Interjurisdictional Coordination for Alternatives Assessment for the Northern Seaside of Virginia's Eastern Shore, Accomack County

Allen, T.R., Tolvanen, H.T., Oertel, G.F., and McLeod, G.M., December 2007. Spatial characterization of environmental gradients in a coastal lagoon, Chincoteague Bay. *Estuaries and Coasts*, 30(6), 959-977.
http://link.springer.com/article/10.1007/BF02841388

Spatial patterns of environmental processes are intrinsic yet complex components of estuaries. Spatial characterization of environmental gradients is a necessary step to better understand and classify estuarine environments. A geographic information system is developed to analyze the major abiotic environmental processes, to evaluate accuracy and spatial uncertainty, and to analyze potential zonation within the choked coastal lagoon of Chincoteague Bay in Maryland and Virginia, USA. Spatially extensive grid-based models of environmental gradients are constructed from existing geospatial and environmental databases, including tidal prism, bathymetry, salinity, wave exposure, and Secchi disk depth. Integration of wetland boundaries and bathymetric data provide for full basin analysis of flushing and tidal prism. Multivariate Principal Components Analysis demonstrates the covariation among gradients and provides an empirical approach to mapping multidimensional zones within the lagoon. The project documents the development of an estuarine geographic information system that can be used to analyze and compare estuarine environments and provide data for environmental decision making.

Buynevich, I.V., FitzGerald, D.M, and Goble, R.J., 2007. A 1500 yr record of North Atlantic storm activity based on optically dated relict beach scarps. *Geology*, 35 (6), 543-546.
Understanding of long-term dynamics of intense coastal storms is important for determining the frequency and impact of these events on sandy coasts. Researchers use optically stimulated luminescence (OSL) dates on relict scarps within a prograded barrier sequence to reconstruct the chronology of large-magnitude erosional events in the western Gulf of Maine. OSL dates obtained on quartz-rich sediments immediately overlying relict scarps indicate severe beach erosion and retreat due to erosional events ca. 1550, 390, 290, and 150 cal yr B.P. The data provide new evidence of increased storm activity (most likely frequency and/or intensity of extratropical storms) during the past 500 yr, which was preceded by a relatively calm period lasting ~1000 yr. The width of the coastal sequence preserved between successive paleoscarps shows strong correlation with the time interval elapsed between storms. Findings indicate that diagnostic geophysical and sedimentological signatures of severe erosional events offer new opportunities for assessing the impact and timing of major storms along sandy coasts.

Carruthers, E.A., Lane, D.P., Evans, R.L., Donnelly, J.P., and Ashton, A.D. , 2013. Quantifying overwash flux in barrier systems: An example from Martha's Vineyard, Massachusetts, USA. *Marine Geology*. 343, 15-28.

Coastal barriers are particularly susceptible to the effects of accelerated sea-level rise and intense storms. Over centennial scales, barriers are maintained via overtopping during storms, which causes deposition of washover fans on their landward sides. Understanding barrier evolution under modern conditions can help evaluate the likelihood of future barrier stability. This study examines three washover fans on the undeveloped south shore of Martha's Vineyard using a suite of vibracores, ground penetrating radar, high resolution dGPS, and LiDAR data. From these data, the volumes of the deposits were determined and range from 2.1 to 2.4 × 104 m3. Two of these overwash events occurred during Hurricane Bob in 1991. The water levels produced by this storm have a calculated return interval of ~28 years, implying an onshore sediment flux of 2.4–3.4 m3/m/yr. The third washover was deposited by a nor'easter in January 1997, which has a water level return interval of ~6 years, suggesting a flux of 8.5 m3/m/yr. These onshore fluxes are smaller than the erosional flux of sediment resulting from shoreline retreat, suggesting that the barrier is not in long-term equilibrium, a result supported by the thinning of the barrier in recent years.

Chesapeake Bay Foundation, September 2007. *Living Shorelines for the Chesapeake Bay Watershed*. Richmond, Virginia: Chesapeake Bay Foundation. Web.September 24, 2015, 10p.

The document discusses erosion and the characteristics and advantages of living shorelines. It provides a chart developed by the Maryland Department of Natural Resources identifying which erosion control treatment option is best for certain conditions. The three erosion control treatment options are:

- Nonstructural Projects (beach replenishment, marsh fringe, marshy islands, biologs, groins)
- Hybrid Projects (marsh fringe with groins, marsh fringe with sills, marsh fringe with breakwaters, beach replenishment with breakwaters)
- Structural Projects (bulkheads, revetments, stone reinforcing, groins and jetties)

Chincoteague and Wallups Island National Wildlife Refuge CCP/EIS, May 2014. N.p. *Chapter 3: Affected Environment*. Web.September 23, 2015. p. 3-1 through 3-43.

This chapter describes the physical, biological, and socioeconomic environment of the refuge. The physical environment section includes the refuge's geography, hydrogeomorphic features, soil information, and air and water quality. Biological resources are covered in sections on vegetation and wildlife that discuss how those resources have been influenced by human activity and management. With respect to the refuge's current sociological environment, the area's socioeconomics, land use and transportation, and visitor services are explained. Cultural and historic resources on the refuge, as well as aspects of refuge administration are discussed. The information in this chapter acts as a reference for chapter 4, which documents the Environmental Consequences of each alternative on these resources.

***Chincoteague National Wildlife Refuge Beachfill: Abbreviated Analysis and Cost Opinion for Maintaining the Existing Parking Areas and Recreational Beach (Appendix J)*, May 2014. N.p. Web.September 23, 2015.**
Beach erosion along the open ocean of Assateague Island is well documented with average net long-term rates of -1.2 meters/year. Federal resources are expended yearly to maintain the recreational beach and parking areas. This report conveys a cost opinion of stabilizing (not protecting) the parking areas and recreational beaches based on a similar recent United States Army Corps of Engineers (USACE) beach-fill project at Wallops Island. The term *protection* is used when armoring (for example, revetments and seawalls) the shoreline and protecting inland development. The term *stabilization* is used to decelerate shoreline erosion using breakwater systems and/or increase the longevity of a beach by beach fill and maintain a wide berm for damage reduction. The design proposes establishment of a dune position on the beach berm and beach nourishment that would extend towards the ocean. The intent and objective is to stabilize existing parking areas. This report is not an economic analysis, alternative analysis or detailed design analysis.

Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change, Phase 1: Sea-level Rise and Coastal Storms, Chapter 5, July 2008. Report of the Maryland Commission on Climate Change Adaptation and Response Working Group. Web.September 28, 2015, 32p.
A key recommendation of the report is to retain and expand Maryland's forests, wetlands, and beaches to protect areas from coastal flooding. In support of this, it is important do the following: (1) identify high priority protection areas and to strategically and cost-effectively direct protection and restoration actions; (2) develop and implement a package of appropriate regulations, financial incentives, and educational, outreach, and enforcement approaches to retain and expand forests and wetlands in areas suitable for long-term survival; and (3) promote and support sustainable shoreline and buffer area management practices.

Cronin, T.M., Szabo, B.J., Ager, T.A., Hazel, J.E., and Owens, J.P., 1981. Quaternary climates and sea levels of the U.S. Atlantic coastal plain. *Science,* 211(4479), 233-240.
Uranium-series dating of corals from marine deposits of the U.S. Atlantic Coastal Plain coupled with paleoclimatic reconstructions based on ostracode (marine) and pollen (continent) data document at least five relatively warm intervals during the last 500,000 years. On the basis of multiple paleoenvironmental criteria, we determined relative sea level positions during the warm intervals, relative to present mean sea level, were 7 +/- 5 meters at 188,000 years ago, 7.5 +/- 1.5 meters at 120,000 years ago, 6.5 +/- 3.5 meters at 94,000 years ago, and 7 +/- 3 meters at 72,000 years ago. The composite sea level chronology for the Atlantic Coastal Plain is inconsistent with independent estimates of eustatic sea level positions during interglacial intervals of the last 200,000 years. Hydroisostatic adjustment from glacial-interglacial sea level fluctuations, lithospheric flexure, and isostatic uplift from sediment unloading due to erosion provide

possible mechanisms to account for the discrepancies. Alternatively, current eustatic sea level estimates for the middle and late Quaternary may require revision.

Dean, R.G., and Perlin, M., 1977. Coastal engineering study of Ocean City Inlet, Maryland. *Proc. Coastal Sediments '77*, ASCE, Reston, Virginia, 520-540. Web. September 23, 2015.
The paper reports on a study to identify causes of and develop recommendations for reducing the requirement for increased frequencies and quantities of dredging in the westerly segment of the inlet channel. Although the problem of primary concern to this study is shoaling of the inlet channel, it appears that the cause of the shoaling is also responsible for anomalous recession along the northern portion of Assateague Island. The low and permeable inshore portion of the south jetty allows sand to flow downslope past the south jetty and onto the north shore of Assateague Island. The major recommendation is that the south jetty be increased in elevation and rendered sand-tight. With the sediment supply reduced considerably to the northern shore of Assateague Island, this shoreline will tend to erode. The recommended alternative to stabilizing this shoreline would be to construct one or more structures preventing westward transport of this sand.
Department of Natural Resources and Environmental Control, N.d. Assawoman Canal, Map 2: Potential Sea Level Rise Scenarios. Department of Natural Resources and Environmental Control, Division of Parks and Recreation. 1 sheet. Web.September 16, 2015.
Legend of sea level rise scenarios include the following:

- current MHHW
- .5 meters SLR
- meters SLR
- 1.5 meters SLR.

Dominguez, O.M., December 13, 2010. *Record of Decision/Wallups Island Facility Record of Decision/Wallups Flight Facility Shoreline Restoration and Infrastructure Protection Program/Programmatic Environmental Impact Statement.* Wallups Island, Virginia: National Aeronautical and Space Administration, Goddard Space Flight Center, Wallups Island Facility.
The National Aeronautics and Space Administration prepared this Record of Decision (ROD) for the Wallops Flight Facility (WFF) Shoreline Restoration and Infrastructure Program (SRIPP) Final Programmatic Environmental Impact Statement (PEIS). This ROD includes a summary of the Final PEIS, public involvement in the decision-making process, alternatives considered, key environmental issues evaluated, the alternative selected, and the basis for the decision.

Donnelly, C., 2008. Coastal Overwash: Processes and Modelling. Lund, Sweden: Lund University, Doctoral thesis, 52p.
Overwash is the flow of water and sediment over the crest of a beach system when the

runup level of waves or the water level, often enhanced by storm surge, exceeds the local beach or dune crest height. The impacts of overwash on coastal barriers or low lying mainland coasts are striking. It would therefore be highly useful to be able to predict the occurrence of overwash events and the magnitude and shape of the washover deposited during them. Although a number of studies describing overwash and washover deposits have been published, there remains a large scope to describe overwash processes, overwash hydrodynamics and to develop models for predicting the magnitude and shape of washover deposits on the back barrier. The objective of this study was to improve the capability to predict sediment transport caused by overwash, and hence the resulting topographic changes. One of the main tasks for this study was therefore to identify and describe both the forcing and back barrier processes that affect overwashing flow. Overwash was shown to occur due to both wave runup overtopping the beach crest and surge levels exceeding the beach crest height.
On the back barrier, overwash hydrodynamics and sediment transport were shown to be affected by the back barrier water level, friction, infiltration, lateral spreading and anthropogenic influences. Laboratory experiments of runup overwash were conducted to gain an understanding of back barrier flow hydrodynamics. The laboratory data were supplemented with published field data to derive relationships to estimate overtopping depths and wave front velocities on the beach crest and back barrier. Additionally, three different types of overwash models (parametric, analytical, and numerical) were developed. All three models were calibrated, validated and verified against a large, new data set of pre- and post-storm beach profiles measured where overwash had occurred and show promising results for predicting beach profile change.

Eastern Shore Hazard Mitigation Planning Committee and Accomack-Northampton Planning District Commission, 2011. *The Eastern Shore of Virginia 2011 Hazard Mitigation Plan*. Accomac, Virginia: Accomack-Northampton Planning District Commission. Report funded by the Federal Emergency Management Agency through the Virginia Department of Emergency Management via grant agreement # FMA2009-001-022, 278p.
In part, the Hazard Mitigation Plan addresses hazard and vulnerability related to coastal flooding (chapter 4) and coastal erosion (chapter 7). Hazard refers to sources of potential danger or adverse conditions, while vulnerability refers to how exposed or susceptible to damage an asset is. The documents addresses flooding, coastal erosion, and hazard maps and planning documents for the Town of Chincoteague. It also charts Accomack County areas experiencing coastal erosion, and identifies the overall mitigation strategy.

Englehart, S.E., Horton, B.P., and Kemp, A.C., 2011. Holocene sea level changes along the United States' Atlantic coast. *Oceanography Special Issue*, *24(2), 70-79.*
Reconstructions of Holocene relative sea level (RSL) have valuable applications in a number of topics within the Earth sciences, including calibrating and constraining geophysical models of Earth's rheology and glacial isostatic adjustment. The usefulness of these reconstructions depends on application of a standardized methodology that fully considers all age and vertical errors. The authors outline this methodology and

provide a detailed example from New Jersey. They describe Holocene RSL reconstructions from the US Atlantic coast that illustrate both spatial and temporal variability. Spatially, rates of Holocene RSL rise were greatest in the Mid Atlantic (New Jersey and Delaware) with decreasing rates of rise to the north and south. Temporally, rates of RSL rise have decreased since the early Holocene due to the combined effects of continued relaxation of the solid Earth in response to deglaciation and reduction in ice melt since 7,000 years ago. A comparison of late Holocene (last 4,000 years) geological reconstructions to long-term tide-gauge measurements reveals that sea level rise increased above background rates by an average of 1.7 mm yr–1 during the twentieth century.

Fenster, M.S., and Bundick, J.A., 2015. Morphodynamics of Wallops Island, Virginia: A Mixed-Energy, Human-Modified Barrier Island. Ashland, Virginia: Randolph-Macon College. Wallups Island, Virginia: National Aeronautics and Space Administration. Chapter within McBride, R.A., Fenster, M.S., and Seminack, C.T. Holocene Barrier Island Geology and Morphodynamics of the Maryland and Virginia Open-Ocean Coasts: Fenwick, Assateague, Chincoteague, Wallops, Cedar, and Parramore Islands. Fairfax, Virginia: George Mason University. Ashland, Virginia: Randolph-Macon College.

Wallops Island is the northernmost barrier island in Virginia's barrier-island chain, bounded on the north and south by Chincoteague Inlet and Assawoman Inlet, respectively. Currently, Wallops Island has a drumstick shape typical of mixed-energy hydrographic regimes, but is strongly influenced by Chincoteague Inlet processes and wave refraction around Assateague Island's southern terminus (Fishing Point). The latter process creates a divergent nodal zone near Wallops' southern end, along which 6.4 × 104 m3/yr of sediment moves north and south—with the southern cell losing three times as much sediment as the northern cell gains (9.6 × 104 m3/yr vs. 3.6 × 104 m3/yr). These flux rates are evident in shoreline change rates, as the southern 3.5 km has retreated nearly 8.5 m/yr and the northern 2.5 km has advanced 6.7 m/yr. The rapid retreat of Wallops' southern end and of the other islands in the "arc of erosion" has caused a concomitant decrease in tidal prism and, with the aid of a breach fill on south Wallops following the 1962 Ash Wednesday storm, the closing of Assawoman Inlet in the mid-1980s. For these reasons, NASA has continually worked to mitigate the effects of coastal storms on its infrastructure and mission, most recently undertaking a beach nourishment program slated for implementation over 50 years. This chapter covers the dynamics (forcings) that impact Wallops Island, including the complexities associated with calculating sediment budgets (e.g., the impacts that sediment sinks and temporal variation have on sediment transport), changes in wave-refraction patterns over time, and the effect of Chincoteague Inlet on Wallops Island. This chapter also covers the history of shore protection used by NASA to protect its infrastructure, including the most recent effort, the Shoreline Restoration and Infrastructure Protection Program (SRIPP). Finally, this chapter discusses historical changes to Assawoman Inlet to the south of Wallops Island in response to changes in tidal prism.

Fenster, M., and Dolan, R., Winter 1996. Assessing the impact of tidal inlets on adjacent barrier island shorelines. *Journal of Coastal Research*, 12(1), 294-310.
Researchers investigated barrier island-tidal inlet sand sharing systems along the United States' mid-Atlantic coast to determine the impact of tidal inlets on adjacent shorelines. They used two reaches in their analyses with different natural (unstructured) settings: the wave-dominated Outer Banks of North Carolina and the mixed-energy, tide-dominated Virginia barrier islands. Three criteria were used to delineate inlet domination and inlet influence on adjacent barrier shorelines based on spatial distribution of shoreline rate-of-change values: (1) the cessation of abrupt changes, i.e., the reduction in variability in the rates of change along-the-shore; (2) a change in the sign of the rate value from erosion to accretion or vice versa; and (3) a change in the increasing or decreasing trends in rate values. The maximum distances of inlet influence extend to 6.8 km updrift and 5.4 km downdrift of inlets along the Virginia barrier islands and 6.1 km and 13.0 km for the updrift and downdrift inlet shorelines along the Outer Banks barriers. Additionally, shoreline changes can be dominated by inlet processes to a maximum distance of 4.3 km. Results support previous conclusions that sand bypassing processes exert greater influence on mixed-energy, short barrier island shorelines than on wave-dominated, long, linear barrier island shorelines.

Field, M.E., June 1980. Sand bodies on coastal plain shelves: Holocene record of the U.S. Atlantic inner shelf off Maryland. *Journal of Sedimentary Petrology*, 50(2), 505-528.
The inner continental shelf of Maryland, Delaware, and northern Virginia has been examined with high-resolution seismic reflection equipment and vibracores to develop an understanding of Quaternary processes and history on a coastal plain shelf. Morphology of the study region is dominated by the large shelf valley of the ancestral Delaware River and estuary and a linear-ridge field. Shallow subsurface strata consist of gently seaward-dipping Neogene sedimentary units showing no evidence of tectonic deformation. Eleven major acoustic surfaces, including the presumed Tertiary-Quaternary nonconformity at about -30 m to -60 m, are present within the upper 120 m of the shelf subbouom. Buried channels are common to the seafloor of the entire region', in the Delaware Bay entrance, most are cut to 45 m below sea level and were filled laterally by split platform progradation from both the New Jersey and Delaware shelves. Many small channels on the Maryland shelf are aligned with existing onshore drainage or historical inlet sites and display a linear relationship between maximum thalweg depth and distance from shore. The upper 6 m of the sedimentary sequence of the inner shelf consists of terrigenous sand and silt derived from the adjacent Coastal Plain and Piedmont Provinces. Four major sediment types are recognized: three of these are subarkosic arenites varying only in modal grain size and sorting; the fourth is a slightly sandy mud. Environments of deposition preserved on the present shallow shelf are: modern marine, back-barrier, lagoonal, and fluvial. Gray-brown, fine to coarse, well-sorted quartz sand is the dominant type of surface sediment and its relative abundance decreases in the subsurface. Increases in sand thickness occur locally in ridge areas and correspond directly to topographic relief. The ridge sand unconformably overlies poorly sorted fine sand and mud remnant from Holocene backbarrier and lagoonal deposition; coarse constituents of the unit are commonly incorporated into the

base of the ridge sand. Linear ridges are a dominant topographic feature of the U.S. mid-Atlantic shelf, and they are particularly well-defined on the Maryland shelf. Marked similarities in geometry and sediment relations of these features provide evidence of their origin on the Holocene shoreface and later segmentation and isolation on the shelf. Individual ridges commonly display a progressive south to north change from a well-defined, narrow, single-crested shape to a poorly defined, broad, multi-crested shape. This axial trend and the variation in coastal intersection angle are inherited from the ridge's origin on the shoreface where growth and bifurcation occur along the northeastern tip. Shelf sand bodies off the central Delmarva Peninsula have formed by wave and current processes acting on previously deposited sediments, and these sand bodies are being formed and modified at present. The inner shelf of this region represents the trailing edge of a marine transgression; as such, it is the coastal sedimentary facies most likely to be preserved in the rock record.

Fisher, J.S., and Stauble, D.K., December 1977. Impact of Hurricane Belle on Assateague Island washover. *Geology*, 5(12), 765-768.
The occurrence of Hurricane Belle on August 9, 1976 supplied additional data on the role of overwash on Assateague Island. Approximately 19m^3 of sand per metre of washover centerline (oriented normal to shoreline) was deposited at the survey site as a result of the storm. The major source of sand appears to be the beach and near-shore regions as opposed to the foredunes adjacent to the washover throat, because there is a lack of measured dune erosion. Unlike most winter storms, there was no concurrent offshore wind to deflate this deposit as the storm subsided. However, strong offshore winds in January 1977 eroded some 16 m^3/m from this centerline and redeposited this sand on the beach. This study suggests that overwash of the magnitude experienced during storms of less than major proportions may not be processes for significant long-term sand accumulation to this barrier island.

Fletcher III, C.H., Knebel, H.J., and Kraft, J.C. March 1990. Holocene evolution of an estuarine coast and tidal wetlands. *Geological Society of America Bulletin*, 102, 283-297.
http://www.soest.hawaii.edu/coasts/publications/FletcherEtAl1990.pdf
Modern facies-distribution patterns, extensive core data, and chronostratigraphic cross sections provide a detailed history of Holocene inundation within the Delaware Bay estuary and sedimentation in adjacent coastal environments. Flooding of the estuary occurred with rising sea level as the shoreline retreated northwest along a path determined by the pre-transgression topography. Simultaneous migration of an estuarine turbidity maximum depocenter provided the bulk of fine sediments which form the coastal Holocene section of the estuary. Prior to 10 Ka, the ancestral bay was predominantly a tidal river, and the turbidity maximum depocenter was located southeast of the modern bay mouth. By 10 Ka, lowlands adjacent to the ancestral channel of the Delaware River were flooded, forming localized tidal wetlands, and the depocenter had initiated high rates of fine-grained sedimentation near the present bay mouth. At that time, coastal Holocene strata began to onlap the interfluve highlands. By 8 Ka, the fine-grained depocenter had migrated northwest along the main channel

of the Delaware River, although the widened mouths of tributary valleys continued to be active sites of sediment accumulation. Following the passage of the fine-grained depocenter, coarse-grained sediments accumulated along the coast in response to increased wind-wave activity. During the middle Holocene, portions of the estuarine coast began to resemble modern geomorphology, and washover barrier sands and headland beach sandy gravels accumulated along the southwest shore. The late Holocene was characterized by erosional truncation and submergence of aggraded coastal lithofacies and by planation of remnant highland areas. Knowledge of the eroded Holocene section is fragmentary. At present, continued sea-level rise is accompanied by deposition of tidally transported muds in coastal environments and deposition of sandy sediments in some offshore regions. An unconformity marks the base of the developing open estuarine sequence of coarse clastic lithofacies and denotes the end of coastal accumulations. Modeling of coastal-lithofacies transitions identifies specific lithofacies complexes in the Holocene stratigraphic section which were influential in the evolution of the coast. Development of the Holocene section of the estuary coast involved both constructive, or aggradational, and destructive, or erosional, phases.

Galano, F.A., 2009. Beach erosion adjacent to the stabilized microtidal inlets. *Middle States Geographer*, 42, 18-32.
Stabilized tidal inlets have caused severe downdrift erosion that threatens structures and barrier island stability. This problem has long been established, but the full impact has often been misinterpreted, as most researches have not recognized the “s” signature of this mode of shoreline behavior. Furthermore, damaging erosion along beaches in front of coastal communities has sometimes been attributed to tidal inlets because simple sediment budget models have been used (incorrectly) to quantify the problem. A comparison of six inlets along the U.S. Northeast coast demonstrates a consistent pattern of change: the arc of erosion is a mobile planform feature, its spatial behavior is time dependent, it expands downdrift at a non-linear rate, and the area of change consistently manifests an “s” pattern. Long-term (100+ year) shoreline change data were used to identify these relationships and quantify the impact of tidal inlets on downdrift beaches. This paper will focus on Moriches Inlet along the southern shore of Long Island, New York.

Guo, J., December 8, 2014. The old man and the rising sea. *The Washington Post*. Web.September 23, 2015.
Assateague is one of the most vulnerable islands in the United States, and is almost certain to be one of the first places claimed by sea level rise. This article is based on an interview with National Park Service Chief of Maintenance for Assateague Island National Seashore, and raises the issue of whether East Coast shorelines should hold fast, or retreat. Assateague is one of the first places in the National Park system to develop a master plan for all climate change contingencies.

Hapke, C.J., Himmelstoss, E.A., Kratzmann, M., List, J.H., and Thieler, E.R., 2010, *National assessment of shoreline change: Historical shoreline change along the*

New England and Mid-Atlantic coasts. **U.S. Geological Survey Open-File Report 2010-1118, 57p.**
The U.S. Geological Survey (USGS) is analyzing historical shoreline changes along open-ocean sandy shores of the conterminous United States and parts of Hawaii, Alaska, and the Great Lakes. One purpose of this work is to develop standard, repeatable methods for mapping and analyzing shoreline movement so that periodic, systematic, internally consistent updates regarding coastal erosion and land loss can be made nationally. In this study, shoreline is the interpreted boundary between the ocean water surface and the sandy beach. This report is the fifth in a series on historical shoreline change, and like earlier reports, it summarizes methods of analysis, interprets results, provides explanations regarding long- and short-term trends and rates of change, and describes how different coastal communities are responding to coastal erosion. This report differs from the earlier USGS reports in the series in that previous shoreline change analyses incorporated only four total shorelines to represent specific time periods. The New England and Mid-Atlantic assessment incorporates all shorelines that are available and can be quality-checked. Shoreline change evaluations are based on a comparison of historical shoreline positions digitized from maps or aerial photographic data sources with recent shorelines, at least one of which is derived from lidar (light detection and ranging) surveys. Coastal engineering structures along the New England and Mid-Atlantic coasts affect the rates of shoreline change, which vary substantially along the coast. However, it is difficult to isolate the influence of structures and nourishment projects on the regional long- and short-term rates, and such an endeavor is beyond the scope of this report.

Hardaway Jr., C.S., and Byrne, R.J., 1999. *Shoreline Management in Chesapeake Bay*. Gloucester Point, Virginia: Virginia Institute of Marine Science, College of William and Mary, 54p.
This book addresses shoreline management from a comprehensive standpoint. It takes into account shoreline erosion, and explains the basic physical parameters behind shoreline change. Furthermore, this book presents solutions to management problems with an eye to cost effectiveness, sound construction, coastal hazards, property loss, habitat preservation, and water quality. This document describes and illustrates specific, practical responses to shoreline management issues. It looks at the evolution of the Chesapeake Bay and its ongoing, long-term processes, and discusses the daily, physical mechanisms that affect shoreline change and the topics professionals address in evaluating sites. It discusses strategies for managing shorelines, such as bulkheads, seawalls, revetments, groins, breakwaters, beach nourishment, and marsh fringes, as well as taking no action. It offers a framework to apply these ideas in terms of the physical environment at the site and the applicable shoreline strategies. In the past, shoreline erosion has often been addressed in a haphazard fashion without a basic understanding of how the physical environment, man-made constructions, and land-use patterns impact each other. Yet the impact of these changes can be substantial.

Hinds III, L.S., October 19, 2011. CNWR Comprehensive Management Plan. Town of Chincoteague, Office of the Mayor. http://www.chincoteague-va.gov/pdf/123%20combined.pdf. Web.September 4, 2015.

This reference is a letter with attachment describing the “1-2-3 Common Sense Plan” that presents an alternative to the August 2011 U.S.FWS Draft Comprehensive Conservation Plan. The document offers three steps and detailed actions to reduce storm damage at Tom’s Cove. The steps include (1) taking immediate action to protect the existing infrastructure; (2) implementing a two to three year action plan; (3) implementing a three to five year action plan.

Hobbs III, C.H., Krantz, D.E., Wikel, G.L., N.d. Coastal processes and offshore geology. Submitted as a chapter for *The geology of Virginia*, edited by Chuck Bailey, College of William and Mary. Web.September 23, 2015, 44p.
The modern coastal geology of Virginia results from the interactions of modern processes, primarily waves, tidal currents and sea-level rise, with the antecedent geology. The ancient and major rivers draining the Piedmont and interior highlands of eastern North America carried sediments that were deposited in various areas across the physiographic continuum of the coastal plain and continental shelf as sea level fluctuated in response to global climate changes. The scarps that formed by shoreline erosion during highstands of sea level and the very low-gradient intervening flats are the proximal underpinning of the contemporary coastal zone. The ocean shoreline of Virginia comprises parts of two major coastal compartments: one spanning the distance between Delaware and Chesapeake Bays; the other running from Cape Henry, the southern side of the mouth of the Chesapeake, to Cape Lookout, North Carolina. The location within the broader coastal compartment and the local interplay of the processes with the geography determine the development of the shoreline within each segment of the shore. The gross characterization of Virginia’s coast as the Delmarva Peninsula, the Bay Mouth, and Southeastern Virginia sections insufficiently describes the variation. The two major subaerial compartments can be further segmented. The Delmarva Peninsula embraces, from north to south, the Cape Henlopen spit complex, the eroding headlands of Bethany and Rehoboth, the long Fenwick-Assateague barrier island terminating in a potentially developing cape adjacent to Chincoteague Island, the Virginia Barrier Islands, and the distal Fishermans Island at Cape Charles. The Virginia Barrier Islands can be partitioned into a wave-dominated, severely eroding northern segment, a central transitional segment, and a southern segment with greater tidal influence. The Chesapeake Bay Mouth is a complex region of shoals and channels responding to wave energy and reversing tidal currents flowing into Chesapeake Bay. The Southeastern Virginia compartment mimics Delmarva with the northern spit of Cape Henry, the Virginia Beach headland, and the long barrier-island complex that continues to Cape Lookout, where the shoreline turns sharply west toward the mainland.

Johnson, Z.P., October 2000. *A sea level rise response strategy for the state of Maryland*. Annapolis, Maryland: Maryland Department of Natural Resources, Coastal Zone Management Division, 49p.
Low-lying coastal plains and barrier islands, such as those located along Maryland’s outer coast, its coastal bays, and the low-lying eastern shore, are particularly susceptible to erosion, flooding and inundation. Sea level rise also threatens to exacerbate and prolong the process of erosion along the developed western rim of the Chesapeake Bay. Perhaps most dramatic, however, is the threat sea level rise poses to

low-lying islands and extensive marsh systems within the Bay. Recognizing the need to begin advance planning, Maryland's Coastal Zone Management Program worked to develop a sea level rise response strategy for Maryland. The Strategy was developed through: (1) an extensive review of related technology, data and research; (2); an assessment of Maryland's vulnerability based on the range and magnitude of impact, the physical characteristics of the coastline, and population and growth patterns; and, (3) an assessment of Maryland's existing response capability. Specific recommendations for reducing the State's overall vulnerability to sea level rise are contained in the proposed Strategy, which will guide the State toward the development of a networked means of response, crossing over inter-governmental boundaries to address the three primary impacts of sea level rise in Maryland (i.e., erosion, flooding and inundation), and the associated environmental and socio-economic implications of each. The Strategy is comprised of the following four components to achieve the desired outcome within a five-year time horizon.
***. Outreach and Engagement*:** Engage the general public, State and local planners, and elected officials in the process of implementing a sea level rise response strategy.
. Technology, Data and Research Support: Gain a better understanding of the regional impacts of sea level rise and applicable policy response alternatives.
. Critical Applications: Incorporate sea level rise planning mechanisms into existing State and local management programs and on-going coastal initiatives.
. ***Statewide Policy Initiatives*:** Enhance, and where necessary, modify key State statues to remedy barriers and advance sea level rise planning initiatives.
Implementation of the Strategy will evolve over time.

King Jr., D.B., Ward, D.L., Hudgins, M.H., and Williams, G.G., October 2011. *Storm Damage Reduction Project Design for Wallops Island, Virginia.* ERDC/CHL TR-11-9. Vicksburg, Mississippi: U.S. Army Corps of Engineers, Coastal and Hydraulics Laboratory. Norfolk, Virginia: U.S. Army Engineer District, Norfolk.
A succession of beach protection measures have had limited success in mitigating Wallops Island shoreline erosion, which has reached a critical state. This report describes the modeling effort and technical details that have gone into the development of a comprehensive storm damage reduction project that does not negatively impact adjacent shorelines. The plan incorporates a tiered approach with a beach fill as the first line of defense, reducing storm damage for up to 30 year return interval events. The fill, combined with a rehabilitated and extended rock seawall, increases protection to include up to approximately 100 year return interval storm events. Flood protection is provided on a structure-by-structure basis. Alternatives examined included a plan with a terminal groin and one with a detached breakwater, although the recommended alternative includes no sand retention structure. Sand volumes needed for initial and renourishment fills are presented, and shoreline impacts from mining offshore borrow sites and from extending the rock seawall are examined.

Kraft, J.C., August 1971. Sedimentary facies patterns and geologic history of a Holocene marine transgression. *Geological Society of America Bulletin*, 82, 2131-2158.

Abstract at: http://gsabulletin.gsapubs.org/content/82/8/2131. Login to access article.

Studies of Holocene sediments in coastal Delaware show complex sediment distribution patterns resulting from lateral and vertical movement of successive environments of deposition over a Pleistocene unconformity. These sediments are infilling a drowned topography with a local relief of 70 ft and possibly up to 125 ft eroded on highly variable Pleistocene sediments. Identification of the Pleistocene surface remains a problem. However, it may be recognizable at the unconformity as a soil zone or intermixture of firm marsh clay-silts with Pleistocene sands, as well as on the basis of radiocarbon dates.

Larger depositional features forming around eroding Pleistocene headlands and infilling the estuaries include characteristic shoreline environments, such as spits, dunes, baymouth barriers, an intermeshing network of tidal deltas, nearshore marine erosional-depositional sands and gravels, and lagoons or estuaries with fringing *Spartina, Distichlis,* and *Phragmites* marshes, which form the westernmost edge of the transgressive units. The thickness and areal extent of the sedimentary bodies are to a large degree controlled by the morphology of the Pleistocene unconformity. A large portion of the Holocene sedimentary units is being eroded by the transgressing Atlantic Ocean.

Cores of sediment under the shallow lagoons, such as Rehobeth, Indian River, and Assawoman Bays, and in the fringing marsh environment, show that the depositional units are thin, highly irregular in areal extent, extremely variable in thickness, and difficult to project. Sedimentary processes active in the shallow bays include shoreline marsh erosion and the formation of thin, possibly ephemeral, beach-dune washover complexes consisting of clean, well-sorted sand, with typical beach and washover sedimentary structures. These washover beaches are an anomaly completely surrounded by *Spartina* marshes on the landward side and extremely muddy sands grading into dark gray lagoonal muds on the bay side. It appears that distinctive sedimentary structures and sediment size-sorting relationships, such as those that characterize the larger, more common sedimentary units of the coastal area, may be formed in miniature at the very thin edge of transgression and may lead to considerable confusion in the interpretation of sediments of this type in the geologic record.

Kraft, J.C., John, C.J., and Maurmeyer, E.M., 1978. Chapter 7: Morphology of Coastal Barriers, Delaware, U.S.A. Newark, Delaware: University of Delaware Department of Geology. Found in Coastal Engineering Proceedings, No. 16, 232-1244. Web. October 1, 2015. https://icce-ojs-tamu.tdl.org/icce/index.php/icce/article/viewFile/3333/3001

The Atlantic Coast of Delaware consists of four separate but continuous segments including (from north to south): (1) a northward-projecting spit complex (Cape Henlopen); (2) eroding Pleistocene headlands; (3) a linear coastal washover barrier; and (4) an area of migrating inlets with associated modern and relict ebb and flood tidal deltas. Coastal process studies show that continuing coastal erosion is accompanied by longshore transport of sand eroded from headlands, offshore transport to the nearshore

marine area, and overwash processes transporting sand landward across the barrier. Studies of the adjacent nearshore marine area show that the barrier and its various geomorphic elements lay at the outer edge of the continental shelf approximately 12,000 years ago, and migrated landward and upward to the present position as the Holocene marine transgression continued. The sequence of coastal sediments of the barrier system consist of (landward to seaward) tidal marsh fringe, lagoonal muds and sands, barrier sands (including washover, dune, and beach deposits), and shallow nearshore sand and gravel. Drill-hole studies provide information on the subsurface configuration of the barrier from which the three-dimensional structure and stratigraphy of coastal sedimentary environmental lithosomes may be defined.

Krantz, D. E., 2010. *A hydrogeomorphic map of Assateague Island National Seashore, Maryland and Virginia*. Natural Resource Report NPS/NRPC/GRD/NRR—2010/215. Fort Collins, Colorado: National Park Service/Natural Resource Program Center, 63p.
The landforms and hydrology of Assateague Island National Seashore are interpreted and categorized in a hydrogeomorphic map of the barrier island. This report accompanies a digital map in GIS format, defines the primary map units and subunits, and explains the approach for classifying sections of the island. The base for the map is a color infrared photomosaic of the National Seashore that covers two-thirds of Assateague Island. A lidar digital elevation model of the island with 10-cm vertical resolution was used as a supplement to the photomosaic for interpretation of landforms. The interpretation of island hydrology relies on a previous study of ponds on the island and geophysical surveys of representative sites to delineate the vertical character and horizontal continuity of the surficial aquifer and fresh ground-water lens. Geophysical methods included gamma and electromagnetic induction logging of existing deep wells, ground-penetrating radar, and electrical resistivity. This hydrogeomorphic map has substantial explanatory and predictive value for evaluating the spatial character of many components of the barrier-island ecosystem, including the distribution of plant species and communities, fresh-water resources for large vertebrates, and living and breeding habitat for numerous invertebrates and smaller vertebrates.

Kraus, N.C., March 2002. *Reservoir Model for Calculating Natural Sand Bypassing and Change in Volume of Ebb-Tidal Shoals, Part I: Description*. Vicksburg, Mississippi: U.S. Army Corps of Engineers, Engineer Research and Development Center, Coastal Hydraulics Laboratory. ERDC/CHL CHETN-IV-39, 14p.
This Coastal and Hydraulics Engineering Technical Note (CHETN) provides information on a mathematical model developed to calculate natural sand bypassing and change in volume of ebb-tidal shoals. Subsequent CHETN's in this series will describe the interface and generalizations of the model to cover flood-tidal shoals, inlet-entrance channel, and other morphologic features at inlets.

Laczo, T.D., Gomez, M.L., and Blama, R.N., September 2013*. Regional Sediment Management for Atlantic Coast of Maryland and Assateague Island Seashore*

(Assateague Island By-Pass Project). **U.S. Army Corps of Engineers, ERDC/CHL CHETN-XIV-35, 10p.**
This document describes Regional Sediment Management (RSM) activities and investigations performed by the U.S. Army Corps of Engineers, Baltimore District (NAB), along Maryland's Atlantic Coast at Fenwick Island, the Ocean City Inlet, and the Assateague Island National Seashore. An evaluation was performed of beach renourishment and sand bypassing along the Atlantic Coast of Maryland at the Assateague Island shoreline to develop a holistic approach to understanding the overall sediment transport system. This evaluation was undertaken to investigate the fate of dredged material placed along the shore, and the short- and long-term impacts of that placement to the ebb shoal. Understanding these impacts will assist in predicting the ability of the ebb shoal to replenish itself, to estimate the effects dredging will have on the borrow area compared to the overall system, and to optimize NAB dredging operations with better informed decisions regarding where to dredge.

This report concludes that the ability of NAB to implement ERDC CMS models to assist in planning and implementing effective decisions should lower costs for dredging and restoration of the NAB Atlantic Coast region. Shorter hauling distances to the placement site, knowledge that allows for selection of optimal borrow and placement sites as well as more precise volumes to be placed, identification of sand deficient areas, and solutions to reduce the amount of sand entering the inlet from the ebb shoal, are benefits of well-implemented RSM. These benefits will arise from field surveys, sampling, analyses, and insight provided from the NAB RSM Ocean City Inlet and Assateague/Fenwick Island numerical simulation modeling with CMS.

Leatherman, S.P., (February 1979). Migration of Assateague Island, Maryland, by inlet and overwash processes. *Geology*, v. 7, 104-107.
The northern part of Assateague Island, Maryland, has a history of rapid shoreline erosion, with washovers much in evidence. A comparison of aerial photography shows that the greatest island widths and highest rates of landward migration are associated with inlet dynamics. The over-wash process, at maximum transport conditions in this sand-starved area, is effective only in maintaining the island as a low, narrow barrier.

Leatherman, S.P., Zhang, K., and Douglas, B.C., February 8, 2000. Sea level rise shown to drive coastal erosion. *Eos*, 81(6), 55-57.
The authors state that their research has shown that an important relationship exists between sea level rise and sandy beach erosion. The link is highly multiplicative, with the long-term shoreline retreat rate averaging about 150 times that of sea level rise. For example, a sustained rise of 10 cm in sea level could result in 15 m of shoreline erosion. Sea level is one of many factors causing long-term beach change. Shoreline revisions from inlet dynamics and coastal engineering projects are more pronounced in most areas of the US east coast and tend to mask the effect of a rise in sea level even over extended intervals. The implication is that sea level rise is a secondary but inexorable cause of beach erosion in such areas. Despite this link between sea level and erosion, the exact mechanism requires more investigation. At the least, however, it is plausible

that rising sea level enables high-energy waves to reach farther up the beach and redistribute sand offshore.

Global sea level will increase about 20 cm by 2050 according to best estimates *[IPCC,* 1996]. Combined with local subsidence caused by ongoing glacial isostatic adjustment, sea level along New Jersey, Delaware, and Maryland will rise up to 40 cm by the year 2050.This projected rise will result in as much as 60 m of erosion, about two times the average beach width, and cause enormous problems in these highly urbanized coastal areas. The article addresses causes of sea level rise, reasons for the difficulty in gaining insight into coastal erosion processes, erosion trends from New York to South Carolina, observation of subtle shoreline erosion effects, and methods for computing long-term shoreline change.

Lewis, D.A., Cooper, J.A.G., and Pilkey, O.H., October 2005. Fetch limited barrier islands of the Chesapeake Bay and Delaware Bay. *Southeastern Geology*, 44 (1), 1-17.
http://www.wcu.edu/WebFiles/PDFs/psds_Fetch_Barrier_2005.pdf
Barrier islands within bays, lagoons, estuaries and other protected waters have never been the subject of systematic research on a large scale. Within both the Chesapeake and Delaware Bays, barrier islands are numerous and widely distributed. Totaling more than 300 in number, these fetch limited barrier islands exhibit a range of morphologies uncommon along open ocean shorelines. We group the barrier islands in the two bays into three primary categories based on their morphology and location. In general, they are much shorter (-lkm), narrower (<25m), and lower (1-2m) than their open ocean analogs, yet they behave in much the same way in their response to oceanographic processes. The greatest difference between ocean and bay barriers is the strong control of evolutionary processes by vegetation, usually salt marsh, in the bays.

McNeill, R., Nelson, D.J., and Wilson, D. , September 4, 2014. The Rising Crisis of Sea Levels: Water's Edge. *A Reuters Series*. Web.September 23, 2015.
This article is the first in a series that examines sea level rise, its effect on the United States, and our country's response to the problem. Seawater and tidal marsh have consumed farmland and once-inhabited islands. In Accomack County alone, the Environmental Protection Agency says rising sea water is converting approximately 50 acres of farmland into wetlands each year. More than 300 counties claim tidal coastline in the United States, but the government has developed no clear national policy to determine which locations receive help to protect shorelines. Communities are competing for attention and resources, "lest they be abandoned to the sea, as is playing out in Chincoteague."

Morang, A., Williams, G., and Swean, J., September 2006. *Beach Erosion Mitigation and Sediment Management Alternatives at Wallops Island, VA.* Vicksburg, Mississippi: U.S. Army Corps of Engineers Coastal and Hydraulics Laboratory. Norfolk, Virginia: U.S. Army Engineer District, Norfolk. ERDC/CHL TR-06-21, 97p.

The Goddard Space Flight Center, Wallops Flight Facility (WFF) has experienced erosion throughout the six decades that NASA has occupied the site. Near the south part of the island, at the Mid-Atlantic Regional Spaceport (MARS) spaceport, shoreline retreat from 1857 to the present averaged about 3.7 m/year. Further south, adjacent to Assawoman Inlet, retreat exceeded 5 m/year. Since the early 1990s, part of the island has been protected with a stone rubblemound seawall, which is being undermined because there is little or no protective sand beach remaining and storm waves break directly on the rocks. The south end of the island is unprotected except for a low revetment around the MARS launch pad. As a result, NASA officials are concerned that launch pads, infrastructure, and test and training facilities belonging to NASA, the U.S. Navy, and the (MARS) spaceport, valued at over $800 million, are vulnerable to damage from storm waves and that the foundations of structures and the Unmanned Autonomous Vehicle (UAV) runway may be undermined. ERDC and U.S. Army Engineer District, Norfolk, have developed a plan to protect Wallops Island from ongoing beach erosion and storm wave damage incurred during normal coastal storms and northeasters. The key aspect of the plan is that the beach will have to be rebuilt with a sand fill along the entire island. The ultimate purpose will be to move the zone of wave breaking well away from the vulnerable infrastructure. This plan is not intended to protect against inundation and other impacts during major hurricanes and exceptional northeasters, when water levels can rise several meters. The more comprehensive of two alternatives includes beach fill and the construction of sand-retention structures such as detached breakwaters. Despite higher initial costs, structures will probably reduce life-cycle costs because of reduced requirements for renourishment volumes.

National Aeronautics and Space Administration, April 2013. *Draft Environmental Assessment: Wallups Island Post-Hurricane Sandy Shoreline Repair*. Wallups Island, Virginia: Goddard Space Flight Center, Wallups Flight Facility, 84p.
This Environmental Assessment (EA) addresses the proposed repair of the Wallops Island shoreline owned by the NASA Goddard Space Flight Center's Wallops Flight Facility. Under the Proposed Action, NASA would fund placement of up to approximately 800,000 cubic yards of sand dredged from an offshore sand shoal. Additionally, should funds permit, NASA would repair a portion of its rock seawall. The project would restore the shoreline to its condition prior to Hurricane Sandy. This EA analyzes potential direct, indirect, and cumulative environmental effects of two alternatives – the Proposed Action, and the No Action Alternative. Resources evaluated in detail include the following: coastal processes; water quality; the coastal zone; air quality; noise; benthos; wildlife; finfish and habitat; marine mammals; threatened and endangered species; and cultural resources.

National Parks Conservation Association, August 2007. *State of the Parks: Assateague Island National Seashore*. Washington, D;C.: National Parks Conservation Association, Center for the State of the Parks, 36p.
The National Parks Conservation Association initiated the State of the Parks program in 2000 to assess the condition of natural and cultural resources and to determine how well equipped the National Park Service is to protect the parks. One goal is to provide information that will help policy-makers and the National Park Service improve

conditions in national parks. Overall conditions of Assateague's natural resources rated a "fair" score of 75 out of 100. Ratings were assigned through an evaluation of park research and monitoring data using NPCA's Center for State of the Parks comprehensive assessment methodology. Challenges include contamination of bayside waters with nutrient and sediment runoff from agriculture and residential development on the mainland, and from atmospheric deposition of nitrogen. Non-native feral horses and sika deer overgraze native plant communities, disrupt island soils, and interfere with natural processes such as dune formation. Recently introduced aquatic invasive species may threaten the integrity of the estuarine ecosystem, and a number of nonnative plants, including the common reed, are found throughout the island. These and other threats are being systematically addressed through monitoring, assessment, mitigation, and protection by park staff and a broad-based coalition of partners. Overall conditions of the park's known cultural resources rated a score of 58 out of 100, indicating "poor" conditions. The majority of resource management funding is directed toward natural resources. No staff are devoted exclusively to cultural resources management, which limits the park's ability to study and care for cultural resources.

The Nature Conservancy, May 2011. The Eastern Shore of Virginia: Strategies for Adapting to Climate Change. (Report from the Eastern Shore Climate Change Adaptation Strategies Workshop). Web.September 27, 2015, 58p.
The Nature Conservancy launched a climate change adaptation project for the Eastern Shore of Virginia to more specifically characterize the current understanding of potential ecological effects due to climate change through an expert workshop, literature review and assessment of resource vulnerability using LiDAR data. In addition, the Conservancy, in collaboration with partners and the local community, set out to use this understanding to inform the identification of strategic actions that will enhance resilience and facilitate adaptation of this globally important and productive coastal area upon which local communities and wildlife depend. To accomplish the latter, the Conservancy hosted the Eastern Shore Climate Change Adaptation Strategies Workshop in August 2010. Workshop participants included a range of industries and communities that will be affected by sea-level rise and other climate change effects, including local representatives from aquaculture, agriculture, local government and community organizations. Participants agreed on five priority climate change adaptation strategies to pursue in the future, related to the following: local adaptation planning; shoreline management; restoration and protection of natural systems; groundwater management; and education and outreach.

With respect to shoreline management, participants envisioned development of shoreline management plans for all Eastern Shore stream reaches in consultation with VIMS that are incorporated into county comprehensive plans per the new statewide statutory requirement, and promotion of new general permit for living shorelines with land owners through education and demonstration projects. The report discusses the following two steps in order to accomplish this:

(1) Promote and implement new legislation passed by the General Assembly that requires localities to incorporate coastal resource management guidance (aka plans) into scheduled revision of comp plans.
(2) Promote new general permit for “living shorelines” as the preferred alternative to stabilize shorelines by continuing to build on past public outreach and education programs regarding alternative shoreline management through workshops and demonstration projects such as Occohannock Creek.

Nieves, D.P., August 26, 2009. *Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0.2) in the Lower Delmarva Peninsula: Northampton and Accomack Counties, VA; Somerset and Worcester Counties, MD.* Arlington, Virginia: Conservation Biology Program, National Wildlife Refuge System, 43p.
Sea-level rise is expected to affect tidal marshes and other near-shore habitats causing serious retreat in the world’s shorelines. According to The International Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES), sea level is expected to increase in the range of 0.18 to 0.59 m by the end of the 21st century (IPCC 2007). Coastal habitats, particularly tidal marshes, are among the most vulnerable regions from climate change induced sea-level rise. The impacts of sea-level rise will be an increasing challenge to National Wildlife Refuge System managers that have the responsibility of maintaining the biological integrity of wetland and coastal habitats. The Eastern shores of the Chesapeake Bay may retreat more than 5 km by the year 2100 and evidence suggests that coastal marshes are starting to migrate along the Eastern Shores of the Bay (Titus and Richman 2001). The effect of sea-level rise on the coastal wetlands of Assateague Island is of special concern given its importance for migratory birds and other species.

An increase in sea levels as projected by IPCC (2007) represents potentially drastic impacts to barrier islands. A USGS report projects that areas with the highest occurrence of overwash and rates of shoreline change on Assateague Island are likely to be most affected by sea-level rise (Pendeleton et al. 2004). In addition, impacts from sea-level rise may also be more significant in these areas because of on-going human impacts. Productivity of salt marshes has been significantly reduced due to horse grazing (Sturm 2008) and construction of artificial dunes (personal communication with Mark Sturm). To address potential effects of sea-level rise, the USFWS is applying the Sea Level Affecting Marsh Model (SLAMM) on coastal refuges. The SLAMM analysis will help field stations plan for the effects of sea-level rise on wildlife habitats and refuge operating needs. The aim of this study is to project the effects of sea-level rise on coastal habitats of the region extending from Ocean City Inlet, MD to Fisherman Island, VA in the Delmarva Peninsula. Habitats within Chincoteague National Wildlife Refuge and Assateague Island are the main focus of this project.

Nikitina, D.L., Pizzuto, J.E., Schwimmer, R.A., and Ramsey, K.W., 2000. An updated Holocene sea level curve for the Delaware coast. *Marine Geology*, 171, 7-20.
The authors present an updated Holocene sea-level curve for the Delaware coast based on new calibrations of 16 previously published radiocarbon dates (Kraft, 1976;

Belknap and Kraft, 1977) and 22 new radiocarbon dates of basal peat deposits. A review of published and unpublished 137Cs and 210Pb analyses, and tide gauge data provide the basis for evaluating shorter-term (102 yr) sea-level trends. Paleosea-level elevations for the new basal peat samples were determined from the present vertical zonation of marsh plants relative to mean high water along the Delaware coast and the composition of plant fossils and foraminifera. Current trends in tidal range along the Delaware coast were used to reduce elevations from different locations to a common vertical datum of mean high water at Breakwater Harbor, Delaware. The updated curve is similar to Belknap and Kraft's [J. Sediment. Petrol., 47 (1977) 610-629] original sea-level curve from 12,000 to about 2000 yr BP. The updated curve documents a rate of sea-level rise of 0.9 mm/yr from 1250 yr BP to present (based on 11 dates), in good agreement with other recent sea-level curves from the northern and central U.S. Atlantic coast, while the previous curve documents rates of about 1.3 mm/yr (based on 4 dates). The precision of both estimates, however, is very low, so the significance of these differences is uncertain. A review of 210Pb and 137Cs analyses from salt marshes of Delaware indicates average marsh accretion rates of 3 mm/yr for the last 100 yr, in good agreement with shorter-term estimates of sea-level rise from tide gauge records.

Oertel, G.F., 1985. The barrier island system. In G.F. Oertel and S.P. Leatherman (Editors) Barrier Islands. *Marine Geology*, 63, 1-18. http://ac.els-cdn.com/0025322785900775/1-s2.0-0025322785900775-main.pdf?_tid=d390430a-692b-11e5-a138-00000aab0f6c&acdnat=1443807445_176c271a957bbf32c5cabb32617a604a
Barrier islands are part of a major coastal system composed of six interactive sedimentary environments. The six environments are also elements needed to impose the designation “barrier island” on littoral sand bodies. The elements are: (1) mainland; (2) backbarrier lagoon; (3) inlet and inlet deltas; (4) barrier island; (5) barrier platform; and (6) shoreface. The morphodynamic and sedimentary evolution of each element affects adjacent environments, as well as the entire system. The interactive elements are defined and described by their morphologic, sedimentologic and stratigraphic relationships to the barrier island and the barrier island system. The stratigraphic relationships of the various elements of the system may be a valuable tool for paleogeographic reconstruction and sand body mapping.

Pendleton, E.A., Williams, J.S., and Thieler, E.R., 2004. *Coastal Vulnerability Assessment of Assateague Island National Seashore (ASIS) to Sea-Level Rise.* Woods Hole, Massachusetts: U.S. Geological Survey. U.S. Geological Survey Open-File Report 2004-1020, Electronic Book, 20p.
A coastal vulnerability index (CVI) was used to map relative vulnerability of the coast to future sea-level rise within Assateague Island National Seashore (ASIS) in Maryland and Virginia. The CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: geomorphology, regional coastal slope, rate of relative sea-level rise, shoreline change rates, mean tidal range and mean wave height. Rankings for each variable were combined and an index value calculated for 1-minute

grid cells covering the park. The CVI highlights those regions where the physical effects of sea-level rise might be the greatest. This approach combines the coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, yielding a quantitative, although relative, measure of the park's natural vulnerability to the effects of sea-level rise. The CVI provides an objective technique for evaluation and long-term planning by scientists and park managers. Assateague Island consists of stable and washover dominated portions of barrier beach backed by wetland and marsh. Areas within Assateague that are likely to be most vulnerable to sea-level rise are those with the highest occurrence of overwash and the highest rates of shoreline change.

Rankin, R., November 2009. *Dynamic Sustainability: Shoreline Management on Maryland's Atlantic Coast.* Alexandria, Virginia: U.S. Army Corps of Engineers Institute for Water Resources, 174p.
Dynamic Sustainability details the history of Ocean City and Assateague Island, Maryland, on the Atlantic coast of the United States. As coastal communities, these locations have been significantly impacted by the waters surrounding them, the storms that strike them and the inlet that passes between them. This case study examines the ways in which residents and officials have managed the issues inherent to living next to an ocean and how the U.S. Army Corps of Engineers has participated in these management efforts.

Ritter, Jr., R.G., December 3, 2014. *Letter of Support for a Proposed Feasibility Study of Coastal Resiliency within the Environs of the Town of Chincoteague*. Web.September 3, 2015.
This document is a letter from the Chincoteague Island Town Manager to the U.S. Army Corps of Engineers requesting a study to address the Flood Risk/Coastal Storm Risk Management, Navigation and Aquatic Ecosystem Restoration problems and opportunities on the Eastern Shore. Chincoteague is interested in putting academic research and technical studies to work in the following areas: storm damage reduction; barrier island/inlet change; flooding, drainage and shoreline erosion; navigation; and transportation.

Rosati, J.D., March 2005. Concepts in sediment budgets. *Journal of Coastal Research*, 21(2), 307-322.
The sediment budget is fundamental in coastal science and engineering. Budgets allow estimates to be made of the volume or volume rate of sediment entering and exiting a defined region of the coast and the surplus or deficit remaining in that region. Sediment budgets have been regularly employed with variations in approaches to determine the sources and sinks through application of the primary conservation of mass equation. This paper reviews commonly applied sediment budget concepts and introduces new considerations intended to make the sediment budget process more reliable, streamlined, and understandable. The need for both local and regional sediment budgets is discussed, and the utility of combining, or collapsing, cells is shown to be

beneficial for local budgets within a regional system. Collapsing all cells within the budget creates a “macrobudget,” which can be applied to check for overall balance of values. An automated means of changing the magnitude of terms, while maintaining the same dependency on other values within the sediment budget, is presented. Finally, the need for and method of tracking uncertainty within the sediment budget, and a means for conducting sensitivity analyses, are discussed. These new concepts are demonstrated within the Sediment Budget Analysis System with an application for Long Island, New York, and Ocean City Inlet, Maryland.

Rosati, J.D., Frey, A.E., Grezegorzewski, A.S., Maglio, C.K., Morang, A., and Thomas R.C., March 2015. *Conceptual Regional Sediment Budget for USACE North Atlantic Division.* Vicksburg, Mississippi: U.S. Army Corps of Engineers Coastal Hydraulics Laboratory, ERDC/CHL SR-15-2, 54p.
This report documents development of a conceptual regional sediment budget (CRSB) for the U.S. Army Corps of Engineers (USACE), North Atlantic Division (NAD). The NAD requested preparation of a CRSB as part of the post-Hurricane Sandy assessment to provide information about sediment sources and opportunities for strategic placement of sediment within the Division. A conceptual sediment budget is intended to provide a general framework based on existing transport information from which a more detailed sediment budget can be later prepared based on rigorous data analysis and numerical modeling. For this CRSB, literature and databases were reviewed and analyzed to characterize sediment transport pathways and magnitudes, and morphologic zones of erosion and accretion. The CRSB highlights areas with data gaps, conflicts in existing budgets, and opportunities for better sediment management within the NAD and is available via a geographic information system (GIS) portal.

Rosati, J.D., and Stone, G.W., 2007. Critical Width of Barrier Islands and Implications for Engineering Design. New Orleans, Louisiana: American Society of Coastal Engineers Coastal Sediments ’07, 1-14. Web. September 29, 2015. http://www.wavcis.lsu.edu/pubs/156.pdf
The critical width of a barrier island is defined as the smallest cross-shore dimension that minimizes net loss of sediment from the island over periods from decades to centuries. This concept is of importance for large-scale restoration of barrier islands which involves rebuilding these islands to a specified geometry. Within constraints of coastal forcing and geologic and regional characteristics at the site, islands having critical width will capture deposition of washover sediment onto the subaerial beach over the project lifetime. This study reviews previous investigations of barrier island critical width and applies a newly-developed model of barrier island migration, consolidation, and overwash to assist engineering design.

Rosati, J.D. and Stone, G.W., 2009. Geomorphologic evolution of barrier islands along the northern U.S. Gulf of Mexico and implications for engineering design in barrier restoration. *Journal of Coastal Research,* 25(1), 8–22.

file:///C:/Users/milligan/Downloads/ADA508727%20(1).pdf
Aspects of northern Gulf of Mexico (NGOM) (Louisiana, Mississippi, Alabama, and Florida panhandle) processes and barrier islands that are pertinent to their geomorphologic response are contrasted with the broader knowledge base summarized by SCHWARTZ (1973) and LEATHERMAN (1979, 1985). Salient findings from studies documenting the short-term (storm-induced; timescales of hours, days, and weeks) and long-term (timescales of years, decades, and centuries) response of barrier island systems in the NGOM are synthesized into a conceptual model. The conceptual model illustrates the hypothetical evolution of three barrier island morphologies as they evolve through a typical Category 1–2 hurricane, including poststorm recovery (days to weeks) and long-term evolution (years to decades). Primary factors in barrier island geomorphologic response to storms, regardless of location, are the elevation of the island relative to storm (surge plus setup) elevation, and duration of the storm. Unique aspects of the NGOM barrier islands, compared with knowledge summarized for other barrier types, include (1) storm paths, wind speed, and large bays that create the potential for both Gulf and bayshore erosion and (2) in Louisiana and Mississippi, the potential for loading of the underlying substrate by the barrier island, which, through time, increases consolidation, relative sea level rise, overwash, morphologic change, and migration. We recommend that design of large-scale beach restoration projects incorporate the potential for (1) time-dependent consolidation of the underlying sediment due to project loading and future migration, (2) Gulf and bayshore erosion and overwash, and (3) eolian transport toward the Gulf from north winds.

Sallenger, A.H., 2000. Storm impact scale for barrier islands. *Journal of Coastal Research*, 16(3), 890-895.
A new scale is proposed that categorizes impacts to natural barrier islands resulting from tropical and extra-tropical storms. The proposed scale is different in that the coupling between forcing processes and the geometry of the coast is explicitly included. Four regimes, representing different levels of impact, are denned. Within each regime, patterns and relative magnitudes of net erosion and accretion are argued to be unique. Borders between regimes represent thresholds denning where processes and magnitudes of impacts change dramatically. Impact level 1 is the 'swash' regime describing a storm where runup is confined to the foreshore. The foreshore typically erodes during the storm and recovers following the storm; hence, there is no net change. Impact level 2 is the 'collision' regime describing a storm where the wave runup exceeds the threshold of the base of the foredune ridge. Swash impacts the dune forcing net erosion. Impact level 3 is the 'overwash' regime describing a storm where wave runup overtops the berm or, if present, the foredune ridge. Associated net landward sand transport contributes to net migration of the barrier landward. Impact level 4 is the 'inundation' regime describing a storm where the storm surge is sufficient to completely and continuously submerge the barrier island. Sand undergoes net landward transport over the barrier island; limited evidence suggests the quantities and distance of transport are much greater than what occurs during the 'overwash' regime.

Sanford, W.E., Pope, J.P., and Nelms, D.L., 2009, Simulation of groundwater-level and salinity changes in the Eastern Shore, Virginia: U.S. Geological Survey Scientific Investigations Report 2009–5066, 125 p.
Groundwater-level and salinity changes have been simulated with a groundwater model developed and calibrated for the Eastern Shore of Virginia. Groundwater is the sole source of freshwater to the Eastern Shore, and it is important that the groundwater supply be protected from overextraction and seawater intrusion. The best way for water managers to use all of the information available is usually to compile this information into a numerical model that can simulate the response of the system to current and future stresses. The purpose of this report is to describe the development and calibration of a groundwater model for the Eastern Shore of Virginia. The report includes discussions of (1) the hydrogeologic framework of the Eastern Shore, (2) the nature of the digital model used to simulate the aquifers, (3) the water-level and chemical conditions used to calibrate the model, (4) hydraulic characteristics of the calibrated model, (5) current and future water levels and chloride concentrations simulated with the model, and (6) potential errors and limitations of the model.

Schupp, C., September 2013. *Assateague Island National Seashore Geologic Resources Inventory Report*. U.S. Department of the Interior, National Park Service, Natural Resource Report NPS/NRSS/GRD/NRR-2013/708. Denver, Colorado: National Park Service Geologic Resource Division, 74 p.
The Natural Resource Report Series provides high-priority, natural resource management information with managerial application. The Geologic Resources Division held a Geologic Resources Inventory (GRI) scoping meeting for Assateague Island National Seashore in Maryland and Virginia on 26-28 July 2005 to discuss geologic resources, the status of geologic mapping, and resource management issues and needs. This report synthesizes those discussions and is a companion document to the previously completed GRI digital geologic map data. The report discusses geologic issues of significance for resource management at Assateague Island National Seashore that were identified during a 2005 GRI scoping meeting. Those issues include the following: storm impacts; coastal vulnerability and sea-level rise; inlet impacts on transport processes; hydrology; benthic habitats; landscape and shoreline erosion; recreation and watershed land use; disturbed lands; archeological resources; paleontological resources; seismicity; wave and current activity; wind activity; tidal activity; sediment transport processes, and barrier island system units.

Sergent, E., Bond, T., Oakley, A. and Cornell, S., November 2012*. Monitoring Sediment Transport and Grain Size Distribution along Wallops Island, Virginia, Pre and Post-Beach Replenishment.* Paper No. 12. 2012 GSA Annual Meeting and Exposition. Geological Society of America, Inc.
Wallops Island has experienced severe erosion for more than a century. This erosion, combined with rising sea level, is causing the shoreline to retreat rapidly to within meters of NASA's Wallops Flight Facility. A narrowing beach, wind-driven wave activity and storm surge periodically cause massive flooding and sand overwash on the island and threaten the existing infrastructure. In response to these threats, NASA began to replenish the beach in April 2012. Millions of cubic yards of sand from two shoals ~6-10

NM offshore are being added to the beach face and in front of the seawall to widen and elevate the beach. In order to understand how beach replenishment will affect sediment transport and deposition, as well as habitats for endangered species along the 12-km shoreline, researchers established baseline conditions pre-replenishment. They collected surface sediment samples along the dune and beach face from March 2011-April 2012 to determine sediment transport trends and grain size distribution. Research also included rapid storm response and biotic surveys. Pre-replenishment results show a south-north trend in grain size distribution with the coarsest sand (Phi = -2 to 2) dominating beaches to the south and the finest sand (Phi=3 to 4) north of the seawall. Severe erosion, averaging 3.7 m/yr since 1857, occurs on the southern portion of Wallops Island while significant accretion is occurring to the north. The observed south to north sediment transport trend is reversed from mid-Atlantic regional transport. This is in part caused by a local reversal in longshore current created by the interaction between tidal outflow from the Chincoteague Inlet and the geometry of Wallops Island and adjacent Assateague Island. Researchers continue to monitor post-replenishment grain size distributions along Wallops Island, and will use these data to compare pre-replenishment baseline conditions to post- replenishment conditions in order to determine how the addition of offshore sand will affect this barrier island system. This report presents baseline conditions and the first few months of post-replenishment data.

Shideler, G.L., Swift, D.J.P., Johnson, G.H., and Holliday, B.W., 1972. Late quaternary stratigraphy of the inner Virginia continental shelf: A proposed standard section. *Geological Society of America Bulletin*, 83, 1787-1804.
A continuous seismic reflection survey indicates that the post-Miocene section of the inner Virginia Shelf is 27 m in average thickness and unconformably overlies a discordant Tertiary substrate. Vibracore data and a faunal analysis reveal three distinct sedimentary sequences separated by prominent unconformities.

- The oldest post-Miocene sequence has a radiocarbon age of more than 37,000 yrs B.P. It consists largely of a muddy, fine-grained sand and is characterized by lenticular stratification and prominent local channeling. It appears to represent a pre-Wisconsinan and early Wisconsinan assemblage, containing both a transgressive fluvial complex and a regressive coastal barrier complex.
- The overlying sequence has a radiocarbon age ranging from 25,700 ± 800 yrs, to possibly as young as 20,400 ± 850 yrs B.P. It is comprised primarily of mud, and is characterized by relatively uniform horizontal stratification. The assemblage appears to represent a regressive paralicneritic sequence developed at the end of the mid-Wisconsinan interstadial.
- The youngest sequence has yielded a radiocarbon age of 4,200 ± 140 yrs B.P. It is comprised of a discontinuous sand sheet that mantles the modern sea floor, and which appears to have been generated through the shore face erosion of a retrograding coastal barrier complex during the Holocene transgression. Evidence suggests that it accumulated as a lag deposit on the sea floor, where it was subsequently molded into a ridge and swale topography by the Holocene hydraulic regime.

Smith, C., April 2015. *Community Leader Workshop Summary Report: Enhancing Coastal Resilience on Virginia's Eastern Shore (November 12 and 13, 2014).* Accomack-Northhampton Planning District Commission.
This report represents the proceedings from the *Enhancing Coastal Resilience on Virginia's Eastern Shore Community Leader Workshop* held on November 12 and 13, 2014 at the Chincoteague Bay Field Station in Wallops Island. This is the first of a series of stakeholder workshops and part of a comprehensive Coastal Resilience Project, both of which are described in the report. Community leaders from local, state, and federal governments and non-government organizations provided input to customize the *Coastal Resilience* planning tool that will address sea-level rise, marsh migration, storm surge, and seaside barrier island-inlet evolution. The storm surge application included in the *Coastal Resilience* tool will provide simulations for storm tracks and storm types/intensities. Participants provided information regarding locations of historic storm tracks and areas known to be most vulnerable to storm surge as well as areas expected to become increasingly vulnerable to future storm surge with accelerated sea-level rise. The seaside barrier island-inlet evolution application is expected to provide a perspective for how shoreline management actions along seaside barrier islands may impact adjacent barrier island shorelines.

Steele, C.W., Pontzer, P.R., and Antonelli, J., July 2012. Distribution of inland silversides, Menidia beryllina (Cope), as a function of wave crest velocity around Pelian Island, Virginia, USA. *Thalassas: An International Journal of Marine Science* 28(2), 57-63.
The study examines the size distribution of inland silversides, Menidia beryllina, as a result of wave crest velocity around Pelican Island, a sand spit island located near the mouth of Chincoteague Inlet. Measurements were taken of wave crest height at six sampling sites. Water temperature, salinity, and dissolved oxygen measurements were also taken at each site (no significant differences among sites were found for any of these variables). Fish were collected using three seine hauls per site during each collecting period (n = 50 fish per site, minimum). All water sampling and fish collecting were conducted during three consecutive afternoon high tides. Results of linear regression and analysis of variance of crest velocity and fish length, and of crest velocity and fish weight indicate that larger inland silversides are found predominantly in areas of lesser wave energy, while smaller inland silversides are found predominantly in areas of greater wave energy.

Stutz, M.L., and Pilkey, O.H., 2011. Open-ocean barrier islands: Global influence of climatic, oceanographic, and depositional settings. *Journal of Coastal Research,* 27(2), 207-222.
http://www.bioone.org/doi/full/10.2112/09-1190.1
A satellite-based inventory of barrier islands was used to study the influence of depositional setting, climate, and tide regime on island distribution and morphology. The survey reveals 20,783 km of shoreline occupied by 2149 barrier islands worldwide. Their distribution is strongly related to sea level history in addition to the influence of

tectonic setting. Rising sea level in the late Holocene (5000 YBP–present) is associated with greatest island abundance, especially on North Atlantic and Arctic coastal plains. Stable or falling sea level in the same time frame, a pattern typical of the Southern Hemisphere, is associated with a lower abundance of islands and a higher percentage of islands along deltas rather than coastal plains. Both coastal plain and deltaic island morphology are sensitive to the wave–tide regime; however, island length is 40% greater along coastal plains whereas inlet width is 40% greater on deltas. Island morphology is also fundamentally affected by climate. Island lengths in the Arctic are on average (5 km) only half the global average (10 km) because of the effect of sea ice on fetch and thus wave energy. Storm frequency in the high and middle latitudes is suggested to result in shorter and narrower islands relative to those on swell-dominated low-latitude coasts. The ratio of storm wave height to annual mean wave height is a good indicator of the degree of storm influence on island evolution. The potential for significant climate and sea level change this century underscores the need to improve understanding of the fundamental roles that these two factors have played historically in island evolution in order to predict their future impacts on the islands.

Tarr, J.H. September 9, 2011. Letter regarding Assateague Island National Seashore General Management Plan Alternative Concepts. Chincoteague, Virginia: Office of the Mayor. Web.September 20, 2015. http://www.chincoteague.com/preserve-access/nps-gmp-response1.pdf
This document is a letter from the Mayor, Town of Chincoteague, Inc. to the Superintendent of the Assateague Island National Seashore, presenting comments and concerns regarding the General Management Alternative Concepts for the Assateague Island National Seashore. It identified eight elements which Chincoteague strongly opposes, 11 elements it supports, and requests ten additional items of information.

Titus, J.G., D.E. Hudgens, C.Hershner, J.M. Kassakian, P.R. Penumalli , M. Berman, and W.H. Nuckols, 2010. "Virginia". In James G. Titus and Daniel Hudgens (editors). ***The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic.*** **Report to the U.S. Environmental Protection Agency. Washington, D.C., 691-888.**
Sea level is rising 1 inch every 7 to 8 years (3-4 millimeters per year) along the coast of Virginia, and beaches are eroding along the Atlantic Ocean and Chesapeake Bay. The Intergovernmental Panel on Climate Change estimates that by the end of the next century, sea level is likely to be rising 0 to 8 mm/yr (3 inches per decade) more rapidly than today (excluding the possible impacts of increased ice discharges from the Greenland and Antarctic ice sheets). Rising sea level erodes beaches, drowns wetlands, submerges low-lying lands, exacerbates coastal flooding, and increases the salinity of estuaries and aquifers. Coastal communities must ultimately choose between one of three general responses – (1) armor the shore with seawalls, dikes, revetments, bulkheads, and other structures; (2) elevate the land and perhaps the wetlands and beaches as well, or (3) retreat by allowing wetlands and beaches to take over land that is dry today. Each of these approaches is being pursued somewhere in Virginia; nevertheless, there is no explicit plan for the fate of most low-lying coastal lands as sea level rises. This report develops maps that distinguish shores that are likely to be

protected from the sea from those areas that are likely to be submerged, *assuming current coastal policies, development trends, and shore protection practices*. The authors' purpose is primarily to promote the dialogue by which society decides where to hold back the sea and where to yield the right of way to the inland migration of wetlands and beaches.

A key step in evaluating whether new policies are needed is to evaluate what would happen under current policies. The maps in this report represent neither a recommendation nor an unconditional forecast of what will happen, but simply the likelihood that shores would be protected if current trends continue. Their work resulted in a statewide series of maps that uses existing data, filtered through the local governments who plan and govern how land is used. By "shore protection" they mean activities that prevent dry land from converting to either wetland or water. Activities that protect coastal wetlands from eroding or being submerged were outside the scope of this study. This study does not analyze the timing of possible shore protection; it simply examines whether land would be protected once it became threatened. The maps divide the dry land close to sea level into four categories of shore protection:

- Shore protection almost certain;
- Shore protection likely;
- Shore protection unlikely; and
- No shore protection, i.e., protection is prohibited by existing policies.

Toscano, M.A., and York, L.L., 1992. Quaternary stratigraphy and sea-level history of the U.S. Middle Atlantic Coastal Plain. *Quarternary Science Reviews* 11, 301-328.

No link – worked from hard copy of article

Middle-Atlantic, inner continental shelf stratigraphic studies document a regional, Late Pleistocene, fossiliferous mud deposit, from northern New Jersey to Cape Lookout, North Carolina. Seismic reconnaissance and detailed stratigraphic analyses reveal the nature of the mud, termed unit Q2, on the Maryland inner continental shelf. Extensive amino acid relative age determinations (from the single genus Mulinia), combined with additional amino acid analyses from onshore deposits having radiometric dates for calibration, indicate an age range for unit Q2 corresponding to Oxygen Isotope Stage 5. Ostracode assemblages delineate four distinct climatic episodes in unit Q2, enabling correlation of the zones in Q2 to the deep sea isotopic record of climatic fluctuations (substages) in Stage 5. Late Stage 5 is represented, on the Maryland shelf, by the 6 meter-thick mud of unit Q2, deposited in an open-shelf environment at slightly depressed sea levels relative to Substage 5e. Late Stage 5 sea levels (including sea-level minima) can be estimated for the mid-Atlantic Coastal Plain by direct measurement of the altitudes of ostracode zone boundaries offshore, and from peak transgressive facies in correlative deposits onshore. Late Stage 5 sea levels determined from the inner shelf and adjacent nearshore facies on the Atlantic coast comprise the most complete sea-level history for Stage 5 yet proposed. Some recent revisions of glacioeustatic sea-level models advocate slightly higher sea levels during late Stage 5 (Substage 5c in particular) than originally estimated from uplifting reef tracts, and support sea levels higher than estimates from deep-sea isotopic records. The sea-level

record from the Maryland inner continental shelf confirms these recent estimates in an area of minimal tectonism, and adds sea-level minima estimates for Substages 5d and 5b. Offshore, a more complete record of Stage 5 is preserved than in onshore deposits, which are limited to peak transgressive facies. Discrepancies in correlation among emerged coastal plain facies therefore become resolvable within the context provided by the shelf stratigraphy.

U.S. Army Corps of Engineers, January 2013. *NASA Wallops Island Post Hurricane Sandy Analysis Report.* Norfolk, Virginia: U.S. Army Corps of Engineers Norfolk District.
In October 2012, Wallops Island was hit by Hurricane Sandy, displacing a large volume of sand from the onshore beach. This report summarizes the Norfolk District's analysis of the volume of sand lost/gained in three areas -- the Dune, the Berm, and offshore from the first 12,000 feet (construction stations 0+00 to 120+00) of the beach nourishment project. It contains a visual on how the shoreline has change and receded, and how beach profiles have changed due to Hurricane Sandy. The report concludes that approximately 550,000 cubic yards was displaced from the Dune and Berm areas of shoreline, and recommended that the 550,000 cubic yards be re-nourished to the first 12,000 feet of the Wallops Island shoreline.

U.S. Department of the Interior, Fish and Wildlife Service, August, 2015. *Chincoteague and Wallups Island National Wildlife Refuges Final Comprehensive Conservation Plan and Environmental Impact Statement.* Chincoteague, Virginia: Chincoteague and Wallups Island National Wildlife Refuges. Web.September 25, 2015, 366p.
The U.S. Fish and Wildlife Service (USFWS) finalized this Comprehensive Conservation Plan (CCP) and draft Environmental Impact Statement for Chincoteague National Wildlife Refuge (NWR) and Wallops Island NWR that analyzes three alternatives to managing the Chincoteague NWR and Wallops Island NWR over the next 15 years. This document contains appendices providing additional information supporting the analysis. The alternatives are:
Alternative A -- maintain the status quo and current management alternative as required by the National Environmental Policy Act. This alternative would continue current management strategies as established by the Master Plan approved in 1992, and is referred to as the "No Action" alternative.
Alternative B -- continue established habitat and wildlife management strategies but focus them in light of the new goals and vision established by the CCP. This alternative balances habitat management, public use and access, and administration of the refuge. Alternative B is the preferred alternative.
Alternative C -- direct staffing and funding towards maximizing habitat and wildlife management strategies. As a result of prioritizing habitat and wildlife management, public use activities and access may be reduced.
The final document has two volumes of supporting appendices, cited separately below.

U.S. Department of the Interior, Fish and Wildlife Service, August 2015. *Chincoteague and Wallups Island National Wildlife Refuges Final Comprehensive*

Conservation Plan and Environmental Impact Statement Volume 2: Appendix A through O. **Chincoteague, Virginia: Chincoteague and Wallups Island National Wildlife Refuges. Web.September 25, 2015, 433p.**

Volume 2's appendices to the *Chincoteague and Wallups Island National Wildlife Refuges Final Comprehensive Conservation Plan and Environmental Impact Statement* includes the following sections:

A. The Proposed Assateague Wilderness
B. Other Federal Mandates and Relevant Plans and Initiatives
C. Laws and Executive Orders Applicable to Chincoteague and Wallops Island NWR CCP
D. Interim Chincoteague Pony Management
E. Memorandum of Agreement: Interagency Cooperate at Assateague Island National Seashore and Chincoteague National Wildlife Refuge
F. Biological Opinion on Monitoring and Management Practices for Piping Plovers, Loggerhead Sea Turtle, Green Sea Turtle, Leatherback Sea Turtle, and Seabeach Amaranth
G. Notes on Sea Level Rise and Projected Impacts on Chincoteague NWR
H. Adapting Now to a Changing Climate: Wallups Flight Facility and the Eastern Shore
I. Summary of Costs of Draft Alternatives and Comparison of Beach Access Costs
J. Chincoteague National Wildlife Refuge Beachfill. Abbreviated Analysis and Cost Opinion for Maintaining the Existing Parking Areas and Recreational Beach
K. Staffing Charts for All Alternatives
L. Species Lists for Chincoteague and Wallops Island NWRs
M. Chincoteague NWR Economic Analysis in Support of CCP
N. Chincoteague NWR: Recreational Beach Structured Decision-Making Process, Locating the Best Site for a Recreational Beach and Parking Lot
O. Section 7 Biological Opinion for Alternative B.

U.S. Department of the Interior, Fish and Wildlife Service, August, 2015. ***Chincoteague and Wallups Island National Wildlife Refuges Final Comprehensive Conservation Plan and Environmental Impact Statement Volume 3: Appendix P through S.*** **Chincoteague, Virginia: Chincoteague and Wallups Island National Wildlife Refuges, 335p.**

Volume 3's appendices to the *Chincoteague and Wallups Island National Wildlife Refuges Final Comprehensive Conservation Plan and Environmental Impact Statement* includes the following the following sections:

P. Compatibility Determinations. These include:
- Wildlife Observation Wildlife Photography, and Interpretation
- Environmental Education
- Fishing (Recreational)
- Migratory Game Bird Hunting
- Big Game Hunting
- Commercial Filming, Still Photography, and Photography Workshops
- Grazing of Chincoteague Ponies
- Horseback Riding

- Research and Studies Conducted by non-USFWS Staff
- Shell Collection
- Big Game Hunting (Wallops Island NWR)
- Research and Studies Conducted by non-USFWS Staff (Wallops Island)

Q. Findings of Appropriateness

R. Summary of Public Comments and USFWS Responses on the Draft Comprehensive Conservation Plan and Environmental Impact Statement for Chincoteague and Wallops Island National Wildlife Refuges

S. Federal Consistency Determination.

USR Group, Inc., November 2009. Benthic Habitat Survey of Two Offshore Borrow Sites/Wallops Flight Facility Shoreline Restoration and Infrastructure Protection Program. (Appendix B to Final Programmatic Environmental Impact Statement Wallops Island Flight Facility Shoreline Restoration Infrastructure Protection Program.) Gaithersburg, Maryland. Prepared for NASA Goddard Flight Center, Wallops Island, Virginia, 30 p.

This Technical Memorandum summarizes results of a video survey of benthic habitats conducted in July 2009 at the two potential offshore borrow sites for the SRIPP. The video survey was conducted on two offshore sand shoals (Unnamed Shoal A and B) that are being evaluated as potential borrow sources for beachfill sand for NASA's SRIPP. The report concludes that sub bottom profiler data analysis for both Unnamed Shoal A and B indicated that these sand features have relatively poor bedding, which indicates that the sands are homogenous in nature. This sediment homogeneity has likely resulted from long-term preferential grain size sorting by current, wave action, and large storm events. Bbnthic habitats and epifaunal communities were similar on the two shoals. The majority of the benthos on the shoal crests are adapted to the energetic conditions, live within the sediment, and were not visible to the camera. They do not construct tubes or feeding mounds, resulting in the "clean" appearance of the sand (Cutter and Diaz 1998).

USR Group, Inc., October 2010. Final Programmatic Environmental Impact Statement/Wallops Island Flight Facility Shoreline Restoration and Infrastructure Protection Program. Volume I of II. Prepared for the NASA Goddard Space Flight Facility, Wallups Island, Virginia. Gaithersburg, Maryland, 429p.

NASA has prepared a Final Programmatic Environmental Impact Statement (PEIS) for the Shoreline Restoration and Infrastructure Protection Program (SRIPP) at Wallops Flight Facility in accordance with the National Environmental Policy Act to assist in decision making for the SRIPP. The BOEMRE and USACE have served as Cooperating Agencies in the preparation of this PEIS. The purpose of the SRIPP is to reduce the potential for damage to, or loss of, existing NASA, U.S. Navy, and MidAtlantic Regional Spaceport assets on Wallops Island from wave impacts induced by storms. The potential effects to physical, biological, and socioeconomic environments were studied to determine how the Proposed Action Alternatives and the No Action Alternative could affect these resources. The Proposed Action would have both adverse and beneficial

impacts on environmental resources. Adverse impacts would be mitigated to the greatest extent practicable. Volume II contains the following appendices to this report that can be found at: http://sites.wff.nasa.gov/code250/final_sripp_peis_document.html The appendices are:

A. Storm Damage Reduction Project Design for Wallops Island, VA
B. SRIPP Benthic Video Survey Technical Memorandum
C. Biological Assessment
D. U.S. Fish and Wildlife Service Biological Opinion
E. National Marine Fisheries Service Biological Opinion
F. SRIPP Cultural Resource Remote Sensing Survey of Two Proposed Offshore Sand Borrow Locations in Federal Waters
G. SRIPP Proposed Groin, Breakwater, and Shoreline Cultural Resources Surveys, Accomack County, VA
H. Federal Consistency Determination and Virginia Department of Environmental Quality Resource
I. Essential Fish Habitat Assessment
J. Essential Fish Habitat Consultation
K. Section 106 Consultation
L. Comments received on Draft PEIS
M. Response to Comments Received on Draft PEIS.

Wells, D.V., Hennessee, E.L., and Hill, J.M., 2003. *Shoreline Erosion as a Source of Sediments and Nutrients Middle Coastal Bays Maryland*. Baltimore, Maryland: Maryland Department of Natural Resources, Resource Assessment Service, Maryland Geological Survey/Coastal and Estuarine Geology File Report No. 03-07, 163p.

The Maryland Coastal Bays Program has developed a four-pronged action plan to restore and protect natural resources of the State's coastal bays (MCBP, 1999). The plan addresses (1) water quality, (2) fish and wildlife, (3) recreation and navigation, and (4) community and economic development. Meeting the goals associated with the first three of these depends in part on understanding the sediment and nutrient input contributed by shoreline erosion to the coastal bays. Shoreline erosion releases sediments to the water column. Finer-grained sediments tend to remain suspended in the water, reducing water clarity and affecting underwater habitat (e.g., reducing light penetration for submerged aquatic vegetation). The eventual deposition of eroded sediments contributes to the in- filling of navigational channels. Shoreline erosion also acts as a non-point source of nutrients (nitrogen and phosphorus), which affect the water quality of the coastal bays.

Although shoreline erosion has been identified as a source of sediments and nutrients to nearby waters, there has been little effort to quantify that input and to compare it to other sources. Thus, the Maryland Geological Survey (MGS) began a multiyear study to determine the flux of sediments and nutrients eroding from unprotected shorelines bordering Maryland's coastal bays. The first year of the study focused on the

northernmost coastal bays: Assawoman Bay, Isle of Wight Bay, and the St. Martin River. Results of that study were detailed by Wells and others (2002). The second year of the study focused on the middle third of Maryland's coastal bays: Sinepuxent Bay, Newport Bay, and the northern third of the Chincoteague Bay. To estimate nutrient and sediment loads contributed by shoreline erosion to the middle coastal bays of Maryland, MGS set the following objectives: (1) Identify unprotected reaches of shoreline at greatest risk of erosion, based on historical linear rates of change; (2) Measure certain physical, chemical, and biological properties of eroding sediments; and (3) Determine the volume of eroding sediments and the flux of sediments and nutrients into the middle coastal bays. Examine the flux of material from shoreline erosion in the context of existing nutrient budgets for the study area. Results for the second year study are presented in this report.

Wikar, C.P. (editor). September 2, 2010. Navigation and Dredging Planning Guide for Maryland's Coastal Bays. Navigation and Dredging Advisory Group. Web.23 September 2015, 64p.
Worcester County residents worked together to devise common sense ways of protecting the bays adjacent to Ocean City and Assateague. This effort, the Maryland Coastal Bays Program, has culminated in a comprehensive conservation and management plan (CCMP) aimed at preserving this precious coastal resource. The CCMP deals with a variety of topics including water quality, fisheries resources, and economic development. An entire section is devoted to recreation and navigation issues, covering boating safety, water based recreational opportunities, harbor and marina management practices, and navigation and dredging management issues. Due to the relatively shallow nature of Maryland's Coastal Bays, the maintenance of navigable waterways to support recreational and commercial boating is a critical regional need. Improved planning and coordination between federal, state, local and private interests is needed to enhance the economic and recreational benefits of navigation improvements and dredging while minimizing their adverse effects on natural resources. The Mission of the Navigation and Dredging Advisory Group is to develop a Master Plan to guide the management of navigation and dredging in the Coastal Bays, provide a forum for public input into related decision-making, and enhance and protect natural resources either at risk or that may benefit from navigation-related activities.

Woodruff, J.D., Irish, J.L., and Camargo, S.J. December 2013. Coastal flooding by tropical cyclones and sea-level rise. *Nature*, 504, 44-52. http://www.nature.com/nature/journal/v504/n7478/pdf/nature12855.pdf
The future impacts of climate change on landfalling tropical cyclones are unclear. Regardless of this uncertainty, flooding by tropical cyclones will increase as a result of accelerated sea-level rise. Under similar rates of rapid sea-level rise during the early Holocene epoch most low-lying sedimentary coastlines were generally much less resilient to storm impacts. Society must learn to live with a rapidly evolving shoreline that is increasingly prone to flooding from tropical cyclones. These impacts can be mitigated partly with adaptive strategies, which include careful stewardship of sediments and reductions in human-induced land subsidence.