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Krantz, DK, Wells, DV, Schupp, CA, and Shedlock, R. In prep. "Dynamic Systems at the Land-Sea Interface." In: Thomas, J. [ed.], *Maryland Coastal Bays*. U. of Maryland Center for Environmental Science, Horn Point, MD.

Rodriguez, AH. 2006. "Assateague Island National Seashore North End Restoration Project Introduction." Available online at

<http://www.nps.gov/asis/naturescience/upload/ProjectIntroduction.pdf>. Accessed 31 August 2006.

Underwood, SG, and Hiland, MW. 1995. Historical Development of Ocean City Inlet Ebb Shoal and Its Effect on Northern Assateague Island. U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

A Geologic Overview of Assateague Island National Seashore

Physical Setting

Assateague Island is a barrier island that extends 58 km along the coast of Maryland and Virginia. Its width ranges from 300 m to 1200 m, and elevations are generally around 2 m, though dunes may rise up to 10 m high. Wide areas of Assateague Island exhibit typical barrier island zonation. West of the ocean shoreline is an intertidal zone that transitions into a beach, which often has dunes on its western side. West of the dunes is the maritime forest. On the other side of the forest is a salt marsh that fringes the Coastal Bays, which separate the island from the mainland Delmarva Peninsula.

The northern 10 kilometers of Assateague Island National Seashore (referred to as the North End of Assateague Island) is an extremely unique environment. Terminated to the north by the Ocean City Inlet, much of this area is composed of a beach and low berm on the ocean side of the island, with a low elevation, sparsely vegetated back barrier flat and a narrow fringing salt marsh along Sinepuxent Bay, one of Maryland's Coastal Bays. This dynamic area is prime habitat for state- and federally-listed endangered species, including the piping plover (*Charadrius melodus*) and seabeach amaranth (*Amaranthus pumilus*). This area also protects the mainland directly to the west from storm events, and wave and tidal energy.

The Coastal Bays are shallow, averaging 1–1.2 m (3.3–3.9 feet) deep, except in the navigation channels and inlets. A sandy subtidal flat less than one meter (3.3 feet) deep created by storm overwash extends as much as two kilometers into the bays from Assateague Island.

Offshore of the Delmarva Peninsula lie 77 shoreface attached or detached sand ridges (McBride and Moslow 1991). These features are found along much of the mid-Atlantic coast in regions that feature barrier island transgression, mixed energy wave-dominated shorelines, and lateral inlet migration to the south or southwest. These sand ridges are generally over 1 km long, up to 10 m high, and are 1-3 km wide. In the past, the shoals have been used as sand sources for beach nourishment at Ocean City (Anders and Hansen 1990).

The island lies along the Delmarva Peninsula, which is within the Atlantic Coastal Plain, a physiographic province that is characterized by a low and flat landscape underlain by unconsolidated or only partially consolidated sediments such as gravel, sand, silt, and clay. If viewed in cross-section, the Coastal Plain sediments would be wedge-shaped, thinnest in the west and thickening eastward to almost 2.4 km (1.5 miles) thick at the Atlantic coastline.

Geologic Formation of Assateague Island

Although modern processes shape the character of Assateague Island and the Coastal Bays, the landforms are products of their geologic history. The Delmarva Peninsula as we now know it began forming during the Pliocene and early Pleistocene (from about 5 to 1.5 Ma) as the ancestral Potomac and Delaware rivers deposited deltas and braided-river outwash plains that would become the core of the peninsula. The closest continental glaciers were approximately 160 km to the north, and many of the sediments deposited on Delmarva were derived from glaciers scraping off the land surface of Ontario, Quebec, Pennsylvania, and New York, and dumping large volumes of water and sediment into the major river systems.

During the glacial lowstands of sea level in the Middle Pleistocene (1–0.5 Ma), the Delaware and Susquehanna rivers started cutting down through the Coastal Plain to create the basins for Delaware Bay and Chesapeake Bay, respectively. During the interglacial highstands of sea level, the ocean flooded landward across the Coastal Plain (presently the continental shelf), and wave action eroded the deltaic sediments deposited previously and redistributed them into sandy shorelines. As sea level dropped at the beginning of the each cooling phase, the highest shorelines were stranded, creating long linear features that can be traced most of the length of the Delmarva coast (Demarest and Leatherman, 1985; Mixon, 1985).

During the Last Glacial Maximum of the Wisconsin glaciation, 22–20 ka, global climate cooled and sea level fell to about 125 m below present. As a result, the Maryland Atlantic coastline was located roughly 97 km (60 miles) east of where it is today, at the edge of the continental shelf, which at that time was a broad, exposed coastal plain incised by a stream drainage network that created the basins which would later be flooded to form the Coastal Bays. This is evidenced by data indicating the presence of drowned river valleys extending out along the continental shelf.

Sea level began rising after the height of the last glacial period of the Pleistocene epoch, approximately 18,000 years ago (Pielou, 1991). During deglaciation, the water from the melting continental glaciers flowed back into the ocean and sea level rose. During several intervals between 15 and 10 ka, sea level was rising 10 times faster than today. The barrier islands that existed on the edge of the shelf during the lowstand migrated rapidly landward across the flooded continental margin. Sea level rose rapidly enough between 6,000 and 12,000 years ago to allow some remnants of earlier shoreline features to survive shoreface scouring (Belknap and Kraft, 1985; Kraft et al, 1987). These remnants are underwater and buried under more recent features such as linear shoals (McBride and Moslow, 1991).

As sea level rose, the low-lying areas between the barrier islands offshore and the Pleistocene shoreline ridges on the mainland flooded to create the Coastal Bays. By about 5 ka, the rate of sea level rise had slowed, and the barrier islands were near their present positions.

It is possible that about 2,500 years ago, a precursor to Assateague Island formed slightly west of the modern island; however, no radiocarbon dates are currently available to substantiate this hypothesis. The presence of an earlier shoreline complex would explain the linear alignment of the western part of Wallops Island, Chincoteague Island, Pope Island, and Green Run Island; the latter two islands are behind Assateague Island near the Maryland-Virginia state line.

The morphology of this older coastline is similar to that of the barrier islands of the Virginia Eastern Shore, with short island segments separated by tidal inlets—a mixed-energy coast instead of the wave-dominated modern Assateague Island. Expansive flood-tidal deltas and sets of beach ridges on the north end of Chincoteague Island and Green Run Island mark the locations of former inlets and suggest that the inlets were stable for long periods of time.

Because of the large, stable inlets, the ancestral Chincoteague Bay would have been different in character from the modern Bay. The dynamics were probably similar to those of the marshy coastal lagoons behind the Virginia barrier islands, with greater influence of seawater and exchange with the coastal ocean, more fine suspended sediment entering the Coastal Bays from the ocean, substantially larger tidal range, more vigorous tidal currents, and considerably shorter residence time. If a new inlet were to form and stabilize in central Assateague Island, the dynamics of the Coastal Bays would revert to this former character.

Today, Assateague Island is seaward of this older set of islands. There are two hypotheses for the process that created this configuration. The first possibility is a major increase in the sediment supply to this section of the coast from the north. The second hypothesis suggests that sea level fell by a few meters after the older islands were emplaced, moving the active barrier islands seaward; sea level then rose a second time to the present sea level elevation and island location. If the latter scenario proves to be true, it will offer the first evidence of an earlier late Holocene highstand along this section of the Mid-Atlantic coast.

Recent seismic surveys of Chincoteague Bight discovered several large, deep paleochannels, possibly of an ancestral Potomac River, which explain the presence of what appears to be a broad shelf valley extending toward Washington Canyon, and which may be the reason for the offset of Wallops Island and Assateague Islands (Krantz, Levin, and Wikel, unpublished data, 2005).

Estuarine Sediments

The distribution of sediments in the coastal bays is related directly to the wave and tide energy available to transport the sediment particles. The two dominant sediment types in the Coastal Bays are medium to fine sand and organic-rich mud (a watery mixture of silt and clay). Sediments deposited in the bays are derived from several local sources: suspended sediments transported by the streams, turbid seawater churned up on the shelf during storms, erosion of the mainland shoreline, and overwash across the barrier islands. A minor contribution comes from windblown sand lifted off the islands.

The tidal inlets, which have deep channels and complex flood-tidal deltas, are composed almost entirely of sand with some gravel, with finer silty sand present along the western edge of the inlet. The overwash sheets on the backbarrier flat also are predominantly sand, but commonly are interbedded with marsh peat and lagoonal silts deposited between storm events. Away from the inlets and channels, the Coastal Bays essentially are a large settling basin for fine-grained sediments. In Chincoteague Bay, sands dominate the eastern section, silts fill the navigation channel, and silt-clay mud covers the western one-third. The protected upper reaches of the bays, such as Newport Bay and the western tributaries of St. Martin River, Turville Creek, and Grey's Creek, have minimal wave and tide action, and clays are deposited there.

Groundwater

Because much of Delmarva has sandy sediments near the land surface, as much as 25–50% of annual precipitation infiltrates through the soil and recharges the water table (Bachman and Wilson 1984). This groundwater fills the pore spaces between sediment grains and flows through the surficial, or water-table, aquifer. Many municipal water supplies, including those for Ocean City and Salisbury, Maryland, draw from deeper confined aquifers.

Groundwater flow in the vicinity of the Coastal Bays or other estuaries is complicated by the dynamics of fresh water and salt water mixing in the subsurface beneath the bays. In general, fresh groundwater flows out toward the bay from areas close to the mainland shore; meanwhile, denser saline groundwater recharges through the bay floor, sinks beneath the fresh water, and flows landward. In many coastal settings, this interaction produces a zone of fresh groundwater discharge that extends tens to a few hundred meters into the bay, with an underlying wedge of saline ground water pushing landward.

Modeling by Dillow and Greene (1999) predicted that in narrow coastal bays, such as Sinepuxent Bay, groundwater recharged on the mainland would flow beneath the bay and discharge offshore in the ocean. In wider bays, such as Chincoteague Bay with its widths up to 10 km, the fresh groundwater would meet significant resistance to flow from the saline groundwater recharged from the bay; the buoyant fresh water, then, would either be forced upward and discharge through the bay floor or, more likely, would mix with the saline groundwater and form a brackish 'subterranean estuary' (Moore, 1999).

This modeling was verified by field observations in Indian River and Rehoboth Bays in Delaware, and Chincoteague, Sinepuxent, and Isle of Wight bays in Maryland. The electrical resistivity surveys showed a complex interaction between fresh and saline groundwater beneath the coastal bays (Krantz et al., 2004; Manheim et al., 2004). Plumes of fresh or nearly fresh groundwater extend 1–2 km from shore beneath thin semi-confining layers under sections of the coastal bays (Bratton et al., 2005; Bratton et al., in press).

The Coastal Bays also isolate the shallow groundwater of the island from fresh groundwater flowing from the mainland. Long, narrow barrier islands such as Assateague and Fenwick islands have a relatively shallow lens of fresh groundwater floating on salt water that flows under the island from both the ocean and the bay. Field observations indicate that the fresh lens on Assateague Island is 6–7 m thick in the middle of the island and thins to less than one meter thick toward the ocean beach and the bayside marshes. A layer of salt water vertically separates the freshwater lens from the deeper fresh groundwater flowing from the mainland (Hall, 2005).

Physical Processes

The physical factors that sculpt the protecting barrier islands and control the hydrologic characteristics of the bays occur over many time scales, from daily changes, such as tidal fluctuations, to

centennial changes, such as storm climate. The Delaware–Maryland coast is classified as wave-dominated (average height of 1 m) and microtidal (0-2 m tide range). It has a semidiurnal tide with a mean range of 1.0 m, and the extreme range (spring tide) is approximately 4 m, fluctuating from 1 m below to 3 m above MLW (Field 1979).

Alongshore currents carry sand along the coast. In the winter, strong northeastern winds and storms force a lot of sand southward; in the summer, waves from the southeast drive sand transport less vigorously northward. As a result, the net annual alongshore transport is southward from South Bethany Beach, Delaware (a nodal point, north of which the net alongshore sand transport is to the north) and is estimated to be between 115,000 and 214,000 m³ (4–7.5 million cubic feet) per year. This sand eventually reaches the southern end of Assateague Island in Virginia, where the island terminates in Toms Cove Hook, a recurved spit that bends sharply to the west and wraps around Chincoteague Island. South of Chincoteague Inlet, the Virginia barriers of Wallops, Assawoman, and Metompkin Islands are offset landward by almost 10 km from Assateague Island, forming an embayed area referred to informally as the Chincoteague Bight.

Assateague Island dunes represent a transition zone between northeast and southeast topography. This region has low, wide, and flat islands, with dunes present, but extending further landward than in other regions. North of Assateague, New England has long, continuous barriers with extensive dune ridges that are well-vegetated and close to the beach. South of Assateague Island, the Southeast barriers are short, segmented islands, with numerous permanent natural inlets, and dune systems are low, irregular, discontinuous, and sparsely vegetated.

Some of the dunes on Assateague Island were constructed to protect infrastructure from the ocean. Others form naturally after seaweed and other organic material is deposited by high tides. The organic material supplies nutrients and retains water, allowing vegetation to grow and trap windblown sand and forming embryo dunes. Where the sand supply is abundant and the shore is prograding, there will be low, closely spaced, parallel dune ridges. Erosion leads to a steep seaward edge of the dune. Beaches with fine sand often have larger dunes, because the wind can carry the sand higher.

Storm Processes

The greatest changes to the coastal system occur during intense storm events, which last only a few days but which may alter the shape and function of the islands and bays for the next several decades. Assateague and Fenwick Islands protect the Coastal Bays and mainland Maryland from major storms and some of the impacts of sea level rise, which is currently estimated at 3.1-3.5 mm/yr in this area, by absorbing much of the energy of waves and currents.

During storms and periods of high wave energy, particularly during the winter, waves wash sand off of the beach and trap it as a nearshore sand bar, leaving a low and flat beach; in the summer, the beach builds up to a steeper profile.

During especially strong storms, the waves may combine with high tide or storm surge and carry sand from the beach and frontal dunes across the barrier island. Overwash may be extensive, covering kilometers of the island as seen after the 1962 Ash Wednesday storm, or more localized, forming overwash fans. Overwash deposits sand in the interior of the island, maintaining or building island elevation and serving as a source of loose windblown sand that is critical to the formation of new dunes. Sometimes, sand is also carried completely across the barrier island and deposited in Sinepuxent and Chincoteague Bays, thereby widening the island. The resulting sand platform or tidal flat provides the base for growth of salt marshes. The overwash sand can bury or partially bury vegetation on the island; depending on the thickness of the overwash deposit, existing vegetation may survive and grow through the sand.

On time scales of hundreds to thousands of years with gradual sea level rise, overwash and the opening and closing of inlets allow the barrier islands to roll over and migrate landward. The landward movement of sediment buries backbarrier lagoonal environments on the western side, and as the ocean side of the island is eroded, older marsh peat and sediments are exposed on the ocean side.

Since 1850, the bay shoreline of northern Assateague Island has migrated westward into Sinepuxent Bay while the mainland shoreline has lost very little land (less than 100 m) to erosion, thereby

narrowing the bay by up to 1 kilometer in some places. Approximately 600 meters of this migration has occurred since 1942.

Inlets

Low-lying areas of the islands are particularly susceptible to overwash and, historically, have occasionally been breached. Historical maps and charts going back to the first European colonists in the late 1600s show a sequence of ephemeral tidal inlets that have formed along Assateague Island during storm conditions and then have closed within a few years due to natural coastal processes and sediment supply, infilling by sand transported alongshore from the north.

During the mid-1800s, North Beach Inlet formed at a site across from South Point. Although it is not clear exactly when or how long this inlet existed, early accounts indicate that this inlet was navigable and may have coexisted with the Sinepuxent Inlet, which was located just to the south of this site (Truitt, 1968). Great Egging Beach and Little Egging Beach Islands are remnants of the tidal shoal formed from North Beach Inlet.

A storm in February 1920 cut an inlet through the island opposite Grays Cove near Snug Harbor (Hite, 1924). This inlet was navigable for several years, closing sometime before Ocean City Inlet formed (Gawne, 1966; Truitt, 1968). A broad marsh flat on the bay side of Assateague marks the remains of the inlet's tidal delta. Ocean City Inlet formed during a hurricane in 1933, and it still connects Sinepuxent Bay to the Atlantic Ocean today because it was stabilized with jetties.

The 1962 Ash Wednesday storm, created an inlet opposite Ocean City Airport. This inlet was very shallow and had no commercial use as a navigation channel. Because the inlet was not adversely affecting the Federal Navigation channel in Sinepuxent Bay, it was not eligible for closure by the Corps. When the Corps pumped sand from Sinepuxent Bay onto Assateague Island to repair a breach along the south jetty, material from that activity drifted into the inlet, closing it at low tide (U.S. Army Corps of Engineers, 1963).

The North End Restoration Project

The northern end of Assateague Island is classified by the U.S. Geological Survey as having 'very high vulnerability' because of its low elevation, frequent overwashing, and high rates of shoreline erosion (Pendleton et al., 2004). The fragile nature of the North End environment is thought to be primarily caused by an interruption in alongshore sediment transport by the jetties built around the Ocean City Inlet in 1933 (Rosati and Ebersole 1996).

Prior to 1933, Fenwick Island and Assateague Island were part of the same continuous barrier spit located off the coast of Delaware, Maryland and Virginia. In the 1920's, Ocean City, MD was already undergoing rapid development, while the area now known as Assateague Island remained in a mostly natural state. On August 23, 1933 a major hurricane came through the area, breaching the barrier spit at the Ocean City Inlet, and dividing the previously continuous peninsula into Fenwick Island to the north, and Assateague Island to the south (Bass 1998). Jetty construction began on each side of the newly formed inlet in September of 1933 and was designed to create a navigable waterway between coastal lagoon and ocean. The jetty construction was completed in 1935 with an initial channel depth of 3 meters and a width of 76 meters (Rosati and Ebersole 1996).

This stabilization resulted in immediate changes in the shoreline configuration south (downdrift) of the inlet. The jetties interrupted the alongshore transport of sand, essentially "starving" northern Assateague Island of sand, causing unnaturally accelerated erosion and shoreline migration. Since the inlet was stabilized, erosion rates have risen from 1 m/yr between 1859 and 1933 up to 12 m/yr between 1942 and 2005. As a result of the reduced sediment supply, the ocean shoreline in this area has shifted westward as much as 400 meters along the northernmost 2 kilometers since 1943, resulting in whole scale geomorphologic, habitat, and biotic changes that would not have occurred under natural circumstances.

Coastal geologists predicted that without mitigation the northern portion of the island would continue to destabilize and that a new inlet or inlets would be created by storm events in the near future. Such a scenario would have a significant impact on the values and purpose of Assateague Island National Seashore. A new inlet or inlets would also have serious implications for the adjacent mainland communities and region as whole, including increased rates of shore erosion, loss of estuarine habitats,

and decreased flows through the existing Ocean City and Sinepuxent channels resulting in increased maintenance needs.

As a result of the continual acceleration of shoreline migration, a regional feasibility study was initiated in the mid-late 1990's, sponsored by the U.S. Army Corps of Engineers (COE) with Assateague Island National Seashore (ASIS) serving as an active partner. Other partners in this study included the National Park Service (NPS), the state of Maryland, Maryland Department of Natural Resources, Worcester County, Maryland, and the Town of Ocean City, Maryland. This report investigated the Assateague erosion problem and other priority issues in the Ocean City/Assateague Island vicinity.

The study resulted in the development of a comprehensive restoration plan that focuses on restoring Assateague Island to as natural a condition as possible. This plan is referred to as the North End Restoration Project, and has met with widespread support by the study partners and local community. The first, or "short-term," phase of the restoration program was designed to provide a one-time infusion of sand to replace a portion of the sediment lost over the past 60 years due to the effects of the jetties. The second phase, the "long-term sand management" component, addresses the ongoing and future effects of the jetties by re-establishing a "natural" sediment supply for northern Assateague that reflects historic, pre-inlet rates.

On January 28th and February 4th, 1998, prior to the start of the restoration plan, extra-tropical cyclones occurred over Assateague Island. During each storm, wave heights were recorded at 7 meters off the coast of Ocean City, MD, and one of the most severely impacted areas included the north end of Assateague Island ('1998 Assateague Island Northeasters Impact Studies' 1999). After 65 years of the Ocean City Inlet jetty system acting as a barrier to alongshore transport, a major breach on the North End had become a distinct possibility. In an effort to prevent this breach from occurring, an emergency storm berm was constructed along the most severely hit portion of the island. The berm was to be put in at an elevation of approximately 10.8 ft (3.3 m) National Geodetic Vertical Datum (NGVD), and the source of the fill was Great Gull Bank, an offshore shoal, east of the Ocean City Inlet (Bass 1998).

The first stage of the North End Restoration Project was undergone in September, 2002 (Figure 3) as 1.4 million cubic meters (1.8 million cubic yards) of sand was placed seaward of the mean high water line to minimize disturbance to upland habitats. The second stage of the beach replenishment project was then initiated in January of 2004. Twice each year, 72,000 m³ (2.5 million cubic feet) of sand are moved from the ebb and flood tidal deltas around Ocean City and deposited in the surf zone of Assateague Island, approximately 2.5–5 km (1.5–3 miles) south of the inlet. Natural processes of waves and alongshore transport then deposit this sand in the surf zone and on the beach.

The long-term sand management project deposits sand about 2.5–5 km (1.5–3 miles) south of the inlet, instead of starting at the northernmost point of Assateague Island, because hydrodynamic models developed by the U.S. Army Corps of Engineers show that north of this location, sediment has a localized net northward transport toward the jetty. South of this point, net alongshore transport moves sand southward. This difference is probably due to the morphology of the ebb tidal delta, which curves around the Ocean City Inlet and, at its southernmost point, is nearly perpendicular to Assateague Island. Waves coming from the northeast are refracted around the shoal, changing the direction at which they hit the shoreline to the south of the shoal.

Physical Monitoring Efforts

Because of the rapid pace and scope of change in this dynamic barrier island system, long term monitoring is crucial to the understanding of natural barrier island conditions as well as anthropogenic influences. In 1995, ASIS initiated a long-term program to begin monitoring key aspects of island geomorphology. In addition to documenting baseline conditions and assisting in change monitoring, the data is used to examine the ongoing North End Restoration project, including the effects of nearshore dredging.

At present, the data collection program includes four primary elements:

1. Documentation of the shoreline position on a quarterly basis in order to describe and evaluate trends in shoreline stability, rates of shoreline change, and storm-driven change.

2. Documentation of cross-island topographic profile elevations on a biannual basis in order to describe and evaluate trends in island topographic relief and storm-driven change.
3. Use of lidar (light detection and ranging) data, an airborne laser technology that provides detailed topographic data on bare earth and canopy cover.
4. Use of orthorectified aerial photographs to examine habitat extents and geomorphologic features.

Information resulting from the Monitoring Program is intended to provide a general description of island conditions and to provide a basis for evaluating long-term management strategies. Data generated by the program also supports coastal processes research, habitat characterization studies, and evaluation of beach and berm restoration projects.

Literature Cited

Anders, F.J., and Hansen, M. 1990. Beach and Borrow Site Sediment Investigation for a Beach Nourishment at Ocean City Maryland. T.R. CERC-90-5, Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS, 77 p.

Bachman, L.J., and Wilson, J.M. 1984. The Columbia aquifer of the eastern shore of Maryland. Maryland Geological Survey Report of Investigations No. 40.

Bass, G.P. 1998. Ocean City / Assateague Island, Maryland Studies. *Proceedings of the 67th Meeting of the Coastal Engineering Research Board*. US Army Corps of Engineers.

Belknap, D.F., and Kraft, J.C. 1985. Influence of Antecedent Geology on Stratigraphic Preservation Potential and Evolution of Delaware's Barrier Systems. *Marine Geology* 63, pp. 235-262.

Demarest, J.M., and Leatherman, S.P. 1985. Mainland influence on coastal transgression: Delmarva Peninsula. *Marine Geology* 63, pp. 19-33.

Dillow, J.J.A. and Greene, E.A. 1999. *Ground-Water Discharge and Nitrate Loadings to the Coastal Bays of Maryland*. U.S. Geological Survey Water-Resources Investigations Report 99- 4167, 8 p.

Gawne, C.E. 1966. *Shore changes on Fenwick and Assateague Islands, Maryland and Virginia*. Unpub. B.A.Thesis. University of Illinois, Urbana, IL, 140 p.

Hall, S.Z. 2005. *Hydrodynamics of freshwater ponds on a siliclastic barrier island, Assateague Island National Seashore, Maryland*. Master's Thesis. University of Maryland Eastern Shore, Princess Anne, MD.

Hite, M.P. 1924. Some observations of storm effects on ocean inlets. *American Journal of Science* 5(7), pp. 319-326.

Kraft, J.C., Chrzastowski, M.J., Belknap, D.F., Toscano, M.A., and Fletcher, C.F. III. 1987. The transgressive barrier-lagoon coast of Delaware: Morphostratigraphy, sedimentary sequences and responses to relative rise in sea level. In: Nummedal, D., Pilkey, O.H., and Howard, J.D. [eds.], *Sea level Fluctuations and Coastal Evolution*. Society of Economic Paleontologists and Mineralogists Spec. Pub., Tulsa, OK.

Krantz, D.E., Manheim, F.T., Bratton, J.F., and Phelan, D.J. Hydrogeologic Setting and Ground Water Flow Beneath a Section of Indian River Bay, Delaware. *Ground Water* 42(7), pp. 1035-1051.

Manheim, F.T., Krantz, D.E., and Bratton, J.F. 2004. Studying Ground Water Under Delmarva Coastal Bays Using Electrical Resistivity. *Ground Water* 42(7), pp. 1052-1068.

McBride, R.A., and T.F. Moslow. 1991. Origin, evolution, and distribution of shoreface sand ridges, Atlantic inner shelf, U.S.A. *Marine Geology* 97, pp. 57–85.

Mixon, R. B. 1985. *Stratigraphic and geomorphic framework of uppermost Cenozoic deposits in the southern Delmarva Peninsula, Virginia and Maryland*. U. S. Geological Survey Professional Paper 1067-G, p. 1-53.

Moore, W.S. 1999. The subterranean estuary: a reaction zone of ground water and sea water. *Marine Chemistry* 65, pp. 111–125.

Pendleton E.A., S.J. William, and E.R. Thieler. 2004. *Coastal vulnerability assessment of Assateague Island National Seashore (ASIS) to sea-level rise*. U.S. Geological Survey Open-File Report 2004-1020.

Pielou, E.C. 1991. *After the Ice Age: The return of life to glacial North America*. U. of Chicago Press, Chicago, IL.

Rosati, J. D., and Ebersole, B. A. (1997). Littoral impact of Ocean City Inlet, Maryland, USA. *Proceedings 2Sh Coastal Engineering Conference*. ASCE, NY, pp. 2779-2792.

Truitt, R.V. 1967. *High Winds...High Tides A Chronicle of Maryland's Coastal Hurricanes*. National Resources Institute, U. of Maryland, Educ. Ser. 77, 48p.

U.S. Army Corps of Engineers Baltimore District. 1963. *The March 1962 storm along the coast of Maryland: A report of district activities during and immediately following the storm*. Baltimore, Maryland, U.S.A.

U.S. Geological Survey Center for Coastal Geology. 1999. "1998 Assateague Island Northeasters Impact Studies." Available online at <<http://coastal.er.usgs.gov/hurricanes/assateague/>>. Accessed 7 September 2006.