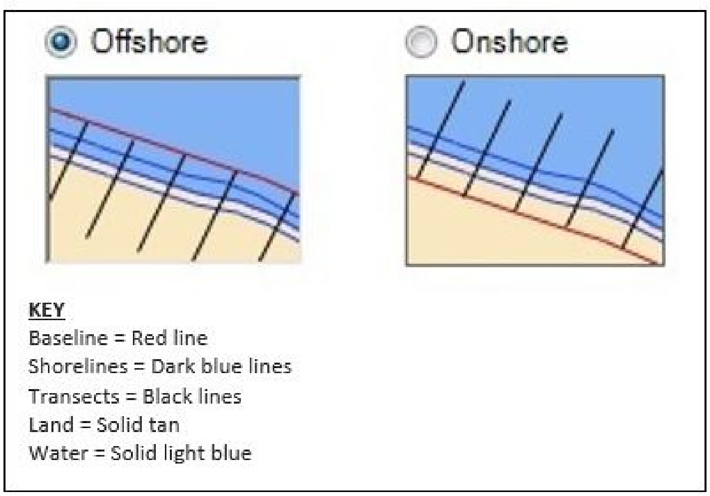


Figure 2. Illustration of offshore and onshore baseline positions.

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 in a GIS platform. 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.

Once baselines are finalized, DSAS creates straight-line 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 rate calculation 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-year (yr) period, the shoreline has retreated, or moved landward, a distance of 25 meters (m), then the rate of change is 25 m/50 yr = 0.50 m/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.

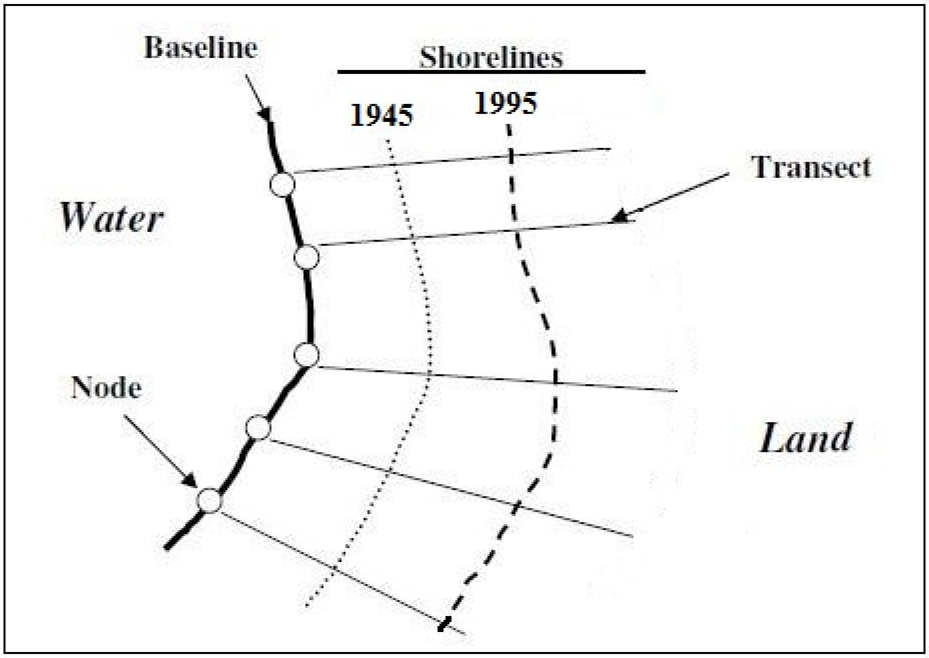
MGS initially calculated long-term rates of change for each county utilizing the LRR method. Although the LRR, WLR, and LMS methods all calculate rates of change utilizing all shorelines available at a transect, MGS chose the LRR method because the "LRR is a much better understood metric, and it is simpler to evaluate and communicate its underlying assumptions" (Thieler, 2014). Additionally, although the WLR 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).

To capture rates of change at transects with only two shoreline data sets available, MGS also calculated a long-term EPR rate. Typically, the shorelines spanned a 70-80 year time period at each transect. However, users must look at the individual transects to determine the exact time span across which the LRR and EPR rate was calculated.

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).



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.

To describe short-term rates of change, MGS utilized the EPR method. The EPR method was chosen to provide consistency with MGS's previous projects, which also utilized EPR to calculate short-term rates of change. The USGS also calculated short-term rates of change utilizing the EPR method in their recent study of shoreline change along the New England and Mid-Atlantic coasts (Hapke and others, 2010).

For short-term rates of change, MGS prefers to calculate a 30-year EPR wherever possible. In counties with comprehensive NOAA CUSP coverage and a ca. 1970 NOAA National shoreline, a 30-year EPR compares two NOAA shorelines referenced to MHW. Additionally, approximately 30 years is the "short term" time span utilized for DSAS analysis in the USGS's recent study of shoreline change along Maryland's coasts (Hapke and others, 2010).

Unfortunately, historical shoreline coverage by decade in Maryland varies by county. Based on the available NOAA and MGS shoreline data sources, only eight of 16 tidewater counties in Maryland have ca. 1970 shoreline coverage, and in most cases, these ca. 1970 shorelines are not comprehensive. Late 1950s and ca. 1960 shorelines are available in three counties with no ca. 1970 shoreline coverage. Currently, five counties do not have any 1950s, 1960s, or 1970s shoreline available.

Calvert County has ca. 1960 shoreline coverage in approximately 12% of the county, but no ca. 1970 shoreline coverage. Conversely, Prince George's County has ca. 1970 shoreline coverage in approximately 32% of the county, but no ca. 1960 shoreline. In counties like Calvert, where it was impossible to calculate a 30-year EPR due to a lack of ca. 1970 shoreline, MGS calculated a 40-year EPR if possible between the ca. 1960 shoreline and the recent ca. 2000/2010 shoreline. MGS also calculated a 10-year EPR to capture short-term rates across a larger shoreline area. This calculation utilized solely the ca. 1990 MGS shoreline and the ca. 2000/2010 recent shoreline (comprised of NOAA CUSP and CAC data) as inputs to DSAS. Both of these shorelines have excellent shoreline coverage i.e. they span approximately the entire county and thus rates can be calculated at most transects. Note that the ca. 1990 MGS and ca. 2000 CAC shorelines are not referenced to a tidal datum; and thus the calculated 10-year rate may be based on the comparison of two non-tidally referenced shorelines if the CAC shoreline is utilized in the EPR analysis.

In summary, MGS generated the following distance and rate statistics (associated supplemental statistics were also calculated automatically by DSAS):

Calvert and Prince George's Counties

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

Calvert County Only

- Short-Term 40-year EPR – Run on the ca. 1960 and ca. 2000 shorelines

Prince George's County Only

- Short-Term 30-year EPR – Run on the ca. 1970 and ca. 2000/2010 shorelines

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 shoreline data set. 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 NOAA shorelines were used in place of those previously digitized by MGS wherever possible. The mean high water (MHW) shorelines used in NOAA nautical chart production are 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.

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). MGS created these two DSAS-required fields, and also created five additional attribute fields in the shoreline files to aid in file management and organization. These seven total attribute fields in 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 the attributed shoreline feature class files. Attribute table 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; 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 (extracted from a wetlands delineation, based on photo interpretation of DOQQs; not tidally referenced), a conservative uncertainty value of 7.5 meters was assigned, taking into account the work of Hapke and others (2010) and Crowell and others (1991). Likewise, MGS assigned a conservative uncertainty value of 7.5 meters to the CAC shoreline, which is also not tidally referenced. 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 1.8 meters in Calvert County, and 1.0 to 1.8 meters in Prince George's 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 individual shoreline data set files 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 individual shoreline files, plus the seven MGS-created fields either required for DSAS analysis or helpful in DSAS file management. The MGS-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 Calvert and Prince George's Counties, MGS decided to eliminate the pre-1930s shorelines from 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 shoreline positions. Even with the pre-1930s shorelines eliminated from the final DSAS analysis, MGS still analyzed approximately 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 requires at least two shorelines to calculate rates of change. Baselines were carefully edited to 1) increase smoothness; 2) ensure baselines ran roughly parallel to the majority of the shorelines; and 3) ensure the most comprehensive baseline coverage possible.

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 (note that this is a comprehensive list from all projects thus far; groups utilized in the Calvert and Prince George's County baseline files are in bold):

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

- **<u>Group 2 – Tributary/River Baselines</u>**
  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. In general, these baselines stop when the river width becomes less than approximately 15 meters.

- **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. In general, these baselines stop when the river width becomes less than approximately 15 meters.

- **Group 9 – Baselines Adjacent to Historical Shorelines**
  Baselines drawn adjacent to historical shorelines (typically from the 1930s or 1940s) at the mouth of certain inlets or coves. If the Mainstem baseline was drawn adjacent to these shorelines, rates of change would not be captured in the interior banks of the inlet due to the orientation of the transects. Since the Mainstem baselines typically dip into these coves and inlets, the Group 9 baselines capture rates across the full spectrum of shorelines available at the mouth of these coves/inlets.

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, Groups 3-7, and Group 9 baselines. Transects were cast in both directions (to the right and left) along the

Group 2 and Group 8 baselines. All transects were cast perpendicular to the baseline and extended across the shorelines.

Transect orientations were edited to ensure that the transects ran roughly perpendicular to the majority of the shorelines. In areas where the shorelines were highly variable, MGS adjusted transect orientation so that the transects were roughly perpendicular to the most recent shorelines (even if this meant that the transect was not perpendicular to the baseline anymore). In some areas, such as narrow peninsulas, MGS shortened transects so that they did not cross over one set of shorelines, and extend over the same set of shorelines on the opposite shore of the peninsula. In other areas, transects were lengthened to ensure that they crossed all of the available shorelines at the particular transect location. The DSAS program captures edits to transect length and orientation in the “Autogen”, “StartX”, “StartY”, “EndX”, “EndY”, “Azimuth”, and “Shape_Length” attribute table fields in the transect files.

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).

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

Often times, the original county transect file is too large to run through DSAS successfully. Through trial and error, MGS determined that transect files of approximately 8,000-10,000 records (transects) will typically process successfully. In Calvert County, the original transect file contained 16,292 transects. This transect file was split into two smaller files, containing

8,000 transects and 8,292 transects. In Prince George's County, the original transect file contained 8,163 transects which MGS successfully processed through DSAS analysis as one file.

MGS ran each Calvert County transect sub-file and maser shoreline feature class file 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 40-year EPR – Run on the ca. 1960 and ca. 2000 shorelines
- Short-Term 10-year EPR – Run on the ca. 1990 and ca. 2000 shorelines

MGS ran the following DSAS statistics on the Prince George's County transect file and maser shoreline feature class file:

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

All rates were calculated at a 90% confidence interval. DSAS statistics were output to a Microsoft Access 2013 database. For Calvert County, the statistical output from each individual run was joined to each individual transect feature class attribute table in ArcMap 10.1. Then, MGS merged Calvert County's individual transect feature classes into a final, county-wide merged transect feature class. The statistical output from the Prince George's DSAS analysis was joined to the original Prince George's County transect file.

Fields containing rate and supplemental statistics were re-named to more fully describe their contents. DSAS calculates rates and applicable supplemental statistics in meters/year and meters, respectively. MGS converted all rates and applicable supplemental statistics to feet/year and feet, respectively. See Table 7 for a listing and description of all distance, rate, and supplemental statistic fields in the final transect files.

Table 7. Distance, rate and supplemental statistic field names in final transect attribute tables.

Field Name	Stands For	Description
SCE	Shoreline Change Envelope	Distance (meters) between the shoreline farthest from and closest to the baseline at each transect.
SCE_ft	Shoreline Change Envelope	Distance (feet) between the shoreline farthest from and closest to the baseline at each transect.
NSM	Net Shoreline Movement	Distance (meters) between the oldest and youngest shorelines for each transect.
NSM_ft	Net Shoreline Movement	Distance (feet) between the oldest and youngest shorelines for each transect.
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. Reported in meters/year.
LT_EPR_ft	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. Reported in feet/year.
LT_ECI	Confidence of the LT_EPR	Measures the shoreline uncertainties used in the end-point calculation. Reported in meters.
LT_ECI_ft	Confidence of the LT_EPR	Measures the shoreline uncertainties used in the end-point calculation. Reported in feet.
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. Reported in meters/year.
LT_LRR_ft	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. Reported in feet/year.
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	Describes the uncertainty of the reported LRR rate; “90" indicates the statistics were run at a 90% confidence interval. Reported in meters.
LT_LCI90_ft	Uncertainty of the LT_LRR	Describes the uncertainty of the reported LRR rate; “90" indicates the statistics were run at a 90% confidence interval. Reported in feet.
ST_40_EPR	Short-Term 40-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. 1960 vs. ca. 2000 shorelines. Reported in meters/year. Calculated in Calvert County only.
ST_40_EPR_ft	Short-Term 40-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. 1960 vs. ca. 2000 shorelines. Reported in feet/year. Calculated in Calvert County only.
ST_40_ECI	Confidence of the ST_40_EPR	Measures the shoreline uncertainties used in the ST_40_EPR calculation. Reported in meters.

Field Name	Stands For	Description
ST_40_ECI_ft	Confidence of the ST_40_EPR	Measures the shoreline uncertainties used in the ST_40_EPR calculation. Reported in feet.
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. Reported in meters/year. Calculated in Prince George's County only.
ST_30_EPR_ft	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. Reported in feet/year. Calculated in Prince George's County only.
ST_30_ECI	Confidence of the ST_30_EPR	Measures the shoreline uncertainties used in the ST_30_EPR calculation. Reported in meters.
ST_30_ECI_ft	Confidence of the ST_30_EPR	Measures the shoreline uncertainties used in the ST_30_EPR calculation. Reported in feet.
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. Reported in meters/year.
ST_10_EPR_ft	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. Reported in feet/year.
ST_10_ECI	Confidence of the ST_10_EPR	Measures the shoreline uncertainties used in the ST_10_EPR calculation. Reported in meters.
ST_10_ECI_ft	Confidence of the ST_10_EPR	Measures the shoreline uncertainties used in the ST_10_EPR calculation. Reported in feet.

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

Determine Shoreline Condition

In the final 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-yr period, a shoreline has eroded 50 feet, 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 ft/yr before bulkhead construction and 0 ft/yr afterwards. The problem in determining rates of change for protected shorelines lies in not knowing the precise 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 ca. 2000/2010 shoreline. Note that in Calvert and Prince George's Counties, this recent shoreline consisted of the NOAA CUSP shoreline, supplemented with CAC shoreline data. Shoreline protection data was not included in the CAC shoreline attribute table or metadata.

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 NOAA CUSP shoreline segment identified in the "ATTRIBUTE" field as any of the following:

- 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 NOAA CUSP shoreline segment identified in the "ATTRIBUTE" field as any of the following:

- Natural.Apparent.Marsh Or Swamp
- Natural.Mean High Water
- Natural.Mean High Water.Approximate
- Natural.River Or Stream
- Natural.Great Lake Or Lake Or Pond
- Natural.Great Lake Or Lake Or Pond.Approximate
- Undetermined
- Undermined.Approximate

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

For additional shoreline condition information, MGS referenced the Virginia Institute of Marine Science (VIMS) shoreline inventory data collected in Calvert and Prince George’s Counties in 2004-2005 (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 downloaded the GIS files, reprojected the files to MD State Plane NAD83 (m), and referenced the “STRUCTURE” attribute table field in the Calvert County "calv_sstru.shp” and the Prince George’s County “pg_sstru.shp" ArcGIS shapefiles. MGS created a new field in the final transect file attribute table named “VIMS_SL_Condition”.

The transect was labeled “Protected” if it crossed a VIMS shoreline segment identified in the “STRUCTURE" field as any of the following:

- 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 position did not mirror the NOAA CUSP or CAC shoreline positions exactly. Transects that did not cross the VIMS shoreline (or wouldn't, even if their lengths were extended by a few meters) 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 (or both), 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".

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

Generalize the Short-Term Erosion Rate Results

Once shoreline condition was determined, MGS grouped the rate values in the ST_40_EPR_ft, ST_30_EPR_ft, and ST_10_EPR_ft fields in the final transect files according to generalized erosion rate categories using the Select by Attribute tool in ArcMap 10.1 (see Table 8). The short term 40- and 10-year EPR rates were generalized in the Calvert County transect file; and the short-term 30- and 10-year EPR rates were generalized in the Prince George's County transect file.

The rate categories used were similar to those employed in previous MGS projects. MGS created three additional attribute table fields in the transect files to store the categorized values. These fields included 1) "Level_ID" (a numerical category ID); 2) "Erosion_Level" (a general description of the category); and 3) "Erosion_ft" (a detailed description of the category). In order to designate which rate was categorized in the transect file, MGS appended either "ST_40_EPR_ft_", "ST_30_EPR_ft_" or "ST_10_EPR_ft_" to the beginning of the field names.

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) ST_40_EPR; 2) ST_30_EPR; or 3) ST_10_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 in the Erosion_ft description.*
** * This category only used in the attributed shoreline files.*

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

MGS investigated those transects with moderate and high rates of change reported for the LT_LRR, LT_EPR, ST_40_EPR, ST_30_EPR, and the ST_10_EPR rate method. Based on MGS's experience in previous projects in Anne Arundel and Baltimore Counties, these high and moderate rates of change may be suspect due to several factors: 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 create 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. MGS chose not to deliver rates across a transect in Prince George's County due to reason #3 above.

For all transects with suspect change rates, the rate values and associated calculation uncertainties stored in the following attribute fields were made null:

- LT_LRR
- LT_LR2
- LT_LSE
- LT_LCI90
- LT_LRR_ft
- LT_LCI90_ft
- LT_EPR
- LT_ECI
- LT_EPR_ft
- LT_ECI_ft
- ST_40_EPR
- ST_40_ECI
- ST_40_EPR_ft
- ST_40_ECI_ft
- ST_30_EPR
- ST_30_ECI
- ST_30_EPR_ft
- ST_30_ECI ft
- ST_10_EPR
- ST_10_ECI
- ST_10_EPR_ft
- ST_10_ECI_ft

The distance metrics for SCE and 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.

In general, areas of moderate and high rates of change were identified in the following areas:

- Areas with only two historical shorelines e.g. from the 1940s. In these locations, the shoreline dates were nearly identical and yet the shoreline positions did not coincide exactly. As a result, high rates of change were calculated;
- Rivers, tributaries, and inlets exhibiting extensive marshy areas along the shoreline (based on interpretation of 2013 National Agriculture Imagery Program (NAIP) imagery);
- Peninsulas subject to large fetch and thus high wind and wave energy;
- Islands that have either migrated or disappeared over time;
- Shorelines along the mainstem of the Chesapeake Bay, subject to large fetch and thus high wind and wave energy;
- Upper reaches of tributaries, where historical shoreline positional uncertainty may be higher than the reported uncertainty; and
- Shorelines located adjacent to erosion control structures.

In Calvert and Prince George's Counties, MGS delivered rates in the areas noted above. However, MGS advises users to employ caution when utilizing rates calculated in marshy areas and in upstream tributary/river areas. Shoreline positional uncertainty may be higher than reported in areas of extensive marsh and the upper reaches of tributaries due to the difficulty in determining the land/water interface in these areas from aerial photographs. In marshy areas, or any area of relatively low relief, the location of the land/water interface can change drastically based on the tidal cycle. As such, a shoreline position determined from tide-coordinated photography may differ from a shoreline derived from non-tide coordinated photography in that same area. Utilize the rates calculated in these areas as a general indicator of change, but note the inherent uncertainties in the rate calculation and use caution.

Assign Rate-of-Change Attributes to Recent County Shorelines

Determine Which Recent Shoreline to Attribute

When a county-wide, complete NOAA CUSP shoreline is available, MGS chooses to use this shoreline in DSAS analysis and attribute this recent shoreline with generalized rate-of-change data for several reasons. First, the majority of the historical shorelines used in this DSAS analysis were sourced from NOAA. Utilizing the NOAA CUSP data set as a source of recent, post-2000 shoreline data for DSAS analysis maintains consistency with regards to shoreline data source. Second, the majority of the historical shorelines used in the analysis (NOAA National data set shorelines) are referenced to MHW. The NOAA CUSP shoreline 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 is also already attributed with shoreline condition information.

Fortunately in Calvert County, the NOAA CUSP data set covered approximately 90% of the shoreline in the county. MGS decided to supplement the NOAA CUSP data with CAC data in the following areas where NOAA CUSP data was missing:

- Hunting Creek;
- Upper two-thirds of Hall Creek; and
- Patuxent River, from approximately 1 kilometer south of the Merkle Wildlife Sanctuary, north to (and including) Lyons Creek.

As such, both NOAA CUSP and CAC shoreline data were utilized in DSAS rate calculations; and the "recent" Calvert County shoreline attributed with generalized rate-of-change data consisted of approximately 90% NOAA CUSP shoreline data and 10% CAC shoreline data.

In Prince George's County, the NOAA CUSP data set covered approximately 60% of the shoreline in the county. MGS decided to supplement the NOAA CUSP data with CAC data in the following areas where NOAA CUSP data was missing:

- Anacostia River, from approximately the Bladensburg Road bridge, north to the Decatur Street bridge;
- Northwest Branch Anacostia River, from approximately the 38th Street bridge, south to its confluence with the Anacostia River;
- The lower reaches of Swanson Creek, west of Chalk Point;
- Spice Creek and a small unnamed creek north of Spice Creek; and
- Patuxent River and its major tributaries, from approximately the Merkle Wildlife Sanctuary, north to the upper reaches of the Patuxent River.

As such, both NOAA CUSP and CAC shoreline data were utilized in DSAS rate calculations; and the "recent" Prince George's County shoreline attributed with generalized rate-of-change consisted of approximately 60% NOAA CUSP shoreline data and 40% CAC shoreline data.

Attribute the Recent Shoreline with Generalized Short-Term Erosion Rate Categories

With CCS input, MGS created the following attributed shoreline files for Calvert County (please reference Table 8 for a list of the generalized erosion rate categories):

- Recent shoreline attributed with generalized erosion rate categories based on the ST_40_EPR_ft values; and
- Recent shoreline attributed with generalized erosion rate categories based on the ST_10_EPR_ft values.

Note that while the recent shoreline coverage in Calvert County is comprehensive, the ca. 1960 shoreline in Calvert County only totals 29.5 miles (12% of the total county shoreline length). As such, short-term 40-year EPR rates can only be calculated for up to 12% of the total county shoreline. Historical shorelines from the 1970s were not available from the NOAA National, NOAA Historical, or MGS shoreline data sets.

The following attributed shoreline files were created for Prince George's County:

- Recent shoreline attributed with generalized erosion rate categories based on the ST_30_EPR_ft values; and
- Recent shoreline attributed with generalized erosion rate categories based on the ST_10_EPR_ft values.

Although recent shoreline coverage in Prince George's County is comprehensive, the county's ca. 1970 shoreline only totals 45.0 miles (32% of the total county shoreline length). As such, short-term 30-year EPR rates could only be calculated for up to 32% of the total county shoreline. Historical shorelines from the 1960s were not available from the NOAA National, NOAA Historical, or MGS shoreline data sets.

In ArcMap 10.1, MGS color-coded the transects according to the generalized rate categories listed in Table 8. 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. MGS created four new fields in the attributed shoreline files: 1) "Level_ID"; 2) "Erosion_Level"; 3) "Erosion_ft"; and 4) "Notes". 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 file.

Similar to previous projects, MGS changed shoreline rate-of-change attribution 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 a 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 a 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, MGS attributed small stretches of unprotected shoreline that 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.

Level_ID values of 0-5 contain quantitative rate categories and are self-explanatory (reference Table 8). 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_40_EPR, ST_30_EPR, or

ST_10_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 field in the transect and attributed shoreline files contains an explanation of why the transect/shoreline segment was attributed as Level_ID 9. Additionally, the “Notes” attribute table field in the attributed shoreline files also describes any areas of high and moderate erosion occurring in marshy areas; users should use caution when utilizing rates in these areas.

Final Deliverables

The following deliverables are available for this project:

GIS Files

- **"SLRoC_Final_Files_CALV_PG.mdb"**
    - Personal geodatabase; contains the master shoreline, baseline, transect, and attributed shoreline feature class files for Calvert and Prince George’s Counties. As specified in the Scope of Work (SOW), all files are georeferenced to MD State Plane NAD 1983 meters.
    - Files contained within:
        - **"Calvert_Co_Shorelines"**
            - This line feature class contains the shoreline data sets used in the final DSAS analysis for Calvert County. MGS recommends symbolizing this file by the “DSAS_SLINF” attribute table fields.
        - **“Calvert_Co_Baselines"**
            - This line feature class contains all of the seaward (offshore) baselines utilized in the final DSAS analysis in Calvert County. The baselines were created approximately 10 meters away from the shorelines.
        - **“Calvert_Co_Transects"**
            - This line feature class contains 16,292 transects with associated DSAS statistics. Only transects that cross unprotected shoreline segments are attributed with rate of change data.
        - **"Calvert_Co_Attributed_Shoreline_40"**
            - This line feature class consists of the recent NOAA CUSP shoreline in Calvert County, supplemented with CAC shoreline. This recent shoreline was clipped to Calvert County boundaries and attributed with generalized short-term 40-year EPR rate of change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields.
        - **"Calvert_Co_Attributed_Shoreline_10"**
            - This line feature class consists of the recent NOAA CUSP shoreline in Calvert County, supplemented with CAC shoreline. This recent shoreline was clipped to Calvert County boundaries and attributed with generalized short-term 10-year EPR rate of

change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields.

  - **"Prince_Georges_Co_Shorelines"**
    - This line feature class contains the shoreline data sets used in the final DSAS analysis for Prince George's County. MGS recommends symbolizing this file by the "DSAS_SLINF" attribute table fields.
  - **"Prince_Georges_Co_Baselines"**
    - This line feature class contains all of the seaward (offshore) baselines utilized in the final DSAS analysis in Prince George's County. The baselines were created approximately 10 meters away from the shorelines.
  - **"Prince_Georges_Co_Transects"**
    - This line feature class contains 8,163 transects with associated DSAS statistics. Only transects that cross unprotected shoreline segments are attributed with rate of change data.
  - **"Prince_Georges_Co_Attributed_Shoreline_30"**
    - This line feature class consists of the recent NOAA CUSP shoreline in Prince George's County, supplemented with CAC shoreline. This recent shoreline was clipped to Prince George's County boundaries and attributed with generalized short-term 30-year EPR rate of change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields.
  - **"Prince_Georges_Co_Attributed_Shoreline_10"**
    - This line feature class consists of the recent NOAA CUSP shoreline in Prince George's County, supplemented with CAC shoreline. This recent shoreline was clipped to Prince George's County boundaries and attributed with generalized short-term 10-year rate of change categories. MGS recommends symbolizing this file by either the "Erosion_Level" or "Erosion_ft" fields.

<u>Metadata</u>

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

- Calvert_Co_Shorelines_FGDC_Metadata.xml
- Calvert_Co_Baselines_FGDC_Metadata.xml
- Calvert_Co_Transects_FGDC_Metadata.xml
- Calvert_Co_Attributed_Shoreline_40_FGDC_Metadata.xml
- Calvert_Co_Attributed_Shoreline_10_FGDC_Metadata.xml
- Prince_Georges_Co_Shorelines_FGDC_Metadata.xml
- Prince_Georges_Co_Baselines_FGDC_Metadata.xml
- Prince_Georges_Co_Transects_FGDC_Metadata.xml
- Prince_Georges_Co_Attributed_Shoreline_30_FGDC_Metadata.xml
- Prince_Georges_Co_Attributed_Shoreline_10_FGDC_Metadata.xml

Final Report

"Updating_Shoreline_Rates_of_Change_CALV_PG_Final_Report_v1.docx"

RESULTS AND DISCUSSION

Once short-term rate-of-change attributes were assigned to the recent county shorelines, MGS compiled summary information about the shoreline change for each county.

Total Shoreline Length

Based on the length of the recent shoreline utilized in rate-of-change analysis, Calvert County's shoreline totals 243.6 miles and Prince George's County shoreline totals 138.6 miles (Table 9). Both county's total shoreline lengths surpass the previous lengths reported of 230.2 and 119.1 miles for Calvert and Prince George's Counties, respectively (Hennessee and others, 2003). The lengths reported in the 2003 MGS report were extracted from the ca. 1990 MGS shoreline.

In Calvert County, the current shoreline length increase is due to the NOAA CUSP and CAC shoreline's inclusion of more headwater reaches in tributaries (e.g. Buzzard Island Creek, Hall Creek). The NOAA CUSP and CAC shorelines also both delineate the shoreline further inshore in several marshy areas than the ca. 1990 MGS shoreline (e.g. Fishing Creek, Hunting Creek). Additionally, the NOAA CUSP shoreline includes several inland ponds in Calvert County (e.g. Lake Charming) which were not included as part of the ca. 1990 MGS shoreline. The NOAA CUSP shoreline also digitized several breakwater and jetty structures, not digitized in the ca. 1990 MGS shoreline (e.g. jetties at the entrance to Fishing Creek).

In Prince George's County, the current shoreline length increase is due to the CAC shoreline's inclusion of the Anacostia River, upstream portions of the Patuxent River, and several minor tributaries to the Patuxent River. These areas were not included in the ca. 1990 MGS shoreline. Additionally, both the NOAA CUSP and CAC shorelines delineated the shoreline further inshore in several marshy areas (e.g. in the Merkle Wildlife Sanctuary and Patuxent River Park). The NOAA CUSP shoreline also captured an inland pond area, which was not part of the ca. 1990 MGS shoreline. The NOAA CUSP shoreline also captured several headwater reaches of streams not included in the ca. 1990 MGS shoreline (e.g. Piscataway Creek).

Length of Protected Shoreline

Based on shoreline condition status (i.e. protected vs. unprotected) extracted from the NOAA CUSP shoreline data set and the VIMS shoreline inventory data set, 54.7 miles (or 22.4%) of Calvert County's shoreline are protected. In Prince George's County, only 8.8 miles (or 6.3%) of the shoreline are protected (Table 9). The protected statistics reported in the 2003 MGS report are 9.7 miles (4.2%) and 0.8 miles (0.7%) for Calvert and Prince George's 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 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 Calvert and Prince George's Counties – the ca. 2000/2010 NOAA CUSP shoreline data set and the ca. 2000 VIMS shoreline inventory data set. MGS decided to utilize both sources in its determination of shoreline condition to take advantage of each data set's strengths. Much of the NOAA CUSP shoreline data in Calvert and Prince George's Counties (dated 2005-2010) is more recent than the VIMS data set for these counties (2004-2005). However, the NOAA CUSP shoreline condition information was primarily interpreted from air photos and collected at a coarser resolution than the VIMS shoreline condition data. The VIMS data, generally older than the NOAA CUSP data, was collected by operators in motor boats who traveled along the shoreline and manually digitized the shoreline conditions in real-time. As such, although slightly older, this data set is likely to have higher resolution and accuracy 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. In summary, it is likely that 1) the protected statistics reported in the 2003 MGS report underestimated the length of protected shoreline in Calvert and Prince George's Counties; and 2) the length of protected shoreline has increased since the 1990s due to the installation of more shoreline protective structures.

Calvert County Short-Term DSAS Results

Short-Term 10-Year EPR Results

Of the 243.6 miles of Calvert County shoreline, MGS assigned quantitative rates of change (erosion, accretion, or no change) based on the ST_10_EPR_ft analysis to 152.4 miles (or 62.6%) of the total shoreline length (Table 9). Protected shorelines and shorelines with no data or suspect data were assigned qualitative attributes. MGS attributed a total of 54.7 miles, 0.7 miles and 35.8 miles to the qualitative categories of Protected, No Data (insufficient shorelines to calculated desired rate), and No data (no transects cast), respectively. No miles were attributed with the qualitative category of Rates not delivered (calculated rates suspect).

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 152.4 miles of Calvert County shoreline attributed with ST_10_EPR_ft quantifiable change, 36.1% of the shoreline is accreting, 0.0% of the shoreline is not changing, 53.2% of the shoreline is exhibiting slight erosion, 7.3% is exhibiting low erosion, 2.1% is exhibiting moderate erosion, and 1.3% is exhibiting high erosion (Table 10). The average annual rate of change in Calvert County, calculated over an approximate 10-year period between the ca. 1990 and the ca. 2000 shoreline, was -0.51 feet/year (slight erosion) (Table 10).

Short-Term 40-Year EPR Results

Of the 243.6 miles of Calvert County shoreline, MGS assigned quantitative rates of change (erosion, accretion, or no change) based on the ST_40_EPR_ft analysis to 22.6 miles (or 9.3%) of the total shoreline length (Table 11). Note that the total length of the ca. 1960 shoreline in Calvert County is only 29.5 miles, and thus 40-year rates could only be calculated along these stretches. Protected shorelines and shorelines with no data or suspect data – comprising the balance of the total shoreline – were assigned qualitative attributes. MGS attributed a total of 54.7 miles, 130.7 mile, and 35.8 miles to the qualitative categories of Protected, No Data (insufficient shorelines to calculate ST_40_EPR) and No data (no transects cast), respectively. No miles were attributed with the qualitative category of Rates not delivered (calculated rates suspect).

Of the 22.6 miles of Calvert County shoreline attributed with ST_40_EPR_ft quantifiable change, 22.0% of the shoreline is accreting, 0.0% of the shoreline is not changing, 71.8% of the shoreline is exhibiting slight erosion, 1.8% is exhibiting low erosion, 3.5% is exhibiting moderate erosion, and 0.9% is exhibiting high erosion (Table 12). The average annual rate of change in Calvert County, calculated over an approximate 40-year period between the ca. 1960 and the ca. 2000 shoreline, was -0.63 feet/year (slight erosion) (Table 12).

Prince George's County Short-Term DSAS Results

Short-Term 10-Year EPR Results

Of the 138.6 miles of Prince George's County shoreline, MGS assigned quantitative rates to 75.1 miles (or 54.1%) of the total shoreline length (Table 9). Protected shorelines and shorelines with no data or suspect data were assigned qualitative attributes. MGS attributed a total of 8.8 miles, 11.7 miles, and 43.0 miles to the qualitative categories of Protected, No Data (insufficient shorelines to calculated desired rate), and No data (no transects cast), respectively. Only 79.6 meters (0.0 miles) were attributed with the qualitative category of Rates not delivered (calculated rates suspect).

Table 9. Shoreline length (miles), based on ST_10_EPR_ft rate-of-change category, in Calvert and Prince George's Counties.

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) Percentage of total length %
Calvert	55.0	0.0	81.1	11.1	3.3	1.9	54.7	0.7	35.8	0.0	243.6	152.4	62.6
Prince George's	17.3	0.0	47.9	6.1	2.1	1.7	8.8	11.7	43.0	0.0	138.6	75.1	54.2

Based on the length of the recent shoreline assigned rate-of-change attributes from ST_10_EPR DSAS analysis. The numbers in parentheses in the column heads correspond to the Level_ID codes in Table 8.

Table 10. Mean rate of change based on ST_10_EPR_ft analysis in Calvert and Prince George's Counties. Includes shoreline length for rate categories 0-5, and each category's percentage of the total length assigned numerical rate attributes (erosion, accretion, and no change).

COUNTY	Mean rate of change (ft/yr)	(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 (%)
Calvert	-0.51	55.0	36.1	0.0	0.0	81.1	53.2	11.1	7.3	3.3	2.1	1.9	1.3	152.4	100.0
Prince George's	-1.27	17.3	23.0	0.0	0.0	47.9	63.8	6.1	8.2	2.1	2.8	1.7	2.2	75.1	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.

Table 11. Shoreline length (miles), based on ST_40_EPR_ft rate-of-change category, in Calvert 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) Percentage of Total Length %
Calvert	5.0	0.0	16.2	0.4	0.8	0.2	54.7	130.7	35.8	0.0	243.6	22.6	9.3

Based on the length of the recent shoreline assigned rate-of-change attributes from ST_40_EPR DSAS analysis. The numbers in parentheses in the column heads correspond to the Level_ID codes in Table 8.

Table 12. Mean rate of change based on ST_40_EPR_ft analysis in Calvert County. Includes shoreline length for rate categories 0-5, and each category's percentage of the total length assigned numerical rate attributes (erosion, accretion, and no change).

COUNTY	Mean rate of change (ft/yr)	(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 (%)
Calvert	-0.63	5.0	22.0	0.0	0.0	16.2	71.8	0.4	1.8	0.8	3.5	0.2	0.9	22.6	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.

Of the 75.1 miles of Prince George's County shoreline attributed with quantifiable change, 23.0% of the shoreline is accreting, 0.0% of the shoreline is not changing, 63.8% of the shoreline is exhibiting slight erosion, 8.2% is exhibiting low erosion, 2.8% is exhibiting moderate erosion, and 1.7% is exhibiting high erosion (Table 10). The average rate of change in Prince George's County, calculated over an approximate 10-year period between the ca. 1990 and the ca. 2000/2010 shoreline, was -1.27 feet/year (slight erosion) (Table 10).

Short-Term 30-Year EPR Results

Of the 138.6 miles of Prince George's County shoreline, MGS assigned quantitative rates of change (erosion, accretion, or no change) based on the ST_30_EPR_ft analysis to 26.6 miles (or 19.2%) of the total shoreline length (Table 13). Note that the total length of the ca. 1970 shoreline in Prince George's County is only 45.0 miles, and thus 40-year rates could only be calculated along these stretches. Protected shorelines and shorelines with no data or suspect data – comprising the balance of the total shoreline – were assigned qualitative attributes. MGS attributed a total of 8.8 miles, 60.2 miles, and 43.0 miles to the qualitative categories of Protected, No Data (insufficient shorelines to calculate ST_30_EPR) and No data (no transects cast), respectively. Only 79.6 meters (0.0 miles) were attributed with the qualitative category of Rates not delivered (calculated rates suspect).

Of the 26.6 miles of Prince George's County shoreline attributed with ST_30_EPR_ft quantifiable change, 53.8% of the shoreline is accreting, 0.2% of the shoreline is not changing, 45.2% of the shoreline is exhibiting slight erosion, 0.6% is exhibiting low erosion, 0.1% is exhibiting moderate erosion, and no portion of the shoreline is exhibiting high erosion (Table 14). The average rate of change in Prince George's County, calculated over an approximate 30-year period between the ca. 1970 and the ca. 2000/2010 shoreline, was 0.01 feet/year (no change) (Table 14).

Long-Term DSAS Results

Long-term rates of change in Calvert and Prince George's Counties were generally calculated across an approximate 70-80 year time span, depending on the shoreline data available at each transect. Note that the EPR method requires only two shorelines; the LRR method requires three or more shorelines to calculate a rate.

For those areas of Calvert County with at least two shorelines available for analysis, MGS calculated a mean long-term EPR of -0.20 feet/year (slight erosion). For those areas with three or more shorelines, a mean long-term LRR of -0.30 feet/year was calculated (slight erosion).

In Prince George's County, a mean long-term EPR of -0.58 feet/year was calculated in areas with at least two unprotected shorelines available for analysis. A mean long-term LLR of -0.44 feet/year was calculated for those areas with three or more unprotected shorelines.

Table 13. Shoreline length (miles), based on ST_30_EPR_ft rate-of-change category, in Prince George's 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 (%)
Prince George's	14.3	0.1	12.0	0.2	0.0	0.0	8.8	60.2	43.0	0.0	138.6	26.6	19.2

Based on the length of the recent shoreline assigned rate-of-change attributes from ST_30_EPR DSAS analysis. The numbers in parentheses in the column heads correspond to the Level_ID codes in Table 8.

Table 14. Mean rate of change based on ST_30_EPR_ft analysis in Prince George's County. Includes shoreline length for rate categories 0-5, and each category's percentage of the total length assigned numerical rate attributes (erosion, accretion, and no change).

COUNTY	Mean rate of change (ft/yr)	(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 (%)
Prince George's	0.01	14.3	53.8	0.1	0.2	12.0	45.2	0.2	0.6	0.0	0.1	0.0	0.0	26.6	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.

Please see Table 15 below for a summary of the mean long-term and short-term rates of change calculated in Calvert and Prince George's Counties (shaded in yellow).

Per the SOW and discussion with CCS, MGS did not attribute the recent shoreline in Calvert County or Prince George's Counties with generalized long-term EPR or LRR rates of change, as most users of Coastal Atlas (where this data will be viewed) are likely most interested in the short-term rates of change occurring over the 10-40+ years between the 1960s and 2010s. As such, MGS is not providing an estimate of the length of shoreline (or percentage of the entire shoreline) that falls into the different rate-of-change categories for the long-term rate analyses. However, users interested in the calculated long-term LRR and EPR may view the individual long-term rates of change calculated at each transect by viewing the rate data contained within the transect attribute table field.

Table 15. Summary of mean long-term and short-term rates of change by county.

COUNTY	Mean Long-Term Rate (ft/yr)		Mean Short-Term Rate (ft/yr)		
	LRR	EPR	40-year EPR	30-year EPR	10-year EPR
Anne Arundel	-0.18	-0.29	N/A	-0.28	-0.94
Baltimore *(incl. Baltimore City)*	-0.44	-0.42	N/A	-0.40	-0.38
Calvert	-0.30	-0.20	-0.63	N/A	-0.51
Prince George's	-0.44	-0.58	N/A	0.01	-1.27

Based on the results of MGS's Shoreline Rates of Change and Shoreline Management projects (2014-2016); counties of focus in this report are shaded yellow. N/A indicates no data available for that rate calculation; negative values indicate erosion; positive values indicate accretion.

Discussion of DSAS Results

Table 15 presents a summary of the mean long-term and short-term rates of change calculated for both Calvert and Prince George's Counties. These mean rates only apply to those segments of shoreline where quantifiable rates of change were calculated.

With the exception of the mean 30-year EPR in Prince George's County, all other mean short-term rates calculated in Calvert and Prince George's Counties fall within the slight erosion category of -0.01 to -2.00 feet/year. The mean 30-year EPR in Prince George's County is 0.01 feet/year, which falls within the "no change" category.

In Calvert County, the mean short-term 10-year EPR (-0.51 feet/year) is slightly less erosional than the mean short-term 40-year EPR of -0.63 ft/year. This trend is mirrored in Baltimore County, where the mean 10-year rate of change was also slightly less erosional than the mean 30-year rate of change.

In Prince George's County, the mean short-term 10-year EPR (-1.27 feet/year) is more erosional than the mean short-term 30-year EPR of 0.01 feet/year. This trend is mirrored in Anne Arundel County, where the mean 10-year EPR was also more erosional than the mean 30-year EPR. Possible reasons for the higher mean rate 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 utilized in the 30-year EPR calculation; 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 may be tempered due to the longer time period over which the rate was calculated. As such, longer term trends of lower erosion may be reflected in the 30-year rate.

When looking at short-term rates, MGS recommends using the 30- or 40-year EPR rate over the 10-year EPR rate when possible. In Calvert County, the 40-year rate was calculated between the ca. 1960 NOAA National shoreline and the ca. 2000 recent shoreline, which was 90% comprised of NOAA CUSP shoreline data. In Prince George's County, the 30-year rate was calculated between the ca. 1970 NOAA National shoreline and the ca. 2000/2010 recent shoreline (60% comprised of NOAA CUSP shoreline data). The NOAA shorelines are tidally referenced to MHW, and thus rates were calculated across two shorelines referenced to the same tidal datum. Note that the ca. 1990 MGS shoreline and the ca. 2000 CAC shorelines were not referenced to a tidal datum.

In Calvert County, the mean long-term LRR (-0.30 feet/year) is slightly more erosional than the mean long-term EPR (-0.20 feet/year). Again, Calvert County mirrors Baltimore County in this trend. In Prince George's County, the mean long-term LRR (-0.44 feet/year) is slightly less erosional than the mean long-term EPR (-0.58 feet/year). Again, Prince George's County mirrors the trend in Anne Arundel County, which also exhibited a more erosional mean long-term EPR.

In general, the long-term rates were calculated across a 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.

The mean long-term rate of change (EPR or LRR) was less erosional than the short-term 10-year EPR in Calvert and Prince George's Counties. In Calvert County, both the mean long-term EPR and the mean long-term LRR were also less erosional than the short-term 30-year EPR. The short-term 30-year EPR calculated in Prince George's County (0.01 feet/year) indicated that the shoreline only accreted 0.01 feet/year on average, during the approximate 30 years captured in the short-term 30-year EPR.

The mean rates of change in the 1990s MGS projects were calculated between the two most recent shorelines available at each transect, which at the time, were typically a ca. 1940 MGS shoreline and ca. 1990 MGS shoreline (thus, an approximate 50-year time frame) (Hennessee, pers. comm.). The historical mean rates of change calculated during the 1990s projects for Calvert and Prince George's Counties were -0.57 feet/year and -0.13 feet/year, respectively. Based on this project's updated mean rates, Calvert County shorelines between the 1960s –

2000s were generally more erosional (-0.63 feet/year) than Calvert County shorelines between the 1940s – 1990s (-0.57 feet/year). In Prince George's County, shorelines between the 1970s – 2010s were eroding very slightly (0.01 feet/year; essentially no change), whereas Prince George's County shorelines between the 1940s – 1990s were eroding (-0.13 feet/year).

SUMMARY AND CONCLUSIONS

For Calvert and Prince George's Counties, MGS acquired historical and recent (post-2000) shorelines from various sources, including the NOAA National, NOAA CUSP, and MD DNR CAC shoreline data sets. These newly acquired 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 Calvert and Prince George's 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 Calvert County DSAS analysis ranged in date from 1933-2007; shorelines used in the final Prince George's County DSAS analysis ranged in date from 1937-2010. DSAS analyzed rates of change across 16,292 transects in Calvert County, and 8,139 transects in Prince George's County. Using DSAS, MGS calculated the long-term LRR, long-term EPR, and short-term 10-year EPR in both counties. Additionally, MGS calculated a short-term 40-year EPR in Calvert County, and a short-term 30-year EPR in Prince George's County.

In both counties, MGS then grouped the short-term rates of change into generalized categories (accretion, no change, slight erosion, low erosion, moderate erosion, high erosion) based on the results of the short-term 10-year EPR analysis. MGS repeated this process for the 40-year EPR analysis and the 30-year EPR analysis in Calvert and Prince George's Counties, respectively. MGS then assigned the rate categories as attributes to a recent shoreline for each county. This recent shoreline consisted of the available NOAA CUSP shoreline, supplemented with CAC shoreline in areas where the NOAA CUSP shoreline was missing. 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. In summary, MGS attributed two recent shorelines for Calvert County: one with generalized 10-year EPR rates, and one with generalized 40-year EPR rates. In Prince George's County, MGS attributed one recent shoreline with generalized 10-year EPR rates, and a second recent shoreline with generalized 30-year EPR rates.

Based on the length of the recent shoreline utilized in rate-of-change analysis, Calvert County's shoreline totals 243.6 miles and Prince George's County shoreline totals 138.6 miles. Both county's total shoreline lengths surpass the previous lengths reported of 230.2 and 119.1 miles for Calvert and Prince George's Counties, respectively (Hennessee and others, 2003). The lengths reported in the 2003 MGS report were extracted from the ca. 1990 MGS shoreline. In both counties, the current shoreline increase is due to the NOAA CUSP and CAC shoreline's inclusion of several headwater reaches of tributaries, several minor tributaries, and delineation of further inshore marsh areas. Additionally, the NOAA CUSP shoreline included several inland ponds, breakwaters, and jetties that were not digitized in the ca. 1990 MGS shoreline. In Prince George's County, the CAC shoreline also included the Anacostia River, which was not included in the ca. 1990 MGS shoreline.

Numerical short-term 10-year rate-of-change categories were assigned to 62.6% of the shoreline in Calvert County, and 54.2% of the shoreline in Prince George's County. Numerical short-term 40-year rate-of-change categories were assigned to 9.3% of the Calvert County shoreline. Numerical short-term 30-year rate-of-change categories were assigned to 19.2% of the Prince George's County shoreline. The balance of the shoreline was either protected, did not have any associated rate data, or the calculated rates were suspect.

Overall, the mean short-term 10-year rate of change for the quantifiable shorelines in Calvert County is -0.51 feet/year; for Prince George's County, the mean short-term 10-year rate is -1.27 feet/year. These rates were calculated using the ca. 1990 MGS shoreline and the recent ca. 2000/2010 shoreline (comprised of both NOAA CUSP and CAC shoreline data). Of the 152.4 shoreline miles in Calvert County attributed with the 10-year EPR, an estimated 97.4 miles (63.9%) are eroding and 55.0 miles (36.1%) are accreting. Of the 75.1 shoreline miles in Prince George's County attributed with the 10-year EPR, an estimated 57.8 miles (77.0%) are eroding and 17.3 miles (23%) are accreting.

In Calvert County, the mean short-term 40-year rate of change for the quantifiable shorelines in Calvert County is -0.63 feet/year. These rates were calculated using the ca. 1960 shoreline and the recent ca. 2000 shoreline (comprised of both NOAA CUSP and CAC shoreline data). Only 22.6 miles were attributed with the 40-year EPR, due to the limited ca. 1960 shoreline coverage in the county. Of these attributed miles, an estimated 17.6 miles (77.9%) are eroding and 5.0 miles (22.1%) are accreting.

The mean short-term 30-year rate of change for the quantifiable shorelines in Prince George's County is 0.01 feet/year. These rates were calculated using the ca. 1970 shoreline and the recent ca. 2000/2010 shoreline (comprised of both NOAA CUSP and CAC shoreline data). Only 26.6 shoreline miles were attributed with the 30-year EPR, due to the limited ca. 1970 shoreline coverage in the county. Of these attributed miles, an estimated 12.2 miles (45.9%) are eroding and 14.3 miles (53.8%) are accreting.

Of the eroding shorelines in both Calvert and Prince George's Counties, the majority of the erosion is slight – less than 2.0 feet/year. Erosion exceeds 2.0 feet/year along the remaining miles of retreating shoreline. Note, however, that these areas exceeding -2.00 feet/year of erosion only comprise between 0 and 8.2% of the attributed shoreline.

The mean long-term LRR and EPR rates calculated for Calvert County were -0.30 feet/year and -0.20 feet/year, respectively. The mean long-term LRR and EPR rates calculated for Prince George's County were -0.44 feet/year and -0.58 feet/year, respectively. The mean short-term 10-year EPR rates calculated for both counties are more erosional than the long-term LRR and EPR rates. In Calvert County, the mean short-term 10-year EPR (-0.51 ft/yr) is less erosional than the mean short-term 40-year EPR (-0.63 ft/yr). In Prince George's County, the mean short-term 10-year EPR (-1.27 ft/yr) is more erosional than the mean short-term 30-year EPR (accreting at a very low 0.01 ft/yr; essentially no change).

MGS recommends using the 30- or 40-year EPR to describe short-term change where possible. In counties with comprehensive NOAA CUSP coverage and a ca. 1960 or ca. 1970 NOAA shoreline, these short-term rates compare two NOAA shorelines referenced to the common tidal datum of MHW. Additionally, other agencies employed in similar studies of shoreline change utilize a 30-year time span to describe their "short-term" rates. The short-term 10-year EPR rate is calculated using the ca. 1990 MGS shoreline which is not tidally referenced, and as such, may not be as accurate of a descriptor of short-term change. Additionally, MGS recommends using the long-term LRR rate over the long-term EPR rate wherever possible, since the LRR method takes into account all shoreline position information available at a transect when calculating a rate of change.

MGS does not recommend using these updated rates of change to predict future shoreline positions or rates of change. The DSAS rates computed at each transect only describe the historic shoreline behavior up to the date of the most recent shoreline used in the particular DSAS rate analysis. Although rates calculated across marshy shorelines are delivered as part of this project, MGS advise users to utilize these rates with caution.

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.

To date, MGS has calculated updated shoreline rates of change data for Anne Arundel, Baltimore, Calvert and Prince George's Counties in Maryland. MGS is currently in the process of calculating updated rate-of-change statistics for Harford County. This project is scheduled to be completed in September 2016. These projects comprise the beginning stages of an effort to complete a much-needed statewide shoreline change update for all sixteen tidewater counties in Maryland. Pending available NOAA CUSP coverage, MGS recommends the following counties as potential candidates for the next shoreline rates of change update: Charles and St. Mary's Counties (to complete the update for the western shore tidewater counties); or Dorchester and Queen Anne's Counties on Maryland's Eastern Shore.

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