ERDC/CHL TR-06-21

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
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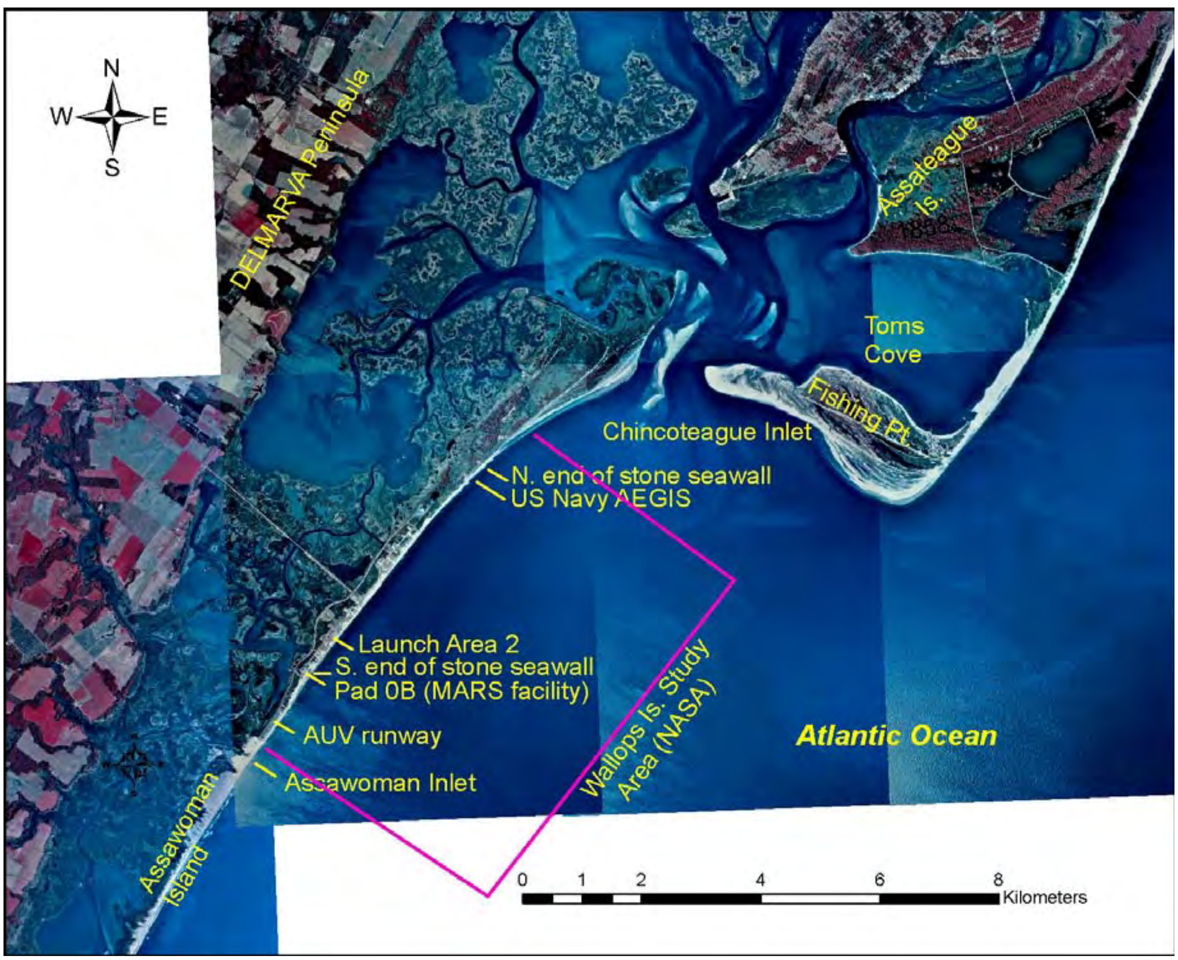
Andrew Morang, Greggory G. Williams, and Jerry W. Swean

September 2006



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Final report

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Goddard Space Flight Center
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ABSTRACT: The Goddard Space Flight Center, Wallops Flight Facility (WFF), is located on the eastern shore of Virginia facing the Atlantic Ocean. The island 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, a replacement for an older wood wall that deteriorated. Although the seawall has temporarily fixed the shoreline position, the structure 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 currently unprotected except for a low revetment around the MARS launch pad.

As a result, NASA officials are highly 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 increasingly vulnerable to damage from storm waves and that the foundations of structures and the Unmanned Autonomous Vehicle (UAV) runway may be undermined as the beach continues to erode.

ERDC and U.S. Army Engineer District, Norfolk, have developed a shore protection 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 the higher initial costs, structures will probably reduce life-cycle costs because of reduced requirements for renourishment volumes.

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Executive Summary

The Goddard Space Flight Center, Wallops Flight Facility (WFF), is located on the eastern shore of Virginia facing the Atlantic Ocean. One of the most significant elements of WFF is an Atlantic Ocean barrier island, Wallops Island. The island has experienced erosion throughout the six decades that NASA has occupied the site. Since the early 1990s, part of the island has been protected with a stone rubble-mound seawall, a replacement for an older wood wall that deteriorated. Although the seawall has temporarily fixed the shoreline position, the structure 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 currently unprotected except for a low revetment around the Mid-Atlantic Regional Spaceport (MARS) spaceport (Pad 0B). Near the pad, shoreline retreat from 1857 to the present averaged about 3.7 m/year. Further south, adjacent to Assawoman Inlet, retreat exceeded 5 m/year.

As a result, the National Aeronautics and Space Administration (NASA) officials are highly 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 increasingly vulnerable to damage from storm waves and that the foundations of structures and the Unmanned Autonomous Vehicle (UAV) runway may be undermined as the beach continues to erode.

Based on our review of existing conditions and previous engineering studies performed at Wallops on the subject, it is the U.S. Army Corps of Engineer's (USACE's) professional opinion that NASA's concerns on the vulnerability of the Wallops Island assets are valid. This vulnerability includes two categories of potential risk. The first is the interruption of Federal and states of Virginia and Maryland missions supported from Wallops Island facilities due to flooding and the temporary loss of the functionality of the facilities. The second is the long-term threat to the infrastructure investment in these unique launch range facilities, even to the degree of permanent loss of these national capabilities. If NASA and the other Wallops partners do not take steps to install protective measures, either in the form of a sand beach fill and marine structures to dissipate wave energy and retain sand, or preferably both, then the Federal

(including MARS) assets on Wallops Island will increasingly be at risk from even moderate storm events.

The scope and intent of this study is to develop a plan to protect Wallops Island from ongoing beach erosion and storm wave damage incurred during normal coastal storms and northeasters. To retard further erosion and protect the facilities on the island from storm waves, 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. Protection against hurricane inundation and multi-decade sea level rise will require dikes, island elevation, or other major efforts, to be determined in the future.

At this site, low-cost or experimental shore protection methods have little potential to succeed in retarding erosion or preventing further retreat of the shoreface. Hard structures alone, such as a seawall, will not address the geologic issues inherent in this inlet environment, in particular, the longshore movement of sediment to the south toward Assawoman Island.

We recommend two shore protection plans, depending on budget.[1] If initial construction funds are limited, one plan depends on beach fill alone. The more comprehensive plan includes beach fill and the construction of sand-retention structures such as detached breakwaters. Despite the higher initial costs, structures will probably reduce life-cycle costs because of reduced requirements for renourishment volumes. For either plan, two points must be emphasized: First, regular beach nourishment will be required indefinitely. The sand-retention structures will help reduce the loss of sand from the southern zone but will not stop it entirely. In addition, some sand must be allowed to move south to Assawoman Island to replicate the natural transport patterns in this system. Second, a monitoring program must be conducted on a regular basis to determine sand movement patterns and plan renourishment cycles.

The annual quantity dredged from Chincoteague Inlet is between 61,000 and 76,000 cu m, while a sediment budget prepared by Moffatt & Nichol

[1] Prices are approximate. Beach-fill costs adapted from USACE project at Sandbridge, VA. Structure construction costs adapted from detached breakwater project at Fort Story, VA. Both sites have a similar wave climate as Wallops Island.

(1986) concluded that the net annual sand loss from the Wallops shoreface exceeds 150,000 cu m. Therefore, future beach nourishment will need sand from an external source unless inlet dredging can be expanded to meet the need of beach maintenance.

Beach fill only plan

Year 1. Allocate resources for engineering design, contracting process, and environmental permitting. Begin topography and physical processes monitoring program, design project, conduct sediment search. Cost: ≈$1 million. (Note: Permitting, surveys, and environmental assessments may require more than 1 year to complete.)

Year 2. Construct beach fill along half of Wallops Island (3,400 m). Include dune construction over seawall and planting vegetation. Continue monitoring program. Cost: ≈ $7 million (exact cost will depend on width and height of fill and source of sand).

Year 3. Continue beach fill for 3,400 m to the northern end of the NASA seawall. Include dune construction over seawall and vegetation planting. Continue monitoring. Cost $7 million.

Year 4. Continue monitoring, and adjust programs as needed to adapt to conditions. Renourish beach if needed to maintain design template. Cost: variable. If funds are available and if geologically needed, initiate building sand retention structures at erosion hot spots.

Optimum plan, structures and beach fill

Year 1. Allocate resources for engineering design, contracting process, and environmental permitting. Begin topography and physical processes monitoring program, design project, conduct sediment search. Cost: $1 million. (Note: Permitting, surveys, and environmental assessments may require more than 1 year to complete.)

Year 2. Construct sand retention structures (detached offshore breakwaters, T-head groins, or combinations) along 1,600 m of unprotected southern end of Wallops Island. Continue monitoring program. Cost $10 million.

Year 3. Build 6,800 m beach fill from Assawoman Inlet to northern end of the NASA seawall. Continue monitoring. Cost: $14 million.

Years 4+. Continue monitoring, and adjust programs as needed to adapt to conditions. Renourish beach if needed to maintain template. Cost $0.5-1 million +. If funds are available and if geologically necessary, build sand-retention along other sections of the NASA property (based on results of site monitoring).

In summary, the intent of the optimal plan is to provide an engineering solution that would mitigate the ongoing erosion and loss of sand from Wallops Island and protect against the disruption to operations and potential damage to infrastructure caused by ordinary storms and northeasters. The purpose of the sand-retention structures is to provide additional protection from storm waves and reduce the volumes of sand needed for maintenance renourishing compared to placing fill alone.

Preface

The National Aeronautics and Space Administration's (NASA's) Goddard Space Flight Center, Wallops Flight Facility is located on a barrier island facing the Atlantic Ocean just south of Chincoteague Inlet, VA. The island has experienced erosion throughout the five decades that NASA has occupied the site, and NASA officials have become increasingly concerned that launch pads, various buildings and infrastructure are vulnerable to storm wave damage. NASA contracted with the U.S. Army Engineer District, Norfolk to evaluate previous studies, assess the conditions of the beach and seawall, and make recommendations regarding a comprehensive sediment management and shore protection program at the site. This report presents the results of this study.

Dr. Andrew Morang of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Greggory G. Williams, P.E., and Jerry W. Swean, Norfolk District, conducted the study and prepared this report. Dr. Jennifer Irish, U.S. Army Engineer District, New York, William R Curtis, CHL, and Dr. David R. Basco, Professor of Civil Engineering, Old Dominion University, Norfolk, VA, reviewed the report.

At CHL, work was performed under the general supervision of Edmond Russo, Chief, Coastal Engineering Branch, CHL; Dr. Rose Kress, Division Chief, Navigation Division, CHL; Dr. William D. Martin, Deputy Director, CHL; and Thomas W. Richardson, Director, CHL. At the Norfolk District, work was performed under the supervision of Richard L. Klein, Section Chief, Design Section, Operations Branch, Technical Services Division.

The authors wish to thank Caroline R. Massey, William D. Phillips, Paul Bull, Ron Walsh, and A. J. Kellam, NASA Wallops Flight Facility, Wallops Island, VA, for data and assistance with this project.

Colonel Richard B. Jenkins was Commander and Executive Director of ERDC. The Director was Dr. James R. Houston.

Conversion Factors

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers

1 Background and Study Purpose

The National Aeronautics and Space Administration's (NASA's) Goddard Space Flight Center's (GSFC's) Wallops Flight Facility, located on Virginia's eastern shore, was established in 1945 by the National Advisory Committee for Aeronautics to conduct aeronautic research. The U.S. Navy operated the site from 1942 to 1959, when it was transferred to NASA. Wallops is now NASA's principal facility for managing and implementing suborbital research programs. The facility is divided into two parts: a main base, located on the Delmarva Peninsula, and a smaller area consisting of launch pads and support buildings on the nearby Wallops Island. Much of the island is wetland, and the test facilities and rocket pads occupy a sand strip only 100-200 m wide.

The island location for missile launching is essential because of the immediate proximity of the Atlantic Ocean to the east and uninhabited Assawoman Island to the south. During a project-coordinating visit in February 2006, NASA officials stressed that the safety and integrity of the launch facilities were essential to their goals of an expanded mission and for their continued support of the U.S. Navy and the Mid-Atlantic Regional Spaceport (MARS), both of whom rent space on the island. The current replacement value of the buildings, infrastructure, and equipment on the island is approximately $170 million for NASA, >$600 million for the Navy, and $5 million for MARS.

NASA's concerns regarding erosion, flooding, and infrastructure on Wallops Island can be divided into three main categories:

a. Oceanographic conditions:

- Buildings, launch pads, and roads can be flooded during high tide or storm surges.
- Storm waves overtop the seawall.
- There is significant standing water during and after storms.

b. Structural damage:

- The seawall is losing elevation and losing rock from the ocean side.
- The seawall may need to be extended to the south to protect Pad 0B and the Unmanned Autonomous Vehicle (UAV) runway.

- There is a potential to lose south end of the island at the UAV runway.

c. Geological conditions:

- No beach in front of seawall (priority 1).
- Flanking at south end of the island (priority 2).
- Possible future need for increased elevation on the island.

The purpose of this study is to:

a. Review coastal engineering studies prepared for the GSFC by Moffatt & Nichol Engineers (M&N).
b. Determine if additional studies are necessary. If additional studies are indicated, identify the scope of work required in the studies.
c. Identify other ongoing engineering and technical activities in the study area, which may complement development of the shoreline management plan and provide cost leveraging opportunities.
d. Prepare several alternative scenarios for shore protection and shoreline management. Include identification of work to be done under each alternative, pros and cons for each alternative, and ROM (Rough Order of Magnitude) cost for each alternative.

2 Setting and Geomorphology

Setting and geology

Wallops Island is a barrier island on the Virginia eastern shore about 90 km north of the mouth of Chesapeake Bay (Figure 1). The island is bounded by Chincoteague Inlet to the north and Assawoman Inlet at its south, which is currently silted in and is only open intermittently after storms (Figure 2). Much of the Atlantic shoreline of Wallops Island has been lined with an armor stone seawall to protect NASA, the U.S. Navy, and MARS facilities. The unarmored segments north and south of the seawall are low sloping sandy beaches. The sandy portion of Wallops Island has an elevation of only about 2.1 m above mean sea level (msl) (M&N 1986), making it vulnerable to storm surges from both the Atlantic and Bouges Bay. The island is separated from the Delmarva Peninsula by a marshy bay containing a network of tidal channels, ponds, and Hog Creek to the south. M&N (1986) contains a more detailed description of the island's morphology and underlying geological conditions.

Wallops and the three narrow barrier islands to the south, Assawoman, Metompkin, and Cedar, are unusual in that they are indented to the west compared to the other barrier islands along the Virginia shore. The reasons for this indentation are unknown, but may be related to tectonic movements, wave refraction, and the underlying Pleistocene topography (Rice and Leatherman 1983). The inlets between the islands approximately follow the courses of paleochannels formed during the late Wisconsin sea level regression (Halsey 1979).

Assawoman Island is a 5,000-m-long sand barrier separated from the mainland by marsh and tidal channels. It is bounded on the south by Gargatha (also spelled Gargathy) Inlet and on the north with the usually-silted Assawoman Inlet. The secluded island is a nesting area for piping plovers, Wilson's plovers, least terns, common terns and American oystercatchers. Net longshore sediment movement is from north to south, and material eroded from the shoreface at Wallops Island moves south to Assawoman. Most of the island comprises the Assawoman Island Division of the Chincoteague National Wildlife Refuge, and is managed by the U.S. Fish and Wildlife Service (USFWS).

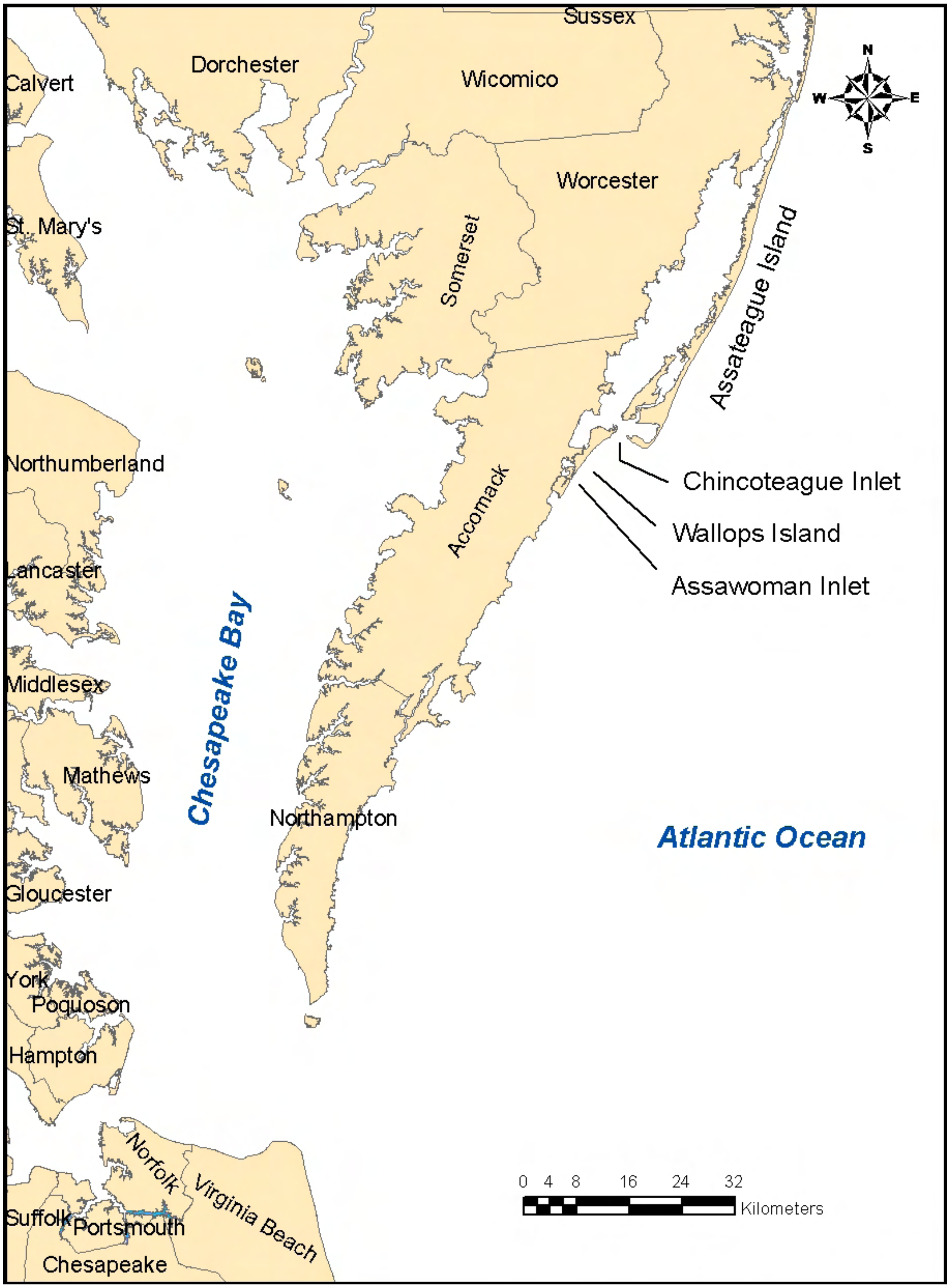

Figure 1. Virginia eastern shore and Wallops Island study area. Names on land are counties.

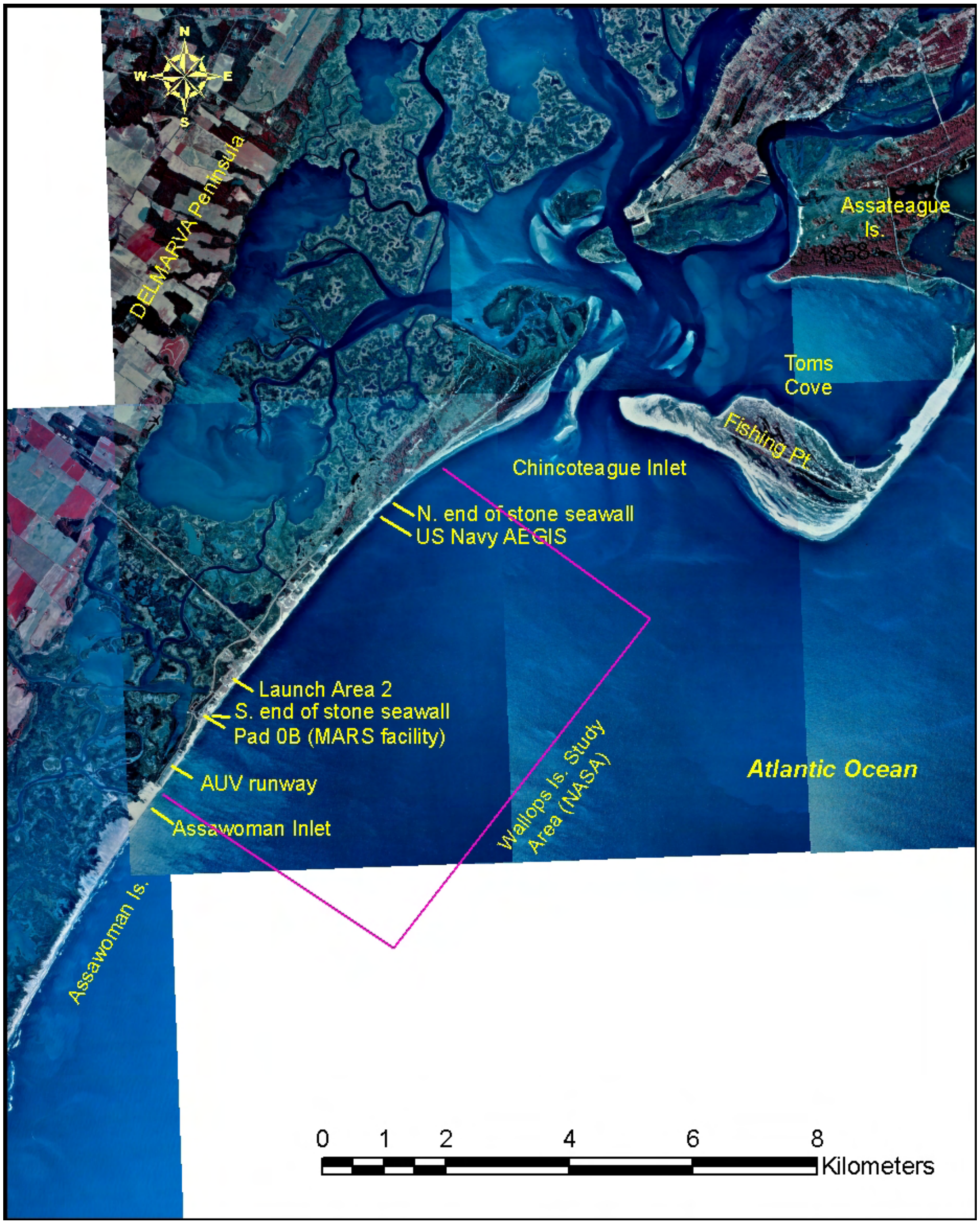

Figure 2. Wallops Island study area. Aerial photograph: 20 March 1994 Digital Ortho Quarter Quadrangle downloaded from Virginia Economic Development Partnership Web page: http://virginiascan.yesvirginia.org, 22 August 2006.

Chincoteague Inlet is a Federal navigation project and is dredged annually to a depth of 3.7 m with additional overdredging of about 1 m over the ebb shoal. Chincoteague is unique amongst the inlets along the Delmarva Peninsula because the main ebb channel has a north-south orientation. In early Colonial times, Chincoteague Bay had at least three openings to the Atlantic Ocean, Chincoteague, Morris, and an unnamed inlet further to the north (Halsey 1979). Because of an abundant sediment supply, the two northern inlets closed, but Chincoteague remained open because it captured the entire tidal prism of Chincoteague Bay. The predominant direction of longshore transport in this area is from north to south. The supply of sand caused sand spits to grow south from the end of Assateague Island, forcing the inlet to curve southward. The recurved sand spit at the south end of Assateague Island, known as Fishing Point, is evidence of this southward transport. First mapped in 1909 by the U.S. Coast and Geodetic Survey (USC&GS), the point has progressively grown south and west as well as become more voluminous (Figure 3). The shorelines in the figure represent the high water line, as mapped by USC&GS topographers in the field. The National Park Service, Department of the Interior, administers Assateague Island, which was designated a National Seashore in 1965.

Fishing Point spit and the ebb and flood shoals of Chincoteague Inlet form a highly efficient sediment trap, allowing only about 5 percent of the littoral transport to bypass to the south (M&N 1992). M&N (1986) estimated that the average annual entrainment of sediment in the Chincoteague system amounted to about 1 million cu m from 1934 to 1984. One of the consequences of this sink is that Wallops Island and the barriers to the south have been deprived of sediment and have eroded, resulting in shoreline retreat to the northwest.

From 1857 (the date of the first USC&GS shoreline) to 1994, the southern part of Wallops Island has retreated about 400 m (Figures 4 and 5). Based on this 1857 survey, the shoreline retreat rate near Pad 0B has been about 3.7 m/year, while further south, near Assawoman Inlet, the rate increased to ≈ 5.5 m/year. When using the USC&GS 1911 survey, the retreat rate near Assawoman Inlet was less, about 2.5 m/year. The reduction might be natural, due to a change in storminess or possibly because of the sheltering effect of the growing Fishing Point. It may also be a mapping artifact, depending on what feature the surveyors mapped in the field or positioning error.

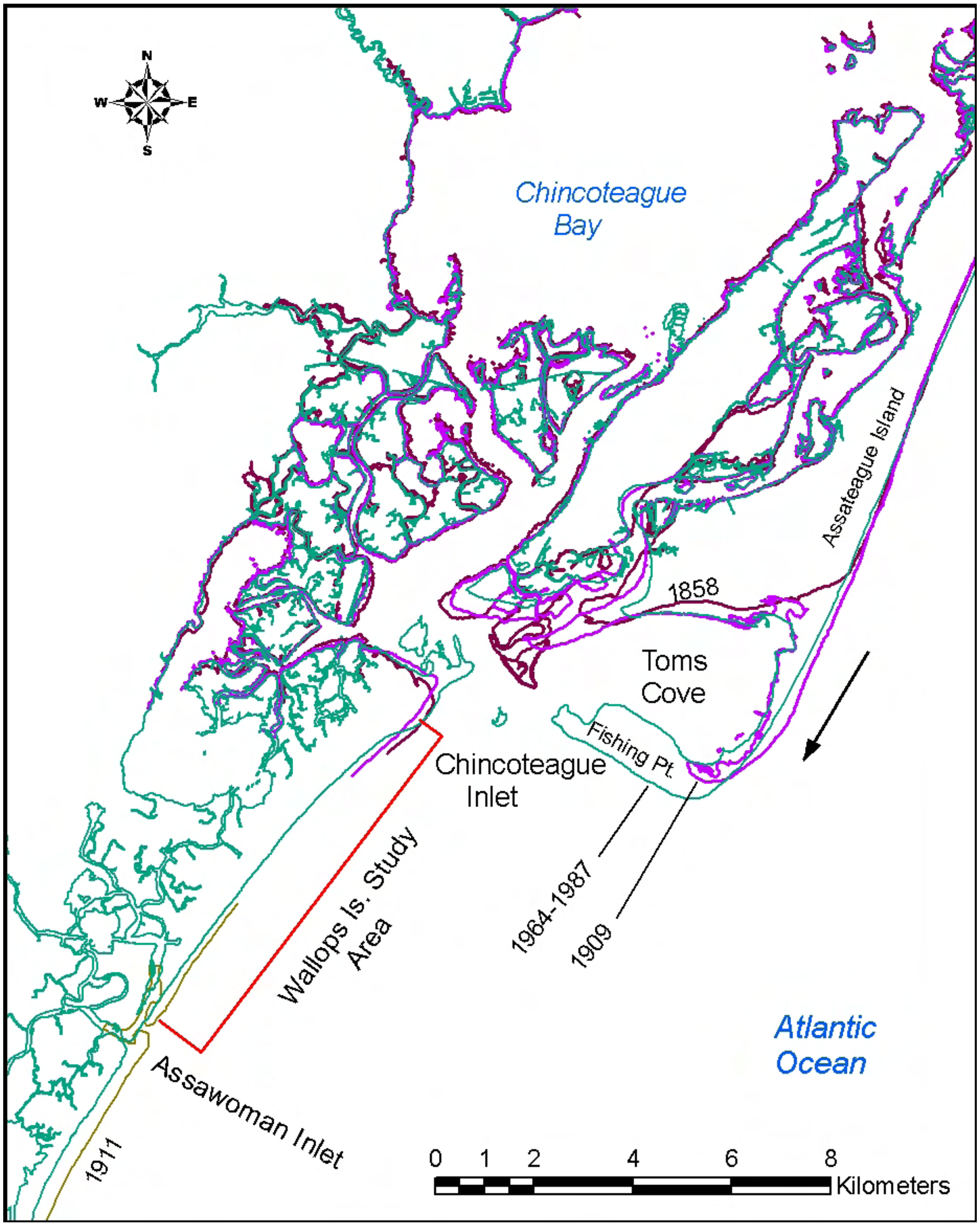

Figure 3. Fishing Point spit grew over 4 km southward in about 120 years. Shorelines from NOAA and state of Virginia.

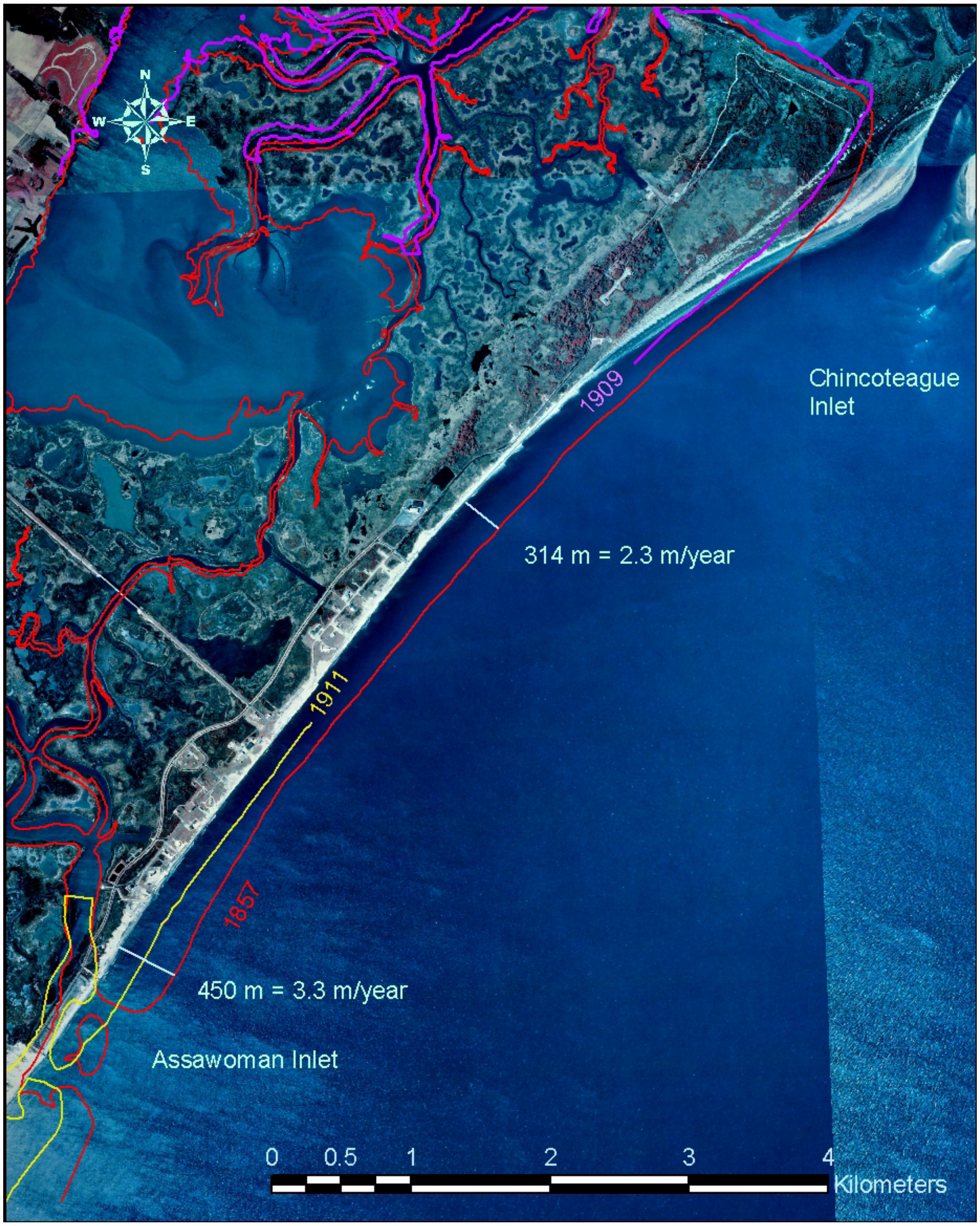

Figure 4. Shoreline changes at Wallops Island from 1857 to mid-1980s. Shoreline data from NOAA and state of Virginia. NASA's facilities are located on narrow sand strip. Aerial photograph: 1994 Digital Ortho Quarter Quadrangle downloaded from Virginia Economic Development Partnership.

Figure 5. Oblique 1991 aerial photograph of south end of Wallops Island showing approximate position of 2005 shoreline. Photograph courtesy of Goddard Space Flight Center.

Along Assawoman Island, the shoreline retreat rate, based on the 1911 shoreline and the 1994 aerial photograph, has been between 4.9 and 5.2 m/year (Figure 6). Presently, Assawoman Island is so low, the beach is an expanse of overwash fans, and it is difficult to even define what the shoreline should be on the air photograph.

The year 1934 is significant because it is when jetties at Ocean City, MD, were first built. The north jetty immediately began to trap littoral material, and as a result, Assateague Island to the south began to erode. To date, the shoreline just south of the south jetty has retreated almost 1 km compared to its pre-1934 position (Pendleton et al. 2004). The National Park Service (NPS), USACE, and Minerals Management Service (MMS) have begun a restoration plan which involves placing sand on Assateague from offshore borrow sites. The Maryland Geological Survey and the MMS identified 16 shoals beyond the 3-mile limit containing about 275 million cu m of sand. In 1998, the NPS placed about

1,500,000 cu m of sand from Gull Shoal on low parts of Assateague to prevent breaching.[1]

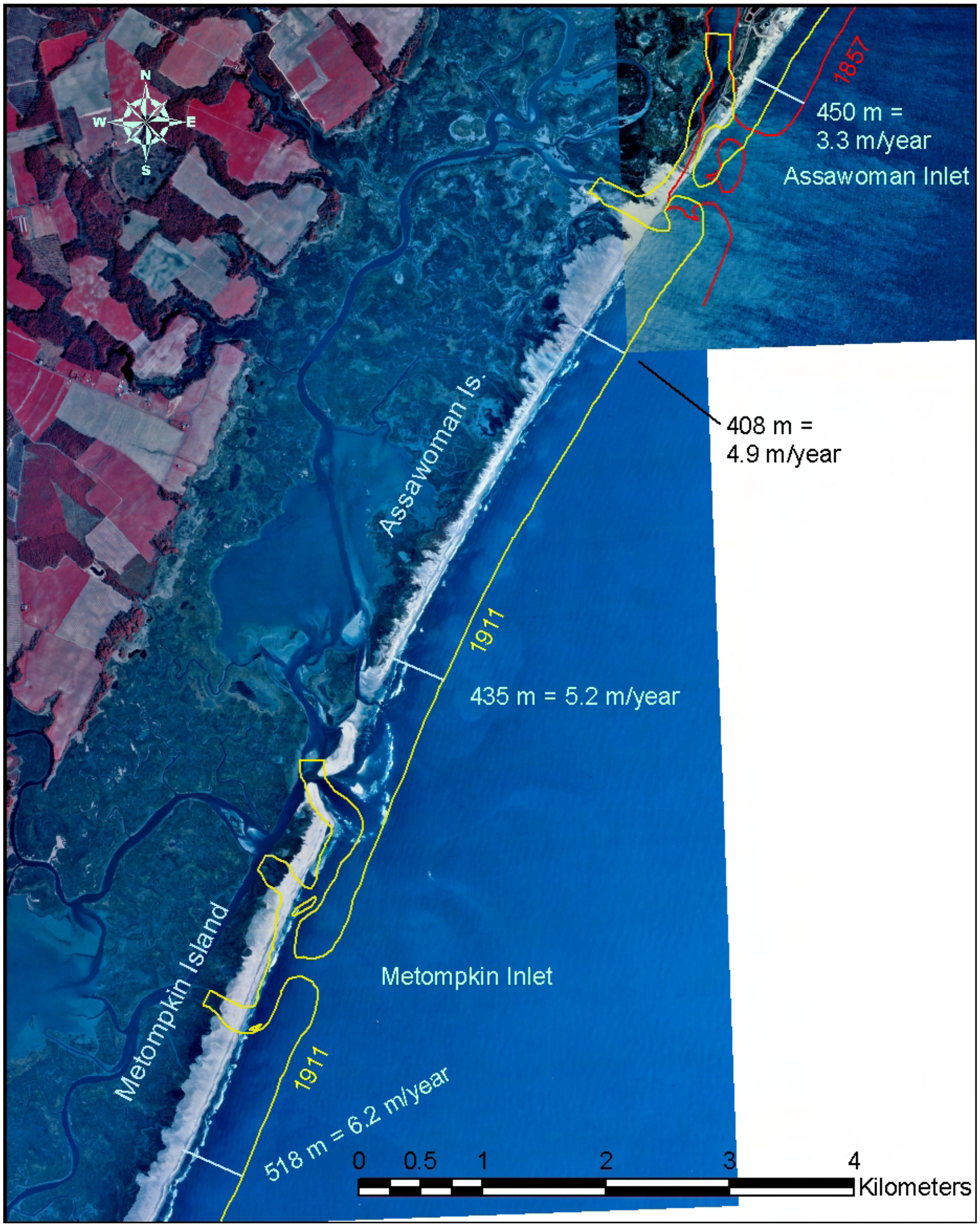

Figure 6. Shoreline change along Assawoman Island has ranged from 4.9 to 5.2 m/year based on the 1911 shoreline and 1994 photograph.

[1] From MMS Web page: http://www.mms.gov/SandAndGravel/maryland.htm (accessed 4 August 2006).

Although the north jetty and the ebb shoal trapped millions of cubic meters of sand, erosion of Assateague Island and sand from ancient ebb shoals continued to resupply the littoral system, allowing Fishing Point to continue to grow during the twentieth century. Whether the material provided by the erosion of Assateague equals the littoral transport that existed before the jetties were installed is unknown. A mid-1980s sediment budget for Wallops Island is discussed later in this report.

Structures

Wood groins and seawall

Starting around 1961, NASA installed 47 shore-perpendicular wood timber groins along the Atlantic shore of Wallops Island (M&N 1986 and Figure V-3-25 of Basco 2006). The groins ranged in length from 30 to 120 m and the spacing varied from 60 to 200 m, but most of the units were 76 m long and spaced at 135 m (see Table 2 in M&N (1986) for an inventory). The last groins were built in 1972, and there is no record of beach fill.

In 1958, NASA began to construct a timber seawall in the north launch area. The seawall paralleled the shoreline and tied the landward end of the groins together. Construction continued through 1963 for the rest of the island. During 1963-1964, the seawall was repaired and possibly fill placed, but the low dollar amount associated with this work suggests that the fill must have been minor. There is no record of any other beach fill until 2003, when the USACE placed about 60,000 cu m of sand on the beach after dredging Chincoteague Inlet. The groins and seawall were repaired on an as-needed basis through the 1970s (see Table 1 in M&N 1986).

In the early 1960s, the shoreline was near the seaward end of the groins. A 1970 photograph still shows the groins to be largely intact (Figure 7). By 1976, the shoreline had moved to about the halfway mark on the groins (Figure 8). By 1983, the groins were in poor condition with many collapsed sections (Figure 9). The beach in each cell had retreated almost to the landward side of the groins or had disappeared entirely, and waves were lapping against the remains of the wood seawall (Figure 10). Therefore, the shoreline retreated about 75 m in 20 years, averaging about 3.75 m/year. In Appendix A of M&N (1998), Williamsburg Environmental Group noted, “In the absence of periodic beach nourishment, however, the majority of the groins and seawall failed.” The groins failed because, as the beach retreated, the seaward portion of each structure was exposed to water of increasing depth. The groins did not have deep enough king-piles to remain anchored in the increasing depth water and, coupled with direct impact of waves, they unraveled and sections collapsed. The damage was most prevalent at the seaward end, in the zone where troughs and bars form on the seabed, and at the inner ends of the groins, where waves broke against the vertical seaward face of the seawall (M&N 1986). In the early 1990s, NASA hired a contractor to remove the remains.

The fundamental reason that many sections of the wood seawall failed was that it, too, was dependent on the existence of a protective beach strand to prevent waves from undermining the toe.

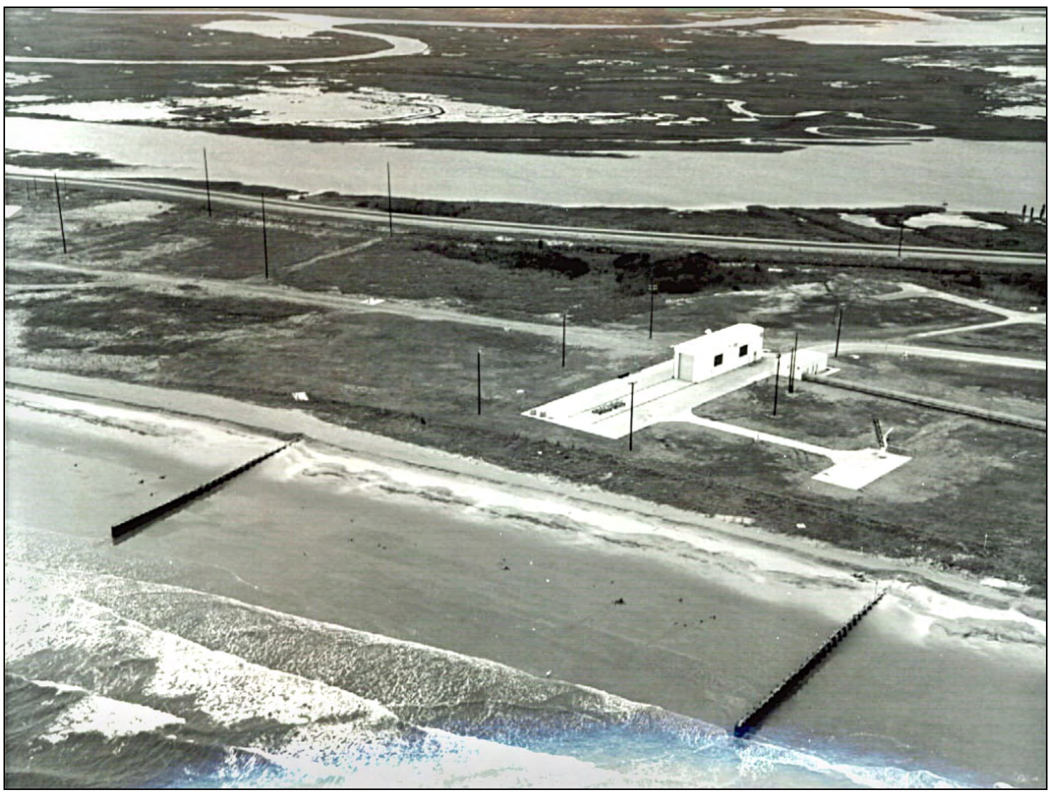

Figure 7. Wallops Island near Pad 1, date assumed to be 1970. NASA photograph 70-210, courtesy of Goddard Space Flight Center.

Figure 8. By 1976, shoreline had moved to approximately halfway mark on groins. Chincoteague Inlet and Fishing Point can be seen in upper part of frame. NASA photograph 76-142, courtesy of Goddard Space Flight Center.

Figure 9. 1983 view looking north along Wallops Island showing poor condition of southern groins. NASA photograph 83-102-14, courtesy of Goddard Space Flight Center.

Figure 10. 1983 view taken in same area as Figure 7. Part of wood seawall has collapsed. NASA photograph 83-102-14, courtesy of Goddard Space Flight Center.

Rock revetment – seawall

In July 1992, the Virginia Marine Resources Commission issued a permit authorizing the Wallops Flight Facility to construct a stone riprap extending north from the southern end of the Range Operation Zone for a length of 4,840 m. During the permit review, Virginia Institute of Marine Sciences predicted that accelerated erosion would continue downdrift of the riprap terminus. M&N (1986, Figures 33 and 34) developed preliminary designs for a stone riprap. Their design called for the new structure to be built over the remains of the 1960s wood seawall using armor stones of about 3.5 tons. They were to be placed with a seaward slope of 1:3 over a 24-in. underlayer of 50-500 lb stone, in turn placed over a synthetic sheet filter cloth (Figure 11).

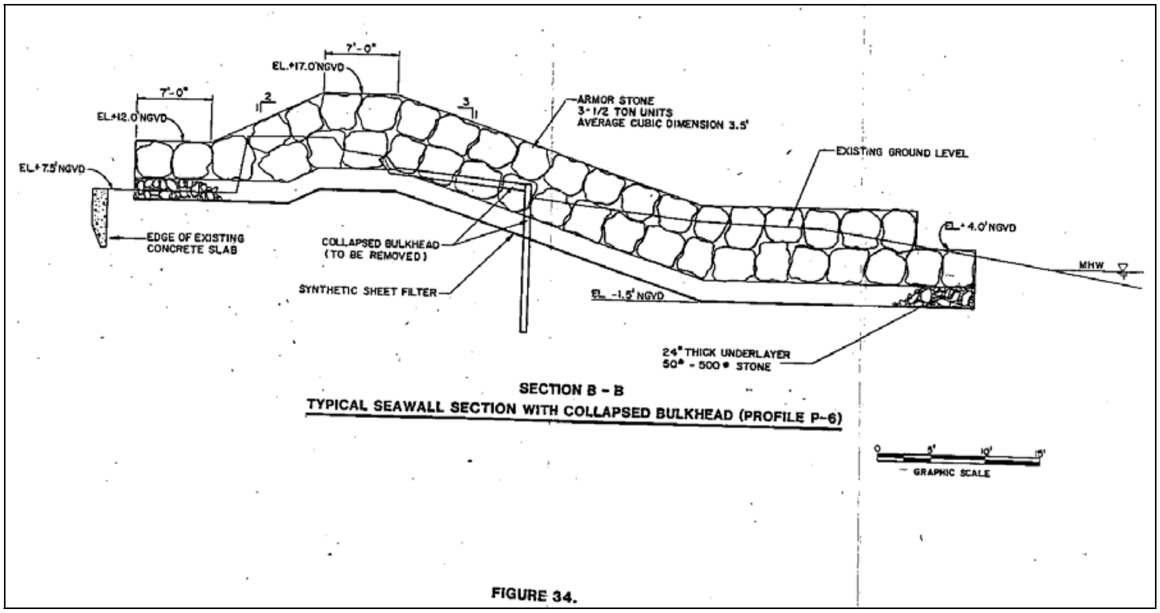

Figure 11. Plan of a seawall prepared by Moffatt & Nichol, Engineers, designed to withstand a 20-year return period storm (M&N 1986, Figure 34). Design specified a 24-in. layer of underlayer stone and a seaward slope of 1:3.

The riprap, now commonly called the seawall, was built during the early 1990s by NASA in-house labor.[1] Sixty percent of the stone was 2-3-ton granite, brought in by rail from Lawrenceville, VA, and at a cost of $35/ton delivered plus $10/ton placed. In 1994, the seawall was 4,620 m long and had a crest elevation of about 3.7 m msl. Details are unavailable for construction dates or on the total amount of stone imported to the site. The structure deviates significantly from the recommended M&N design, for reasons unknown (Figures 12 and 13). The slope is much greater, as much as 1:1 in many places, and lacks a core stone or underlayer. The structure is highly permeable because of the voids, some of which are large enough for a person to crawl through. In areas where the older wood seawall was intact, the combined system probably prevents some wave runup from penetrating to the beach behind. But where the old seawall had collapsed, the current structure transmits significant water. During storms, individual stones have been displaced or knocked off, and NASA has made repairs to the crest since the mid-1990s (dates and quantities unknown).

[1] Based on notes recorded during a 7 September 1999 meeting between NASA and USACE personnel, cited in "Transmittal of Trip Report for Site Visit to Goddard Space Flight Center, Wallops Island, Virginia," Memorandum for Record, 19 October 1999, Coastal and Hydraulics Laboratory, Vicksburg, MS.

Figure 12. Contemporary stone seawall, near Aegis training facility, view looking south (photograph 11 February 2005).

Figure 13. Photograph near north end of seawall, 11 February 2005. Individual stones have been displaced during storms.

During a site visit in March 2006, it was observed that the crest of the seawall was irregular in height and stones had fallen into the shallow water on the ocean side. Along some areas, sand has been scoured from behind the structure, forming depressed areas that have standing water. M&N (1998) noted that this was already occurring in the late 1990s, as sand was progressively lost from the system. Photographs taken during Hurricane Dennis show significant standing water behind the seawall (Figures 14 and 15).

During the mid-1990s, NASA built a narrow-crested dune on the landward side of the seawall to protect structures and launch pads from coastal flooding. The crest elevation of the dune was approximately equivalent to the seawall's crest. Significant dune erosion occurred at discrete locations behind the seawall during Hurricane Dennis, which lingered in the Atlantic from 1-4 September 1999. It is likely that the eroded dune material was lost to the nearshore through the permeable seawall as overtopped and transmitted waves drained seaward through the rock voids.

Figure 14. Waves from Hurricane Dennis overtopping the seawall (photograph taken approximately 1-4 September 1999.

Figure 15. South end of Wallops Island during Hurricane Dennis (photograph taken approximately 1-4 September 1999. Standing water has reached the revetment in front of Pad 0B.

Dredging

The USACE periodically dredges the Federal Navigation Project through Chincoteague Inlet (Table 1). The quantity removed from the channel has ranged from 53,000 to 92,000 cu m (70,000 to 120,000 cu yd) for each contract. In October 2002, NASA covered the additional cost to place about 61,000 cu m of dredged material on the beach in front of the seawall (listed as “beach work” in the table). This was an unusually high cost per yard because of the small scale of the operation. A major beach-fill project on Wallops Island would use a larger and more efficient dredge.

The sediment in the channel includes a significant proportion of fines. Therefore, if channel material will be used on a Wallops beach fill, a higher overfill ration may have to be anticipated to accommodate the higher rate of loss of the fine-grained material compared to sand. Material from maintenance dredging can probably be used for periodic renourishment to help rebuild the template to project dimensions.

The inlet south of Wallops Island, Assawoman Inlet, is not maintained. The channels in the marsh west of the island are rarely dredged.

Table 1. Chincoteague Inlet dredging.

Date	Dredge	Mob and Demob ($)	Beach Work ($)	Yardage	Price Per Yard ($)	Total Cost ($)	Days Dredging	Cost Per Yard ($)
Mar-06	Atchafalaya	234,817		70,000	4.99	584,117		8.34
Mar-05	Currituck			12,455		102,505	10	8.23
Oct-02	Northerly Island	163,260	592,226	91,292	14.32	2,062,787	26	22.60
Dec-99	Atchafalaya	210,000		85,000	4.50	592,500	13	6.97
Aug-98	Mermentau	120,000		72,592	3.15	348,665	17	4.80
Nov-97	Mermentau	275,000		122,889	3.87	750,580	34	6.11
Jul-96	Mermentau	150,000		120,079	3.58	579,883	30	4.83
Apr-95	Mermentau	270,000		120,835	3.72	719,506	22	5.95
Notes: Dredging statistics reported in English units. All operations by hopper dredge.								

3 Review of Previous Studies

Introduction

Moffatt & Nichol, Engineers[1] conducted studies for NASA at Wallops Island during the 1980s and 1990s (Table 2). We have reviewed the reports and conclude that the studies were conducted with sound engineering and scientific practice. The following paragraphs summarize key findings.

Table 2. Reports by Moffatt & Nichol, Engineers.

Date	Title	Notes
Feb 1986	Wallops Island Shore Protection Study, Wallops Island, Virginia	General assessment, sediment budget, recommendations
31 Mar 1986	Wallops Island Shore Protection Study Presentation Material	Summary of Feb 1986 study
Aug 1987	Shore Protection Alternatives, Goddard Space Flight Center, Wallops Island, Virginia. Phase A Report Final Submittal	Development of shore protection alternatives: artificial headlands with fill and four types of structures
3 May 1989	Study of Wallops Island Seawall Repair Alternatives, Phase B	Tests of “Beach Beams” and “Beach Prisms” were inconclusive. These structures deemed unsuitable for Wallops Island.
8 May 1992	Wallops Island Shoreline Evolution Modeling Study	Shoreline change data, GENESIS modeling to predict shore evolution
28 Aug 1998	Wallops Island Seawall Study	Examination of seawall condition, summary of previous studies, suggestions for additional structures

1986 Shore protection study

The first report prepared by Moffatt & Nichol for NASA (M&N 1986) comprehensively examined physical and geological conditions at Wallops Island, made an inventory of the groins and seawall, and presented options for protecting the shore in the future. At that time, launch area 2

[1] Moffatt & Nichol Engineers, 2209 Century Drive, Suite 500, Raleigh, NC 27612. Phone (919) 781-4626.

was of most immediate concern to NASA, and M&N provided a design for a rubblemound seawall (Figure 11).

Based on hurricane and northeaster water elevations at Lewes, DE, and Norfolk Navy Yard, VA, M&N prepared a plot of design storm tide elevations for Wallops Island (Figure 16). One of the twentieth century's record storms on the Atlantic Seaboard was the Ash Wednesday Northeaster of 6-8 March 1962. The measured surge at Ocean City, MD, reached 2.29 m (7.5 ft) msl. Tide elevations were not recorded at Wallops Island, but flooding and storm waves caused $2.2 million (in 1962 dollars) damage to NASA buildings and structures. Appendix B of M&N (1986) is an interesting review of storms and hurricanes that have affected this part of the Atlantic Coast. The storm curve needs to be recomputed to include more recent storms such as Hurricanes Dennis of 1999 and Isabel of 2003 and the 1992 northeaster.

A northeaster during 1-4 January 1992 caused elevated water levels and floods along much of the eastern seaboard. Flooding and beach erosion occurred along the New Jersey, Maryland, Delaware, and Virginia coasts as the storm made landfall on the 4th. A wind gust of 83 mph was recorded at Indian River, DE, and a gust to 89 mph occurred at Chincoteague, VA.[1] At the Chesapeake Bay Bridge-Tunnel, the water level rose 0.49 m accompanied with a drop in pressure of 15.5 mb (Paraso and Ville-Levinson 1996). NASA made measurements of water level marks on various building on Wallops Island. On Z-41 (U.S. Navy), the water level was 3.57 m above MSL, above the floor elevation of 2.6 m. In Y-55, the water was 3.12 m, while the stairwell was only 2.08 m. The complete data sheet is reproduced in Appendix A. It is interesting that water elevations recorded on Wallops Island after the January 1992 storm are higher than the elevations for hurricanes and northeasters shown in Figure 16. The differences may be due to the locations of the stations, errors in datum corrections in computing MSL, and the fact that wave runup water levels are typically higher then still-water levels.

[1] From http://www.intellicast.com/Almanac/MidAtlantic/January/, (accessed 4 May 2006).

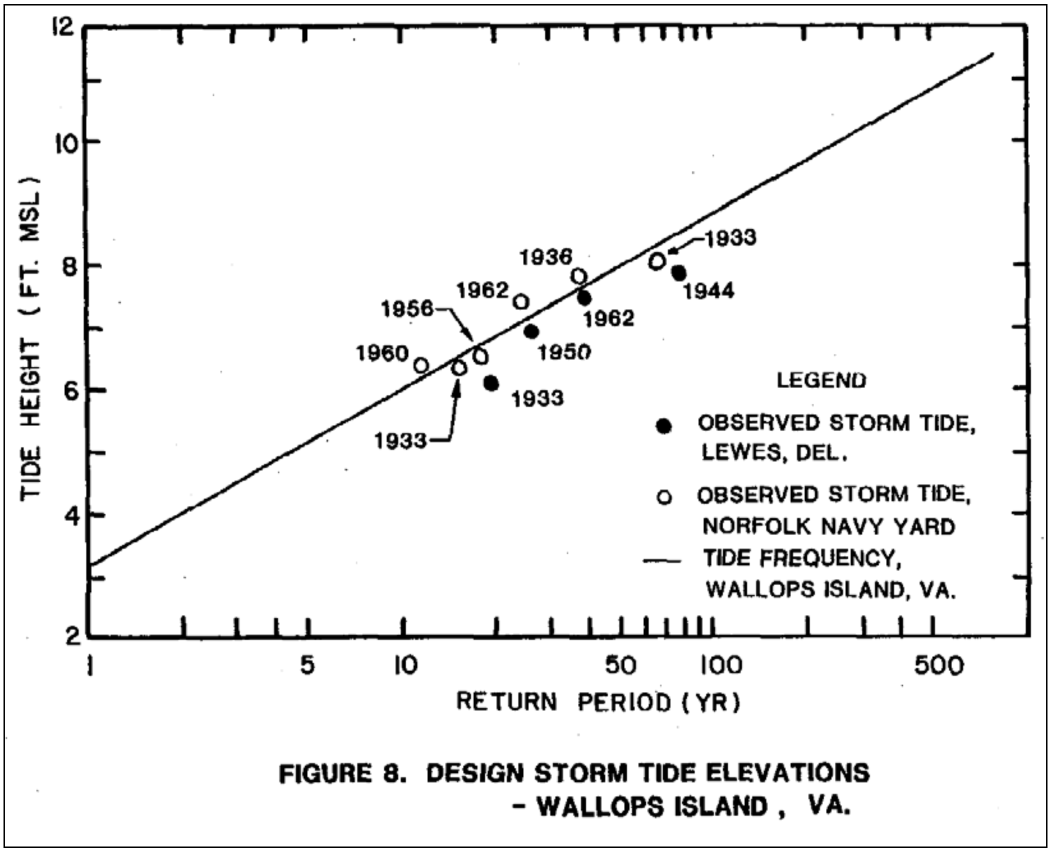

Figure 16. Storm tide frequency curve for Wallops Island, VA (from M&N 1986). This curve will be updated with new data as part of project design.

M&N (1986) computed a sediment budget based on setting up and solving continuity of sediment equations for a series of shoreline and inlet cells (Figure 17). Readers should refer to the original document for details on the methodology. M&N computed budgets for three periods (see Appendix B for reproductions of the original figures):

a. The island was free of structures, so this budget represents "natural" conditions (Figure B-1).

b. This represents the era when the groins were relatively intact and therefore altered beach processes along Wallops Island (Figure B-2).

c. Current conditions, 1986. This was prepared when the groins were in a state of disrepair and presumably were retaining little or no sediment in their compartments (Figure B-3). The stone seawall had not yet been constructed.

For this report, a sediment budget for Wallops Island has not been recomputed. M&N's methodology was thorough and their computed values are reasonable for this inlet/eroding island situation.

M&N (1986) predicted that the 1986 budget should be valid for a period of 10-15 or more years. The stone seawall, built in the early 1990s, fixed the position of the shoreline. This may have reduced the amount of sand available to be suspended by waves and moved alongshore. But, NASA observers have stated that the water depth at the toe of the structure has been deepening, suggesting that sand is still being lost from the shoreface. In the absence of bathymetric data right at the toe, it cannot be evaluated how much sand has been moved out of the system since the seawall was built. The quantities shown in the 1986 budget (Figures 17 and A-3) may have changed, but the trends will still be valid.

One key finding is that cell C is a nodal zone, with sand moving out of the cell both to the north and south. There is no single location for the node because it moves alongshore depending on wave conditions. The annual loss from cell C is about 63,500 cu m. In cell D, the net transport is to the south, towards Assawoman Island. For cells B, C, and D, the combined annual volume change is about -123,000 cu m. The annual dredging of Chincoteague Inlet yields about 61,000 to 76,000 cu m, or about half the amount lost from the adjacent Wallops Island. Because some of the channel material is fine-grained sediment, Chincoteague Inlet can probably only supply one-third or less of the amount of sand annually needed on Wallops Island. Note that because the beach on Wallops Island is not open to the public and is not used for recreation, it is not as essential that exactly compatible material be used. Therefore, material that is finer than the existing beach sand could be used with the understanding that waves would eventually winnow out the fines and reduce the overall volume.

M&N (1986) estimated that the Chincoteague Inlet cell gains about 1,000,000 cu m/year, largely from sediment moving south along Assateague Island. A deposition basin dredged south of Fishing Point would trap some of this material, which could then be pumped or carried across the channel to Wallops Island (in effect, reinitiating natural inlet bypassing).

When the Wallops Island shore protection project is funded, one component of the design needs to be a recalculation of the sediment budget for 2006 conditions using more recent shoreline change and bathymetry data, dredging statistics, and newer Atlantic Wave Information Studies (WIS) wave hindcasts.[1]

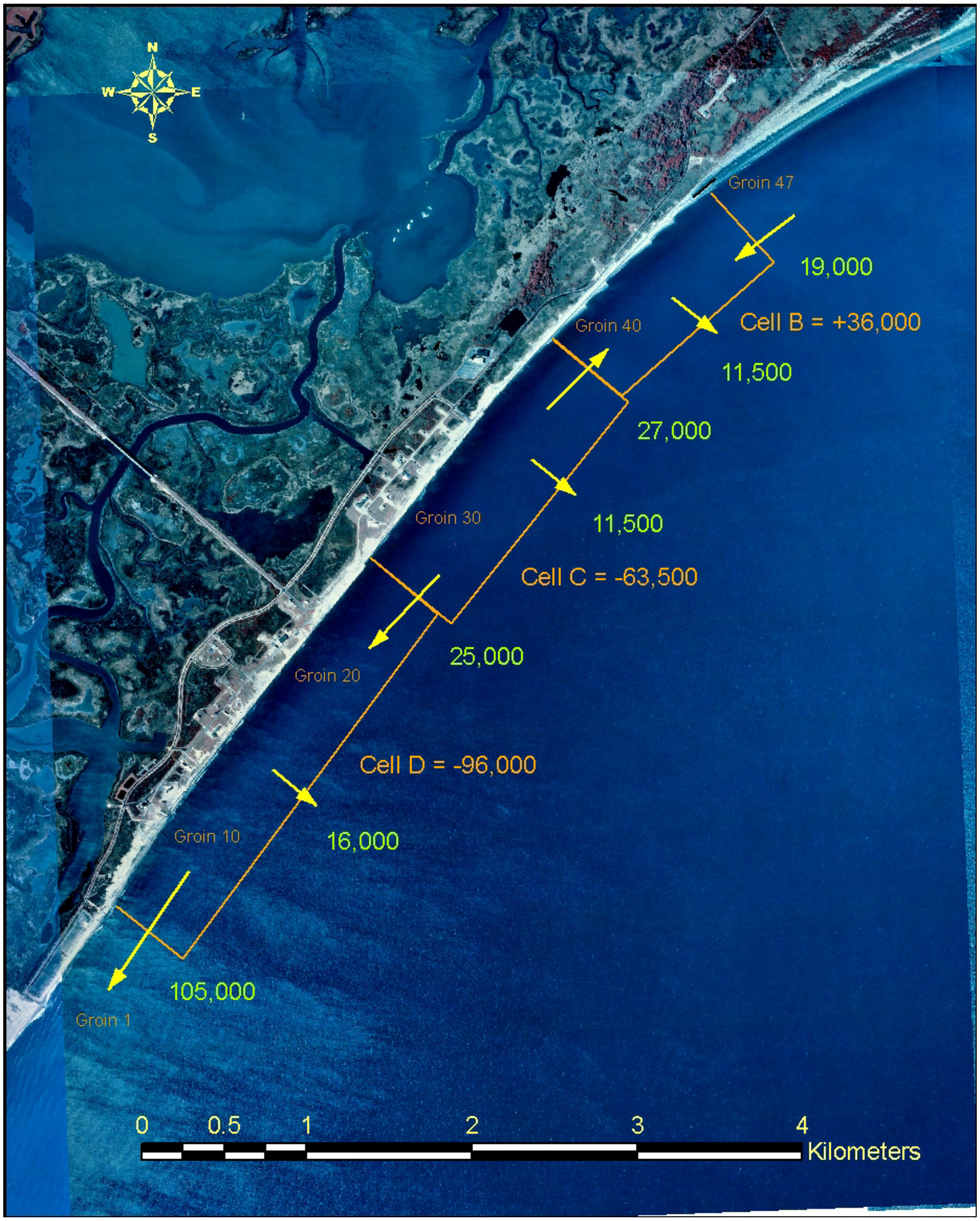

Figure 17. Sediment budget for mid-1980s conditions, computed by M&N 1986. Arrows show net transport direction. Numbers represent transport or net gain or loss per cell in cubic meters/year. Locations of cells based on descriptions in text, replotted in ArcMap™ software

[1] WIS hindcasts for the Atlantic and other coasts are available from the USCAE: http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html, (accessed 3 August 2006).

1987 Phase A report, shore protection alternatives

In this report, M&N (1987) discussed five shore protection alternatives:

- Artificial headlands with beach fill.
- Beach prisms.
- Beach berms.
- Seabee revetment.
- Backslope revetment.

The authors pointed out that, "Worldwide experience over many decades has clearly demonstrated that long-term protection of shorelines on exposed ocean coasts requires massive investments and strict observance of design standards that apply to these works" (M&N 1987, p. 22). They again recommended a series of artificial headlands, as first discussed in the 1986 report. Some key points that M&N (1987, p. 25) outlined regarding artificial headlands are still valid:

"b. Advantages.

1) Utilizes standard stone construction methods which are familiar to marine contractors.

2) Can be built with adequate structure height to provide protection during even large storm surges.

3) Headlands maintain a sandy beach which acts as a buffer zone and limits wave attack against the revetment and dune and reduces runup and overtopping.

4) Armor stone structures, when properly designed and constructed, have a proven record of durability and performance.

c. Disadvantages.

1) Initial construction cost is high.

2) The system does not directly and positively protect the shoreline itself.[1] The beach that is maintained acts as an intermediate buffer zone to provide protection. Waves that pass the

[1] Note that shore-attached headland breakwaters would directly stabilize the shoreline and attenuate wave energy, depending on the size and type of shore-connector.

structures, however, will be reduced in height before they reach the shore.

3) Periodic renourishment of the sand fill between the headlands will be necessary to replace losses from the system. Some maintenance of the headlands themselves will be necessary."

There is no need to review the other suggested alternatives. M&N (1987) warned that three were patented technologies with either nonexistent track records or only limited tests in mild wave environments. The last alternative, the backslope revetment, was only suitable where the wood seawall was largely intact, and this condition no longer exists.

In the conclusions, M&N (1987) stated that NASA's projected budget at that time ($600,000-$700,000) was inadequate to stabilize the entire shoreline in a reasonable amount of time using proven, conventional methods. Therefore, they recommended a test program to examine some lower-cost alternatives. M&N (1987, p. 80) also recommended: "An alternative course of action would be a series of laboratory hydraulic model studies to evaluate all of the alternatives under controlled conditions. This would yield far more useful information for each research dollar spent." With the current state of the knowledge, a hydraulic study is probably no longer needed for this setting.

1989 Phase B, evaluation of permeable sill modules

In this report, M&N (1989) evaluated two kinds of high energy dissipating permeable beach sill modules to help retain sand between the shore-perpendicular groins. In an attempt to counter the persistent erosion that threatened launch facilities, the U.S. Navy and NASA initiated this demonstration project in 1988. The two devices tested were the "Beach Prism," a triangular concrete prism, and the "Beach Berm," a triangular truss-shaped unit. The beach sill modules were deployed in three installations, at Launch Area 0, Launch Area 2, and the Navy's Aegis site between 7 and 9 March 1988. M&N (1989) did not list the cost of this demonstration.

M&N (1989) concluded that both units failed to abate shore erosion. Both shared the failure mode that they could slide over the filter cloth when first placed on the seabed as a result of wave action (Figure 18). The second failure mode was that both modules caused a concentration of energy dissipation at their locations which otherwise would have been spread over a wider beach area. As a result, scour removed sand in the vicinity and subsequently caused the units to settle into the seabed (Figure 19). The sinking clearly degraded their effectiveness.

The following conclusions by M&N (1989) are worth quoting:

> "(1) Our analysis of the repetitive profiles from the various installations reveals that none of the launch facilities are significantly better protected with the modules than they would be without them.
>
> (4) The repetitive profiles seem to indicate that the beach is getting steeper along this entire reach from Launch Area 0 to the Aegis site. If this is the case, then even success with this installation would be ultimately be doomed to failure as deeper water moves progressively closer to shore."

Only a few perched beaches with sills have been built around the world, and their performance has not been uniformly successful (Basco 2006). Most Great Lakes experiments were failures, possibly because of varying water levels. Chesapeake Bay examples have performed better, but the bay has a restricted wave climate compared to Wallops Island. One fundamental problem with sills is that they retain sand in an elevated position. During storms, waves can mobilize the sand and flush it seaward over the sill. But during the recovery phase after the storm, there are no obvious hydrodynamic mechanism that can move sand up and over the sill back into the perched beach.

Figure 18. Experimental “Beach Prism” sand retention units moved out of alignment during an April 1988 storm (photograph courtesy of NASA).

Figure 19. "Beach Beam" units partially sunken into seabed during an April 1988 storm.

1992 Shoreline evolution modeling

M&N (1992) estimated future shoreline changes with the stone revetment in place using the USACE's GENESIS computer model. They ran the model with wave parameters statistically generated to match the wave climate measured at a directional wave gauge at Duck, NC. The deep water wave record was converted to shallow water using the wave refraction coefficients calculated in M&N 1986. M&N (1992) noted that developing a baseline erosion case from which to calibrate the model was particularly difficult at this site because of the history of structures and the lack of surveys.

GENESIS predicted accelerated erosion on Wallops Island following reconstruction of the seawall system (when the wood seawall was replaced with the rock rubble structure). In addition, the GENESIS results showed that while erosion would occur in the 400-m-long zone immediately south of the rubble revetment, the erosion rates on Assawoman Island would be similar to those historically experienced in that area. Hence, M&N (1992) concluded that the seawall would have negligible influence on the erosion experienced on Assawoman Island.

1998 Seawall study

The last report (M&N 1998) evaluated options for shoreline protection. The information and findings in this report are as pertinent today as they were in 1998. Section 6 (p. 28) listed shoreline management alternatives that can be divided into three classes: no action, beach fill, and structural designs (or combinations including structures with beach fill):

a. No action.
b. Beach nourishment.
c. Seawall improvement.
d. Seawall extension.
e. Artificial headlands.
f. Shoreline revetment.
g. Facility relocation.

The two recommendations for seawall improvement and extension (items *c* and *d*) did not include an accompanying beach nourishment program. A massive seawall can be designed with adequate toe protection to withstand storm wave impact and scour for some period. But such a seawall does not move the zone of wave breaking further away from the infrastructure being protected. Even more important, extending the rock seawall further to the south will not address the fundamental problem of a lack of sediment in the littoral system. As noted by Williams Environmental Group (M&N 1998, Appendix A, p. 8):

> "The existing seawall structure offers no convincing evidence of a shoreline erosion solution that successfully addresses the sediment transport characteristics associated with barrier island systems. Depending on the southern extent of the proposed structure, such an action may be viewed to have negative impacts on the avian breeding grounds to the south. It would be expected that the proposed structure would transfer the erosion associated with the existing seawall to the new terminus of the structure further to the south."

For artificial headlands (Item *e*), M&N (1998) recommended, "A program of beach nourishment should be implemented in conjunction with headland construction to prefill the area between the headlands." The need for beach nourishment in conjunction with detached breakwaters or artificial headlands cannot be emphasized too strongly.

Item *f*, the revetment along the road to Launch Area 0B, has been constructed. M&N (1998) recommended that the revetment "will function most effectively with a fronting beach." This was sound advice. Protective fill that is regularly maintained will be the key to long-term stability of any structure along the Atlantic shore of Wallops Island. There is no information on the revetment's design or construction. The stone size is smaller than the stone in the seawall. The revetment appears to be protecting Pad 0B now because during the ERDC site visit in March 2006, the manager of the MARS facility said the pad had not flooded recently. However, the beach south of the NASA seawall is eroding, and eventually waves will break directly on the revetment. Its performance as a wave break structure cannot be predicted.

1999 ERDC and U.S. Army Engineer District, Norfolk, site visit

On 7 September 1999 (shortly after Hurricane/Tropical Storm Dennis caused minor flooding on Wallops Island), personnel from ERDC and the Norfolk District met with NASA to investigate the site and plan a shore protection program. ERDC prepared a trip report with recommendations for future studies. Already in 1999, the seawall was exposed directly to waves, and the ERDC representatives noted that swash was easily penetrating the seawall in the areas where the older wood wall no longer existed and the runup was on the sand behind the structure. Dune material was lost to the nearshore through the seawall when overtopping and transmitted waves drained seaward through the structure. ERDC recommended an emergency response plan. One of the elements was that the dune on the landward side of the seawall should be repaired and widened. ERDC's other findings were similar to Moffatt & Nichol's, emphasizing the vulnerable status of the rock seawall, the erosion to the south, the need for a thorough coastal processes study, and the need for a comprehensive shore protection program based on beach fill and structures in certain areas.

4 Recommendations for Additional Data Collection or Studies

If a comprehensive shore protection program is initiated at Wallops Island, one of the first steps will be to reevaluate geomorphic and physical conditions at the site using data that has become available since M&N (1986) conducted the previous detailed site study. This work would help guide the detailed designs and cost comparisons during the pre-construction engineering studies. The following should be collected to help characterize the geomorphology and physical processes that have contributed to the continuing beach erosion:

a. *Bathymetric data at the seaward base of the seawall.* During the test placement of sand, the Norfolk District collected offshore profiles by boat, but NASA was unable to collect the wading-depth profiles at the same times. Profiling at regular intervals is needed to determine if the shoreface in front of the seawall is deepening over time.

b. *Contemporary shoreline.* A recent shoreline needs to be mapped to serve as a basis for a monitoring program. The shoreline can be interpreted from aerial photographs or mapped by topographers on the ground.

c. *Directional wave data.* If a construction project is authorized, directional data from intermediate depth water would be a valuable resource for planning, and should be part of the monitoring plan if funds permit. In the absence of in situ data, the Atlantic WIS hindcast statistics can be adapted to the nearshore off Wallops.

d. *Geotechnical conditions.* Offshore geotechnical data is needed to determine if detached or T-head breakwaters can be placed on the seafloor without settlement into peat or marsh deposits.

e. *Sand sources.* Suitable sand or coarser material needs to be found for an initial beach fill. This might consist of geophysical surveys and shallow coring. Some data may already be available from the Maryland Geological Survey and the MMS.

f. *Water elevations*. Establish a tide gauge to measure storm surges. These data will be needed to refine the storm tide frequency curve for future planning and construction. In addition, water levels can be derived from an Advanced Circulation (ADCIRC) numerical model grid recently-developed at ERDC for another project.

g. *Numerical simulation to examine alternatives and optimize design*.

h. *Environmental Impact Statement (EIS)*. NASA already has a significant amount of environmental and archaeological information for the site, which will help during the EIS and permitting process.

5 Shore Protection Scenarios

Overview

Shore protection scenarios can be divided into four levels:

a. No project (allow natural process to continue with no intervention).
b. No new project but continue minor maintenance to existing seawall.
c. Project with restricted initial construction budget (primarily beach fill).
d. Optimum project (sand-retention structures combined with beach fill).

No project

Over $800 million in NASA, the U.S. Navy, and MARS equipment, buildings, and infrastructure will be vulnerable to storm waves and undermining if natural processes are allowed to proceed without intervention. Because of the importance of Wallops Island and its facilities to the missions of NASA, the U.S. Navy, and the MARS consortium, the no-project alternative is not acceptable.

During storms, even if structures are not directly damaged, the Navy's training may be interrupted and NASA or MARS launches may have to be postponed. All field evidence and the numerical modeling conducted by M&N (1992) indicates that if no seawall maintenance or beach fill is conducted along the Atlantic shoreline of Wallops Island, several trends are likely to continue.

a. *Seawall damage*. Currently, the seawall is the last line of protection for much of the infrastructure at Wallops Island. This structure will continue to degrade as waves undermine the toe and the water depth along the toe increases. Rock from the seaward slope will slump, in turn causing rock higher on the structure to slump or tumble down the slope (Figure 13).

b. *Loss of sand*. During storms, waves will continue to break directly on the seawall, and water will penetrate to the beach behind the wall via overtopping and percolation (Figure 14). More of the beach behind the seawall will drop in elevation as sand is washed out to sea (Figures 20 and 21). Currently, even in the northern part of the island adjacent to the U.S. Navy's Aegis training facility, broad areas of the beach right behind the rocks are no higher than mid-tide level, and standing water remains in low pockets. Without some field monitoring, it is difficult to predict how rapidly this sand will be lost, but it is of concern because natural processes do not replace the sand. In effect, the seawall behaves as a one-way valve allowing sand to leave the island but not return.

c. Beach erosion. The beach south of the southern end of the seawall will continue to erode. This will eventually threaten the revetment in front of Site 0B and will jeopardize the UAV runway (Figure 22).

Figure 20. Back side of seawall south of U.S. Navy Aegis facility (Building V10/V20), 18 April 2006. Shell fragments and seaweed debris show approximate limit of wave uprush. View looking south.

Figure 21. View north from U.S. Navy Aegis facility (Building V10/V20) toward Building V-24, 18 April 2006. Sand has been lost through seawall, and lowest areas contain standing water even on a calm day.

Without a recent georeferenced aerial photograph or field survey, it is difficult to determine the position of the current Wallops Island shoreline south of the seawall. To estimate the position, we plotted the 1994 shoreline based on the wet-dry line. This was approximate because at the scale of this USGS photograph, a debris line showing the limit of the last high tide was not visible. Then, based on a shoreline retreat rate of 2.5 m/year, an approximate shoreline 25 m further inland was drawn and it was assumed this was the 2005 position. To project the position of the shoreline in 5 and 10 years, parallel lines were drawn at 12.5 m and 25 m further inland (Figure 22). Considering the lack of sediment in the system now that the beach has disappeared from most of the seawall area, the retreat rate in the southern zone might be greater than 2.5 m/year. The 2015 shore encroaches on the area where NASA wants to expand the UAV runway.

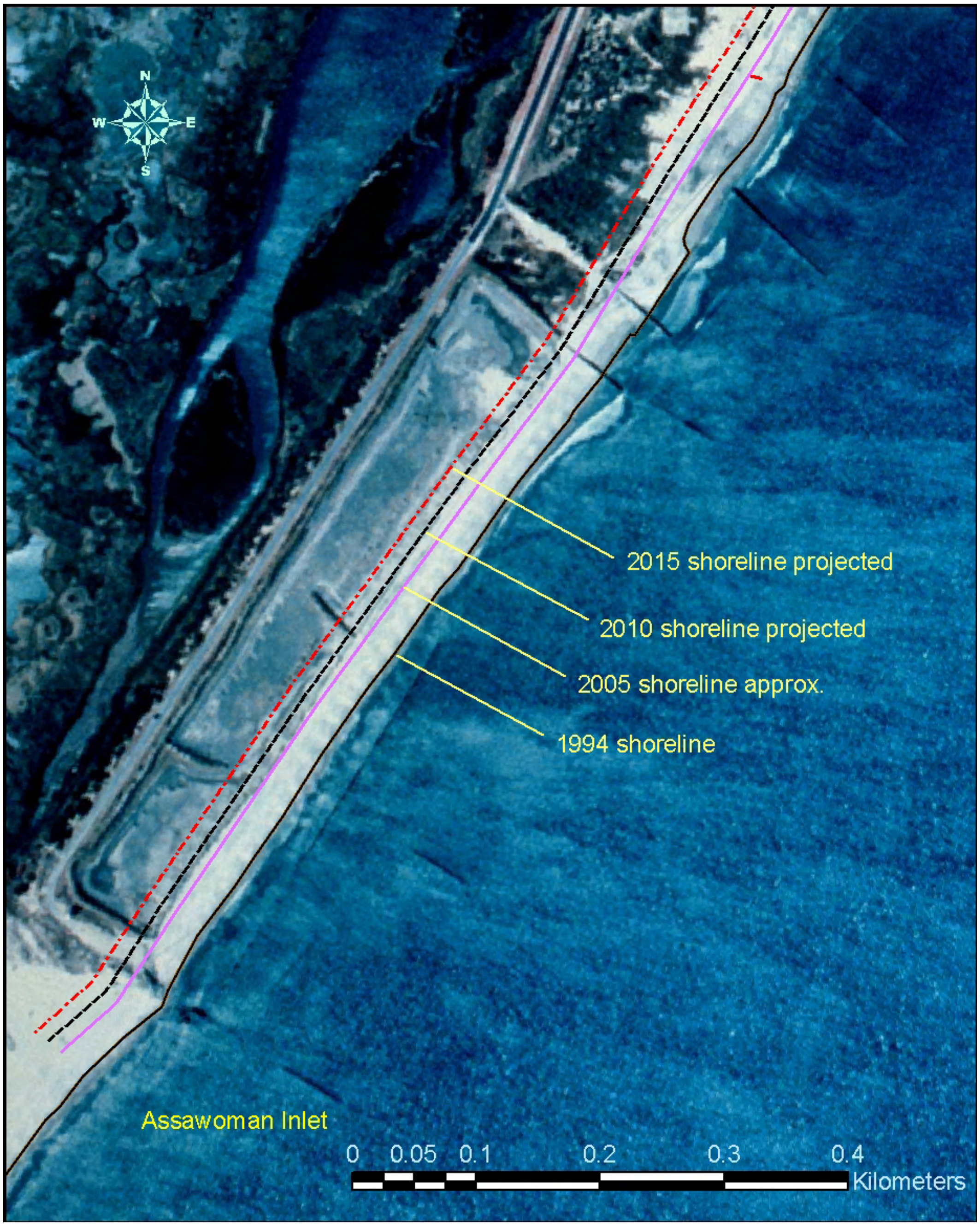

Figure 22. Projected shorelines at south end of Wallops Island for 2010 and 2015 based on a retreat rate of ~2.5 m/year. 2005 shoreline is approximate. 1994 shoreline based on wet-dry line (photograph 20 March 1994).

No new project but continue maintenance to existing structures

This is a variation of the no-project option discussed earlier. This option will not address any of the fundamental problems previously discussed (lack of sediment in the system, erosion of greater then 2.5 m/year south of the seawall, flooding during storms from wave overtopping and penetration through the seawall, etc.). This approach has the following disadvantages:

a. NASA will continue to face emergency repairs on an irregular and unpredictable schedule, as illustrated by recent sand loss from the foundation of camera sta Z-35 (Figure 23).
b. Costs and locations of emergency repairs will be difficult to predict.
c. Operations at the MARS launch pad or the U.S. Navy training facilities may be disrupted during severe storms as a result of wave overtopping and flooding.
d. The MARS facility in the south will be in increasing danger as the shoreline continues to retreat. The stone revetment is not designed to withstand storm waves.

Even rebuilding the dune that is currently behind part of the seawall will not be a fundamental solution. It represents the next step in a multi-decade pattern of retreat in the face of the ocean, starting with the natural beach, groins, wood seawall, and now stone seawall.

Figure 23. Sand loss at base of camera sta Z-35, 18 April 2006. To prevent foundation damage, NASA will install sheet pile and backfill, ocean is only 7 m to right beyond seawall.

Shore protection project with restricted initial construction budget: beach fill

Overview

The scope and intent of this plan is to protect Wallops Island from ongoing beach erosion and storm wave damage incurred during normal coastal storms and northeasters. To retard further erosion and protect the facilities on the island from storm waves, 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 during major hurricanes and exceptional northeasters, when water levels can rise several meters. The plan can be phased over several years depending on the budget.

a. *Year 1.* Allocate resources for engineering design and contracting process. Begin monitoring program, conduct sand search, design project, obtain environmental permits, and coordinate meetings with all participants and agencies who need to be engaged. Cost: ≈ $1 million. A breakdown of estimated costs for this phase is shown in Appendix C. (Note: Permitting, surveys, and environmental assessments may require more than 1 year to complete.)

b. *Year 2.* Construct beach fill from Assawoman Inlet to about half of the length of Wallops Island (≈ 3,400 m). Include dune construction over seawall and vegetation planting (Figure 24). Continue monitoring program. Cost: $7 million. (Note: If funds are available, the entire fill can be completed in one year with some savings in mobilization/ demobilization expenses. Cost: $14 million).

c. *Year 3.* Continue another 3,400 m beach fill to the northern end of the NASA seawall (to the zone where the shoreline curves east toward Chincoteague Inlet). Include dune construction over seawall and vegetation. Continue monitoring. Cost $7 million.

d. *Years 4+.* Continue monitoring, and adjust programs as needed to adapt to conditions. Renourish beach if needed to maintain template. Cost: ≈ $0.5-1 million. If funds are available, initiate building sand retention structures at erosion hot spots.

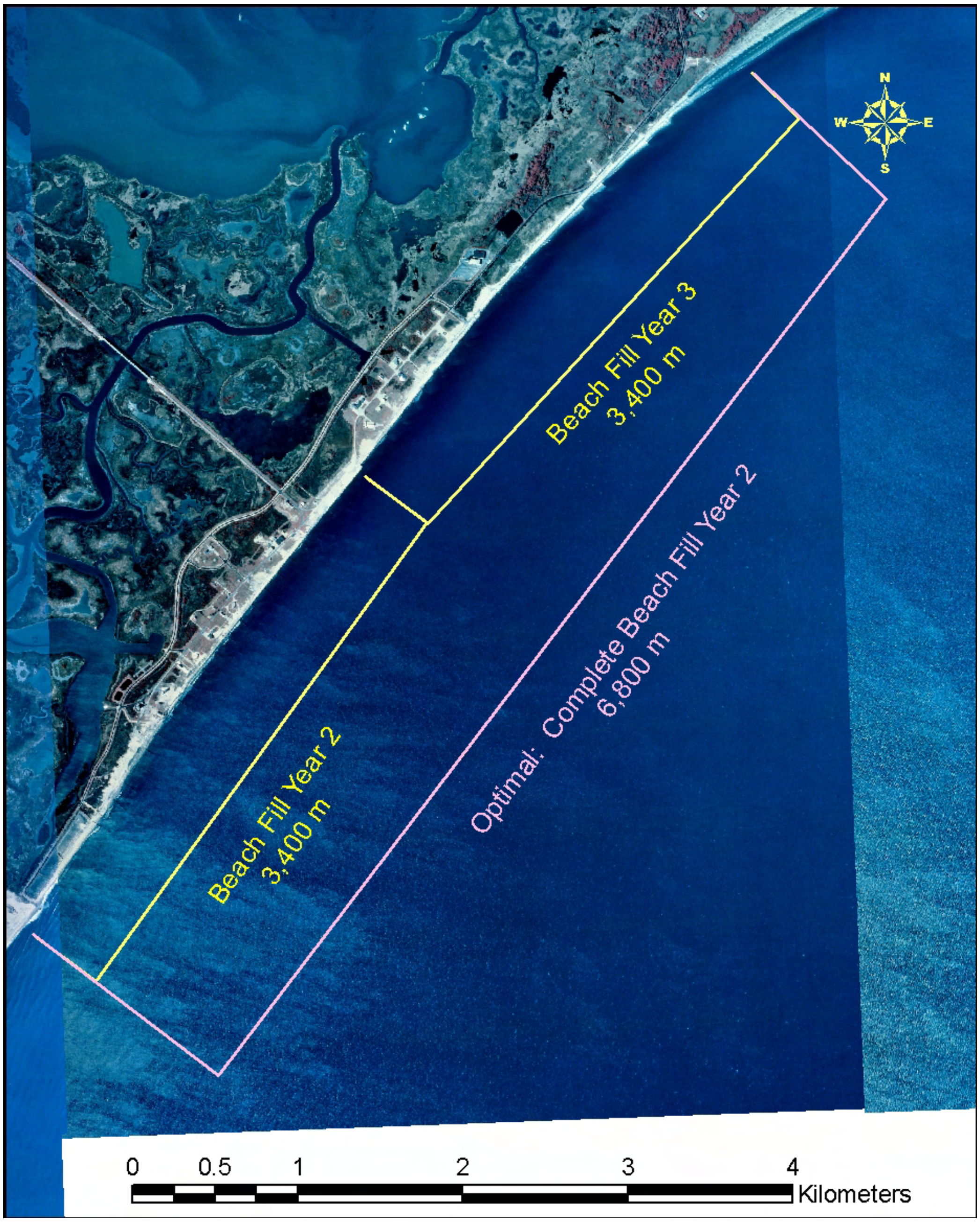

Figure 24. Recommended beach-fill areas. Completing fill in 1 year will reduce mobilization and demobilization costs.

Beach fill advantages

Benefits

Beach fill is a preferred solution to barrier island retreat for many reasons:

a. Sand responds to storms in a flexible manner (i.e., in storms, sand moves offshore, forming bars. Then, during the recovery phase, the bars move onshore, allowing the beach to widen and dunes to reform.).

b. A sand beach helps dissipate wave energy and dunes reduce inundation from storms.

c. Sandy beaches are habitat for many species of birds, plants, and sea life.

d. Repair to erosion areas is relatively simple: place more sand.

e. Erosion of a portion of a fill usually does not lead to the catastrophic failure of the entire project.

f. A project can accommodate rising sea level by increasing the height of the fill over time.

g. Regulatory agencies and environmental agencies usually respond favorably to beach fills on open ocean coasts.

At Wallops Island, a fill would have other benefits:

a. By moving the zone of wave breaking away from the current seawall, it will help prevent overtopping and inland flooding. Therefore, it will prevent the further loss of sand from the back side of the seawall.

b. The fill will help reinitiate the natural movement of sediment in the system, letting sand move south to Assawoman Island.

c. A fill project would serve a dual purpose of both protection and environmental restoration and as such could generate favorable public relations.

Beach fill is increasingly being used in the United States and internationally for many of the reasons listed. Morang and Chesnutt (2003) discussed the gradual shift during the twentieth century from hard structures to soft protection in the United States, and Houston (1995; 1996; 2002) documented the overwhelming benefit to the economy provided by beach restoration. Fill is being used in Australia, Belgium, Denmark, Germany, Spain, and the Netherlands in preference to fixed hard structures (Houston 2000). On the Black Sea coast of Georgia, beach fill proved to be more cost effective in initial costs and in long-term maintenance than concrete structures, and encouraged recreation use, which has been beneficial to the economy (Zenkovich and Schwartz 1988).

Along with the economic benefits, sand fills are much more environmentally natural than hard structures such as seawalls.

Protection provided by nourished versus unnourished beaches

It is difficult to quantify the value of property and infrastructure protected by a beach fill versus the property damaged if the fill were not in place. Hillyer et al. (2000) examined the effects of Hurricane Fran on six North Carolina beaches with and without shore protection.[1] The authors concluded that unprotected communities (i.e., without nourished beaches) on Topsail Island and Kure Beach sustained a greater percent of damages than the protected areas of Wrightsville Beach and Carolina Beach. The damage:value ratio for Carolina Beach was 11 percent and Wrightsville Beach was 13 percent, while the unprotected communities sustained damages of 19-33 percent. An important finding for Wrightsville Beach was that “even though the dune was eroded and generally overtopped, none of the ocean front development received any substantial damage due to wave impacts or storm surge. This lack of wave- or surge-related damage was attributed to the width of the beach above NGVD that existed prior to the storm.” The authors concluded, “Beach nourishment projects similar to the ones at Carolina Beach, Wrightsville Beach, and now at Kure Beach do reduce hurricane storm damages, which, in turn, reduce Federal disaster recovery costs.” Rogers (2000) also concluded that not one building behind the project dune was destroyed by Fran’s waves or erosion. This is an important lesson for Wallops Island: protection will be gained by having a wide beach and substantial dune so that wave breaking, even during hurricanes, occurs far from the NASA, Navy, and MARS infrastructure.

Following Hurricanes Charley, Frances, Ivan, and Jeanne, which struck Florida in 2004, Congress passed the Emergency Hurricane Supplemental Appropriations Act of 2005 (Public Law 108-324) to cover the cost of investigations and repairs to Federal Hurricane and Storm Protection Projects (HSPP) along the Florida coast. Seventeen projects lost 7,600,000 cu yd from the four hurricanes, but are credited with having prevented an average of $54 million in damage annually since the projects

[1] Available online: http://www.water-resources.us/inside/products/pub/iwrreports/00-R-61.pdf (accessed 8 June 2006).

were built.[1] In the areas protected by HSPPs, little or no damage occurred to upland structures from wave damage or beach erosion.

Clark and LaGrone (2006) examined property damaged by hurricanes in Florida Panhandle counties. They documented that in Bay County, Hurricanes Ivan (2004) and Dennis (2005) inflicted only a small fraction of the coastal construction damage that had previously been so severe during Hurricane Opal (1995), even though storm tide conditions were essentially the same. The main factor was the presence of the Panama City beach restoration project, completed in 1999. This study examined the number of structures with major damage but did not assess property values or damages.

Dam Neck, VA, nourishment project

In the early-1990s, the U.S. Navy faced a serious erosion problem at their Fleet Combat Training Center at Dam Neck, VA, where $100 million in buildings and facilities were at risk of flooding and wave damage. The optimum solution included a beach fill as well as an innovative sand dune with a 50-ft-wide crest, 1:2 side slopes, and an innovative buried rubble-mound rock core. Economic analysis showed that soft protection was cheaper than a hard seawall over a 25-year cycle: $1,820/ft for the soft solution versus about $2,350 for a Core-Loc™ armor unit seawall on an annual, life-cycle cost basis (Basco and Shin 1996).

The project was built in 1996, and the first maintenance renourishment was planned for 2003, when Hurricane Isabel moved north along the Atlantic Coast (Basco 1998). Isabel, the only category 5 hurricane of the 2003 Atlantic hurricane season, made landfall on 18 September 2003 just south of Cape Hatteras, NC. Storm surges of 1.0-1.5 m above normal tide levels were observed over the central portions of the Chesapeake Bay and 1.5-1.8 m over the southern portion of the bay near Hampton Roads, VA.[2] Storm waves displaced so much sand from the dune at Dam Neck, that the rock core was exposed. However, beach profile surveys showed that sand was not lost from the system but rather had been redistributed over the

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[1] Schmidt, D. V., and McMillen, R. 2005. U.S. Army Corps of Engineers Response to the Hurricanes of 2004, 2005 National Conference on Beach Preservation Technology, Florida Shore & Beach Preservation Technology (unpublished paper).

[2] National Hurricane Center data: http://www.nhc.noaa.gov/2003isabel.shtml (accessed 9 June 2006).

profile. Therefore, the renourishment plan was modified to rebuild the dune to the original project template. Work was completed in 2004.

Without the fill and dune project, about $18 million of damage could have been expected at the Fleet Combat Training Center based on the water level of the storm. Actual storm damage at the base was zero.[1] This successful project provides further demonstration of the benefits of soft shore protection and can serve as a template for Wallops Island.

Design considerations

Several factors have to be considered if a fill is added to Wallops Island:

a. Regular maintenance will be necessary. This will take the form of periodic renourishment to rebuild the beach profile to its design template.

b. A source of suitable material for the initial fill and the regular maintenance must be found. The source(s) must be close enough to the project and in shallow enough water to be economically usable. As of 2002, bid estimates for the Sandbridge, VA, hurricane protection project ranged from $4.50 to 6.60/cu yd for 1,500,000 cu yd. Costs at Wallops Island may be different depending on quantities and sand sources.

c. Because Wallops Island is not open to the public, NASA has options in the design of a fill that could help reduce cost:

- The color of the fill does not have to exactly match the color of the native material as at a bathing beach.
- The fill can contain shell or limestone fragments that would be objectionable on a public beach.
- The grain size of the fill can be slightly different than the native material. If finer grain is used, the fill will be more vulnerable to storm waves. But, placing more material during the initial construction (using a larger overfill ratio) can partially overcome this disadvantage. If the fill is coarser, it will result in a steeper beach than the native and one that may be more resistant to erosion.

[1] D. R. Basco, personal communication, 9 June 2006, Old Dominion University, Norfolk, VA.

d. The Wallops fill should be completed in 1 year for greatest efficiency, or at most over 2 years. Spreading the work out over more years will be unproductive because each subsequent year's project will need to renourish much of the previously-placed sections of beach. Length of a fill is one of the key parameters determining how long it will last. Because of end effects, a long fill loses much less of a percentage of its volume in a given time interval than a shorter fill. This is one reason that some of the larger projects, such as Miami Beach, FL, and Ocean Township, NJ, have performed well, requiring less renourishment than anticipated except at a few hot spots. At Wallops Island, a rectangle-shaped fill's half-life ($t_{50\%}$, time for the fill to lose 50 percent of its volume) is 8.7 years for the full 6,800-m fill, 2.17 years for 3,400 m, and only 0.54 years for 1,700 m. In other words, a fill covering only a quarter of the Wallops area will likely lose half of its volume in about 6 months. Appendix D outlines the procedure used to compute the $t_{50\%}$ values.

Table 3 is a comparison of several beach width and berm height options for Wallops Island. For these calculations, the length of the fill area was assumed to be 6,800 m (22,500 ft) (Figure 24). In addition, the active depth of the shoreface was assumed to be –8.5 m (–28 ft) NAVD. The calculations were based on fill design for Sandbridge, VA. Note that the last column, plotted in Figure 25), shows that increasing the height of the berm (5.95, 6.95, or 7.95 ft NAVD) has only a minor effect on overall cost compared to changing the width of the dry beach. If the fill will be placed over 2 years, then extra mobilization and demobilization costs must be added to the table and the plot.

As part of the fill, the rock seawall should be buried to form a rock-core dune (Figure 26). The dune should be artificially vegetated with grass immediately to reduce aeolian transport. An option to consider is to attempt to fill some of the voids in the rock seawall with gravel or grout before it is covered with sand. This would help reduce porosity in the event that a major storm washed away part of the overlying dune. At this time, cost of this option is unknown. Major rebuilding of the seawall should not be necessary if a beach fill is to be placed along Wallops Island, and any major changes or rebuilding could add significant cost (these have not been included in the estimates).

Removal of remaining groins, concrete foundations, and other debris from the nearshore may be necessary before sand placement.

Table 3. Wallops Island estimated beach-fill costs.

Width (ft)	Elevation (ft NAVD)	Volume/Length (cu yd/ft)	Length (ft)	Overfill Ratio	Total Fill Volume (cu yd)	Assumed Cost/cy yd ($)	Fill cost ($)	Mobilization & Demob. ($)	Fill with Mobilization ($)
50	5.95	64.722	22,500	1.35	1,965,931	6	11,796,000	1,000,000	12,796,000
70	5.95	88.019	22,500	1.35	2,673,577	6	16,041,000	1,000,000	17,041,000
90	5.95	113.167	22,500	1.35	3,437,448	6	20,625,000	1,000,000	21,625,000
50	6.95	66.574	22,500	1.35	2,022,185	6	12,133,000	1,000,000	13,133,000
70	6.95	90.611	22,500	1.35	2,752,309	6	16,514,000	1,000,000	17,514,000
90	6.95	116.5	22,500	1.35	3,538,688	6	21,232,000	1,000,000	22,232,000
50	7.95	68.426	22,500	1.35	2,078,440	6	12,471,000	1,000,000	13,471,000
70	7.95	93.204	22,500	1.35	2,831,072	6	16,986,000	1,000,000	17,986,000
90	7.95	119.834	22,500	1.35	3,639,958	6	21,840,000	1,000,000	22,840,000

Notes:
English units used in this table because of compatibility with normal U.S. dredging practice.
Assume mobilization and demobilization = $1,000,000.
Depth of active shoreface (closure depth) = -28 ft NAVD.

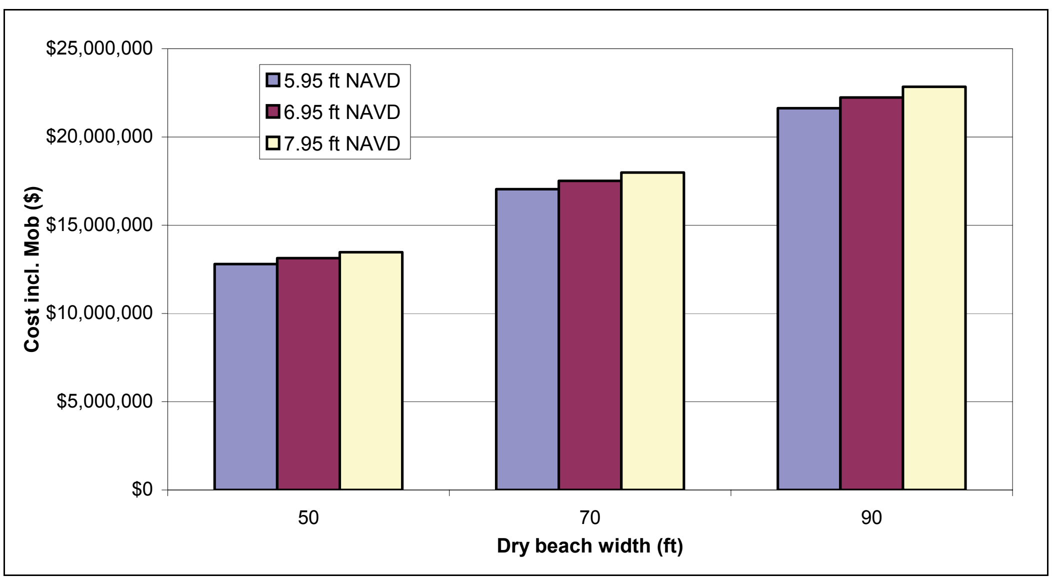

Figure 25. Assumed cost of beach fill at Wallops Island for various width and height beaches. Length of shore protected = 6,800 m (22,500 ft). Cost based on $6/cu yd and depth of closure = -8.5 m (-28 ft).

Figure 26. Construction of rock core dune at Dam Neck, VA (from Basco 2006)

Optimum shore protection plan: Sand-retention structures and beach fill

Overview

This section outlines the optimum shore protection plan. It includes sand-retention structures in the south and a beach fill along the entire Wallops Island. The immediate need for structures is in the 1,600-m unprotected zone south of the seawall. The net longshore transport is south along this zone. As stated earlier, the M&N (1986) sediment budget determined that Wallops Island loses over 150,000 cu m/year. The sand retention structures will help reduce the loss but will not stop it entirely. It is essential that structures do not deprive Assawoman Island of all longshore drift or it is likely to start eroding at greater than the twentieth century rate, thereby jeopardizing nesting habitat, and, eventually, the wetland. It is not known if more structures will be needed further north. This may have to be determined empirically or predicted via numerical modeling.

As with the sand-only plan, two factors must be anticipated and included in budgeting. First, regular beach nourishment will be required indefinitely. Timing will depend on the amount of fill placed each time and unanticipated factors like severe storms. Second, the topography and bathymetry of the beach must be monitored on a regular basis to determine sand movement patterns and plan when renourishment is needed.

The plan for shore protection can be phased depending on the budget.

a. *Year 1.* Allocate resources for engineering design and contracting process. Begin monitoring program, conduct sand search, design project, obtain environmental permits, and coordinate meetings with all participants and agencies that need to be engaged. Evaluate geotechnical conditions to determine potential settlement. Cost: ~$1 million. (Note: Permitting, surveys, and environmental assessments may require more than 1 year to complete.)

b. *Year 2.* Construct sand retention structures (detached offshore breakwaters, T-head groins, or combinations) along 1,600 m of unprotected shore at southern end of Wallops Island (Figure 27). Spacing and offshore siting of structures to be determined during engineering design. Continue monitoring program. Cost $10 million.[1]

c. *Year 3.* Build 6,800 m beach fill from Assawoman Inlet to northern end of the NASA seawall. Include constructing dune over seawall and planting vegetation. Continue monitoring. Cost $14 million (exact cost will depend on width and height of fill and source of sand).

d. *Years 4+.* Continue monitoring, and adjust programs as needed to adapt to conditions. Renourish beach if needed to maintain template. Cost $1 million +. If funds are available and if geologically necessary, build additional sand retention structures north of the first units.

Offshore breakwater options

Nearshore breakwaters are structures that reduce the amount of wave energy reaching a protected area. Some are shore-parallel structures sited a short distance offshore, whose purpose is to behave as natural bars, reefs, or nearshore islands that dissipate wave energy. The reduction in wave energy slows the littoral drift and therefore produces sediment deposition and a shoreline bulge or salient feature in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind these breakwaters (Basco 2006).

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[1] Cost based on Fort Story, VA, breakwater project.

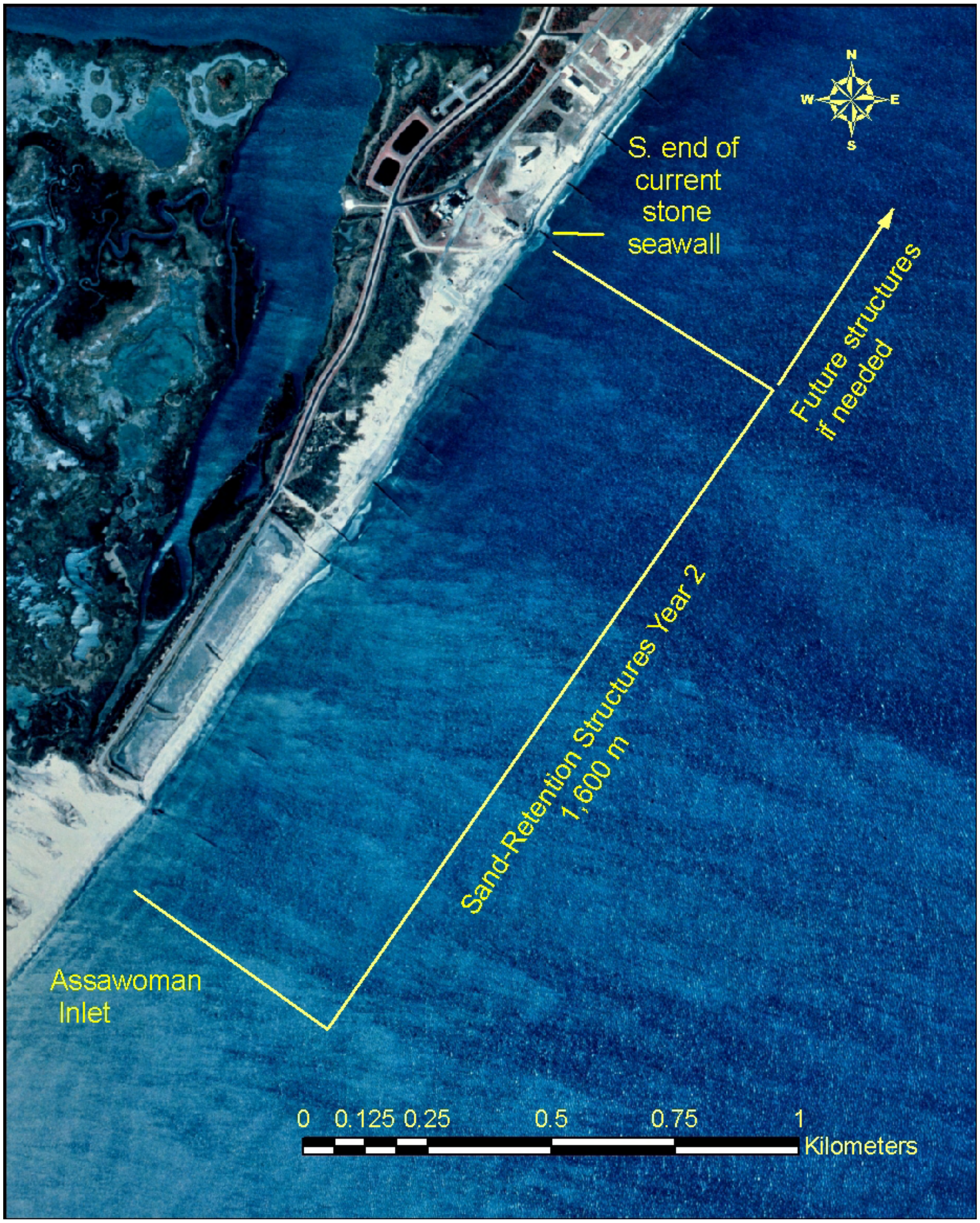

Figure 27. Approximate boundaries for placement of sand-retention structures in vulnerable area south of seawall. Exact locations to be determined during engineering design.

Figure 28 shows a salient behind a single breakwater and a multiple breakwater system with both salient and a tombolo when the shoreline is attached to the breakwater. The tombolo may occur naturally or be built during construction to produce a headland breakwater. The tombolo blocks normal, longshore sediment transport behind the structure. Daily tidal variations may expose a tombolo at low tide while only the salient is visible at high tide. One highly-successful example of detached breakwaters is Presque Isle, PA (Figure 29). A second successful example is Fort Story, VA, where the breakwaters were built from land, using land-based equipment (Figures 30 and 31). Breakwaters at Wallops Island will probably be similar to those at Fort Story because both sites have similar wave exposure. The specific design, spacing between units (width of the gap), and location offshore will have to be determined during the engineering design of the project. One option to consider is that possibly some stone from the existing seawall can be used in the offshore units if the size of individual armor stones is suitable.

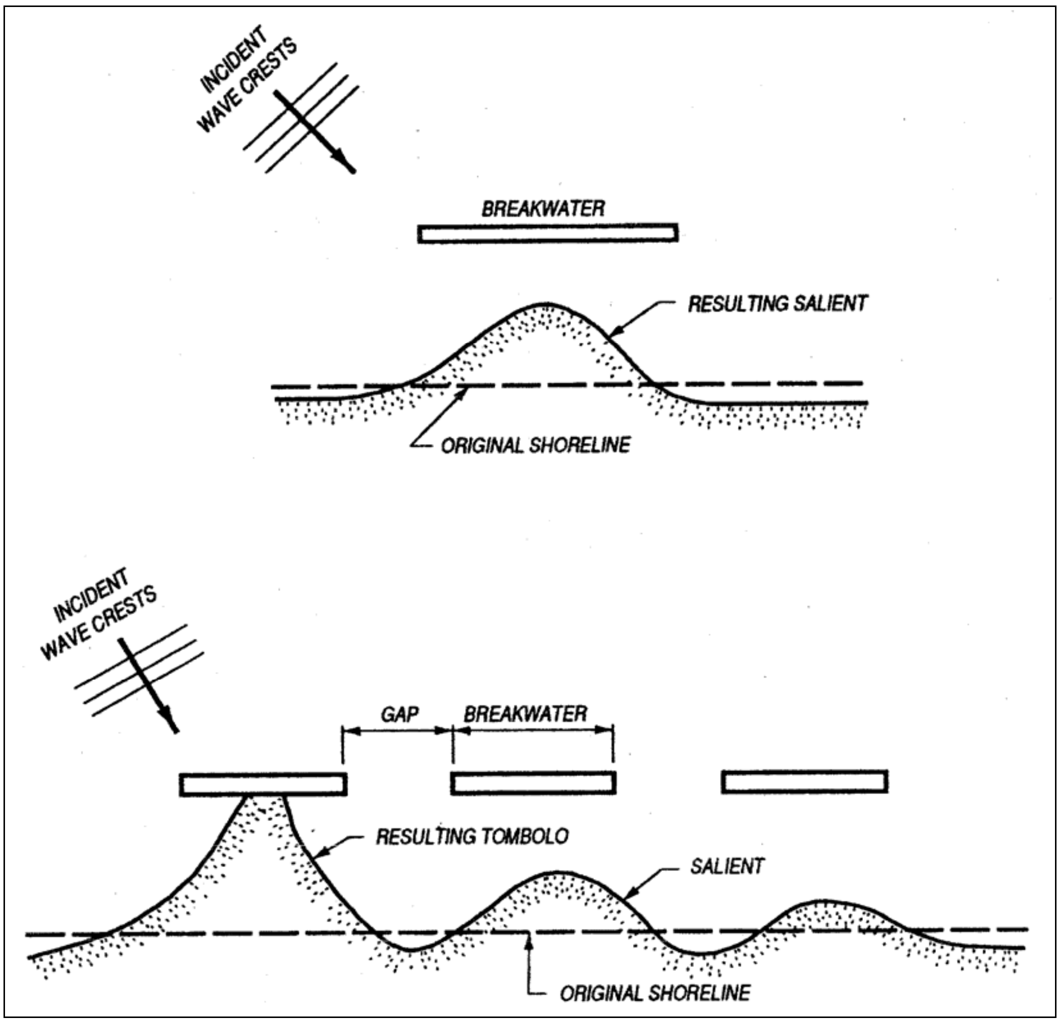

Figure 28. Shoreline changes associated with construction of single or multiple detached breakwaters (from Basco 2006).

Figure 29. Detached breakwaters at Presque Isle, PA, in Lake Erie (from Mohr 1994). Since this photograph was taken in 1994, many of tombolos have grown out almost to breakwaters.

Figure 30. Breakwaters at Fort Story, VA, 31 March 2005. These were designed as headland breakwaters and built from land.

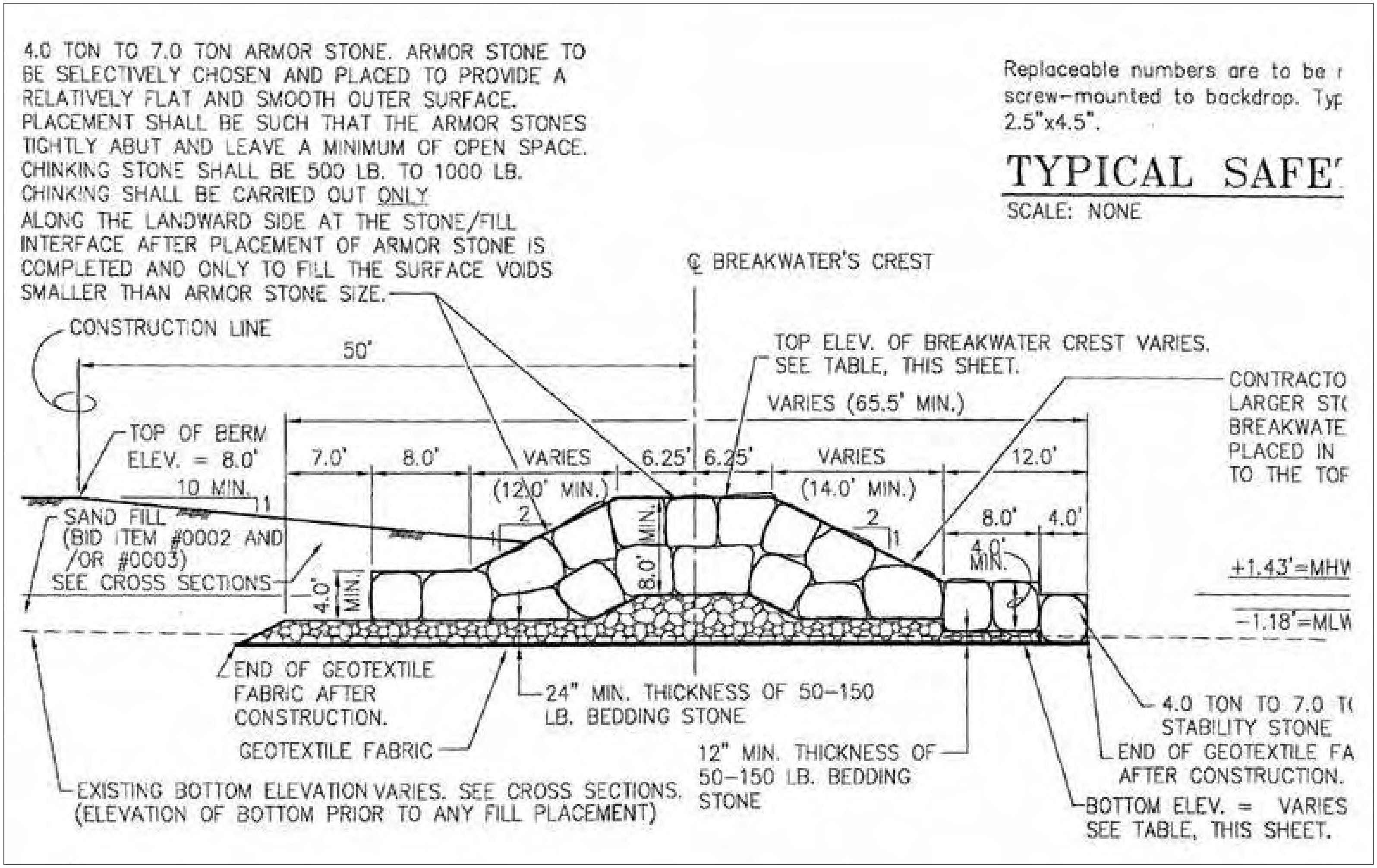

Figure 31. Typical cross section of detached breakwater used at Fort Story, VA. A similar design can be used at Wallops Island.

Multidecade strategy: fill, structures, elevate island

If NASA and the U.S. Navy plan to occupy Wallops Island for decades or centuries, eventually they will have to consider how to protect the island and its infrastructure from flooding. This is likely to become a more frequent and more severe problem as relative sea level rises.

The rate of sea-level rise in Lewes, DE, is 3.16 ± 0.16 mm/year (81 years of data) and 3.59 ± 0.27 mm/year in Kiptopeke, VA (49 years of data) (Zervas 2001). These values include both eustatic sea-level rise as well as regional relative sea-level rise due to isostatic and tectonic adjustments of the land surface. It is important to recognize that relative sea-level change data are based on historical records, and thus only portray sea-level trend during the era of trustworthy measurements (<150 years). The significance of sea level rise is not just that the still-water level itself is higher, but that the shoreline is translated horizontally across the shoreface, therefore moving the surf zone horizontally (and closer to man-made structures). It also plays a role in barrier island translation, a process that affected Assawoman, Metompkin, and Cedar Islands, as well as Wallops Island, until it was developed.

As shown in Figure 16, hurricanes in 1933 and 1936 produced water elevations of close to 2.4 m msl at Lewes, DE. There are no hurricane observations at Wallops Island, but the January 1992 northeaster produced water levels above 3 m (Appendix A). Flooding can occur from the ocean side and from the bay. At present, the bypass road with an elevation of ± 3 m (10 ft) protects the west side of the island, but the seawall on the Atlantic side is not a floodwall because it is so porous.

Four broad approaches to flood protection can be considered:

a. *Protect important structures by building dikes or levees around them*. This approach is used in many places in the Mississippi River Valley, where gas pumping stations and microwave transmission facilities have their own levees. The disadvantage of this approach is that although the facilities may be protected in a flood, they may be inaccessible for days or weeks after a major storm as water drains slowly off the island. Roadways have to be built up and over the levees, and levees need maintenance to ensure their integrity.

b. *Elevate the important structures and roadways.* Similar to the previous option, this lets the surrounding terrain be flooded occasionally. Also, although structures and launch pads may be safe, they may be inaccessible and unusable for days or weeks after a storm. Some of the NASA infrastructure is already at an elevation of 3.0 m NGVD. New construction should probably be higher.

c. *Elevate the entire island by pumping sand and raise the structures.* This approach attempts to counteract sea level rise by raising the land high enough to provide freeboard for a selected storm elevation or predicted future sea level. This approach was used in Galveston Island after the catastrophic 1900 hurricane, when the famous seawall was built and the island elevated with sand pumped from Galveston Bay (Larson 1999).

d. *Build a dike around the entire island to keep out the sea.* This is the approach used on some Dutch North Sea Islands and in parts of Louisiana. This leaves the existing infrastructure largely intact. The ultimate disadvantage, as demonstrated in New Orleans, LA after Hurricane Katrina, is that sometimes levees fail.

It is beyond the scope of this report to explore these options in more detail. But, long-term planning for Wallops Island needs to consider flood protection.

Alternative, innovative, or research approaches

During the ERDC site visit to the Wallops facility on 14 February 2006, NASA officials expressed interest in protecting the shore using innovative technology or experimental methods. Until the beginning of fiscal year 2006, ERDC was engaged in planning or monitoring a set of demonstration sites around the country. The Water Resources and Development Act of 1996 (WRDA 1996) authorized the National Shoreline Erosion Control Development and Demonstration Program (Section 227). The program was aimed at advancing the state-of-the-art in coastal shoreline protection. The program expired, and its status within WRDA is unknown. These demonstrations were of limited scope, designed to test a particular type of structure, construction technique, or quantity of sand fill, not protect a beach extending for kilometers.

NASA has already experimented with innovative structures. M&N (1989) monitored two proprietary structures designed to serve as sills to retain sand on the shoreface. These were the “Beach Prism,” a precast concrete triangular prism, and the "Beach Beam," a concrete triangular-shape open lattice. M&N concluded, "The Beach Beams and Beach Prisms have been only marginally successful. Therefore, their continued use to protect critically needed facilities at Wallops Island is not advised" (p. 57). ERDC's experience in monitoring other forms of experimental structures is that they are not a viable substitute for traditional shore protection methods.

Other structures, such as old railroad cars or ships filled with sand, will not survive long in the nearshore environment because of corrosion and wave action. The shape of old equipment is usually unsuitable to serve as breakwaters, anchoring can be very difficult, they are too rigid, they are aesthetically nasty, and pieces which break off become hazardous debris. At Fort Story, old hulls, which were sunk in the nearshore, did not stabilize the beach. Invariably, this debris has to be removed at considerable expense. Old ships are often sunk on the continental shelf to become artificial reefs, but they are in much deeper water than the active shoreface.

In summary, at Wallops Island, there are no innovative or inexpensive approaches that can retard erosion and prevent retreat of the shoreface. This exposed Atlantic beach will have to be protected by well-proven technologies, either a beach fill or a series of carefully engineered stone or concrete coastal structures combined with fill.

One worthwhile innovative option might be to build sand dunes along the south section of the NASA property with various types of cores. The cores help stabilize the dunes when they are hit with storm waves and help prevent blowouts. After storms, the structures must be recovered with sand and revegetated. Among the options are:

a. Rock cores. Burying the existing seawall will create a rock core dune.

b. Semirigid containers filled with rock or sand.

c. Geotextile tubes filled with sand or grout.

d. Clay-core dune.

Regardless of shore protection alternative selected for Wallops Island, the project should be monitored regularly to assess when and what type of maintenance is needed. An Operations and Maintenance (O&M) plan will be prepared as part of the engineering design.

6 Sources of Sediment and Construction Stone

As shown in Table 3, the initial Wallops Island beach fill will require in the range of 1,500,000 to 2,700,000 cu m of sand, depending on which option is selected. The volume might be even greater if the fill includes a proportion of silts and clays and a higher overfill ration is used. If the project is approved, a sand search will be necessary during Year 1 in conjunction with the engineering design. Sand is likely to be available at:

a. Chincoteague Inlet ebb shoal (outer bar). This could be tapped by means of a deposition basin. M&N (1986) concluded that the annual sediment input to the inlet and shoal area is about 1,000,000 cu m/year. Although this value may change when a new sediment budget is computed, there appears to be a generous surplus of sand in the system. One challenge in using sand from a deposition basin would be transportation to Wallops Island across Chincoteague Inlet. The second challenge would be securing environmental permits. Assateague Island is a National Seashore, administered by the NPS. The NPS has experience with sediment bypassing and beach fill at Ocean City, MD, and could be a valuable partner during a Wallops project.

b. Offshore linear sand shoals (ridges). A seismic survey will be necessary to identify offshore sand sources. The disadvantage of the shoals is the dredging equipment will be exposed to Atlantic waves and swell and transport costs may be high. The greatest number of these ridges is found north of Fishing Spit, where the sediment grain size on the shoreface and inner continental shelf is slightly coarser than further south (McBride and Moslow 1991). One advantage of using sand from offshore sources is that it provides new material to the littoral system; it augments the sediment budget rather than shift sand from one region to another.

Mixtures of sand and fine-grained material may be available from:

a. Chincoteague Inlet navigation channel. Current dredging is in the range of 60,000 – 75,000 cu m/year, which potentially can be placed on the beach at Wallops Island. The channel is likely to be the lowest cost for transport compared to other sources.

b. Channels in Chincoteague Bay and between Wallops Island and the mainland. Channels in the bays are likely to contain mostly silts and clays, but some areas may contain sands. Again, the main disadvantage is transport cost.

7 Environmental Concerns

The sediment management alternatives proposed in this document would require permitting through the USACE for discharge of dredged material, the Virginia Marine Resources Commission for impacts to submerged lands, and local wetlands boards if applicable. A water quality certification would be required by the Virginia Department of Environmental Quality to ensure Virginia water quality standards are met. An Environmental Assessment would likely need to be prepared due to the overall scope of the proposed projects.

The placement of sand along the shoreline, in this area, typically raises environmental concern on two main levels with respect to migratory species. The first level is impacts caused by removal of the sand for shoreline nourishment. The second level is impacts during or after placement of the material. Hopper dredges are typically used in beach nourishment because of their ability to work in the open ocean and their ability to discharge material close to the project area. They remove material by vacuuming it through dragarms, which are pipes jointed to the sides of the vessel that discharge into a central hopper. Material is then pumped out by a connecting buoy and placed along the shoreline. During removal of the sand off the seafloor, migratory turtles can become entrained in the dredged material and subsequently killed when passing through the pumps. The turtles in this area are typically the loggerhead, Kemp's Ridley, green, and leather back sea turtles, all of which are protected by the Endangered Species Act. Several restrictions have been placed on the use of hopper dredges for sand mining for this reason. Typical restrictions include turtle excluder devices on the dragheads, National Marine Fisheries Service certified marine endangered species observers on board the dredge, and other operational measures to minimize turtle takes.

Ordnance, often dating back to World War II or earlier, is occasionally encountered offshore. This is filtered using screens on the dragarms. Occasionally, magnetometer surveys must be conducted to delineate the extent of the ordnance, which adds cost to the dredge program.

The placement of material along a shoreline can have environmental impacts, as well. The main concerns in this area are for migratory nesting birds – specifically Piping Plover and Least Tern. These birds prefer sandy beaches for nesting and are protected by the Endangered Species Act. There would obviously be a conflict between active bird nesting and the ability to place material along the shoreline simultaneously. This is less likely to be a restriction along most of Wallops Island because there is no longer a permanent dry beach in front of the seawall, but nesting species will have to be considered in the southern part of island beyond the end of the seawall. The U.S. Fish and Wildlife Service is responsible for delineating plover nesting locations at Wallops Island for NASA.

NASA has already completed a review of cultural resources and archaeological significant features for the island.

Similarly, a general review of hazardous or toxic materials should be performed to reveal any items that warrant cleanup or disposal prior to construction. NASA has completed an Archived Search Report (ASR) with USACE to search for historical sites from the 1942-1959 era. NASA will complete an ASR for later years during fiscal year 2006.

8 Options for Project Funding with Other Agencies

Several other organizations share space on Wallops Island and have invested significant funds in infrastructure and equipment. Therefore, it should be possible for NASA to partner with these agencies to help fund a comprehensive shore protection and sediment management program that would mutually benefit all users of the island.

The U.S. Navy has operated two training facilities on the barrier island for decades. Total Navy assets on the island are about $0.88 billion. It is currently building a training structure for the Navy's first shipboard phased array radar. The building will cost $16 million and will be outfitted with approximately $500 million worth of equipment. As stated in a Northrop Grumman press release:[1]

> "Northrop Grumman's Ship Systems sector will construct a SPY-3 land-based test center here, which will provide for the integration of research and development activities for the next-generation surface combatant. The test center will provide approximately 30,000 sq ft of space for radar, communications equipment, a full systems mission center, and a complete data analysis capability. The center will accommodate 45 staff members in the near future with infrastructure in place to handle more than 100 people."

The states of Virginia and Maryland now jointly operate the Mid-Atlantic Regional Spaceport (MARS), formerly known as the Virginia Space Flight Center. MARS has built a launch pad at the south end of the island (Pad 0B) in the vulnerable area immediately south of the rock seawall (Figure 32). During the ERDC site visit on 15 February 2006, MARS construction workers were pouring concrete and making modifications to the tower.

[1] http://www.engineeringmvp.com/news/northropgrumman10.shtml, (accessed 23 February 2006).

Figure 32. The MARS space flight facility (tower in upper right) is located just south of southernmost limit of seawall. Concrete rubble in surf zone is debris from former launch pads (photograph, 11 February 2005).

The U.S. Air Force has contracted with MARS, and NASA for commercial spaceport facilities and services to launch satellites and spacecraft for the Air Force and other government agencies.[1] It is not known if the Air Force has other options for launching the payloads now intended for the MARS facility, but the precarious situation of Pad 0B may be of concern.

[1] http://appel.nasa.gov/node/434, (accessed 21 August 2006).

9 Conclusions

The Wallops Island flight facility has suffered erosion since NASA assumed command of the site in the 1950s. The erosion has progressed to the stage that NASA, the U.S. Navy, and MARS property and equipment are vulnerable to damage and mission activities are in danger of being periodically interrupted. To protect the facilities and prevent further barrier island erosion and loss of elevation, Wallops Island will need a comprehensive shore protection program that should include:

a. Beach fill.

b. Structures to reduce the loss rate of the fill.

c. Regular maintenance (renourishment).

d. Regular monitoring of project performance.

This conclusion is based on an examination of historical shoreline changes, discussions with NASA representatives, inspection of the site, and an evaluation of reports prepared by M&N, who conducted a number of studies for NASA in the 1980s and 1990s. The scope of this plan is to protect against winter storms and northeasters and ongoing erosion of the island, not prevent inundation from hurricanes and extraordinary events or from multidecade sea level rise.

Experiments with innovative sand retention units during the 1980s were unsuccessful. The current stone seawall is becoming increasingly vulnerable as the toe is exposed to waves. M&N also concluded that any breakwaters or seawalls to be built on the Atlantic side of Wallops Island would have to be substantial engineered structures designed to survive the ocean environment.

M&N (1986) calculated a sediment budget for Wallops Island and the southern part of Assateague Island. They concluded that 1.3 million cu m/year moves south into the inlet cell, where it accumulates in shoals south of Fishing Point. Therefore, there is no lack of sand in this system; the challenge is how to move it across Chincoteague Inlet and onto the beach at Wallops Island.

This study examined erosion and geological problems at Wallops Island and developed conceptual designs and rough order of magnitude cost estimates. Specific details of the beach fill and sand-retention structures will need to be developed in a follow-up study when the project is approved and funded. Wallops Island can become a showpiece for coastal stewardship, environmental enhancement, and preservation of invaluable national science and engineering assets.

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Appendix A: January 1992 Water Elevations

Figure A1 shows elevations measured at various buildings after the January 1992 northeaster. Measurements are not available for the Ash Wednesday storm of 1962, in which levels may have exceeded the 1992 storm.

28 February 1992

To: Code 823.1/Head, Mechanical Systems Section

From: CSC, Mechanical Systems Section

Subject: January Storm Tide Elevations

This document records the maximum constant water levels achieved by the January storm of '92 at the Wallops Flight Facility (WFF). Wave action may have brought higher intermittent values. The water levels were determined by a combined examination of facility damage, water marks and debris trails within 48 hrs of the subsidence of the storm.

Location		Elevation above Mean Sea Level
Code 834.1 areas		
X-15	Water Level	10.33 Ft
	Floor	8.23 Ft
X-35	Water Level	10.69 Ft
	Floor	8.70 Ft
V-80	Water Level	6.97 Ft
	Floor	7.27 Ft
W-22	Water Level	10.01 Ft
	Floor	7.79 Ft
Blockhouse 2 (Y-30)	Water Level	10.83 Ft
	Floor	8.96 Ft
Blockhouse 3 (W-20)	Water Level	9.56 Ft
	Loading Dock Deck	9.56 Ft
Scout Assembly (W-65)	Water Level	9.84 Ft
	Floor Bay I	7.75 Ft
	Floor Bay VI	7.85 Ft
Code 833.3 areas		
Y-60	Water Level	9.84 Ft
	Floor	5.51 Ft
Y-55	Water Level	10.25 Ft
	North Stairwell Landing	6.81 Ft
	Floor	7.20 Ft
Transformer Pad (Y-56)		6.06 Ft
Spin Bay Facility	North Floor	9.31 Ft
	South Floor	9.23 Ft
Bayside Island Near Causeway		6.08 Ft
Naval Areas		
Z-41	Water Level	11.72 Ft
	Floor	8.52 Ft
V-10	Water Level	8.89 Ft

MF Natzet/CSC

cc:
RE Maddox/CSC
JA Scott/CSC

Figure A1. Storm tide elevation data sheet provided by NASA, 19 April 2006.

Appendix B: Sediment Budget

The following figures are reproduced from M&N (1986).

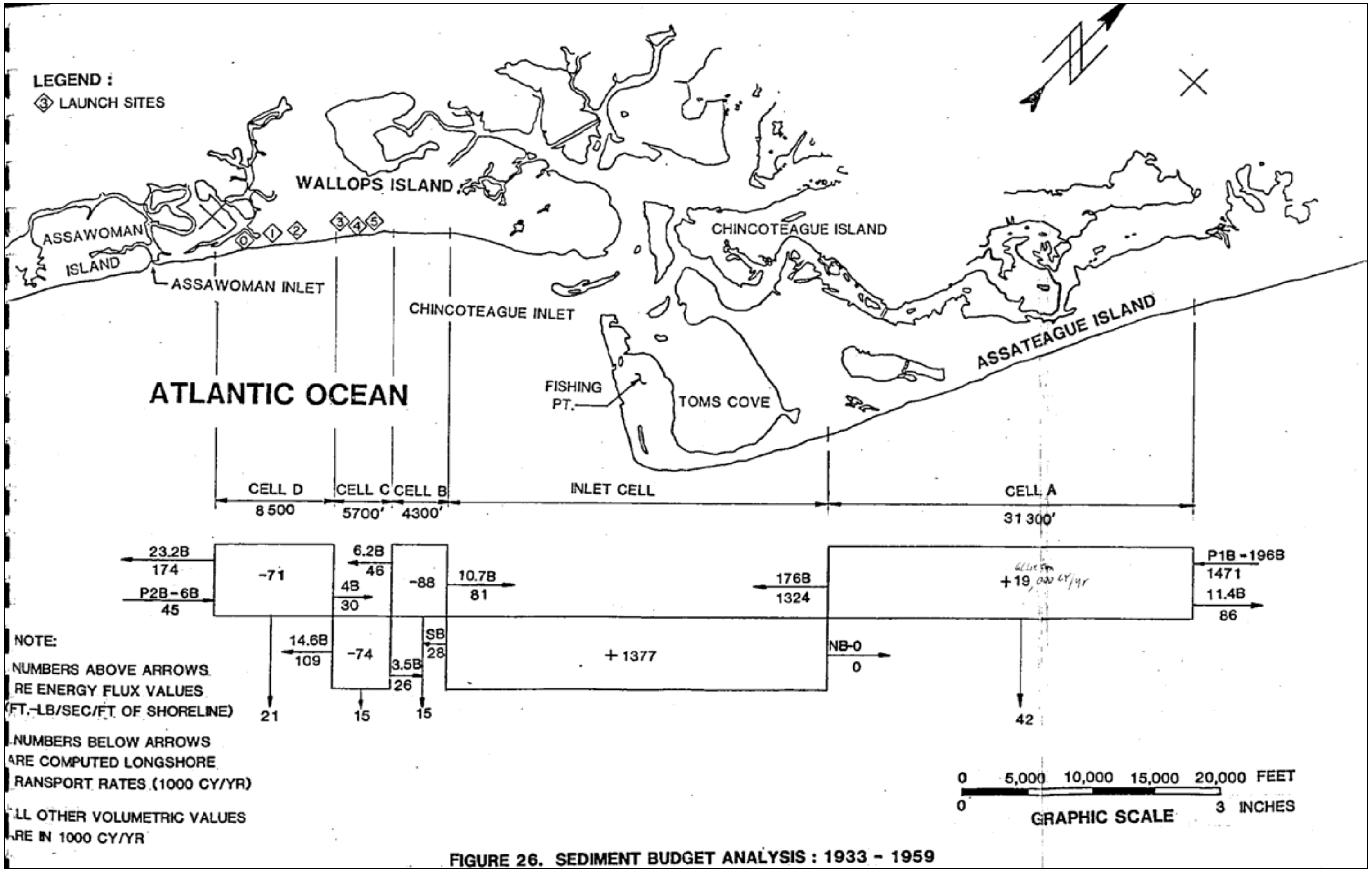


Figure B1. Sediment budget for 1933-1959, the era before shore protection structures. Note: units are in cubic yards per year, not metric.

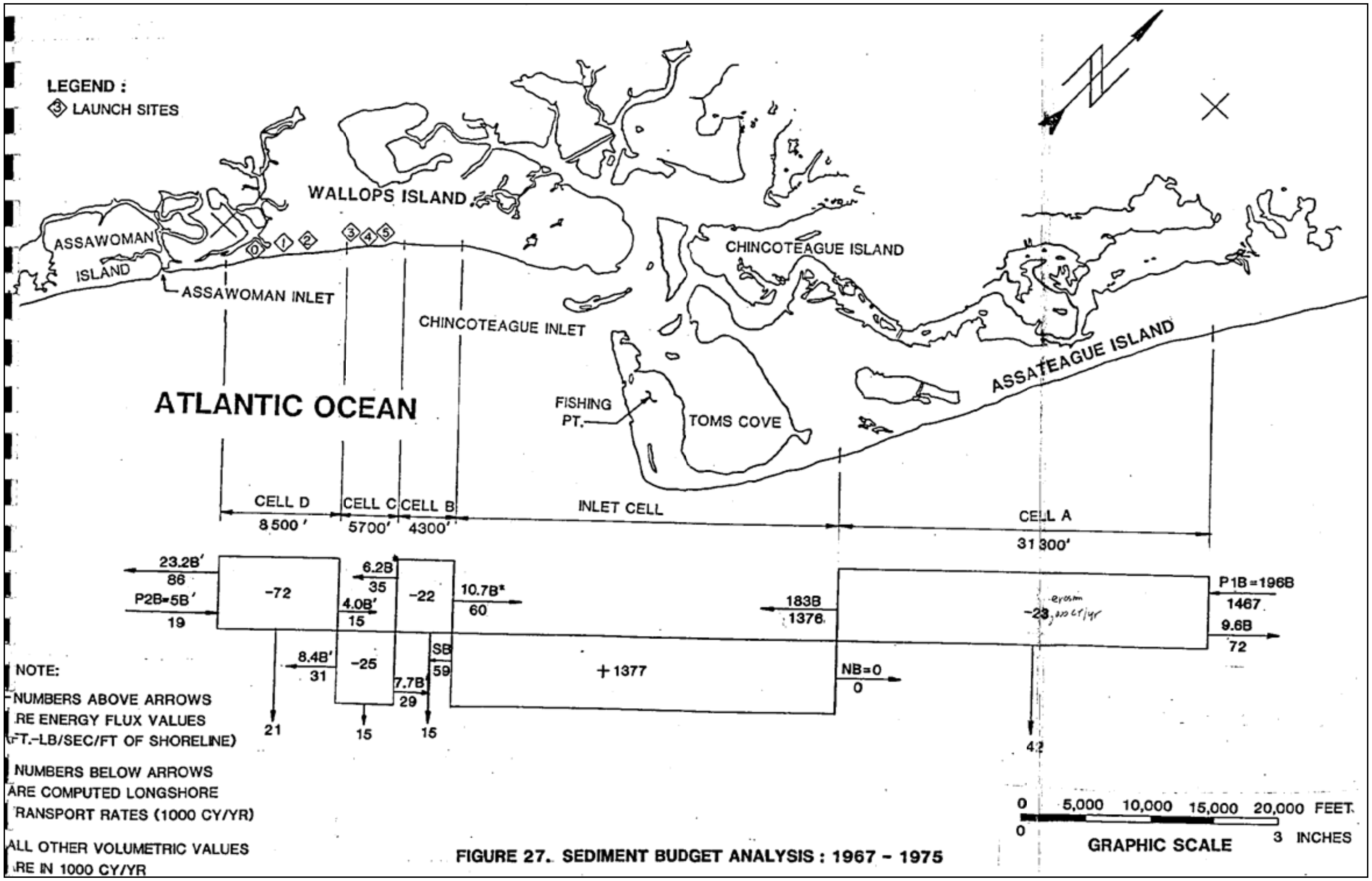


Figure B2. Sediment budget for 1967-1975, when groins were possibly helping retain some sediment on beach.

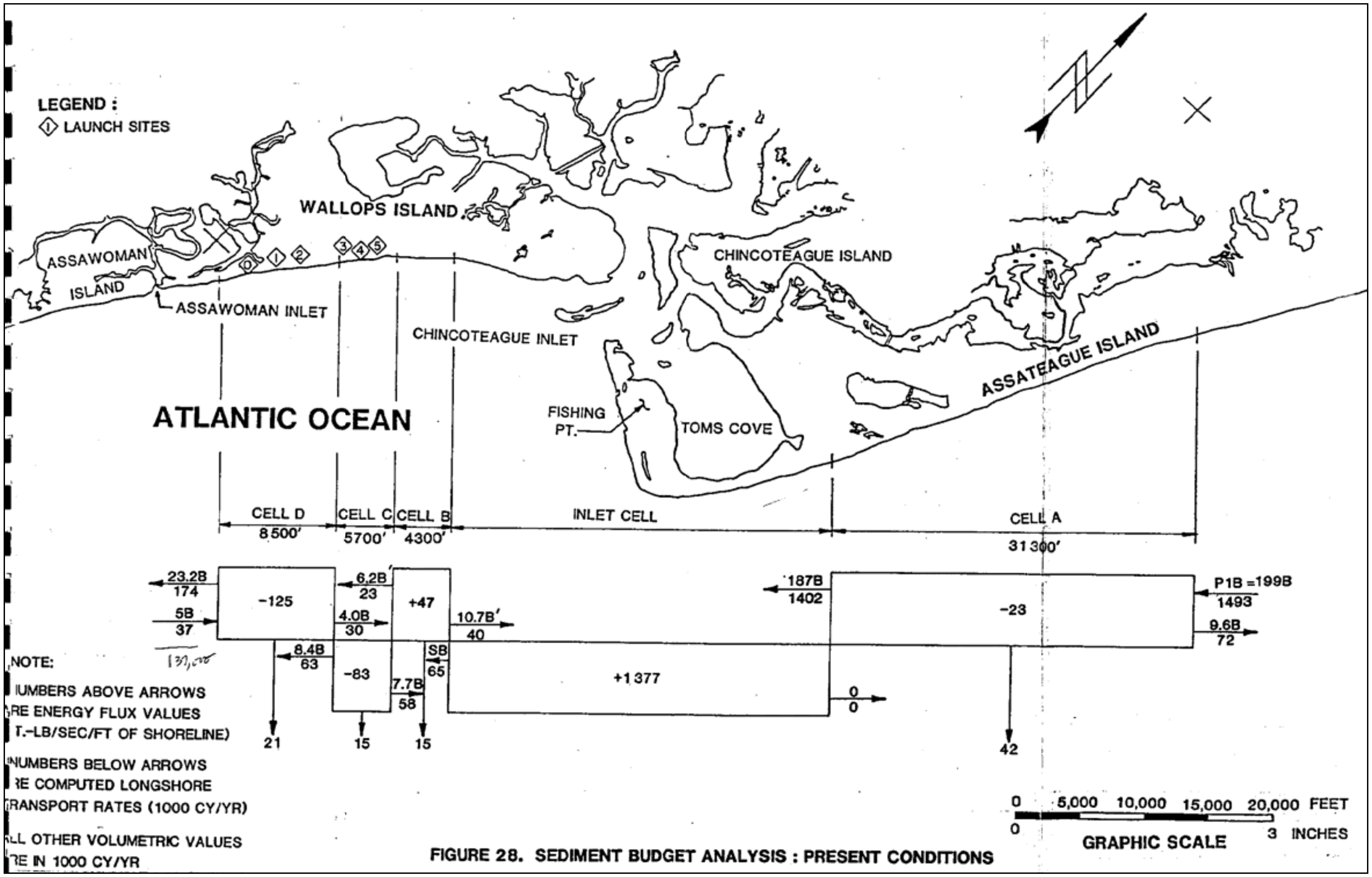


Figure B3. Sediment budget for mid-1980s, when groins were in disrepair but before stone seawall had been erected.

Appendix C: Cost Breakdown for Preconstruction, Engineering and Design

Table C1 lists estimated cost breakdown and work task description for preconstruction, engineering and design of the recommended project. Please note that these figures are subject to adjustment with more detailed investigation and planning. The costs also assume a single phase of design and would increase if single elements were to be designed and constructed versus the entire project.

Table C1. Estimated work task breakdown and costs.

Item No.	Work Task	Total Cost ($)
1	Public involvement documents	67,000
2	Social studies/report	37,000
3	Archaeological investigations contract	67,000
4	All other cultural resources studies/report	42,000
5	Environmental contract	37,000
6	All other environmental documents	77,000
7	Fish & wildlife coordination act report	37,000
8	Offshore borrow source contract	81,000
9	Hydrology and hydraulic analyses/report	157,000
10	Borrow source laboratory testing contract	41,000
11	Geotechnical analyses/report	62,000
12	Hazardous, toxic, and radiological wastes studies/report	41,000
13	Surveys and mapping	87,000
14	Engineering and design analysis / report	87,000
15	All other engineering documents	60,000
21	Interagency agreement	20,000
	Total	1,000,000
Note: Table updated 7/6/2006 by Greggory Williams, Norfolk District.		

Work Task Descriptions

1. Public Involvement Documents: This work task includes the preparation of public notices for study initiation and completion (including its findings), for the intent to prepare/file National Environmental Policy Act documentation, and for public meetings/workshops; the coordination with Federal, state, and local agencies; the response to inquiries from the general public and elected officials; and the preparation and follow-up required for meetings. Coordination with Federal, state, and local agencies will be initiated immediately and will be maintained throughout the study process. These efforts will be summarized as part of the Environmental Assessment (EA) or EIS, and they will be documented in the "Pertinent Correspondence" section of the supporting documentation.

2. Social Studies/Report: This work task includes the studies that are required to determine and assess the social impacts of the alternative plans under consideration. The existing population, housing, land use, employment, income, transportation, utilities, and other related items for the project area will be defined, and projections of these items will be prepared for the "Existing and Future Conditions" portion of the project report and summarized in the EA or EIS and the "Benefit Evaluation" section of the supporting documentation. In addition, this information will be used in assessing the social impacts of the project and in the EA or EIS.

3 & 4. Cultural Resources Studies/Report: This work task includes all tasks required for compliance with Section 106 of the National Historic Preservation Act of 1966. Specifically, an analysis of the historical and archaeological aspects of the study area and borrow area will be conducted. This will involve a literature search for the potential borrow area and a remote sensing survey of this borrow area to determine the possible existence of historical resources there. A review of the known resources associated with the land portion of the study area will be carried out. Coordination of the results of these reviews and studies with the Virginia Department of Historic Resources will take place as part of the efforts associated with this work task. A baseline description of the historical and archaeological aspects of the study area will be prepared for the "Existing and Future Conditions" portion of the project report and summarized in the EA or EIS. The impact of the various alternative plans on the historical and archaeological features in the study area and the

possible mitigation measures, if necessary, will also be assessed and summarized in the EA or EIS.

5 & 6. Environmental Studies/Report (Except for U.S. Fish and Wildlife): This work task includes managing all aspects of the mandatory USFWS contract, collecting environmental data including field evaluations, providing a baseline identification and description of environmental aspects of the project area, assessing of the impacts on these aspects resulting from the various alternative plans, developing mitigation and restoration measures as needed, preparing all appropriate National Environmental Policy Act and other environmental compliance action documents, coordinating a review of the documents, obtaining all necessary permits and certificates, and issuing the necessary public notices. The baseline description of the environmental aspects of the project area will be prepared for the "Existing and Future Conditions" portion of the project report. The impact of the various plans on the environmental features in the project area and the possible mitigation measures, if necessary, will also be assessed and summarized. The EA or EIS, although an independent document, will be physically included in the project report. The USFWS Coordination Act Report will be included as a separate section in the supporting documentation. A formal document, either an EA or EIS, will be required in compliance with the National Environmental Policy Act. This document, along with the feasibility report, will be coordinated for review and comment with all interested Federal, state, and local agencies. Work in waters and/or wetlands within the Commonwealth of Virginia are regulated through the acquisition of appropriate permits. In compliance with Federal, state, and local regulations, applicable permits should be applied for and obtained. These would include, but may not necessarily be limited to, the Virginia Marine Resources Commission permit, the Virginia Water Protection Permit, and the Local Wetlands Board Permit.

7. Fish and Wildlife Coordination Act Report: This work task includes the participation of the USFWS (as required by the Fish and Wildlife Coordination Act) in technical environmental investigations, such as a baseline description of the existing and future project conditions; an evaluation of potential impacts resulting from the various plans; identification of possible mitigation, restoration, and enhancement measures; and a Fish and Wildlife Coordination Act Report.

8, 9 & 10. Hydrology and Hydraulic Studies/Report: This work task includes accomplishing the following specific tasks: Determine the physical dimensions of the design berm and the construction berm, including height, width, foreshore slope, and closure depth for various renourishment cycles. Estimate of the volume of material required for the design berm and the construction berm, including overfill ratios and the losses due to the dredging process for various renourishment cycles. Estimate of the volume, suitability (grain size, quality, etc.) and location of borrow area(s). Conduct surface and subsurface investigations in the borrow areas. Estimate the shoreline erosion rate with and without project conditions. Estimate of the direction and volume of sediment transport for with and without project conditions. Provide the engineering and concept design of structures such as groins and breakwaters. Conduct numerical model investigations using the GENESIS shoreline change model or other appropriate models to determine the effects of coastal hydraulics on shoreline processes with and without project conditions. Provide hydrologic and hydraulic data regarding still-water inundation; wave setup, runup, and overtopping; direct wave attack; and undermining for various storm conditions with and without project conditions. Provide interior drainage schemes as appropriate. Recommend the best method for the construction of the project, including the coordination of construction schedule, costs, etc. Conceptualize the operation and maintenance plan, including the coordination of maintenance schedule, costs, etc. Prepare documentation, provide text and graphics for the report, and conduct coordination.

11. Geotechnical Studies/Report: This work task includes providing assumed soils parameters for foundations for hard structural plans, as required; providing laboratory sieve analyses of samples obtained from surface and subsurface investigations in the borrow area, as required; and identifying alternate borrow sources.

12. Hazardous, Toxic, and Radiological Wastes Studies/Report: This work task includes coordinating with others, conducting research, and identifying appropriate ordnance and explosive waste sweeping and screening methods for dredging and nourishment operations.

13. Surveys and Mapping: This work task includes all surveying, mapping, drafting, and digitizing that may be required. Specific tasks include conducting horizontal and vertical control verification surveys,

conducting hydrographic and topographic surveys in the borrow and construction areas.

14. Engineering and Design Analysis/Report: This work task includes evaluating the beach berm and detached breakwater designs; providing conceptual engineering and design of beach berm and detached breakwaters; preparing the technical supporting documentation; and conducting coordination.

15. All Other Engineering Documents: This work task includes providing the engineering and design for dredging operations necessary for the removal and deposition of beach-quality material on the project beach area and supporting other functions. Specific tasks include plans for sequencing, excavation, and the transition from the borrow site to the beach.

16. Cost Estimates: This work task includes providing conceptual cost estimates for the plans that include beach nourishment and detached breakwaters.

17. All Other Management Documents: This work task includes all activities related to the administration of the project by supervisory personnel and their staff. It includes all supervisory participation in public involvement, study management, coordination, contracting, plan formulation and evaluation, meetings/conferences/workshops, and review. It also includes all routine clerical support such as typing, records management, funds reporting, timekeeping, etc.

18. Draft/Final Report Documentation: This work task includes assembling, writing, editing, drafting, reproduction, reviewing, and distributing the EA or EIS, and other related documentation required for transmittal to authorities. Work will entail preparing a draft EA or EIS; soliciting comments from the team, and Federal, state, and local agencies; responding to those comments; and preparing a final EA or EIS.

19. Project Management Plan (PMP): This work task includes the preparation of the PMP by the Project Manager (PM) with the assistance of the team, incorporating the recommended plan baseline cost estimate; the PED (in the case of this project this refers to the plans and specifications) and project construction work tasks and schedules; and the operations and maintenance requirements.

20. Programs and Project Management Documents: This work task includes all activities related to the management of the project by the PM, such as organizing, managing, and leading the team, conducting further study of the area, developing detailed schedules, preparing correspondence, monitoring progress on work tasks, managing funds, preparing budgetary data, processing the schedule and cost change requests, preparing and reviewing the budget documents, and identifying problems and issues.

21. Interagency Agreement (IAG): This activity involves the preparation of the draft IAG by USACE and NASA. The appropriate members of USACE and NASA, including legal counsel, are given an opportunity to review and comment on the draft IAG. A final IAG is prepared based on this review and comment. This activity also consists of the signing of the final IAG by the District Engineer, USACE, and the designated contracting officer for NASA.

Appendix D: Effects of Beach Fill Length

The USACE's *Coastal Engineering Manual* covers beach-fill design in Part V-4 (Gravens et al. 2006). The effect of beach-fill length (the alongshore extent of the fill) on project longevity is examined in section V-4-1-*g*:

> "If two projects were exposed to the same wave climate but had different alongshore lengths, then the project with the greatest length would be predicted to last longer (with all other factors being the same). If more than 50 percent of the placed beach-fill volume remains within the placement area ($0.5<p(t)<1.0$), Equation III-2-32 can be approximated using the following relationship (with an accuracy of ±15 percent).
>
> $$p(t) = 1 - \frac{\sqrt{\varepsilon}\, t}{a\sqrt{\pi}}$$
>
> Example Problem V-4-7 illustrates the importance of project length on project longevity. In this example, a fill with twice the length will last four times as long. The effect of project length on fill longevity is critical for short fills. It is also important in long fills which may be built in stages. For example, construction may be limited to a particular season to avoid turtle nesting season or the tourist season. Therefore it may take 2 or 3 years to complete the work. Projects built in stages will temporarily perform as short fills until the other portions of the project are completed. Actual loss rates from the constructed subreaches will likely exceed losses predicted for the completed as designed project. Any short-term accelerated losses due to construction of the project in stages should be factored into the advance nourishment quantity."

The method used in Example V-4-7 was adapted for Wallops Island, with results shown in Computation Box D-1. The diffusivity parameter, ε, was calculated using parameters typical for the mid-Atlantic Coast.

The important conclusion is that any amount of fill less than one-half of the recommended full project length (less than ≈ 3,400 m) can be expected to lose 50 percent of its volume in a year or less. Therefore, each successive stage of the project will expend considerable effort in refilling the previous year's stage. This cost would have to be added to the additional mobilization and demobilization fees for the dredges.

Computation Box D-1

Wallops Island Beach Fill - Length versus Time for Half-Life ($t_{50\%}$)

Andrew Morang 3-May-06

Calculation method from *Coastal Engineering Manual* Part V-4, Example Problem V-4-7

t = time in seconds

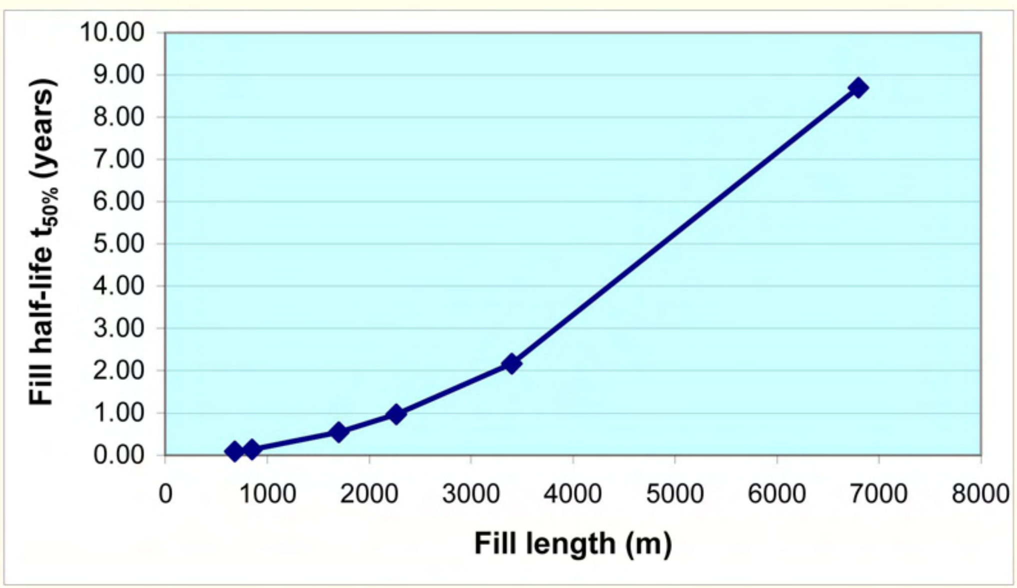
a = half length of rectangle fill

ε = shoreline diffusivity parameter = 0.0331 sq m/sec

$t_{50\%} = (a^2\pi)/(4\varepsilon)$

1 year = 31,557,600 sec

Fill length (m)	*a*	π	ε	$t_{50\%}$ (sec.)	$t_{50\%}$ (year)	Fill proportion
6,800	3400	3.14159	0.0331	2.74E+08	8.69	Full
3,400	1700	3.14159	0.0331	6.86E+07	2.17	Half
2,267	1133	3.14159	0.0331	3.05E+07	0.97	Third
1,700	850	3.14159	0.0331	1.71E+07	0.54	Quarter
850	425	3.14159	0.0331	4.29E+06	0.14	Eighth
680	340	3.14159	0.0331	2.74E+06	0.09	Tenth



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14. ABSTRACT

The Goddard Space Flight Center, Wallops Flight Facility (WFF), is located on the eastern shore of Virginia facing the Atlantic Ocean. The island 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, a replacement for an older wood wall that deteriorated. Although the seawall has temporarily fixed the shoreline position, the structure 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 currently unprotected except for a low revetment around the MARS launch pad.

(Continued)

15. SUBJECT TERMS

Shoreline change	Beach erosion	Sediment
	Wallops Island	Chincoteague Inlet

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Andrew Morang
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14. ABSTRACT

As a result, NASA officials are highly 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 increasingly vulnerable to damage from storm waves and that the foundations of structures and the Unmanned Autonomous Vehicle (UAV) runway may be undermined as the beach continues to erode.

ERDC and U.S. Army Engineer District, Norfolk, have developed a shore protection 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 the higher initial costs, structures will probably reduce life-cycle costs because of reduced requirements for renourishment volumes.