

Virginia

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CHAPTER 8

VIRGINIA

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SUMMARY

Sea level is rising 1 inch every 7 to 8 years (3-4 millimeters per year) along the coast of Virginia. Beaches are eroding along the Atlantic Ocean and Chesapeake Bay. Marshes are converting to open water, and low-lying farms, forests, and residential yards are gradually converting to marsh—including Jamestown and Tangier islands. Water levels in roadside ditches rise and fall with the tides in Poquoson and portions of Gloucester and Accomack counties. All of these effects would become more commonplace if rising global temperatures cause the rate of sea level rise to accelerate. The Intergovernmental Panel on Climate Change, for example, estimates that by the end of the next century, sea level is likely to be rising 0 to 8 mm/yr (3 inches per decade) more rapidly than today (excluding the possible impacts of increased ice discharges from the Greenland and Antarctic ice sheets).

Rising sea level erodes beaches, drowns wetlands, submerges low-lying lands, exacerbates coastal flooding, and increases the salinity of estuaries and aquifers. Coastal communities must ultimately choose between one of three general responses:

- *Armor the shore* with seawalls, dikes, revetments, bulkheads, and other structures. This approach preserves existing land uses, but wetlands and beaches are squeezed between the development and the rising sea.
- *Elevate the land* and perhaps the wetlands and beaches as well. This approach can preserve both the natural shores and existing land uses, but often costs more than shoreline armoring
- *Retreat* by allowing the wetlands and beaches to take over land that is dry today. This approach can preserve natural shores, but existing land uses are lost.

Each of these approaches is being pursued somewhere in Virginia. Wooden bulkheads and stone revetments are common along developed shores of Chesapeake Bay and the Potomac River. The federal or state government has placed sand on the eroding recreational beaches along the Atlantic Ocean, Chesapeake Bay, Hampton Roads, and the Potomac River. In the aftermath of Hurricane Isabel, homes have been elevated in many communities. The elevation of low-lying homes has become common during the last decade. Few homes have been lost to erosion recently, but farms and forests are converting to marsh in Virginia Beach and Gloucester and Accomack counties, and eroding in many areas.

Nevertheless, there is no explicit plan for the fate of most low-lying coastal lands as sea level rises. Environmental planners do not know whether to assume that the coastal wetlands will be lost or simply migrate inland. Those who plan coastal infrastructure do not know whether to assume that a given area will be submerged by rising waters or protected from the sea. And even in developed low lands that will presumably be protected, public works departments do not know whether to assume that the land surfaces will gradually be elevated or that the area will be protected with a dike.

This report develops maps that distinguish shores that are likely to be protected from the sea from those areas that are likely to be submerged, *assuming current coastal policies, development trends, and shore protection practices*. Our purpose is primarily to promote the dialogue by which society decides where to hold back the sea and where to yield the right of way to the inland migration of wetlands and beaches. A key step in evaluating whether new policies are needed is to evaluate what would happen under current policies. The maps in this report represent neither a recommendation nor an unconditional forecast of what will happen, but simply the likelihood that shores would be protected if current trends continue.

We obtained land use and planning data from the 12 coastal localities where it was available, digitized comprehensive plans for 4 other localities, and obtained land use/land cover and conservation data throughout the state. We also consulted with planners representing the six planning district commissions along Chesapeake Bay and the Potomac River, and the 30 localities most vulnerable to sea level rise within those districts, on how to best interpret the data given existing statutes, regulations, and policies. The result is a statewide series of maps that uses existing data, filtered through the local governments who plan and govern how land is used.

By “shore protection” we mean activities that prevent dry land from converting to either wetland or water. Activities that protect coastal wetlands from eroding or being submerged were outside the scope of this study. This study does not analyze the timing of possible shore protection; it simply examines whether land would be protected once it became threatened. Nor do we analyze whether shore protection is likely to be a transitional response or sustained indefinitely.

The maps divide the dry land close to sea level into four categories of shore protection:

- Shore protection almost certain (brown);
- Shore protection likely (red);
- Shore protection unlikely (blue); and
- No shore protection, i.e., protection is prohibited by existing policies (light green).

For reasons related to data quality, our study area includes lands within about 17–18 feet (5 meters) above the tides. (We did not project the fates of secured installations in rural areas but depicted them in red so that they stand out.)

One can also view these maps as representing three shore protection scenarios. For example, in an “enhanced wetland migration” scenario, only the areas depicted in brown would be protected; but in an “enhanced shore protection” scenario, only the areas depicted in light green would be submerged. Thus the prospects for shore protection are best understood in the areas shown in brown and light green, and those shown in red and blue are most amenable to coastal planning. “Expected shore protection” is an intermediate scenario in which the areas depicted in brown and red are protected, while those shown in blue and light green are submerged.

Results

Map 8-1 shows our assessment of the likelihood of shore protection for the coastal zone of Virginia and adjacent areas in North Carolina, Maryland, and the District of Columbia. Table 8-1 quantifies the area of land within approximately 3 feet (1 meter) above the tides for each of the shore protection categories by county. Table 8-2 quantifies the length of shoreline along the Atlantic Ocean, Chesapeake Bay, and Potomac River by likelihood of shore protection.

All of the Virginia Eastern Shore's 77-mile ocean coast is owned by either The Nature Conservancy or the federal or state government. Except for NASA's Wallops Island, all of these lands are managed by agencies committed to preserving natural shoreline processes. Behind the barrier islands, planners expect development to remain light in most areas. Hence shore protection is unlikely on the sea side of the Eastern Shore, except for Chincoteague, Wachapreague, and a few other communities.

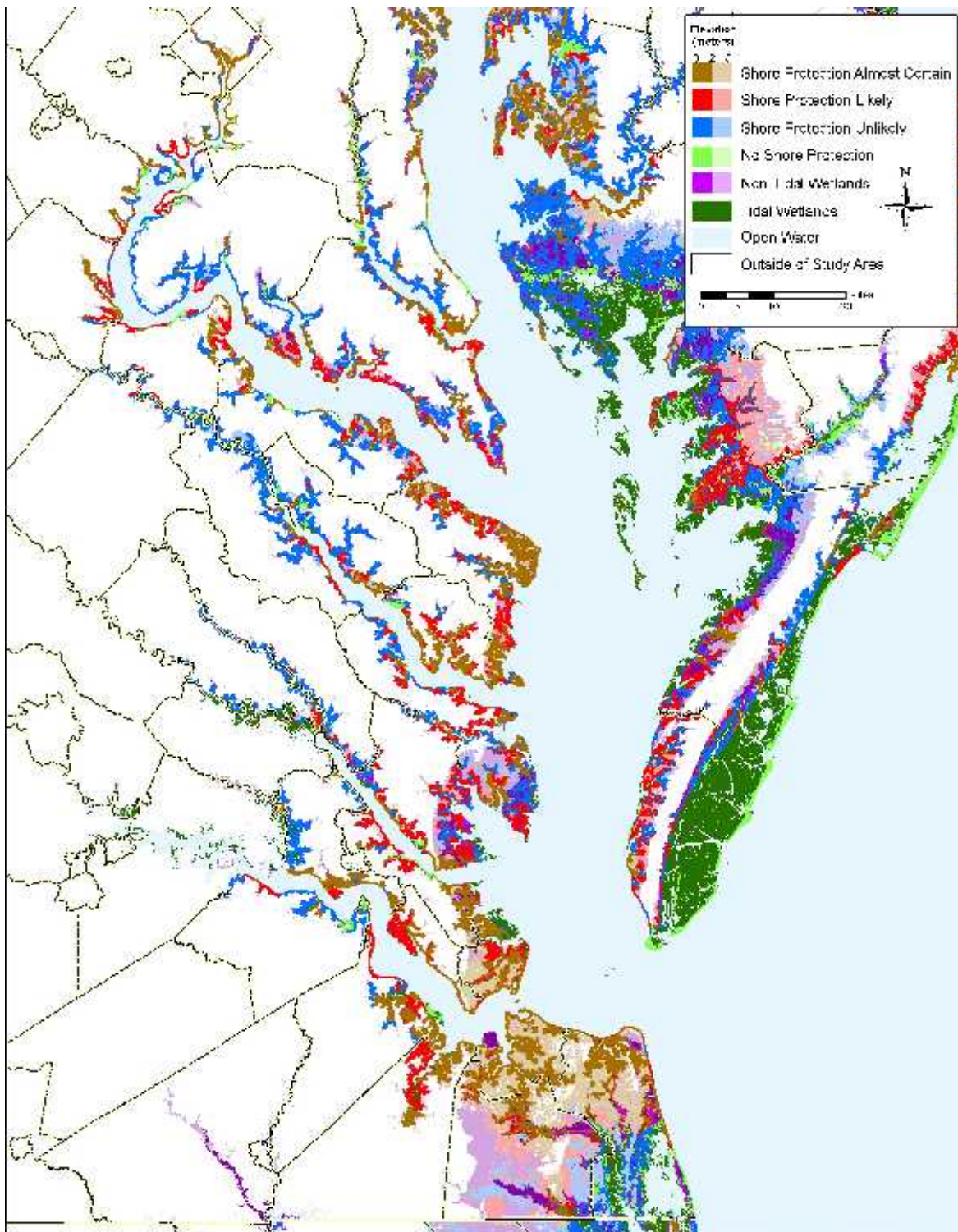
The bay side of the Eastern Shore, by contrast, has very low land north of Onancock. The very low lands are gradually converting to marsh, and viewed by county officials as least promising for development. The 27.5 square miles of dry land close to sea level on the bay side of Accomack County is one of the two largest areas of land available for wetland migration as sea level rises. South of Onancock, by contrast, slopes are generally steeper, and the greater proximity to the Hampton Roads area makes development—and hence shore protection—more likely.

Across the mouth of Chesapeake Bay, the northern two-thirds of Virginia Beach's ocean shore is certain or likely to be protected. As the state's only ocean resort, this city has many different land uses along the shore, all with high property values. But the southern third of the ocean coast is within a state park or Back Bay National Wildlife Refuge, and shore protection would be precluded by current policies. Although the mainland opposite these conservation lands is privately owned, the city is committed to maintaining the rural character of the land south of its "Rural Line." In effect, the city expects that its land use plan to preserve rural areas is likely to preserve the coastal environment as sea level rises throughout the coming century and beyond. This area also has one of the two largest concentrations of very low dry land onto which wetlands are likely to migrate.

Along the western shore of Chesapeake Bay and several major tributaries, shore protection is becoming increasingly likely as shores become more developed. Of the nearly 100 square miles of dry land within 3 feet above the tides, more than 52 square miles are in the Hampton Roads area; the Guinea Neck in Gloucester County also has a large concentration of very low land. Elsewhere, most shore protection would involve erosion-control structures or beach nourishment rather than dikes or elevating land and buildings. Because erosion protection is relatively inexpensive compared with coastal property values, developed areas are almost certain to be protected. Nevertheless, planners view development as less imminent in the upstream areas of the Rappahannock, York, and some smaller rivers with substantial wetlands along the shore. Those areas appear to have the greatest potential for tidal wetland conservation as sea level rises. In the upper tidal Potomac River, shoreline armoring is commonplace—but a substantial portion of the shore is publicly owned and hence unlikely to be developed.

Findings

1. *The prospects for shore protection appear to be largely established along 87percent of the 106-mile Atlantic Ocean coast.*
 - High property values and dense development make shore protection almost certain along 11 miles in Virginia Beach.
 - Conservation policies preclude shore protection along approximately 76 percent of the ocean coast, including almost all of the barrier islands north of Cape Charles.
2. *Shore protection is still uncertain along about 13 percent of the Atlantic Coast.*
 - This report did not examine the likelihood of shore protection for secured federal installations, including NASA's Wallops Island and the Navy's Surface Combat System Center.
 - Wide beaches where shore protection is not immediately needed account for about 3 miles of shoreline in Virginia Beach. The land behind these beaches is almost certain to be protected if the beaches erode.
3. *Along the 634 miles of estuarine shoreline, the prospects for shore protection are much less certain than along the ocean. These lands include approximately 120 square miles of dry land within about 3 feet (1 meter) above the tides.*
 - Only 50 square miles are developed enough for planners to view shore protection as almost certain to be protected.
 - Less than 10 square miles of low lands are within conservation areas.
4. *Despite the momentum toward coastal development, all of our options still appear to be open for about 70 square miles of low dry land in Virginia.*
 - Development and shore protection are likely on about 30 square miles within about 3 feet (1 meter) above the tides; but it is not too late to design land use plans that could accommodate both development and wetland migration.
 - On the other 40 square miles, development and shore protection seem unlikely today; but people may want to move into many of these areas in the future.



Map 8-1. Virginia: Likelihood of Shore Protection. For each shore protection category, the darker shades represent lands that are either less than 6.6 feet (2 meters) above spring high water, or within 1,000 feet of the shore. The lighter shades show the rest of the study area. This map is based on data published between 1997 and 2004, and site-specific changes suggested by planners in 2003 and 2004.

Table 8-1.
Area of Land within 3.3 feet (1 meter) above Spring High Water by Likelihood of Shore Protection (square miles)

Locality	Likelihood of Shore Protection				Nontidal Wetlands	Total ¹	Elevation Error ² (inches)	Tidal Wetlands ³
	Almost Certain	Likely	Unlikely	No Protection				
Eastern Shore	5.4	7.3	11.9	7.5	13.2	46.1		365.1
Accomack	4.7	4.8	9.0	3.5	12.4	35.0	16	186.7
Northampton	0.6	2.5	2.9	4.1	0.8	11.1	16	178.4
Northern Virginia	1.2	0.3	0.4	0.2	0.2	2.3		4.0
Arlington	0.1	0.0	0.0	0.0	0.0	0.1	26	0.0
Alexandria	0.2	0.0	0.1	0.0	0.0	0.3	26	0.1
Fairfax	0.6	0.2	0.3	0.0	0.1	1.2	26	1.9
Prince William	0.3	0.1	0.1	0.2	0.1	0.6	26	2.0
Rappahannock Area	0.9	0.9	0.7	0.1	0.6	3.3		10.3
Stafford	0.4	0.2	0.2	0.0	0.3	1.1	26	2.6
Fredericksburg	0.0	0.0	0.0	0.0	0.0	0.0	25	0.0
King George	0.5	0.6	0.3	0.1	0.3	1.8	28	5.2
Spotsylvania	0.0	0.0	0.0	0.0	0.0	0.1	26	0.0
Caroline	0.0	0.0	0.2	0.0	0.0	0.3	26	2.4
Northern Neck	5.6	2.7	3.3	0.4	1.4	13.9		22.1
Westmoreland	0.7	0.5	1.3	0.0	0.3	3.0	28	5.5
Richmond	0.6	0.3	1.5	0.2	0.5	3.1	28	8.4
Northumberland	1.7	1.1	0.3	0.0	0.3	3.6	28	4.4
Lancaster	2.6	0.8	0.3	0.2	0.3	4.3	26	3.8
Middle Peninsula	4.7	8.7	10.4	0.0	7.0	31.3		63.5
Essex	0.2	0.4	1.6	0.0	0.4	2.6	26	10.7
King and Queen	0.0	0.4	1.2	0.0	0.5	2.1	26	8.3
King William	0.1	0.1	0.6	0.0	0.2	1.1	26	13.5
Middlesex	0.6	0.5	0.7	0.0	0.4	2.3	24	3.7
Gloucester	1.6	4.4	2.9	0.0	3.2	12.4	17	16.8
Mathews	2.2	2.8	3.4	0.0	2.2	10.8	16	10.5
Hampton Roads	31.1	8.4	13.7	0.5	31.7	86.3		127.6
James City	1.2	0.2	0.7	0.0	0.4	2.6	26	12.7
York	2.6	0.8	0.1	0.1	0.6	4.2	17	6.6
Newport News	1.4	2.1	0.0	0.0	0.2	3.7	16	5.8
Poquoson	2.5	0.0	0.0	0.0	0.1	2.6	16	9.1
Hampton	2.7	1.3	0.0	0.0	0.1	4.2	16	5.5
Surry	0.1	0.1	0.5	0.2	0.4	1.2	26	4.4
Isle of Wight	1.0	0.4	0.4	0.1	0.7	2.6	26	11.2
Norfolk	4.0	0.0	0.0	0.0	0.2	4.2	16	1.8
Virginia Beach	6.8	1.1	11.0	0.0	7.9	26.9	16	43.4
Suffolk	1.5	0.7	0.3	0.0	1.1	3.6	22	10.2
Portsmouth	2.3	0.1	0.0	0.0	3.4	5.9	16	1.4
Chesapeake	5.1	1.6	0.8	0.0	9.6	17.0	16	15.3
Franklin City	0.0	0.0	0.0	0.0	0.5	0.6	16	0.0
Southampton	0.0	0.0	0.0	0.0	6.5	7.1	16	0.0
Williamsburg	0.0	0.0	0.0	0.0	0.01	0.04	26	0.2
Virginia	48.8	28.3	40.3	8.8	54.1	183.2		592.6

1. Total Land includes the five categories listed plus land for which no data were available.

2. This table is based on the area of map polygons within 3.3 feet (1 meter) above the tides. Although the area of the polygons can be tabulated very precisely, the 3.3 ft (1 m) elevation estimate is subject to the accuracy limits of the underlying elevation data. The elevation error column displays the accuracy limits (root mean square error) of the data used to identify the 1-m elevation contour.

3. Includes mudflats.

Table 8-2. Shoreline Length by Major Water Body and Likelihood of Shore Protection (miles)¹

County	Likelihood of Shore Protection				Nontidal Wetlands	Totals
	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection		
Chesapeake Bay	61	35	41	2	27	166
Accomack	6	8	21	0	22	57
Hampton	7	3	<0.1	0	0	10
Lancaster	5	0.4	3	0	<0.1	8.4
Mathews	2	3	7	0	4	16
Middlesex	0	0	<0.1	0	0	0
Norfolk	7	0	0	0	0	7
Northampton	6	10	10	2	0.2	28.2
Northumberland	10	9	0.2	0	0	19.2
Poquoson	6	0	0	0	0	6
Virginia Beach	9	1	<0.1	0	0	10
York	4	1	0	0	1	6
Atlantic Ocean	11	11	3	81	0.1	106.1
Accomack	0	6	0.7	34	0.1	40.8
Northampton	0	0	0	36	0	36
Virginia Beach	11	5	2	10	0	28
Potomac River	70	30	45	8	4	157
Alexandria	4	0	0.8	0	0	4.8
Arlington	9	0.9	1	0	0	10.9
Fairfax	13	2	18	0.9	3	36.9
King George	10	10	1	3	<0.1	24
Northumberland	13	4	2	0	<0.1	19
Prince William	2	3	3	0	0	8
Stafford	0.9	5	5	0.7	0	11.6
Westmoreland	19	5	14	3	0.3	41.3
York River	19	16	15	8	3	61
Gloucester	13	6	5	2	2	28
James City	1	0.5	5	0	0	6.5
King and Queen	<0.1	2	5	0	0.2	7.2
York	4	8	0.3	6	0.3	18.6
James River	76	27	23	7	<0.1	133
Hampton	4	0.1	0	0	0	4.1
Isle of Wight	8	11	4	2	<0.1	25
James City	15	2	1	0.6	<0.1	18.6
Newport News	17	8	<0.1	0	<0.1	25
Norfolk	10	0	0	0	0	10
Portsmouth	8	<0.1	0	0	0	8
Suffolk	12	0.9	0	0	0	12.9
Surry	3	5	18	4	0	30
Rappahannock River	45	25	44	3	0.4	117.4
Essex	11	7	13	0	0	31
Lancaster	23	4	3	2	<0.1	32
Middlesex	5	9	13	0	0.2	27.2
Richmond	6	5	15	1	0.2	27.2
Westmoreland	<0.1	0	0.2	0	0	0.2
Back Barrier Bays	36	20	53	139	26	274
Accomack	30	13	32	56	1	132
Northampton	2	6	11	67	17	103
Virginia Beach	4	1	10	16	7	38
State Total¹	2871	1735	2205	607	295	7713

¹Includes tributaries to the major water bodies.

INTRODUCTION

The levels of Chesapeake Bay and other tidal waters in Virginia have risen almost 5 feet since Captain John Smith first sailed up the James River. What was then a narrow river is now very wide. Low-lying islands in the Bay have gradually disappeared. Wetlands are being eroded and submerged, and salt marsh is now found in the front yards of many homes in Accomack and Gloucester counties, and in the City of Poquoson. Tidal floods now threaten historic homes that were above the floodplain when constructed. Shore erosion induced by rising sea level and other factors threatens homes, and the structural solutions to shore erosion threaten the intertidal habitat required by terrapins, horseshoe crabs, and a wide variety of migratory birds and commercially important fish. Those structures also eliminate narrow beaches on which the public traditionally has had a right to hunt, fish, or land a boat.

During the last 50–75 years, sea level has been rising 0.125 in/yr (3.2 mm/yr) at Washington, D.C., 0.13 in/yr at Kiptopeke Beach, 0.16 in/yr at Gloucester Point, and 0.17 in/yr at Sewells Point in Norfolk.¹ Tide gauge stations at Lewesetta, Colonial Beach, and the Chesapeake Bay Bridge Tunnel have less than 35 years of data, but show a similar trend. In the coming decades, rising global temperatures may cause the sea to rise another foot or two beyond what one would expect from current trends alone.² Over the next several centuries, the rate of sea level rise may continue to accelerate.

A continued rise in sea level at the historical rate of 1 foot per century will have significant impacts along the low-lying areas of Virginia. Most sandy shores along the ocean, Chesapeake Bay, and wide portions of tidal rivers erode approximately 50–200 feet for every foot that the sea rises,³ and often this land is very valuable. Table 8-3 shows preliminary estimates of the land that could potentially be inundated from a 2-ft rise in sea level. (See also Figure 8-1.) Statewide, more than 600 square miles of land are within 2 feet of the ebb and flow of the tides and hence vulnerable to the 2-ft rise in sea level that could occur over the next century.⁴ Most of that land is already wetland, including 350 square miles of tidal wetlands in the two counties on the Eastern Shore. The state also has 75 square miles of dry land that would be inundated by a 2-ft rise, however, unless measures are taken to hold back the sea; one-third of this low land is in the densely populated Hampton Roads area.

Lands that are several feet above the tides are not likely to be completely lost in the next century, but they may still be affected by rising sea level. Much of the Hampton Roads area, including most of Hampton, Norfolk, and Virginia Beach, lies within the 100-year flood plain. Because rising sea levels increase the heights of storm surge flooding, most of these cities could be affected by sea level rise over the next century. Poquoson, Tangier, and Gloucester County's Guinea Peninsula, however, face more immediate threats. In these communities, many neighborhoods are already flooded frequently, and water in ditches rises and falls with the tides. Lands at higher elevations along Chesapeake Bay and major rivers may also be threatened by erosion

¹See the webpages for Permanent Service for Mean Sea Level (<http://www.pol.ac.uk/psmsl/>) and Sea Levels Online of NOAA's National Ocean Service (<http://www.co-ops.nos.noaa.gov/sltrends/sltrends.shtml>).

²Intergovernmental Panel on Climate Change, 2001, *The Science of Climate Change*, Cambridge University Press, New York; Titus, J.G., and V.K. Narayanan, 1995, *The Probability of Sea Level Rise*, EPA Office of Policy, Planning, and Evaluation, EPA 230-R-95-008. Washington, D.C.: U.S. EPA.

³U.S. Environmental Protection Agency, 1989, *The Potential Effects of Global Climate Change on the United States: Report to Congress*. Office of Policy, Planning, and Evaluation at p. 126–127 (citing studies conducted along the mid-Atlantic Coast).

⁴See box on "Reference Elevations and Sea Level Rise" for an explanation of spring high water and sea level rise.

TABLE 8.3. AREA OF LAND VULNERABLE TO SEA LEVEL RISE IN VIRGINIA (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Accomack	208.0	186.7	14.1	7.2	28.5	16.3	59.0	36.6
Virginia Beach	59.8	43.4	11.4	5.0	23.7	9.1	64.9	16.1
Northampton	186.4	178.4	7.6	0.4	12.1	1.2	21.9	3.2
Gloucester	24.0	16.8	5.3	1.9	11.7	4.2	25.6	9.5
Mathews	16.9	10.5	5.1	1.3	11.9	3.1	29.1	7.6
Chesapeake	25.1	15.3	4.0	5.8	10.1	11.8	34.5	21.5
Lancaster	^e	3.8	^e	^e	4.9	0.4	9.9	0.8
Newport News	8.2	5.8	2.3	0.1	4.1	0.2	7.1	0.5
York	8.9	6.6	2.0	0.3	4.7	1.0	10.7	2.6
Northumberland	6.6	4.4	2.0	0.2	4.1	0.4	8.1	0.8
Norfolk	3.9	1.8	2.0	0.1	6.0	0.2	17.4	0.4
Hampton	7.6	5.5	1.9	0.1	6.2	0.1	17.9	0.4
Suffolk	12.5	10.2	1.6	0.7	3.0	1.3	6.4	1.9
Richmond Co	^e	8.4	^e	^e	3.2	0.6	6.3	1.2
Poquoson	10.7	9.1	1.5	0.02	3.2	0.1	6.3	0.4
James City	14.2	12.7	1.3	0.3	2.6	0.5	5.0	1.0
Essex	^e	10.7	^e	^e	2.6	0.5	5.3	1.1
Portsmouth	5.3	1.4	1.3	2.5	3.4	3.4	8.9	3.7
Isle Of Wight	^e	11.2	^e	^e	2.3	0.8	4.8	1.5
Charles City	^e	8.6	^e	^e	2.3	1.3	4.7	2.5
King And Queen	^e	8.3	^e	^e	2.0	0.6	4.2	1.1
New Kent ^f	^e	13.1	^e	^e	1.5	1.6	3.2	3.1
King William	14.2	13.5	0.6	0.1	1.1	0.3	2.7	0.5
Other Jurisdictions ^g	53.0	39.0	8.2	5.9	16.6	10.9	34.7	17.8
STATEWIDE TOTALS	741.6	625.1	81.9	34.7	171.7	70.0	398.7	135.7

^a J.G. Titus and J. Wang, 2008, Maps of Lands Close to Sea Level along the Middle Atlantic Coast of the United States: An Elevation Data Set to Use While Waiting for LIDAR, Chapter 1 in J.G. Titus and E.M. Strange (eds.), *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

^e Value omitted because the topographic information Titus and Wang used for this jurisdiction had poor vertical resolution.

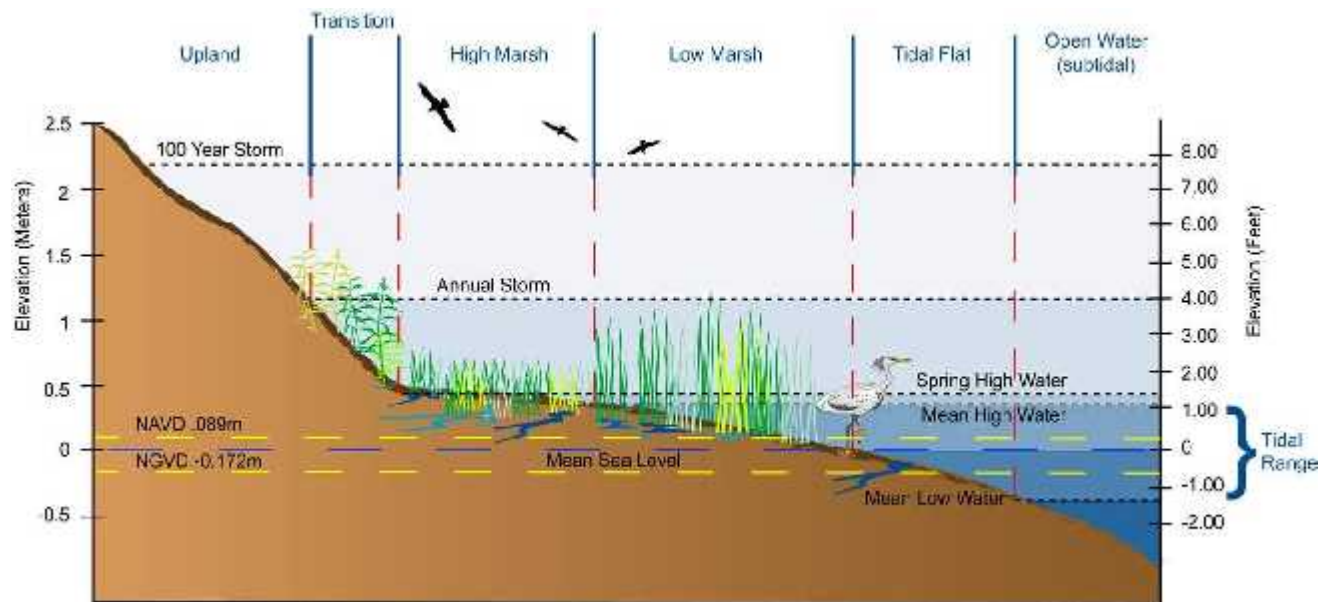
^f Not included in this study.

^g Includes Alexandria, Arlington, Caroline, Fairfax, Fredericksburg, King George, Middlesex, Prince William, Spotsylvania, Stafford, Surry, and Westmoreland which are in the study area, as well as Chesterfield, Colonial Heights, Falls Church, Franklin City, Hanover, Henrico, Hopewell, Petersburg, Prince George, city of Richmond, Southampton, Sussex, and Williamsburg which this study does not analyze.

BOX: TIDES, SEA LEVEL, AND REFERENCE ELEVATIONS

Tides are caused by the gravitational attraction of the moon and sun on the ocean water. Most places have two high and low tides every day, corresponding to the rotation of the earth. The daily tide range varies over the course of the lunar month. *Mean high water* and *mean low water* are the average elevations of the daily high and low tides. During full and new moons, the gravitational pull of the moon and the sun are in alignment, which causes the tide range to be 15–25 percent more than average. The averages of the full and new moon high and low tides are known as *spring high water* and *spring low water*. In addition to the astronomic tides, water levels fluctuate owing to winds, atmospheric pressure, ocean current, and—in inland areas—river flow, rainfall, and evaporation. Daily tide ranges in the mid-Atlantic are as great as 8 feet in parts of the Delaware River and less than an inch in some of the sounds of North Carolina.

In coastal areas with tidal marshes, the high marsh is generally found between mean high water and spring high water; low marsh is found from slightly below mean sea level up to spring high water. In bays with small (e.g. 6 inch) tide ranges, however, winds and seasonal runoff can cause water level fluctuations more important than the tides. These areas are known as “*irregularly flooded*”. In some locations, such as upper Albemarle Sound in North Carolina, the astronomic tide range is essentially zero, and all wetlands are irregularly flooded. Freshwater wetlands in such areas are often classified as “nontidal wetlands” because there is no tide; but unlike most nontidal areas, the flooding—and risk of wetland loss—is still controlled by sea level. Wetlands whose hydrology is essentially that of nontidal wetlands, but lie at sea level along an estuary with a very small tide range, are called *nanotidal wetlands*.



The term *sea level* refers to the average level of tidal waters, generally measured over a 19-year period. The 19-year cycle is necessary to smooth out variations in water levels caused by seasonal weather fluctuations and the 18.6-year cycle in the moon’s orbit. The sea level measured at a particular tide gauge is often referred to as local mean sea level (LMSL).

Tide gauges measure the water level relative to the land, and thus include changes in the elevation of the ocean surface and movements of the land. For clarity, scientists often use two different terms:

- *Global sea level rise* is the worldwide increase in the volume of the world’s oceans that occurs as a result of thermal expansion and melting ice caps and glaciers.
- *Relative sea level rise* refers to the change in sea level relative to the elevation of the land, which includes both global sea level rise and land subsidence.

In this report, the term “sea level rise” means “relative sea level rise.”

Land elevations are measured relative to either water levels or a fixed benchmark. Most topographic maps use one of two fixed reference elevations. USGS topographic maps measure elevations relative to the National Geodetic Vertical Datum of 1929 (NGVD29), which was approximate sea level in 1929 at the major coastal cities. New maps and high-resolution data measure elevations relative to the North American Vertical Datum of 1988 (NAVD88). This report measures elevations relative to spring high water (for 2000), which indicates how much the sea must rise before the land is inundated by the tides. NAVD88 and NGVD29 should not be used as equivalent to present-day sea level.

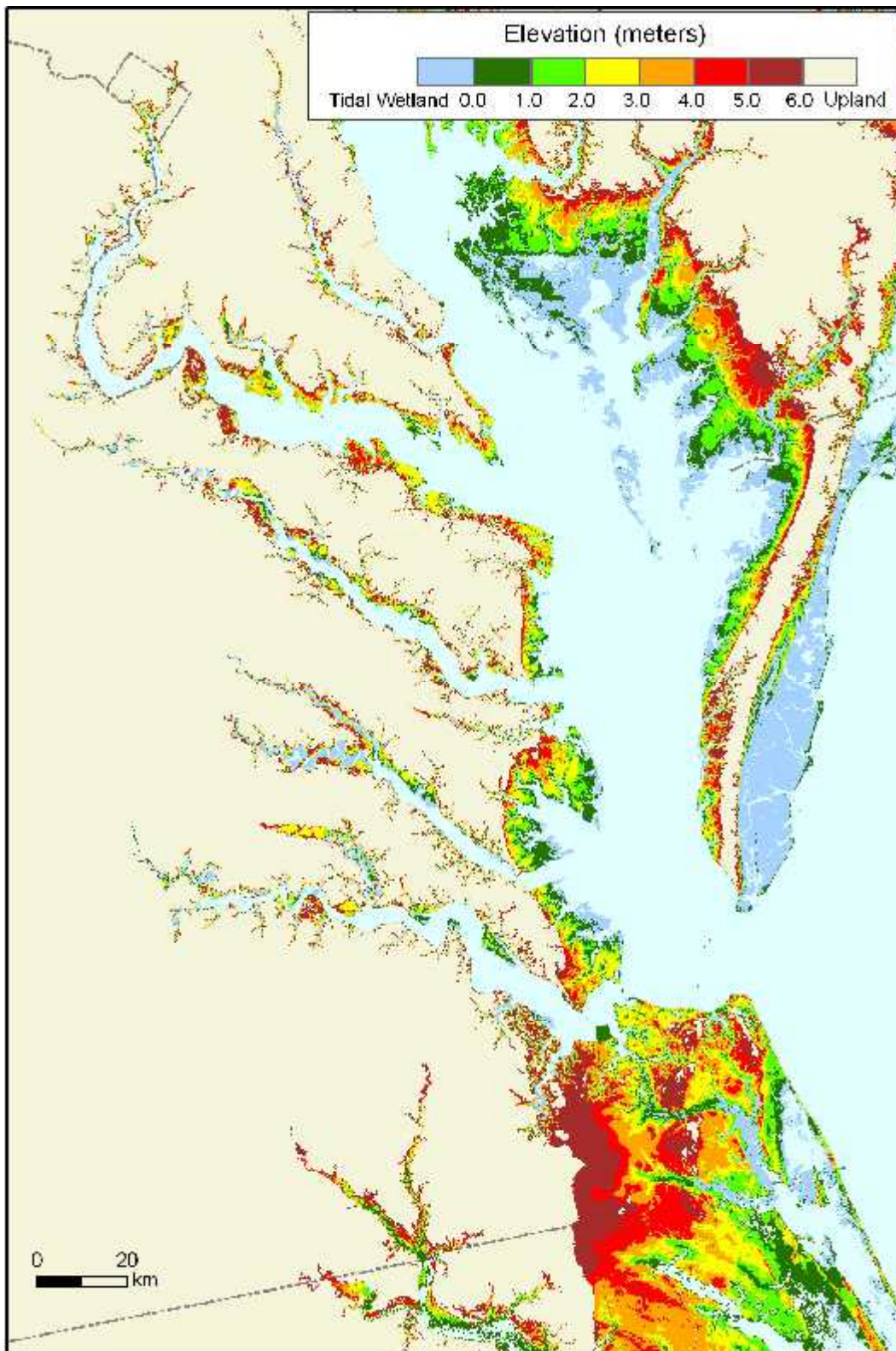


Figure 8-1. Lands Vulnerable to Sea Level Rise. Source: Titus and Wang (2008; see Table 8-3 for full reference). Elevations are relative to spring high water. Because the map has a contour interval of 1 meter (3.28 feet), we have not converted the legend from metric to the English units used in the text of this report.

and storms. Along the Bay, Virginia loses hundreds of acres of land per year. The lost land includes both public and private property, historical and cultural sites, recreational beaches, farmland, and forests.

Purpose of this Study

This study develops maps that distinguish the areas likely to be protected from erosion and inundation as the sea rises from those areas that are likely to be left to retreat naturally assuming that current policies and economics trends continue. The natural retreat may occur either because the cost of holding back the sea is greater than the value of the land or because environmental policies favor natural shorelines over the structures and fill material required to hold back the sea. This report is part of a national effort by the U.S.

Environmental Protection Agency (EPA) to encourage the long-term thinking required to deal with the impacts of sea level rise. Maps illustrating the areas that might ultimately be submerged convey a sense of what is at stake, but they also leave people with the impression that submergence is beyond their control. Maps that illustrate alternative visions of the future, by contrast, can promote a more constructive dialogue.

For each state, EPA is evaluating potential responses to sea level rise, with a focus on maps showing the lands that would probably be protected from erosion and inundation as the sea rises. These maps are intended for two very different audiences:

State and local planners and others concerned about long-term consequences of rising sea level.

Whether one is trying to ensure that a town survives or that wetlands and beaches are able to migrate inland,⁵ or some mix of both, the most

cost-effective means of preparing for sea level rise often require implementation several decades before developed areas are threatened.⁶ For the last 25 years, EPA has attempted to accelerate the process by which coastal governments and private organizations plan for sea level rise, and evaluated whether the nation's wetland protection program will achieve its goals as sea level rises.⁷ Preparing for sea level rise requires society to decide which areas will be elevated or protected with dikes and which areas will be abandoned to the sea. A key step toward such a decision is the baseline analysis of what will happen given current policies and trends. This report provides that baseline analysis.

National and international policy makers concerned about the science, possible consequences, and international agreements related to climate change. National and international policies regarding the possible need to reduce greenhouse gas emissions require assessments of the possible impacts of sea level rise. Such assessments depend to a large degree on the extent to which local coastal area governments will permit or undertake sea level rise protection efforts.⁸ Moreover, the United Nations Framework Convention on Climate Change, signed by President Bush in 1992, commits the United States to taking appropriate measures to adapt to the consequences of global warming.

Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise, EPA 430R07004, Washington, DC: U.S. EPA.

⁵ In some areas, wetlands may accrete sufficient sediment to vertically increase elevation and thus avoid inundation. For further information on the potential for wetland accretion, see Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 2008, Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region, Section 2.1 in J.G. Titus and L. Strange (eds.), *Background Documents Supporting Climate Change Science Program*

⁶See, e.g., Titus, J.G., 1998, "Rising seas, coastal erosion and the takings clause: How to save wetlands and beaches without hurting property owners," *Maryland Law Review* 57:1279–1399.

⁷EPA committed to helping coastal communities prepare for an acceleration of sea level rise in 1982, long before the agency developed a policy for reducing greenhouse gases. See, e.g., EPA, 1983, *Projecting Future Sea Level Rise*. See also the report of EPA's 1983 Sea Level Rise Conference: *Greenhouse Effect and Sea Level Rise: A Challenge for this Generation*, M.C. Barth and J.G. Titus, editors, Van Nostrand Reinhold, New York.

⁸Titus, J.G., et al., 1991, "Greenhouse effect and sea level rise: The cost of holding back the sea," *Coastal Management* 19:171–204; Yohe, G., 1990, "The cost of not holding back the sea: Toward a national sample of economic vulnerability," *Coastal Management* 18:403–431.

Caveat

This report has two fundamental limitations. First, it is literally a “first approximation” of the likelihood of shore protection. Like most first-of-a-kind studies, our effort includes methodological judgments that may later prove ill-advised. We examine the implications of current trends in coastal development and coastal management policies. We have attempted to account for uncertainty by dividing our study area into lands where shore protection is almost certain, likely, unlikely, and precluded by current policies. But many important factors can not be foreseen—and in many cases the only available data are several years old. Therefore, we often relied on planners to fill in the gaps by telling us about recent and expected development. But what is expected now may be different from what was expected when we visited the planners. As new information emerges, assessments of the likelihood of shore protection will change.

Second, this study is not even intended to address all of the issues that some people think about when they hear the term “shore protection.” Our intention is to distinguish those lands where a natural retreat would occur from those areas where people will at least attempt to hold back the sea. Our maps are *not* intended to identify

- the vulnerability of particular lands (we simply evaluate whether lands would be protected *if and when* they are threatened);
- options for protecting existing wetlands (we analyze protection only of dry land);
- which areas will receive government funded shore protection;
- whether people will hold back the sea forever,⁹ which would depend on cost factors and scientific uncertainties outside the scope of this analysis¹⁰;

- whether hard structures, soft engineering, or some hybrid of the two approaches is likely in areas that will be protected, or the environmental impacts of shoreline armoring.

How to Read this Report

This chapter is one of eight state-specific chapters in Volume 1. Each of the eight chapters was written and reviewed as a stand-alone document, because the authors assumed that many readers are interested in the analysis of only a single state. To assist readers interested more than one state, each chapter (except the short chapter on the District of Columbia) is organized in a similar fashion, including a summary of likely responses, introduction, methods, relevant state policies, city and county-specific policies and responses, result appendices, and other appendices as needed.

Some subsections appear verbatim in each chapter, including the subsections on purpose, caveats, and the text box on tides and reference elevations. Subsections on map scale and use of experts have text that is nearly verbatim, except for changes that reflect state-to-state differences. The methods sections reflect differences in available data for each state, but the study area subsection is nearly the same from state to state.

This chapter has separate sections in which we describe:

- *methods* by which we assess the likely sea level rise responses;
- *state policies* that affect the management of the coastal lands; and
- city and county-specific policies and the likely extent of future shore protection, grouped by planning district.

At the end of this chapter, we provide detailed quantitative results in three appendices:

- (A) best estimates of the length of shoreline by likelihood of shore protection;

⁹The analysis in Appendix E, however, identifies those areas that would be protected under almost any conceivable sea level rise scenario.

¹⁰For example, the sea could rise 10–20 feet over several centuries if one of the world’s ice sheets were to melt. See, e.g., IPCC, 2001, *Climate Change Science 2001*, Cambridge University Press, New York and London.

- (B) best estimates of the area of land at various elevations by likelihood of shore protection; and
- (C) uncertainty ranges of the amount of land at various elevations by likelihood of shore protection.

Because the quantitative results were developed after this study was complete, those results are not integrated into the text of this report, other than the summary.

The last two appendices describe:

- (D) the complete list of data sources, and
- (E) a preliminary study by the Virginia Institute of Marine Sciences (VIMS), which examined the possible response to a worst-case scenario.

METHODS

This section provides detailed information on the approaches employed over the course of this study. We divide the discussion in subsections, which address:

- scope of the study area;
- our approach for gathering information from local planners and developing the likelihood of shore protection maps; and
- the appropriate scale for viewing the resulting maps.

Study Area

Our study area is all dry land below the USGS 20-ft contour. We use the 20-ft contour as an inland boundary to be consistent with studies of neighboring states, and to ensure that the study area includes all portions of the state that might be affected by rising sea level during the foreseeable future. (Some researchers are beginning to evaluate the possible impacts of the sea rising 5–10 feet or more over a few centuries.) This large study area is not meant to suggest that sea level rise would inundate all of these lands. We merely are attempting to avoid the possibility that subsequent improvements in elevation data reveal areas we omitted to be vulnerable. *Although our study area extends to the 20-ft contour, those using our results need not include the higher elevations.*¹¹

Our study area also includes all dry land within 1,000 feet of tidal wetlands or open water to account for possible erosion¹² and to ensure that

the study area is large enough to be seen on maps depicting a county on a single sheet of paper. We found that maps without a 1,000 foot study area along bluffs were difficult to read and did not convey the anticipated response.

Within the study area, our maps use the following colors for the four categories depicting likelihood of shore protection:

Brown—areas that will **almost certainly** be protected if and when the sea rises enough to threaten them, assuming a continuation of existing policies and trends.

Red—areas where shore protection is **likely** but where it is still reasonably possible that shores might retreat naturally if development patterns change or scientists were to demonstrate an ecological imperative to allow wetlands and beaches to migrate inland.

Blue—areas where shore protection is **unlikely**, generally because property values are unlikely to justify protection of private lands, but in some cases because managers of publicly owned lands are likely to choose not to hold back the sea.

Light Green—areas where there would be **no shore protection** under existing policies, which already appear to preclude holding back the sea. These areas include both publicly and privately owned lands held for conservation purposes.

Although our maps are based on a continuation of current policies, we were also mindful of the possible implications of changing priorities. If the costs or environmental consequences of shore protection led society to deliberately reduce shore protection compared with what one might expect given current policies, then (ignoring site-specific environmental and shore protection cost issues) the light green, blue, and red identify those areas where retreat would be feasible as a matter of land-use planning. If development and/or land values

¹¹For example, the quantitative results reported in Appendix B estimate the land area within approximately 3 feet (1 meter) above the tides.

¹²Like the 20-ft contour, the 1,000-ft buffer is conservatively overinclusive. Rates of shoreline erosion vary. But given the format of most land use data, extending the study area 1,000 feet inland did not require us to obtain data or engage in discussions that we would not have undertaken otherwise.

increase beyond what is currently expected, the brown, red, and blue areas might all be protected.¹³

Outside the study area, we generally show nontidal wetlands as purple and tidal wetlands as dark green. We differentiate tidal and nontidal wetlands because the effects of sea level rise are potentially very different. We differentiate nontidal wetlands from dry land because this report evaluated only whether dry land would be protected.¹⁴

Discussions with Planners and Map Preparation

This assessment has been conducted in three phases: (1) preliminary assessment of localities along Chesapeake Bay and the Atlantic Ocean; (2) improved maps for the four planning districts along Chesapeake Bay; and (3) extension of the study to the two planning districts along the Potomac River. In the initial phase, the two authors from the Virginia Institute of Marine Sciences (VIMS) reviewed state and local laws and development plans to determine the policies that affect coastal management decisions. Next, VIMS held preliminary meetings with the local planners in counties and independent cities that directly border Chesapeake Bay to develop a “rough cut” shore protection map based on existing and anticipated coastal policies and land uses. That map did not follow the general approach of this study; instead it identified those areas that

would be protected if sea levels were to rise 20 feet within a century. (See Appendix E.)

In the second phase, the three authors from Industrial Economics (IEc) and the EPA project manager sought to correct two limitations of the VIMS study: the unrealistic sea level rise scenario and the exclusion of coastal counties that are not along Chesapeake Bay. Given resource limitations, a detailed assessment of every county along tidal waters did not seem feasible. All but a few of the coastal counties, however, are within one of six planning district commissions (PDCs). Figure 8-2 shows the PDC boundaries. Therefore we decided to work through the planning districts as much as possible, starting with the four districts that include the bayfront counties of the original VIMS study: Accomack-Northampton (Eastern Shore), Hampton Roads, Middle Peninsula, and Northern Neck. Each of these planning districts also includes counties along tidal rivers that had been omitted from the VIMS analysis. We held follow-up meetings with each of those PDCs. For the most part, the bayfront counties that participated in the original VIMS study attended those meetings, which made it possible to refine the decision rules for the maps and make site-specific adjustments based on unique factors.¹⁵ The other coastal counties within the districts generally did not attend those meetings, but the PDCs were able to provide us with decision rules for those counties. Nevertheless, our approach was not precisely the same within each PDC.¹⁶ For example, Figure 8-3 shows the counties within the coastal planning districts for which we were able to obtain recent land use data. (We also obtained land use/land cover data developed by USGS in the late 1970s to early 1980s for the entire state).

Accomack-Northampton

This planning district has the greatest amount of wetlands and dry land at risk, as well as the greatest potential for wetland creation from sea

¹³During the pilot testing of this multistate study, the initial approach was to obtain planner input on three scenarios of shoreline protection. Those scenarios included 1) Enhanced Protection—protection of all areas that can be protected under existing state and local policies; 2) Expected Protection—an assessment of current as well as anticipated behavior; and 3) Enhanced Wetland Migration—an assessment of alternative policies that would provide greater protection to natural resources (e.g., wetlands) or culturally significant resources.

This report uses the four map colors to—in effect—display all three scenarios on a single map. For additional information on the three scenarios and the relationship to the likelihood of shore protection, see the discussion of the project evolution in the Overview (Chapter 1) or New Jersey chapter (Chapter 3).

¹⁴Shore protection designed to protect dry land does not necessarily have the same impact on nontidal wetlands. Erosion control structures designed to prevent homes from eroding into the sea may also protect adjacent nontidal wetlands. Efforts to elevate land with fill to keep it dry would not necessarily be applied to nontidal wetlands. Some nontidal wetlands in developed areas may be filled for development.

¹⁵When planners identified site-specific changes based on the location of certain communities, we would generally implement the change by selecting land-use polygons within the approximate boundaries of the community. Thus, this approach assumes that the boundaries of the land use data selected match those of the community that the planners identified.

¹⁶See sections on specific planning districts, below, for further details.

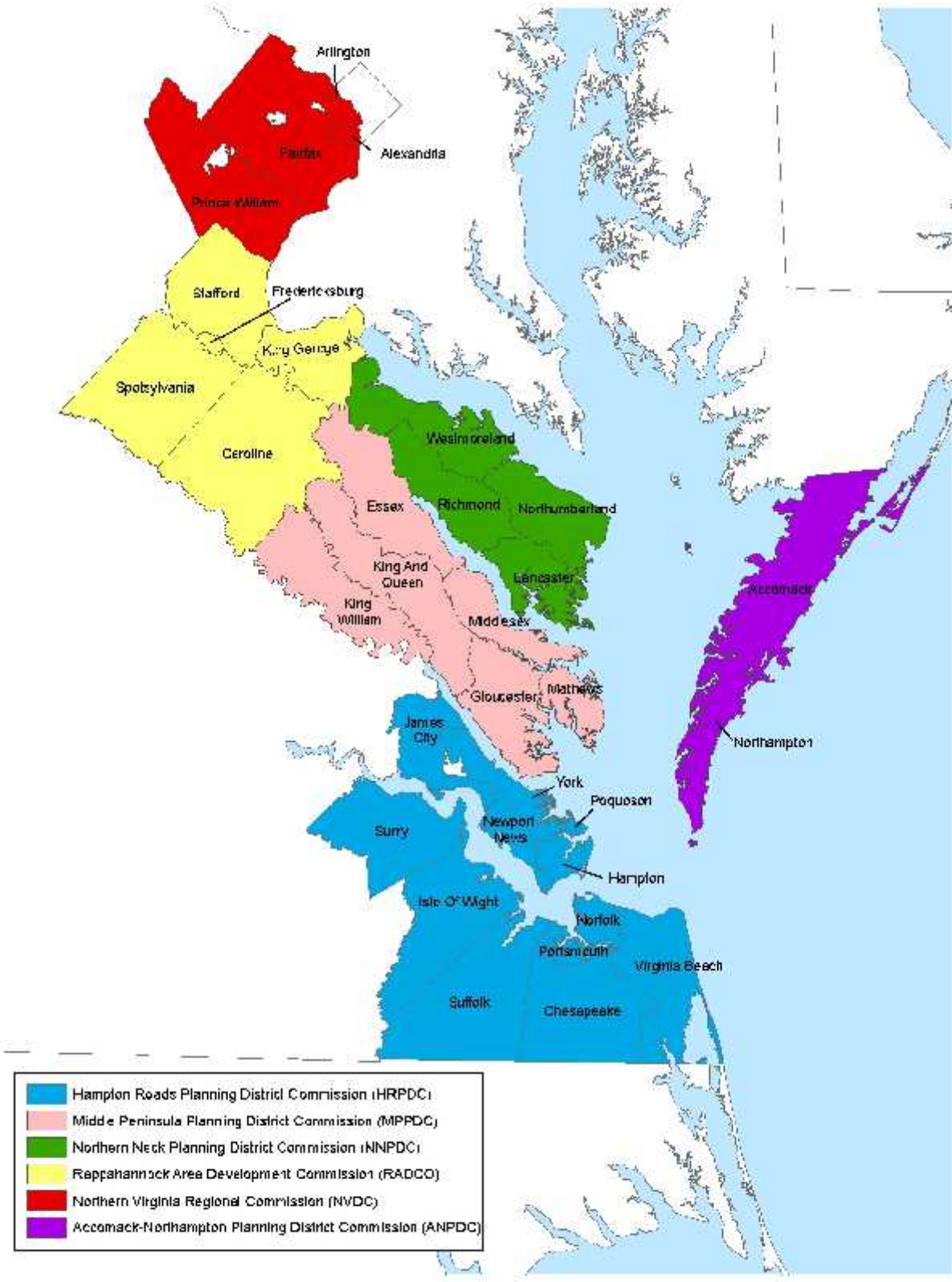


Figure 8-2. Map of Localities Included in Virginia Sea Level Rise Planning Study (grouped by Planning District Commission)

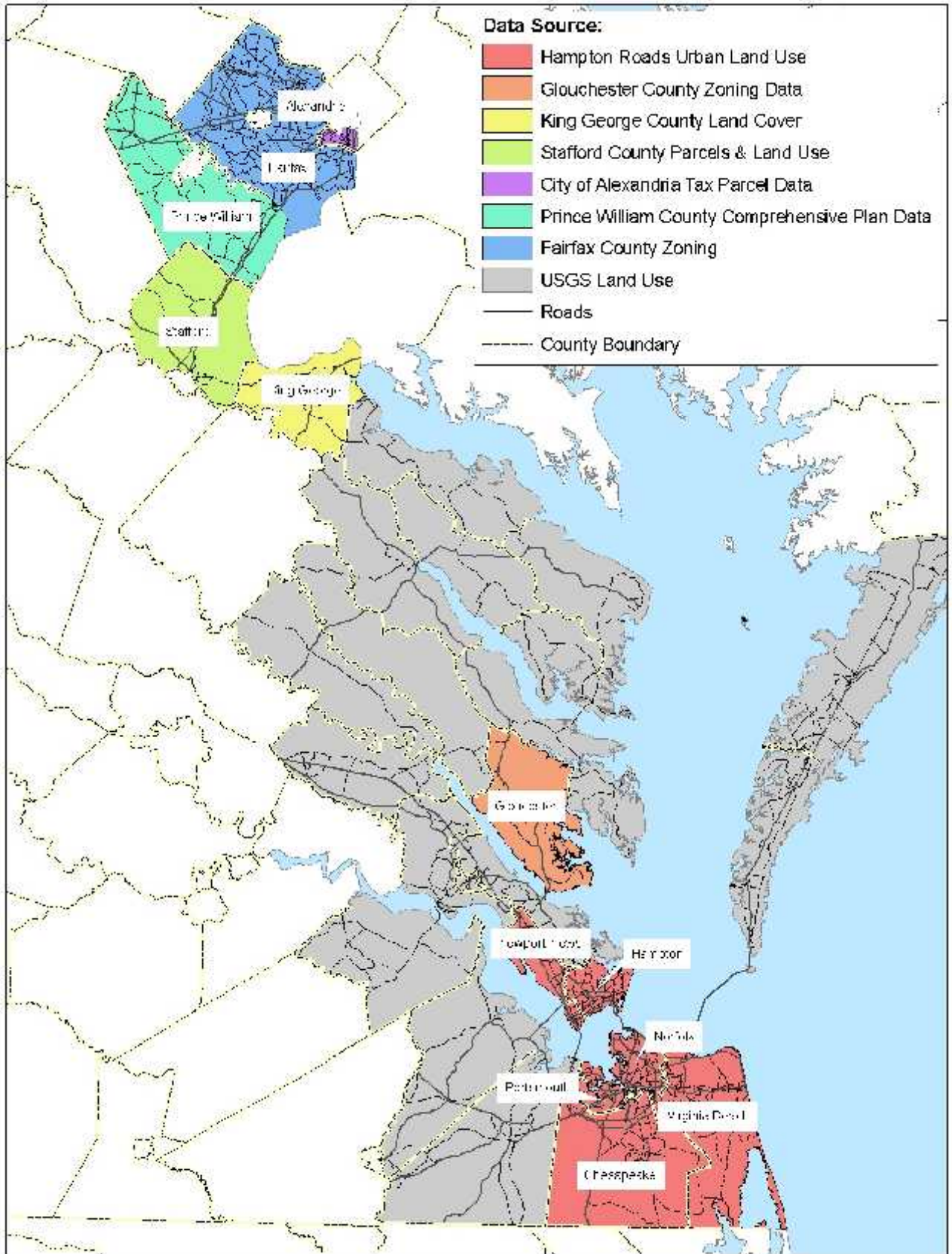


Figure 8-3. Map of Localities for Which This Study Incorporates Recent Land Use Data

level rise. Therefore, we had extensive telephone discussions with the PDC staff and the counties, particularly Accomack. EPA staff has been discussing which areas will be protected with Accomack County since the late 1990s and met with officials from the two most vulnerable island communities on Chesapeake Bay in 1998. Our initial draft maps followed a set of generic decision rules, which we discuss in the section on that planning district. We used those maps to elicit additional suggestions. Those generic decision rules, however, are not completely applicable and hence it was necessary for the local planners to provide site-specific changes, which we edited into the maps. We lacked digital data on future development, and countywide development trends do not necessarily correlate perfectly with shorefront development. In particular, this planning district has considerable high ground along Chesapeake Bay with road access. Given the desirability of a waterfront home and the absence of rules precluding such development, the existence of roads may be a good indicator of future development and shore protection. We then developed stakeholder review draft maps based on both the input from those meetings and the site-specific insights obtained from previous meetings with EPA staff. We sent the stakeholder review draft maps back to the counties, obtained several suggestions, and revised the maps accordingly.

Hampton Roads

Unlike with the other planning districts, we began by meeting with city, county, and regional planners at the PDC offices. The local planners generally felt that our generic approach based on existing data would provide a fairly accurate depiction of what is likely to be protected. They suggested one major change, which we fully implemented: We had identified existing developed areas using USGS and EPA data as certain or likely to be protected (depending on the density); the PDC provided a land use data set that is based on more recent data and has more accurate boundaries, based on previous planning assessments. That data set, however, covered only the “urban core” localities. The final maps use the USGS and EPA data for the other localities.

Middle Peninsula and Northern Neck

We revised the original maps from the VIMS study using generic decision rules and presented those revisions to PDC and local planners, who suggested site-specific changes given the more realistic sea level rise scenarios.

A key difference between these two planning districts and the Hampton Roads area (or Accomack County) is that most waterfront lands have a steep enough slope for waterfront homes to be above the coastal flood plain. As a result, most waterfront lands are suitable for development, and development is likely except for areas where government policies promote conservation. Even in areas that are currently undeveloped, if there is a road along the shore, development is likely to eventually occur.¹⁷ The PDCs lacked data that project coastal development, and so we used data on existing roads along the shore to identify future waterfront development likely to require protection.

A second difference was that, notwithstanding the lack of land use planning data, we were able to obtain shoreline armoring data for Northumberland, Lancaster, Mathews, Westmoreland, and Richmond counties. The fact that a shore has already been partly or completely armored is compelling evidence that it will be armored in the future.

Gloucester County is an exception. It provided zoning data and specific guidelines on which zoning classifications are certain, likely, and unlikely to be protected. Besides being the only county in these two planning districts to provide zoning data, it is also the only county to tell us it has conservation policies that make protection unlikely (and wetland migration likely) in some areas that would otherwise be densely developed and protected.

¹⁷An important exception to this generalization concerns areas near the heads of tide of the various tidal rivers, where sedimentation has generally caused extensive wetlands and dry land within the flood plain. Those areas are less likely to be developed given the availability of land with waterfront (as opposed to marshfront) view. A second exception is the small set of very low-lying communities, which includes the Guinea Peninsula in Gloucester County and Lewisetta along the Potomac River.

The final phase of this study involved the Rappahannock Area and Northern Virginia planning districts. Because VIMS had not already met with planners in these regions, we started by meeting with planners, obtained data where possible, and obtained specific decision rules regarding the land that would probably be protected. We then created maps and returned to the localities to obtain a stakeholder review.

Rappahannock Area

Staff of the Rappahannock Area Development Commission (RADCO) directed us to meet directly with planners in King George and Stafford counties.¹⁸ The King George planner specifically suggested the appropriate shore protection assumption for each portion of shoreline within the county and provided justifications in each case based on existing development. Stafford County provided zoning and land use data and specific assumptions appropriate for each classification.¹⁹ We developed maps for the entire planning district and a draft report based on the information, and sent them to the two counties and the RADCO offices, who then referred us to Caroline County as well. King George, Stafford, and Caroline counties suggested some refinements.

Northern Virginia

We met with representatives from the Northern Virginia Regional Commission, from Alexandria, and from Fairfax and Arlington counties. PDC staff suggested assumptions for Prince William County. We obtained data, created the maps and documentation, and sent the maps to all the jurisdictions except for Fairfax County. We met with local planners and obtained suggested changes. For Fairfax County, the planning data arrived while the other maps were being reviewed; as a result, we created a map using publicly available data and later revised the Fairfax map using county data.

General Comments on Interactions with Local Planning Staffs

The PDC staff facilitated coordination with local planning staff, and where appropriate, provided insights based on their experiences.²⁰ Their collective knowledge about local priorities allowed us to glean broad policy directions based on current and planned land use. For most counties and independent cities, the maps primarily reflect land use data and the judgments of the local planners; for a number of upstream jurisdictions with relatively little land vulnerable to sea level rise, the PDC staff provided the sole stakeholder input to map creation.

During the meetings, local officials indicated which policies and regulations have implications for coastal erosion, flooding, wetlands, or other consequences of rising sea level. For the most part, the local officials focused on the anticipated responses to a rise in sea level of 1 to 3 feet over the next 50 to 100 years.²¹ We also discussed public access to the water, economic conditions, areas of cultural or historical importance, and flood-prone areas.

Most of the planners provided “decision rules” for using land use data to make a map of the areas that are likely to be protected from rising sea level. The decision rules consider existing policies that influence shoreline armoring, beach nourishment, and the likelihood of future shoreline protection. We also asked the local officials to assess more directly the relative likelihood of protection for a given land or type of land. In those areas where the result of the decision rule was different from what the planner expected, we generally made a site-specific exception to the decision rule. In some cases, after additional discussion, the planner would decide that the result from the decision rule

¹⁸RADCO planners offered to provide the necessary assumptions for the other three localities with small amounts of tidal shorelines.

¹⁹King George County provided land cover data, but we used it only for defining the boundaries of government lands and for creating polygons that represented all land in the county along a particular river.

²⁰Because this assessment is intended to reflect the general consensus of officials within the area depicted, we rely heavily on the informed opinions of local planners. Although available land use data and land planning data guide the results and often defined the boundaries in these maps, the expert judgments of local officials generally were the most important source of information.

²¹We conducted a series of follow-up discussions to revise the original feedback the planners had provided regarding potential responses to a more dramatic sea level rise projection (up to 20 feet). The revised feedback reflects a more probable rise of 1 to 3 feet.

was probably more realistic than the planner's initial reaction. In a few cases, the conflict between the two led us to realize that a decision rule had been improperly specified or implemented.

The maps discussed in this report are generally based on various types of geographical data, which we used to match the designations in the decision rules. For example, we used the U.S. Geological Survey (USGS) National Land Cover Dataset from the University of Virginia GIS²² database to delineate currently developed lands (i.e., residential, commercial, industrial lands).²³ Table 8-4 identifies the data used in the analysis, and Appendix D provides additional detail on each source. In the statewide decision guideline and local response sections of this report, we identify key GIS data layers used to prepare the maps (see Table 8-5).

Map Scale

Because our maps are based on decision rules and previously published data, the horizontal resolution at which one should reasonably display our maps is limited by the precision of the input data. Because the quality of those data varies for different localities, so does the scale at which these maps ought to be depicted.

For most localities, the national land use data, with a scale of 1:250,000, served as the core data source. Stakeholder reviews generally were undertaken with county-scale maps at approximately a 1:200,000 scale, although the corrections were often based on features such as roads where the scale of our data was better. Conservation land used to identify specific conservation lands, and other special purpose data sets, generally had a scale of 1:24,000 or better. Nevertheless, those data sets do not dominate the analysis, and hence we recommend that users of our data treat these data as having a scale of 1:250,000 or better, for most jurisdictions.

We did have better data, however, for four jurisdictions along the Potomac River: Alexandria, Fairfax, Prince William, and Stafford. In general, the input data had a scale of 1:24,000 or better, and the stakeholder corrections were few. Therefore, we suggest that those maps can be viewed as having a scale of 1:50,000 or better. Although we also had high resolution local data from King George, most of the map designations were based on the site-specific knowledge provided by the local planner through annotations made on 1:100,000 scale maps. Therefore, we recommend a scale of 1:100,000. Finally, although Arlington did not provide local data, our map designations were based on road networks and other features where data was better than 1:100,000.

In the Hampton Roads area, we also had high resolution local data from Gloucester County as well as the urban Hampton Road PDC localities: Chesapeake, Hampton, Newport News, Norfolk, Portsmouth, and Virginia Beach. These local data were better than 1:24,000. Although a few hand edits were made at the 1:100,000 scale, they were not sufficiently numerous so as to deteriorate the scale to worse than 1:50,000. The maps for the remaining Hampton Roads jurisdictions were based on annotations to 1:100,000 scale maps or better, and were often based on features with scales of 1:24,000 (e.g., roads). Therefore, the maps for those jurisdictions (Isle of Wight, James City, Poquoson, Suffolk, Surry, York) are useful at a scale of 1:100,000.

Nevertheless, the quality of our input data is not the primary uncertainty associated with our map boundaries. Future development and shore protection are very uncertain. Thus, the scales we suggest are simply our advice regarding the maximum scale at which one ought to display the maps for a given location rather than our assessment of the accuracy of what will actually transpire in the decades ahead.

Use of Experts

This study is a hybrid between a pure data-driven assessment and an expert panel assessment. Like most assessments of shore protection, we start with the premise that (under current policies) lands will be protected if the cost of protection is less than the value of the resources being protected, except

²²In this report, geographical information system (GIS) generally refers to computer programs that can create maps and analyze site-specific data.

²³USGS National Land Cover Dataset for Virginia, accessed through University of Virginia Library Online, http://fisher.lib.virginia.edu/nlcd/browse_county.html.

for where specific policies dictate otherwise. But estimating the costs and benefits of shore protection at every location would have been infeasible—and possibly involve wasted efforts for areas where the question is not close.

Instead, we adopted a simpler model: First, we identify areas where conservation lands preclude shore protection, areas that governments have decided to revert to nature for flood mitigation or environmental reasons, and areas that are so densely developed that no one seriously doubts the likelihood of shore protection (given current policies). Second, along estuaries we assume that residential, commercial, and other developed lands will be protected and that undeveloped lands will not be protected.²⁴ We rely on local planners to help us correctly use land use, planning, and zoning data—and to apply current land use policies—to identify current and project future development. Third, along ocean coasts, our premise is that current shore-protection policies generally have defined the areas where beach nourishment is almost certain, and that shore protection is likely in other areas that reach high densities. All of these aspects of the study are essentially data-driven, using a very simple model of the areas where shores are protected.

Nevertheless, we had to rely on local planner opinions in those cases in which the necessary data are unavailable, are out of date, or provide an ambiguous result requiring a human tie-breaker. Most of the map changes provided by local planners involved cases where our data showed no development, but planners were aware of recent or imminent development. Occasionally they knew about plans to create a new park. In a few cases, planners suggested a threshold level of development density where shore protection would be likely—in effect providing a county-specific model parameter. In each of these cases, the planners provided a policy or economic basis, such as expected level of services (e.g., water and sewer) or the relative cost of protecting a low 2-

acre lot from being submerged compared with the cost of protecting a higher lot from shore erosion. Finally, in a small number of cases, planners reviewed our initial results, made a policy-based conjecture, and requested a map change.²⁵

Judgment-based map designations constitute a very small percentage of the land depicted in the maps in this study, which is mostly concentrated in Virginia Beach, Gloucester County, and King George County.

We hope that the way we document our results does not leave researchers with the impression that our estimates of the likelihood of shore protection are simply the opinions of planners on a subject over which they lack expertise. We rely on planners to help us identify current and future land use and identify policies related to development and shore protection—matters that fall within their responsibility. Given expected development, the favorable or unfavorable economics of shore protection—not planner opinions—generally determine our results.

For most readers, these distinctions may be of little interest. For brevity, the report often says “planners expect shore protection” at a specific location, when a more precise exposition of our analysis might say “planners provided us with data on existing land use data and/or master plans. These data, along with site-specific planner knowledge, imply a level of development that would more than justify shore protection if current policies and economic trends continue. Therefore, planners expect shore protection.”

²⁴The cost of shore protection along estuaries is small compared to property values in developed areas—and homes are rarely given up to retreating estuarine shores except for where policies prohibit shore protection.

²⁵For example, Virginia Beach suggested that isolated developments below the city’s rural line were unlikely to be protected.

TABLE 8-4. SUMMARY OF GIS DATA APPLIED IN VIRGINIA STUDY^a

Data Name	Application in Study	Source/Scale/Year Published
Military installations	Boundaries of military installations within study area	Bureau of Transportation Statistics/ 1:125,000/ 2001
Parks	National, state, and local parks and other managed lands within study area	Environmental Systems Research Institute (ESRI) Data CD/ 1:100,000/ 1999
Detailed city and county boundaries	Boundaries of Virginia independent cities and counties; identifies dry land	ESRI Data CD/ 1:100,000/ 2000
Initial study	Major transportation structures, central business districts, major coastal communities, tourist hubs, and lands slated for future development within Accomack, Northampton, Lancaster, Northumberland, Gloucester, Mathews, Middlesex counties as well as cities of Virginia Beach, Hampton, Poquoson, Norfolk, and Newport News	Virginia Institute of Marine Sciences (VIMS)/ 1:24,000/ 2001 (see Appendix A)
Land cover	Low and high intensity residential structures as well as commercial/industrial/transportation structures within study area ^b	University of Virginia/ 30 meters /1993 ^c
Land use/land cover	Developed lands (e.g., residential, commercial, and industrial lands) as well as undeveloped lands (e.g., agricultural and forest lands) ^d	U.S EPA through BASINS/ 1:250,000/ 1999
Nature Conservancy in Virginia	Nature Conservancy owned lands within Accomack-Northampton planning district.	The Nature Conservancy (TNC)/ est. 1:100,000/ 2003
Northern Neck armoring	Rip rap and bulkheads along Northern Neck shoreline based on tax parcel data	Northern Neck PDC/ est. 1:250,000/ 1997–1998
Richmond refuge data	Boundaries of the Rappahannock Wildlife Refuge	Richmond County/ 1:24,000/ 2004
Prince William County Comprehensive Plan data	Federal wildlife refuges, federal and state parks and open spaces, other public land, and private land along the Potomac River and connecting creeks and embayments in Prince William County	Prince William County/ 1:2,400/ 1998
City of Alexandria tax parcel data	Parks, open space, and privately held lands along Potomac River and connecting creeks and embayments in the City of Alexandria	City of Alexandria/1:100 ft/ 2004
Arlington County parks	Parks and open space in Arlington County	Arlington County/ 1:24,000/ 2003
Fairfax zoning	Identifies whether particular properties are public or privately owned and the land use classification zoned for the area.	Fairfax County/+/- 8 to 10 feet/ 2004
Gloucester County zoning data	Comprehensive plan zoning areas such as residential, suburban, rural, and conservation zones	Gloucester County/ 1:4,000/ 2000
Hampton Roads urban land use	Developed residential, commercial, industrial, institutional/educational lands, undeveloped vacant, agricultural, forest lands, and recreational lands within Hampton Roads’ “urban core”	Hampton Roads PDC/est. 1:24,000/ 2002
Virginia Beach Comprehensive Plan	Delineates urban, transitional, and rural areas	Virginia Beach/ not available/ 2003
Projected 2050 Chesapeake land use	Map of 2050 land use approved by Chesapeake City Council to delineate projected urban, transitional, and rural areas in Chesapeake	City of Chesapeake/ not available/ 2003
King George County state lands	State-owned lands within King George County	King George County/ 1:24,000/ 2000
King George County federal lands	Federal-owned lands within King George County	King George County/ 1:24,000/ 2000
King George County land cover	Location of developed and undeveloped areas	King George County/ 1:24,000/ 2000
Stafford County parcels	Boundaries of two parcels north of Potomac Creek and South of Accokeek Creek	Stafford County/ est. 1:24,000/ 2003
Stafford County land use	Location of developed and undeveloped areas.	Stafford County/ est. 1:24,000/ 2003
Delorme Road Atlas	Parks in Hampton Roads planning district that did not provide updated land use data and coastal areas where roads indicate current or future development in Middle Peninsula	Delorme/2000
Major roads	Lands to be protected along a roadway corridor	ESRI Data CD/2001 and U.S. Census Tiger/2000
Study area	Landward boundary of study area (study area includes lands that are lower than 20 feet in elevation or within 1,000 feet of spring high water based on tidal wetlands data)	ICF Incorporated/2003
Wetlands	Location of tidal and nontidal wetlands as well as open water	ICF Incorporated/1971–1992

^a Appendix D gives additional detail on each data source.

^b Land cover data do not necessarily identify the actual boundaries of residential, commercial, or industrial properties. Because they are based on the observed land cover; for example, if the “back 40” acres of an industrial facility consist of trees adjacent to a commercial forest, those 40 acres will often show up as forest rather than industrial.

^c Available at University of Virginia Library Online http://fisher.lib.virginia.edu/nlcd/browse_county.html;

^d This data set was developed from remote sensing data obtained from late 1970s to early 1980s and therefore does not reflect more recent development.

VIRGINIA COASTAL POLICIES AND REGULATIONS

Virginia has not developed an explicit policy to address the consequences of rising sea level. Nevertheless, policies designed to protect wetlands, beaches, and private shorefront property collectively constitute an indirect implicit policy. Overall, the state's policy is to assist local government efforts in nourishing public beaches, preventing new buildings within 100 feet of most tidal shores, preventing most dredging and filling of tidal wetlands, allowing most forms of shore protection structures, and informing property owners of nonstructural options.

Land Use

The Virginia Department of Environmental Quality established the Virginia Coastal Resources Management Program in 1986 as a network of state laws and policies through which the Commonwealth and its coastal localities manage environmentally sensitive coastal lands.²⁶

Tidal Wetlands Act²⁷

The Tidal Wetlands Act seeks to "...preserve and prevent the despoliation and destruction of wetlands while accommodating necessary economic development in a manner consistent with wetlands preservation".²⁸ The act provides for a wetlands zoning ordinance that any county, city, or town in Virginia may adopt to regulate the use and development of local wetlands. Under the ordinance, the localities create a wetlands board consisting of five to seven citizen volunteers. The jurisdiction of local boards extends from mean low water (the Virginia Marine Resources Commission

has jurisdiction over bottom lands seaward of mean low water) to mean high water where no emergent vegetation exists, and to somewhat above spring high water²⁹ where marsh is present. The board grants or denies permits for shoreline alterations within their jurisdiction.

The Marine Resources Commission has jurisdiction over the permitting of projects within state-owned subaqueous lands. It also must "... promulgate and periodically update guidelines which scientifically evaluate vegetated and nonvegetated wetlands by type and describe the consequences of use of these wetlands types."³⁰ VIMS advises the commission. The commission has guidelines for wetlands, subaqueous lands, and coastal primary sand dunes and beaches. The commission has also published a pamphlet of best management practices for shoreline development that might affect wetlands, beaches, and subaqueous lands. The commission also reviews proposed projects in localities that have no local wetlands board by virtue of not having adopted a wetland zoning ordinance.

Coastal Primary Sand Dunes and Beaches Act

Virginia's Dunes and Beaches Act preserves and protects coastal primary sand dunes while accommodating shoreline development. The act identifies eight counties and cities that can adopt a coastal primary sand dune zoning ordinance, somewhat analogous to a Tidal Wetlands ordinance: Accomack, Northampton, Virginia Beach, Norfolk, Hampton, Mathews, Lancaster and Northumberland³¹; all but Hampton and Accomack have done so. The structure of the act is similar to the Tidal Wetlands Ordinances. The act

²⁶For more specifics about the Virginia Coastal Program and the regulations currently in place, see <http://www.deq.state.va.us/coastal/about.html>.

²⁷This discussion is drawn from Trono, K.L., 2003, *An Analysis of the Current Shoreline Management Framework in Virginia: Focus on the Need for Improved Agency*. As of December 1, 2004, the report was posted as *Virginia Shoreline Management Analysis Report* on the Virginia Coastal Program's publications web page at <http://www.deq.state.va.us/coastal/publications/html>.

²⁸VA Code §28.2-1302

²⁹The act grants jurisdiction to an elevation equal to 1.5 times the mean tide range above mean low water.

³⁰VA Code § 28.2-1301.

³¹See C.S. Hardaway, L.M. Varnell, D.A. Milligan, G.R. Thomas, and C.H. Hobbs, 2001, *Chesapeake Bay Dune Systems: Evolution and Status*, Virginia Institute of Marine Science.

defines beaches as (1) the shoreline zone of unconsolidated sandy material; (2) the land extending from mean low water landward to a marked change in material composition or in physiographic form (for example, a dune, marsh or bluff); and (3) if a marked change does not occur, then a line of woody vegetation or the nearest seawall, revetment, bulkhead, or other similar structure.

Chesapeake Bay Preservation Act

The Chesapeake Bay Preservation Act³² seeks to limit runoff into the Bay by creating a class of land known as Chesapeake Bay Preservation Areas. The act has also created the Chesapeake Bay Local Assistance Board (“the Board”) to implement³³ and enforce³⁴ its provisions. Although the act defers most site-specific development decisions to local governments,³⁵ it lays out the broad framework for the preservation areas,³⁶ and provides the Board with rulemaking authority to set overall criteria.³⁷ The Board has issued regulations³⁸ defining the programs that local governments must develop to comply with the act.³⁹

All localities must create maps that define the locations of the preservation areas, which are subdivided into resource management areas⁴⁰ and

resource protection areas (RPAs).⁴¹ RPAs include areas flooded by the tides, as well as a 100-ft buffer inland of the tidal shores and wetlands.⁴² Very little development is expected in this 100-ft buffer. Within the buffer, development is generally limited to water dependent uses, redevelopment, and some water management facilities. Roads may be allowed if there is no practical alternative. Similarly, for lots subdivided before 2002, new buildings may encroach into the 100-ft buffer if necessary to preserve the owner’s right to build; but any building must still be at least 50 feet from the shore.⁴³ Property owners, however, may still construct shoreline defense structures within the RPA. The type of shoreline defense installed is not regulated (beyond certain engineering considerations). Consequently, hard structures can be installed anywhere along Virginia’s shoreline.

For purposes of this study, there is one important difference between Virginia’s laws regarding coastal development along Chesapeake Bay and Maryland’s Critical Areas Act. The Maryland statute has designated specific Resource Conservation Areas within 1,000 feet of the upper edge of the wetlands, where no more than one home is allowed per 20 acres. Virginia has no such density restriction. As a practical matter, the differences between the statutes do not necessarily imply that more of Virginia’s coastal zone will be developed and require shore protection. Economic trends and local land use policies have historically had a greater impact on coastal development than has state regulatory policy. State policies regarding infrastructure such as bridge and tunnel crossings may have an even greater impact.

Although the structures tend to be initially constructed landward of mean high water, neither

which development is concentrated or redevelopment efforts are taking place may be designated as Intensely Developed Areas (IDAs) and become subject to certain performance criteria for redevelopment. Private landowners are free to develop IDA and RMA lands, but must undergo a permitting process as well to prove that these actions will not harm the RPAs.

³²Code VA §10.1-2100 *et seq.* As of August 8, 2003, the Act was posted on the Virginia Legislative Information System website as part of the Code of Virginia at: <http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+TOC1001000002100000000000>.

³³Code VA §10.1-2102.

³⁴Code VA §10.1-2104.

³⁵Code VA §10.1-2109.

³⁶Code VA §10.1-2107(B).

³⁷Code VA §10.1-2107(A).

³⁸Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 *et. seq.*).

³⁹Virginia Administrative Code §10-20-50.

⁴⁰The act also provides for Resource Management Areas (RMAs), which are lands that, if improperly used or developed, have the potential to diminish the functional value of RPAs. Finally, areas in

⁴¹Virginia Administrative Code §10-20-70.

⁴²Virginia Administrative Code §10-20-80 (B).

⁴³Virginia Administrative Code §10-20-130 (4).

Virginia nor Maryland⁴⁴ requires their removal once the shore erodes to the point where the structures are flooded by the tides. Nor has either state prevented construction of new replacement structures within state waters.

Erosion Control Permits

Virginia has a fairly elaborate procedure for issuing permits for erosion control structures. The Virginia Coastal Program's web page recently posted a fairly detailed analysis of this process.⁴⁵ The process is designed to avoid destruction of wetlands or other adverse environmental impacts. The focus of the regulations and the review processes, however, is on direct short-term damage to the environment. The long-term impact on the environment from preventing the landward migration of tidal habitats is not considered.

Beach Nourishment

Until 2003, the Board on Conservation and Development of Public Beaches promoted maintenance, access, and development along the public beaches of Virginia. This board was also known as the "Public Beach Board." The largest beach nourishment projects have been along the 13 miles of public beach along the Atlantic Ocean in Virginia Beach. Annual fill projects have added 200,000 to 300,000 cubic yards of land along the shore between 1st and 59th Streets.⁴⁶ A \$100 million Hurricane Project was completed in 2001, including both a seawall and a major sand replenishment project. During the last 50 years, the State has provided 3 percent of the funding for beach nourishment at Virginia Beach, and the local and federal shares are 67 and 30 percent, respectively.

Virginia has made a greater effort than Maryland to maintain beaches (and public use of beaches) along Chesapeake Bay and its tributaries.

Norfolk's four guarded beaches serve 160,000 visitors each summer. Erosion along the shore threatened property, the tourist economy, and local recreation. At a cost of approximately \$5 million, the Beach Board helped the city construct a series of breakwaters with beachfill and a terminal groin. Across the James River, the City of Newport News and the Beach Board split the cost of a \$1 million beach restoration project at Anderson Park, Huntington Park, and King-Lincoln Beach Park. The City of Hampton's Buckroe Beach along Chesapeake Bay has had a severe erosion problem. Throughout the Beach Board's lifetime, it provided \$1.3 million for headland breakwaters and beach nourishment. Immediately to the north, at the Salt Ponds public beach, the Beach Board funded a geotube project with a small amount of sand covering the tubes. More recently, the Beach Board provided \$300,000 for a breakwater and beach nourishment project along the public beach of the Town of Cape Charles on the Eastern Shore. Along the Potomac River, the Beach Board supported efforts by the Town of Colonial Beach to maintain its beach with a combination breakwater and beachfill project, contributing \$274,000 to this effort. Farther up the river at Aquia Landing in Stafford County, the Board provided \$235,000 and technical support for a headland breakwater system and beachfill project. The Board has also supported beach restoration efforts along the York River.

⁴⁴The Maryland/Virginia border along the Potomac River is the low water mark. Courts have not ruled whether Maryland or Virginia environmental rules would govern a structure in Maryland waters attached to Virginia land. See the section on Northern Virginia, below.

⁴⁵This discussion is drawn from Trono, 2003 (see note 27 for full reference).

⁴⁶Virginia Public Beach Board, 2000, *20 Years of Coastal Management*, Board on Conservation and Development of Public Beaches, Richmond, VA.

STATEWIDE TENDENCIES REGARDING LONG-TERM SHORE PROTECTION

Table 8-5 summarizes the general procedures that this report uses to identify the likelihood that specific parcels of dry land will be protected. Planners tended to agree that the state's general policy favoring shore erosion control provides us with a basis for anticipating responses to sea level rise.⁴⁷ This section reviews how we applied our general approach statewide, including typical GIS decision rules used to create maps, given the state policies. The actual assumptions used to create the maps are documented in the sections on the specific planning districts; this section simply provides a general overview. Even within specific planning districts the maps depart from this general approach in many cases for site-specific reasons, which are documented in the region-specific sections of this report.

Areas colored brown in our maps depict places where coastal protection is almost certain. Those areas include highly developed residential (typically with houses within 150 feet of each other), commercial, and industrial areas, as well as locally designated growth areas.⁴⁸ In most cases, private or public investment is considerable and expected to continue. Many of these areas are already armored with hard structures. Existing armoring does not necessarily mean that the shore will be protected no matter how much the sea rises, only that the shore will be protected at some point in the future.

In addition to those areas where available data allow one to automatically map the areas likely to be protected using the decision rules, the study followed a number of general procedures based on the input from local planners. The VIMS study

obtained initial judgments from planners of Atlantic and Chesapeake Bay localities defining the areas that would be protected from erosion and inundation under any imaginable sea level rise scenario. Some versions⁴⁹ of our maps depict those areas in orange, unless stated otherwise.⁵⁰ Following that initial meeting, local planners reviewed the general decision rules based on land classifications, and generally accepted those rules. During follow-up meetings, planners often provided modifications, identifying areas where protection is almost certain regardless of the data classification. For example, coastal areas with low-density development often have development concentrated along the Bay, a river, or a creek, and frequently the waterfront homes have extremely high property values even though nonwaterfront lots are inexpensive. The planners generally agreed that these homes will not be abandoned. In many cases we identified these areas based on a roads data layer.

⁴⁹The VIMS study is unusual and no similar assessment exists for any other area. For statewide (and nationwide) consistency, we exclude the orange in one set of maps. To provide all the information available, however, we include the orange in another set of maps.

⁵⁰Northampton and Middlesex county planners told us that a few of the VIMS areas were incorrect, and asked us to revise the maps to show those areas as "protection likely" or "protection unlikely." Because the Gloucester zoning data have precise boundaries whereas the VIMS study digitized boundaries at a coarse but unknown scale, we relied on the zoning data wherever they contradicted the polygons provided by VIMS. Northumberland also made a minor refinement to the VIMS assumption during our initial discussions. Maps distributed during the stakeholder review for those counties did not distinguish the orange and brown. Operationally, this study accepted the VIMS study as valid and thus as one source of areas that are almost certain to be protected. We only overrode its designations when there was no logical alternative.

⁴⁷We identify anticipated response guidelines based on discussions with local planners.

⁴⁸We delineate these areas based on information provided by local planners.

TABLE 8-5. STATEWIDE GENERAL APPROACH FOR IDENTIFYING LIKELIHOOD OF SHORELINE PROTECTION OF DRY LAND^a

Likelihood of Protection	Land Use Category
Protection almost certain (brown)	Existing developed land (commercial/industrial/residential) within growing and densely populated areas
	Areas currently protected by hard coastal armoring structures
	Undeveloped lands within growth areas ^b
	Valuable waterfront homes in areas where protection would otherwise be classified as “likely”
Protection likely (red)	Existing development ^c outside of growth areas
	Recreational parks in developed areas, especially those along the shore
	Secured federal installations (except for installations within highly urbanized areas)
	Valuable waterfront development in areas where protection would otherwise be classified as “unlikely”
	Projected future development outside of growth areas
Protection unlikely (blue)	Anticipated growth areas identified based on existence of nearby shore parallel roads or dense network of roads
	Undeveloped, privately owned lands with no expectation of significant future development
No protection (light green)	Recreational parks and other publicly owned lands where shore protection seems unlikely but would not impair intended use
	Private lands owned by conservation groups (when data available) ^d
	Publicly owned natural lands such as state parks and national wildlife refuges, ^d where policies imply a preference of natural processes over protecting dry land
	Private lands where government policy precludes shore protection

^a These general procedures describe the initial assumptions, before site-specific modifications were made to the maps. All site-specific departures from this procedure are discussed in the planning district sections of this report.

^b Growth areas are identified from local comprehensive plans and conversations with local officials.

^c Existing development is identified based on the USGS National Land Cover Dataset from 1992 for Virginia, accessed through University of Virginia Library Online at http://fisher.lib.virginia.edu/nlcd/browse_county.html.

^d Conservation and publicly owned lands are identified from USGS Dataset, US Geographic Data Technology Inc., accessed from 2000 ESRI Data and Maps CD number 3.

Areas depicted in red represent lands that are probably going to be protected from the sea. Although protection is likely for a given locality, at least a few of the areas depicted as likely to be protected will ultimately not be protected. Possible reasons might include that expected development does not occur as planned; that environmental concerns about the need to preserve natural shores lead governments or conservancies to prevent the armoring of this shore through regulation or acquisition; that undeveloped land ultimately becomes parkland as part of the subdivision process; or that the costs of coastal protection prove to be greater than expected.

As a general rule, areas that planners identify as rural development or suburban (typically zoned for plots of less than 2 acres) are considered likely to be protected. In addition, those areas where planners anticipate future development are also identified as likely to be protected. Given that

shoreline armoring is relatively inexpensive relative to property values along most of the Virginia shore, most developed areas are likely to be protected. Nevertheless, lands outside of major growth areas are less likely to have sewer and other major infrastructure investments, and less likely to be densely developed. Therefore, if economic or environmental concerns precluded as much shore protection as currently seems likely, growth areas would have a higher priority for shore protection than nongrowth areas. For the most part, planners told us the areas where they expected significant development; in a few cases, they provided digital planning or zoning data⁵¹ or a hard-copy map.^{52,53} We supplement their input

⁵¹ Gloucester, Stafford, Prince William, and Fairfax counties.

⁵² Suffolk, York, and James City counties.

⁵³ Planners indicated that in general, residential areas (typically 2-acre lots or smaller) are certain to be protected, whereas the more rural areas (typically between 2- and 5-acre zoning) are likely to be

with an analysis of the road networks in each locality. For our purposes, a highly developed road network and roads parallel to the shore in an undeveloped area that is expected to otherwise remain agricultural would indicate future shorefront development and an increased likelihood of protection.

We also depict secured federal installations in red, unless they are located in areas that are almost certain to be protected or we had evidence that the area is currently protected from erosion and flooding. State and local officials were generally not in a position to make authoritative statements about the fate of such installations, and federal facilities are generally exempt from the coastal land use planning that applies to private lands. Hence this study does not attempt to identify the response to sea level rise by military bases or other secured installations.

The blue areas represent lands whose owners are currently allowed to erect shoreline armoring but are not likely to do so. The most common reason for assuming that an area will not be protected would be a planning policy that explicitly prohibits or discourages development. In many remote areas in Virginia (where zoning typically sets the minimum plot size as 5 acres), development is unlikely for the foreseeable future even if local officials would welcome it. Coastal development is a reasonable possibility even in many remote areas, however, because so many Americans would like to own waterfront property. Nevertheless, Virginia allows property owners to hold back the sea to protect their land, undeveloped or otherwise⁵⁴; and some farmland has been protected with rock revetments. Moreover, development could occur in areas where local officials do not foresee it. Therefore, one might reasonably expect that some of the areas shown in blue may eventually be protected.

Finally, we depict areas that would not be protected given current policies in light green. For the most part, these are publicly owned lands that

are managed for conservation.⁵⁵ In addition, where information is available, we also depict privately owned lands managed for conservation in light green.⁵⁶ Parks and other lands that are important recreational areas, however, are considered likely to be protected and mapped as red whereas government lands used for schools, offices, residential, and industrial uses are typically considered almost certain to be protected. This study considers only shore protection for dry land. Measures may be undertaken to protect wetlands as well, but because such decisions would be made by different people and based on different considerations, we leave those matters for another study. Nevertheless, these maps include wetlands for context. The majority of tidal wetlands are within The Nature Conservancy's barrier island reserves along Virginia's Eastern Shore. The next largest block is the tidal wetlands of the Big Salt Marsh and the Plum Tree Island National Wildlife Refuge in Poquoson. Depending on the wetlands data set used, some lands may be depicted as tidal wetlands (dark green), nontidal wetlands (purple), or dry land such as conservation areas (light green).⁵⁷ For example, dunes and other high ground on undeveloped barrier islands are sometimes classified as "wetlands" even though they may be as dry as similarly situated land on developed islands. Recognizing that wetlands data sets may be improved—and that wetlands are migrating inland as sea level rises—we designed this study so that the data we produce can be used to with different wetlands data sets.

⁵⁵We map national, state, and local parks and forests based on data available from US Geographic Data Technology Inc., accessed from 2000 ESRI Data and Maps CD number 3.

⁵⁶Maps from The Nature Conservancy also outline major and private lands managed for conservation in the Chesapeake Bay region: The Nature Conservancy—Virginia: available at <http://nature.org/wherewework/northamerica/states/virginia/>.

⁵⁷Even with a given wetlands data set, whether a particular parcel shows up as wetland or dry land often depends on the particular criteria used for wetland delineation. In addition, newer data sets show recent changes in land use and may have more accurate boundaries.

protected. Only Gloucester County, however, provided data to identify these areas by zoning areas.

⁵⁴Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et seq.).

REGIONAL POLICIES AND SEA LEVEL RISE RESPONSE SCENARIOS

The coastal zone of Virginia includes both rural areas (e.g., Accomack, Northampton, Northumberland, Lancaster, Middlesex, Mathews, and Gloucester) and a highly developed urban core at the mouth of Chesapeake Bay collectively known as Hampton Roads (Poquoson, Hampton, Newport News, Norfolk, and Virginia Beach). The jurisdictions all operate with locally elected governments (city councils or county boards of supervisors). City and County zoning ordinances are the predominant planning and land use regulatory mechanisms. In this section, we provide background information on each locality's⁵⁸ potential vulnerability to the impacts of sea level rise, and then describe the anticipated future response. This information begins with the Accomack-Northampton PDC and is then organized from south to north by planning district commission (PDC).

⁵⁸The state of Virginia is subdivided into counties and independent cities. Cities have some governmental powers that counties lack. Although cities generally have higher population densities and less land than counties, some cities have annexed adjacent counties (e.g., Virginia Beach). This report uses the term “locality” to refer to both cities and counties in Virginia. Counties also have incorporated towns; but their participation in this study was minimal.

THE VIRGINIA EASTERN SHORE: ACCOMACK AND NORTHAMPTON COUNTIES

Background

Most of Virginia's lands close to sea level are in the Eastern Shore counties of Accomack and Northampton. These two counties contain 70 percent of the state's tidal wetlands. Accomack also contains 18 percent of the dry land within 2 feet above the tides, as well as three developed islands that are potentially vulnerable: Tangier, Saxis, and Chincoteague.

The rural Eastern Shore of Virginia is approximately 70 miles long and 5 to 10 miles wide, with the Atlantic Ocean to the east and Chesapeake Bay to the west. These shorelines provide a wealth of recreational and tourist opportunities for residents and visitors alike. A number of small towns and villages lie along the shoreline, but the majority of the land area is either undeveloped or used for agricultural purposes. The population of the region grew modestly from approximately 45,000 in 1990 to 51,000 in 2000. Development pressures are not heavy yet.

The need to cross the 17-mile Chesapeake Bay Bridge-Tunnel to reach the Hampton Roads area has made commuting impractical for most people, given the \$20 round trip toll and the occasional severe traffic jams when an accident occurs. Recently, however, the bridge portion was expanded to two lanes in each direction, and the one-day roundtrip toll was reduced to \$14. As a result, many observers expect development to increase soon in the southern portion of the county, especially along the bayside. Some people commute from northern Accomack County to Salisbury and other towns in southern Maryland, and Chincoteague is a popular resort and gateway to Assateague Island National Seashore. This county seems likely to develop slowly for the foreseeable future. Still, the coming decades may see an increase in development of seasonal homes,

tourism, and commercial activity given the natural beauty of the region.

The vulnerabilities of Accomack and Northampton counties are very different: Ecosystems are potentially vulnerable in Northampton, and several communities are vulnerable in Accomack.

Accomack County

Vulnerability to Sea Level Rise

Rising sea level is already converting farmlands to tidal wetlands. Oftentimes one can observe corn and other crops on low land near the Bay or a tributary, and on closer inspection some of the rows of crops will be broken by wetland vegetation. Land that might have been arable a few years ago gradually becomes nonarable because of salt contamination from tidal flooding. (See Photos 8-1 through 8-5.) Given the 14.1 square miles of dry land within 2 feet above the wetlands, a linear interpolation implies that the county has 47 acres within one eighth of an inch (3 millimeters) above the tides. As a result, it may be realistic to assume that 474 acres of wetland are created per year from the gradual inundation of low-lying farms.

The county's land use policies recognize the low-lying character in several ways that will tend to influence the ultimate response to sea level rise.⁵⁹ Currently, only Onancock and Tangier have sewage treatment plants. Because of the reliance on septic tanks, soils determine where development goes. Moreover, densities are restricted in the coastal floodplain. Because of these factors, along Chesapeake Bay, development is mostly occurring toward the southern half of the county, where elevations are relatively high. The

⁵⁹The County currently requires floor elevations of new homes to be 1 foot above the base flood elevation; Dave Fluhart, Stakeholder Review Meeting.

barrier islands are all owned by the federal government, state government, or The Nature Conservancy. Along the coastal bays on the Atlantic side, the combination of county policies, environmental factors, and economic trends tends to encourage development in the northern areas near Chincoteague, Wallops Island/NASA, and the Maryland line while discouraging development along the bays opposite The Nature Conservancy's lands. The county continues to grow.⁶⁰

Accomack's three developed islands, Tangier, Saxis, and Chincoteague, have their own town governments with land use authority. Tangier Island is in the middle of Chesapeake Bay, with passenger ferries to Crisfield, Maryland, on the Eastern Shore, Onancock in Accomack County, and Reedville on the Northern Neck of Virginia. Photos 8-6 through 8-9 provide an overview of this Tangier. The town is built on several ridges that once represented the highest ground, but now represent the only dry land. Channels separate each of these ridges now, so that strictly speaking there are several islands. Shore erosion is also severe, necessitating shoreline armoring, particularly on the north side. Approximately 90 percent of the structures are within the 100-year floodplain.⁶¹ USGS topographic maps show the entire island as below the 5-ft contour, except for about half of Canton Ridge. Given the tide range and historical sea level rise, the USGS maps imply that the entire island would be flooded by the tides with a rise in sea level of 2 to 3 feet.

Tangier is as vulnerable as many of the "Small Island States" that researchers and the news media often discuss as potential victims of rising sea level, such as Tuvalu, Marshall Islands, and the Republic of Maldives. Like those atoll republics, here a unique culture is threatened with extinction, only it may be even more immediately vulnerable than those nations. Although one might normally assume that a picturesque island in the United States would have greater resources for holding back the sea, Tangier is a fishing community. The decline of oysters and other shellfish in Chesapeake Bay has reduced incomes, and the fill

dirt necessary to enable the island to keep pace with rising sea level is relatively expensive given the island's remote location.⁶² Town officials believe that subsidence is exacerbating the effects of sea level rise on some portions of the island.⁶³

Yet despite its vulnerability, there are reasons to believe that Tangier could survive rising sea level. First, the island has a sewage treatment system, so homes will not be condemned as yards are saturated. It also has a new K-12 school, and a small but viable summer tourism industry. Thus the state has shown a willingness to invest a level of resources that presumed the continued existence of this community. Moreover, the U.S. Army Corps of Engineers has an ongoing project to halt erosion on Tangier Island, based in part on the historical significance of the island.

Saxis is also vulnerable island community. Fortunately, two-thirds of the developed part of the island is above the 5-ft contour, but the northern portion of the island is only about 4 feet above NGVD,⁶⁴ that is, approximately 2 feet above the tidal wetlands. The island has a severe erosion problem. The community is actively attempting to secure Corps assistance with its erosion problem.

Moreover, the population is at risk during storms because the nearest high ground is 15 miles away, and the evacuation route along Saxis Road runs through Sanford, which is lower than Saxis; slow drainage there can leave water a foot or so above the water level in the Bay. The causeway through the marsh appears to be compacting, possibly because the fill includes pine logs.⁶⁵ Moreover, the marsh through which the road passes is starting to degrade, increasing the threat of waves and washout during storms even today. Although protection of infrastructure is outside the scope of this study, Saxis officials communicated a strong concern that infrastructure planners consider whether the road needs to be redesigned to withstand and possibly mitigate problems

⁶²One possible source of relatively inexpensive fill would be oyster shells. Historically, oysters harvested by Tangier residents were processed in Crisfield, Maryland.

⁶³Stakeholder Review Meeting.

⁶⁴Based on statement made to Jim Titus by an owner of one of the houses in this area, who had paid for a survey, August 1998. USGS 7.5-minute maps depict this area as below the 5-ft NGVD contour.

⁶⁵Stakeholder Review Meeting.

⁶⁰Stakeholder Review Meeting.

⁶¹The airport and about 25 structures are outside the floodplain; Stakeholder Review Meeting.

associated with marsh degradation, subsidence,

commercial fishermen, and it somewhat higher



Photos 1–5. Low-Lying Areas in Accomack County: South Chesconessex. Photos 1 and 2 show very low agricultural lands that are converting to wetlands as salt contamination prevents corn from growing but fertile lands promote growth of equally tall transition wetlands vegetation. Note the low dike in 2. Photos 3 and 4 provide two angles from the end of the road in Chesconessex. Photo 5 shows grass turning brown because of salt contamination, with wetland vegetation in background.

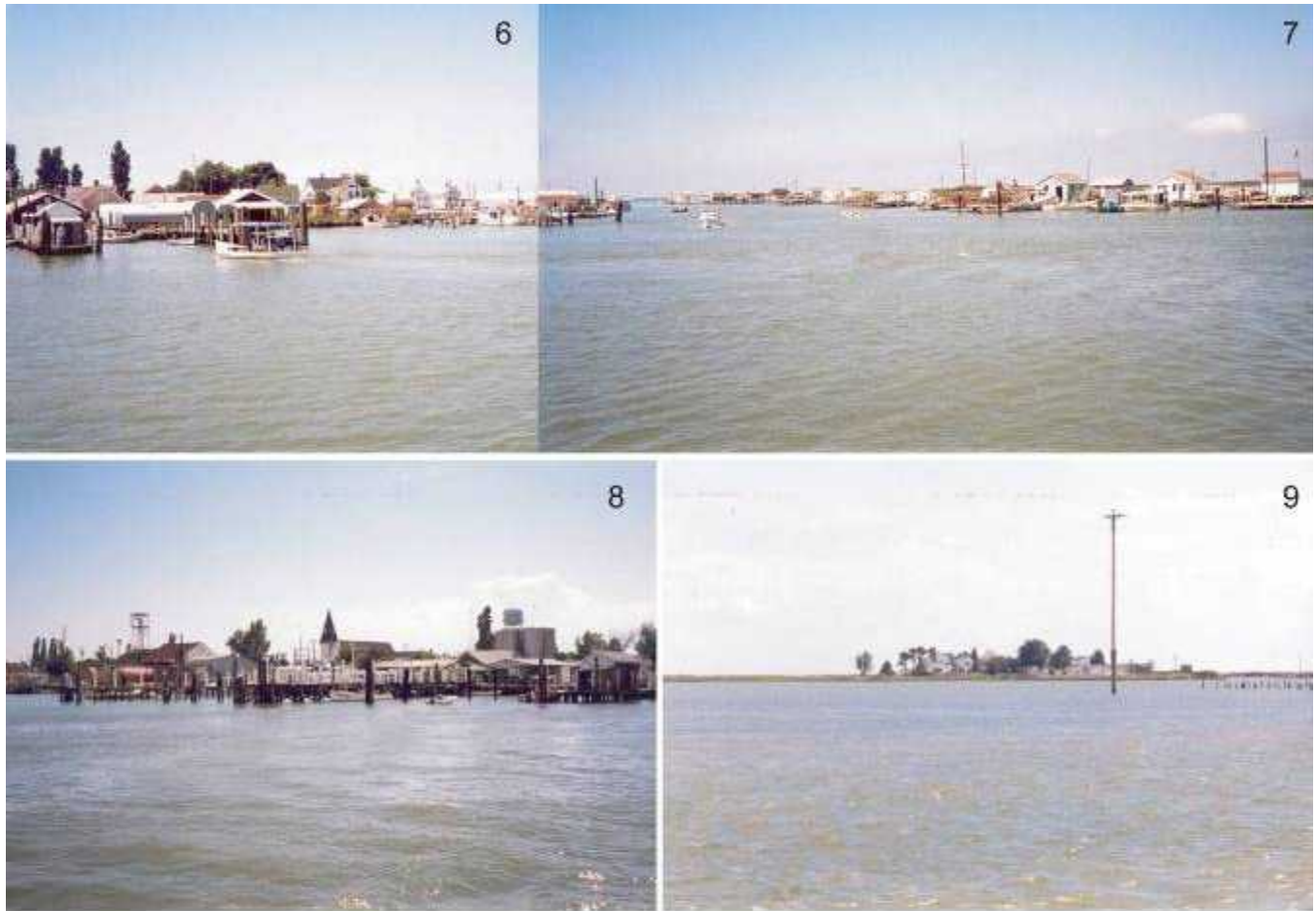
and rising sea level.⁶⁶

Chincoteague is a coastal resort community just inland of the southern portion of Assateague Island, a barrier island that extends into Maryland and is entirely within Assateague Island National Seashore. As the southern gateway to the national seashore, Chincoteague provides overnight accommodations for people making day trips to the barrier island, and many restaurants and shops. The island also has both recreational and

than both Saxis and Tangier. Given the tourism revenues, Chincoteague has the economic ability to maintain itself in the face of rising sea level, and erosion protection costs are less than those for Tangier and Saxis because the wave climate is more benign in Chincoteague Bay than in Chesapeake Bay.

Photos 8-1 and 8-2 show very low agricultural lands that are converting to wetlands as salt contamination prevents corn from growing but fertile lands promote growth of equally tall transition wetlands vegetation. Note the low dike in 8-2. Photos 8-3 and 8-4 provide two angles from

⁶⁶Stakeholder Review Meeting.



Photos 6–9. Tangier, Virginia. Photos 6 and 7 show both sides of the navigation channel that now bisects the island. Aside from fishing shanties, the north side is uninhabited. Photo 8 shows the main part of the town, approaching on a ferry from the Eastern Shore. Photo 9 depicts a remote section separated from the rest of the town by marsh.

the end of the road in Chesconessex. Photo 8-5 shows grass turning brown because of salt contamination, with wetland vegetation in background.

Photos 8-6 and 8-7 show both sides of the navigation channel that now bisects the island. Aside from fishing shanties, the north side is uninhabited. Photo 8-8 shows the main part of the town, approaching on a ferry from the Eastern Shore. Photo 8-9 depicts a remote section separated from the rest of the town by marsh.

Anticipated Sea Level Rise Responses

Unless otherwise stated, based on meetings and correspondence with⁶⁷:

Jim McGowan, Accomack-Northampton PDC; David Fluhart and Sandy Manter, Accomack County; Dennis Crockett, Tangier Town Council and principal, Tangier Combined School; Dewey Crockett, mayor of Tangier; Barbara Dawby, Town Council, Saxis; and Charles Tull, mayor of Saxis.

Report and maps revised based on Stakeholder Review Meeting⁶⁸ with:

Jim McGowan, Elaine Meil, and John Aigner, Accomack-Northampton PDC; David Fluhart,

⁶⁷Pratap Penumalli spoke with McGowan in October 2002, Manter on November 7, 2002, and Fluhart on November 26, 2002. Jim

Titus met with Sandy Manter and David Fluhart at Accomack in July 1998, with the Tangier officials on Tangier in August 1998, and with Saxis officials (including Mayor Tull) and Dave Fluhart at Saxis in September 1998.

⁶⁸Meeting with Will Nuckols, February 13, 2004, at the Accomack-Northampton Planning District Commission (ANPDC) offices.

Accomack County; Bill Reynolds, Town of Tangier; and Charles Tull, mayor of Saxis.

Most of the development is being concentrated either along Chesapeake Bay (bayside) in the southern half of the county or along the coastal bays (oceanside) in the northern and southern portions of the county (but not along the central portion). With some exceptions, those are the primary areas that county officials expect to be protected. Map 8-2 shows the three populated islands as almost certain to be protected.

The island towns of Saxis and Tangier are confronting erosion and inundation and are committed to their own continued existence. The county planners are unsure about whether Tangier and Saxis can economically justify holding back the sea if the rate of sea level rise accelerates, and hence were inclined to classify those communities as likely—but not certain—to be protected. Nevertheless, for purposes of these maps, they agreed to defer to the responsible town officials, who have primary land use authority. Although Chincoteague is not currently threatened, the planners all agree that the revenues it generates make it more likely to survive almost any reasonable sea level rise scenario than the other two islands.

Our maps show NASA-owned lands as red because of EPA's general approach of showing secured federal installations as protection uncertain, unless we have additional information showing that another classification is appropriate.⁶⁹

On the mainland oceanside, the planners of Accomack County generally expect the growing communities of Greenbackville and Captains Cove to be protected. Those areas are thus shown as brown. Development there is likely to be extended south to the entrance to NASA, and hence that area is shown as likely to be protected. In the southern

portion of the county along the coastal bays, Accomack planners also consider protection to be almost certain for Wachapreague and Quinby, and for Bradford Neck in between those two communities. Along Chesapeake Bay, the historic villages of Harbortown and Onancock are sure to be protected, as well as Broadway Neck and other areas around Onancock.

Protection is likely, but less certain, for a number of more lightly developed areas. Local planners suggested that interior areas in and around Whitesville are in the likely-to-be-protected category, as is Custis Neck on the mainland opposite Cedar Island. They suggested that although these communities are reasonably well developed, they have not demonstrated a commitment to taking measures to hold back the sea and therefore cannot be listed as certain. Sanford is also marginal. The demand to live in this remote, nonwaterfront community is not great, and the costs of maintaining an operating septic system and elevating homes may encourage the abandonment of this community, particularly if a severe hurricane were to destroy it. Still, as long as Saxis survives, the state's commitment to maintaining Saxis Road will provide Sanford with an anchor of dry land. Moreover, rising sea level may eventually convert the miles of marsh between Sanford and Saxis to open water, in which case the value of buildable waterfront lots would be greater than the value of today's marshfront lots.

Most of the farms and forests in this county seem unlikely to be protected. Nevertheless, Accomack County planners identified two areas where agricultural productivity is great enough to justify protection even if they are not developed: the areas southwest of Onancock and west of Wachapreague.

To protect the rural way of life, subdivisions are discouraged in some of the traditionally agricultural areas. Yet development is likely to continue in this coastal county, especially in waterfront areas. Given the areas where growth is generally being directed, the planners agreed that a reasonable way to account for future growth in undeveloped areas would be to assume that those areas south of Onancock with shore-parallel roads

⁶⁹Local officials indicated that NASA would continue to fortify the island if faced with rising costs of shore protection at its Wallops Island facility. Our general approach in this study is that federal expectations yield to states, which yield to counties, which yield to incorporated towns, which yield to property owners, because the smallest unit has the best understanding of the situation. In the case of a federal installation, the federal agency is the property owner and hence is best equipped to project the fate of its land as sea level rises.

will probably be developed over time with waterfront homes, and that those homes will probably be protected. Because of the high ground in that region, protecting waterfront homes from erosion has the effect of protecting the inland areas as well.⁷⁰

The remaining undeveloped areas are unlikely to be protected. Along the oceanside, The Nature Conservancy has a policy of allowing the barrier islands to respond to natural processes, so the barrier islands south of Wallops Island are light green. Because development is directed toward the bayside in southern Accomack, the land along the coastal bays is unlikely to be protected. Similarly, most private farms and forests on the bayside in the northern part of the county will probably continue to gradually convert to wetlands as sea level rises.

Table 8-6 summarizes the data used to implement these planning judgments. The planning agencies for Accomack County do not currently have land use or zoning maps in digital format. Therefore, the boundaries of the existing developed communities are based on USGS land use data.

The Stakeholder Review meeting included representatives from the PDC, the county, Saxis, and Tangier. The reviewers provided numerous changes for the text, but suggested only two map changes regarding the land that is likely to be protected.⁷¹

- ***The southern portion of Tangier Island should not be shown as protected.*** The most accurate depiction would be to show it as

⁷⁰This assumption was applied to the entirety of Northampton County's bayside as well.

⁷¹Planners also suggested that the maps should show the road leading to Saxis as protection almost certain. The road is low lying and floods periodically. Planners believe that the road is subsiding because the periodic inundation leads to compaction of the pine log fill. This study, however, shows protection of only land, not infrastructure. Even if the roadway is protected with fill, the roadbed through the marsh is too narrow to show up on the scale of maps depicted in this study.

wetland, but to the extent that a particular



Photo 8-10. Cape Charles, Virginia. Dunes along the beach at Cape Charles are just to the left of the photo, with the primary road along the shore to the right.

classification scheme might consider the sandy beach to be dry land, it will probably not be protected.

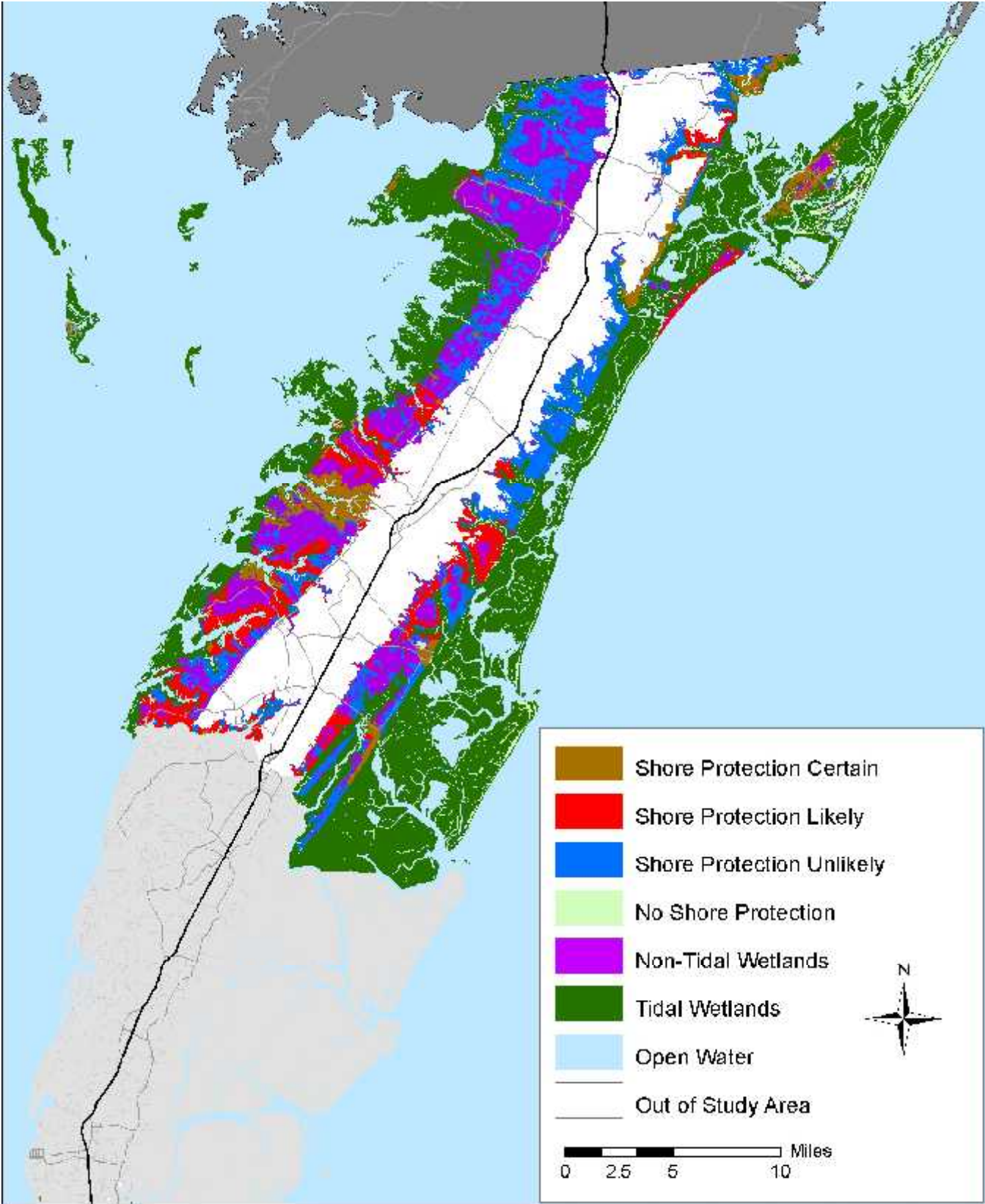
- ***The NASA Wallops Island facility is certain to be protected.*** The planners were aware of the nationwide approach to depicting secured facilities as red pending input from the agencies that manage them, unless it is certain that the land would be protected even if the installation were to close. The planners are quite certain that this facility will not be closed and will be protected. Nevertheless, we leave this area as red, until NASA indicates a preference regarding the most appropriate way to classify the likelihood of shore protection.⁷²

Northampton County

Vulnerability to Sea Level Rise








As the second poorest county in Virginia, Northampton County's median income in 1998 was \$19,000, whereas the state median income

⁷²Our nationwide approach is to code federal secured installations in rural areas as "military" and depict them as red, rather than ask local officials to speculate on the intentions of federal officials.



Map 8-2. Accomack: Likelihood of Shore Protection. The caption and detailed legend for this and the other locality-specific maps is located on the following page.

Map 8-2. Accomack County: Likelihood of Shore Protection. For each shore protection category, the darker shades represent lands that are either less than 20 feet above spring high water. This map is based on data published between 1997 and 2004. Although the map also reflects site-specific changes suggested by planners in 2003 and 2004, the intended use of this map is to convey city and county-wide prospects for shore protection, not to predict the fate of specific neighborhoods. Changes in the policies and trends we considered—or factors that we did not consider—may lead actual shore protection to deviate from the likelihoods depicted in this map.

Map Legend	
Transportation Network	
	Toll and Other Limited Access Roads
	Highway
	Major Road
	Local Road
	Railroad
Political Boundaries	
	State Boundary
	County Boundary

Map 8-2 (continued). Accomack County: Likelihood of Shore Protection. This legend defines the meaning for the transportation network and political boundary symbols used in the city and county-specific maps.

was \$28,000. Less than 3 percent of the county land has residential, commercial, or industrial development today. The county's planners generally view the county's prospects for future development as limited by its lack of drinking water and its relatively remote location. Nevertheless, some people believe that the current perception that Northampton is a long way from the Hampton Roads area will eventually be replaced with the equally valid perception that it is less than 20 miles from that metropolis. Some have speculated that the reduction in tolls from \$20.00 to \$14.00 per round trip and the increased bridge capacity⁷³ may fuel development.⁷⁴ County planners believe that the recent rush to buy land around the Town of Cape Charles in the past 3 years may be partly due to the decline in toll rates. The Bay Creek Development in Cape Charles continues to grow.⁷⁵ Nevertheless, planners expect that Northampton will remain a largely undeveloped region for the foreseeable future.

Northampton, like Accomack, has about one-third of the state's coastal wetlands (see Table 8-3). The county also has about 6 square miles of dry land within 2 feet above the tides, which ranks third behind Accomack and Virginia Beach. Nevertheless, the implications of sea level rise are very different. Northampton's lands along Chesapeake Bay are relatively high, with substantial cliffs near the mouth of the Bay. As Photo 8-10 shows, the Town of Cape Charles has wide sandy beaches along Chesapeake Bay, unlike the narrow beaches and muddy bay shores along Accomack County. Although it is entirely above

the 5-ft (NGVD) contour, it is the lowest lying community in the county. Most of the town is below the 10-ft contour, and vulnerable to severe storms; the dunes shown in the photograph provide protection from moderate surges. Northampton's lowest dry⁷⁶ land, however, is mostly on the barrier islands, all of which are undeveloped.

The absence of low lands on the mainland implies that aside from the Town of Cape Charles, the primary impact of sea level rise for the foreseeable future will probably be erosion. Because of the relatively high ground, the county has many potential bayfront lots with elevations above the 20-ft contour, compared with Accomack County where tidal marshes and forested wetlands are between the dry land and the Bay.

Anticipated Sea Level Rise Response

Unless otherwise stated, based on meetings and correspondence with:

Jim McGowan, Accomack-Northampton PDC⁷⁷; and Beverly Harper, Northampton County⁷⁸

Report and maps revised based on Stakeholder Review Meeting⁷⁹ with:

Jim McGowan, Elaine Meil, and John Aigner, Accomack-Northampton PDC; Samantha Pitts, The Nature Conservancy; Sandra Benson, Northampton County; and Laura Attwood, Town of Cape Charles.

Accomack County officials have developed a thorough perspective on sea level rise, so it was possible to create maps reflecting numerous site-specific considerations. Within Northampton County, local officials have not spent a great deal of time thinking about sea level rise; therefore our mapping approach followed a more data-driven approach, based primarily on an assessment of where development is likely in the future. (See Map 8-3).

⁷³The bridge-tunnel originally consisted of a two-lane bridge over most of the bay, with two-lane tunnels under the shipping lanes. To reduce accidents and accident-related congestion, the Authority constructed parallel bridges, so that there are two lanes in each direction for the bridge portion of the crossing, but not the tunnel crossing.

⁷⁴The Joint Legislative Audit and Review Commission (JLARC) in Virginia, however, concluded that this would not have a significant effect on growth in the Eastern Shore. See Leone, P.A., "The future of the Chesapeake Bay Bridge-Tunnel," p. 27, November 2002. Accessed September 3, 2003 at <http://jlarc.state.va.us/Reports/rpt287.pdf>. Nevertheless, ANPDC expects that development probably would increase if the toll were to drop. Paradoxically, advocates for keeping the high toll include both those who want to limit development in southern Northampton County and those who want to raise the funds necessary to build a second set of tunnels.

⁷⁵Stakeholder Review Meeting.

⁷⁶Dry is a relative term here, because those islands are occasionally overtopped by storm surges.

⁷⁷Daniel Hudgens spoke with McGowan in October 2002.

⁷⁸Telephone conversations with Pratap Penumalli, October 17 and October 29, 2002.

⁷⁹Meeting with Will Nuckols, February 13, 2004, at the ANPDC offices.

The Nature Conservancy owns most of the ocean coast in Northampton County. The planners in Northampton—as well as TNC itself—agree that The Nature Conservancy has a policy to not hold back the sea with shoreline armoring or beach nourishment. Therefore, the barrier islands are shown in light green. Currently, TNC manages its islands, known as the Virginia Coastal Reserve, primarily for nature preservation, but also allows public visitation.⁸⁰ Fisherman’s Island is also shown in light green, because it is part of a National Wildlife Refuge.

The few developed areas where protection is certain are defined by the USGS land use and land cover data for developed areas. These represent the location of residential, industrial, commercial, and institutional (e.g., county office building) lands.

The most difficult part of this exercise was identifying those undeveloped areas that will probably be developed eventually and protected. Along Chesapeake Bay, looking several decades into the future, it is realistic to assume that wherever there is a road along the water, someone will eventually build a home. The proximity to Hampton Roads, the high ground, and the spectacular waterfront views all make development inevitable (unless shorefront lands are acquired by the government or conservancies, or dedicated as part of the subdivision). Thus, the bayfront areas will probably be protected. Because this is high ground threatened with erosion but not inundation, protection of the shorefront inherently protects areas immediately inland. On the eastern side of the county, we followed a similar approach. A greater portion of the coastal lands there, however, is along wetlands rather than open water. The maps assume that development (and hence shore protection) is unlikely for areas that currently lack roads and for areas where the roads service farms along wetlands but not open water. The PDC offered one exception to this general approach: All of Willis Wharf is at least likely to be protected.

Development pressures are not nearly as strong today in the Eastern Shore as in many other areas

of the Virginia coastal zone, so the planners do not believe that it would be justified to assume that development will certainly occur along these coastal areas, or that landowners will definitely choose to hold back the rising seas. Therefore, as evidenced by the planning maps for the region, red—or likely to be protected—prevails as the decision rule for much of the undeveloped land.⁸¹

The Stakeholder Review Meeting identified more changes for Northampton County than for Accomack, probably because Northampton had not participated during the original phase of the study. The County asked for the following map changes:

- ***All of the historic portion of Willis Wharf is certain to be protected.*** This historic community has homes that were originally on Hog Island, before that island was abandoned and converted to a wildlife refuge. Our original maps showed only a portion of the area as certain to be protected, based on relatively coarse land cover data.
- ***Show the Village of Red Bank as certain to be protected.*** The original map had shown this important fishing village as unlikely to be protected.
- ***Show the Village of Oyster as certain to be protected.*** Based on the road density, the original map had shown this area as likely to be protected.
- ***Show all of the Town of Cape Charles as certain to be protected.*** The original report showed a mixture of brown, blue, and red, depending on existing development and road densities. Development is continuing and all land within the town borders will be developed soon.
- ***Change Old Town Neck from protection certain to protection likely.*** This lightly developed neck had been shown as protected even in the VIMS worst-case analysis. The

⁸⁰The Nature Conservancy–Virginia; available at <http://nature.org/wherewework/northamerica/states/virginia/>.

⁸¹Given that landowners are allowed to armor their shoreline to protect their property from rising seas and increased erosion, the decision on whether or not to do so will be largely an economic one.

planners suggested that this designation had probably resulted from a mapping error.⁸²

- ***Show the state park on Savage Neck as a conservation land.*** The draft had erroneously assumed this polygon to be private land unlikely to be protected.

⁸²The planners' best guess was that perhaps VIMS had mistakenly digitized this neck, thinking it to be Cape Charles. We examined the VIMS data and found that both Old Town Neck and the downtown portion of Cape Charles were assumed protected in the VIMS study. We made the requested change without investigating further.

TABLE 8-6. ASSUMPTIONS FOR SHORE PROTECTION MAP: ACCOMACK-NORTHAMPTON PLANNING DISTRICT^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Military lands			b		Military installations
NASA lands, including Wallops Island			b		Land use/land cover
Old Town Neck			✓		Stakeholder review comments implemented using initial study data ^c
Major coastal jurisdictions: downtown area of Cape Charles, Accomack, Chincoteague				✓	Planner input from initial study ^c
Nature Conservancy lands	✓				The Nature Conservancy in Virginia
Conservation land at southern end of Savage Neck	✓				Stakeholder review comments implemented using land use/land cover
National and state park lands	✓				Virginia parks
Historic portion of Willis Wharf				✓	Stakeholder review comments implemented using land use/land cover
Other residential developments in Northampton (including Village of Red Bank, Village of Oyster, and Town of Cape Charles)				✓	Stakeholder review comments implemented using land use/land cover
Developed land cover				✓	Land cover ^d
Coastal areas with higher potential for development that have existing shore parallel roads			✓		Implemented using TIGER roads and land use/land cover ^e
Lightly developed areas within Accomack County, including Whitesville, Curtis Neck, and Sanford			✓		Manual edit implemented using land use/land cover
Land with high agricultural productivity southwest of Onancock and west of Wachapreague				✓	Manual edit implemented using land use/land cover
Island towns of Tangier and Saxis				✓	Manual edit implemented using land use/land cover ^f
Developed private and public lands				✓	Land use/land cover ^g
Remaining public and private lands (including agriculture)		✓			Land use/land cover ^h

^a Where land areas overlap, classifications higher in the table take precedence.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

^c The initial 2001 VIMS study created polygons representing areas that were certain to be protected in the event of a 20-ft sea level rise. These areas are depicted in orange in some versions of our maps.

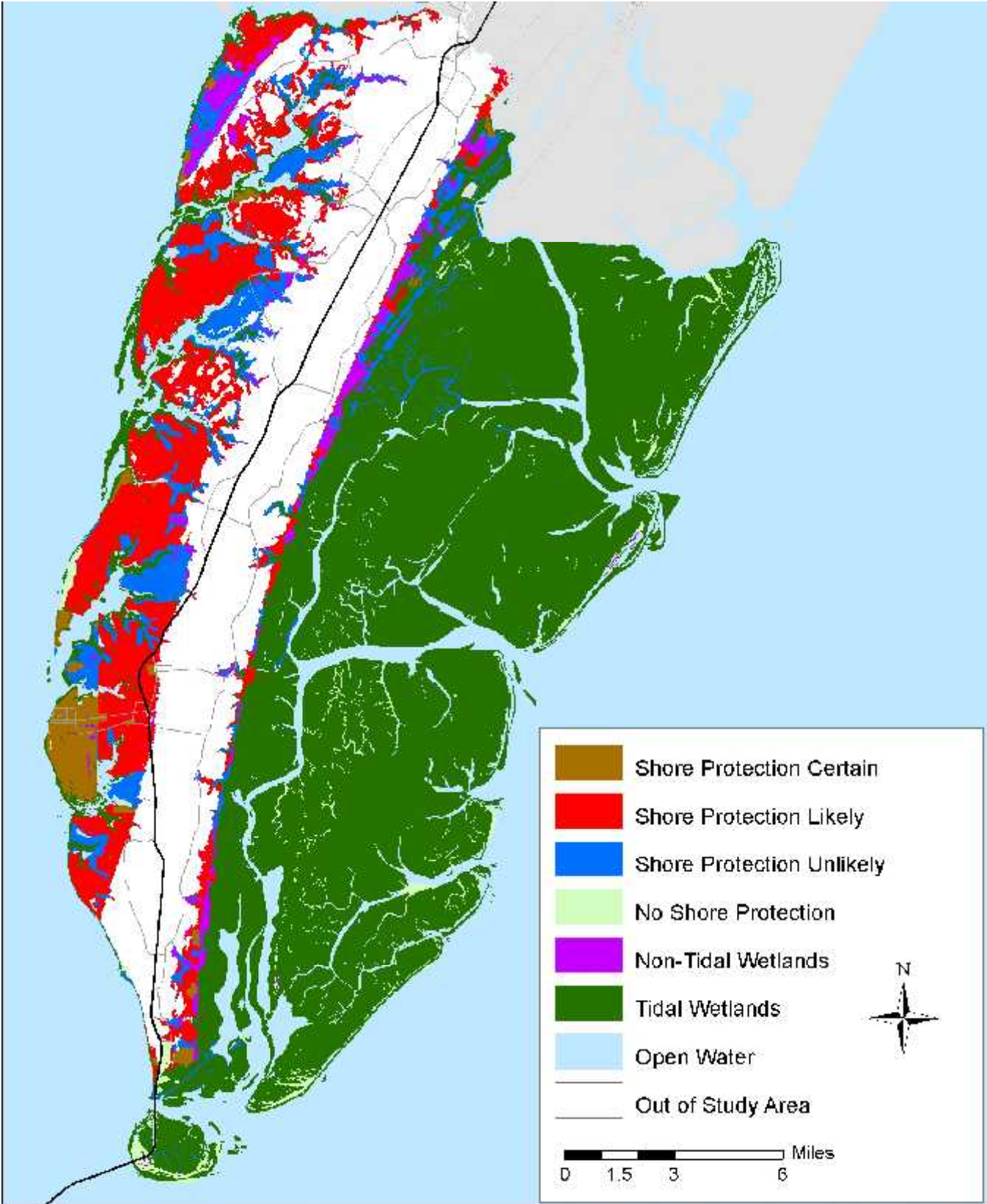
^d We identify developed land cover, which includes both public and privately owned lands, based on residential, commercial, industrial, and transportation structure land covers in data provided by USGS.

^e To identify coastal areas with likelihood of further development, we identified polygons from the land use/land cover data that were within 1,000 feet of a shore parallel road (from 2000 TIGER roads layer).

^f In the fall of 1998, Jim Titus of EPA briefed the mayors and some members of the town councils of these two island towns. Both town governments assured EPA that they have been—and will continue to do—everything within their power to ensure that their communities survive, including shore armoring or elevating land surfaces with fill if necessary.

^g Developed lands included residential, commercial/services, transportation/communication/utilities, institutional, and other urban/built-up land use/land covers in data provided by USGS.

^h Undeveloped lands included cropland/pasture, confined feeding operations, other agricultural land, deciduous forest land, evergreen forest land, mixed forest land, nonforested wetland, beaches, sandy area, and strip mine land use/land covers in data provided by the USGS.



Map 8-3. Northampton: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

HAMPTON ROADS PLANNING DISTRICT

Background

Hampton Roads is the southernmost coastal planning district in Virginia, extending from the North Carolina border to the York River. The PDC coordinates planning activities among 16 localities whose combined population is more than 1.5 million. Lands vulnerable to sea level rise include beaches along the Atlantic Ocean and Chesapeake Bay, both sides of the lower James River, a barrier spit and back barrier bays near North Carolina's Outer Banks, and parts of the York River.

Because of data limitations, our discussion divides the Hampton Roads Planning District⁸³ into two groups: localities for which the PDC has recent data on land use and those for which it does not. Figure 8-4 depicts the jurisdictions within each group. The PDC provided land use data for Virginia Beach, Chesapeake, Norfolk, Newport News, Hampton, and Portsmouth. Lacking a better term, we call these six cities the "urban core localities." Virginia Beach and Chesapeake⁸⁴ also have rural and transitional developing areas. By "urban core" we mean all the urban core localities except for the rural and transitional areas of Chesapeake and Virginia Beach. The localities for which we lack recent land use data are the independent cities of Suffolk and Poquoson, plus Isle of Wight, Surry, York, and James City counties. Lacking a better term, we call these six localities "outlying jurisdictions." Poquoson and part of York County are along Chesapeake Bay; the remaining localities are along the James and York rivers west of the urban core.

Norfolk is home to the central business district of the Hampton Roads region and consists of more

than 90 percent developed land, but both the city's economy and population have been declining for a number of years. According to the U.S. Census Bureau, the city's population dropped from more than 261,000 in 1990 to approximately 234,000 in 2000. Therefore, the local government is taking measures to redevelop and revitalize the urban core. One example is the successful revitalization of the Oceanview area along the northern shore of Norfolk over the past decade. Previously infamous for its high crime rate and undesirable living conditions, Ocean View is now a thriving community with a number of growing single-family-home neighborhoods and a drastically reduced crime rate. A similar effort with a number of civic groups is under way to redevelop the Ward Five area in the south.

Virginia Beach relies heavily on tourism to drive its local economy. The beaches and beachfront commercial and residential property in the north are highly developed, and the south remains pristine and largely undisturbed. Newport News has development similar to Norfolk along its southern shores, with bluffs and less dense residential areas farther north along the coast. The city of Hampton is also highly developed, but overall has a much smaller percentage of commercial and industrial development than Norfolk or Newport News. Norfolk and Newport News are also home to a number of private naval shipyards and coastal military naval establishments. In Norfolk, these shipyards are located on the western shore near the central business district and served as the backbone of the local economy for nearly a hundred years. The Fort Eustis military reservation occupies the majority of the northern third of Newport News.

Outside the urban core, localities are more rural in nature. Although Norfolk is undertaking a number of efforts to draw residents and development back into the city, many localities outside of the urban core are trying to keep development out. These

⁸³The VIMS study and our initial meeting for the second phase of this study involved meetings with Virginia Beach, Norfolk, Newport News, Hampton, and Poquoson. Pratap Penumalli met with Surry County, and Jim Titus discussed study assumptions over the telephone with officials from Chesapeake. For the remaining jurisdictions, the maps are based primarily on the data and input from the Hampton Roads PDC staff.

⁸⁴Hampton and Newport News also have undeveloped areas, but within the coastal zone those areas are expected to become developed within the foreseeable future.

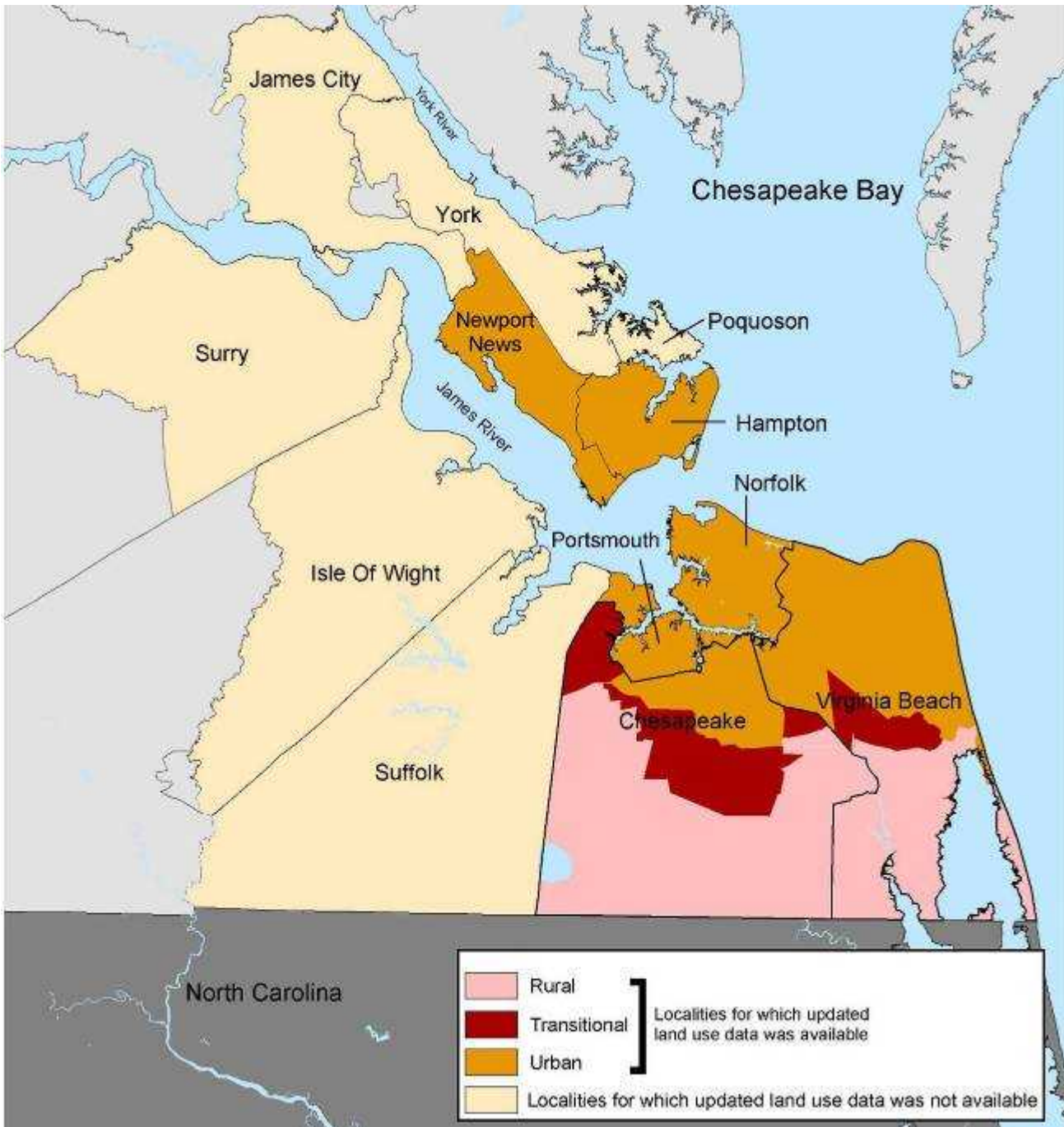


Figure 8-4. The Hampton Roads Planning District. The Planning District Commission was able to provide updated land use data for 6 of its 12 localities. Among those 6 localities, our analysis distinguishes the urban core, the rural area, and the transitional developing area.

localities find themselves facing mounting development pressures, and their comprehensive plans outline how they plan to respond to these pressures. Isle of Wight, Surry, James City, and York counties all face development pressure. Overall, however, the makeup of these outlying localities is a mix of urban and rural development,

with historic towns and residential development dotting the landscape. The Town of Poquoson is an exception, being both extensively developed and very vulnerable to sea level rise: The town is approximately 50 percent wetland and is almost entirely below 10 feet in elevation.

Vulnerability to Sea Level Rise

Table 8-7 summarizes the amount of land close to sea level within each of the Hampton Road localities. As shown, most of the vulnerable dry land is located within Virginia Beach and Chesapeake. These low areas are not, however, in the urban portions of those jurisdictions. As the map shows, most of Virginia Beach's very low land above the ebb and flow of the tides is either along the back-barrier bays near the North Carolina border or along the North Landing River. The southern and modestly developed half of this city is mostly within 10 feet above spring high water. Most of Chesapeake's low land is around the Northwest River near the North Carolina border, or the along the Intracoastal Waterway.⁸⁵ The Great Dismal Swamp along the border between Suffolk and Chesapeake is mostly between the 10- and 25-ft contours. Hampton and Newport News have substantial areas between the 5- and 10-ft contours, with a few areas that are within 2 feet above the tides.

Poquoson is probably the community that is most vulnerable to rising water levels. (See Photos 8-11 and 8-12.) Virtually the entire community is below the 10-ft contour, with several neighborhoods vulnerable to even minor surges in Chesapeake Bay. In the wake of Hurricane Isabel, dozens of homes were elevated (Photos 8-13 and 8-14).

Shore erosion may confront areas with higher ground. Virginia Beach has sandy shores along both the Atlantic Ocean and the mouth of Chesapeake Bay. Much of the developed ocean shore is protected by a seawall (Photos 8-15 and 8-16), and periodic beach nourishment projects have been necessary. Its bay shore, by contrast, has substantial dunes, with homes set well back from the shore in some areas. The shoreline areas have relatively high ground, although they may be vulnerable to erosion. Norfolk and Suffolk have higher ground, but the dense development there has already led to shoreline armoring along many shores.

⁸⁵The Intracoastal Waterway includes the North Landing River, which flows into Currituck Sound (North Carolina); the southern branch of the Elizabeth River, which flows into Chesapeake Bay; and an east-west canal that connects these two rivers.

The less developed localities are also less vulnerable to sea level rise because they are farther up the James and York rivers. Nevertheless, shore protection may be very important for some areas. Parts of historic Jamestown have, for example, eroded or been inundated. (See Photos 8-19 and 8-20.)

Anticipated Sea Level Rise Responses

Initial maps based on meeting⁸⁶ and followup conversations with:

Hugo Valverde, Hampton Roads PDC; Clay Bernick, Virginia Beach⁸⁷; Lee Rosenberg⁸⁸ and Barbara McCallum, Norfolk; Keith Cannady, Hampton⁸⁹; Jody Hollingsworth⁹⁰, Poquoson; Kathy James-Webb, Newport News⁹¹; Tyrone Franklin, Surry County; and Amy Ring⁹² and Watson Lawrence Chesapeake⁹³

We also used the comprehensive plans of Suffolk⁹⁴ and York⁹⁵, Isle of Wight,⁹⁶ and James City⁹⁷ counties.

⁸⁶Meeting between Dan Hudgens and Pratap Penumalli of IEc and local officials at the Hampton Roads PDC offices, November 23, 2002, except for representatives from Newport News, Poquoson, and Surry County. Pratap Penumalli met with Surry County the following day at the county offices.

⁸⁷Telephone conversations with Pratap Penumalli, September 24 and October 17, 2002.

⁸⁸Telephone conversations with Pratap Penumalli, October 10, 2002.

⁸⁹Telephone conversations with Pratap Penumalli, October 14, 2002.

⁹⁰Telephone conversations with Pratap Penumalli, October 7 and October 18, 2002.

⁹¹Telephone conversations with Pratap Penumalli, October 15 and December 16, 2002.

⁹²Telephone conversation between Jim Titus and Amy Ring, planner, City of Chesapeake, October 28, 2003.

⁹³Telephone conversation between Jim Titus and Chesapeake City's agricultural director, Watson Lawrence, to whom Amy Ring deferred on the question of additional agricultural lands being developed, October 28, 2003.

⁹⁴City of Suffolk Department of Planning, *The Comprehensive Plan for 2018: City of Suffolk, Virginia*, adopted March 25, 1998.

⁹⁵*Charting the Course to 2015: The York County Comprehensive Plan*.

⁹⁶Isle of Wight Planning and Zoning Department, *Isle of Wight Proposed Comprehensive Plan* (as of August 1, 2004, the Planning Department website lists this plan as "to be adopted 2001"); Proposed Land Use Types and Proposed Maps.

⁹⁷James City County. *2003 Comprehensive Plan*. Adopted by the James City County Board of Supervisors on August 12, 2003. Chapters on Land Use and Environment, and *2003 Land Use Map*. Adopted August 12, 2003.

Unless otherwise stated, map revisions are based on Stakeholder Review Briefings⁹⁸ and communication with:

Clay Bernick, planner, Virginia Beach⁹⁹; Amy Ring, planner, Chesapeake¹⁰⁰; Fred Brusso, special projects administrator, Planning and Zoning, Portsmouth¹⁰¹; Lee Rosenberg, Department of Environmental Services, Norfolk¹⁰²; Kathy James-Webb, senior district planner, Newport News¹⁰³; Greg Goetz, physical planning coordinator, City of Hampton¹⁰⁴; Deborah Vest, Planning Department, City of Poquoson¹⁰⁵; Anna Drake, Department of Environmental and Development Services, York County¹⁰⁶; Tyrone Franklin, Surry County¹⁰⁷; Wayland Bass, Development Management, James City County¹⁰⁸; Jonathan W. Hartley director, Department of Planning and Zoning, Isle of Wight County¹⁰⁹; and Cynthia Taylor, assistant planning director, City of Suffolk¹¹⁰;

State law allows property owners to armor or elevate their land.¹¹¹ When we asked, officials from each of the participating localities in the Hampton Roads planning district told us that they

had no local policies that would prohibit landowners from protecting their land from encroachment caused by sea level rise.¹¹² Given that landowners are allowed to armor their shoreline to protect their property from rising seas and increased erosion, the primary question for this study is whether a level of development will occur that would lead landowners to choose to invest the resources necessary to do so. Such development is likely or certain for most dry land in the urban core (Norfolk, Portsmouth, Hampton, and Newport News and parts of Virginia Beach and Chesapeake). By contrast, in the rural portions of Virginia Beach, Chesapeake, and the outlying jurisdictions, a significant amount of land may remain undeveloped and thereby afford the opportunity for wetland migration.

The Hampton Roads urban core localities are dominated by urban development. However, both Chesapeake and Virginia Beach also have rural areas between the developed areas and the North Carolina border. Between the urban and rural areas is a developing transition area. Planners indicate that the urban core will almost certainly be protected, with the possible exception of some publicly owned waterfront lands. In many areas, the shoreline is already protected. The PDC provided land use data for identifying commercial, industrial, urban, and suburban residential areas, all of which are certain to be protected. The planners also confirmed that those areas deemed certain to be protected in the VIMS analysis are almost certain to be protected for the more moderate sea level scenarios used by this study.

⁹⁸Jim Titus presented the maps at the Hampton Roads PDC's monthly meeting of the Chesapeake Bay and Stormwater Management Committee, October 7, 2004, at the PDC office in Chesapeake, Virginia. He also met with Deborah Vest, city planner, and Karen Brauer, planning technician of the City of Poquoson, at the city offices on October 6, 2004. See Stakeholder Review section below for additional details.

⁹⁹Marked-up map provided to Jim Titus at Stakeholder Review Briefing, October 7, 2004. Follow-up email from Clay Bernick to Jim Titus on October 15, 2004.

¹⁰⁰Email from Amy Ring to Jim Titus, September 27, 2004.

¹⁰¹See email from Jim Titus to Fred Brusso, October 13, 2004, reporting all of the map changes that Brusso recommended during telephone conversation that afternoon with Titus.

¹⁰²Email to Daniel Hudgens, October 5, 2004.

¹⁰³Marked-up map provided to Jim Titus at Stakeholder Review Briefing, October 7, 2004.

¹⁰⁴Email from Greg Goetz to Jim Titus, October 15, 2004.

¹⁰⁵Meeting between Deborah Vest, city planner, Karen Brauer, planning technician, the City of Poquoson Planning Department, and Jim Titus at the city offices, on October 6, 2004.

¹⁰⁶Telephone conversation with Jim Titus, September 20, 2004.

¹⁰⁷See email from Jim Titus to Tyrone Franklin, October 5, 2004, repeating the substance of a telephone conversation an hour earlier.

¹⁰⁸See email from Jim Titus to Wayland Bass, September 27, 2004, quoting entirety of voicemail message left by Bass.

¹⁰⁹Marked-up map provided to Jim Titus at Stakeholder Review Briefing, October 7, 2004.

¹¹⁰Email to Jim Titus, September 21, 2004; email to Daniel Hudgens, October 8, 2004. Private comments at Stakeholder Review Briefing.

¹¹¹See the state section, above.

¹¹²Meeting between Dan Hudgens and Pratap Penumalli of IEc and local officials at the Hampton Roads PDC offices, November 23, 2002.

TABLE 8-7. AREA OF LAND VULNERABLE TO SEA LEVEL RISE: HAMPTON ROADS PLANNING DISTRICT (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Virginia Beach	59.8	43.4	11.4	5.0	23.7	9.1	64.9	16.1
Chesapeake	25.1	15.3	4.0	5.8	10.1	11.8	34.5	21.5
Hampton	7.6	5.5	1.9	0.1	6.2	0.1	17.9	0.4
York	8.9	6.6	2.0	0.3	4.7	1.0	10.7	2.6
Newport News	8.2	5.8	2.3	0.1	4.1	0.2	7.1	0.5
Norfolk	3.9	1.8	2.0	0.1	6.0	0.2	17.4	0.4
Poquoson	10.7	9.1	1.5	0.02	3.2	0.1	6.3	0.4
James City	14.2	12.7	1.3	0.3	2.6	0.5	5.0	1.0
Suffolk	12.5	10.2	1.6	0.7	3.0	1.3	6.4	1.9
Portsmouth	5.3	1.4	1.3	2.5	3.4	3.4	8.9	3.7
Surry	^e	4.4	^e	^e	1.0	0.5	1.9	0.9
Isle Of Wight	^e	11.2	^e	^e	2.3	0.8	4.8	1.5
Total^f	174.1	127.5	31.1	15.5	70.3	29.1	185.8	50.9

^a J.G. Titus and J. Wang, 2008, see Table 8-3 for full reference.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

^e Value omitted because the topographic information Titus and Wang used for this jurisdiction had poor vertical resolution.

^f Excludes three jurisdictions from the Hampton Roads Planning District: Southampton County and the cities of Franklin and Williamsburg, which this study does not analyze.



Photos 11–12. Tidal Ditches in Poquoson. Photo 11 shows wetland vegetation in a tidal ditch. Photo 12 shows a wooden bulkhead along the shore of a tidal ditch, to prevent a front yard from eroding into the ditch and blocking drainage (October 2002).



Photos 13–14. Elevating Homes in Poquoson One Year after Hurricane Isabel (October 2004).



Photos 15–16. Virginia Beach. Photo 15 shows homes set well back behind the dunes along the north-facing Chesapeake Bay shoreline. Photo 16 shows seawalls along the east-facing Atlantic beaches (October 1998).

Outside of the urban core, however, much of the land is less likely to be developed and protected.

Virginia Beach has long had a “Green Line,”¹¹³ south of which the County tries to maintain the rural agricultural way of life. Recognizing that development had occurred and will continue to occur just south of the Green Line, the County has established a “Rural Area Line” that coincides with the Green Line in the eastern part of the county but crosses the west side of the county above 3 miles south of the Green Line. Below the Rural Area Line, the County strongly discourages development and encourages rural legacy and conservation easements.

Between the Green and Rural Area lines is the Princess Anne Transition Area, in which the County encourages environmentally sensitive development.

Table 8-8 summarizes the GIS decision rules we employed to create the maps. Let us examine how the maps treat the urban core, rural, and transition areas within the urban core localities.

Urban Core

We include all the urban core localities within the “urban core” except for southern portions of Virginia Beach and Chesapeake. Within the urban core, planners identify all currently developed private or publicly owned land as certain to be protected. We consider all currently undeveloped lands (e.g., forest, agriculture, recreational lands) surrounded by existing development as certain to

be protected. In many cases, these lands will be



Photo 8-17. Norfolk. Wide beaches and dunes dominate along the Norfolk shore of Oceanview along Chesapeake Bay (from which one can see the ocean) (October 2004).

developed in the foreseeable future and therefore certainly developed. Those areas not developed will receive protection from the surrounding properties. Within Hampton, Newport News, Norfolk, and Portsmouth, we map all undeveloped lands located adjacent to open water and wetlands as likely, but not certain, to be protected.¹¹⁴ Within Chesapeake and Virginia Beach, we map only vacant lands located adjacent to open water and wetlands as likely to be protected.¹¹⁵ In many cases the land may be developed or the value of the land used for recreation purposes would be sufficient and the shore would almost certainly be protected. A portion of these properties, however, could be preserved and maintained in their natural states.

¹¹³“The Green Line has been the city’s most formidable defense against sprawl since its inclusion in the first Comprehensive Plan. Designed in 1979 to separate that area of the city where facilities and services could be provided within a reasonable time period (and thus where urban development would be appropriate) from that area where there is no reasonable expectation of providing such services within a reasonable time (and thus where urban growth is not appropriate), the Green Line has been rigidly adhered to by the Council in the formulation and implementation of the city’s land use and capital improvement planning.” City of Virginia Beach, Comprehensive Plan Policy Document, p. 19.

¹¹⁴We identified the undeveloped areas using the Hampton Roads urban land use data. Undeveloped land use categories include agriculture, forests, parks, public/semipublic, recreational, undeveloped, and vacant land classes. We treated these areas as likely to be protected, primarily because the undeveloped status of these lands leaves open the possibility that such land might be set aside for conservation or parkland. During stakeholder review, we asked local reviewers to verify which—if any—of these areas are certain to be protected.

¹¹⁵Because Virginia Beach and Chesapeake are focusing development within the urban zone, the maps assume that all recreational, forest, and agriculture are certain to either be developed or have sufficient value to be protected. We have not applied this logic to vacant lands because that category would include lands held for conservation purposes within the urban core; and we had insufficient information to assume that no such lands exist within the urban core of these two cities.

Because of the uncertainty associated with individual properties, we show these lands as likely to be protected.

Virginia Beach is the largest locality within the Hampton Roads PDC and is located along the Atlantic coastline. As shown in Table 8-7, the city has almost 10 square miles of land within 4 feet above the tides, and 20 square miles of land within 4 feet above the tides. Fortunately, most of this land is in the southern part of the city. The northern portion of the city is extensively developed and will be protected to the extent necessary.¹¹⁶ The city of Virginia Beach is also engaged in an active program of beach nourishment along sections of its 35-mile shoreline. According to Clay Bernick,¹¹⁷ Virginia Beach will probably continue its beach nourishment policy, even if costs increase as sea level rises; but the city would protect the development even if it had to rely on seawalls or revetments.

The city of Norfolk is also extensively developed, including the shore. Of the city's 167 miles of shoreline, 70 miles have been hardened.¹¹⁸ Almost none of the shore along Chesapeake Bay is hardened. The bayshore has a wide recreational beach and substantial dunes (Photo 8-17), mostly protected by a series of offshore breakwaters. Local planners indicated that nearly all high- and medium-density residential and commercial lands, regardless of their current value, will also be protected because the prospects for urban revitalization are so strong in the urban core. The aforementioned example of Ocean View serves as evidence of successful revitalization. If these efforts continue to be successful in increasing the desirability and value of the urban core, this would presumably lead to the enhanced possibility of continued protection against the rising seas.

Local officials for Virginia Beach and Norfolk anticipate protecting nearly all city-owned lands such as roads, sewer systems, buildings, and parks.¹¹⁹ In addition, although the state lacks policies to dictate future responses on state-owned lands, local planners anticipate that state lands will probably be protected, especially where the public lands are surrounded by private development. The land use data, however, do not allow us to distinguish state and local parks.¹²⁰ Therefore we had to choose between assuming that parks adjacent to water, wetlands, and undeveloped areas were certain or that they were likely to be protected. We opted to treat these parks as likely to be protected, because it would be easier for reviewers to quickly identify red polygons than brown polygons within a map that is otherwise mostly brown. The maps depict parks that are surrounded by existing development as certain to be protected.

¹¹⁶The PDC data included several polygons as undeveloped within the developed portion of Virginia Beach. The PDC staff changed those "infill areas" to likely to be protected.

¹¹⁷Meetings between Dan Hudgens and Pratap Penumalli of IEc and local officials at the Hampton Roads PDC offices, November 23, 2002.

¹¹⁸Berman, M., H. Berguist, C. Herschner, S. Killeen, T. Rudnicky, D. Schatt, D. Weiss, and H. Woods, 2002, City of Norfolk Shoreline Situation Report, Virginia Institute of Marine Science, Gloucester Point, MD.

¹¹⁹Based on discussions with Barbara McCallum of Norfolk and Clay Bernick of Virginia Beach, November 23, 2002. As discussed above, based on this information and the relative density of development in the urban core, we assume that all developed city-owned lands are certain to be protected within the urban core. Park lands surrounded by existing development are also certain to be protected.

¹²⁰For several states, we had digital data created by the state or local planning agencies that delineated boundaries of publicly owned recreational parks and open space. For Virginia, however, we had no such data set. For the urban core jurisdictions of Hampton Roads, we relied on the PDC's EMC land use data, which identified parks and some other lands as publicly owned. Outside the urban core localities, we relied on a national dataset of federal, state, and local parks.



Photo 8-18. South Shore of Hampton. The public has access along this shore, which is protected with a stone revetment.

To the north, between the James and York rivers, is the Southern Peninsula, which includes Hampton, Newport News, Poquoson, and York (although Poquoson and York County are densely developed, they are excluded from the PDC's data,¹²¹ so we discuss them in the next section). Representing the primarily residential City of Hampton, planning director Keith Cannady stated that none of its coastal development would be abandoned with a rise in sea level of 3 feet (1 meter) per century.¹²² Much of the shore is already armored. (See Photo 8-18.)

In more developed areas where flooding has become too great a problem, localities have taken measures to purchase lands and clear them to restore a natural floodplain. One example is the highly developed southeast area of Newport News, in which the city has implemented a program to purchase homes with severe flooding problems and floor elevations below 4 feet from citizens on a completely voluntary basis. Unfortunately, city

planners cannot identify the specific neighborhoods where such a revision might be justified. Therefore, we did not include these potential purchases in our maps.

Although they cannot authoritatively speak to the protection policies for federal lands, local officials expect that federal land managers would continue their present courses of action in terms of protecting certain public lands. For example, most military lands and private naval shipyards are already heavily armored and will continue to be protected. One exception, however, is Fort Eustis in northern Newport News. Kathy James-Webb of Newport News pointed out that because this military base is largely undeveloped, the government may

choose to protect only the portions currently developed or slated for future development. Following the nationwide approach¹²³ for this study, the maps treat secured installations in urban areas as certain to be protected and installations in other areas as uncertain. Because Langley (Hampton) and Fort Eustis are on the outskirts of these urban jurisdictions, those two facilities show up as red on the maps. The others are depicted in brown.

Rural Areas of Virginia Beach and Chesapeake

The rural areas (see Figure 8-3) are defined as the land below the Rural Area Line in the Comprehensive Plan of Virginia Beach and the rural area depicted in the map approved by the City Council of Chesapeake projecting land use for 2050.¹²⁴ Within this area, the maps (Map 8-4 for

¹²¹Land use data from EMC Analysis of Stormwater Monitoring Data, provided by Hampton Roads PDC for the cities of Virginia Beach, Norfolk, Chesapeake, Portsmouth, Hampton, and Newport News.

¹²²Meeting at Hampton Roads PDC offices, November 23, 2002.

¹²³The premise is that only the Department of Defense can authoritatively speak to this issue. Therefore, our study addresses only county perspectives on what would occur *if* the base were to close. In urban areas, the land would be protected even if the base were to close; in less densely developed areas, by contrast, closed military bases sometimes become conservation or park lands.

¹²⁴Hybrid map endorsed by City Council and Planning Commission, available at

Virginia Beach and Map 8-5 for Chesapeake) depict low-density developed areas as likely to be protected and more developed areas as almost certain to be protected. Undeveloped and vacant land, agriculture, forests, and parks are all unlikely to be protected. The Nature Conservancy owns land along the North Landing River.¹²⁵ Because we did not obtain a true conservation layer for Virginia, The Nature Conservancy's lands are depicted in blue; if we had the data needed to delineate their boundaries, the TNC lands would have been depicted as light green (Map 8-8).

Chesapeake does not have specific policies that preclude development. The comprehensive plan indicates that the city is attempting to attract more development. Therefore some rural areas that we depict as unlikely to be protected may in fact be developed and protected. For the most part, mapping the specific areas that are likely to be developed is not yet possible. Chesapeake's comprehensive plan, however, does have a transportation corridor development along VA-168, with development planned on either side within 1 mile. Therefore, city planners thought it would be reasonable for the map to show that land within 1 mile of the highway is certain to be protected.¹²⁶ Because of the widespread consensus that more development will occur than is included in the PDC's land use data, the maps also assume that areas within 2 miles of VA-168 will probably be protected.¹²⁷ In addition, Chesapeake planners

expect development in the area within about 3 miles of the North Carolina border on either side of Rte. 17, extending eastward about 3 miles and westward to the Dismal Swamp Canal.¹²⁸

Farther to the west, flooding has proven to be a major problem for the communities within both Chesapeake and Suffolk that surround the Great Dismal Swamp. As a result, relatively little development is expected in that area.

Transition Areas in Virginia Beach and Chesapeake

The comprehensive plan for Virginia Beach defines the Princess Anne Transition Area as the land between the Green Line and the Rural Area Line. Environmentally sensitive development is encouraged in this area. Therefore shore protection is likely throughout this region. Nevertheless, the land use policies encourage protection of open space through clustering; so wetland migration would be possible in some portion of this area. Because it is currently infeasible to identify the specific areas that might not have to be protected, for any location, it is possible that the area will not be protected. Therefore, any specific location within the undeveloped areas will probably be developed and protected, once it is developed.¹²⁹ The maps depict existing development as almost certain to be protected and parks as likely to be protected.

For the City of Chesapeake, we use the suburban areas as defined by the draft 2026 for the city's 2004 comprehensive plan update. Our maps employ the same GIS decision rules for these areas as for the Princess Anne Transition Area. Although the growth policies are different than for Virginia Beach, the implications for our maps are similar: These suburban areas represent lands that the County plans to see developed in the foreseeable future. Therefore, undeveloped areas are likely to be protected.

http://www.chesapeake.va.us/services/depart/planning/maps/PhaseII_8by11.pdf, accessed on August 1, 2004.

¹²⁵Hugo Valverde, Hampton Roads PDC, telephone conversation with Jim Titus, October 23, 2003.

¹²⁶Telephone conversation between Jim Titus and Amy Ring, City of Chesapeake, October 28, 2003.

¹²⁷Telephone conversation between Jim Titus and Chesapeake City's agricultural director, Watson Lawrence, to whom Amy Ring deferred on the question of additional agricultural lands being developed, October 28, 2003. Mr. Lawrence indicated that dikes would generally not be built to protect farmland as sea level rises in this region. He is familiar with Tyrill County, and he does not believe that the city has the same level of commitment to protect farmland from the sea that one finds in northeastern North Carolina. He has no doubt that dikes will be built to protect homes, but agriculture is too marginal to justify protection from tidal inundation. He also indicated that more farmers will sell their lands to developers than one would assume based on existing planning maps. The extra 1-mile buffer gives effect to this perception. Moreover, if there is any farm land where protection might be justified, it would be farms along a protected corridor—farmers could provide land for the dike in return for the protection the dike

offers, for example; and the incremental cost of protecting farms is mostly the additional pumping of rainwater that falls on the farmland, if a dike of a given length has to be built anyway.

¹²⁸Telephone conversation between Jim Titus and Amy Ring, City of Chesapeake, October 28, 2003.

¹²⁹Once the area is developed, it would be possible to divide such areas into developed (brown) and open space (blue).

Stakeholder Review

The staff of the Planning District Commission distributed the maps and report to all the jurisdictions at a regular meeting in September 2004. Titus and Hudgens followed up by email and phone calls in the following weeks, obtaining some comments. Titus provided a follow-up briefing to 40 local planners at the regular monthly meeting of the PDC's Chesapeake Bay and Stormwater Management committee, obtaining marked-up maps from all the jurisdictions that had not previously commented.

Representatives from Virginia Beach requested the most noteworthy change of this report¹³⁰: Assume that developed areas below the Rural Line are unlikely to be protected, i.e., that all land below the Rural Area Line is unlikely to be protected. This change is consistent with the general preservation philosophy associated with the original creation of the Green Line and subsequent Rural Line. Planning to protect isolated development within this area might tend to encourage development, and much of the rationale for existing development in this area is the need for settlements that support agriculture; so if the farms were to convert to marsh, the support function of the settlements would no longer apply. Nevertheless, this suggested change is a substantial departure from the approach of most state and local governments, which is to assume that no developed land can be abandoned to the sea.

Virginia Beach also requested several changes relating to nontidal wetlands. Within the transition area they identified four areas where all the nontidal wetlands shown in draft maps should be changed to shore protection likely, either because those wetlands have been or because they will probably be developed and protected. These changes make red even more the dominant color in this area. For the most part, the need for this correction reflected the obsolescence of the NWI

wetland dataset that we have been using.¹³¹ In one case, however, a nontidal wetland polygon had to be extended over an area that was depicted as certain to be protected.

Finally, Virginia Beach asked us to change the area just west of Stumpy Lake, near (maybe including) Stumpy Lake County Club, along the border with Chesapeake, from brown to blue. This area is above the Green Line. The City explained that “the City has acquired ~1,200 acres in that area for open space/natural resource preservation. We are currently developing a strategy to place a perpetual conservation easement over most of the land. Accordingly, no efforts to protect future infrastructure or development will be necessary or take place in this area.”¹³²

Chesapeake, by contrast, only sought one change. In response to a previous conversation with Amy Ring, the draft map showed a large area at the southwest corner of the city as likely to be protected, because of a large planned development along the North Carolina border and US-17. The draft map showed this development as extending about a mile north of Ballahack Rd. Ms. Ring indicated via email that the development would be smaller than our previous conversation may have indicated. Accordingly, we changed the areas north of Ballahack Rd. back to protection unlikely (except for a few developed areas that were shown as likely to be protected for other reasons).

Our draft maps showed the dry land of the other urban jurisdictions as all being likely or certain to be protected, and the city planners generally agreed. Nevertheless, they did request some

¹³⁰The specific changes are depicted in both the hard-copy map that Clay Bernick handed Jim Titus at the Stakeholder Review Briefing and the electronic attachment to “Hampton Roads Fixes: VA Beach and Chesapeake,” email sent by Jim Titus to Kevin Wright, ICF Incorporated, October 24, 2004.

¹³¹We remind the reader that this study analyzes only dry land, but that because the wet/dry land is often in doubt, the dataset we created also gives a shore protection designation that would apply if it turns out that the land is dry (or if it is subsequently drained to become dry). The maps that we publish place a wetland dataset on top of the underlying map of shore protection likelihood. When reviewers specifically state that an area is not wetland, we effectively place the shore protection designation on top of the wetland dataset for that area so that an alternative wetland data set would not alter those polygons. The rationale is that, in general, wetland datasets more precisely define dry/wetland boundaries than land use and zoning data, so wetland data usually go “on top.” But when stakeholders identify an erroneous wetland designation, their correction is assumed to be more reliable than the wetland dataset.

¹³²Clay Bernick, environmental management administrator, City of Virginia Beach, email to Jim Titus, October 15, 2004.

changes between red and brown. Portsmouth had the most extensive comments.¹³³

- ***Change the Craney Island Dredge Spoil from purple to red.*** This area is no longer wetland, and there is considerable talk about possibly developing it.
- ***Change the Hoffer Creek Wildlife Preserve from red to light green.***
- ***Change Churchland Park from red to brown.*** This park would be protected as part of any plan to protect surrounding areas.
- ***Change Elizabeth Marion Country Club from red to brown.*** It is too valuable to be given up to the sea.
- ***Change the large area bounded on the southwest side by VA-164 and Lake Kingman, on the east by the Elizabeth River, and on the northwest side by Coast Guard Boulevard from red to brown.*** This former military land was purchased by Mearsk from a private owner, for a planned \$80 million development.
- ***Numerous small red polygons are now developed and should be changed to brown.***

The net result was that all the red should be changed to brown except for Hoffer Creek Wildlife Preserve, a few isolated red polygons near Churchland Park, and the following areas that had been correctly mapped as protection likely:

- ***The red parcel at the head of Lilly Creek near Kingman, just south of VA-164, should stay red.*** The owner is content to maintain it as wooded land and does not intend to sell it to a developer. The city's current plan would be for the parcel to be developed if it is ever transferred to an owner who wants to do so.
- ***City Park should stay red.*** Protection would be likely if the shore ever erodes. For the foreseeable future, however, erosion is unlikely because sedimentation has converted open water to mudflats in the area.

- ***The red polygon bounded by Cedar Lane, Coast Guard Road, and Craney Island Creek is still undeveloped land owned by the Navy.***

Newport News clarified the implications of its buyout program. Homes along the city's small amount of Chesapeake Bay shore near the border with Hampton are being bought out in the wake of storm damage. The planner suggested that land below 4 feet (NAVD '88) should be changed from brown to red, because homes in this area will probably be bought out, with the land becoming part of the existing waterfront park, where protection is likely, but not certain.¹³⁴ Aside from that area, she suggested all of our nonmilitary lands depicted in red should be changed to brown except for one polygon. The only nonmilitary land that should be depicted as red is a development along the west side of Deep Creek south of Yoder Pond.

Hampton suggested only one change: an area depicted as nontidal wetlands that is, in fact, being developed into an office park. This parcel has about 470 acres and is bounded by Magruder Blvd. to the east, Semple Farm Rd. to the north, and a golf course to the south.

¹³³See email from Jim Titus to Fred Brusso, October 13, 2004, reporting all the map changes that Brusso recommended during telephone conversation that afternoon with Titus.

¹³⁴The planner initially offered to provide the location of the 4-ft NAVD contour, but was unable to do so. Therefore, we used the USGS 5-ft NGVD contour from the 1:24,000 map series. At Sewells Point, NAVD is 0.8 feet higher than NGVD (see National Geodetic Survey web site links from the NOAA-NOS Published Benchmark Sheet). Thus the USGS contour could be viewed as a 4.2-ft NAVD contour. The City's data are presumably more precise.

TABLE 8-8. ASSUMPTIONS FOR SHORE PROTECTION MAP: URBAN CORE LOCALITIES, FOR WHICH HAMPTON ROADS PLANNING DISTRICT COMMISSION PROVIDED UPDATED LAND USE DATA (VIRGINIA BEACH, CHESAPEAKE, NORFOLK, PORTSMOUTH, HAMPTON, NEWPORT NEWS)^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Stakeholder review changes	As specified				See text
Virginia Beach: rural areas ^b		✓			Comprehensive plan
Military installations			^c		Military installations
Central business districts, major coastal communities, and lands slated for future development				✓	Planner input from initial study ^c
Major evacuation routes from protected areas				✓	Planner input implemented using initial study ^d
Hampton Roads bridge-tunnels				✓	Planner input implemented using major roads ^d
Chesapeake: lands within one mile of VA-168				✓	Road buffer delineated using major roads
Undeveloped and vacant lands ^e within urban areas ^f adjacent to open water or wetlands			✓		Hampton Roads urban land use
Developed lands ^e				✓	Hampton Roads urban land use
Urban areas ^f				✓	Projected Chesapeake 2050 land use; VA Beach Comprehensive Plan
Chesapeake: lands within two miles of VA-168, land along Rte. 17 near the North Carolina border extending west three miles and east to the wetlands			✓		Road buffer delineated using major roads
Undeveloped and vacant lands ^e within urban areas ^f adjacent to open water or wetlands			✓		Hampton Roads urban land use
Chesapeake and Virginia Beach: transitional area ^g			✓		Projected Chesapeake 2050 land use; VA Beach Comprehensive Plan
Chesapeake: rural areas ^h		✓ ⁱ			Projected Chesapeake 2050 land use; VA Beach Comprehensive Plan

^a Where land areas overlap, classifications higher in the table take precedence.

^b Rural area includes southern portions of Chesapeake and Virginia Beach (see Figure 8-3). It consists of all lands not specifically identified as part of the urban or transition areas.

^c Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

^d The initial 2001 VIMS study created polygons representing areas that are certain to be protected in the event of a 20-ft sea level rise. These areas are depicted in orange in some versions of our maps. Within HRPDC, their study area included only the urban core and Poquoson City.

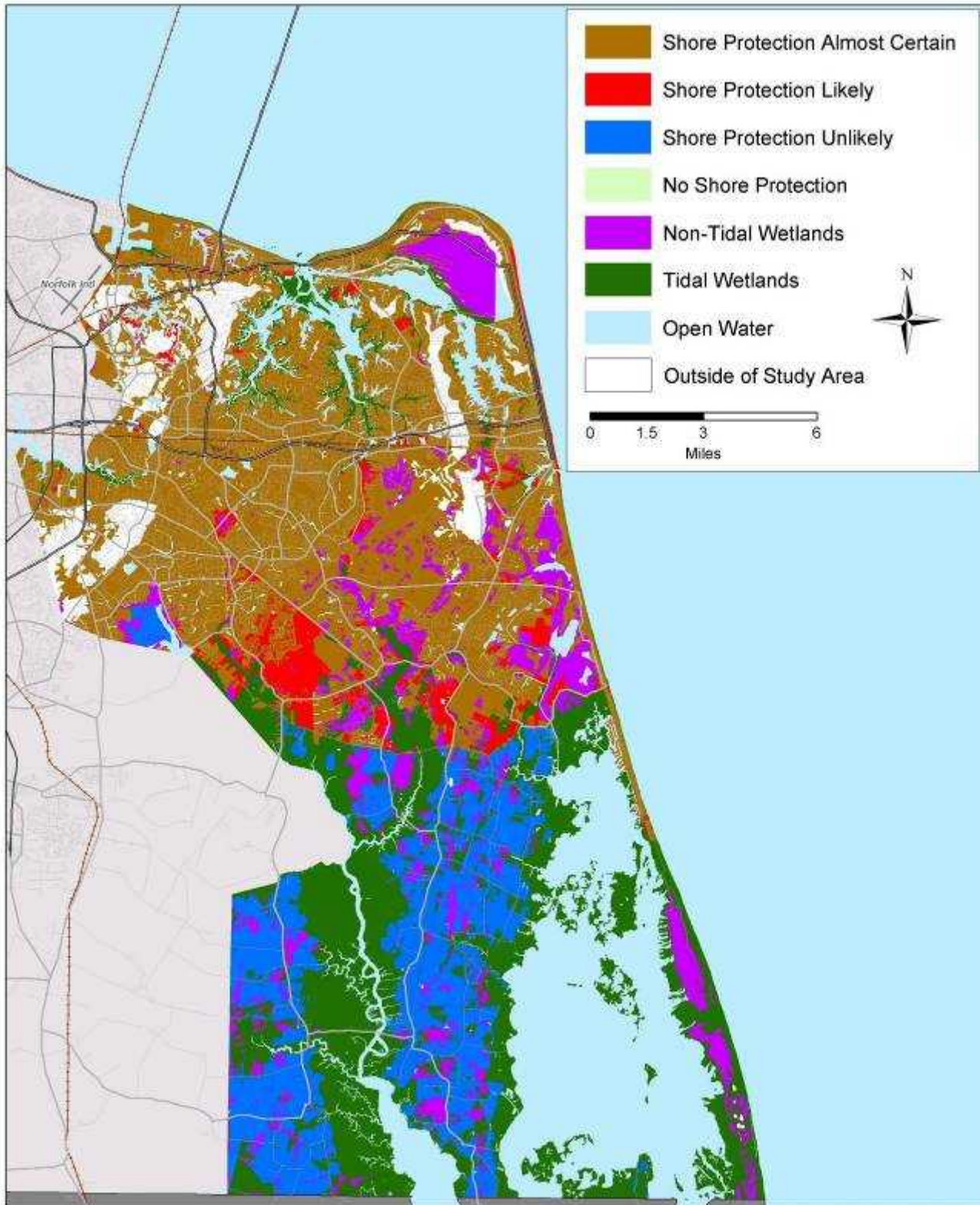
^e Per planner input from the initial 2001 VIMS study, we identify specific transportation structures as certain to be protected using data provided by ESRI.

^f The Hampton Roads urban land use data include the following “developed” classifications: urban and suburban residential, industrial, institutional/educational, and commercial areas.

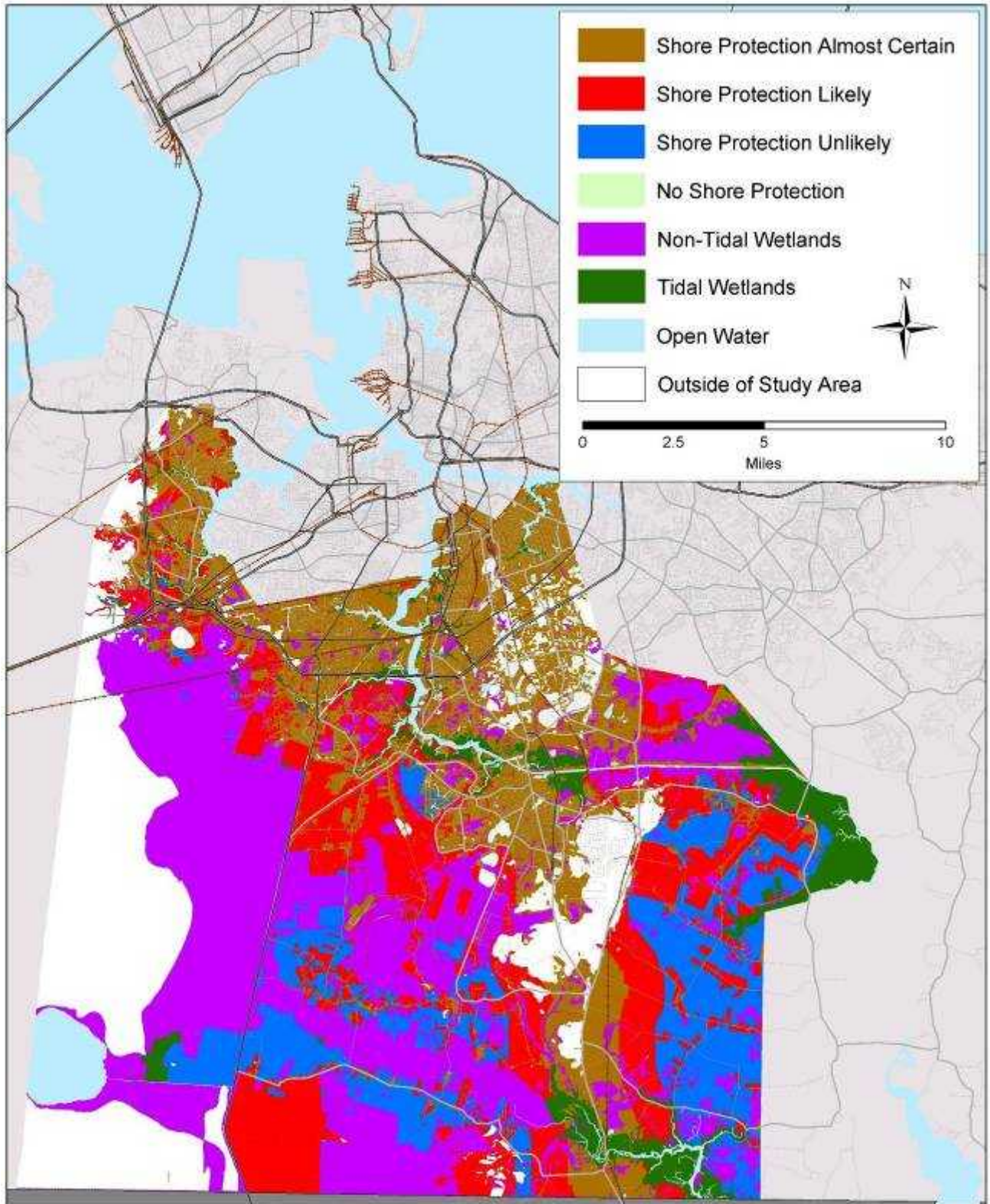
^g The urban areas include the northern portions of Chesapeake and Virginia Beach and all land within Hampton, Newport News, Norfolk, and Portsmouth (see Figure 8-3).

^h Transitional area between urban and rural area of Chesapeake and Virginia Beach (see Figure 8-3). The developed lands are certain to be protected; lands shown as “protection likely” are undeveloped, vacant, parks, public, forest, pasture, agriculture, and recreational uses.

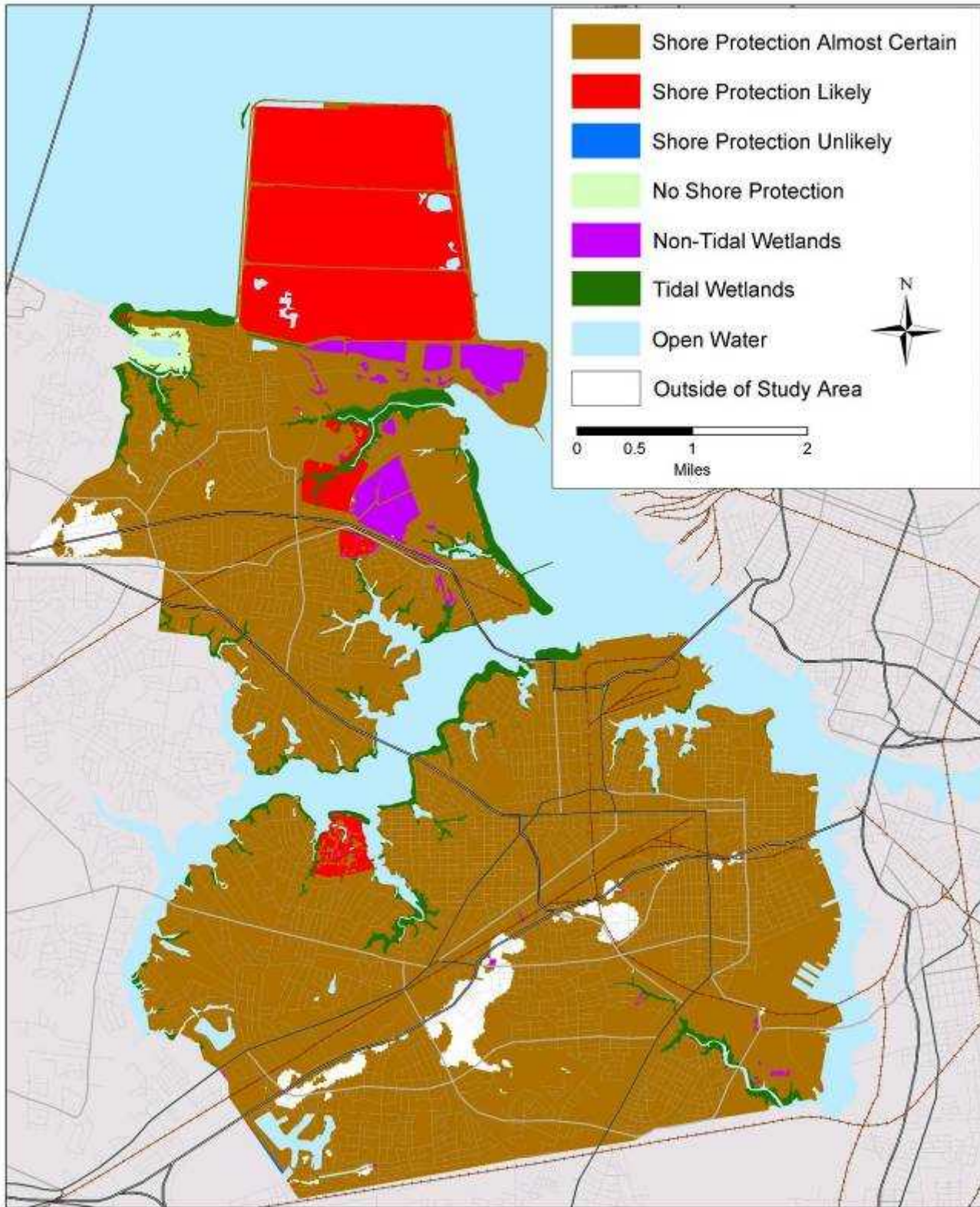
ⁱ The decision rules for the rural area in Chesapeake are parallel to those of the transition area, except that lands not developed are deemed protection unlikely in the rural area and protection likely in the transition area.



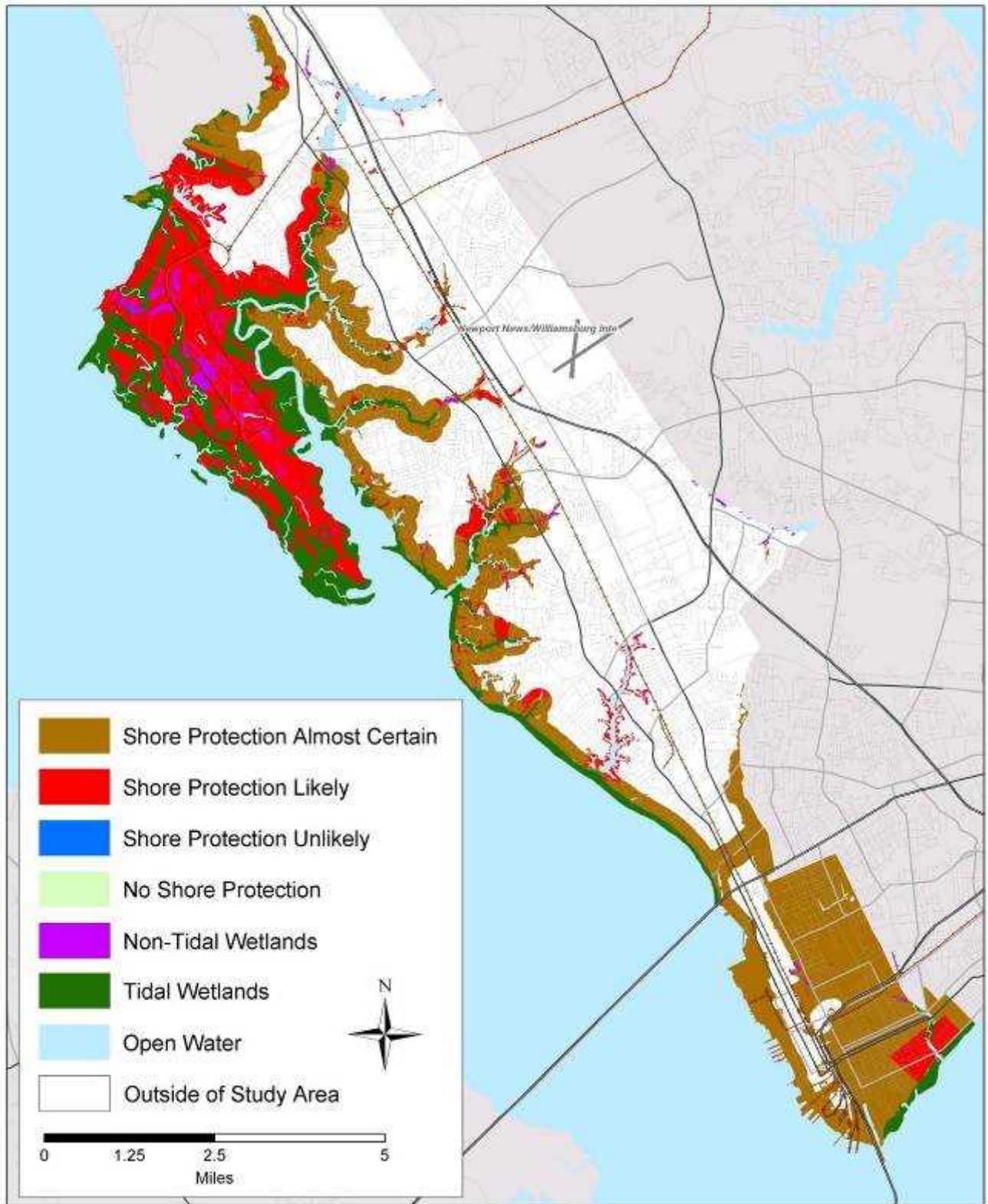
Map 8-4. Virginia Beach: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



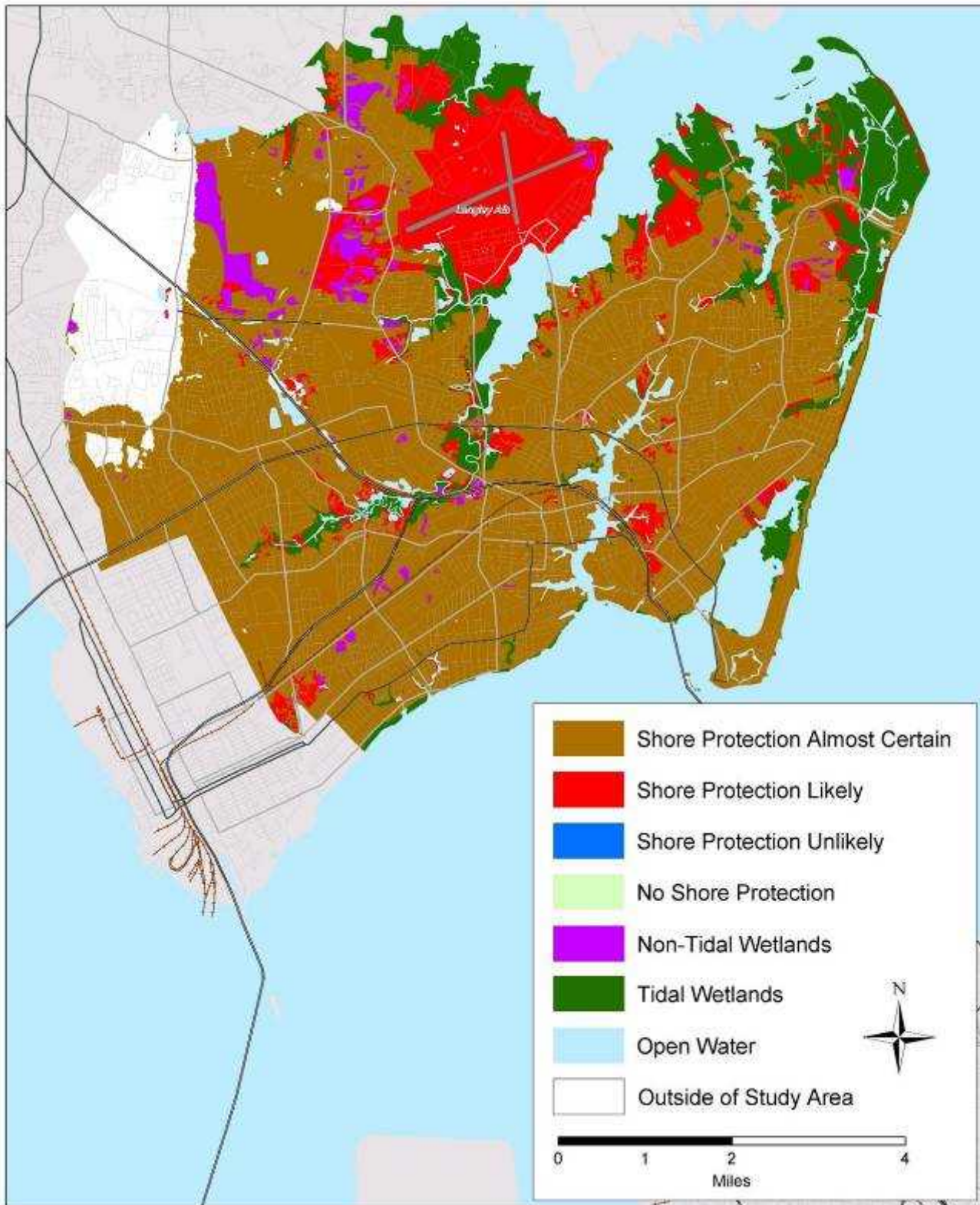
Map 8-5. Chesapeake: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



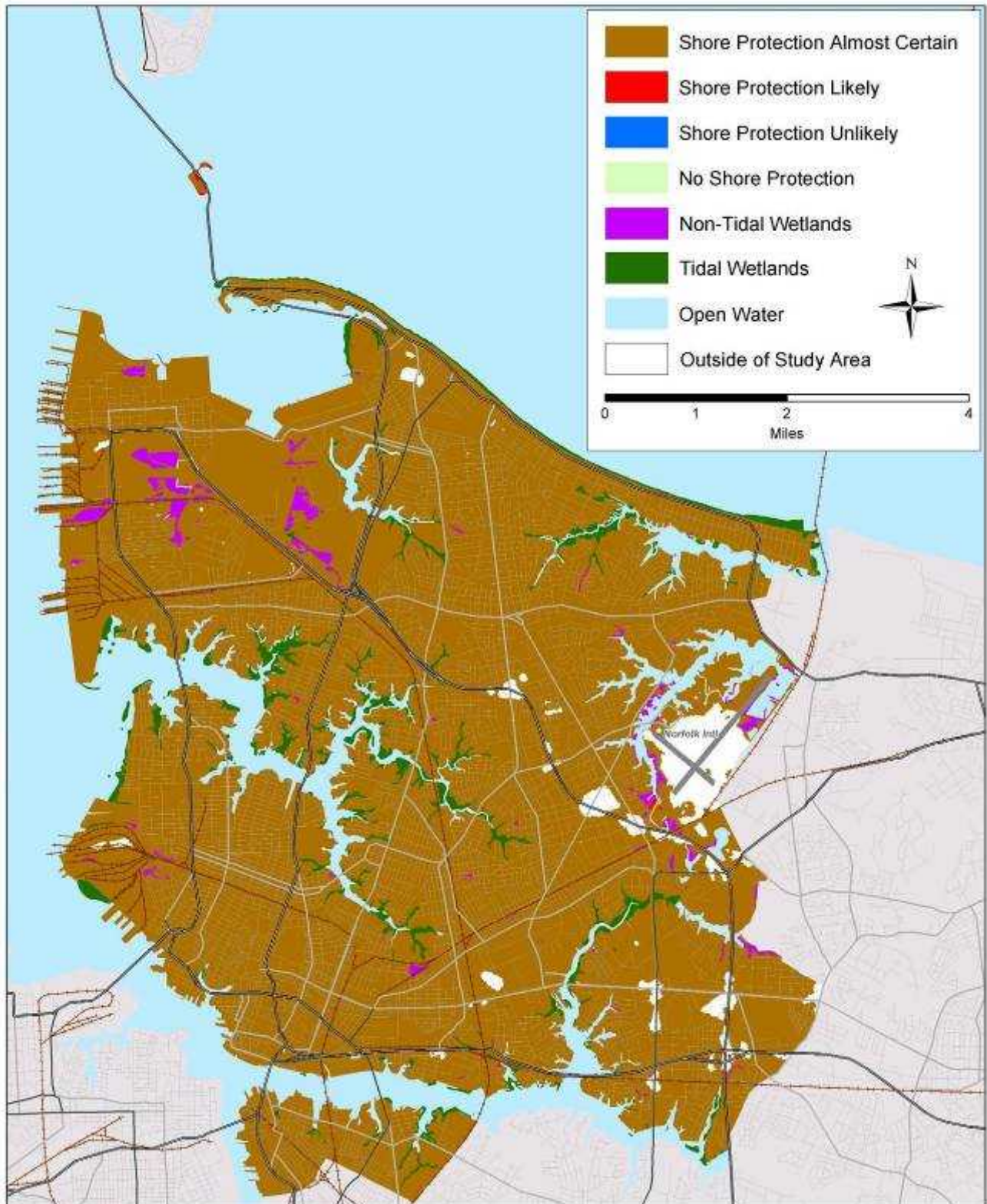
Map 8-6. Portsmouth: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-7. Newport News: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-8. Hampton: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-9. Norfolk: Likelihood of Shore Protection. The City of Norfolk was entirely brown except for a single red polygon, and the City's representative agreed with that depiction. For additional details, see the legend and caption accompanying Map 8-2.

Outlying Jurisdictions

Table 8-9 summarizes the anticipated sea level rise responses for the outlying jurisdictions, where updated land use data were not available from the PDC. Our assessment for this portion of Hampton Roads is based on discussions with planning staff from the City of Poquoson, Surry County, James City County, and the PDC, as well as the land use plans of York, Suffolk, Isle of Wight, and James City. Again, existing developed areas within the localities will almost certainly be protected.

The primary difference between how we generated the maps for these areas, compared with the urban core, is that the PDC was not able to provide a superior land use data source for the area outside the urban core jurisdictions. Therefore, we originally resorted to other information, including site-specific suggestions from local planning staff and nationally available land use and land cover data.¹³⁵ A second difference was that—with the exception of Poquoson—these jurisdictions had not been part of the original VIMS study. As a result, these jurisdictions may have had less familiarity and interest in the long-term ramifications of rising sea level.

After we completed our maps using the available resources, we concluded that we had not obtained enough input from Suffolk, James City, York, or Isle of Wight. Because the comprehensive plans of all or part of these jurisdictions were readily available, we revised the maps for those jurisdictions based on the comprehensive plans. We did not use comprehensive plans for Surry or Poquoson.¹³⁶

We presented all the maps at the Stakeholder Review Briefing. Because each community was

¹³⁵The nationally available land use data applied in this analysis were developed by USGS from photoimages taken in the late 1970s to early 1980s. Hence, alone, these data do not accurately capture more recent development. To supplement these data, we also use National Land Cover Data (NLCD), which was developed by the Multi-Resolution Land Characteristics Consortium. This land cover dataset separately delineates residential areas and has a 30-m resolution.

¹³⁶The Surry plan was not immediately available, and we had obtained substantial input from that county. Poquoson has almost total buildout and hence the plan would not have added any information.

analyzed using a different approach, we discuss each analysis separately.

Poquoson

The independent City of Poquoson was the only jurisdiction outside the urban core that had participated in the VIMS study, where the town indicated that all but the outlying developed areas would be protected. When we presented the Poquoson planner with our initial revision,¹³⁷ he identified two additional areas that are certain to be protected: Messick Point and Big Woods. The Big Woods is currently a 500-acre vacant zone along State Route 171 (and 4 miles east of Interstate 64) that is slated for commercial and retail development. Messick Point is a 14-acre zone of waterfront property that the City is currently improving so that it can be developed privately for water-dependent retail services and recreational uses. Beyond these protected areas, much of Poquoson's 89-mile coastline and the surrounding low-lying lands are made up of salt marsh wetlands (4,398 acres). These wetlands, as well as any small dry land areas within the Plum Island National Wildlife Refuge in the eastern half of the city, will not be protected from the effects of sea level rise. All other areas were depicted in blue.

Even with these changes, however, it was clear to those of us who had visited Poquoson that the map understates existing development. As an alternative map for consideration, we identified potential areas for future shore protection based on the density of existing roads. For example, we interpret the prevalence of roads (from the Census Tiger 2000 road layer) along the northeast corner of the city (including Poquoson Shores and Griffins Beach) as an indication that shore protection may be warranted. We tentatively colored these areas as red, so that planning staff could immediately see the areas where we required their thoughts. The Census Tiger 2000 road layer also identifies substantial road networks in York Haven Anchorage and south of Rte. 171. We also colored these areas red.

¹³⁷This initial revision included all developed areas identified by the land use data.

Jim Titus visited the planning staff during the stakeholder review. During the meeting, planning staff indicated that all but the most outlying or very low areas were certain to be protected, and that protection is likely elsewhere. In the wake of Hurricane Isabel, numerous homes are being elevated. Hence it is reasonable to assume that property will continue to be elevated as sea level rises. Nevertheless, if the wetland buffer that currently protects much of the city from storm waves were to erode, it is at least possible that outlying areas would not be protected. Planning staff suggested that we show the area beyond the intersection of Poquoson and Messick Rd. as likely to be protected, except for Messick Point, which we already assumed is certain to be protected. In addition, the very low portion along Browns Neck Rd. is likely—but not certain—to be protected.

Shortly thereafter, however, the city engineer indicated that the City wanted to discuss the maps with the city manager and council at a regularly scheduled council meeting. Shortly thereafter, the city engineer send a letter indicating that the council had decided that all the areas depicted in red should be changed to brown.¹³⁸ That suggestion was consistent with Titus' observation that many homes were being elevated in the aftermath of Hurricane Isabel.

Surry County

The more rural Surry County has remained largely undeveloped and is just beginning to plan for potential growth as part of its most recent comprehensive plan.¹³⁹ Although those plans do

not address sea level rise, planners find the implications of sea level rise to be sufficiently analogous to other emerging trends to be able to reasonably foresee the implications for future development.

Surry County made several suggestions for improving our maps beyond what we would expect from data on existing land use. The County divides its coastline into four land use zones. In the easternmost zone, Gravel Neck Peninsula, the Surry nuclear power plant along the James River would certainly be protected.¹⁴⁰ Farther north on the peninsula, Hog Island State Park and Wildlife Management Area is conservation land, which will not be protected as sea level rises.¹⁴¹ The second zone is a conservation area known as the Chippokes State Park and Plantation, where natural processes would be allowed to proceed, under current policies.¹⁴² The third zone is the development (and future development) near Scotland, including the terminus of the Scotland-Jamestown Ferry. Mr. Franklin identified the development areas as likely to be protected in the future, with the ferry terminus certain to be protected. The final zone is the western coastline of the county, where more land has been zoned near Claremont for future residential development (with some construction already under way), mainly in the form of modest seasonal homes. (Map 8-11)

During the stakeholder review, the county planning director stressed that Surry is still a very rural county. Unlike Virginia Beach, it is not yet designating areas where it will attempt to discourage development. After viewing the maps based on his input, he reaffirmed that it is reasonable to assume that developed areas will be protected, and that the maps accurately represent expectations for development.

¹³⁸“These markups have been presented to City Council, and represent our final input. We have requested that four areas previously labeled as ‘shore protection likely’ be relabeled as ‘shore protection certain.’ This is because

- Three of the four areas are essentially built out.
- The fourth area is [the only] public road [to] Messick Point...a vital component of the region's recreational and commercial fishing industries....
- Using aerial topography and photographs, we determined that a significant portion of the shoreline in these four areas has already been protected, primarily through the use of bulkheads.

Individual property owners have historically been responsible for protecting their land from rising sea levels. We anticipate that this will continue.” Ellen W. Roberts, PE, Engineering Department, City of Poquoson, letter to Jim Titus, November 10, 2004.

¹³⁹This is also true of James City County, as well as Charles City County and Prince George County in the neighboring planning district.

¹⁴⁰Tyrone Franklin, Surry County planner, meeting with Pratap Penumalli, at the Surry County offices, November 23, 2002.

¹⁴¹Ibid.

¹⁴²Ibid.

Suffolk

The most recent comprehensive plan for Suffolk¹⁴³ expresses a strong desire to stop sprawl by concentrating growth, so that rural open space can be maintained. The plan explicitly pays tribute to the success of Virginia Beach in managing growth.¹⁴⁴ Like Virginia Beach (and more recently, Chesapeake), Suffolk plans to channel growth into the northern part of the city. Unlike those two cities, Suffolk's low land is entirely in the northern part of the city. Therefore, Suffolk's land use plan does not reserve large expanses of land that might be available later for wetland migration as sea level rises.

The plan identifies three areas for relatively dense urban and suburban development: the original urban Suffolk; a new urban area at the northeastern tip of the city between the eastern shore of the Nansemond River and the Portsmouth city line; and the western side of the mouth of the Nansemond River. The rest of the city north and west of the downtown area is planned for low-intensity residential development (with public water but no sewer). The remaining two-thirds of the city is rural/agricultural, park land, or part of Dismal Swamp National Wildlife Refuge.

As sea level rises, the urban/suburban areas will almost certainly be protected. Shore protection is likely, but not certain, however, for currently undeveloped areas in the low-intensity residential area. Most undeveloped land in this area is zoned "rural estate" with a minimum average lot size of 3 acres. If wetland migration became a priority, it would be possible to allow the sea to gradually submerge these large lots, enabling wetlands to form, with elevated roads and driveways. In some cases, the City will encourage clusters, leaving increased open space with 1 acre (or smaller) lots. Nevertheless, under current policies, shore

protection is more likely. The value of waterfront homes is such that larger stretches of tidal shore will probably not remain undeveloped so as to accommodate clusters, and some of the most valuable homes are being built along the water. Therefore the maps assume that currently developed shores in this area will almost certainly be protected, and that shore protection is likely, but not certain, for the remaining shores (Maps 8-11 and 8-12).

The rural agricultural areas are unlikely to be protected. Almost none of these lands, however, are within the tidewater portion of Suffolk. The coastal areas where shore protection is unlikely are generally either parks or conservation lands. Moreover, within the agricultural areas, any land that is already developed was assumed certain to be protected, except for a few areas designated as "transitional developed" by the land use data, which are treated as likely to be protected.

During the stakeholder review, the planning staff had several questions but indicated that they had no suggested map changes.

York County

Most of the York County shoreline is along the York River, but the majority of low land is along Chesapeake Bay and small tidal tributaries such as the Poquoson River, Chisman Creek, and Back Creek. Most development within our study area is east of US-17, within these relatively low-lying areas. West of US-17, most of the York River shore is publicly owned.

The York County comprehensive plan¹⁴⁵ explicitly recognizes some of the environmental implications of shore erosion and discusses areas where hard and soft shore erosion control is most appropriate. The plan suggests that shore erosion causes adverse effects on estuaries through the contribution of sediment; it does not discuss habitat loss from shoreline armoring.

Our maps are based primarily on existing land use and the comprehensive plan's land use for 2015. Although the comprehensive plan recognizes that

¹⁴³*The Comprehensive Plan for 2018: City of Suffolk, Virginia*, City of Suffolk Department of Planning; adopted March 25, 1998.

¹⁴⁴"Chesapeake learned too little from Virginia Beach about how and how not to handle growth. Time will tell if Suffolk is paying attention to Suffolk." Text box on page 3 of City of Suffolk Comprehensive Plan (quoting the *Virginian-Pilot*, January 31, 1998).

¹⁴⁵*Changing the Course to 2015: The York County Comprehensive Plan*.

the military owns much of the lands along the York River, the County recognizes that those lands may eventually be sold. As a result, much of the military lands are zoned for conservation, so if the Department of Defense ever disposes of the land, it would probably be put to a conservation use. Following our nationwide convention, this study does not speculate on how the Department of Defense will manage coastal lands. Military lands that are zoned for conservation are colored red, to reflect the uncertainty about how the military might manage those lands. Military lands that are not zoned for conservation are assumed to be certain to be protected, because the County has indicated that even if the land were sold, it would be redeveloped rather than converted to conservation (Map 8-14).

East of US-17, the plan calls for most civilian land to be developed with a combination of industrial, commercial, and residential land uses. Much of this area is already developed. A large fraction has—or will have—low-density development, which means one unit per acre in York County. Given the high value of waterfront property in the area, these areas—which have been zoned rural residential—are almost certain to be protected. A possible exception concerns the Seaford/Seaford Shores area. The plan calls for low-density housing here, but the area was zoned as a resource conservation area by the zoning adopted in 1995. Environmentally sensitive development in this area is more likely than elsewhere, and hence wetland migration would be possible. Therefore, any privately owned developable land in this resource conservation area is designated as protection likely (unless the land use data show that it has already been developed, in which case shore protection is almost certain).

Most of this area will almost certainly be protected; but the plan also identifies three tracts of conservation lands. The Goodwin Islands are now part of the Chesapeake Bay National Estuarine Research Reserve Program for the Commonwealth of Virginia and hence would not be protected under current policies. The other two parcels, both close to US-17, will probably not be protected.

West of US-17 and south of the Colonial Parkway, the majority of the county is zoned for resource

conservation (although much of this land is owned by the military). Small amounts of surplus military land have been designated for possible commercial development if hazardous waste problems on site can be remedied. The parkway itself is almost certain to be protected.

North of Colonial Parkway, low-density residential exists or is planned for the nonmilitary lands along the shore. The existing Queens Lake Development is certain to be protected if rising water levels in Queen Creek cause the high ground to erode. Shore protection is likely for the still largely undeveloped low-density residential area at the James City County line along Skimino Creek—except for areas that are already developed, where shore protection is almost certain.

During the stakeholder review, environmental staff generally agreed that the draft maps were consistent with the comprehensive plan. The County sought three changes: Both Back Creek Park and Chisman Creek Park had to be changed from blue to brown, given the county's relative shortage of park land. In addition, there is an economic opportunity on the southeast side of a small tributary to Queens Creek west of I-64, requiring this area to be edited from red to brown. The northwest side of the tributary is low-density housing and hence correctly depicted as red.

James City County

In 1607, Captain John Smith and 143 other English settlers founded the first permanent settlement in the colonies that eventually became the United States of America. Smith named the settlement “James Towne” after the reigning sovereign, King James II. Over the following decades, as immigrants continued to settle in Virginia, Jamestown became the center of the “Shire of James City” and the Virginia colony as well. During the 1840s, the shires were renamed as counties. The original James City County contained all of what is now Surry County as well as parts of Charles City County and New Kent County. Jamestown was the capital of Virginia until 1699, when the capital was moved to Williamsburg, also in James City County. Although Williamsburg is no longer part of James City County, it remains the county seat. Since colonial times, rising sea level has eroded or

inundated much of Jamestown. (See Photos 8-19 and 8-20.)

James City County has shores along the York, James, and Chickahominy rivers. According to the current comprehensive plan,¹⁴⁶ the public strongly favors efforts to control development even if doing so results in higher taxes. The county's principal tool for managing growth is its "primary service area" policy. Approximately half the county is in the primary service area, which has sufficient space to approximately double the amount of housing units within the county. The other half of the county is classified as rural or conservation areas. The rural areas include almost all the land within 5 miles of the Chickahominy River and two-thirds of the land within 5 miles of the York River. Along the James River, the conservation area includes Jamestown Island and two parcels that are each approximately 1 mile across. Some development is allowed within these rural areas. If the development is related to forest and agricultural uses of the land, low density (no more than one unit per three acres) is allowed. Residential development not related to agriculture or forestry must meet Rural Lands Development Standards.¹⁴⁷

The maps assume that all currently developed areas will almost certainly be protected. Within the primary service area, shore protection is almost certain even in currently undeveloped commercial, industrial, and residential areas, with the possible exception of low-density housing. In James City County, low-density areas generally have one unit per acre. Given the value of a waterfront home and the relatively high ground, shore protection will almost certainly be cost-effective at such a density. Nevertheless, in low-density areas that have not yet been developed, it would be at least possible to

design a neighborhood to preserve existing riparian lands, which would tend to allow wetlands to migrate inland. Existing subdivisions make such preservation very unlikely along the James River; but along the York River some undeveloped areas remain where shore protection is not certain. Those areas are depicted in red (Map 8-14).

Within the rural areas, shore protection is almost certain along the James River at the west end of the county, because of the development south of



Photos 19 and 20. The Historical Impact of Sea Level Rise on Jamestown. Photo 19 shows the area where the fort once stood, with the wide James River to the right and a statue of John Smith on the left. The river was narrow when John Smith landed, with low marshlands along the shore. Now, there is a deep channel in the center, but most of the river is about four feet deep, consistent with relatively recent inundation. Once the marsh degraded, waves eroded the relatively high ground. The island has eroded where the original fort stood, hence the stone revetments. Photo 20 shows the marsh of the southern part of the island. Old Park Service maps of land use for 17th and 18th centuries show that this area was cultivated during colonial times.

¹⁴⁶*Charting the Course to 2015: The York County Comprehensive Plan.*

¹⁴⁷The plan discourages conventional rural estate types of development and instead encourages rural clusters that leave as open space at least two-thirds of any land that is developed. The plan encourages the development to be on an access road rather than the main road so that the area appears rural from the main highway. The plan does not include an analogous provision for setbacks from the water. Although Virginia law discourages new development within 100 feet of the shore, the economic imperative of providing a waterfront view generally means that the home can be seen from the water.

John Tyler Highway, as well as the neck at the end of Forge Road. In the lightly developed rural area along Treasure Island Road, shore protection is likely, given the desirability of waterfront homes, but not certain given the lack of current development. Otherwise, the maps depict the rural area as “protection unlikely” (unless the land use defines the area as already developed). Agriculture and forestry are generally compatible with the minor shore erosion that might occur along these relatively steep shores as sea level rises. Even though some rural parcels will be developed for housing, the plan requires clusters that would preserve two-thirds of any such parcels for traditional uses or conservation. If these clusters preserve inland open space by densely developing the shore, our maps understate the likelihood of future shore protection. Although such a cluster would not appear to violate any specific Rural Lands Development Standard, it would probably not be consistent with the intent of those standards.

As with other counties, parks are considered unlikely to be protected. The one very important exception is Jamestown, whose historic significance makes shore protection very likely. The maps assume that Jamestown itself is certain to be protected, and that the rest of Jamestown Island is likely to be protected. As with all other counties, military lands are colored red pending a recommendation from the Department of Defense.

During the stakeholder review, the planning staff’s only comment was that the maps are a reasonable representation of expected future shore protection needs.

Isle of Wight

Transitional localities¹⁴⁸ such as Isle of Wight County are facing intense growth pressures today as a result of suburbanization and sprawl. Developed coastal areas along the James River are particularly likely to be protected because the majority of the developable James River shore is

high ground.¹⁴⁹ Therefore, shore protection may require erosion control but not the more expensive flood and inundation protection that may be needed in Poquoson and parts of the urban core. The PDC identified areas that are likely to be developed in Isle of Wight County.¹⁵⁰

We then examined the published comprehensive plan map for the Northern Development Service District. The map depicts areas denoted as “mixed use activity,” suburban residential, village center, and business and employment, as almost certain to be protected. Conservation development areas¹⁵¹ and suburban estate areas¹⁵² will probably be protected. Rural agricultural areas¹⁵³ will probably not be protected.

During the stakeholder review, the planning director indicated that given the long time horizon of this study, all the areas depicted in blue should be changed to red because development is expected to continue. Moreover, within the Northern Development Service District, the conservation development and suburban estate areas are almost certain to be protected. (See Map 8-16. See also Map 8-13 for the extreme southern part of the county.)

¹⁴⁹The county does have substantial low land along Ragged Island and the north side of the Pagan River.

¹⁵⁰The PDC did not suggest any areas of future development for York County.

¹⁵¹The County lists the following appropriate uses: single family residential development in either large lot form (5 acres) or in clustered form with smaller lots at a density of at least 1 unit per 5 acres and substantial areas retained in farm, forest, or open space uses. Densities of approximately 1 unit per 5 acres with densities adjusted depending on the presence of sensitive resources (wetlands and floodplains). Limited public and semipublic uses that are supportive of resource protection, conservation, and open space uses. Proposed Land Use Types, *Isle of Wight Comprehensive Plan 2001*; available at <http://www.co.isle-of-wight.va.us/plnlu.html>; accessed August 1, 2004.

¹⁵²“Existing and new development would be limited to single family residential development at densities ranging from .5 to 1 unit per acre (1 to 2 acre lot sizes)”; Proposed Land Use Types, *Isle of Wight Comprehensive Plan 2001*.

¹⁵³“Agriculture, horticulture, forest lands, and scattered residential development at a low density”; Proposed Land Use Types, *Isle of Wight Comprehensive Plan 2001*.

¹⁴⁸Observation aboard Scotland-Jamestown Ferry by Pratap Penumalli, November 24, 2002. Around the ferry route, development is sparse with small mobile home developments on either side.

TABLE 8-9. ASSUMPTIONS FOR SHORE PROTECTION MAP: OUTLYING JURISDICTIONS, FOR WHICH HAMPTON ROADS PLANNING DISTRICT COMMISSIONS DID NOT PROVIDE UPDATED LAND USE DATA (Poquoson, York, James City, Isle of Wight, Surry, Suffolk)^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Stakeholder review changes	As indicated				See text
Military lands outside urban core			b		Military installations
Public park lands (excludes small recreational parks)	✓				Parks; parks and forests identified from Delorme maps and implemented using land use/land cover data
Central business districts, major coastal communities, and lands slated for future development within Poquoson				✓	Planner input from initial study ^c
Developed public and private land cover				✓	Land cover ^d
Surry County Nuclear Power Plant				✓	Manual edit implemented using land use/land cover ^e
Poquoson: recent development				✓	Planner input implemented using land use/land cover ^f
Lands slated for future development in Surry and Isle of Wight counties			✓		Planner input implemented using land use/land cover ^g
Developed lands				✓	Land use/land cover ^h
Suffolk, York, James City, southern Isle of Wight: comprehensive plan designations commercial and moderate to high density residential				✓	Comprehensive plans ⁱ
Suffolk, York, James City, southern Isle of Wight: comprehensive plan designations low density residential			✓		Comprehensive plans ⁱ
Transitional areas likely to be developed in the future			✓		Land use/land cover ^k
Suffolk, York, James City, southern Isle of Wight: comprehensive plan designations: agriculture and conservation		✓			Comprehensive plans ^l
Remaining agricultural, forest, and undeveloped lands		✓			Land use/land cover

a Where land areas overlap, classifications higher in the table take precedence.

b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

c The initial 2001 VIMS study created polygons representing areas that are certain to be protected in the event of a 20-ft sea level rise. These areas are depicted in orange in some versions of our maps. Within HRPDC, their study area included only the urban core and Poquoson City.

d We identify developed land cover based on residential, commercial, industrial, and transportation structure land covers in data provided by USGS.

e Tyrone Franklin drew the Surry Nuclear Power Plant onto a county planning map, which we digitized.

f Planners identified Poquoson recent development based on the Delorme Virginia Atlas and Gazetteer map and the Poquoson web site, accessed 9/10/03: <http://www.ci.poquoson.va.us/BigWoods.htm> and <http://www.ci.poquoson.va.us/Messick.html>.

g In Isle of Wight, coastal development along the James River was identified by Hugo Valverde using entire land use/land cover polygons. In Surry, Tyrone Franklin drew future development areas onto a county planning map, which we digitized.

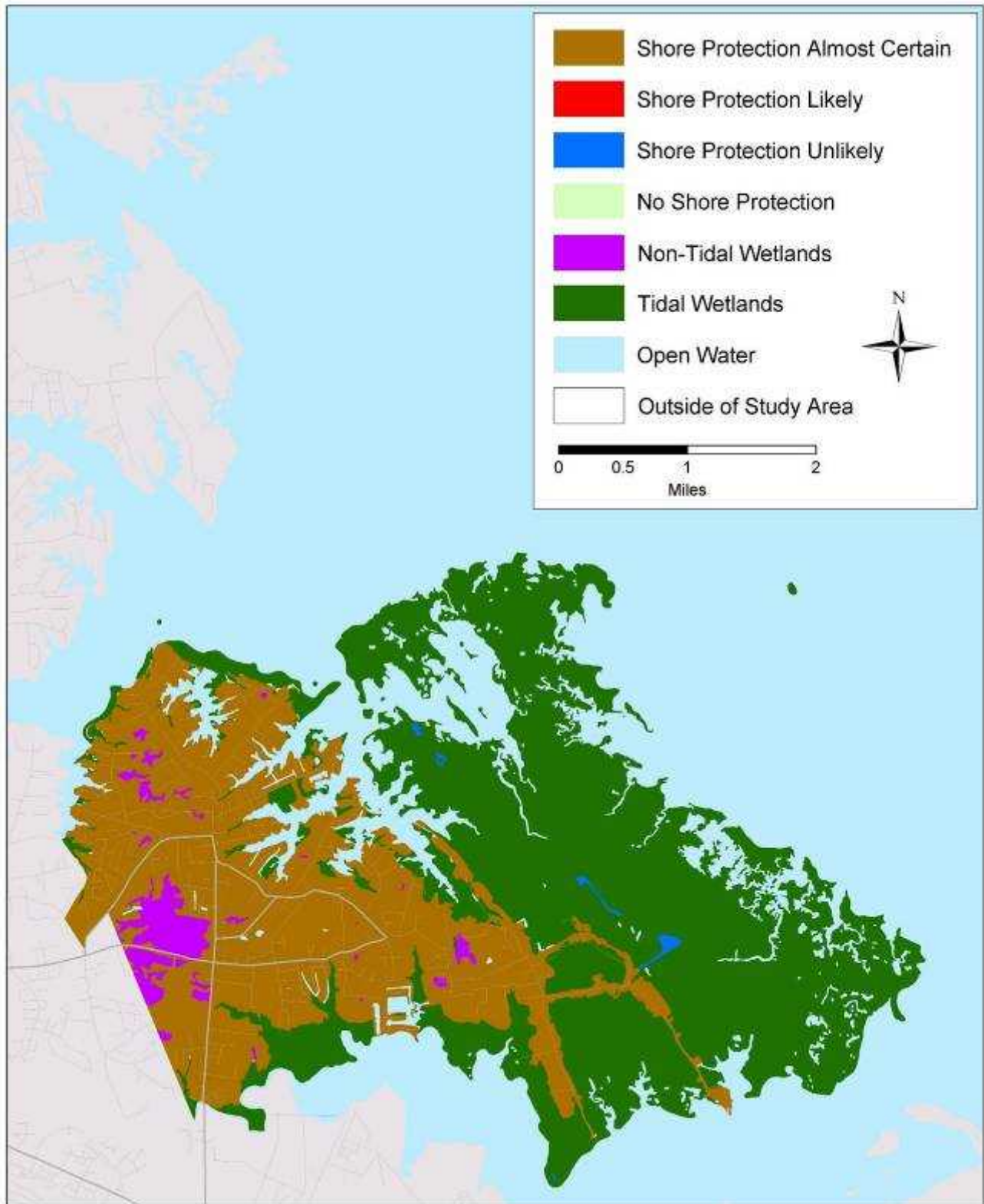
h We identify developed lands based on residential, commercial/services, industrial, transportation/communication/utilities, and other urban/built-up land uses.

i. **For Isle of Wight County (Northern Development Service District only):** Village Center, suburban residential, mixed-use activity center, business and development, and industrial. **For Suffolk:** core city. **For York County:** medium, high, and multifamily residential; business, industrial, and economic opportunity. **For James City County:** Primary Service area (except for low-density housing areas not yet developed) plus within rural land along the James River at the west end of the county south of John Tyler Highway, and development at the neck at the end of Forge Road.

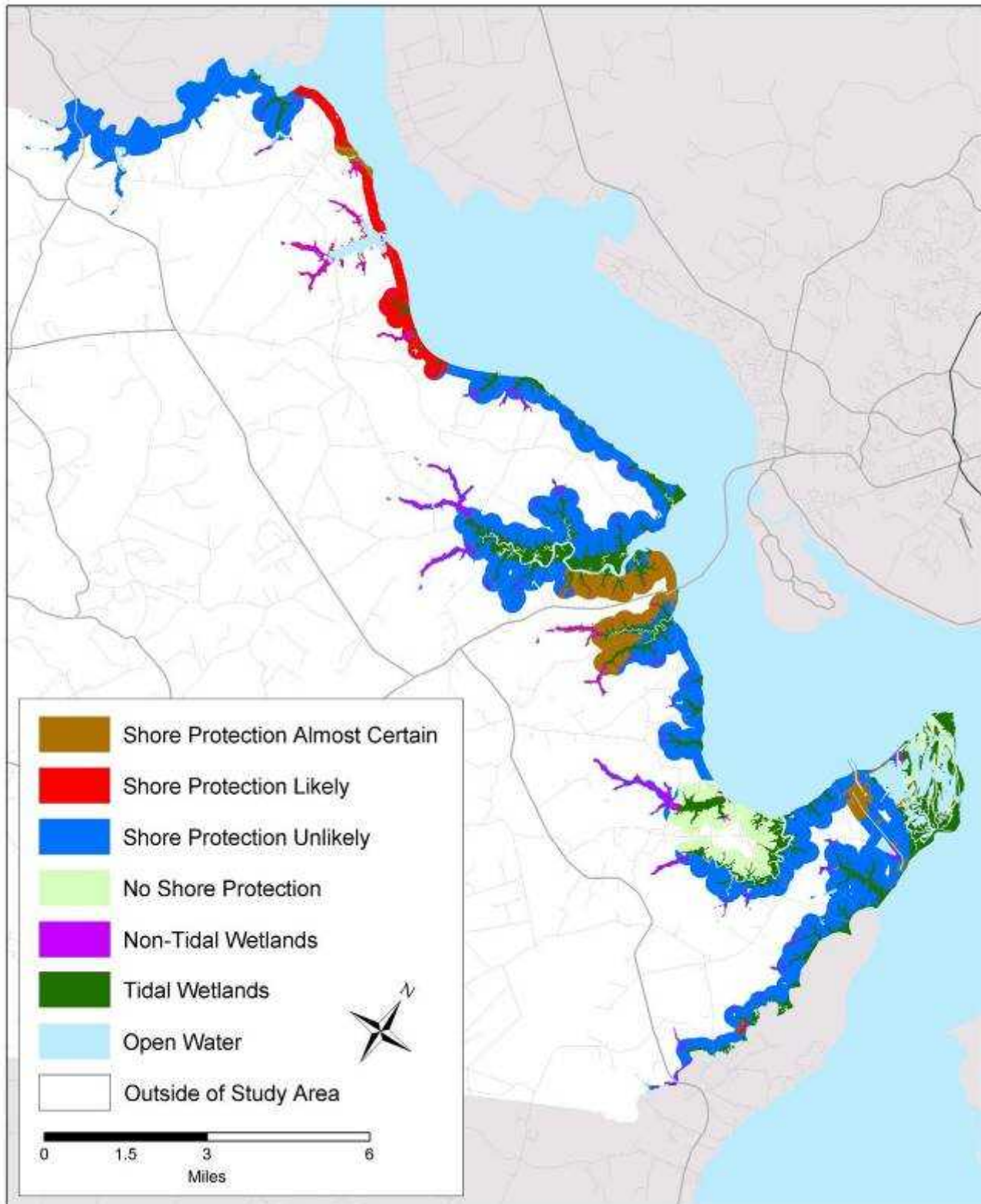
j. **For Isle of Wight County (Northern Development Service District only):** Village Center, suburban residential, mixed use activity center, business and development, and industrial. **For Suffolk:** rural conservation area/low intensity residential (with public water). **For York County:** low density residential. **For James City County:** low intensity housing within primary service area, and the lightly developed areas along Treasure Island Road.

k. **For all Hampton Roads localities except Isle of Wight,** we identify transitional areas likely to be developed in the future based on land use/land cover’s transitional area. **For Poquoson,** we estimated recent development areas using Tiger 2000 roads to identify distinct land use polygons that have extensive road networks. For Poquoson, this effort was eventually moot because after the fourth iteration with us, the extensive post-Isabel elevation of homes and other factors led the city council to conclude that all developable areas are certain to be protected as sea level rises.

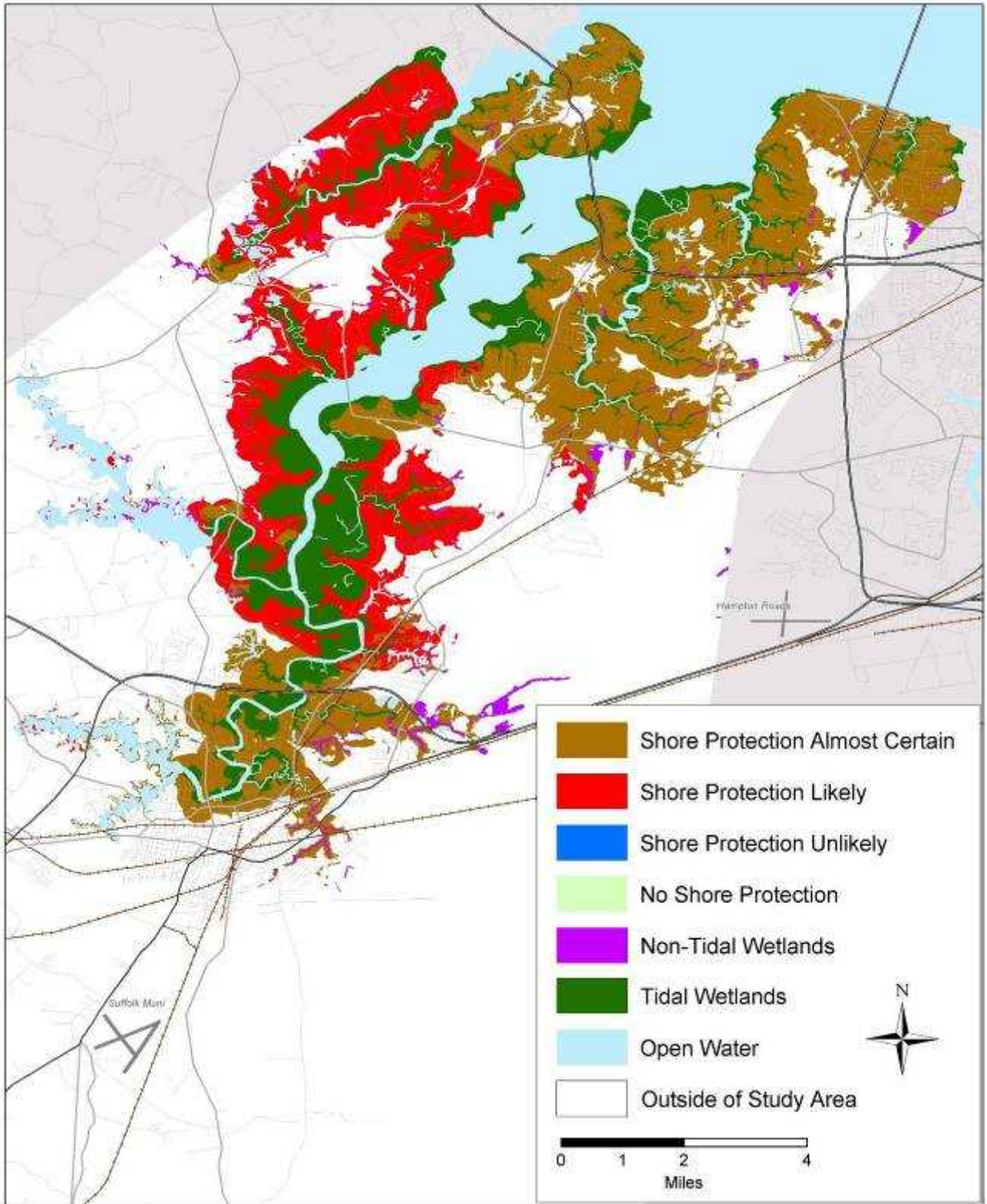
l. **For Isle of Wight County (Northern Development Service District only):** agriculture and conservation areas. **For Suffolk:** rural agriculture conservation area (no utilities). **For York County:** conservation. **For James City County:** rural areas.



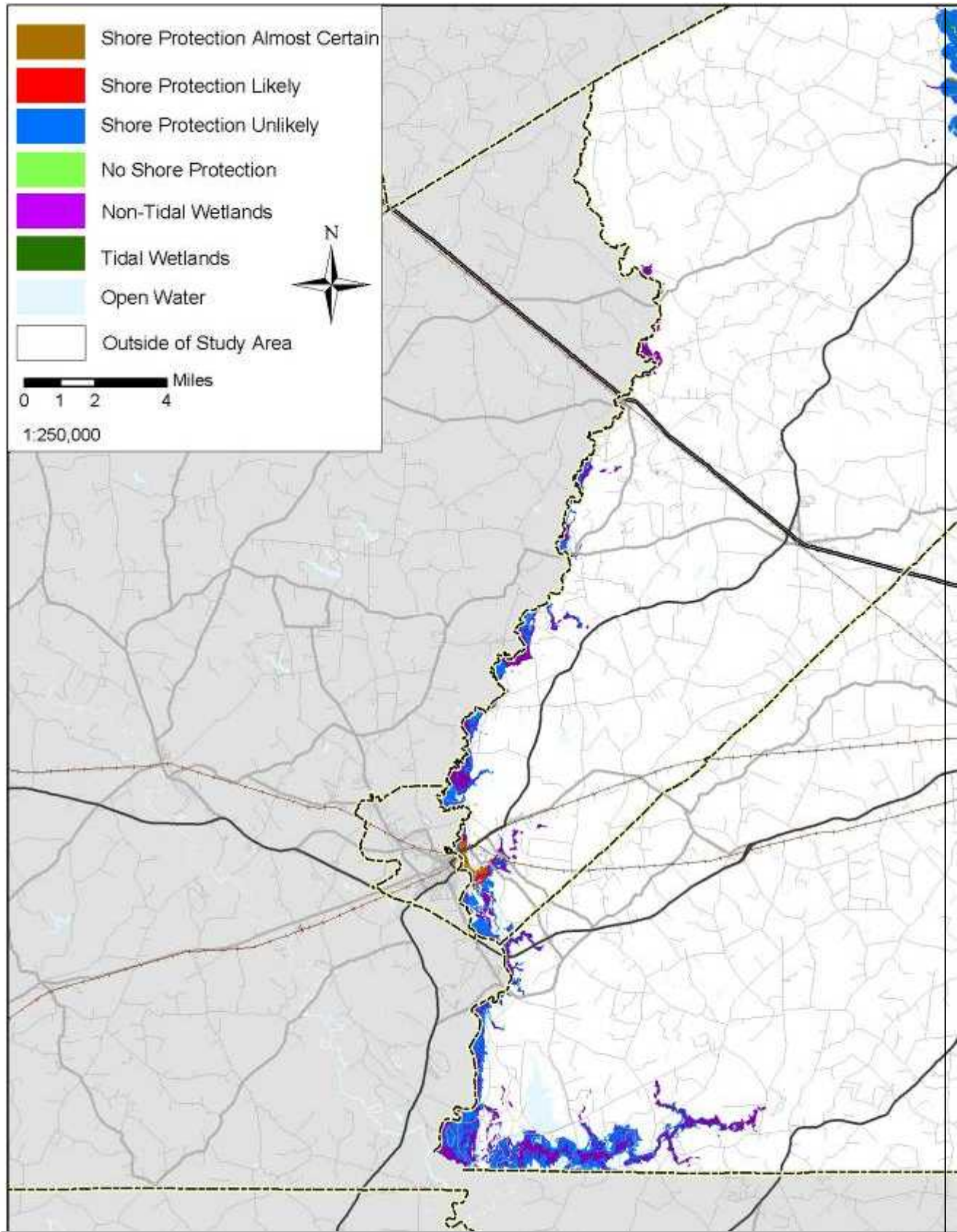
Map 8-10. Poquoson: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



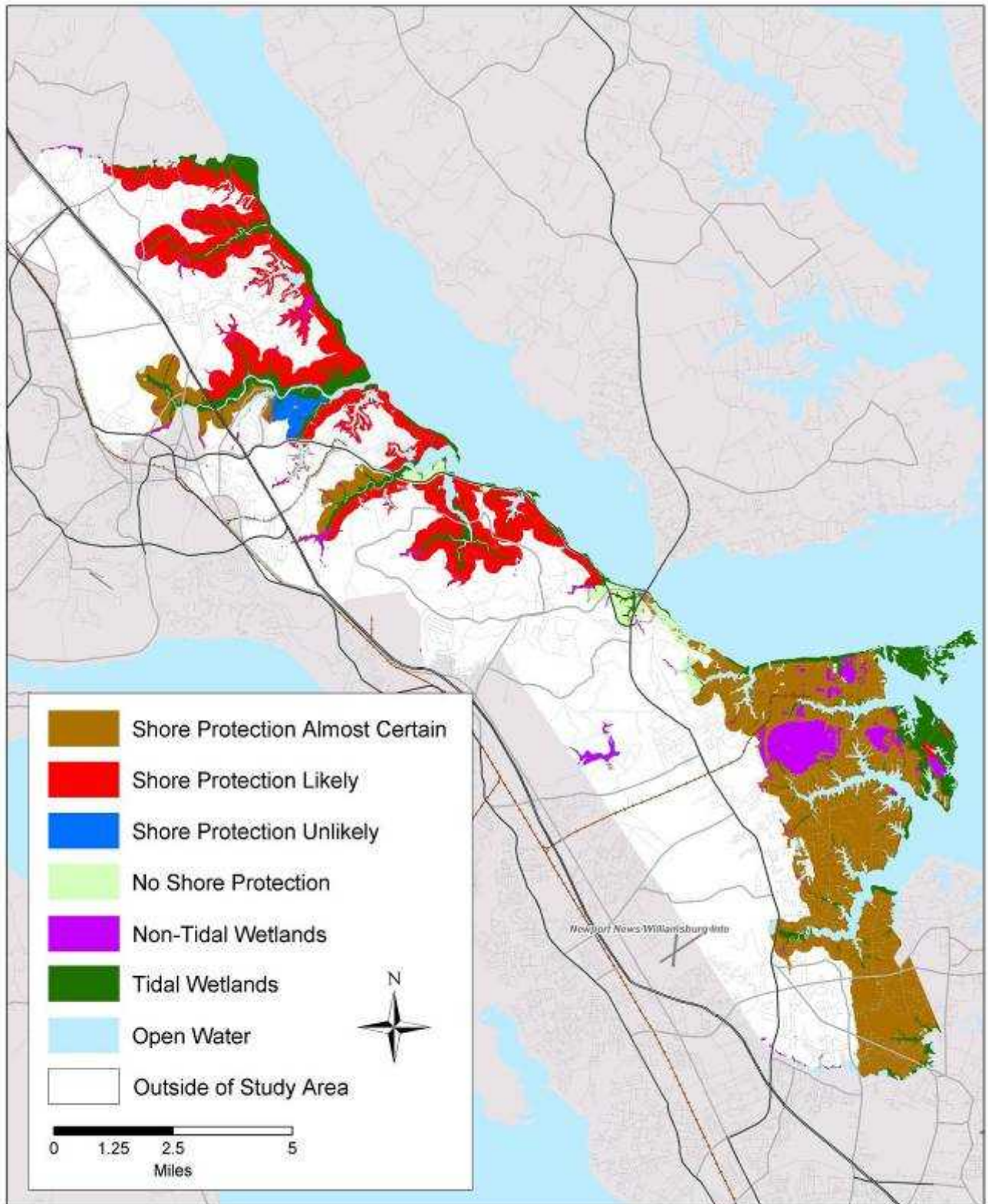
Map 8-11: Surry: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



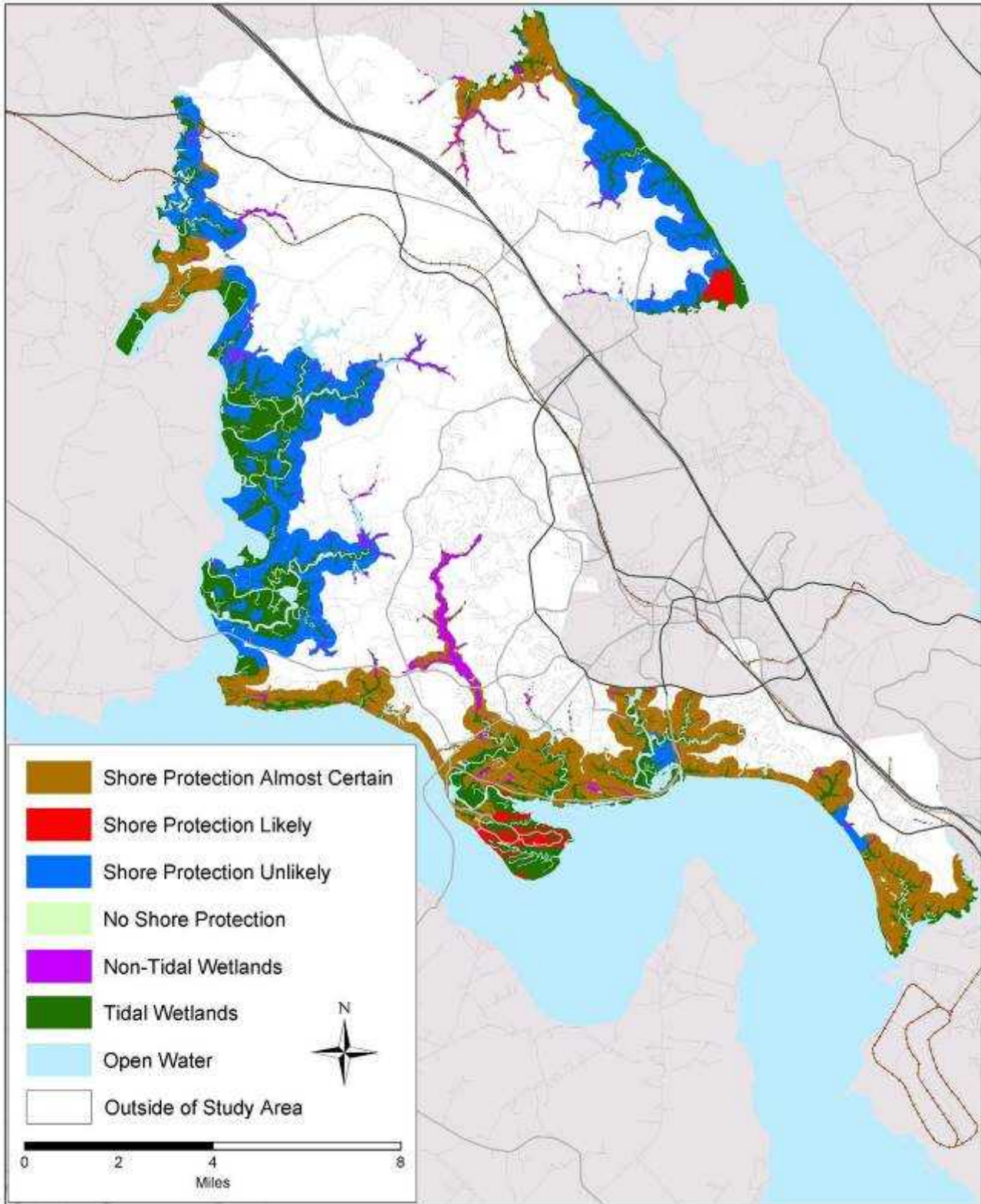
Map 8-12. Suffolk: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



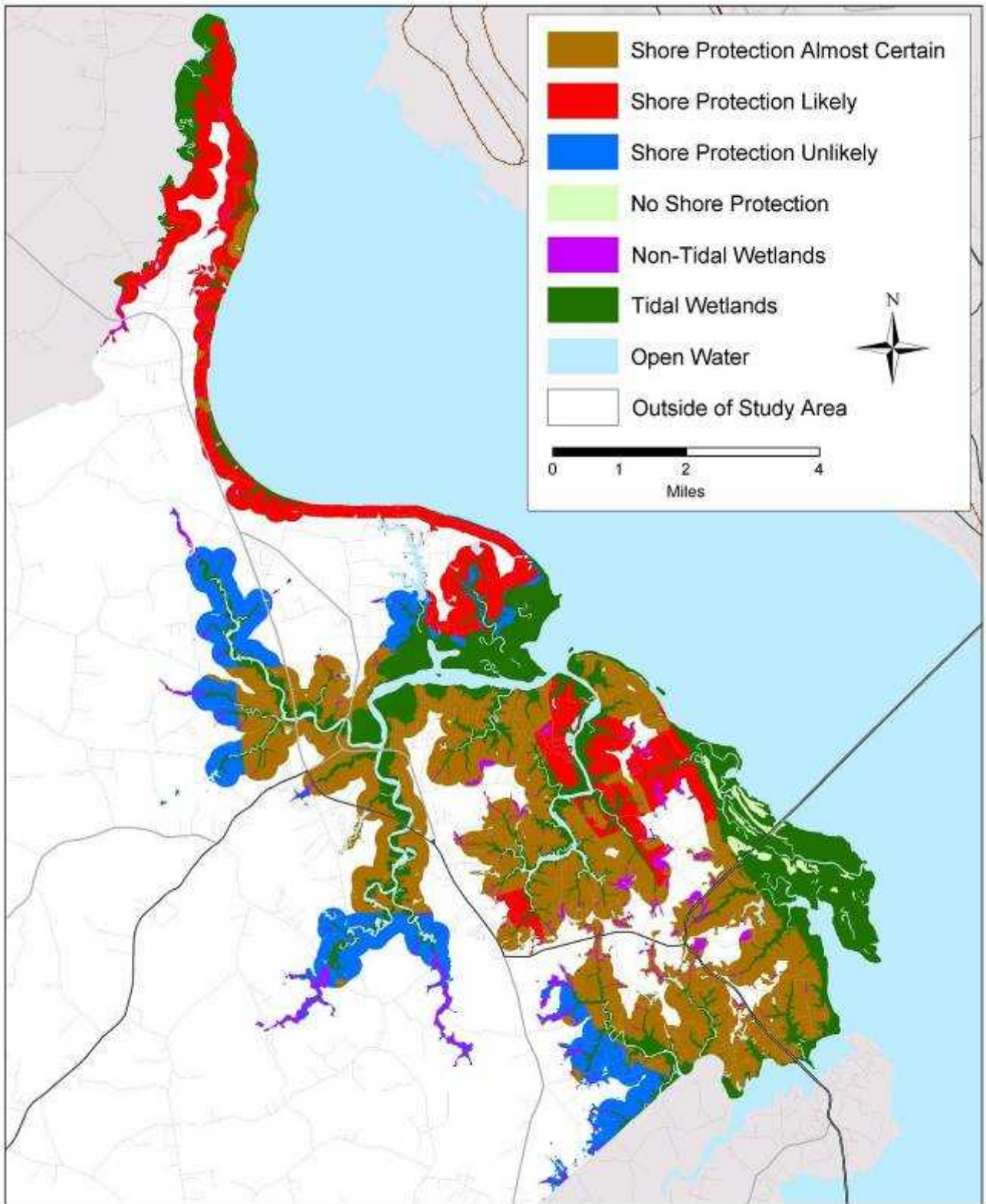
Map 8-13. Southern Suffolk and Southern Isle of Wight: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-14. York: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-15. James City: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-16. Isle of Wight: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

MIDDLE PENINSULA PLANNING DISTRICT

Vulnerability to Sea Level Rise

The Middle Peninsula is immediately north of the Hampton Roads region. The peninsula is surrounded by the York River to the south, the Rappahannock River to the north, and Chesapeake Bay to the east. Mathews and Middlesex counties are along Chesapeake Bay. Gloucester County is between the York River and Mobjack Bay, with very little of the county actually on Chesapeake Bay. King William, King and Queen, and Essex counties lie farther up the York and Rappahannock rivers, with segments of shoreline along the rivers and creeks, but otherwise very little land below the 20-ft contour.

Gloucester is the most developed county, with several relatively dense pockets of suburban development in the southern portion of the county. The remainder of the Middle Peninsula consists of a mix of rural areas and seasonally occupied coastal homes. The population of the region was approximately 87,000 in 2000, up from 73,000 in 1990. Development pressures are strong where land values are highest (in Gloucester County and the coastal portions of Mathews and Middlesex counties). The counties adhere to many local coastal protection policies and ordinances that restrict development of some areas immediately along the coast. In Gloucester County, for example, many coastal areas have been set aside as “Bayside Conservation Districts” by a county ordinance and, as a result, will not be armored.

Table 8-10 summarizes the amount of land close to sea level in the six jurisdictions. Gloucester County has approximately 5 square miles of dry land within 2 feet above the coastal wetlands. Most of that land is on the Guinea Neck, which has a number of long-established communities. This area may be the community most vulnerable to

rising sea level along the Western Shore¹⁴⁵ of Chesapeake Bay. Already, one finds ditches where the water rises and falls with the tides, and in several areas people’s lawns consist of marsh grasses. (See Photos 8-21 through 8-24.) Unlike the low-lying developed communities in the Hampton Roads area, Guinea Neck does not yet have an infrastructure designed to cope with rising water levels.

Mathews County has almost as much very low land, but it is more dispersed. For the most part, the very low dry land in this county tends to be undeveloped forests lying just inland of the tidal wetlands. Photo 8-25 depicts the public beach along Chesapeake Bay east of Matthews. Photo 8-26 shows the marsh immediately behind the beach. Inland of those wetlands lie forests and small farms. Approximately 1 mile north of the public beach is a public landing and a small number of shorefront homes (Photos 8-27 and 8-28). The most vulnerable development, however, is in the southernmost neck, between Horn Harbor and Mobjack Bay. For the most part, the development is 3–4 feet above the ebb and flow of the tides. Because the ditches are not tidal there, to the naked eye these areas do not appear to be as vulnerable as the Guinea Neck in Gloucester County.

Middlesex County has relatively little low land. Its main coastal neck, between the Rappahannock River and Fishing Bay, is mostly more than 10 feet above sea level, with some hills. Despite its name, for example, Deltaville is generally 15 feet above sea level and not vulnerable to inundation. Shoreline armoring, however, is commonplace.

¹⁴⁵Several portions of Accomack County are similarly vulnerable.



Photos 21–24. Guinea Neck. Photos 21 and 22 are near the end of Maryus Road in Guinea Neck, looking north. The front yard of the home in the foreground is only one foot above the level of spring high water. Two piles of fill dirt can be seen along the home in the background, along with crab pots neatly stacked. Photos 23 and 24 show low dikes, which protect the land behind them during minor storm tides and extreme astronomic high tides. They also show the tidal ditches along the street, with various forms of marsh vegetation. In Photos 21 and 24, people mow the high marsh grasses as if they were ordinary lawns (July 1998).

Compared with Hampton Roads and the Eastern Shore, this region has a steep shoreline in most areas. Therefore, as sea level rises, erosion of relatively high ground will be more commonplace than inundation of low land relative to those regions. Shore protection will generally be less expensive in this area than in Hampton Roads and the Eastern Shore, both because shoreline armoring for erosion control is less expensive than dikes with pumping systems and because the rivers and small bays along the Middle Peninsula have calmer seas than the shores of Chesapeake Bay and the Atlantic Ocean.

Anticipated Sea Level Rise Response

Unless otherwise stated, based on communications¹⁴⁶ with:

Lewis Lawrence and Tom Brockenbrough, Middle Peninsula PDC; Jay Scudder, Gloucester County;

¹⁴⁶For Jay Scudder, meeting with Jim Titus at county offices, October 12, 2002; telephone conversations with Pratap Penumalli between December 2002 and June 2003. For Lewis Lawrence, Tom Brockenbrough, Clarissa James, and Rodney Rhodes, meeting with Pratap Penumalli at the offices of the Middle Peninsula Planning District, November 25, 2002. For all others, telephone conversations with Pratap Penumalli between October 2002 and June 2003. In addition to changes noted in text and footnotes, the reviewers pointed to places where map overlay errors showed land as water or water as land. Those types of errors would not have made a difference in the final product, which uses wetland data to define water and land; we regret that reviewer time was consumed fixing errors that would have been fixed eventually anyway. Moreover, the maps Will Nuckols showed the stakeholders did include the orange from the original study.



25



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Photos 25–28. Mathews County Coastal Zone. Photos 25 and 26 show the Mathews County public beach and the wetlands immediately behind that beach. Photo 27 shows light shorefront development about one mile north of the beach. Photo 28 shows a newer home somewhat north of that area. Water in the ditch during a drought provides an indication of the low elevation of this property (October 12, 2002).

Rodney Rhodes, Mathews County; and Matthew Higgins and Clarissa James, Middlesex County;

Final maps and report modified based on meeting¹⁴⁷ with:

David Fuss, Lewies Lawrence, and Tom Brockenbrough, Middle Peninsula PDC; Jay Scudder, Gloucester County; Matthews Higgins and Kevin Jordan, Middlesex County; Alyson Cotton, King William County; Carissa Lee, King and Queen County; R. Gary Allen, Essex County; Jimmy Snyder, Town of Tappahannock; and Dianne Franck, Town of Urbanna.

Shoreline armoring is cost-effective along most of the shores of the Middle Peninsula, given the high ground and relatively moderate wave climate.

With the possible exception of the outer portions of the Guinea Peninsula, there is little reason to expect that any developed area will be abandoned to the rising sea. Therefore, identifying the areas likely to be protected is largely equivalent to identifying the areas that have or will be developed. Tables 8-11 and 8-12 summarize the general tendencies that planners in the Middle Peninsula expect for shore protection as sea level rises.

¹⁴⁷Meeting on February 11, 2004, at the offices of the Middle Peninsula Planning District Commission (MPPDC) with Will Nuckols.

TABLE 8-10. AREA OF LAND VULNERABLE TO SEA LEVEL RISE: MIDDLE PENINSULA PLANNING DISTRICT (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Gloucester	24.0	16.8	5.3	1.9	11.7	4.2	25.6	9.5
Mathews	16.9	10.5	5.1	1.3	11.9	3.1	29.1	7.6
Essex	^e	10.7	^e	^e	2.6	0.5	5.3	1.1
King And Queen	^e	8.3	^e	^e	2.0	0.6	4.2	1.1
Middlesex	^e	3.7	^e	^e	2.4	0.5	5.2	1.0
King William	^e	13.5	^e	^e	1.1	0.3	2.7	0.5
Total	82.1	63.5	14.5	4.1	31.8	9.2	72.1	20.8

^a J.G. Titus and J. Wang, 2008, see Table 8-3 for full reference.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

^e Value omitted because the topographic information Titus and Wang used for this jurisdiction had poor vertical resolution.

Gloucester County

This county was the only jurisdiction with its zoning map in a digital format. Therefore the GIS decision rules that we used to create maps for Gloucester are different than for the rest of planning district. (Table 8-11 summarizes these mapping methods.) Like other counties in Virginia, Gloucester expects most developed areas to be protected. The county land use regulatory policies, however, also have a strong conservation ethic. A large portion of the necks along Mobjack Bay (as well as the land between VA Rte. 3 and the North River) is zoned as conservation, rural conservation, or bayside conservation. Although homes are allowed in these areas, the zoning allows for only low-density residential development “in a manner which protects natural resources in a sensitive environment.” The intent is to preserve contiguous open spaces and protect the surrounding wetlands areas while allowing for a limited amount of low-density, clustered

residential development.¹⁴⁸ Despite the desirability of waterfront homes, the County seeks to maintain coastal ecosystems important for crabbing and fishing. Given both the cost of protecting lightly developed areas and the general conservation

policy for these lines, Gloucester County expects that these areas (i.e., conservation, rural conservation, and bayside conservation) will generally not be protected from rising sea level. As a result, wetlands and beaches would appear to have a high probability of being able to migrate inland as sea level rises along the open bay. We also identified shore-parallel roads and clusters of road networks. In these areas, we identify the corresponding land use polygons as likely to be protected in the future¹⁴⁹ (Map 8-17).

Areas zoned as suburban countryside in Gloucester County allow for low density residential development, including provisions for clustered subdivisions.¹⁵⁰ This zoning applies to part of

¹⁴⁹During the October 12, 2002 meeting, Titus did not discuss this analysis of road networks with Jay Scudder. During the road network analysis required for the other counties, however, we extended the approach to Gloucester County as well. The primary effect of including the roads in Gloucester County is that much of the bayside conservation lands are shifted from protection unlikely to protection likely. During the stakeholder review, Jay Scudder agreed with the resulting maps; therefore we made no attempt to reconstruct the map that would have resulted from a precise implementation of decision rules suggested during the October 2002 meeting.

¹⁵⁰Definition of suburban countryside in Gloucester County Code of Ordinances, accessed through Municode Online Codes on August 22, 2003:

<http://livepublish.municode.com/22/lpext.dll?f=templates&fn=main-j.htm&vid=10843>: “The intent of the SC-1 district is to allow low density residential development. The SC-1 district is intended for limited areas suitable for such development by virtue of their nonprime, nonerodible soils and their suitability for septic systems. In many cases, these areas are already largely committed to low

¹⁴⁸Gloucester County Code of Ordinances, accessed through Municode Online Codes on August 22, 2003; <http://livepublish.municode.com/22/lpext.dll?f=templates&fn=main-j.htm&vid=10843>.

the Guinea Neck and the area between Carter Creek and the Catlett Islands. The somewhat higher densities here, as well as the high quality of the homes and likelihood of future residential development, suggest that shore protection is likely, according to the County. West of Gloucester Point, however, the County suggested that suburban countryside lands will almost certainly be protected, given the modest cost of protecting an area with high ground and moderate wave climate.

Two additional factors tend to make shore protection more likely in some areas than one would expect from these decision rules. First, shoreline armoring to protect from the relatively calm wave climate of the York River west of Gloucester Point is much less expensive than the dike and pumping systems that would be required to protect the Guinea Peninsula from both inundation and the larger storm waves of Chesapeake Bay. Second, the high waterfront property values tend to make protection worthwhile even while a similarly sized property along a marsh with no waterfront might not be worth protecting. Therefore, the County suggested that shore protection is likely for almost all of the York River shoreline upstream from Gloucester Point, with the exception of the conservation and rural countryside areas. Similarly, the part of Guinea Neck zoned as suburban countryside between Cuba Road and the York River will almost certainly be protected. By a similar logic, the area zoned as bayside conservation between Jenkins Neck Road and the York River will probably be protected. Finally, because a sewer line runs under Guinea Road, the corridor along Guinea Road (VA-216) is almost certain to be protected, even though some of it is suburban countryside.

Although most of the York River shore will almost certainly be protected, a number of areas are off limits to development. The Catlett Islands are part of the Chesapeake Bay National Estuarine Research Reserve in Virginia, managed as a

conservation area.¹⁵¹ Upstream from Almondsville to the border with King and Queen County, the undeveloped areas are unlikely to be developed in the foreseeable future, and hence protection currently seems unlikely, according to the planning department. From Clay Bank up the river to Almondsville, by contrast, the seasonal and permanent homes are almost certain to be protected.

During the stakeholder review, the County's main suggested improvement concerned the two necks between Timbemeck and Carter creeks. The County suggested that those areas should be changed from blue to brown. The County indicated that because development is anticipated here, shoreline protection is almost certain.¹⁵² That correction should not have been necessary: The data that County had supplied showed those areas as suburban countryside. The decision rules developed at our original meeting designated suburban countryside as red in general, and brown in the case of land along the York River west of Gloucester Point. Nevertheless, the actual maps we created and distributed during stakeholder review showed a significant amount of land in that region designated as unlikely to be protected. We looked into the causes of this discrepancy,¹⁵³ to make sure that it had not caused other map errors that no one had noticed. Fortunately, the stakeholder review had caught all the errors induced by our mapping

¹⁵¹See <http://www.vims.edu/cbnerr/about/index.htm>; accessed on June 15, 2003.

¹⁵²We incorporated these growth zone data and also added a better open water layer to prevent open water areas from showing as dry land.

¹⁵³Hudgens and Guido Stein of IEC undertook this consistency evaluation. Errors in the map occurred because Penumalli had been unable to use the county GIS data and had instead attempted to roughly (i.e. 1:250,000 scale) duplicate them through a combination of manually selecting polygons in the land use/land cover data, creating polygons based on road layer data, and using other sources. To economize effort, he sought to duplicate only the polygons needed to create the map; unfortunately, he overlooked suburban countryside. By the time the maps went to stakeholder review, Penumalli had left IEC; and the remaining authors (Titus, Nuckols, and Hudgens) all thought that he had used the county data in creating the maps, as indicated in the draft report. Upon discovering how the maps had actually been created, Hudgens and Stein were able to use the county data, and replaced Penumalli's estimated zoning layer with the county's zoning layer. Using the county data corrected the problems that the County had noticed during stakeholder review, and also slightly refined some boundaries.

error, and the final maps use planning data supplied by Gloucester County. The County also suggested a number of changes, most of which related to minor errors in the data or map boundary inconsistencies.¹⁵⁴ The County also explicitly noted areas that were correct.¹⁵⁵

Other Counties

For the remaining counties in the Middle Peninsula, the absence of digital land data made it impractical to base the sea level planning maps on a county's land use plan. Instead, as with the Eastern Shore, the maps are based on a combination of 1:250,000-scale USGS land use data, data on existing roads¹⁵⁶ and shoreline armoring, and site-specific judgments provided by the county planners. The protected areas also include the results from a workshop held by VIMS¹⁵⁷ to identify areas that would be protected even in a worst-case scenario, which are shown in orange in some versions of our maps. Table 8-12

¹⁵⁴The most common map boundary problem was that our maps tended to show small amounts of blue along the shore, wherever the shore indicated by our land use data was seaward of shoreline boundary indicated by the county zoning data. This occurs because our GIS decision rules treated all land as blue if the land use data did not specifically indicate land that should be mapped as a different color. Given the detailed nature of the county's zoning data, however, we should have used the zoning data as the basis of the boundary between dry land and open water. To fix this problem, we later changed the maps by removing the land use data being shown as protection uncertain (blue). The resulting map thus does not include the small amount of erroneous blue along the shore. Other errors that we corrected: At the Rte. 17 bridge over the York River, we omitted two polygons of the land use category SF-1, which caused a park to show up as open water; the VIMS lands that are already armored and include substantial infrastructure showed up as red and the unarmored areas showed up as blue.

¹⁵⁵Significantly, Guinea Peninsula and Ware Neck.

¹⁵⁶Jim Titus spent a day driving around the Northern Neck and Middle Peninsula in October 2002, using sea level planning maps that we had developed based solely on the land use and VIMS data. Those maps depicted most of these peninsulas as blue. Titus used a printed DeLorme Atlas to navigate to the shore along as many necks as time would permit. He quickly observed that even though our maps depicted the area as blue, every time the DeLorme map showed a road parallel to the shore, there were waterfront homes—and often armored shores. Given the dated nature of the land use data, as well as the potential for 1:250,000 scale land use data to overlook narrow strips of development along a body of water, we supplemented the maps with road layer information. Nevertheless, because roads are a less direct means of inferring development than land use data, the stakeholder review maps used the roads to identify areas where shore protection is likely, not certain.

¹⁵⁷See Appendix E.

summarizes the general tendencies that planners expect for shore protection in the Middle Peninsula. Unlike other areas in Virginia, the Middle Peninsula planners disagreed with the assumption that areas with shore protection are almost certain to be protected throughout the next century. The planner for Matthews County stated that shore protection in some low-lying areas¹⁵⁸ is uncertain because the cost of shore protection may increase more than property values in this county.¹⁵⁹ Instead, the planners suggested that we should assume that these areas are likely to be protected, unless there is another reason to believe that such an area is certain to be protected.

Counties along the York River

The York River shores of King and Queen County and King William County are significantly less developed than the shore of Gloucester County. The only areas identified as certain to be protected in either of these counties are the town of West Point and surrounding areas (including the municipal landing strip). A lack of extensive roads along the river suggests that these areas are less likely to be developed in the next few decades. Moreover, the PDC staff point out that upstream portions of the York River tend to have wetland shores, which make docks and marinas less feasible and prevent waterfront construction. Finally, these shores are also farther from populated areas than Gloucester County. Therefore, based on the PDC's suggestion that these marshfront and riverfront areas are not suitable for development, we conclude that they will probably not be protected (Maps 8-16 and 8-17).

¹⁵⁸For example, the area from New Point north to Susan. Auburn Wharf, in the western part of the county, is currently protected, but the area behind it is mostly vacant with a small trailer park farther inland. Unless the vacant areas are developed or the trailer park is upgraded, this area may not be able to justify shore protection.

¹⁵⁹November 2002 meeting with Rodney Rhodes.

TABLE 8-11. ASSUMPTIONS FOR SHORE PROTECTION MAP: GLOUCESTER COUNTY^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Gloucester County Development District and VIMS Campus				✓	Stakeholder review comment implemented using land use/land cover
Potentially developing areas located along clusters of roads within areas zoned for conservation			✓		Implemented using Tiger roads and land use/land cover
Developed public and private lands				✓	Land cover
Catlett Islands	✓				Gloucester County zoning data implemented into maps using land use/land cover ^e
Suburban countryside along the York River west of Gloucester Point				✓	Gloucester County zoning data implemented into maps using land use/land cover ^e
Residential, commercial, and industrial zones ^b				✓	Gloucester County zoning data implemented into maps using land use/land cover ^e
Suburban countryside between Cuba Road and the York River				✓	Gloucester County zoning data implemented into maps using land use/land cover ^e
Within Guinea Neck, VA-216 corridor served by sewer				✓	Gloucester County zoning data implemented into maps using land use/land cover ^e
Suburban countryside and historic land zones ^c			✓		Gloucester County zoning data implemented into maps using land use/land cover ^e
Bayside conservation land between Jenkins Road and the York River			✓		Gloucester County zoning data implemented into maps using land use/land cover ^e
Conservation lands ^d		✓			Gloucester County zoning data implemented into maps using land use/land cover ^e

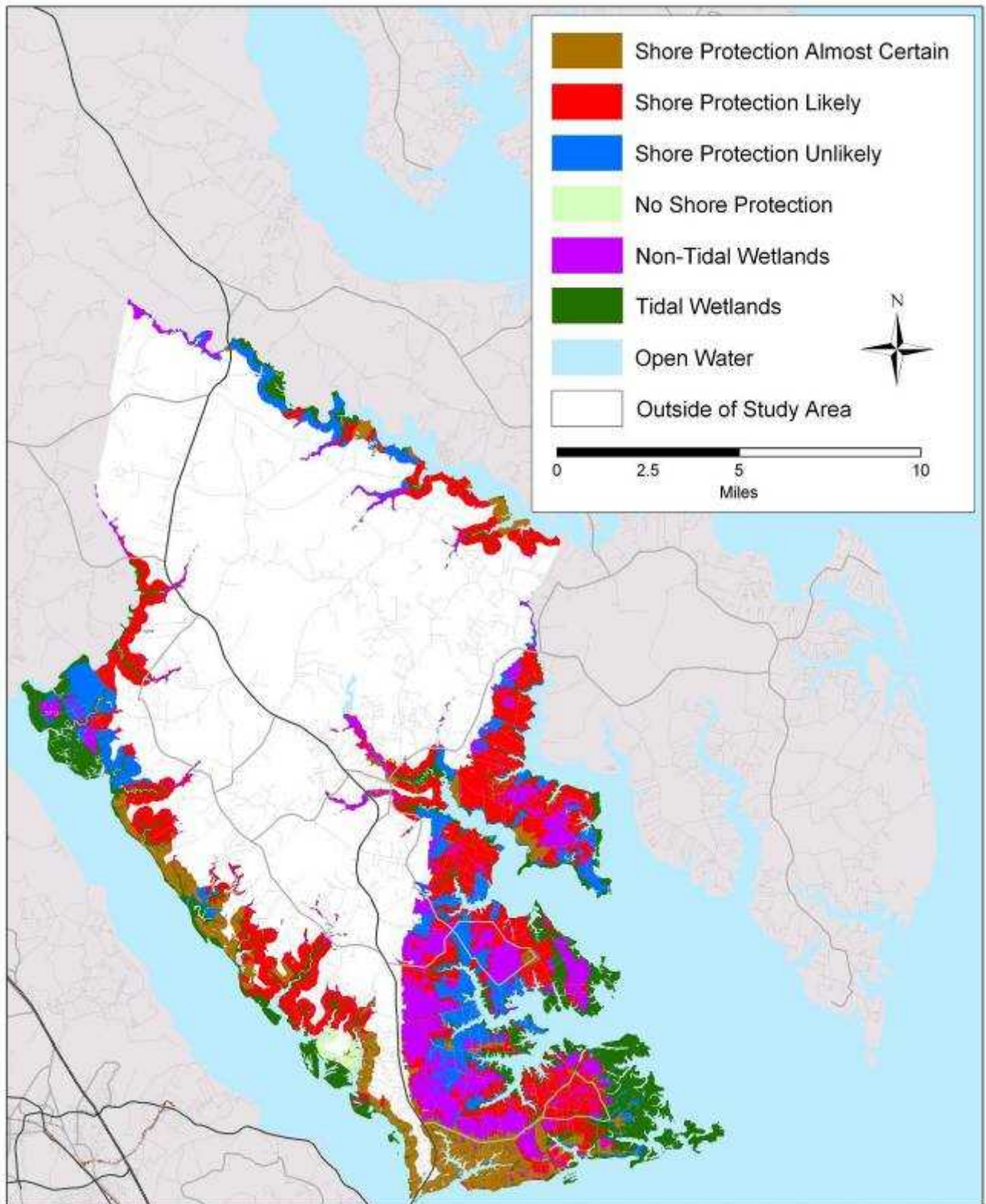
^a Where land areas overlap, classifications higher in the table take precedence.

^b Identified based on Gloucester zoning classifications including business, industrial, multi-family residential, and single family residential.

^c Identified based on Gloucester zoning classifications, including historic overlay, planned unit development, and suburban countryside.

^d Conservation lands from Gloucester County zoning data include conservation, bayside conservation, and rural conservation areas.

^e Map data are based on digital zoning data provided by Gloucester County; however, to define the specific areas identified in the decision rules above, we used land use/land cover to delineate the boundaries.



Map 8-17. Gloucester: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

During stakeholder review, the only change either of these counties requested was that the West Point peninsulas should show additional protection. The original map had mistakenly shown part of the west side of town as likely to be protected, presumably because the land is classified as “other urban or built-up land.” However, the entire town is certain to be protected. King William County views the entire neck as a growth area, and hence it will probably be developed and protected. King and Queen County expects very little shore protection because lots tend to be large and there is currently very little armoring.

Mathews County¹⁶⁰

Mathews County along Chesapeake Bay is one of the lowest lying counties in Virginia. The county is not very developed, and land values are not very high compared to coastal residential areas in Gloucester County. Therefore, the planners are not at all certain that all of the relatively low-lying areas will be protected. In particular, they believe that the area from New Point north to Susan is likely—but not certain—to warrant protection, even though it is currently armored. Similarly, the Auburn Wharf area on Chapel Neck is currently armored, and likely—but not certain—to be protected indefinitely (Map 8-20).

Significantly developed areas will continue to be protected, especially development along Mobjack Bay (other than the New Point area) and the East River heading into (and including) the Town of Mathews. Gwynn Island is almost entirely armored and moderately developed, and is almost certain to be protected in the future as well. Key undeveloped areas that will probably eventually be developed and protected include the interior portions of White’s Neck and the neck between Retz and Mathews.

Many of the interior areas between VA Rte. 14 and Chesapeake Bay to the southeast of Mathews are

undeveloped forests. This region, which includes the Mathews County public beach, is unlikely to be protected.

Counties along the Rappahannock River

The Rappahannock River shore in the Middle Peninsula stretches from Middlesex County into Essex County and is made up mostly of bluffs and other elevated lands. Similar to the banks of the James River, these areas may experience increased problems related to erosion. Given the value, the PDC planners believe that seasonal homes from Middlesex County to Urbanna would certainly be protected. Because development is sparser north and west of there in the areas surrounding Stove Point, the planners believe that protection is likely but not certain.¹⁶¹ Undeveloped areas from Stove Point to the wetlands areas around Piscataway Creek in Essex County are unlikely to be protected because these areas are mainly forested or open lands with little development potential, except for occasional boat landings and marinas such as Bowlers Wharf and Wares Wharf. In Essex County, the only area certain to be protected is the town of Tappahannock, which has cultural, tourist, and commercial importance to the region. In addition to being the hub of activity in Essex County, it is also one of the only developed areas in the county with any vulnerability to the consequences of a 1- to 3-ft sea level rise. Fortunately, the majority of this town is above the 10-ft contour. Its shores are mostly armored already. Increased flooding is the most immediate implication of a rising sea level, and for the foreseeable future, the impact there is likely to be minor (Maps 8-21 and 8-22).

In Middlesex County, planning director Matthew Higgins identified development along the Piankatank River as almost certain to be protected because this area consists of modest to high value residential development. In addition, shoreline development on the peninsula leading to Stingray Point (including Deltaville, Ruark, and Grinels) serves as the commercial, tourist, and residential

¹⁶⁰The general approach and site-specific assumptions were based on telephone conversations between Pratap Penumalli and Rodney Rhodes, Mathews County Department of Planning and Zoning, on October 8 and October 21, 2002, as well as the meeting at the PDC offices on November 25, 2002. County staff did not attend the Stakeholder Review Meeting at the PDC offices; but PDC staff confirmed that the maps accurately represented expectations for shore protection for Mathews County.

¹⁶¹Original planning maps identified Goose Point as likely to be protected; during the stakeholder review, however, Matthew Higgins and Kevin Jordan of Middlesex County indicated that this area is not likely to be developed and therefore should be shown as unlikely to be protected.

hub of the county and is certain to be protected, even if sea level continues to rise enough to threaten these communities.¹⁶²

Middlesex County offered the only major change to the maps based on stakeholder review.

Originally, we had shown the neck along Corbin Hall Drive leading to Goose Point as likely to be protected. The County stated that this area is not likely to be developed for the foreseeable future, and hence should be downgraded to blue.

Otherwise, “the map looked pretty good,” the County added.

¹⁶²Telephone conversations between Pratap Penumalli and Matthew Higgins, Middlesex County Department of Planning and Zoning, October 16 and December 11, 2002.

TABLE 8-12. ASSUMPTIONS FOR SHORE PROTECTION MAP: MIDDLE PENINSULA PLANNING DISTRICT (other than Gloucester County)^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Military lands			^b		Military installations
Public Park lands	✓				Virginia parks
Coastal communities in Middlesex County				✓	Planner input from initial study ^c
Entire town of West Point, King William County				✓	Stakeholder review comment implemented using land use/land cover
Growth area adjacent to West Point, King William County			✓		Stakeholder review comment implemented using land use/land cover
Goose Point Neck, Middlesex County		✓			Stakeholder review comment implemented using land use/land cover
Developed public and private land cover				✓	Land cover ^d
Town of Mathews and Gwynn Island, Mathews Co.				✓	Manual edit implemented using land use/land cover
Town of Cobbs Creek, Matthews County			✓		Manual edit implemented using land use/land cover
Coastal areas where roads indicate current or future development			✓		DeLorme road atlas ^e
Developed commercial, industrial, and residential areas				✓	Land use/land cover
Remaining public and private lands (including agriculture)		✓			Land use/land cover

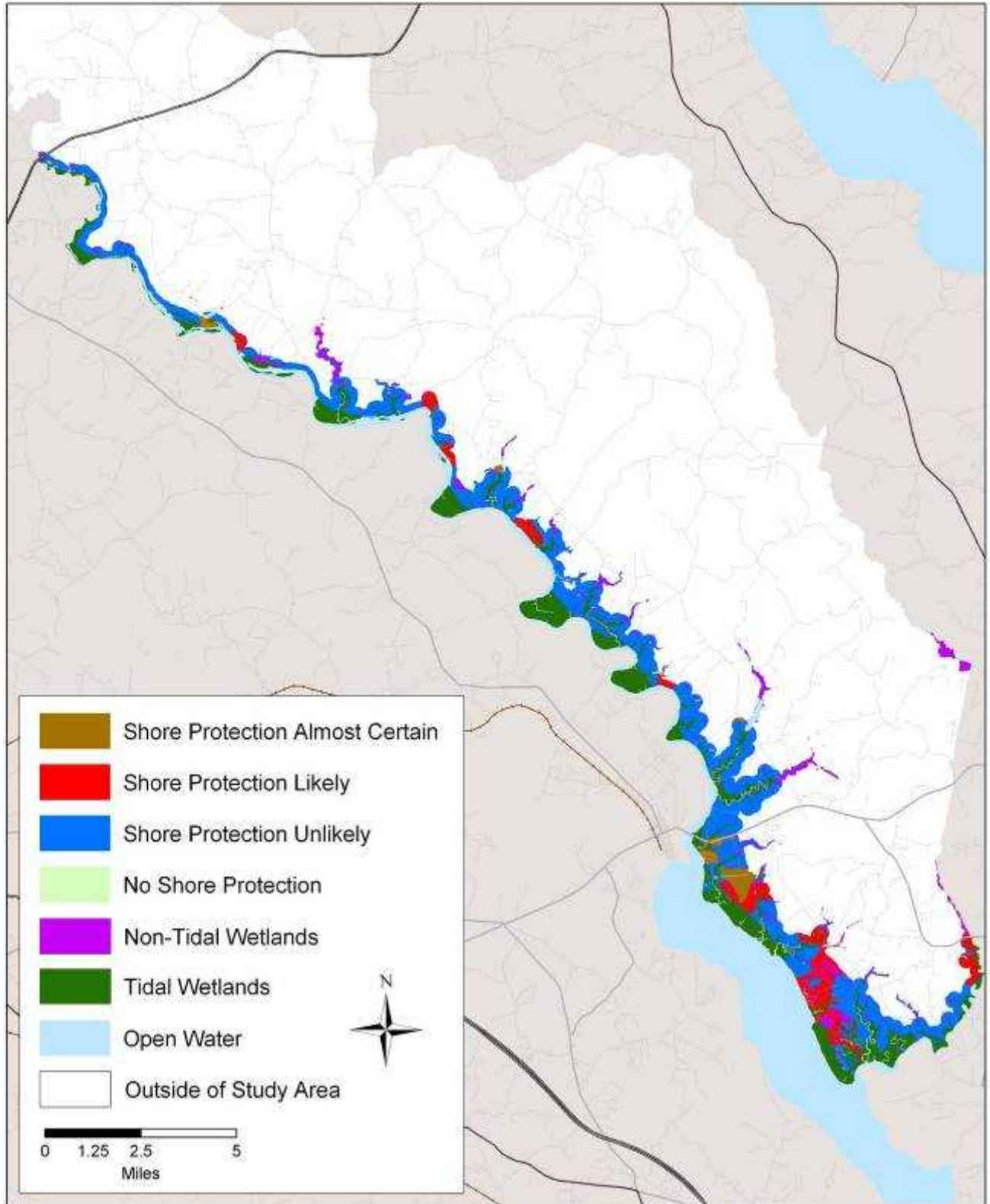
^a Where land areas overlap, classifications higher in the table take precedence.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

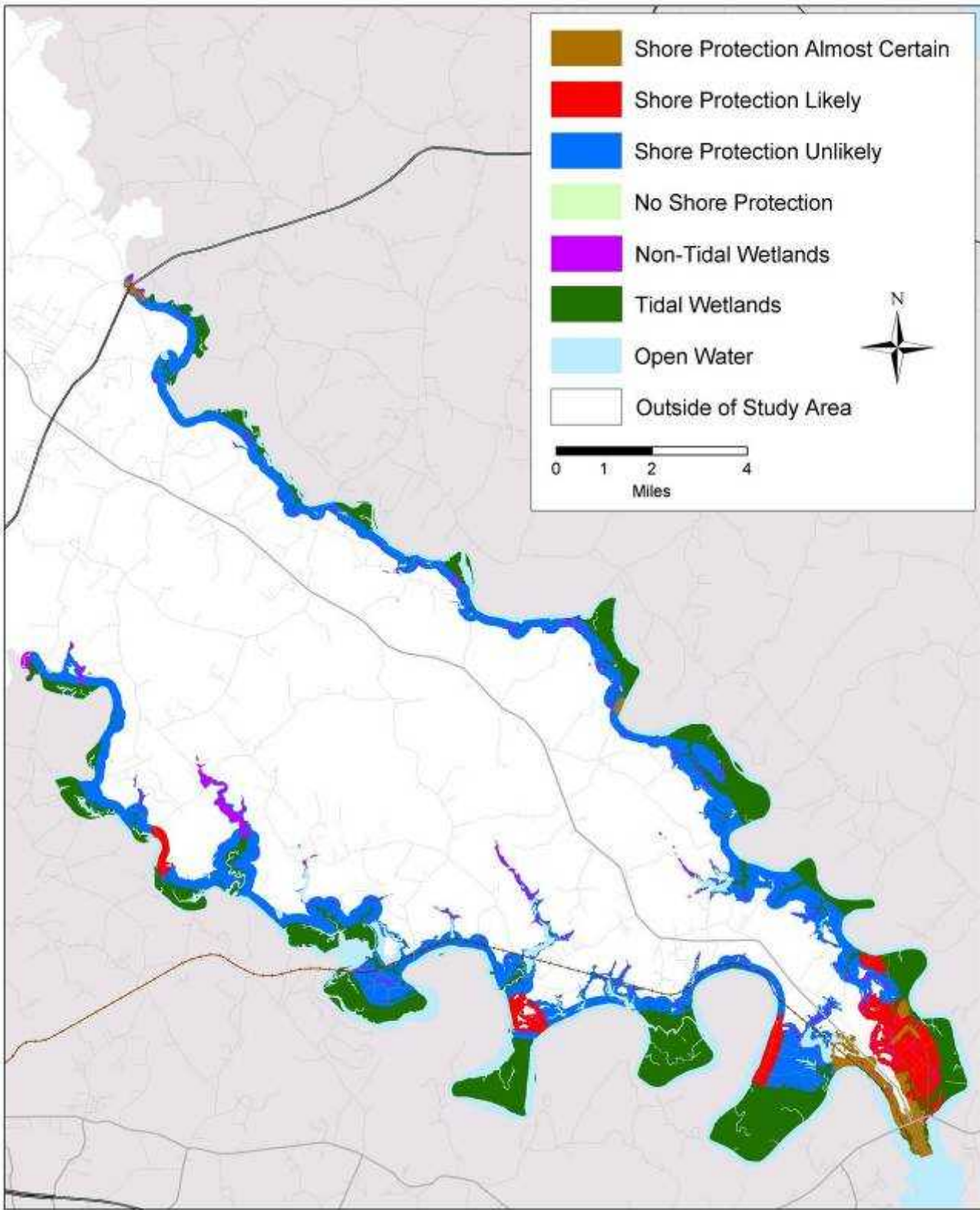
^c The initial 2001 VIMS study created polygons representing areas that were certain to be protected in the event of a 20-ft sea level rise. These areas are depicted in orange in some versions of our maps.

^d Based on residential, commercial, industrial, and transportation structures land covers in data provided by USGS.

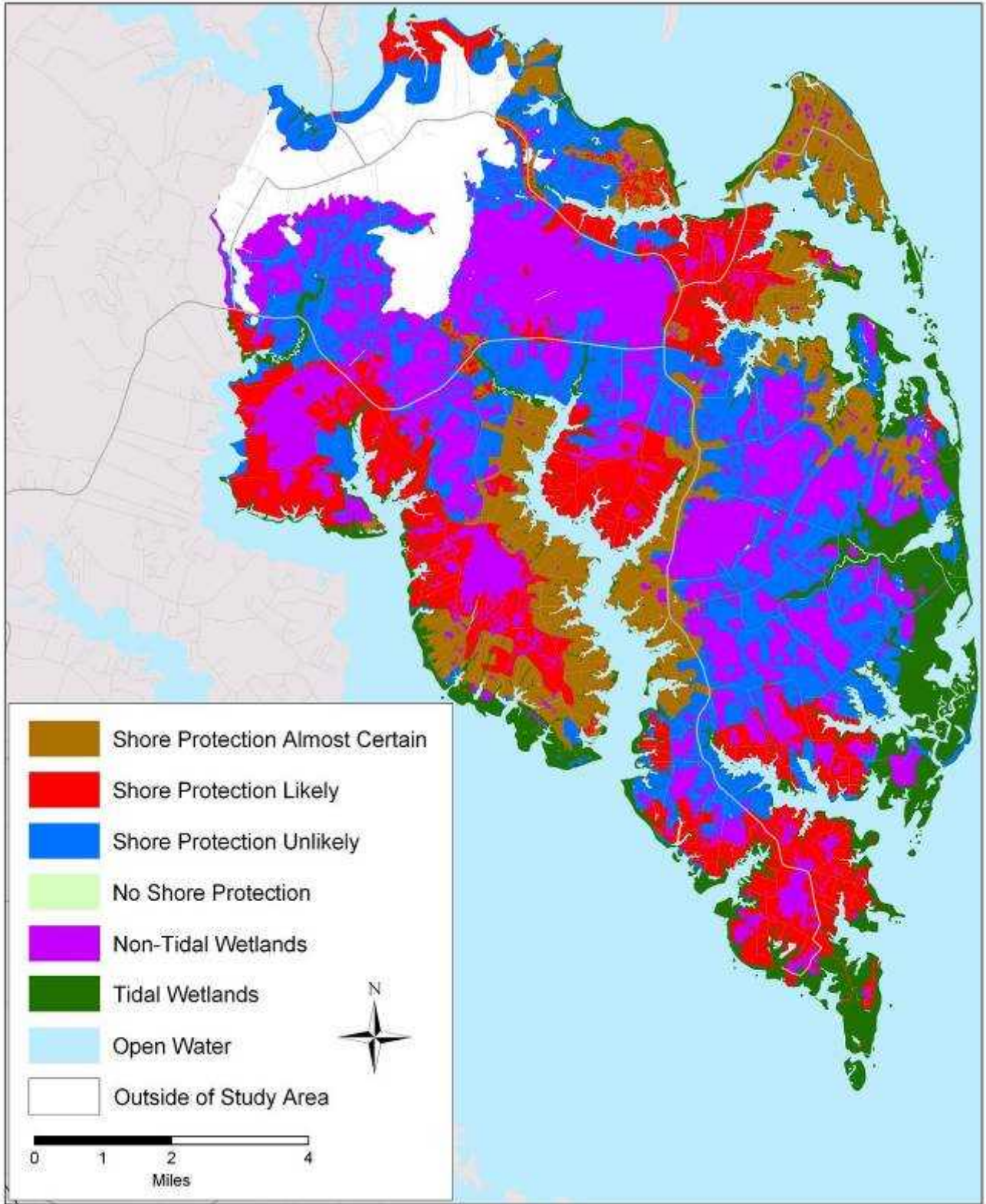
^e We identify coastal areas where roads indicate current or future development as areas with clusters of roads or shore-parallel roads. Wherever the Delorme Virginia Atlas and Gazetteer showed a shore-parallel road or a cluster of roads in King William, King and Queen, and Essex counties, we altered the entire land use/land cover polygon to red. As with areas identified with land use data, the areas delineated through this approach do not necessarily match political (e.g., town) or planning (e.g., zoning area) boundaries.



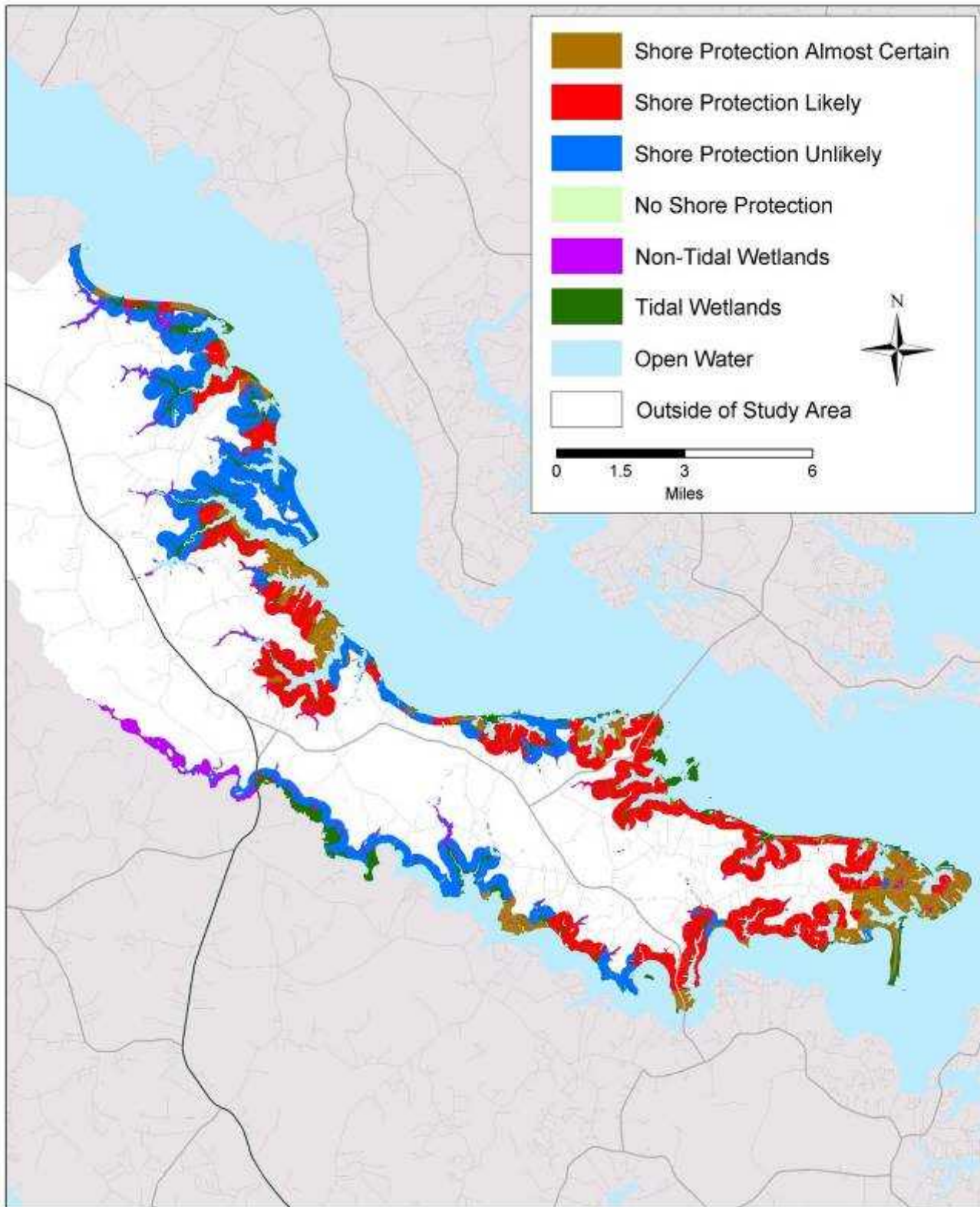
Map 8-18. King and Queen County: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



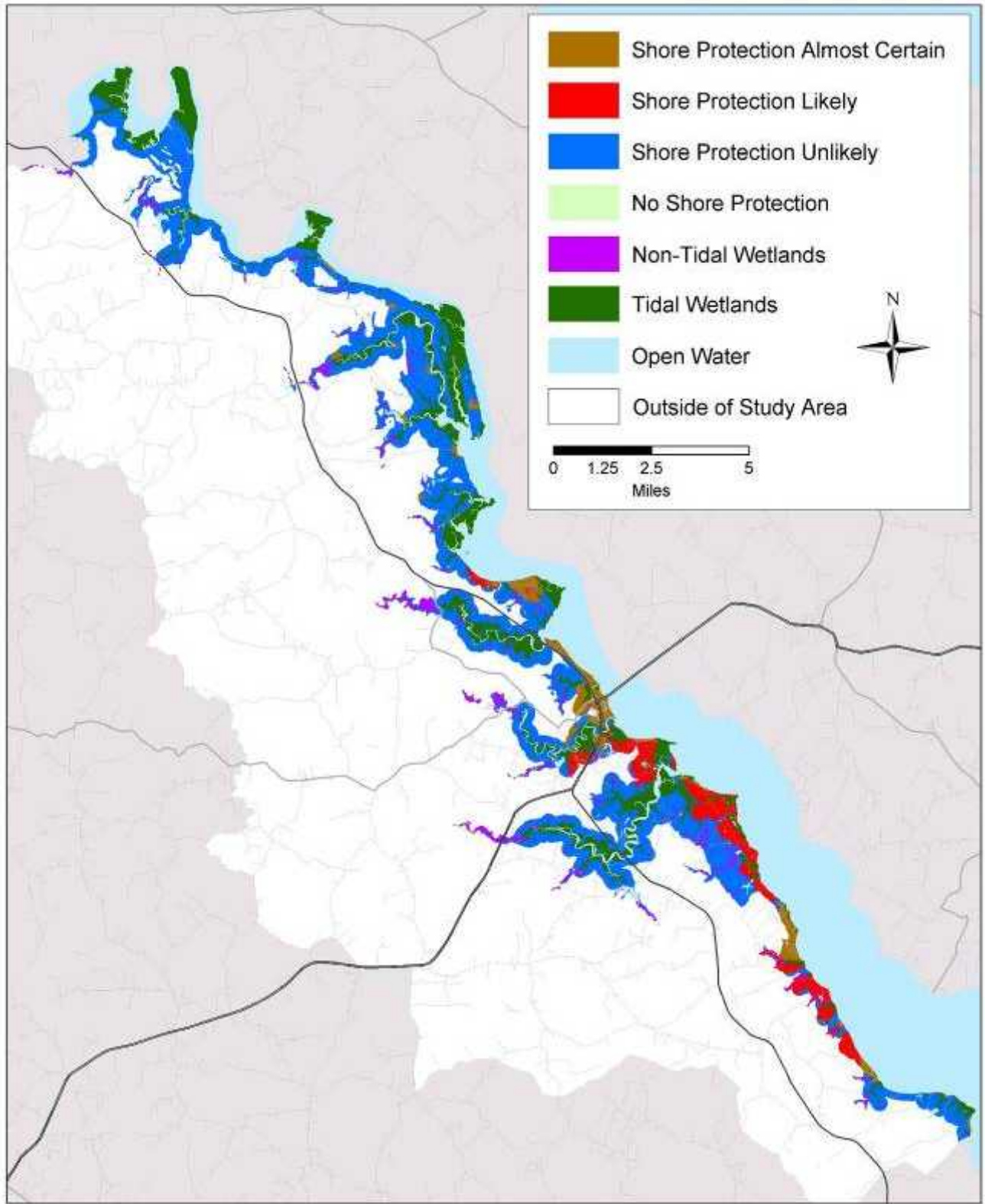
Map 8-19. King William County: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-20. Mathews County: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-21. Middlesex: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-22. Essex: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

NORTHERN NECK PLANNING DISTRICT

Background

The Northern Neck is the land between the Potomac and Rappahannock rivers. The Northern Neck Planning District Commission (PDC) consists of Lancaster, Northumberland, Richmond, and Westmoreland counties, all of which have tidal shores that could be affected by rising sea level. The planning district is primarily rural, with approximately one-third of the land area currently farm land. The population of the entire region is less than 50,000 and is growing at a rate of less than 1 percent per year. Major developed areas lie along the shores of Chesapeake Bay and the Potomac River, while the Rappahannock River banks remain largely undeveloped, especially inland.

For the most part, this region has rolling hills with relatively few low spots. As Table 8-13 shows, the region has approximately 35 square miles of dry

land within 8 feet of the high water mark.

Northumberland and Westmoreland are the only counties for which the available elevation data have enough precision to estimate the amount of land within 2 feet above the tides.

Northumberland's 4.1 square miles of low dry land rank seventh among Virginia jurisdictions. Lancaster County has more land within 4 feet above the high water mark than Westmoreland.

The lowest lying community in this region is Lewisetta in Northumberland County. Lewisetta is unique in that it is the only community along the Potomac River vulnerable to tidal inundation in the next century. Water in some ditches there already rises and falls with the tides, and some areas drain through tide gates. With a fairly modest rise in sea level, wetlands may begin to take over portions of people's yards, the tide gates will close more often, and flooding will be more frequent. (See Photos 8-29 through 32.)

TABLE 8-13. AREA OF LAND VULNERABLE TO SEA LEVEL RISE: NORTHERN NECK PLANNING DISTRICT (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Northumberland	6.6	4.4	2.0	0.2	4.1	0.4	8.1	0.8
Lancaster	^e	3.8	^e	^e	4.9	0.4	9.9	0.8
Westmoreland	7.4	5.5	1.6	0.2	3.3	0.4	6.6	0.7
Richmond Co	^e	8.4	^e	^e	3.2	0.6	6.3	1.2
Total	30.7	22.1	7.7	0.9	15.4	1.7	31.0	3.4

^a J.G. Titus and J. Wang, 2008, see Table 8-3 for full reference.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

^e Value omitted because the topographic information Titus and Wang used for this jurisdiction had poor vertical resolution.

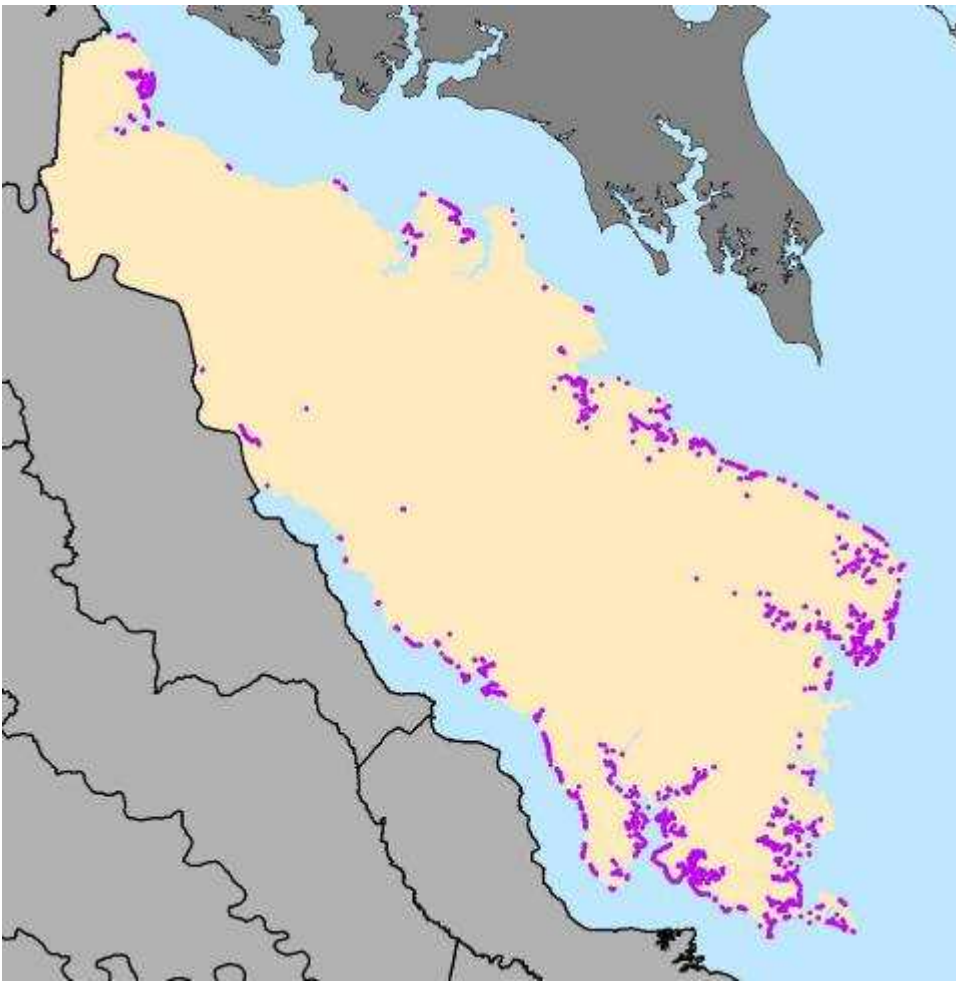


Figure 8-5. Location of Shoreline Armoring within the Northern Neck. Each dot indicates the presence of a bulkhead or revetment within about 1,000 feet. Therefore, the armoring is not necessarily as continuous as the map might appear to imply. The dots that appear to be inland are actually along tidal creeks. Data source: Northern Neck PDC (see Table 8-4).

Elsewhere in this region, the primary impact of sea level rise is the gradual erosion of land that, for the most part, is high enough to avoid flooding during even the most severe storms. Photos 8-33 and 8-34 show properties immediately to the west of Lewisetta, which are protected with groins and bulkheads. Most other coastal property in this region has a much greater elevation. Photos 8-35 and 8-36 show the more typical development along the Potomac River. Homes are set back from the shore a few hundred feet, with land at least 5 feet above the tides. Nevertheless, shore erosion control structures have already been built to protect back yards from shore erosion.

Shoreline armoring is very commonplace in this region, and offered in billboards along major highways. Photo 8-37 shows the stone revetment protecting a vacant lot in a residential area along the Potomac shore of Newman Neck. Photo 8-38 shows a rock revetment protecting open space lands near the Rte. 3 bridge into Lancaster County. Figure 8-5 also depicts parcels of land with existing shoreline armoring in Lancaster and the remaining counties within the Northern Neck.¹⁶³ Photos 8-39 and 8-40 show a low home and the development near the end of the road at Windmill Point in Lancaster County.

Anticipated Responses to Sea Level Rise

Unless otherwise stated, based on communications with:

Stuart McKenzie, Northern Neck PDC¹⁶⁴; Jack Larson, Lancaster County¹⁶⁵; and E. Luttrell Tadlock, Northumberland County¹⁶⁶

Final maps and report modified based on meeting¹⁶⁷ with:

¹⁶³The Northern Neck PDC provided GIS data identifying the location of rip-rap and bulkheads (as of 1997/1998) along Northern Neck shoreline based on tax parcel data.

¹⁶⁴Telephone conversations with Pratap Penumalli in September and October 2002.

¹⁶⁵Meeting with Jim Titus at county offices, October 12, 2002; telephone conversations with Pratap Penumalli, October 17, 2002.

¹⁶⁶Telephone conversations with Pratap Penumalli, September 24 and October 17, 2002.

¹⁶⁷February 9, 2004 at the offices of the Northern Neck Planning District Commission (NNPDC) with Will Nuckols. In addition to changes noted in text and footnotes, the reviewers pointed to places where map overlay errors showed land as water or water as land. Those types of errors would not have made a difference in the final product, which uses wetlands data to define water and land; we regret that reviewer time was consumed fixing errors that would have been fixed eventually anyway. Moreover, the maps Will Nuckols showed the stakeholders did not include the orange from the original study

Stuart McKenzie and Jerry W. Davis, Northern

though the areas immediately inland may remain



Photos 29–32. Lewisetta, Virginia. Photos 29 and 30 show tidal ditches along the streets of Lewisetta. The concrete-lined ditch in the foreground of Photo 31 conveys water from a ditch along the street to the Potomac River. In the background is a seawall along the Potomac, and a tide gate, which allows the ditch to drain except during high tides. Photo 32 shows low, but somewhat higher, development behind bulkheads along the protected shore on the east side of the community. October 12, 2002.

Neck PDC; Jack Larson, Lancaster County; E. Luttrell Tadlock, Northumberland County; Chris Jett, Richmond County.

The sea level planning maps for this region are based on essentially the same approach taken for most of the Middle Peninsula counties: land use data identify developed areas certain to be protected; shoreline armoring data identify areas already protected; and meetings held by VIMS

identified areas that would be protected even in the worst-case scenario. More than most regions, numerous roads along the shore in largely undeveloped areas signal recent or future waterfront development in the years to come, even

agricultural for the foreseeable future.

Table 8-14 lists the GIS decision rules that we originally used to make maps given the general tendencies suggested by local planners.

Discussions about specific areas with these local planners were mostly consistent with these tendencies, with notable exceptions, which we discuss below.



Photos 33–36. Northumberland County. Photos 33 and 34 are immediately west of Lewisetta, 35 and 36 are along Shore Lane north of Middletons Corner (October 12, 2002).



Photos 37–38. Armoring That Protects Undeveloped Land. Photo 37 shows a rock revetment protecting an undeveloped lot in a waterfront community at Newman Neck. Photo 38 shows a revetment protecting undeveloped lands near the VA-3 bridge into Lancaster County (October 12, 2002).



Photos 39–40. Windmill Point, Virginia (July 1999).

Lancaster County and Richmond County

The Lancaster County planning documents show that almost all the county's shoreline along the Rappahannock River and Fleets Bay already has some sort of armoring in place. Given the relatively high ground along these shores, the County generally expects that these areas are almost certain to be protected in the future. Areas without armoring, however, include North Point, Bluff Point, and some shorelines along the tributaries. Nevertheless, most of these areas will be developed as retirees and others who desire pleasant waterfront homes move into the county (Map 8-23).

During the stakeholder review, County and PDC planners noticed several areas where map refinements were necessary:

- ***Change the end of Crab Point Road just west of the VA-3 bridge from blue to brown to match the surrounding areas.*** The coarse land use data we had used had failed to pick up the development at the tip of this peninsula.
- ***Add a 200-ft buffer of brown on either side of VA-3 on both sides of the bridge over the Rappahannock River.*** This major road and any land uses immediately along it are certain to be protected.
- ***All of Windmill Point is certain to be protected, from Vista Lane eastward.*** Windmill Point is not an exception to the general expectation of coastal development along Chesapeake Bay.¹⁶⁸
- ***The area depicted in red along the Merry Point Ferry Landing is certain to be protected.*** The ferry is an important transportation corridor.
- ***Change Bell Island to “no protection.”*** The island is now Bell Island State Park and

should be viewed as a conservation land for purposes of this study.

Upstream along the Rappahannock River, the PDC views currently unprotected boat landings, marinas, and coastal residential development (generally 5-acre zoning) along the river and adjacent creeks in southern Richmond County as likely to be protected. Farther up the river, however, the PDC views development—and hence shore protection—as unlikely (Map 8-24).

During the stakeholder review, Richmond County and the PDC suggested a few refinements:

- ***Along US-360 east of the bridge over the Rappahannock, show the road as a 200-ft wide strip of brown through a wildlife refuge.*** The draft maps showed the area as blue. In reality, this area is now Rappahannock Wildlife Refuge and should be depicted in light green, except for the major U.S. highway, which is certain to be protected as an elevated roadway for the foreseeable future.
- ***Change the small brown area west of Doctor's Creek along the Rappahannock River from brown to blue.*** The coarse land cover data we used had grid cells on either side of this creek; but in reality the area east of the creek is developed whereas the area west of the creek probably will not be developed. Our draft maps also had a blue “X” in the middle of the brown; we edited it so that all of the land east of the creek is brown and the land to the west is blue.
- ***Change the land between the border with Lancaster County and Farnham Creek (west of VA-606/Simonson Road) from red and blue to brown. On the neck immediately to the west, change all the land on either side of Hales Point Road from red to brown, from Oakley landing inland to 200 feet north of VA-648.*** These waterfront areas are being developed with moderate densities.
- ***Change the Sharps Community northwest across the creek from Little Florida from red to brown.*** Again, moderate density developments are expected.

¹⁶⁸Based on initial discussion between the County and the authors, we mistakenly thought that Windmill Point was less likely to be developed. The County also indicated that the road is certain to be protected. Because the County did not indicate that lands along that road would be protected, no map correction was made.



Photos 41–44. Colonial Beach, Virginia (October 12, 2002).

- *Little Florida is correctly depicted as red, because it is very low, like Lewisetta.* But the text should be modified to include this community as another example of a very low-lying community.
- *Change the neck south of Totuskey Creek from blue to red.* This area is likely to be developed and protected.

Northumberland County

Along Chesapeake Bay in Northumberland County, the Northern and Southern necks are fairly densely developed. The County believes the low-lying areas on the neck north of the Great Wicomico River, including the town of Reedville, are almost certain to be protected, even if sea level rises several feet. If the fast ferry service from Crisfield, Maryland, to Virginia is approved, the ferry terminal in Virginia would probably be at the end of US-360 in Reedville, which would further increase development and the likelihood of protection. Therefore, Reedville is shown as

brown.¹⁶⁹ The PDC expects the undeveloped coastal areas in the center of the county’s bayshore to be developed, given the potential for tourism and seasonal homes. As a result, the maps identify them as likely to be protected—and certain where coastal structures already exist (Map 8-25).

Along the Potomac River, the PDC pointed out, land values are higher than along the Rappahannock River. Some coastal developments, however, such as Lewisetta, are much more low-lying. The risk of tidal flooding could lead to an increased cost of protection for those areas where it will be necessary either to elevate land and structures or to encircle communities with dikes and tide gates. Because Lewisetta will require protection from inundation as well as erosion, the maps delineate this town as only likely to be protected. The areas from Lewisetta southeast to

¹⁶⁹ Reedville is orange in versions that show protection in the worst-case scenario.

Vir-Mar Beach are all developed or will be developed, and are also likely to be protected.

The PDC also notes that the cost of above-ground “mounded” septic systems has decreased, thereby reducing an impediment barrier to development in the relatively low-lying areas on Cherry Point Neck north and west of Lewisetta. With development already taking place on Cherry Point Neck (and some coastal armoring structures already in place) the maps assume that Cherry Point Neck is certain to be protected.

During the stakeholder review, County and PDC planners suggested several refinements:

- **Change the portion of Cherry Point Neck between VA-624 and the Potomac River from blue to red.** This was a mapping error, given the original assumption that the entire neck should be shown as brown. Nevertheless, because it is undeveloped and relatively low-lying, protection is not as certain as those areas that are already developed.¹⁷⁰
- **Change small isolated blue polygons otherwise surrounded by red or brown to red or brown, respectively.** These blue polygons were generally map boundary artifacts.¹⁷¹
- **Change isolated red polygons surrounded by brown to brown.** Because erosion, not tidal flooding, is the primary hazard requiring shore protection in most areas, protecting one area will tend to protect inland areas.
- **Change the neck to the west of Kilmarnock Folbert Field from blue to brown.** There are condos on this neck, which is along VA-672.

¹⁷⁰Nuckols’ report of the Stakeholder Review Meeting justifies changing this area to from blue to red because of the need for access to Lewisetta. That reasoning is applicable because (a) most of this land is actually well seaward of the access road; (b) it is more than 1,000 feet wide; and (c) this study depicts land protection rather than road protection.

¹⁷¹These polygons were near the border with Westmoreland County, and numerous polygons along Chesapeake Bay between Dividing Creek and the Potomac River. Nuckols’ report of the Stakeholder Review Meeting does not explicitly state why the planners accepted some of the other isolated blue polygons, but it implies that the isolated blue areas are less likely to be developed in the next few decades. In one case, the County suggested changing the polygon from blue to red even though surrounding areas were brown, because the waterfront property is likely to be protected but has not yet been developed.

- **Change the report and maps to reflect the fact that homes are being built along bluffs overlooking the south side of the Wicomico River from Lee Dale shores west to Knight Run.** Homes within this area are generally set back from the bluff. Hence, the maps should show that these shores would probably not be protected unless they eroded sufficiently to endanger the houses.¹⁷²

Westmoreland County

Westmoreland County has numerous substantial developments along the Potomac River, most important of which is the historic town of Colonial Beach. At the turn of the century, Colonial Beach was a beach resort destination for Washingtonians, who would generally arrive by steamboat. The community had a large boardwalk, many hotels, a skating rink, and a large beach. The gradual decline of river and bay beach resorts during the latter half of the 20th century eliminated most tourism, but the community is still the most important tourist destination in the county. The beach there is still an important recreational center for both tourists and area residents. Much of that beach has been eliminated by shoreline armoring, but the Virginia Beach Board has taken an interest in maintaining the beach that remains.¹⁷³ Colonial Beach will almost certainly be protected for the foreseeable future. (See Photos 8-41 through 8-44, and Map 8-26.)

¹⁷²The maps show the first 200 feet along the waterfront as unlikely to be protected, and land more than 200 feet from the shore as certain to be protected. Lacking estimates of the setback, we chose the 200 foot figure for cartographic purposes: the thin blue line along the otherwise brown buffer conveys the existence of a setback as well as the likelihood of shore protection once the setback zone erodes.

¹⁷³“As the first recipient of public funds through the Beach Board in 1981, the Town of Colonial Beach, with additional assistance from the U.S. Army Corps of Engineers, built two headland breakwater and beach fill systems. These systems at Central Beach and Castlewood Beach Park have created pocket beaches that have remained relatively stable over time. Economic development in Colonial Beach is tied to its waterfront as residents and tourists alike make extensive use of the beaches. The Beach Board has provided almost \$274,000 to Colonial Beach over the past 20 years.” Virginia’s Public Beach Board: 20 Years of Coastal Management; Virginia Beach Board, Richmond; accessed July 23, 2003 at http://www.virginiashoreandbeach.com/pub_bch_brchure.pdf.

To the southeast of Colonial Beach lie a number of undeveloped bluffs and conservation areas, including a state park and George Washington's birthplace. Some of these areas probably will not

been mistakenly depicted as unlikely to be protected, even though the development and road network should have resulted in red or brown. Because Colonial Beach is extending sewer service



Photo 8-45. Homes along Eroding Potomac River Bluffs West of Stratford Hall.

be protected, although Washington's birthplace is certain to be protected. The homes along the bluffs west of Stratford Hall (Photo 8-45) will soon require shore protection. In the Glebe area, townhouses and other residences are being built, which means that this entire area is almost certain to be protected, according to the PDC. On the other land, the development proposed for Coles Neck is likely, but not certain.

The considerations for Cherry Point in Northumberland County also apply to Sandy Point Neck, but development there is not quite as imminent as Cherry Point. As a result, the planning staff views this area as likely to be protected.

The stakeholder review identified a number of errors in the draft maps. Most important, the area between Colonial Beach and Potomac Beach had

to this area, it is certain to be protected. Much of the land between Monroe Bay and VA-205 is still lightly developed, but again, because sewer service is coming to that area, it is certain to be developed and protected from rising sea level.

Coles Neck, a secondary growth area, is also getting sewer service. The planners suggested that the areas previously depicted as red should be changed to brown, with blue changed to red. Jackson Creek and the Potomac River is the approximate eastern boundary of this projected growth area, and Lower Machodoc Creek is the western boundary.

TABLE 8-14. ASSUMPTIONS FOR SHORE PROTECTION MAP: NORTHERN NECK PLANNING DISTRICT^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Military installations			^b		Military installations
National and state park lands	✓				Parks
Rappahannock Wildlife Refuge	✓				Stakeholder review comment implemented using refuge data
Site-specific areas identified during stakeholder review	Mixed (see text for more information)				Stakeholder review comment implemented using land use/land cover
Major coastal communities, including Smith Point area, Kilmarnock, and Irvington				✓	Planner input from initial VIMS study ^c
Town of Lewisetta			✓		Manual edit implemented using land use/land cover
Developed public and private land cover in Westmoreland, Northumberland, and Lancaster counties				✓	Land cover ^e
Coastal lands currently protected by shoreline armoring structures (with the exception of coastal lands included in site-specific changes below; e.g., within historical towns that are likely to be protected)				✓	Northern Neck armoring ^d
Sandy Point Neck and Kinsale (historic sites)			✓		Manual edit implemented using land use/land cover
Routes 360 and 3, including bridges to Middle Peninsula				✓	Manual edit implemented using land use/land cover
Town of Reedville and surrounding areas				✓	Manual edit implemented using land use/land cover
Marinas and adjoining subdivisions along Potomac River west of Lewisetta (including projected future development)			✓		Manual edit implemented using land use/land cover
Richmond and Westmoreland: undeveloped coastal areas where roads indicate recent or future development			✓		Manual edit implemented using Major roads ^f and land use/land cover
Developed lands				✓	Land use/land cover ^g
Remaining public and private lands (including agriculture)		✓			Land use/land cover

^a Where land areas overlap, classifications higher in the table take precedence. This table reflects precedence for specific decision rules over other decision rules (e.g., decisions rules applicable to a particular areas such as Lewisetta take precedence over other rules) and indicates the available data used to map each.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

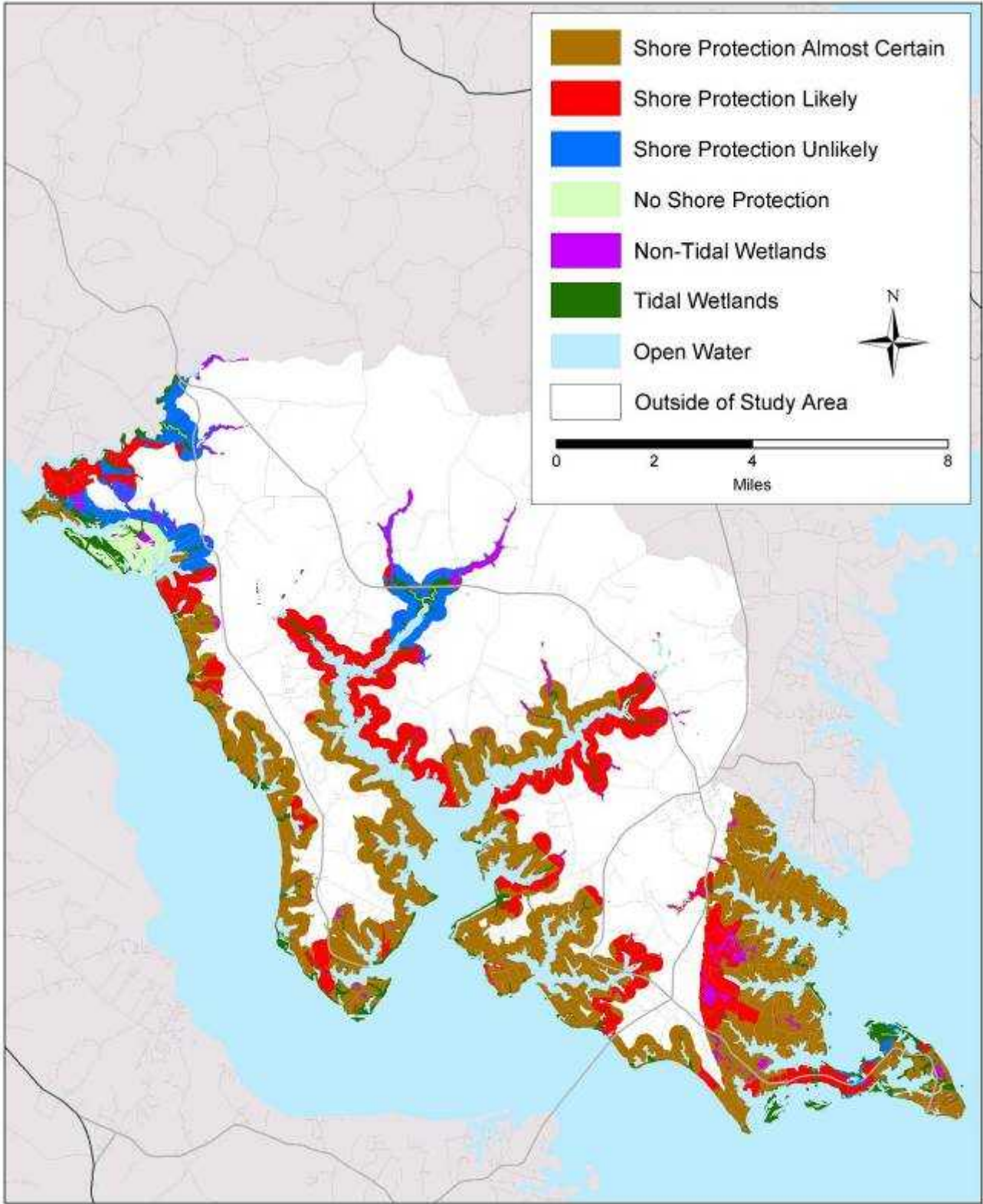
^c The initial 2001 VIMS study created polygons representing areas that were certain to be protected in the event of a 20-ft sea level rise. These areas are depicted in orange in some versions of our maps.

^d We identify lands protected by shoreline armoring based on 1,000-ft buffer around armoring structures.

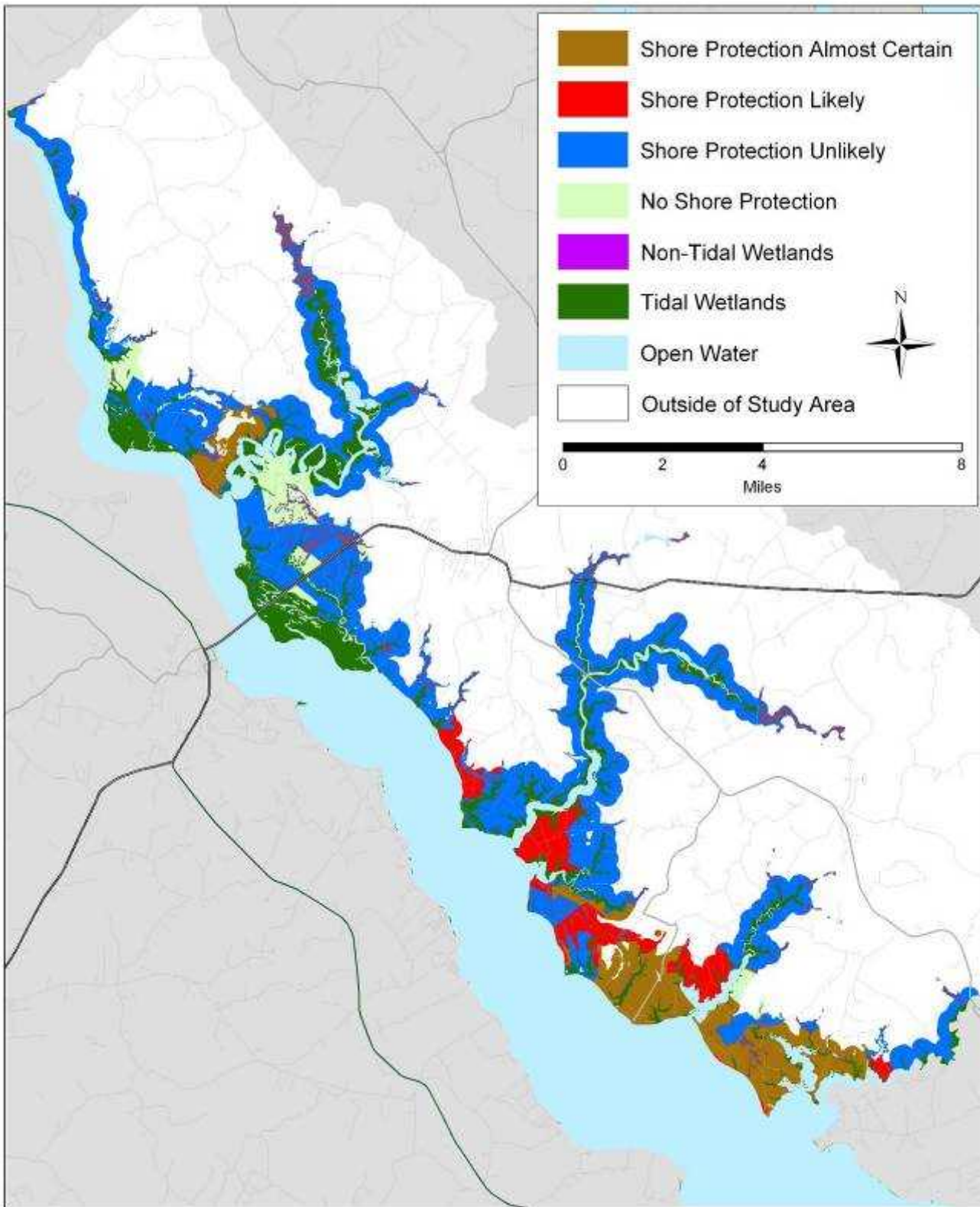
^e We identify developed land cover based on residential, commercial, industrial, and transportation structures land covers in data provided by USGS.

^f We identified undeveloped coastal areas where roads indicate recent or future development as areas with clusters of roads or shore-parallel roads within lands shown as undeveloped according to land use/land cover data. Wherever the Delorme Virginia Atlas and Gazetteer showed a shore-parallel road or a cluster of roads in Richmond and Westmoreland counties, we altered the entire land use/land cover polygon to red. See Middle Peninsula section for further explanation.

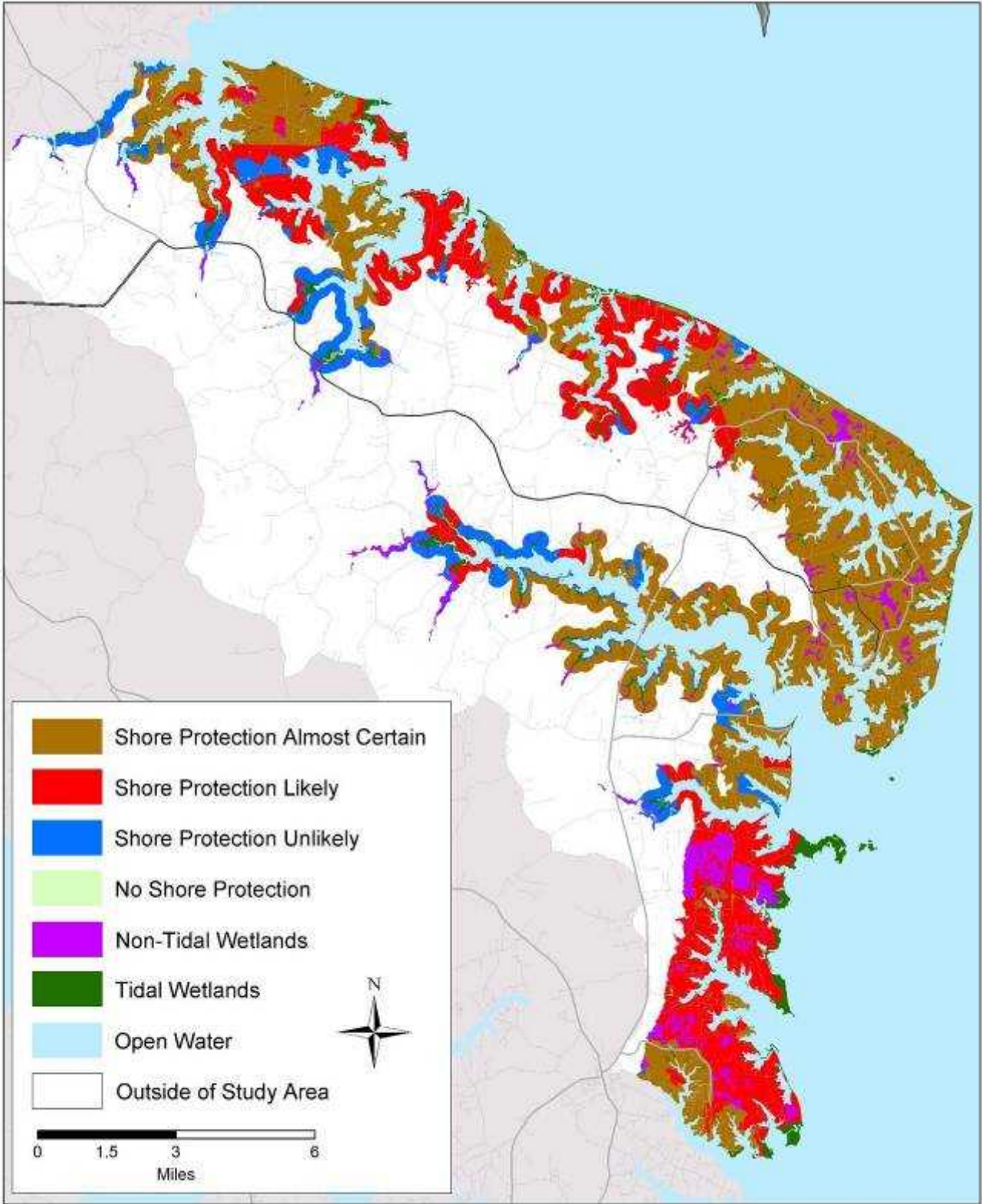
^g We identify developed lands based on residential, commercial, and industrial land use/land covers in data provided by USGS.



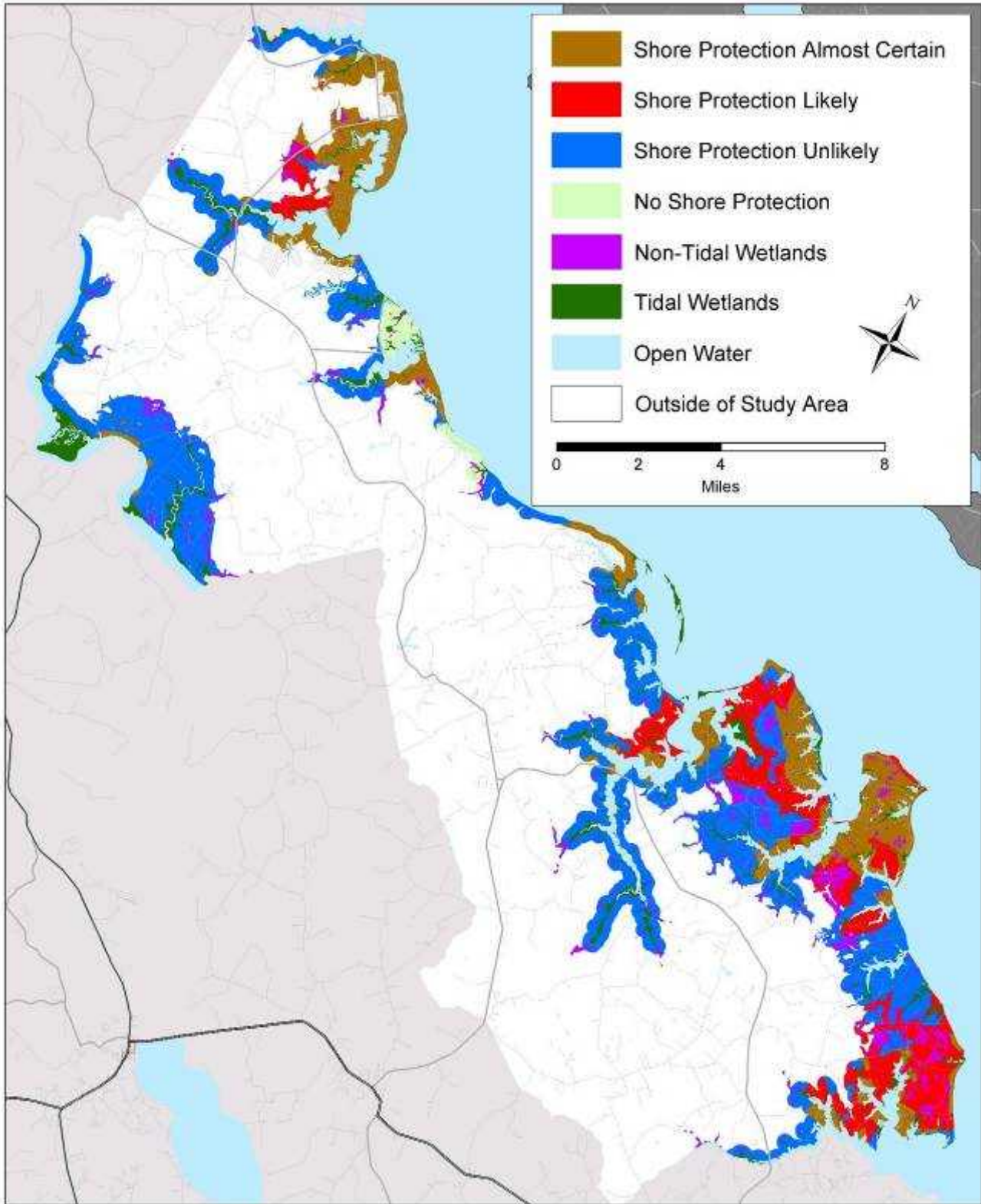
Map 8-23. Lancaster: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-24. Richmond: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-25. Northumberland: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.



Map 8-26. Westmoreland: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

RAPPAHANNOCK AREA PLANNING DISTRICT

Background

All five of the jurisdictions of the Rappahannock Area Development Commission (RADCO) have at least some land that is potentially vulnerable to sea level rise. None of these localities has waterfront along Chesapeake Bay, but all have land along the Rappahannock River, which is tidal up to approximately the US-17 bridge in Fredericksburg.¹⁷⁴ In addition, Stafford and King George counties have vulnerable land along the Potomac River, which is 2 to 3 miles wide in this study area.

Stafford County has a population of 97,000, according to the 2000 census. The county covers approximately 277 square miles, of which 48 square miles are part of the Marine Corps Base at Quantico in the northern portion of the county.¹⁷⁵ Approximately 65 percent of the county's lands are forested and at least 1,000 acres are dedicated to federal, state, and county parks and recreational lands.¹⁷⁶

King George County lies to the southeast of Stafford County and covers 180 square miles. According to the 2000 census, 16, 803 people reside there.¹⁷⁷ The U.S. Naval Surface Warfare Center, Dahlgren Division lies in the easternmost portion of the between Machodoc Creek and US-301. Just north of Dahlgren, US-301 crosses the Potomac River into Maryland via the Governor Nice Bridge. In the northern section of the county,

Virginia's Caledon Natural Area, a National Natural Landmark, is home to one of the largest concentrations of bald eagles on the East Coast.¹⁷⁸

Farther upstream along the tidal portion of the Rappahannock River, Caroline County, Spotsylvania County, and the City of Fredericksburg also have some low-lying land that is potentially vulnerable to sea level rise.

Vulnerability to Sea Level Rise

Table 8-15 summarizes the amount of land close to sea level within each of the RADCO localities. Compared with the counties along Chesapeake Bay, these localities have relatively little low land. Although shore erosion can be expected along most tidal shores, the submergence of low land will be limited to a very small number of areas. Therefore, for the most part, our study area consists of land within 1,000 feet of the high water mark. The primary area where the 20-ft contour extends farther inland is on Mathias Point Neck in King George County. The U.S. Naval Surface Warfare Center, Dahlgren Division occupies a substantial portion of this area, including lands on both sides of Machodoc Creek. The neck just to the south of Mathias Neck, known locally as Pumpkin Neck, is also low lying, and the U.S. Navy owns the majority of the land.

¹⁷⁴The river was dammed a few hundred feet upstream of Lauycks Island until February 23, 2004. See *Washington Post*, February 24, 2004, "Blast breaches landmark dam: water—and shad—pass after 150 years," p. B01.

¹⁷⁵Available at <http://co.stafford.va.us/cames.htm>, accessed April 12, 2004. The base also covers a large portion of Prince William County.

¹⁷⁶Available at <http://co.stafford.va.us/cames.htm>, accessed April 12, 2004.

¹⁷⁷Available at <http://quickfacts.census.gov/qfd/states/51/51099.html>, accessed April 12, 2004.

¹⁷⁸Available at <http://www.dcr.state.va.us/parks/caledon.htm>, accessed April 13, 2004.

TABLE 8-15. AREA OF LAND VULNERABLE TO SEA LEVEL RISE: RAPPAHANNOCK AREA DEVELOPMENT COMMISSION (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
King George	6.3	5.2	1.0	0.2	1.9	0.4	3.8	0.7
Stafford	3.3	2.6	0.5	0.2	1.0	0.4	1.9	0.7
Caroline	2.6	2.4	0.2	0.02	0.3	0.04	0.6	0.1
Fredericksburg ^e								
Spotsylvania ^e								
Total	12.3	10.3	1.6	0.4	3.3	0.8	6.6	1.5

^a J.G. Titus and J. Wang, 2008, see Table 8-3 for full reference.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

^e Titus and Wang estimates of low land for these jurisdictions are less than the error induced by possible errors in their jurisdiction borders.

King George County

Anticipated Sea Level Rise Response

Based on meeting with:

Mark Remsberg, planner, Community Development, King George County¹⁷⁹

Our meeting consisted of a discussion of the entire shore of the county. We started at one end of the county and proceeded up the Potomac River and then up the Rappahannock River. Not only did County staff provide the prognosis for development, but staff also explicitly stated whether we should consider shore protection as certain, likely, unlikely, or precluded by conservation goals. We summarize the anticipated response in Table 8-16; Map 8-27 shows likelihood of protection.

Potomac River

All privately held lands on the Potomac River are valuable and developed or almost certain to be developed in the near future.¹⁸⁰ For this reason, the general rule for the county is that privately held

lands along the river will certainly be protected. Lands along the creeks are not as vulnerable to the effects of sea level rise. Moreover, in some cases they lack navigable waterways and the views are less spectacular. Therefore, some of these areas are less likely to be developed and protected than the areas along the Potomac River. Exceptions to these general guidelines are discussed below.

County planners report that after Hurricane Isabel, which passed through Virginia in the fall of 2004, the volume of applications for shore protection permits increased substantially for property along the Potomac River. No similar increase occurred for property along the Rappahannock River.¹⁸¹

Potomac Creek runs near the border between Stafford and King George counties. From Potomac Creek east to Caledon State Park, most of the land has large lots (between 5 and 20 acres) with homes set back from the river. Within that area are pockets of relatively dense development, especially Fairview Beach, which has numerous bulkheads and rock revetments. (See Photos 8-46 and 8-47.) Waterfront neighborhoods of Potomac Landing are shown in Photos 8-48 and 8-49.

¹⁷⁹December 17, 2004 meeting with Will Nuckols and Jim Titus, at the county offices in King George.

¹⁸⁰Currently the limiting factor to development along the Potomac River is soil suitability for septic tanks. If land values continue to grow then eventually sewer systems may come into the areas, increasing the density of development in riverfront parcels. County Stakeholder Review Meeting, June 11, 2004, Mark Remsberg, planner, Community Development, King George County, and Will Nuckols.

¹⁸¹ County Stakeholder Review Meeting, June 11, 2004.



Photos 46 and 47. Fairview Beach. Natural shorelines are starting to be replaced with shore protection structures in the aftermath of Hurricane Isabel (December 2003).



Photos 48 and 49. Potomac Landing (December 2003).

Eagles Nest and Chatterton also are reasonably close to the shore with moderate density and some shoreline armoring. Therefore, we show the area between Potomac Creek and Caledon State Park as likely to be protected, with the exception of the area from Fairview Beach to Eagles Nest, which is certain to be protected.

The Meadows at Dahlgren subdivision is located between Chotank Creek and VA-218 east of Caledon State Park. In this area, the homes back in the woods are set well back from Chotank Creek, so wetland migration is likely there on the south side of the creek. This development was created when lots greater than 10 acres could avoid

subdivision requirements.¹⁸² As a result of the incentive to have larger lots, many of the houses are set far from the creek and small losses of land would not put structures in danger. This area is thus shown as unlikely to be protected. The area on the north side of the creek, by contrast, is shown as likely to be protected.

King George County operates Barnesfield Park, located on the north side of Route 301 on Mathias Neck Point. The park supports extensive recreational facilities, including three softball fields, a little league field, a concession stand, basketball courts, picnic pavilions, soccer fields, a hiking area, nature trails, a playground, and horseshoe pits.¹⁸³ Riverward of the park, across a

¹⁸²This provision was recently removed from the county code.

¹⁸³Available at

<http://www.virginia.org/site/description.asp?AttrID=12398&MGrp>

road, is another publicly owned area called “the wayside.” The Potomac gateway Welcome Center is adjacent to the wayside. The wayside, its beach, the Welcome Center, and the adjacent road will all be protected.¹⁸⁴ As a result, Barnesfield Park is also certain to be protected.

The Navy’s Dahlgren Surface Weapons Center also lies on Mathias Point Neck. It is shown as red to reflect uncertainty in accordance with the general approach of this study. The adjacent reservation (across Machodoc Creek) is shown as red based on the same criterion.

From Machodoc Creek south to the county line at Rosier Creek, all shores will be developed and protected with one possible exception: the active soybean farm located at the mouth of Rosier Creek. That parcel is viewed as likely, but not certain, to be protected.

The land along Machodoc Creek is prime real estate and much of the shoreline has already been bulkheaded. Land along the creek between the Potomac River and Dudley Drive will certainly be protected and is colored brown. Beyond that point, development and shore protection are unlikely.

The land along Rosier Creek is prime real estate and protection is almost certain downstream from approximately Marengo Farm Lane, other than the farm at the mouth of the creek. The area upstream from Marengo Farm Lane is swampy and has poor road access. It is unlikely to be developed or protected.

The federal lands in the county are all part of the military installations discussed previously. The County identified Caledon State Park and Lands End as conservation lands that will not be targeted for protection. Meeting participants did not discuss any additional public lands in the county.

Rappahannock River

The private lands along the Rappahannock River face less development pressure than land along the

Potomac River. Eventually most waterfront property may be developed, but such development is not yet inevitable, and land values are generally lower. Therefore, these areas are less likely to be protected than those along the Potomac. They are largely used for agriculture and for sand and gravel extraction, and thus property owners can tolerate small amounts of shoreline erosion that might accompany rising sea level. There are, however, three exceptions to this general tendency. Protection is likely for the area west of the 301 bridge to the area between Cleve and Canning roads, from Twin Lanes north to Jones Top Creek, and from Keys Run west to Lambs Creek.¹⁸⁵

Stakeholder Review

The County’s suggested changes¹⁸⁶ were quite minor, not surprising given the specificity with which staff had originally addressed what the map should show. The primary change concerned Toby’s Point, the most downstream peninsula of land in King George County along the Rappahannock River. This point is now part of a conservation area, the County said, and hence should be changed from blue to light green. The County also asked us to edit the map so that the boat ramp at the end of Wilmont Road on this peninsula will almost certainly be protected.

The County also drew our attention to a large low spot along Kings Mill Creek near Dickinson Corner. The County wondered whether this is not some sort of map artifact with no basis in reality. We double-checked the topography, and the USGS 7.5 minute quadrangle does show the 10-ft contour crossing the creek at about the same location where the creek crosses into Westmoreland County, with substantial land between the 10- and 20-ft contours along the creek in western King George County.

=1&MCat=13&MItm=0&Rgn=10000&Page=1&Dir=, accessed on April 13, 2004.

¹⁸⁴RADCO Stakeholder Review Meeting. Will Nuckols and Stephen Manster, executive director, Rappahannock Area Development Commission, at RADCO offices in Fredericksburg, June 10, 2004.

¹⁸⁵The County is processing permits along the latter stretch of river for a development called “Hopyard.” Although some 600 homes will be constructed in this area, the County confirmed that it is appropriate to depict this area as likely to be protected because the developer is working with the County to keep building directly on the riverfront to a minimum, leaving natural areas along most of the riverbank.

¹⁸⁶Stakeholder Review Meeting, June 11, 2004.

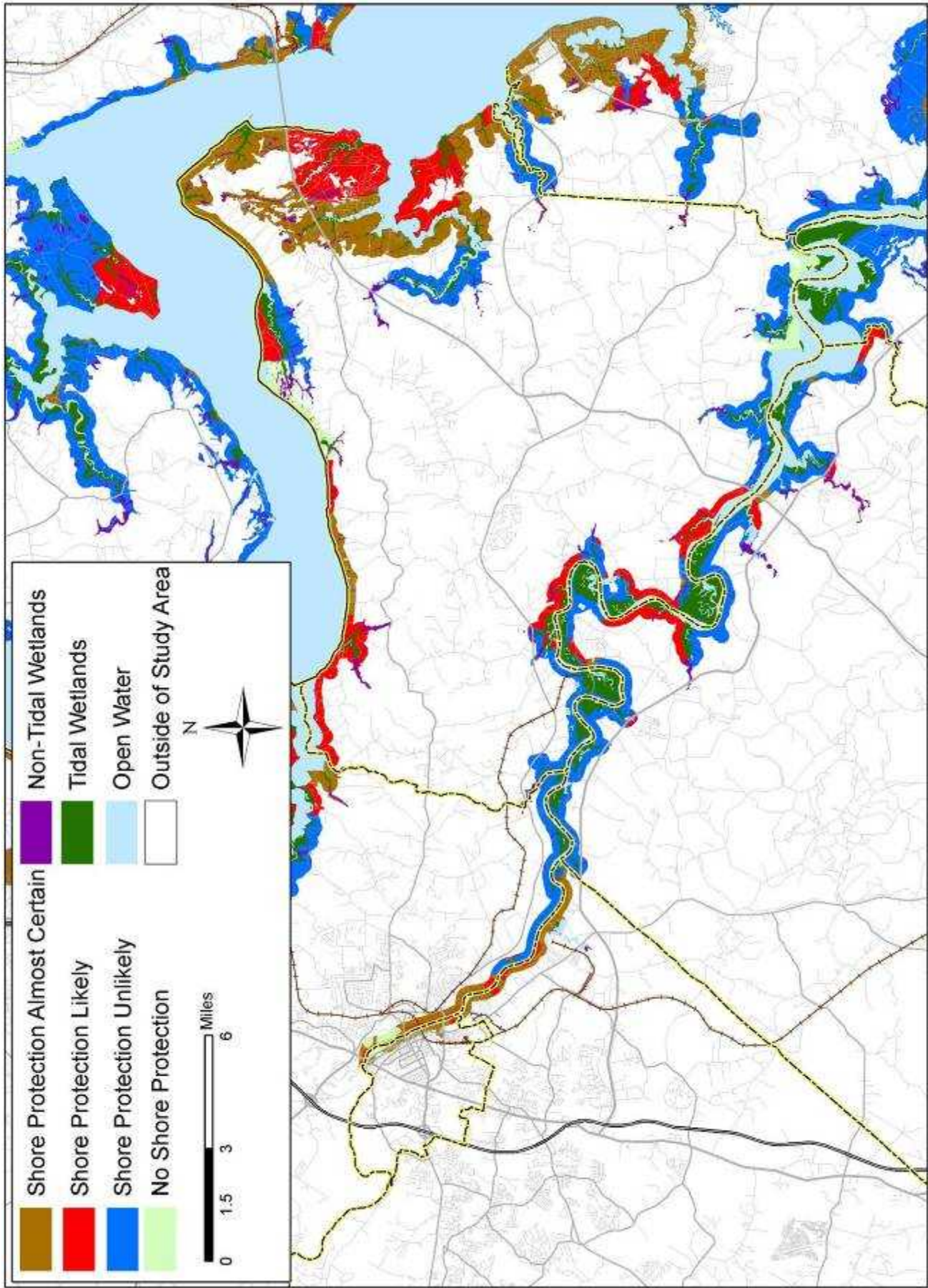
TABLE 8-16. KING GEORGE COUNTY’S ANTICIPATED RESPONSE TO SEA LEVEL RISE^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Boat ramp at end of Wilmont Road				✓	Manual GIS edit per stakeholder review comment
Toby’s Point	✓				Manual GIS edit per county comments
Meadows at Dahlgren north of Chotank Creek			✓		Manual GIS edit per county comments
Meadows at Dahlgren south of Chotank Creek		✓			Manual GIS edit per county comments
Unidentified Subdivision on Mathias Point Neck			✓		Manual GIS edit per county comments
Area from Fairview Beach to Eagle’s Nest Road				✓	Manual GIS edit per county comments
Hopyard development in Haymount area, i.e., lands along the Rappahannock between Key Run and Lambs Creek			✓		Manual GIS edit per county comments
Lands along the Rappahannock between 301 bridge and halfway between Cleve and Canning roads			✓		Manual GIS edit per county comments
Lands along the Rappahannock between Jones Top Creek and Twin Lanes			✓		Manual GIS edit per county comments
Area between Caledon State Park and Potomac Creek			✓		Manual GIS edit per county comments
Military installations			^c		U.S. military installations, Bureau of Transportation Statistics, 2001.
State park north of 301				✓	King George County state lands
Other state lands	✓				King George County state lands
Rappahannock River agricultural lands		✓			King George County land cover ^b
Private lands along Potomac				✓	King George County land cover ^b

^a Where land areas overlap, classifications higher in the table take precedence.

^b King George County land cover was developed for the 2000 Comprehensive Plan. The data identify agriculture, forest, residential, commercial, industrial, gravel, and wetland land cover.

^c Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”



Map 27. King George and Caroline Counties: Likelihood of Shore Protection

Stafford County

Anticipated Sea Level Rise Response

Based on meeting with¹⁸⁷:

Steven Hubble, planner, Environmental Planning, Wetlands, Department of Planning and Community Development, Stafford County; and Kathy Baker, assistant director of Planning, Department of Planning and Community Development, Stafford County

According to county planners, in general, existing developed lands will certainly be protected; undeveloped lands are unlikely to be protected.¹⁸⁸ Within the foreseeable future, almost all of the Potomac River shore will either be developed or become part of a park or wildlife preserve. Development is proceeding more slowly along the Rappahannock. Table 8-17 summarizes the assumptions on which Map 8-28 is based. Most map boundaries are based on land use data that the County provided.

Near the border with King George County, along the peninsula between Potomac and Accokeek creeks, the fates of two large parcels are unknown. Therefore the County thought that these parcels should be listed as likely, but not certain, to be protected. The rest of the peninsula is certain to be protected. The peninsula north of Accokeek Creek, by contrast, is being developed and will almost certainly be protected.

The Widewater Peninsula lies between Aquia Creek and the Potomac River. Unique habitat there requires protection, and some sort of park or preserve has been proposed within the area currently classified as rural residential (certainly protected). Once the precise locations of the parks are identified, we would show the park as light green and the remaining land as brown; but because the park boundaries have not been delineated, we show all of the rural residential areas on this peninsula as red.

¹⁸⁷Meeting with Will Nuckols and Jim Titus at the county offices in Stafford, May 17, 2004.

¹⁸⁸Based on the planner's decision rule that developed lands are certain to be protected, we assume that undeveloped lands, both private and public, are not likely to be protected and are therefore shown as red. We welcome any comment on this assumption.

The CSX railroad has an easement on the land between the Potomac River and the railroad tracks on the northern end of the peninsula, which limits development. Although the railroad itself is certain to be protected, the land between the tracks and the river is shown as unlikely to be protected.

The fate of the Marine Corps base in the northern portion of the county is uncertain. It is shown as red in accordance with the general methodology employed in this study for military lands. Other large parcels of land lie on the peninsula between Potomac and Accokeek creeks. The fate of these largely undeveloped lands is unknown at this point; we classify these lands as likely to be protected.

County planners indicated that the county needs a park along the Potomac River. Along creeks and the Rappahannock River, several parks are identified in the Stafford County land use data. Those areas were depicted as light green in the draft maps.

Along the Rappahannock River, the developed lands south of the city of Fredericksburg are typically very large tracts. Small losses of land would not necessarily be viewed as a threat to the parcel as a whole, and thus these lands are shown as likely, rather than certain, to be protected.

Stakeholder Review

We sent the County the draft report and maps. The County indicated that for the most part, the map was a reasonable depiction of future shore protection. Planning staff suggested several editorial changes as well as the following map changes¹⁸⁹:

- The draft map showed a small park inland of a residential area as certain to be protected near the head of Aquia Creek. Protection of the residential area means that the park will be protected as well. ***Change this polygon from blue to brown.***
- On the north side of Accokeek Creek, the draft map showed the land south of Brooke Road as

¹⁸⁹Meeting between Will Nuckols and Michael Zuraf, senior planner, Department of Planning and Community Development, County of Stafford at the county offices, June 30, 2004.

red with the land north of the creek as brown. The County suggested that the entire area should be depicted as red because it is lightly developed. We later noticed that the suggested change implies that Brooke Road might be lost; the road is the principal access to the neighborhoods to the east.¹⁹⁰

- **Change Potomac Creek Estates from blue to brown.** It is lightly developed, but given the value of the land, it is still likely to be protected.
- **Along the south shore of Potomac Creek, near the border with King George County, change Bell Plains and Jappazanos from blue to brown.** These recent developments did not show up in the County's data, but are almost certain to be protected.
- **Change McDuff Green County Park from light green to red.** This park is along the Rappahannock River, just downstream from Sylvania Heights.
- **Along the Rappahannock River upstream from Sylvania Heights and Little Falls Run, change the brown areas to red.**¹⁹¹

¹⁹⁰ This study focuses on the protection of land, not protection of roads and other infrastructure. When roads are threatened with inundation, a road can be converted to a bridge or a causeway and thus maintained without protecting the surrounding lands. As a result, we can assume that a populated island will be protected without having to assume that unpopulated land along the route to the island will also be protected. In the case of a road that follows ground vulnerable to erosion, however, the road can only be protected with erosion control measures that will also protect any lands behind the road. Given the County's assumption that the neighborhoods to the east are certain to be protected, the assumption that Brooke Road might be abandoned implied either that a new road would have to be cut through existing homes to the north, or ferry transportation to those neighborhoods. Will Nuckols was unable to follow up on this question because of illness, so we retained the assumption that Brooke Road (and hence the land behind it) will be protected.

¹⁹¹ We construed this comment as applying only to the land within 200 feet of the shore. The land within 1,000 feet of the shore includes housing and industrial areas. The County indicated that the area is not hardened now and is unlikely to be hardened because the land slopes up rapidly near the river. The County never indicated that there was any chance that the developed areas might be given up to the river, only that the land is not vulnerable. Because the maps assume that the shore erodes, the unlikelihood of erosion does not change the protection designation for this study. Nevertheless, the County's reasoning indicated that development of the immediate shoreline is far from certain, as is shore protection as long as

- **Change Washington's boyhood home from light green to brown.**

The County provided specific confirmation for the following areas.

- **The land riverward of the CSX tracks along the Potomac is correctly mapped as blue.**¹⁹²
- **Aquia Harbor is correctly mapped as brown even though it is vulnerable to flooding,** as evidenced by ongoing efforts to mitigate flooding. (Most of this community is tens of feet above sea level, but a few homes are built in low-lying areas.)
- **The Potomac River shore near Marlboro Point is correctly shown as certain to be protected.** In the aftermath of Hurricane Isabel, shore protection structures are being built.
- **The south side of Potomac Creek is correctly depicted as blue.** No appreciable development is likely upstream from Potomac Creek Estates, because preserving this area is important to the county.
- **The land along the eastern portion of the county's Rappahannock River shorelines correctly mapped as blue.** These tracts of land are long-held (multigenerational) properties, and unlikely to be subdivided; hence the fact that the land—if subdivided—would be worth protecting does not come into play as one might ordinarily expect. The County strongly doubts that the owners will expend funds to address the relatively minor shore erosion that might occur along this property. By contrast, the land across from Fredericksburg and immediately downstream either has ongoing subdivision applications in place or there is some discussion that subdivision applications might be coming in soon.¹⁹³

The County also suggested two other changes that, in retrospect, appear to have resulted from a

erosion is only modest. This logic also applied to Washington's boyhood home, which is set well back from the shore.

¹⁹² The land seaward of the tracks within the Quantico Marine Base is depicted as red, following the general approach of this study.

¹⁹³ This conjecture was offered by RADCO staff.

TABLE 8-17. STAFFORD COUNTY’S ANTICIPATED RESPONSE TO SEA LEVEL RISE^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Changes resulting from stakeholder review	Varies				Manual changes from stakeholder review
Parks	✓				Stafford County land use
Military installations			^b		Military installations
Railroad easement		✓			Manual GIS edit per county comments
Large parcels on peninsula between Potomac and Accokeek creeks			✓		Stafford County parcels
Developed lands south of Fredericksburg			✓		Stafford County land use
Rural residential lands on Widewater Peninsula			✓		Stafford County land use
Resource Protected Areas adjacent to undeveloped areas ^c		✓			Stafford County land use
Resource Protected Areas adjacent to areas likely to be protected ^c			✓		Stafford County land use
Resource Protected Areas adjacent to developed areas ^c				✓	Stafford County land use
Existing developed lands ^d				✓	Stafford County land use
Undeveloped lands ^e		✓			Stafford County land use

^a Where land areas overlap, classifications higher in the table take precedence.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

^c We identify existing developed lands based on residential, commercial, institutional, and industrial land uses identified in land-use data provided by Stafford County (last update 2003).

^d We include in this category all lands not captured as an existing developed lands.

^e Chapter 20 of the Chesapeake Bay Preservation Act requires local governments to designate Resource Protected Areas (RPAs) which serve to protect the quality of water in the area. RPAs are buffers of environmentally sensitive land that lie alongside a stream, river, or other water body. Stafford County designates lands 100 feet from any water body as an RPA and these lands are included as a unique land use category in the county’s GIS data. The only permitted activities in RPAs are redevelopment and water-dependent facilities such as docks or piers. See <http://www.chesterfield.gov/CommunityDevelopment/Engineering/rpa.asp>, accessed on April 9, 2004. Nevertheless, RPAs have not prevented shore protection in Stafford County or elsewhere. In theory, if shore protection became recognized as an environmental problem, the RPA might be somewhat less likely to be protected. Currently, however, protection has the effect of maintaining the buffer. Hence, this study assumes the RPAs have no effect on the likelihood of protection.

miscommunication between County staff and Will Nuckols, the member of our team conducting the stakeholder review. The draft maps showed the land south (toward the creek) of Brooke Road as likely to be protected, from the bend in the road westward—with the area north of Brooke Road as almost certain to be protected. Viewing a map that did not show the road layer, the County suggested that the brown should be changed to red. Because Will Nuckols and County staff did not discuss the possible abandonment of Brooke Road and the version of the map that they examined did not include the road, we concluded that the County did

not intend to suggest that Brooke Road might be abandoned.

Second, the County suggested that we change the land opposite the City of Fredericksburg from certain to likely to be protected. The reasoning, however, was based on doubts regarding whether the shore will erode, not the possibility that the land will not be developed or that developed areas might be abandoned. This misunderstanding of the scope of this study is common among EPA subcontractors as well as county partners.

Ultimately, we need a map showing the likelihood and timing of future shore protection.¹⁹⁴

Caroline County, Spotsylvania County, and the City of Fredericksburg

Anticipated Sea Level Rise Response

We developed general guidelines for Caroline County, Spotsylvania County, and the City of Fredericksburg, based on planner responses in other areas of the state. Table 8-18 summarizes these assumptions and describes the data used to identify areas that may or may not be protected from inundation.

Generally, existing development will certainly be protected, transitional areas are likely to be protected, and agricultural, forest, and other undeveloped lands are unlikely to be protected. Given uncertainty about the military's expectations for the future of their lands, we show these lands as red. We identify these areas using land use/land cover data (late 1970s to early 1980s) from EPA's BASINS dataset and a USGS National Landcover dataset accessed through the University of Virginia.

The draft maps show almost all of Spotsylvania and Caroline county shores as unlikely to be protected. The City of Fredericksburg included parks where shores will not be protected and urban waterfronts where shore protection is certain.

Stakeholder Review

We met with Stephen Manster, executive director, Rappahannock Area Development Commission, who indicated that the maps generally looked correct. Nevertheless, before we met with him, he had urged us to meet with Caroline County, given the county's long shoreline along the Rappahannock River, the large amount of low

land, and the potential for development. We did so later the same day.¹⁹⁵ We also attempted to contact the other two jurisdictions, but were unsuccessful.

Caroline County planning staff generally concurred with the draft maps, but suggested the following changes:

- ***Change the shoreline area from blue to red for the proposed Haymont development.***
- ***Change the shoreline from Port Royal to Gouldman Pond from blue to red, as a potential growth area for Port Royal.***
- ***Change the shore along Portobago Bay (at the border with King George County) from blue to red for the Portobago development.***

Our inability¹⁹⁶ to contact Spotsylvania County seemed problematic. Given that Spotsylvania is closer to the urban areas of the I-95 corridor than Caroline County, future development seemed at least as likely. In the absence of direct communication with the County, it seemed most reasonable to consult the county comprehensive plan. That plan identifies almost the entire tidal Rappahannock shoreline as part of the "Primary Settlement District." We modified the draft maps to show currently undeveloped areas within the primary settlement district as likely to be protected and developed areas as certain to be protected.

¹⁹⁴Under Bayes' Theorem, the probability of shore protection equals the probability of erosion times the (conditional) probability that the shore will be protected given shore erosion. A separate study—perhaps involving local geologists and engineers as well as planners—needs to estimate the likelihood that the shore will erode by a particular amount. This study addresses the likelihood that the shore will be protected if enough sea level rise or erosion occurs to make protection necessary.

¹⁹⁵Caroline County Stakeholder Review meeting between Will Nuckols and Mike Stafford, Caroline County, June 30, 2004, at county offices.

¹⁹⁶Will Nuckols placed three calls to the Planning Department in Spring 2004, none of which was returned.

TABLE 8-18. ASSUMPTIONS FOR SHORE PROTECTION MAP FOR CAROLINE AND SPOTSYLVANIA COUNTIES AND CITY OF FREDERICKSBURG^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Parks	✓				Parks
Military lands			^b		Military installations
Existing developed lands				✓	Land cover ^c ; Land use/land cover ^d
Spotsylvania County: Primary Settlement District			✓		1:100,000 scale hand edit based on county comprehensive plan ^e
Transitional lands			✓		Land use/land cover ^f
Undeveloped lands (including gravel pits)		✓			Land use/land cover ^g

^a Where land areas overlap, classifications higher in the table take precedence.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

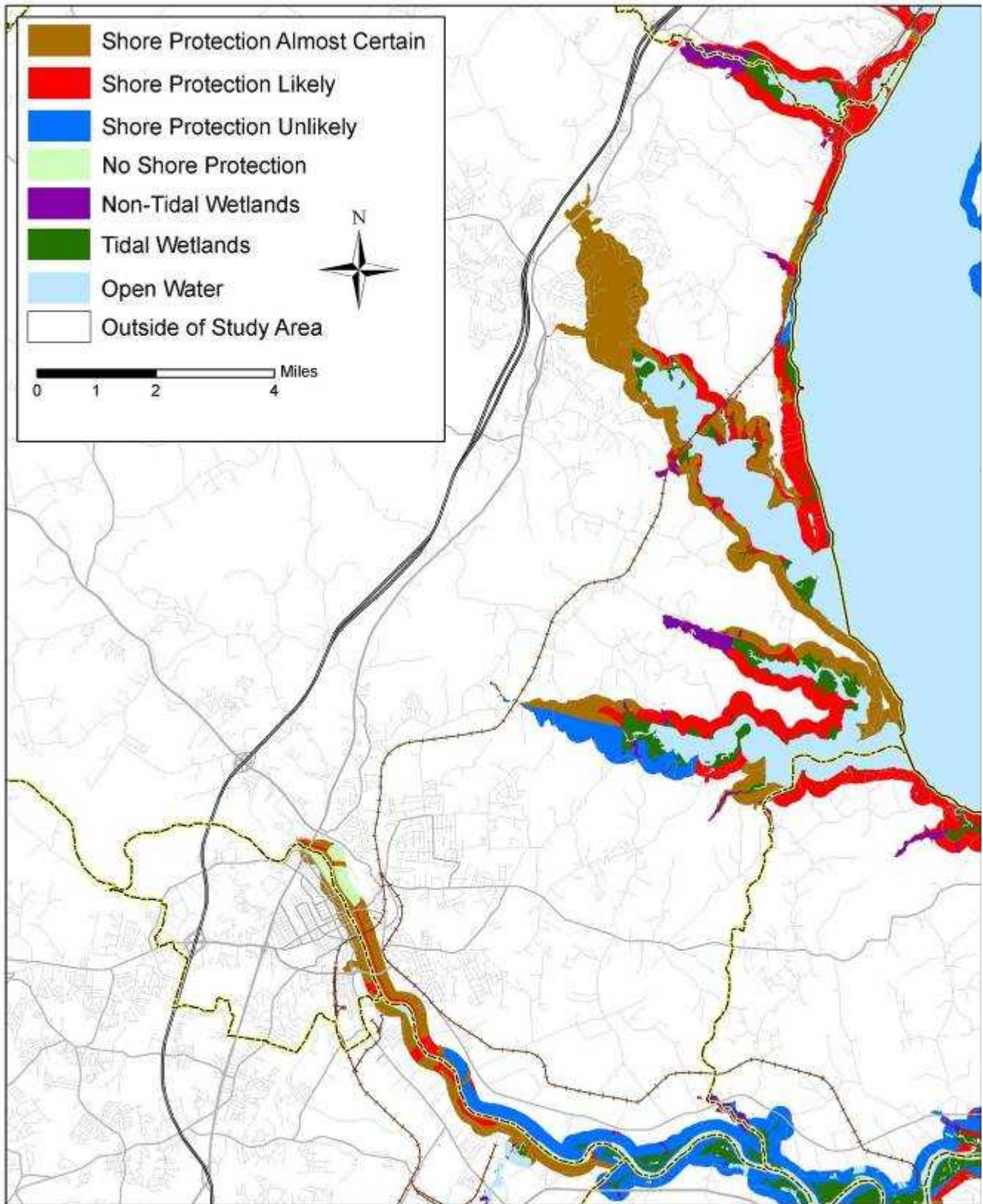
^c This category includes all low and high density residential development (codes 21 and 22) as well as commercial/industrial/transportation lands (23).

^d We identify existing developed lands based on residential, commercial/services, mixed urban/built-up, transportation/communication/utility, and industrial land uses.

^e Spotsylvania County Department of Planning, Comprehensive Plan, 2002, Primary Settlement District Map.

^f We include in this category all transitional and other urban/built-up lands.

^g We include in this category all forest, crop/pastureland, other agricultural lands, and strip mines.



Map 8-28 .Stafford and Spotsylvania Counties and City of Fredericksburg: Likelihood of Shore Protection For additional details, see the legend and caption accompanying Map 8-2.

NORTHERN VIRGINIA

Editor’s note: the Northern Virginia PDC is known as the Regional Commission (RC).

Background¹⁹⁷

The Northern Virginia region is the farthest inland and northernmost planning district examined in this study. We examine the Potomac River shore from the Quantico Marine Corps Air Station upstream to the head of tide at Little Falls, along with the tidal portion of the Occoquan River and a few tidal creeks. The four coastal jurisdictions within the Northern Virginia Regional Commission’s jurisdiction are Prince William, Fairfax, and Arlington counties and the City of Alexandria.

The Potomac River is the border between Maryland and Virginia, west of Chesapeake Bay. The precise location of the border was uncertain for hundreds of years, because colonial charters for Maryland and Virginia had each included the Potomac River. Virginia’s Constitution of 1776 “ceded ownership of the River to the extent the River was included in Maryland’s 1632 Charter.”¹⁹⁸ The precise location of the boundary, however, was not decided until Virginia and Maryland submitted their boundary dispute to binding arbitration in 1874. The arbitration panel placed the boundary along the low-water mark of the river, the legislatures of both states ratified this award, and in 1879, the U.S. Congress approved it pursuant to the Interstate Compacts Clause of the U.S. Constitution.¹⁹⁹

The U.S. Congress had established the seat of government of the new nation near the head of tide of the Potomac River. The “ten miles square”²⁰⁰ District of Columbia included about 30 square miles of Virginia. Most of this land had been part of Fairfax County; but it also included the City of

Alexandria. Shortly before the Civil War, Congress returned the western portion of the District to Virginia, which became Arlington County, except for the City of Alexandria. Thus, when the boundary between Maryland and Virginia was finally determined, it also applied to the boundary between the District of Columbia and Virginia.

For our purposes, this story has two practical implications. First, islands in the Potomac River, no matter how close they are to the Virginia side of the river, are part of Maryland or the District of Columbia. Second, shore protection structures built by Virginia residents are located partly in Maryland and thus could potentially be subject to Maryland policies. Because most of the Potomac shoreline in Northern Virginia is owned by the federal government, however, this potential conflict in state policies is less likely to be an issue here than in the areas downstream.

The National Park Service owns much of the Potomac River shoreline in Northern Virginia. The George Washington Memorial Parkway was installed in the National Park Service System in 1932 to preserve the natural scenery along the Potomac. One portion runs along the river from Mount Vernon in Fairfax County to the southern border of Alexandria. A second portion extends from the northern end of Old Town Alexandria to the Arlington county line. In Arlington, the parkway runs inland of Reagan National Airport and then along the Potomac River all the way to Little Falls. About 1.5 miles of the northern portion of the parkway is on Columbia Island, which is part of the District of Columbia, separated from the Virginia mainland by Boundary Channel. The Pentagon, Arlington Cemetery, and the Iwo Jima Memorial are located on the Virginia shoreline of Boundary Channel. Between Mount Vernon and Great Falls, the only other areas that are not part of the George Washington National Park are (1) about 1.5 miles of residential neighborhoods, (2) River Farm between Fort Hunt and Dyke Marsh, (3) Old Town Alexandria (whose

¹⁹⁷The original draft of this section was based on discussions with representatives from the Northern Virginia PDC and Fairfax County.

¹⁹⁸*Maryland v. Virginia*, 540 US (2003), slip opinion at 2.

¹⁹⁹*Ibid.*

²⁰⁰U.S. Constitution, Article 1, Section 17.



Photo 8-50. Shoreline Armoring along the Potomac River South of Mount Vernon (October 2003).

waterfront is largely open to the public), (4) a large power plant in Alexandria with an apartment building next door, and (5) Reagan National Airport. South of Mount Vernon, one finds a mixture of residential, park, industrial, railroad, and military lands. (See Photo 8-50).

The Northern Virginia/District of Columbia area is one of the most densely developed metropolitan areas in the country. According to the 2000 census, approximately 1.8 million people lived in the cities and counties of Northern Virginia Regional Commission's jurisdiction. The economies of Arlington and Alexandria rely heavily on federal government employment. The economy of Fairfax County is based largely on high tech operations and supports no fewer than 33 Fortune 500 company headquarters. Prince William County has experienced recent growth in the electronics, computer, commercial, telecommunications, and engineering sectors.²⁰¹ Therefore, the planners were unable to conceive of any plausible scenarios that would reverse development trends and lead people to move away from the Potomac shores.

Vulnerability to Sea Level Rise

Compared with portions of the state's coastal zone, Northern Virginia has very little land close to sea level. (See Table 8-19.) Shore erosion, rather than inundation, would be the most common impact of sea level rise. The two exceptions are Old Town in Alexandria and Belle Haven in Fairfax County, both of which flood occasionally from high levels in the Potomac River.

Anticipated Sea Level Rise Response

Based on meeting held December 15, 2003, at the PDC offices with:

²⁰¹See <http://www.petrapub.com/newcomer/dc/>, accessed on April 16, 2004.

TABLE 8-19. AREA OF LAND VULNERABLE TO SEA LEVEL RISE: NORTHERN VIRGINIA REGIONAL COMMISSION (square miles)^a

Jurisdiction ^b	Vulnerable Land ^c	Tidal Wetlands	Elevation ^d					
			0–2 feet		0–4 feet		0–8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Fairfax	2.7	1.9	0.7	0.1	1.4	0.1	2.8	0.27
Prince William	2.3	2.0	0.3	0.1	0.7	0.1	1.4	0.2
Alexandria	0.2	0.1	0.2	0.01	0.3	0.02	0.6	0.04
Arlington	0.1	0.0	0.1	0.0	0.2	0.0	0.4	0.0001
Total	5.4	4.0	1.3	0.1	2.6	0.3	5.2	0.5

^a J.G. Titus and J. Wang, 2008, see Table 8-19 for full reference.

^b Jurisdictions ranked by amount of dry land within 2 feet above the ebb and flow of the tides.

^c The area of tidal wetlands plus the area of land within 2 feet above spring high water.

^d Elevations relative to spring high water, that is, the average highest tide during full moons and new moons. Therefore, the land within 2 feet of spring high water is the area that would be tidally flooded if the sea rises 2 feet.

Doug Pickford, director, Environmental and Heritage Resources, Northern Virginia Regional Commission; Katherine Mull, environmental planner for Coastal Programs, Northern Virginia Regional Commission; Jim Van Zee, director, Regional Planning Services, Northern Virginia Regional Commission; and Don Demetrius, Fairfax County Public Works

The value of a waterfront view is great enough to ensure that all private land that can be developed will be developed, along both the Potomac River and its tributaries. Unlike counties across the river in Maryland, environmental land use regulations to protect Chesapeake Bay do not prevent development of any riparian forests and farms.²⁰² Given the benign wave climate and relatively high ground, the cost of shore protection is low compared with property values, so developed areas will almost certainly be protected.

Nevertheless, a large portion of the Northern Virginia shore will probably not be armored for at least the next several decades. The federal government owns the majority of riparian lands, and some private industrial lands could tolerate tens of feet of shore erosion before shore protection became necessary. Eventually, shore erosion might threaten the CSX Railroad tracks

and the George Washington Memorial Parkway, requiring shores to be protected.

Accordingly, local planners indicated that the most reasonable approach to take is to assume that all privately owned lands available for residential development are certain to be protected. Shorefront highways, railroads, and other infrastructure are also certain to be protected, but wherever the facilities are set back from the water, shore protection would not be necessary unless the shore eroded enough to threaten the structure. Except for where infrastructure is threatened, federal park and refuge lands will almost certainly not be protected. State and local parklands will probably not be protected either except to protect infrastructure, but unlike federal parks, they have no explicit mandate to maintain natural shorelines.

Let us now examine the assumptions for each of the counties.

Prince William County

The principal railroad line for southbound trains from Washington, D.C. runs along most of the shore of Prince William County. Although the tracks are set well back from the shore, the existence of this line may tend to alter development and shore protection compared to what would otherwise occur.

At the southern end of the study area is the Quantico Marine Corps Development and Education Command. This military area is shown in red in accordance with the nationwide study's project protocol to not ask county planners to

²⁰² Maryland and Virginia both prohibit new construction of homes within 100 feet of a tidal shoreline, but that limitation does not prevent the conversion of waterfront farms and forests to housing subdivisions. Maryland's Critical Areas Act also restricts densities to one home per 20 acres within 1,000 feet of the shore in a few areas along the shores of Charles and St. Mary's counties.

speculate on the intentions of the Department of Defense. Within the base is the town of Quantico, which is certain to be protected. Outside the base, shore protection is likely or certain along all of Quantico Creek. Near the head of tide at Dumfries, the shores are developed on both sides, rendering protection almost certain. We show the area closer to the river along Possum Point Road as certain to be protected, although it is less densely developed than the surrounding areas.

On the northeast side of Quantico Creek along the river lies Virginian Dominion Power's Possum Point power plant. The ground rises rapidly to about 50 feet above sea level, protecting the plant from flooding; and there is no doubt that the facilities here will be protected from shore erosion. Terminal facilities 2 miles to the north at Cockpit Point will certainly also be protected. In between these two facilities, however, shore protection seems less likely. In this area, the railroad is approximately 500 feet from the shore. Given both the difficulty of squeezing residential housing into such a narrow area and the proximity of the power plant, the area between Possum and Cockpit points will probably not be protected. Similarly, development seaward of the railroad tracks is unlikely for most of the shore between Cockpit Point²⁰³ and Powell's Creek. Here, the railroad line is somewhat closer to the river and trains are visible from water.

Most of Powell's Creek is undeveloped, but almost certain to be developed in the coming decades. As a result, privately owned land is shown as certain to be protected. Between Powell's Creek and Occoquan Bay is Leesylvania State Park, which we show as unlikely to be protected. The railroad is farther inland and hence unlikely to require shore protection. Most of the shore of Neabsco Creek will be developed. Two small parks along this creek, Rippon Landing Community Park and Neabsco Eagles Park, however, are unlikely to be protected.

On the north side of Neabsco Creek is Featherstone National Wildlife Refuge. Various

wildlife refuges extend 6 miles up Occoquan Bay, interrupted by about 1 mile of development (Featherstone Farms and Featherstone Shores). North of that development lie two more wildlife refuges: Occoquan Bay and Marumsco. The southern 2 miles of Marumsco refuge, however, do not extend very far inland; so if sea level were to rise enough to inundate or erode existing wetlands, the shore might reach the railroad, which would be protected. Hence our maps in this area show a mixture of green and brown. Between Marumsco National Wildlife Refuge and the railroad tracks is Veterans Memorial Park, which is treated as unlikely to be protected.

Ospreys Golf Course occupies the Occoquan Bay shore from the Occoquan Bay Refuge to the railroad bridge over the Occoquan River, with a few streets leading to the river in the middle of the golf course. Given the investment, this golf course is almost certain to be protected as well. Just offshore from the refuge, near the border with Fairfax County in Occoquan Bay, lies Conrad Island, which is unlikely to be protected. Upstream from the railroad bridge is a combination of marinas, homes, and infrastructure, all of which are certain to be protected.

The county's comprehensive plan identifies a land use category of "public land." In addition to the publicly owned lands discussed above, the data identified a number of other publicly owned parcels of land within the study area. We have assumed them to be reasonably likely to be protected.

Table 8-20 summarizes our assumptions for Prince William County. Map 8-29 depicts the likelihood of shore protection results of our analysis.

²⁰³Our maps show the shore as blue between the river and 50 feet seaward of the tracks. The protected area around Cockpit Point extends north to Cherry Hill, where the road to Cockpit Point crosses the tracks.

TABLE 8-20. PRINCE WILLIAM COUNTY’S ANTICIPATED RESPONSE TO SEA LEVEL RISE^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Stakeholder review changes	As specified				See text
Federal wildlife refuges ^b	✓				Prince William County Comprehensive Plan data
Federal parks and open space ^c	✓				Prince William County Comprehensive Plan data
State and local parks and open space ^d		✓			Prince William County Comprehensive Plan data
Military installations				^e	Military installations
Other public land			✓		Prince William County Comprehensive Plan data
Private land more than 100 feet seaward of center of CSX tracks along the Potomac River		✓			Manual GIS edit
Privately held lands along the Potomac River and connecting creeks and embayments ^f				✓	Prince William County Comprehensive Plan data

^a Where land areas overlap, classifications higher in the table take precedence.

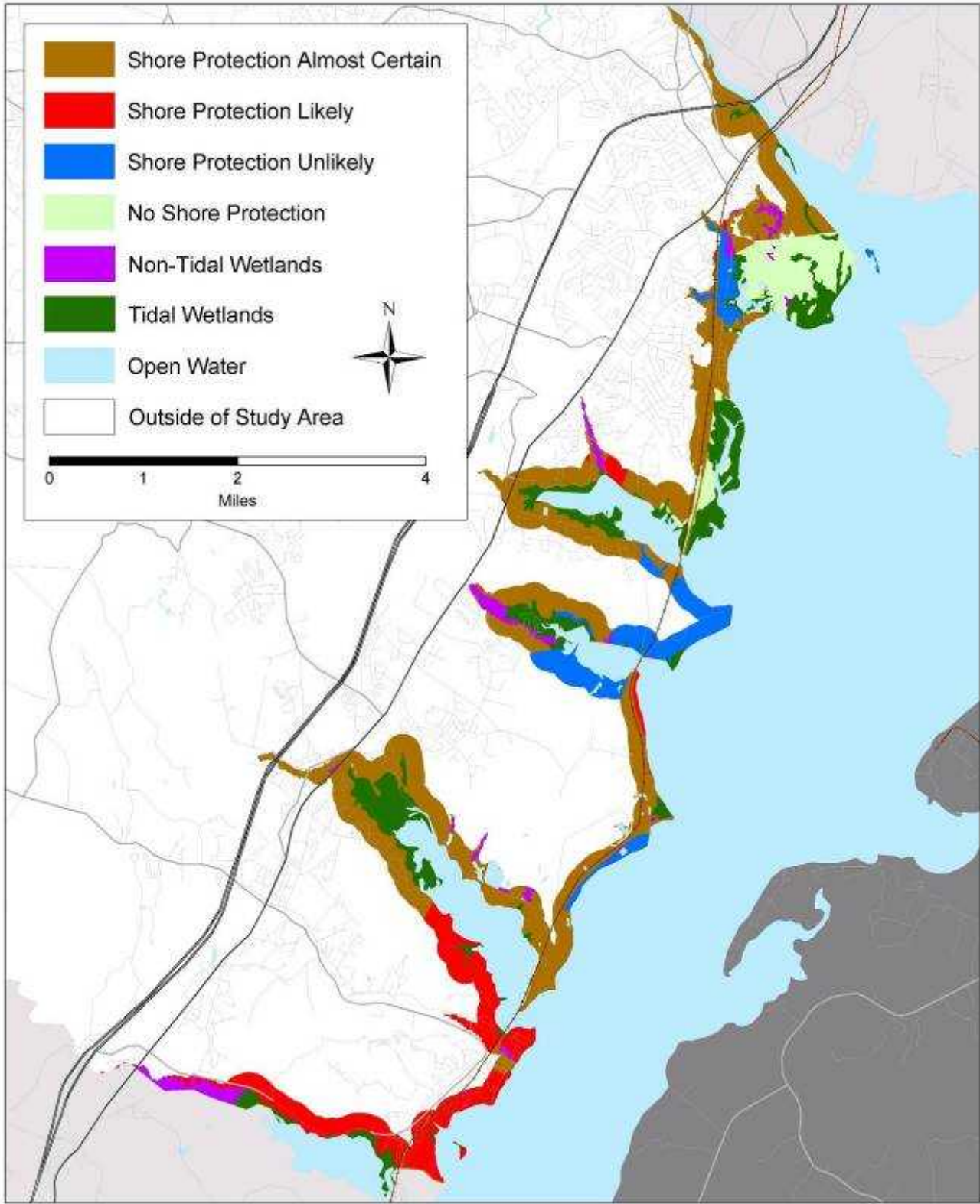
^b Includes areas identified as public land and wildlife refuge in the comprehensive plan data.

^c Includes areas identified as federal parks and open space in the comprehensive plan data.

^d Includes areas identified as state and local parks and open space in the comprehensive plan data.

^e Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”

^f Includes all lands other than those designated as public land or parks and open space.



Map 8-29. Prince William: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 8-2.

Fairfax County

The shoreline along most of the Potomac River in the Northern Virginia RC jurisdiction is owned by the National Park Service, which maintains the George Washington Memorial Parkway along the river's banks. Between the parkway and the river lies the 18.5-mile Mount Vernon Trail (which constitutes a portion of the East Coast Greenway bicycle trail). This bikepath was installed in 1973 and connects Mount Vernon with Theodore Roosevelt Island in the District of Columbia. Planners believe that the Park Service will probably allow the shore to erode up to the bikepath. The bikepath will probably be protected, but relocation is possible. The parkway, by contrast, will be protected in its current location. Therefore, along the portion of the Fairfax shoreline owned by the Park Service, the land between the Potomac River and the bikepath is unlikely to be protected (blue), except for the Belle Haven Marina, which is likely to be protected.²⁰⁴ The area between the bikepath and the parkway is likely to be protected (red) and the George Washington Parkway will certainly be protected (brown). Because we have no digital data depicting the location of the bikepath, however, we are unable to identify the small strip of land between the bikepath and parkway. As a result, the current

version of the map—in effect—assumes that the bikepath is next to the road, understating the amount of land requiring shore protection.

The Fort Belvoir Military Reservation is located along the Potomac in the southern portion of the county. Following the general methodology of this study, we show the military reservation as red to reflect uncertainty (given the lack of availability of information concerning the area).

Another federal holding along the Potomac is George Washington's home, Mount Vernon. Because of its value as a national historic site it will certainly be protected. In contrast, another of George Washington's estates, River Farm, is now owned by the American Horticultural Society. The estate lies on a 25-acre tract of land and small losses may be acceptable. Thus this estate is shown as likely, but not certain, to be protected.

Mason Neck State Park is located on the southernmost peninsula of Fairfax County. As a large recreational park whose primary uses are picnicking and water-related recreation, our draft maps assumed that its shores will probably not be protected. The maps also assume that the shores of Mason Neck National Wildlife Refuge will not be protected.

Table 8-21 summarizes our assumptions for Fairfax County. Map 8-30 depicts the likelihood of shore protection results of our analysis.

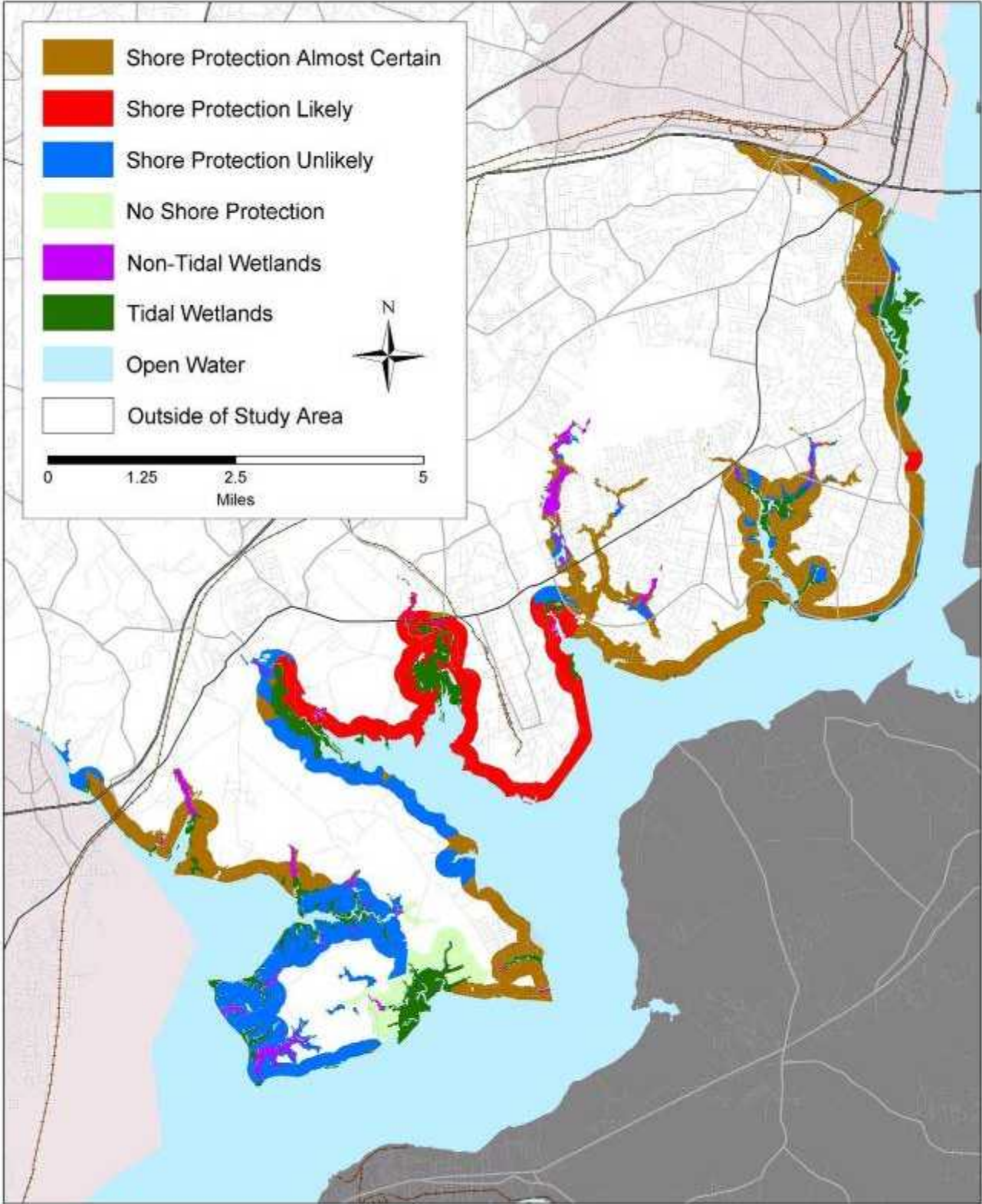
²⁰⁴Because the National Park Service occasionally considered closing this small marina, we cannot be certain that it will be protected.

TABLE 8-21. ASSUMPTIONS FOR SHORE PROTECTION MAP FOR FAIRFAX COUNTY^a

Land Area	Protection Likelihood				Source
	No protection	Unlikely	Likely	Certain	
Military installations			^b		Military installations
Mason Neck Wildlife Refuge	✓				Parks and major roads
George Washington Memorial Parkway and NPS-held land inland of George Washington Memorial Parkway				✓	Parks and major roads
NPS-held land between George Washington Memorial Parkway and Mount Vernon Trail			✓		Parks and major roads
NPS-held land between Mount Vernon Trail and the Potomac River		✓			Parks and major roads
Mount Vernon				✓	Detailed county boundaries
Remaining public lands			✓		Fairfax zoning
River Farm			✓		Hand edit implemented based on depiction in Alexandria Drafting Company 1:24,000 street map
Privately held lands along the Potomac River and connecting creeks and embayments				✓	Fairfax zoning

^a Where land areas overlap, classifications higher in the table take precedence.

^b Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assigns the code “military” rather than “protection likely.”



Map 8-30. Fairfax County: Likelihood of Shore Protection . For additional details, see the legend and caption accompanying Map 8-2.

City of Alexandria

Alexandria’s first three blocks along the river are already experiencing flooding, and efforts are under way to address the issue. Because these ongoing efforts are expected to continue, Alexandria’s private lands will certainly be protected.

City and county parks and recreational land in densely developed areas are frequently targeted for protection. Absent specific information from the city on the fate of recreational lands in Alexandria, we show these parks as certainly protected. The only exception is Four Mile Run Park. Its location adjacent to wetlands makes protection less than certain, but still possible. As such, we color it red and assume it to be likely to be protected.

The Mount Vernon Bike Trail follows city streets through most of Alexandria. It also runs along Dangerfield Island and Washington Sailing Marina. We show the marina as certain and the rest of Dangerfield Island as likely to be protected. For the very small part of the bike trail that runs along the river within a riverfront park, we intended to follow the same approach as for Fairfax County; that is, land seaward of the bikepath will probably not be protected, but the path itself probably will be protected. As with Fairfax, however, we lacked a digital depiction of the bikepath.

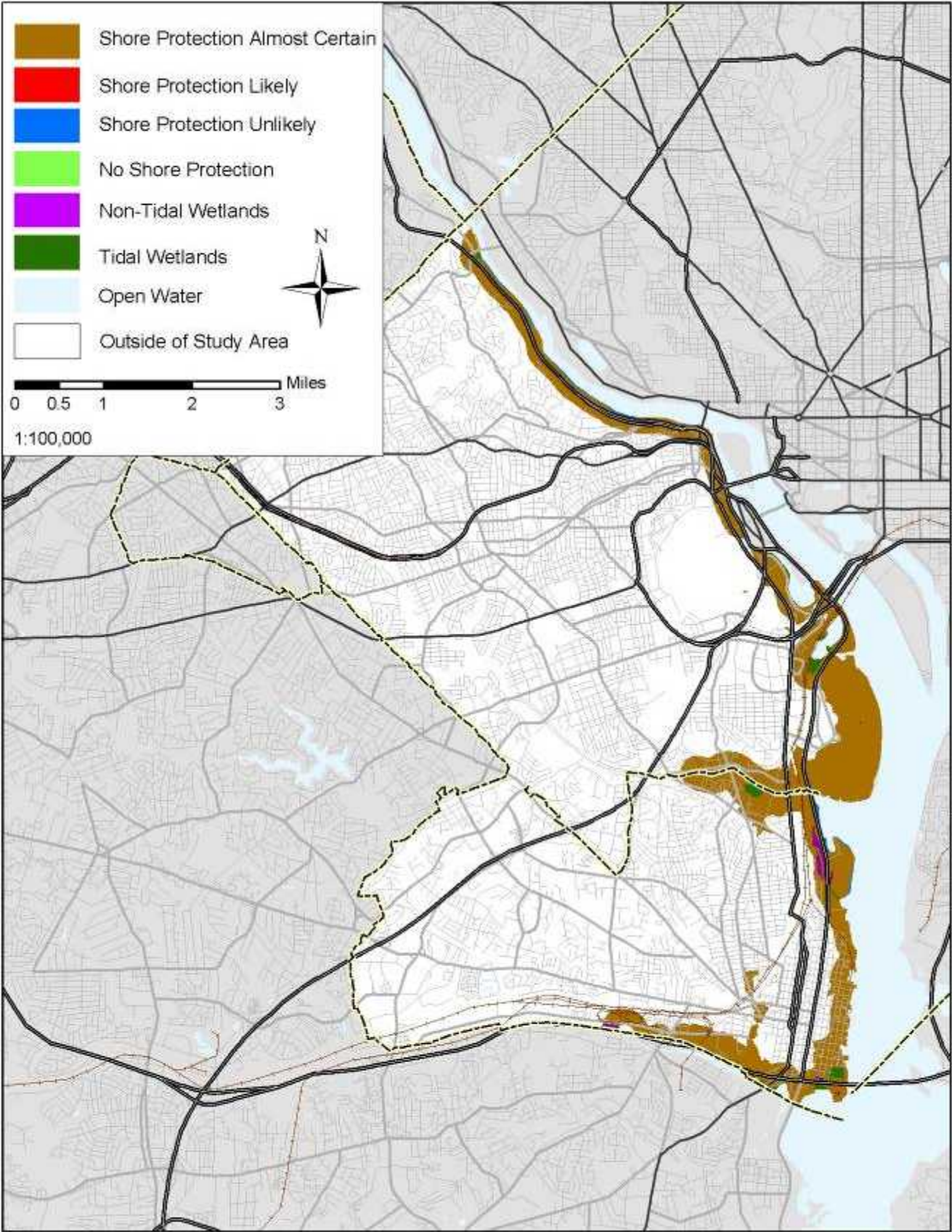
Table 8-22 summarizes our assumptions for the City of Alexandria. Map 8-31 depicts the likelihood of shore protection results of our analysis.

TABLE 8-22. ALEXANDRIA’S ANTICIPATED RESPONSE TO SEA LEVEL RISE^a

Ownership	Land Area	Protection Likelihood				Data Source
		No protection	Unlikely	Likely	Certain	
Public	Parks and open space ^b				✓	City of Alexandria tax parcel data
	Four Mile Run Park			✓		City of Alexandria tax parcel data
	George Washington Memorial Parkway and NPS-held land inland of George Washington Memorial Parkway				✓	Parks and major roads
	NPS-held land between George Washington Memorial Parkway and the Potomac River		✓			Parks and major roads
Private	Privately held lands along the Potomac River and connecting creeks and embayments				✓	City of Alexandria tax parcel data

^a Where land areas overlap, classifications higher in the table take precedence.

^b Regional and city parks and playgrounds are identified using land use codes 722 and 731 in Alexandria’s tax parcel data.



Map 31. Alexandria and Arlington: Likelihood of Shore Protection

Arlington County

Reagan National Airport serves the District of Columbia and surrounding metropolitan area. The riverbank adjacent to the airport is already structurally protected and the airport is a valuable component of the transportation infrastructure. It will almost certainly be protected.

The George Washington Memorial Parkway runs along the entire Potomac River shore in Arlington County and is almost certain to be protected. Local planners believe that the Park Service might allow the shore to retreat as far inland as the bikepath, but that the bikepath itself will be protected in its current location. The bikepath ends at the Key Bridge, and the relatively minor human use of the shore upstream from that point tends to be water dependent, such as fishing and landing kayaks. Therefore, the maps show Park Service lands between the Potomac and the parkway as unlikely to be protected from the head of tide near the Chain Bridge south to the Key Bridge.²⁰⁵

South of the Key Bridge, we show the land between the Potomac River and the bikepath as likely to be protected (red) and the area inland of the path as certain to be protected (brown), with one exception. We show the shore from the southern end of Boundary Channel down to the railroad bridge as certain to be protected, given the various bridges requiring protection.

Although we generally show military lands as red to reflect planners' desire not to speak for the Department of Defense, we make an exception for the Pentagon and Arlington National Cemetery. As a security precaution in the aftermath of the September 11 attack on the Pentagon, VA-110 traffic has been relocated to run along Boundary Channel and Pentagon Lagoon. This road is certain to be protected.

Parks and recreational land in densely developed areas are frequently targeted for protection. Absent specific information from the

city on the fate of recreational lands in Arlington County, we show these parks as likely to be protected.²⁰⁶

Table 8-23 summarizes our assumptions for Arlington County. Map 8-31 depicts the likelihood of shore protection results of our analysis.

Stakeholder Review

We held follow-up meetings with the Northern Virginia Regional Commission²⁰⁷ and the planning staff of Prince William County.²⁰⁸ The planners made several suggested changes for the text, and spotted a number of map boundary errors. The substantive map changes requested were as follows:

Arlington: The shore near the 14th Street Bridge is certain to be protected. The draft text said that the Potomac shore from the mouth of Boundary Channel to the CSX bridge was certain to be protected, but this areas had been erroneously mapped as a combination of blue and red.

Alexandria: Change southern half of Dangerfield Island from blue to red. The text had stated that Washington Sailing Marina would be protected. However, the map erroneously showed the entirety of Dangerfield Island as unlikely to be protected. We revised the maps to show the entirety of Dangerfield Island as likely to be protected, with the marina certain to be protected.

Fairfax County: Change Mason Neck from blue to red. Efforts are already under way to halt erosion there, according to NVRC staff.

Prince William requested several changes:

- ***Change all the small red polygons to brown.*** These areas showed up as red

²⁰⁶There are no privately held open lands in Arlington County within the area vulnerable to sea level rise.

²⁰⁷Meeting between Will Nuckols and Doug Pickford, director, Environmental and Heritage Resources; Katherine Mull, environmental planner for coastal programs, and Jim Van Zee, director, Regional Planning Services, Northern Virginia Regional Commission, June 11, 2004, NVRC office.

²⁰⁸Ray Utz, chief of long range planning, meeting with Will Nuckols, June 18, 2004, at the county offices in Prince William.

²⁰⁵Between Chain Bridge and Little Falls, the shore is privately owned and shown as brown. We have not analyzed this small stretch of land in detail because the shore is rocky and steep.

because our data classified it as “other public land.” In one case it was part of a golf course; in other cases it may have been small local parks. The County sees no reason to expect less shore protection than the surrounding lands.

- ***Change the south side of Powell’s Creek from brown to blue.*** The County places a high priority on ensuring that this shoreline remains undeveloped.
- ***Change the area seaward of the railroad tracks between Cockpit Point and Powell’s Creek from blue to red.*** The County told Will Nuckols that expansion of passenger rail traffic is likely to result in a new passenger terminal here. Although this land is too steep for a parking lot or rail yard, the County indicated that the railroad will probably find some use for it, and hence it will probably be protected.
- ***Change the area seaward of the CSX tracks south of the end of Possum Point Road from brown to blue.*** This area has no infrastructure and is unlikely to be developed.
- In addition the County confirmed that Veterans Memorial Park should be blue rather than light green, because there is no specific mandate for preserving natural shores.

Finally, the District of Columbia reminded us that the Nation’s Capital owns the shoreline below mean low water along the western shore of the Potomac River, comprising all of the shore of Arlington and most of Alexandria. As a result, Washington would have an interest in any protection measures taken to prevent the waters of the District of Columbia from advancing inland. Nevertheless, the planning department indicated that for the foreseeable future, the District of Columbia’s efforts to preserve natural shores will focus on the Anacostia River and the eastern shore of the Potomac River.²⁰⁹

²⁰⁹See email from Jim Titus to Uwe Brandes, D.C. Office of Planning, February 1, 2004 (summarizing stakeholder review of sea level rise planning maps for the District of Columbia). Dr. Brandes did not object to the fact that our sea level planning

maps for DC only showed Columbia Island on the western side of the Potomac River, given that our study area includes only land above the high water mark. He simply wanted to ensure that the reports recognize DC’s interest in the western shore.

TABLE 8-23. ARLINGTON COUNTY’S ANTICIPATED RESPONSE TO SEA LEVEL RISE ^a

Ownership	Land Area	Protection Likelihood				Data Source
		No protection	Unlikely	Likely	Certain	
Public	NPS-held land north of Key Bridge and between the Potomac River and Mount Vernon Trail north of Theodore Roosevelt Island		✓			Parks
	NPS land landward of Mt. Vernon Bike Trail, including George Washington Memorial Parkway				✓	Parks and major roads
	NPS-held land between the Potomac River and Mount Vernon Trail south of Theodore Roosevelt Island	Likely but mapped as certain ^b				Parks
	Parks and open space			✓		Parks and Arlington County parks
	Arlington National Cemetery and Fort Myer				✓	Military installations
	Reagan National Airport				✓	Manual GIS edit
Private	Privately held lands along Potomac River and connecting creeks and embayments				✓	Detailed county boundaries

^a Where land areas overlap, classifications higher in the table take precedence.

^b The decision rule was to map this land as likely, but lacking the data on bikepath location, we map it as certain to be protected. Please see text for detailed description of decision rules in this area.

Appendix A

LENGTH OF SHORELINES BY LIKELIHOOD OF SHORE PROTECTION

Authors: John Herter and Daniel Hudgens

Table of Contents: List and description of tables included in this appendix

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Shoreline length of primary water bodies	Shoreline length reported for Primary Water Bodies by Water Body Name (aggregated across).	A-3
Shoreline lengths for all bodies of water by county	Shoreline length reported by unique County, Water Body Category, and Water Body Name.	A-4
Military lands	Shoreline length reported by unique County, Water Body Category, and Water Body Name where the shoreline is located within a Military Facility.	A-5
Islands with roads	Shoreline length reported by unique County, Water Body Category, and Water Body Name where the shoreline is located on an island that contains roads.	A-6

Notes

This appendix estimates the lengths of tidal shoreline for each of the categories of shore protection likelihood. By “shoreline” we mean the land immediately adjacent to tidal open water or tidal wetlands. We provide several alternative summaries of our tidal shoreline estimates, including shoreline length by county, type of water body, and major body of water. For information on how we created, categorized, and measured the shoreline, see Appendix 1 of this report.

Table A-1: Definitions: Water body categories used in this Appendix

Water Body Category ¹	Description
Shorelines Along Primary Water Bodies ²	
Primary Bay	Shoreline located along a major bay such as Chesapeake Bay.
Barrier/Bayside	The side of barrier islands adjacent to the inner coastal bay.
Primary River	The portion of a major river that flows either into the Atlantic Ocean or a Primary Bay where the river is wider than one kilometer. In this case, a major river is subjectively determined but represents the most significant waterways in the region based on relative size (e.g., Potomac River, Delaware River, Nanticoke River, etc.).
Barrier Bay/Mainland	Shoreline that is located along the major county landmass and, at least partially, shielded by a barrier island.
Barrier/Oceanside	The side of barrier islands adjacent to the Atlantic Ocean.
Ocean Front	Land located immediately adjacent to the Ocean. Excludes land located along a barrier island (which is characterized as Barrier/Oceanfront).
Other Types of Shores	
Dredge and Fill	Shoreline characterized by multiple "finger" canals that run from the primary shoreline area inland and provide access to the water for the local community development.
Other/Road	A general term used for land that might not always be considered to be land. In particular, 1) dry land located at the base of causeways leading to barrier islands and 2) docks and piers that extend into the water are included in this category.
Island	A piece of land completely surrounded by water except for a barrier island. Shores along Primary Water Bodies are not included in the "Island" category.
Secondary Bay	Shoreline located along a smaller bay that is further sheltered from the wave action of a major bay or Ocean.
Secondary River	A river that is smaller in relative size than the major rivers identified as Primary River, or where the width of a major river falls below one kilometer.
Tributary ³	Small tributaries, creeks, and inlets flowing into a Primary Water Body. The water body name reflected in the GIS data is either the actual name of the tributary or the name of the water body into which the tributary flows.

Notes:

1. With the exception of shoreline identified as "Dredge and Fill", all Water Body Categories are mutually exclusive. Dredge and Fill areas are identified separately and are associated with shoreline that would otherwise be identified as Tributary.
2. For the purpose of this study, "Primary Water Body" distinguishes larger water bodies where the more immediate effects of sea level rise are likely to occur. These areas are less protected by land barriers and offer a more favorable environment for the promotion of wave action caused by wind.
3. When categorizing the shoreline, we identify "Unclassified Tributaries" where the water body name reflects the name of the water body into which the tributary flows. For the results presented in this appendix, we combine the "Unclassified Tributaries" within the "Tributary" category and aggregate the shoreline lengths.

County	Shoreline Length (Kilometers)					Totals
	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Accomack	213	269	512	332	96	1422
Alexandria	11	1	3	0	0.3	15
Arlington	18	1	2	0	0	22
Caroline	2	12	82	0	1	97
Chesapeake	304	97	33	15	58	507
Essex	33	44	272	0	7	355
Fairfax	71	30	92	7	14	213
Gloucester	123	290	193	9	51	667
Hampton	164	87	0.1	0	2	253
Isle of Wight	219	99	58	22	3	401
James City	231	39	241	1	9	521
King and Queen	5	29	200	0	7	240
King George	90	97	98	16	4	304
King William	17	24	186	0	7	233
Lancaster	358	110	41	22	4	536
Mathews	157	182	138	3	25	505
Middlesex	104	158	156	0	5	423
Newport News	112	132	0.3	0	1	246
Norfolk	282	0.2	0	0	0.3	283
Northampton	53	271	257	268	48	896
Northumberland	514	231	95	0	9	849
Poquoson	94	0	5	0	<0.1	98
Portsmouth	134	9	<0.1	2	0.3	146
Prince William	39	14	12	16	3	84
Richmond	61	47	269	22	11	410
Spotsylvania	2	0.4	5	0	0	7
Stafford	33	56	31	1	2	123
Suffolk	234	169	1	0	2	407
Surry	28	19	167	36	4	255
Virginia Beach	533	53	105	172	88	951
Westmoreland	169	103	286	16	7	579
Williamsburg	7	0	0	0	0.3	8
York	206	118	9	17	7	357
Totals	4621	2792	3548	977	474	12412

* Excludes the Richmond Regional and Crater Planning Districts, three jurisdictions from the Hampton Roads Planning District (Southampton County and the cities of Franklin and Williamsburg), Fredericksburg County, and the City of Falls Church.

Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Barrier/Bayside	Assateague Bay	4	0	0.1	14	<0.1	18
Barrier/Bayside	Assateague Channel	9	0.6	0.3	8	0.2	17
Barrier/Oceanside	Atlantic Ocean	7	10	1	130	0.2	148
Ocean Front	Atlantic Ocean	10	8	3	0	0	21
Barrier Bay/Mainland	Back Bay	0.6	0	15	19	0	34
Barrier/Bayside	Back Bay	5	2	0	8	12	27
Barrier Bay/Mainland	Bradford Bay	3	0.5	4	0	0	8
Barrier/Bayside	Cedar Bay	0	0	0.3	13	0	13
Barrier/Bayside	Chesapeake Bay	0	0	0	3	0	3
Primary Bay	Chesapeake Bay	99	57	65	4	44	269
Barrier Bay/Mainland	Chincoteague Bay	12	2	10	0	0	25
Barrier/Bayside	Chincoteague Bay	13	13	2	0	0.5	29
Barrier/Bayside	Cobb Island Sound	0	0	0	7	0	7
Barrier Bay/Mainland	Floyds Bay	<0.1	<0.1	3	4	0.2	7
Barrier Bay/Mainland	Gargathy Bay	0	0	4	0	0.2	5
Barrier/Bayside	Gargathy Bay	0	0	0	8	0	8
Barrier Bay/Mainland	Hog Island Bay	1	1	10	0	3	15
Barrier/Bayside	Hog Island Bay	0	0	0	50	0	50
Primary River	James River	123	44	37	11	0.1	215
Barrier Bay/Mainland	Kegotank Bay	2	0	9	0	0	11
Barrier/Bayside	Kegotank Bay	0	4	0.5	7	0	11
Barrier Bay/Mainland	Magothy Bay	2	2	0.8	3	10	18
Barrier Bay/Mainland	Metompkin Bay	0	0	5	0	0.6	6
Barrier Bay/Mainland	Mockhorn Bay	0	<0.1	5	0	4	9
Barrier Bay/Mainland	Outlet Bay	0.1	6	7	0	11	24
Barrier/Bayside	Outlet Bay	0	0	0	13	0	13
Primary River	Potomac River	113	48	72	12	6	251
Primary River	Rappahannock River	73	41	71	5	0.6	190
Barrier/Bayside	Smith Island Bay	0	0	0	20	0	20
Barrier/Bayside	South Bay	0	0	0	12	0	12
Barrier/Bayside	Swash Bay	0	0	0.3	27	0	28
Barrier/Bayside	Toms Cove	0	0	1	10	0	11
Barrier Bay/Mainland	Upshur Bay	5	0.2	5	0	0	11
Primary River	York River	30	27	24	13	4	98
Totals		512	266	359	399	96	1632

Table A-4: Shoreline lengths for all water bodies*

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Accomack	Barrier/Bayside	Assateague Bay	4	0	0.1	14	<0.1	18
Accomack	Tributary	Assateague Bay	17	0	6	59	<0.1	81
Accomack	Barrier/Bayside	Assateague Channel	9	0.6	0.3	8	0.2	17
Accomack	Tributary	Assateague Channel	4	0.1	1	32	0.4	38
Accomack	Barrier/Oceanside	Atlantic Ocean	0	9	1	55	0.2	65
Accomack	Island	Atlantic Ocean	0	0	<0.1	0.4	0	0.5
Accomack	Tributary	Atlantic Ocean	<0.1	0	0.7	32	1	34
Accomack	Barrier Bay/Mainland	Bradford Bay	3	0.5	4	0	0	8
Accomack	Island	Bradford Bay	0	0	1	0	0	1
Accomack	Tributary	Bradford Bay	1	11	12	0	0.5	24
Accomack	Barrier/Bayside	Cedar Bay	0	0	0.3	13	0	13
Accomack	Island	Cedar Bay	0	0	0	2	0	2
Accomack	Island	Chesapeake Bay	20	2	35	0	5	62
Accomack	Other	Chesapeake Bay	7	6	5	0	0.4	19
Accomack	Primary Bay	Chesapeake Bay	9	13	34	0	35	91
Accomack	Tributary	Chesapeake Bay	72	156	149	0	28	405
Accomack	Barrier Bay/Mainland	Chincoteague Bay	12	2	10	0	0	25
Accomack	Barrier/Bayside	Chincoteague Bay	13	13	2	0	0.5	29
Accomack	Island	Chincoteague Bay	0.2	5	5	0	1	11
Accomack	Other	Chincoteague Bay	12	0	10	0	0	22
Accomack	Tributary	Chincoteague Bay	16	9	31	0	0.9	56
Accomack	Barrier Bay/Mainland	Floyds Bay	<0.1	<0.1	3	4	0.2	7
Accomack	Island	Floyds Bay	0	0	0.4	0	0	0.4
Accomack	Tributary	Floyds Bay	0.5	23	26	4	0.8	54
Accomack	Barrier Bay/Mainland	Gargathy Bay	0	0	4	0	0.2	5
Accomack	Barrier/Bayside	Gargathy Bay	0	0	0	8	0	8
Accomack	Tributary	Gargathy Bay	<0.1	0	39	0	0.2	39
Accomack	Barrier Bay/Mainland	Hog Island Bay	<0.1	0	5	0	0.6	6
Accomack	Barrier Bay/Mainland	Kegotank Bay	2	0	9	0	0	11
Accomack	Barrier/Bayside	Kegotank Bay	0	4	0.5	7	0	11
Accomack	Island	Kegotank Bay	0.2	3	2	0	0	5
Accomack	Tributary	Kegotank Bay	2	0	25	0	<0.1	27
Accomack	Island	Machipongo River	1	0.2	21	0	3	25
Accomack	Other	Machipongo River	0	0	0.6	0	0	0.6
Accomack	Secondary River	Machipongo River	2	5	22	0	16	45
Accomack	Tributary	Machipongo River	0	2	7	0	1	10
Accomack	Barrier Bay/Mainland	Metompkin Bay	0	0	5	0	0.6	6
Accomack	Island	Metompkin Bay	0	0	0.2	3	0	3
Accomack	Tributary	Metompkin Bay	0.1	4	24	0.3	0.2	29
Accomack	Barrier/Bayside	Swash Bay	0	0	0.3	27	0	28

Table A-4: Shoreline lengths for all water bodies*

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Accomack	Island	Swash Bay	0	0	2	42	0	43
Accomack	Barrier/Bayside	Toms Cove	0	0	1	10	0	11
Accomack	Tributary	Toms Cove	0	0	0.7	14	<0.1	15
Accomack	Barrier Bay/Mainland	Upshur Bay	5	0.2	5	0	0	11
Accomack	Tributary	Upshur Bay	0.4	0	0	0	0	0.4
Alexandria	Primary River	Potomac River	6	0	1	0	0	8
Alexandria	Tributary	Potomac River	4	1	2	0	0.3	8
Arlington	Primary River	Potomac River	15	1	2	0	0	18
Arlington	Tributary	Potomac River	4	0	0.1	0	0	4
Caroline	Secondary River	Rappahannock River	2	12	82	0	1	97
Chesapeake	Other	Albemarle and Chesapeake Canal	7	0.9	0	0	5	13
Chesapeake	Tributary	Albemarle and Chesapeake Canal	<0.1	0	0	0	2	2
Chesapeake	Island	James River	2	0	0	0.3	0	3
Chesapeake	Tributary	James River	249	67	1	12	8	338
Chesapeake	Island	North Landing River	0	0	0.4	0	1	2
Chesapeake	Other	North Landing River	7	1	1	0	0	9
Chesapeake	Secondary River	North Landing River	3	8	14	1	11	38
Chesapeake	Other	Northwest River	8	3	0.4	0	9	20
Chesapeake	Secondary River	Northwest River	28	17	16	2	21	83
Essex	Island	Rappahannock River	1	1	12	0	0	15
Essex	Primary River	Rappahannock River	17	12	20	0	0	49
Essex	Secondary River	Rappahannock River	5	0	47	0	0.6	53
Essex	Tributary	Rappahannock River	10	31	191	0	6	238
Fairfax	Secondary Bay	Occoquan Bay	2	0	5	0	0	7
Fairfax	Island	Potomac River	0	0.4	0.8	0	0	1
Fairfax	Primary River	Potomac River	20	2	28	1	5	58
Fairfax	Tributary	Potomac River	48	27	58	6	8	147
Gloucester	Secondary Bay	Mobjack Bay	22	165	132	0	33	353
Gloucester	Secondary River	Piankatank River	7	15	3	0	0.4	25
Gloucester	Island	York River	0.9	1	5	0	4	11
Gloucester	Other	York River	0	1	0	0	0.6	2
Gloucester	Primary River	York River	21	10	8	3	3	45
Gloucester	Secondary River	York River	3	13	18	0	2	36
Gloucester	Tributary	York River	68	85	28	6	7	194
Hampton	Secondary River	Back River	81	69	0	0	2	152
Hampton	Island	Chesapeake Bay	2	1	0	0	0	3
Hampton	Other	Chesapeake Bay	0	0.5	0	0	0	0.5
Hampton	Primary Bay	Chesapeake Bay	11	4	0.1	0	0	15
Hampton	Tributary	Chesapeake Bay	23	9	0	0	0	32
Hampton	Primary River	James River	7	0.2	0	0	0	7

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Hampton	Tributary	James River	39	3	0	0	0	43
Isle of Wight	Island	James River	0	0	0	15	0	15
Isle of Wight	Primary River	James River	13	18	6	4	<0.1	40
Isle of Wight	Tributary	James River	206	81	52	3	3	345
James City	Island	Chicahominy River	<0.1	0	36	0	0.1	36
James City	Secondary River	Chicahominy River	22	0	148	0	2	172
James City	Island	James River	9	25	0	0.3	0	35
James City	Primary River	James River	24	4	2	1	<0.1	31
James City	Tributary	James River	156	4	7	0	2	168
James City	Primary River	York River	2	0.8	8	0	0	11
James City	Tributary	York River	18	5	41	0	5	68
King and Queen	Island	York River	0	0.6	4	0	0	5
King and Queen	Primary River	York River	<0.1	3	8	0	0.3	12
King and Queen	Secondary River	York River	5	8	135	0	4	152
King and Queen	Tributary	York River	0.1	17	52	0	3	72
King George	Primary River	Potomac River	16	17	2	5	<0.1	40
King George	Tributary	Potomac River	72	60	32	3	3	170
King George	Secondary River	Rappahannock River	1	20	64	7	1	93
King William	Secondary River	Pamunkey River	11	6	98	0	2	118
King William	Secondary River	York River	5	18	88	0	4	115
Lancaster	Island	Chesapeake Bay	20	1	1	0	0.7	23
Lancaster	Other	Chesapeake Bay	3	0.5	<0.1	0	0	4
Lancaster	Primary Bay	Chesapeake Bay	8	0.6	4	0	<0.1	13
Lancaster	Tributary	Chesapeake Bay	90	8	2	0	<0.1	100
Lancaster	Island	Rappahannock River	11	0	0	0.3	0	11
Lancaster	Primary River	Rappahannock River	38	7	5	3	<0.1	52
Lancaster	Tributary	Rappahannock River	188	94	29	19	3	333
Mathews	Island	Chesapeake Bay	2	3	7	0	3	15
Mathews	Other	Chesapeake Bay	16	14	8	0	0	38
Mathews	Primary Bay	Chesapeake Bay	3	6	11	0	7	26
Mathews	Tributary	Chesapeake Bay	30	43	46	0	7	127
Mathews	Secondary Bay	Mobjack Bay	88	96	35	3	8	231
Mathews	Secondary River	Piankatank River	18	21	30	0	<0.1	69
Middlesex	Primary Bay	Chesapeake Bay	0	0	<0.1	0	0	<0.1
Middlesex	Secondary River	Piankatank River	34	36	11	0	0.4	82
Middlesex	Island	Rappahannock River	0.3	0	2	0	0	2
Middlesex	Primary River	Rappahannock River	8	15	21	0	0.3	45
Middlesex	Tributary	Rappahannock River	53	101	98	0	2	254
Middlesex	Secondary River	York River	8	6	24	0	2	40
Newport News	Island	James River	2	30	0	0	0.3	32
Newport News	Other	James River	6	2	0	0	0	8
Newport News	Primary River	James River	27	12	<0.1	0	<0.1	39
Newport News	Tributary	James River	77	88	0.3	0	1	166

Table A-4: Shoreline lengths for all water bodies*

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Norfolk	Primary Bay	Chesapeake Bay	12	0	0	0	0	12
Norfolk	Tributary	Chesapeake Bay	27	0	0	0	0	27
Norfolk	Other	James River	19	0	0	0	0	19
Norfolk	Primary River	James River	16	0	0	0	0	16
Norfolk	Tributary	James River	208	0.2	0	0	0.3	209
Northampton	Barrier/Oceanside	Atlantic Ocean	0	0	0	59	0	59
Northampton	Island	Atlantic Ocean	0	0	0	6	0	6
Northampton	Tributary	Atlantic Ocean	0	0	0	2	0	2
Northampton	Barrier/Bayside	Chesapeake Bay	0	0	0	3	0	3
Northampton	Island	Chesapeake Bay	2	0	0	0	0	2
Northampton	Primary Bay	Chesapeake Bay	10	16	16	4	0.4	47
Northampton	Tributary	Chesapeake Bay	34	225	146	6	2	414
Northampton	Barrier/Bayside	Cobb Island Sound	0	0	0	7	0	7
Northampton	Island	Cobb Island Sound	0	0	0	0.1	0	0.1
Northampton	Barrier Bay/Mainland	Hog Island Bay	0.9	1	5	0	2	9
Northampton	Barrier/Bayside	Hog Island Bay	0	0	0	50	0	50
Northampton	Island	Hog Island Bay	0.1	2	26	37	3	69
Northampton	Tributary	Hog Island Bay	1	1	5	0	4	11
Northampton	Island	Machipongo River	0	0	12	0	0.1	12
Northampton	Secondary River	Machipongo River	1	3	3	0	1	8
Northampton	Tributary	Machipongo River	2	5	4	0	4	15
Northampton	Barrier Bay/Mainland	Magothy Bay	2	2	0.8	3	10	18
Northampton	Island	Magothy Bay	<0.1	0	5	13	0.5	19
Northampton	Other	Magothy Bay	0	0	0.6	0	0	0.6
Northampton	Tributary	Magothy Bay	0.3	2	0.4	0	0.5	3
Northampton	Barrier Bay/Mainland	Mockhorn Bay	0	<0.1	5	0	4	9
Northampton	Island	Mockhorn Bay	0	0	0.2	0	0	0.2
Northampton	Tributary	Mockhorn Bay	<0.1	1	4	0	0.6	6
Northampton	Barrier Bay/Mainland	Outlet Bay	0.1	6	7	0	11	24
Northampton	Barrier/Bayside	Outlet Bay	0	0	0	13	0	13
Northampton	Island	Outlet Bay	0	0	6	0.8	1	8
Northampton	Other	Outlet Bay	0	0.9	0	0	0	0.9
Northampton	Tributary	Outlet Bay	0.4	5	9	22	3	40
Northampton	Barrier/Bayside	Smith Island Bay	0	0	0	20	0	20
Northampton	Island	Smith Island Bay	0	0	0	11	0	11
Northampton	Barrier/Bayside	South Bay	0	0	0	12	0	12
Northumberland	Island	Chesapeake Bay	0.1	1	0.2	0	0	2
Northumberland	Primary Bay	Chesapeake Bay	16	14	0.3	0	0	30
Northumberland	Tributary	Chesapeake Bay	267	88	53	0	7	416
Northumberland	Island	Potomac River	2	0	0	0	0	2

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Northumberland	Primary River	Potomac River	20	7	3	0	<0.1	30
Northumberland	Tributary	Potomac River	208	120	39	0	2	369
Poquoson	Secondary River	Back River	31	0	0.2	0	<0.1	31
Poquoson	Island	Chesapeake Bay	0.4	0	3	0	0	3
Poquoson	Other	Chesapeake Bay	0	0	2	0	0	2
Poquoson	Primary Bay	Chesapeake Bay	9	0	0	0	0	9
Poquoson	Tributary	Chesapeake Bay	53	0	0	0	0	53
Portsmouth	Primary River	James River	13	<0.1	0	0	0	13
Portsmouth	Tributary	James River	122	9	<0.1	2	0.3	133
Prince William	Secondary Bay	Occoquan Bay	4	0	0.6	8	0.1	12
Prince William	Other	Potomac River	1	0.1	0	0	0	1
Prince William	Primary River	Potomac River	3	5	5	0	0	12
Prince William	Tributary	Potomac River	31	10	7	8	3	58
Richmond	Island	Rappahannock River	1	0	12	6	0.2	19
Richmond	Primary River	Rappahannock River	10	7	24	2	0.3	44
Richmond	Tributary	Rappahannock River	49	40	234	14	10	347
Spotsylvania	Secondary River	Rappahannock River	2	0.4	5	0	0	7
Stafford	Island	Potomac River	0	0.8	0	0	0	0.8
Stafford	Primary River	Potomac River	2	7	8	1	0	18
Stafford	Tributary	Potomac River	31	48	6	0.4	2	87
Stafford	Secondary River	Rappahannock River	0	0	16	0	0.5	17
Suffolk	Primary River	James River	19	1	0	0	0	21
Suffolk	Tributary	James River	215	168	1	0	2	386
Surry	Island	James River	0	0	0	0.2	0	0.2
Surry	Other	James River	0	0	2	0	0	2
Surry	Primary River	James River	4	8	28	7	0	47
Surry	Tributary	James River	24	11	137	30	4	206
Virginia Beach	Barrier/Oceanside	Atlantic Ocean	7	0.5	0.3	16	0	24
Virginia Beach	Ocean Front	Atlantic Ocean	10	8	3	0	0	21
Virginia Beach	Barrier Bay/Mainland	Back Bay	0.6	0	15	19	0	34
Virginia Beach	Barrier/Bayside	Back Bay	5	2	0	8	12	27
Virginia Beach	Dredge and Fill	Back Bay	10	0	0	0.3	0	10
Virginia Beach	Island	Back Bay	0	0.3	<0.1	14	0	15
Virginia Beach	Tributary	Back Bay	20	4	17	23	27	91
Virginia Beach	Primary Bay	Chesapeake Bay	15	2	<0.1	0	0	17
Virginia Beach	Tributary	Chesapeake Bay	413	26	0	0.1	10	449
Virginia Beach	Tributary	James River	40	3	<0.1	0	<0.1	42
Virginia Beach	Island	North Landing River	0	0	4	12	3	20
Virginia Beach	Other	North Landing River	3	0	3	3	0	8
Virginia Beach	Secondary River	North Landing River	10	7	63	76	36	192
Westmoreland	Primary River	Potomac River	31	9	23	5	0.5	67
Westmoreland	Tributary	Potomac River	136	94	220	11	6	466
Westmoreland	Primary River	Rappahannock River	<0.1	0	0.4	0	0	0.5

Table A-4: Shoreline lengths for all water bodies*

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Westmoreland	Secondary River	Rappahannock River	2	0	41	0	0.6	44
Westmoreland	Tributary	Rappahannock River	0	0	0.9	0	0	0.9
Williamsbrug	Tributary	James River	3	0	0	0	0.2	4
Williamsbrug	Tributary	York River	4	0	0	0	0.1	4
York	Secondary River	Back River	12	0	<0.1	0	0.6	13
York	Island	Chesapeake Bay	0.2	2	0	0	0	2
York	Primary Bay	Chesapeake Bay	6	2	0	0	2	10
York	Tributary	Chesapeake Bay	142	3	0	0	1	146
York	Island	York River	0	0.2	0	0	0	0.2
York	Primary River	York River	6	13	0.4	10	0.5	30
York	Tributary	York River	38	99	9	7	3	156
Totals			4621	2792	3548	977	474	12412

* Excludes the Richmond Regional and Crater Planning Districts, three jurisdictions from the Hampton Roads Planning District (Southampton County and the cities of Franklin and Williamsburg), Fredericksburg County, and the City of Falls Church.

Table A-5: Military lands

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)			Totals
			Shore Protection Certain	Shore Protection Unspecified ¹	Non-Tidal Wetlands	
Hampton	Primary Bay	Chesapeake Bay	7	0	0	7
Hampton	Secondary River	Back River	3	16	<0.1	20
Hampton	Tributary	Chesapeake Bay	5	0	0	5
James City	Primary River	York River	0	0.8	0	0.8
James City	Tributary	York River	0	5	0	5
Newport News	Island	James River	0.3	30	0.3	31
Newport News	Other	James River	0.4	0.8	0	1
Newport News	Primary River	James River	1	8	<0.1	10
Newport News	Tributary	James River	1	71	0.7	73
Norfolk	Other	James River	16	0	0	16
Norfolk	Primary River	James River	9	0	0	9
Norfolk	Tributary	James River	13	0	0	13
Portsmouth	Primary River	James River	5	0	0	5
Portsmouth	Tributary	James River	7	4	0	11
Virginia Beach	Ocean Front	Atlantic Ocean	6	0	0	6
Virginia Beach	Primary Bay	Chesapeake Bay	7	0	0	7
Virginia Beach	Tributary	Chesapeake Bay	11	0	0.1	11
York	Island	York River	0	0.2	0	0.2
York	Primary River	York River	1	13	0	14
York	Tributary	York River	4	91	0.8	97
Totals			98	241	2	341

Note:
 1. The general approach of this study was to not speculate on the intentions of the military, but to avoid an excessive number of map colors. The protection response maps depict unclassified military lands in red, however, the protection response for the shoreline was classified as "Unspecified". Military lands in urban areas were classified as shore protection certain in those cases where county officials indicated that the land would be developed and protected even if the installation were to close.

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Accomack	Barrier/Bayside	Assateague Bay	4	0	0.1	9	<0.1	12
Accomack	Barrier/Bayside	Assateague Channel	9	0.6	0.3	7	0.2	17
Accomack	Barrier/Bayside	Chincoteague Bay	13	13	2	0	0.5	29
Accomack	Barrier/Bayside	Kegotank Bay	0	4	0.5	1	0	6
Accomack	Barrier/Bayside	Toms Cove	0	0	1	5	0	7
Accomack	Barrier/Oceanside	Atlantic Ocean	0	9	0.6	17	0.2	27
Accomack	Island	Chesapeake Bay	13	0.5	14	0	0	28
Accomack	Island	Chincoteague Bay	0	0	0.2	0	0	0.2
Accomack	Island	Kegotank Bay	0	0	0.6	0	0	0.6
Accomack	Island	Machipongo River	1	0	15	0	3	19
Accomack	Other	Chincoteague Bay	0	0	9	0	0	9
Accomack	Tributary	Assateague Bay	16	0	5	37	<0.1	59
Accomack	Tributary	Assateague Channel	4	0.1	1	16	0.4	22
Accomack	Tributary	Atlantic Ocean	<0.1	0	0.7	32	1	33
Accomack	Tributary	Chincoteague Bay	2	0	0	0	0	2
Accomack	Tributary	Toms Cove	0	0	0.1	2	0	2
Caroline	Secondary River	Rappahannock River	0	0	1	0	0	1
Chesapeake	Tributary	James River	2	1	0	0	0	3
Essex	Island	Rappahannock River	1	1	11	0	0	13
Essex	Primary River	Rappahannock River	<0.1	0.5	<0.1	0	0	0.5
Gloucester	Island	York River	0.8	1	2	0	4	8
Gloucester	Primary River	York River	0	0	1	0	1	3
Gloucester	Secondary Bay	Mobjack Bay	0.9	2	3	0	0	5
Hampton	Island	Chesapeake Bay	1	1	0	0	0	2
Hampton	Other	Chesapeake Bay	0	0.2	0	0	0	0.2
Hampton	Primary Bay	Chesapeake Bay	1	<0.1	0	0	0	1
Hampton	Secondary River	Back River	6	4	0	0	0	10
Hampton	Tributary	Chesapeake Bay	4	0.4	0	0	0	5
Isle of Wight	Island	James River	0	0	0	6	0	6
Isle of Wight	Primary River	James River	0	0	0	2	0	2
Isle of Wight	Tributary	James River	0	0	0	0.4	0	0.4
James City	Island	Chicahominy River	<0.1	0	13	0	0.1	13
James City	Island	James River	5	17	0	0	0	22
James City	Primary River	James River	3	4	0	0.6	0	8
James City	Tributary	James River	4	3	0	0	0	6
King and Queen	Island	York River	0	0	3	0	0	3
King and Queen	Primary River	York River	<0.1	0	2	0	<0.1	2
King William	Secondary River	Pamunkey River	0	0	0.8	0	0	0.8
Lancaster	Island	Chesapeake Bay	18	1	0	0	0.7	20
Lancaster	Primary Bay	Chesapeake Bay	2	0.3	0.2	0	<0.1	3
Lancaster	Primary River	Rappahannock River	2	0	0	0	0	2
Mathews	Island	Chesapeake Bay	2	2	4	0	3	10
Mathews	Other	Chesapeake Bay	14	0	5	0	0	19
Mathews	Primary Bay	Chesapeake Bay	2	2	3	0	2	9

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					Totals
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	
Mathews	Secondary Bay	Mobjack Bay	1	0	0	0.3	0	1
Mathews	Secondary River	Piankatank River	8	0	0	0	0	8
Mathews	Tributary	Chesapeake Bay	0.3	0.1	0	0	0	0.4
Middlesex	Primary River	Rappahannock River	0	0	0.2	0	0	0.2
Northampton	Barrier/Bayside	Chesapeake Bay	0	0	0	3	0	3
Northampton	Barrier/Oceanside	Atlantic Ocean	0	0	0	3	0	3
Northampton	Island	Atlantic Ocean	0	0	0	0.6	0	0.6
Northampton	Island	Hog Island Bay	<0.1	2	18	0.9	3	24
Northampton	Island	Machipongo River	0	0	2	0	0.1	2
Northampton	Island	Magothy Bay	0	0	2	0	0	2
Northampton	Tributary	Atlantic Ocean	0	0	0	2	0	2
Northampton	Tributary	Chesapeake Bay	0	0	0	6	0	6
Richmond	Island	Rappahannock River	0	0	1	0	0	1
Stafford	Tributary	Potomac River	0	0.1	0	0.4	0	0.5
Suffolk	Tributary	James River	0.8	0	0	0	0	0.8
Virginia Beach	Barrier/Bayside	Back Bay	0	0.3	0	0	0	0.3
Virginia Beach	Island	Back Bay	0	0.3	<0.1	2	0	3
Virginia Beach	Island	North Landing River	0	0	2	0.3	0	2
Virginia Beach	Other	North Landing River	0.1	0	0	0.2	0	0.3
Virginia Beach	Secondary River	North Landing River	0.2	0	0.7	0.6	0.6	2
Virginia Beach	Tributary	Chesapeake Bay	18	0	0	0	0	18
Westmoreland	Secondary River	Rappahannock River	0	0	0.4	0	0	0.4
York	Island	Chesapeake Bay	0	2	0	0	0	2
Totals			160	72	127	155	19	533

Appendix B

AREA OF LAND BY SHORE PROTECTION LIKELIHOOD (Planning Districts and Counties in Same Order as Discussed in the Text)

Authors: James G. Titus, Russ Jones, and Richard Streeter

The following tables were created by overlaying the shore protection planning maps developed in this report, with EPA’s 30-meter digital elevation data set.

The EPA data set used the National Wetlands Inventory (NWI) to distinguish dry land, nontidal wetlands, tidal wetlands, and open water. The boundaries of that wetlands data set do not perfectly match the boundaries of the land use data used in this report. Some areas that the wetlands data treated as dry land, for example, are wetlands or open water according to the land use data sets. This table treats such lands as “not considered” because our planning study did not estimate shore protection likelihood there. Most of these lands are along the shore and are as likely as not to be wetlands or open water today, even if they were still dry land when the wetlands data were created. The “not considered” category also includes Charles City, Chesterfield, Colonial Heights, Franklin, Hanover, Henrico, Hopewell, New Kent, Petersburg, Prince George, Southampton, and Williamsburg Counties which this study did not examine. See Appendix 2 of this report for additional details on how these tables were created.

Table B-1. Area of Land by Shore Protection Likelihood

Virginia (jurisdictions within the study area only)

Elevation above Spring High Water (m)		Area (square kilometers)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	59.0	35.4	51.6	14.9	11.2	172.1	73.1	245.2
0.5	1.0	67.4	37.9	52.9	7.9	10.8	176.8	75.0	251.8
1.0	1.5	94.5	50.9	63.5	3.1	11.0	223.0	70.4	293.3
1.5	2.0	97.6	52.7	72.6	3.0	11.0	236.9	68.6	305.5
2.0	2.5	109.3	54.6	74.2	2.7	12.6	253.4	72.6	326.0
2.5	3.0	157.7	70.4	84.2	2.3	17.4	332.0	74.3	406.4
3.0	3.5	165.1	78.0	83.3	2.3	17.4	346.2	73.7	419.9
3.5	4.0	157.8	77.6	82.7	2.3	17.4	337.9	74.1	412.0
4.0	4.5	116.6	66.5	69.6	2.1	20.1	274.9	66.5	341.4
4.5	5.0	112.9	60.2	57.3	2.1	20.4	252.9	64.1	317.0
5.0	5.5	110.7	60.5	58.1	2.5	21.8	253.5	80.6	334.1
5.5	6.0	81.5	54.0	62.6	2.7	29.6	230.3	84.3	314.7

Note: While this report was in peer review we noticed that two barrier islands in Accomack County had been mistakenly coded as “shore protection unlikely” instead of “no shore protection”. Those islands have approximately 1.1 square kilometer within 50 cm above spring high water. Had those islands been coded correctly when this table was produced, the 50 cm estimates for no shore protection would have been 16.0 and shore protection unlikely would have been 50.3. This error has been corrected in the tables estimating shoreline length: because the mistakenly codes islands were the only cases of “shore protection unlikely” along the Atlantic Ocean on the Eastern Shore, a failure to correct the statistics would have been seriously misleading. Given the substantial uncertainty in our elevation estimates, however, the late date at which we noticed the error, and the risk that we would fail to change all of the summary tables, we decide that an error of 1.1 square kilometers is not large enough to change all the tables.

Eastern Shore: Accomack

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	606	612	1075	569	91	2954	1500	4454
0.5	1.0	623	643	1251	334	62	2912	1699	4611
1.0	1.5	560	928	1636	126	23	3274	2202	5476
1.5	2.0	565	942	1640	120	23	3290	2219	5510
2.0	2.5	538	918	1550	99	21	3126	1995	5121
2.5	3.0	282	537	1218	32	6	2075	1057	3132
3.0	3.5	258	493	1210	30	5	1996	1010	3005
3.5	4.0	241	486	1149	26	5	1908	971	2879
4.0	4.5	176	386	959	7	5	1534	686	2219
4.5	5.0	162	371	959	4	5	1501	660	2161
5.0	5.5	172	405	1000	4	5	1587	649	2236
5.5	6.0	286	813	1499	1	7	2605	547	3153

Note: While this report was in peer review we noticed that two barrier islands had been mistakenly coded as “shore protection unlikely” instead of “no shore protection”. Those islands have approximately 113 hectares within 50 cm above spring high water, and 1 hectare between 50 and 100 cm. Had those islands been coded correctly when this table was produced, the estimates for no shore protection would have been correspondingly higher, and the estimate for shore protection unlikely would have been correspondingly lower.

Eastern Shore: Northampton

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	76	310	416	756	37	1594	84	1679
0.5	1.0	82	331	329	296	31	1069	123	1192
1.0	1.5	156	463	345	32	22	1018	225	1243
1.5	2.0	156	461	348	32	22	1019	229	1248
2.0	2.5	157	585	343	25	20	1130	189	1318
2.5	3.0	185	1057	373	12	10	1637	161	1798
3.0	3.5	184	1067	373	12	10	1646	164	1810
3.5	4.0	184	1084	362	16	10	1655	156	1812
4.0	4.5	55	1315	419	22	4	1814	109	1923
4.5	5.0	49	1347	429	22	3	1850	100	1950
5.0	5.5	47	1359	442	19	3	1870	100	1970
5.5	6.0	48	1431	490	8	1	1977	137	2114

Hampton Roads: Virginia Beach

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	826	144	1420	2	9	2401	1049	3449
0.5	1.0	930	147	1429	1	8	2516	1002	3518
1.0	1.5	1715	186	1594	0	3	3499	703	4202
1.5	2.0	1909	219	2270	0	5	4402	748	5151
2.0	2.5	2041	213	2272	0	5	4531	733	5264
2.5	3.0	3570	315	1744	0	4	5633	460	6094
3.0	3.5	3918	412	1110	0	2	5442	339	5781
3.5	4.0	3839	412	1102	0	2	5355	335	5690
4.0	4.5	2637	249	685	0	0	3571	252	3823
4.5	5.0	2293	107	132	0	0	2532	179	2711
5.0	5.5	2276	106	132	0	0	2514	178	2692
5.5	6.0	1387	55	88	0	0	1530	79	1609

Hampton Roads: Chesapeake

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	565	181	96	0	2	844	1217	2060
0.5	1.0	746	223	99	0	2	1070	1265	2335
1.0	1.5	1166	480	371	0	2	2019	1005	3024
1.5	2.0	1249	615	592	0	2	2459	772	3230
2.0	2.5	1454	797	714	0	2	2966	1608	4574
2.5	3.0	2068	1952	1545	0	1	5566	3008	8574
3.0	3.5	2233	2495	2024	0	1	6753	3074	9826
3.5	4.0	2292	2506	2046	0	1	6845	3179	10024
4.0	4.5	2533	2003	1449	0	0	5986	3219	9205
4.5	5.0	2540	1504	762	0	0	4806	3097	7903
5.0	5.5	2262	1365	662	0	0	4290	3045	7335
5.5	6.0	1183	548	210	0	0	1942	2187	4128

Hampton Roads: Hampton

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	269	139	0	0	3	412	13	424
0.5	1.0	436	204	0	0	2	642	15	657
1.0	1.5	855	369	0	0	0	1224	20	1243
1.5	2.0	855	369	0	0	0	1224	20	1243
2.0	2.5	1010	304	0	0	0	1314	34	1348
2.5	3.0	1352	75	0	0	0	1428	65	1493
3.0	3.5	1352	75	0	0	0	1428	65	1493
3.5	4.0	1173	62	0	0	0	1236	77	1313
4.0	4.5	466	16	0	0	0	482	111	593

4.5	5.0	466	16	0	0	0	482	111	593
5.0	5.5	406	29	0	0	0	435	97	532
5.5	6.0	154	78	0	0	1	232	41	273

Hampton Roads: York

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	292.9	107.1	7.7	19.5	0.7	427.9	62.6	490.5
0.5	1.0	374.1	101.6	6.9	15.6	0.5	498.6	101.8	600.4
1.0	1.5	544.7	90.0	5.2	7.6	0.1	647.6	185.3	832.9
1.5	2.0	544.7	90.0	5.2	7.6	0.1	647.6	185.3	832.9
2.0	2.5	495.4	94.8	4.0	8.9	0.1	603.2	151.4	754.6
2.5	3.0	355.4	105.7	2.3	12.0	0.1	475.5	64.0	539.5
3.0	3.5	355.4	105.7	2.3	12.0	0.1	475.5	64.0	539.5
3.5	4.0	305.7	106.3	2.7	12.7	0.1	427.5	58.2	485.7
4.0	4.5	145.1	108.3	3.7	15.3	0.1	272.5	40.2	312.8
4.5	5.0	145.1	108.3	3.7	15.3	0.1	272.5	40.2	312.8
5.0	5.5	144.5	133.6	6.7	16.5	0.9	302.2	39.3	341.4
5.5	6.0	127.5	207.9	18.5	21.7	4.6	380.3	32.4	412.7

Hampton Roads: Newport News

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	205.2	274.8	1.9	0.0	5.8	487.7	22.9	510.6
0.5	1.0	151.0	270.0	1.2	0.0	4.0	426.3	25.9	452.2
1.0	1.5	51.9	262.7	0.0	0.0	0.7	315.3	31.6	346.9
1.5	2.0	51.9	262.7	0.0	0.0	0.7	315.3	31.6	346.9
2.0	2.5	116.6	205.3	0.0	0.0	0.8	322.7	23.0	345.7
2.5	3.0	264.8	79.5	0.0	0.0	0.9	345.2	3.8	349.0
3.0	3.5	264.8	79.5	0.0	0.0	0.9	345.2	3.8	349.0
3.5	4.0	299.7	76.6	0.0	0.0	0.8	377.2	4.9	382.0
4.0	4.5	398.7	68.4	0.1	0.0	0.7	467.9	8.0	475.8
4.5	5.0	398.7	68.4	0.1	0.0	0.7	467.9	8.0	475.8
5.0	5.5	561.2	93.8	0.1	0.0	2.9	657.9	13.1	671.0
5.5	6.0	1139.0	186.3	0.0	0.0	10.7	1336.0	32.0	1368.0

Hampton Roads: Norfolk

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	408	1	0	0	0	410	19	429
0.5	1.0	624	1	0	0	0	625	21	646
1.0	1.5	1129	1	0	0	1	1131	24	1155
1.5	2.0	1129	1	0	0	1	1131	24	1155
2.0	2.5	1444	1	0	0	0	1445	23	1468
2.5	3.0	2446	1	0	0	0	2447	20	2467
3.0	3.5	2446	1	0	0	0	2447	20	2467
3.5	4.0	2050	0	0	0	0	2051	16	2067
4.0	4.5	415	0	0	0	0	416	2	417

4.5	5.0	415	0	0	0	0	416	2	417
5.0	5.5	368	0	0	0	0	369	1	370
5.5	6.0	120	0	0	0	0	120	0	120

Hampton Roads: Poquoson

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	311.4	0.0	6.4	0.0	0.6	318.3	4.5	322.9
0.5	1.0	334.2	0.0	4.8	0.0	0.5	339.4	14.3	353.7
1.0	1.5	358.8	0.0	0.0	0.0	0.0	358.8	33.0	391.8
1.5	2.0	358.8	0.0	0.0	0.0	0.0	358.8	33.0	391.8
2.0	2.5	265.9	0.0	0.0	0.0	0.0	265.9	23.8	289.7
2.5	3.0	10.5	0.0	0.0	0.0	0.0	10.5	0.7	11.2
3.0	3.5	10.5	0.0	0.0	0.0	0.0	10.5	0.7	11.2
3.5	4.0	8.1	0.0	0.0	0.0	0.0	8.1	0.5	8.6
4.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.5	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.5	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Hampton Roads: James City

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	158.3	29.4	87.2	0.2	3.8	279.0	55.5	334.4
0.5	1.0	150.7	29.1	87.3	0.2	3.8	271.1	55.4	326.5
1.0	1.5	133.8	28.5	87.5	0.2	3.8	253.8	55.2	309.0
1.5	2.0	133.8	28.5	87.5	0.2	3.8	253.8	55.2	309.0
2.0	2.5	139.2	26.8	99.5	0.2	3.7	269.4	52.6	321.9
2.5	3.0	200.0	14.3	164.1	0.3	2.7	381.3	42.3	423.6
3.0	3.5	200.0	14.3	164.1	0.3	2.7	381.3	42.3	423.6
3.5	4.0	202.4	14.3	164.1	0.3	2.7	383.7	42.5	426.2
4.0	4.5	211.3	14.3	163.9	0.3	2.7	392.5	43.1	435.6
4.5	5.0	211.3	14.3	163.9	0.3	2.7	392.5	43.1	435.6
5.0	5.5	223.7	14.5	171.2	0.3	2.7	412.5	45.6	458.1
5.5	6.0	277.0	4.0	176.5	0.0	1.0	458.5	54.9	513.5

Hampton Roads: Suffolk

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	215.7	88.9	34.9	0.1	0.6	340.1	149.2	489.2
0.5	1.0	176.7	88.9	34.9	0.1	0.4	301.0	147.5	448.5
1.0	1.5	129.8	88.9	61.7	0.1	0.5	280.9	66.1	346.9
1.5	2.0	129.8	88.9	62.0	0.1	0.5	281.2	65.1	346.3
2.0	2.5	298.4	177.0	62.1	0.1	0.4	538.0	87.5	625.5

2.5	3.0	490.4	264.9	100.3	0.2	0.5	856.2	102.6	958.8
3.0	3.5	490.4	264.9	102.7	0.2	0.5	858.7	102.5	961.2
3.5	4.0	584.7	267.9	102.8	0.2	0.4	956.0	113.7	1069.7
4.0	4.5	746.3	272.8	150.9	0.2	0.5	1170.6	155.7	1326.3
4.5	5.0	746.4	272.8	156.8	0.2	0.5	1176.6	158.6	1335.2
5.0	5.5	811.0	328.2	161.4	34.5	0.7	1335.8	1860.4	3196.2
5.5	6.0	868.1	395.5	232.3	92.4	1.6	1589.8	3407.1	4996.9

Hampton Roads: Portsmouth

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	248.3	20.5	0.2	2.0	1.0	271.8	532.0	803.8
0.5	1.0	346.7	17.8	0.1	2.0	0.6	367.3	352.3	719.5
1.0	1.5	503.0	13.0	0.0	2.2	0.0	518.2	22.1	540.3
1.5	2.0	503.0	13.0	0.0	2.2	0.0	518.2	22.1	540.3
2.0	2.5	721.7	13.9	0.2	3.1	0.0	738.8	28.2	767.0
2.5	3.0	1133.9	15.5	0.4	5.0	0.0	1154.7	39.8	1194.5
3.0	3.5	1133.9	15.5	0.4	5.0	0.0	1154.7	39.8	1194.5
3.5	4.0	946.2	12.1	0.4	4.0	0.0	962.6	34.2	996.8
4.0	4.5	473.1	3.1	0.4	1.5	0.0	478.0	17.4	495.4
4.5	5.0	473.1	3.1	0.4	1.5	0.0	478.0	17.4	495.4
5.0	5.5	369.5	2.4	0.3	1.1	0.0	373.3	13.9	387.2
5.5	6.0	65.8	0.1	0.0	0.0	0.0	66.0	1.6	67.6

Hampton Roads: Surry

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	10.9	8.6	61.6	19.8	1.9	102.8	47.7	150.6
0.5	1.0	10.9	8.6	61.6	19.8	1.9	102.8	47.7	150.6
1.0	1.5	10.9	8.6	61.6	19.8	1.9	102.8	47.7	150.6
1.5	2.0	10.9	8.6	61.6	19.8	1.9	102.8	47.7	150.6
2.0	2.5	10.5	8.0	62.2	19.0	1.7	101.4	44.2	145.7
2.5	3.0	7.4	3.2	60.9	14.6	0.5	86.6	15.3	101.9
3.0	3.5	7.4	3.2	60.9	14.6	0.5	86.6	15.3	101.9
3.5	4.0	7.4	3.2	60.9	14.6	0.5	86.6	15.3	101.9
4.0	4.5	7.4	3.2	60.9	14.6	0.5	86.6	15.3	101.9
4.5	5.0	7.4	3.2	60.9	14.6	0.5	86.6	15.3	101.9
5.0	5.5	7.4	3.4	63.9	14.5	0.5	89.8	15.6	105.4
5.5	6.0	15.3	13.8	129.8	11.6	0.7	171.1	24.8	195.9

Hampton Roads: Isle of Wight

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	132.0	50.4	53.9	18.0	1.1	255.4	91.4	346.8
0.5	1.0	130.0	46.6	47.6	17.0	1.2	242.3	91.1	333.4
1.0	1.5	129.0	42.2	49.2	15.3	0.9	236.6	68.2	304.8
1.5	2.0	129.0	42.2	49.3	15.3	0.9	236.8	67.9	304.7

0.0	0.5	23.1	47.2	202.6	0.0	3.8	276.7	56.7	333.3
0.5	1.0	23.1	47.2	202.6	0.0	3.8	276.7	56.7	333.3
1.0	1.5	23.1	47.2	202.6	0.0	3.8	276.7	56.7	333.3
1.5	2.0	23.1	47.2	202.6	0.0	3.8	276.7	56.7	333.3
2.0	2.5	23.7	47.7	218.2	0.0	3.8	293.3	56.7	350.0
2.5	3.0	55.7	62.5	466.8	0.0	1.6	586.5	44.9	631.4
3.0	3.5	55.7	62.5	466.8	0.0	1.6	586.5	44.8	631.3
3.5	4.0	55.7	62.5	466.8	0.0	1.6	586.5	44.8	631.3
4.0	4.5	55.7	62.5	466.8	0.0	1.6	586.5	44.8	631.3
4.5	5.0	55.7	62.5	466.8	0.0	1.6	586.5	44.8	631.3
5.0	5.5	55.7	62.5	465.9	0.0	1.5	585.6	44.9	630.4
5.5	6.0	43.6	49.8	636.9	0.0	3.0	733.3	66.1	799.4

Middle Peninsula: King and Queen

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	2.7	57.0	149.8	0.0	4.1	213.6	62.5	276.1
0.5	1.0	2.7	57.0	149.8	0.0	4.1	213.6	62.5	276.1
1.0	1.5	2.7	57.0	149.8	0.0	4.1	213.6	62.5	276.1
1.5	2.0	2.7	57.0	149.8	0.0	4.1	213.6	62.5	276.1
2.0	2.5	17.3	51.0	199.6	0.0	4.4	272.3	50.3	322.6
2.5	3.0	33.2	41.0	249.7	0.0	5.3	329.2	41.3	370.5
3.0	3.5	33.2	41.0	249.7	0.0	5.3	329.2	41.3	370.5
3.5	4.0	33.2	41.0	249.7	0.0	5.3	329.2	41.3	370.5
4.0	4.5	33.2	41.0	249.7	0.0	5.3	329.2	41.3	370.5
4.5	5.0	33.2	41.0	249.7	0.0	5.3	329.2	41.3	370.5
5.0	5.5	23.8	37.3	281.4	0.0	4.3	346.9	44.8	391.7
5.5	6.0	6.3	27.9	295.0	0.0	3.1	332.3	61.1	393.4

Middle Peninsula: Middlesex

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	71.4	67.3	93.6	0.0	14.1	246.3	51.9	298.2
0.5	1.0	71.4	67.3	93.6	0.0	14.1	246.3	51.9	298.2
1.0	1.5	120.1	67.3	91.4	0.0	11.2	290.0	53.6	343.6
1.5	2.0	133.9	67.3	90.8	0.0	10.5	302.4	54.0	356.4
2.0	2.5	133.9	67.3	90.8	0.0	10.5	302.4	54.0	356.4
2.5	3.0	130.3	102.1	150.8	0.0	6.5	389.6	36.6	426.2
3.0	3.5	126.0	109.6	161.5	0.0	5.5	402.5	33.6	436.1
3.5	4.0	126.0	109.6	161.5	0.0	5.5	402.5	33.6	436.1
4.0	4.5	101.9	114.8	159.5	0.0	4.9	381.1	32.1	413.2
4.5	5.0	90.7	117.2	158.6	0.0	4.7	371.1	31.4	402.5
5.0	5.5	90.7	117.2	158.6	0.0	4.7	371.1	31.4	402.5
5.5	6.0	53.0	157.8	246.9	0.0	4.4	462.2	44.3	506.5

Middle Peninsula: King William

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	18.1	15.5	80.0	0.0	3.9	117.5	26.4	143.9
0.5	1.0	18.1	15.5	80.0	0.0	3.9	117.5	26.4	143.9
1.0	1.5	18.1	15.5	80.0	0.0	3.9	117.5	26.4	143.9
1.5	2.0	18.1	15.5	80.0	0.0	3.9	117.5	26.4	143.9
2.0	2.5	23.5	54.9	194.8	0.0	4.4	277.6	26.7	304.3
2.5	3.0	30.1	102.8	300.8	0.0	4.9	438.7	29.3	468.0
3.0	3.5	30.1	102.8	300.8	0.0	4.9	438.7	29.3	468.0
3.5	4.0	30.1	102.8	300.8	0.0	4.9	438.7	29.3	468.0
4.0	4.5	30.1	102.8	300.8	0.0	4.9	438.7	29.3	468.0
4.5	5.0	30.1	102.8	300.8	0.0	4.9	438.7	29.3	468.0
5.0	5.5	28.4	75.3	335.9	0.0	7.3	446.9	33.5	480.3
5.5	6.0	24.9	24.6	367.1	0.0	9.5	426.0	35.4	461.4

Northern Neck: Northumberland

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	220	147	36	0	27	430	40	471
0.5	1.0	220	147	36	0	27	430	40	471
1.0	1.5	220	147	36	0	27	430	40	471
1.5	2.0	220	147	36	0	27	430	40	471
2.0	2.5	220	147	36	0	27	430	40	471
2.5	3.0	962	476	89	0	25	1552	114	1666
3.0	3.5	1214	586	105	0	24	1930	142	2072
3.5	4.0	1214	586	105	0	24	1930	142	2072
4.0	4.5	1214	586	105	0	24	1930	142	2072
4.5	5.0	1214	586	105	0	24	1930	142	2072
5.0	5.5	1214	586	105	0	24	1930	142	2072
5.5	6.0	553	295	91	0	10	948	80	1028

Northern Neck: Lancaster

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	330.3	98.5	34.5	30.4	18.7	512.4	40.1	552.5
0.5	1.0	330.3	98.5	34.5	30.4	18.7	512.4	40.1	552.5
1.0	1.5	346.0	106.9	32.4	30.4	17.9	533.6	41.0	574.5
1.5	2.0	350.1	109.1	31.9	30.4	17.7	539.1	41.2	580.3
2.0	2.5	350.1	109.1	31.9	30.4	17.7	539.1	41.2	580.3
2.5	3.0	426.3	137.2	39.1	16.1	7.6	626.2	33.5	659.7
3.0	3.5	438.5	142.2	38.7	14.6	5.2	639.2	32.6	671.9
3.5	4.0	438.5	142.2	38.7	14.6	5.2	639.2	32.6	671.9
4.0	4.5	439.6	141.6	38.8	14.6	5.2	639.8	32.6	672.4

4.5	5.0	440.1	141.3	38.8	14.6	5.2	640.0	32.6	672.6
5.0	5.5	440.1	141.3	38.8	14.6	5.2	640.0	32.6	672.6
5.5	6.0	394.6	150.7	60.1	2.8	3.4	611.7	39.1	650.8

Northern Neck: Westmoreland

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	96	68	165	4	14	347	37	384
0.5	1.0	96	68	165	4	14	347	37	384
1.0	1.5	96	68	165	4	14	347	37	384
1.5	2.0	96	68	165	4	14	347	37	384
2.0	2.5	103	70	172	5	14	364	39	403
2.5	3.0	440	319	652	21	8	1440	148	1588
3.0	3.5	449	342	687	21	8	1507	159	1666
3.5	4.0	449	342	687	21	8	1507	159	1666
4.0	4.5	449	342	687	21	8	1507	159	1666
4.5	5.0	449	342	687	21	8	1507	159	1666
5.0	5.5	449	342	687	21	8	1507	159	1666
5.5	6.0	221	148	480	15	2	865	131	997

Northern Neck: Richmond

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	81.7	35.9	192.5	20.6	4.2	334.9	62.4	397.3
0.5	1.0	81.7	35.9	192.5	20.6	4.2	334.9	62.4	397.3
1.0	1.5	81.7	35.9	192.5	20.6	4.2	334.9	62.4	397.3
1.5	2.0	81.7	35.9	192.5	20.6	4.2	334.9	62.4	397.3
2.0	2.5	81.8	36.1	193.3	20.7	4.2	336.2	62.4	398.5
2.5	3.0	159.3	80.4	322.8	52.6	2.0	617.1	57.6	674.7
3.0	3.5	160.4	80.8	323.2	52.6	2.0	619.0	57.7	676.6
3.5	4.0	160.4	80.8	323.2	52.6	2.0	619.0	57.7	676.6
4.0	4.5	160.4	80.8	323.2	52.6	2.0	619.0	57.7	676.6
4.5	5.0	160.4	80.8	323.2	52.6	2.0	619.0	57.7	676.6
5.0	5.5	160.4	80.8	323.2	52.6	2.0	619.0	57.7	676.6
5.5	6.0	85.5	52.2	317.3	41.7	2.7	499.3	60.1	559.3

Rappahannock Area: King George

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	59.8	76.9	43.5	13.0	8.5	201.6	37.4	239.0
0.5	1.0	59.8	76.9	43.5	13.0	8.5	201.6	37.4	239.0
1.0	1.5	59.8	76.9	43.5	13.0	8.5	201.6	37.4	239.0
1.5	2.0	59.8	76.9	43.5	13.0	8.5	201.6	37.4	239.0
2.0	2.5	59.9	77.3	46.8	14.5	7.3	205.8	37.9	243.7
2.5	3.0	201.9	179.6	72.9	31.9	5.2	491.5	41.0	532.5
3.0	3.5	205.0	180.8	73.1	32.2	5.2	496.2	40.9	537.2
3.5	4.0	205.0	180.8	73.1	32.2	5.2	496.2	40.9	537.2
4.0	4.5	205.0	180.8	73.1	32.2	5.2	496.2	40.9	537.2
4.5	5.0	205.0	180.8	73.1	32.2	5.2	496.2	40.9	537.2
5.0	5.5	207.0	184.8	83.1	32.2	4.9	512.0	41.5	553.5
5.5	6.0	222.8	128.7	150.9	31.0	2.6	536.1	56.7	592.8

Rappahannock Area: Stafford

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	46.0	32.3	22.7	1.7	0.0	102.8	38.3	141.0
0.5	1.0	46.0	32.3	22.7	1.7	0.0	102.8	38.3	141.0
1.0	1.5	46.0	32.3	22.7	1.7	0.0	102.8	38.3	141.0
1.5	2.0	46.0	32.3	22.7	1.7	0.0	102.8	38.3	141.0
2.0	2.5	44.0	30.9	18.6	1.3	0.0	94.8	34.5	129.3
2.5	3.0	50.7	60.0	14.8	1.4	0.0	126.9	31.6	158.5
3.0	3.5	50.8	60.1	14.8	1.4	0.0	127.2	31.6	158.8
3.5	4.0	50.8	60.1	14.8	1.4	0.0	127.2	31.6	158.8
4.0	4.5	50.8	60.1	14.8	1.4	0.0	127.2	31.6	158.8
4.5	5.0	50.8	60.1	14.8	1.4	0.0	127.2	31.6	158.8
5.0	5.5	52.5	60.6	16.2	1.6	0.0	130.9	31.9	162.8
5.5	6.0	72.3	58.5	21.4	2.2	0.0	154.3	27.0	181.3

Rappahannock Area: Caroline

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	0.6	2.7	26.8	0.0	2.7	32.7	4.3	37.0
0.5	1.0	0.6	2.7	26.8	0.0	2.7	32.7	4.3	37.0
1.0	1.5	0.6	2.7	26.8	0.0	2.7	32.7	4.3	37.0
1.5	2.0	0.6	2.7	26.8	0.0	2.7	32.7	4.3	37.0
2.0	2.5	0.7	3.6	28.2	0.0	2.0	34.5	8.3	42.8
2.5	3.0	1.2	6.5	40.8	0.0	0.5	48.9	18.5	67.4
3.0	3.5	1.2	6.5	40.8	0.0	0.5	48.9	18.5	67.4
3.5	4.0	1.2	6.5	40.8	0.0	0.5	48.9	18.5	67.4
4.0	4.5	1.2	6.5	40.8	0.0	0.5	48.9	18.5	67.4

4.5	5.0	1.2	6.5	40.8	0.0	0.5	48.9	18.5	67.4
5.0	5.5	2.6	8.7	46.9	0.0	0.5	58.7	18.4	77.1
5.5	6.0	9.3	17.1	72.9	0.0	0.3	99.7	16.5	116.1

Rappahannock Area: Fredericksburg

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	3.4	0.0	0.0	1.6	0.0	5.0	0.3	5.3
0.5	1.0	3.4	0.0	0.0	1.6	0.0	5.0	0.3	5.3
1.0	1.5	3.4	0.0	0.0	1.6	0.0	5.0	0.3	5.3
1.5	2.0	3.4	0.0	0.0	1.6	0.0	5.0	0.3	5.3
2.0	2.5	2.9	0.1	0.0	1.3	0.0	4.3	0.1	4.4
2.5	3.0	2.6	0.1	0.0	1.2	0.0	3.9	0.0	3.9
3.0	3.5	2.6	0.1	0.0	1.2	0.0	3.9	0.0	3.9
3.5	4.0	2.6	0.1	0.0	1.2	0.0	3.9	0.0	3.9
4.0	4.5	2.6	0.1	0.0	1.2	0.0	3.9	0.0	3.9
4.5	5.0	2.6	0.1	0.0	1.2	0.0	3.9	0.0	3.9
5.0	5.5	2.7	0.2	0.8	1.0	0.0	4.6	0.0	4.7
5.5	6.0	2.7	0.2	1.6	0.8	0.0	5.2	0.0	5.2

Rappahannock Area: Spotsylvania

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	3.1	0.6	2.4	0.0	0.1	6.3	1.2	7.5
0.5	1.0	3.1	0.6	2.4	0.0	0.1	6.3	1.2	7.5
1.0	1.5	3.1	0.6	2.4	0.0	0.1	6.3	1.2	7.5
1.5	2.0	3.1	0.6	2.4	0.0	0.1	6.3	1.2	7.5
2.0	2.5	3.5	0.8	2.0	0.0	0.4	6.6	0.9	7.5
2.5	3.0	3.7	0.9	1.5	0.0	0.6	6.7	0.8	7.4
3.0	3.5	3.7	0.9	1.5	0.0	0.6	6.7	0.8	7.4
3.5	4.0	3.7	0.9	1.5	0.0	0.6	6.7	0.8	7.4
4.0	4.5	3.7	0.9	1.5	0.0	0.6	6.7	0.8	7.4
4.5	5.0	3.7	0.9	1.5	0.0	0.6	6.7	0.8	7.4
5.0	5.5	4.0	1.0	1.9	0.0	0.6	7.4	2.0	9.4
5.5	6.0	4.3	1.1	2.3	0.0	0.7	8.3	3.3	11.6

Northern Virginia: Fairfax

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	79.3	26.4	33.8	4.5	2.5	146.6	14.1	160.6
0.5	1.0	79.3	26.4	33.8	4.5	2.5	146.6	14.1	160.6
1.0	1.5	79.3	26.4	33.8	4.5	2.5	146.6	14.1	160.6
1.5	2.0	79.3	26.4	33.8	4.5	2.5	146.6	14.1	160.6
2.0	2.5	75.6	25.9	34.3	5.3	1.8	143.0	13.8	156.7
2.5	3.0	75.7	24.7	39.9	7.5	0.6	148.3	10.8	159.2
3.0	3.5	75.7	24.7	39.9	7.5	0.6	148.3	10.8	159.2
3.5	4.0	75.7	24.7	39.9	7.5	0.6	148.3	10.8	159.2

4.0	4.5	75.7	24.7	39.9	7.5	0.6	148.3	10.8	159.2
4.5	5.0	75.7	24.7	39.9	7.5	0.6	148.3	10.8	159.2
5.0	5.5	95.8	27.8	48.7	9.3	0.9	182.4	11.8	194.2
5.5	6.0	153.4	42.0	88.6	17.6	1.8	303.3	12.1	315.5

Northern Virginia: Prince William

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	35.3	9.3	7.6	20.5	0.0	72.7	11.4	84.2
0.5	1.0	35.3	9.3	7.6	20.5	0.0	72.7	11.4	84.2
1.0	1.5	35.3	9.3	7.6	20.5	0.0	72.7	11.4	84.2
1.5	2.0	35.3	9.3	7.6	20.5	0.0	72.7	11.4	84.2
2.0	2.5	37.1	9.4	7.8	19.0	0.0	73.3	11.0	84.3
2.5	3.0	47.1	13.0	7.4	11.3	0.0	78.8	6.2	84.9
3.0	3.5	47.1	13.0	7.4	11.3	0.0	78.8	6.2	84.9
3.5	4.0	47.1	13.0	7.4	11.3	0.0	78.8	6.2	84.9
4.0	4.5	47.1	13.0	7.4	11.3	0.0	78.8	6.2	84.9
4.5	5.0	47.1	13.0	7.4	11.3	0.0	78.8	6.2	84.9
5.0	5.5	46.9	13.1	7.0	10.9	0.0	77.9	6.1	84.1
5.5	6.0	52.1	18.5	4.5	5.0	0.0	80.1	2.3	82.4

Northern Virginia: Alexandria

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	25.4	0.0	7.5	0.0	0.0	32.9	2.6	35.5
0.5	1.0	25.4	0.0	7.5	0.0	0.0	32.9	2.6	35.5
1.0	1.5	25.4	0.0	7.5	0.0	0.0	32.9	2.6	35.5
1.5	2.0	25.4	0.0	7.5	0.0	0.0	32.9	2.6	35.5
2.0	2.5	28.6	1.2	4.4	0.0	0.0	34.2	1.3	35.5
2.5	3.0	31.8	2.4	1.2	0.0	0.0	35.4	0.0	35.5
3.0	3.5	31.8	2.4	1.2	0.0	0.0	35.4	0.0	35.5
3.5	4.0	31.8	2.4	1.2	0.0	0.0	35.4	0.0	35.5
4.0	4.5	31.8	2.4	1.2	0.0	0.0	35.4	0.0	35.5
4.5	5.0	31.8	2.4	1.2	0.0	0.0	35.4	0.0	35.5
5.0	5.5	36.7	1.4	0.8	0.0	0.0	38.9	0.4	39.3
5.5	6.0	43.8	0.0	0.1	0.0	0.0	43.9	0.9	44.8

Northern Virginia: Arlington

Elevation above Spring High Water (m)		Area (hectares)							
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
Above	Below								
0.0	0.5	14.2	3.0	0.5	0.0	0.0	17.6	0.0	17.6
0.5	1.0	14.2	3.0	0.5	0.0	0.0	17.6	0.0	17.6
1.0	1.5	14.2	3.0	0.5	0.0	0.0	17.6	0.0	17.6
1.5	2.0	14.2	3.0	0.5	0.0	0.0	17.6	0.0	17.6

2.0	2.5	37.5	4.0	0.3	0.0	0.0	41.8	0.0	41.9
2.5	3.0	59.7	5.0	0.2	0.0	0.0	64.8	0.1	64.9
3.0	3.5	59.7	5.0	0.2	0.0	0.0	64.8	0.1	64.9
3.5	4.0	59.7	5.0	0.2	0.0	0.0	64.8	0.1	64.9
4.0	4.5	59.7	5.0	0.2	0.0	0.0	64.8	0.1	64.9
4.5	5.0	59.7	5.0	0.2	0.0	0.0	64.8	0.1	64.9
5.0	5.5	46.3	3.8	0.3	0.0	0.0	50.4	0.1	50.5
5.5	6.0	27.4	2.2	0.3	0.0	0.0	30.0	0.2	30.1

Table B-2. Area of Land Vulnerable to a One Meter Rise in Sea Level (square kilometers)
By Planning District and County by Likelihood of Shore Protection

County	Likelihood of Shore Protection						Tidal Wetlands
	Certain	Likely	Unlikely	No Protection	Nontidal Wetlands	Total Nontidal Land ¹	
Eastern Shore	13.9	19.0	30.7	19.5	34.1	119.4	945.5
Accomack ³	12.3	12.5	23.3	9.0	32.0	90.6	483.5
Northampton	1.6	6.4	7.4	10.5	2.1	28.7	462.0
Northern Virginia	3.1	0.8	1.0	0.5	0.6	6.0	10.2
Arlington	0.3	0.1	0.0	0.0	0.0	0.4	0.1
Alexandria	0.5	0.0	0.2	0.0	0.1	0.7	0.2
Fairfax	1.6	0.5	0.7	0.1	0.3	3.2	4.9
Prince William	0.7	0.2	0.2	0.4	0.2	1.7	5.1
Rappahannock Area	2.3	2.3	1.9	0.3	1.6	8.6	26.7
Stafford	0.9	0.6	0.5	0.0	0.8	2.8	6.7
Fredericksburg	0.1	0.0	0.0	0.0	0.0	0.1	0.0
King George	1.2	1.5	0.9	0.3	0.7	4.8	13.5
Spotsylvania	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Caroline	0.0	0.1	0.5	0.0	0.1	0.7	6.3
Northern Neck	14.6	7.0	8.6	1.1	3.6	36.1	57.3
Westmoreland	1.9	1.4	3.3	0.1	0.7	7.7	14.4
Richmond	1.6	0.7	3.8	0.4	1.2	7.9	21.8
Northumberland	4.4	2.9	0.7	0.0	0.8	9.4	11.4
Lancaster	6.6	2.0	0.7	0.6	0.8	11.0	9.8
Middle Peninsula	12.1	22.5	26.8	0.1	18.1	81.1	164.4
Essex	0.5	0.9	4.1	0.0	1.1	6.7	27.6
King and Queen	0.1	1.1	3.0	0.0	1.2	5.5	21.5
King William	0.4	0.3	1.6	0.0	0.5	2.9	35.0
Middlesex	1.4	1.3	1.9	0.0	1.0	6.0	9.7
Gloucester	4.2	11.5	7.6	0.1	8.4	32.1	43.5
Mathews	5.6	7.3	8.7	0.0	5.8	28.0	27.1
Hampton Roads	80.5	21.8	35.4	1.2	64.0	203.5	330.2
James City	3.1	0.6	1.7	0.0	1.1	6.6	32.8
York	6.7	2.1	0.1	0.4	1.6	10.9	17.0
Newport News	3.6	5.4	0.0	0.0	0.5	9.6	15.1
Poquoson	6.5	0.0	0.1	0.0	0.2	6.8	23.7
Hampton	7.0	3.4	0.0	0.0	0.3	10.8	14.4
Surry	0.2	0.2	1.2	0.4	1.0	3.0	11.5
Isle of Wight	2.6	1.0	1.0	0.3	1.8	6.8	28.9
Norfolk	10.3	0.0	0.0	0.0	0.4	10.8	4.7
Virginia Beach	17.6	2.9	28.5	0.0	20.5	69.7	112.4
Suffolk	3.9	1.8	0.7	0.0	3.0	9.4	26.3
Portsmouth	5.9	0.4	0.0	0.0	8.8	15.2	3.7
Chesapeake	13.1	4.0	2.0	0.0	24.8	44.0	39.7
Virginia^{2,3}	126.4	73.3	104.4	22.8	122.0	454.7	1534.3

1. Total includes the five categories listed plus the "not considered" category.

2. Excludes the Richmond Regional and Crater Planning Districts, as well as three jurisdictions from the Hampton Roads Planning District: Southampton County and the cities of Franklin and Williamsburg. The excluded jurisdictions have about 16.2 square kilometers of dry land and 26.2 square kilometers of nontidal wetlands within one meter above spring high water, as well as 84 square kilometers of tidal wetlands.

3. Note: While this report was in peer review we noticed that two barrier islands in Accomack County had been mistakenly coded as “shore protection unlikely” instead of “no shore protection”. Those islands have approximately 1.1 square kilometer within one meter above spring high water. Had those islands been coded correctly when this table was produced, the estimates for no shore protection and shore protection unlikely for Accomack would have been 22.2 and 10.1, instead of 23.3 and 9.0, and the statewide estimates would have been 103.3 and 23.9. This error has been corrected in the tables estimating shoreline length: because the mistakenly coded islands were the only cases of “shore protection unlikely” along the Atlantic Ocean on the Eastern Shore, a failure to correct the statistics would have been seriously misleading. Given the substantial uncertainty in our elevation estimates, however, the late date at which we noticed the error, and the risk that we would fail to change all of the summary tables and thus confuse people with inconsistent tables, we decide that an error of 1.1 square kilometers is not large enough to change the elevation-based tables.

Appendix C: Elevation Uncertainty

Authors: James G. Titus, Russ Jones, and Richard Streeter

C-1. Low and High Estimates of the Area of Land Close to Sea Level, by Jurisdiction: Virginia¹ (square kilometers)

Jurisdiction	Meters above Spring High Water																			
	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high		
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0										
-----Cumulative (total) amount of Dry Land below a given elevation-----																				
Eastern Shore	21	63	56	111	93	159	137	204	180	243	221	279	258	315	294	349	329	382	362	416
Accomack	13	41	37	78	65	115	98	149	131	172	160	192	180	211	200	227	218	242	233	257
Northampton	7.4	22	20	33	29	44	39	55	49	71	61	87	78	104	94	122	111	140	129	159
Northern Virginia	0	5.1	2.8	10	6.3	15	9.7	20	13	25	17	29	21	34	25	39	30	44	35	49
Arlington	0	0.2	0.1	0.5	0.3	0.7	0.5	1.3	0.6	1.9	0.8	2.6	1.4	3.3	2.1	4	2.7	4.7	3.4	5
Alexandria	0	0.4	0.3	0.9	0.6	1.3	0.9	1.7	1.2	2.1	1.5	2.5	1.8	2.9	2.2	3.2	2.5	3.6	2.9	4
Fairfax	0	2	1.1	3.9	2.5	5.9	3.8	7.6	5.2	9.2	6.6	11	8	12	9.5	14	11	15	12	18
Prince William	0	1	0.5	2	1.2	3	1.9	3.9	2.6	4.7	3.3	5.5	4	6.3	4.8	7.2	5.6	8	6.4	8.8
Rappahannock Area	0	3.3	1.8	6.5	4.1	9.9	6.4	14	8.7	20	11	26	15	31	20	37	26	43	32	49
Stafford	0	1.4	0.8	2.7	1.7	4.2	2.7	5.4	3.6	6.8	4.6	8.1	5.7	9.4	6.9	11	8.2	12	9.5	14
Fredericksburg	0	0.1	0.04	0.1	0.1	0.2	0.1	0.2	0.2	0.3	0.2	0.3	0.3	0.4	0.3	0.4	0.3	0.5	0.4	0.5
King George	0	2.7	1.5	5.4	3.3	8.1	5.2	11	7.1	16.7	9	22	12	27	17	32	22	37	27	43
Spotsylvania	0	0.09	0.05	0.2	0.1	0.3	0.2	0.3	0.2	0.4	0.3	0.5	0.3	0.5	0.4	0.6	0.5	0.7	0.5	0.8
Caroline	0	0.4	0.3	0.9	0.6	1.3	0.9	1.8	1.2	2.3	1.5	2.8	1.9	3.3	2.4	3.8	2.9	4.4	3.4	5.2
Northern Neck	0.1	22	11	43	27	66	42	92	58	141	74	190	100	239	147	287	193	336	240	378
Westmoreland	0	4.7	2.4	9.3	5.7	14	9	21	12	37	16	53	24	69	39	84	54	100	69	112
Richmond	0	4.6	2.4	8.9	5.5	13	8.7	18	12	25	15	32	20	38	26	44	32	51	38	57
Northumberland	0	5.9	2.8	11	6.9	17	11	24	15	44	19	64	27	84	46	104	65	124	85	141
Lancaster	0.1	7	3.6	14	8.5	21	14	28	19	35	24	42	29	48	36	55	42	61	48	68

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

Middle Peninsula		9.1 42	33 89	66 139	108 190	149 230	186 268	220 307	258 336	292 364	319 392
Essex		0 3.8	2 7.3	4.6 11	7.1 15	9.7 22	12 28	17 34	22 40	28 46	34 53
King and Queen		0 2.9	1.7 5.7	3.7 8.6	5.5 12	7.5 15	9.6 19	13 22	16 26	19 30	23 33
King William		0 1.6	0.9 3.2	2 4.8	3.1 8.4	4.2 13	5.4 18	9.6 22	14 27	18 32	23 36
Middlesex		0.2 3.4	2 6.8	4.4 11	7 14	10 19	13 23	16 27	20 31	24 35	28 39
Gloucester		4.1 16	13 33	26 50	41 67	55 76	67 84	75 93	84 99	91 104	96 111
Mathews		4.7 15	13 33	26 54	44 73	62 85	79 97	90 108	101 113	111 117	115 121
Hampton Roads		24 91	78 200	154 333	264 469	381 650	519 848	711 1045	907 1192	1089 1307	1215 1424
James City		0.1 3.8	2 7.2	4.7 11	7 14	9.4 18	12 22	15 26	19 30	23 34	27 39
York		1.4 6	5 13	9.9 21	16 28	23 33	28 37	33 42	38 45	42 48	44 51
Newport News		2.2 6.9	6 11	9.7 15	13 18	16 21	19 25	23 28	26 33	30 38	35 42
Poquoson		1.4 4.5	4 8.8	7.4 13	11 16	15 16	16 17	17 17	17 17	17 17	17 17
Hampton		1.9 5.9	5 18	13 32	25 45	38 60	51 74	65 88	80 93	90 98	95 102
Surry		0 1.4	1 2.7	1.7 4.1	2.7 5.3	3.6 6.2	4.6 7.1	5.5 8	6.4 9	7.2 9.9	8.1 11
Isle of Wight		0.2 3.4	2 6.2	4.2 9.1	6 12.8	8 17	10 22	14 26	18 31	22 35	27 42
Norfolk		1.9 5.8	5 17	13 30	24 42	35 67	52 91	77 115	101 120	118 124	122 128
Virginia Beach		9.3 33	30 69	55 117	94 163	138 219	185 273	241 327	295 368	347 393	378 418
Suffolk		0.7 4.3	3.1 7.1	5.4 10	7.5 15	10 23	13 31	21 39	28 50	37 60	47 73
Portsmouth		1.2 3.9	3.5 9.6	7.6 15	13 22	18 33	27 45	38 56	50 61	58 65	63 70
Chesapeake		3.5 12	11 31	22 57	45 87	69 137	100 205	162 272	229 337	298 385	353 430
Other Jurisdictions		0 9.9	5.7 19	12 29	19 40	26 54	32 67	44 80	56 93	68 106	81 122
Charles City		0 3.2	1.8 6.3	4 9.6	6.2 13	8.4 18	11 23	15 28	19 32	23 37	28 43
Chesterfield		0 1.3	0.8 2.6	1.7 3.9	2.5 4.8	3.4 5.5	4.3 6.2	5 7	5.7 7.7	6.3 8.4	7 8.9
Colonial Heights		0 0.04	0.02 0.1	0.05 0.1	0.07 0.12	0.09 0.14	0.12 0.15	0.1 0.2	0.1 0.2	0.15 0.19	0.16 0.24
Hanover		0 0.02	0.02 0.05	0.03 0.1	0.05 0.2	0.1 0.3	0.1 0.4	0.2 0.5	0.3 0.6	0.4 0.7	0.5 0.7
Henrico		0 0.8	0.5 1.5	1 2.3	1.5 2.8	2 3.2	2.5 3.7	2.9 4.1	3.3 4.6	3.8 5.1	4.2 6.3

Hopewell		0 0.4	0.2 0.8	0.5 1.1	0.7 1.3	1 1.4	1.2 1.6	1.4 1.7	1.5 1.8	1.6 1.9	1.7 2.2
New Kent		0 2.1	1.2 4.1	2.6 6.2	4 9.4	5.4 13	6.9 17	10 21	14 25	18 29	22 34
Petersburg		0 0	0 0	0 0	0 <0.01	0 0.01	<0.01 0.01	<0.01 0.01	0.01 0.02	0.01 0.02	0.01 0.03
Prince George		0 1.9	1.1 3.8	2.4 5.7	3.7 8.1	5 11	6.3 14	8.8 17	12 20	15 23	17 26
Williamsburg		0 0.05	0.03 0.1	0.06 0.1	0.1 0.2	0.1 0.3	0.2 0.3	0.2 0.4	0.3 0.4	0.3 0.5	0.4 0.6
Statewide		54 236	189 479	362 751	585 1029	816 1362	1060 1707	1368 2051	1708 2332	2028 2582	2283 2830

Jurisdiction		Meters above Spring High Water															
		low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0						
		-----Cumulative (total) amount of Nontidal Wetlands below a given elevation-----															
Eastern Shore	946	7 22	20 48	39 76	63 101	87 114	107 126	119 137	131 146	141 153	149 161						
Accomack	484	7 21	19 45	36 70	58 92	80 104	98 114	108 124	119 132	128 138	134 145						
Northampton	462	0.4 1.2	1 3.4	2.5 5.9	4.7 8.1	7 9.7	8.8 11	10 13	12 14	14 15	15 16						
Northern Virginia	17	0 1	0 2	1 3	2 3	2 4	3 4	3 5	4 5	4 6	5 6						
Stafford	6.8	0 0.5	0.3 1	0.6 1.5	1 1.9	1.3 2.3	1.7 2.6	2 2.9	2.3 3.3	2.6 3.6	3 3.9						
Alexandria	0.2	0 0.03	0.02 0.07	0.04 0.1	0.06 0.11	0.09 0.11	0.11 0.11	0.11 0.11	0.11 0.11	0.11 0.11	0.11 0.12						
Fairfax	4.9	0 0.2	0.1 0.4	0.2 0.6	0.4 0.7	0.5 0.8	0.6 0.9	0.7 1.1	0.9 1.2	1 1.3	1.1 1.4						
Prince William	5.1	0 0.2	0.1 0.3	0.2 0.5	0.3 0.6	0.4 0.6	0.5 0.7	0.6 0.8	0.7 0.8	0.7 0.9	0.8 0.9						
Rappahannock Area	20	0 0.6	0.3 1.2	0.7 1.7	1.1 2.4	1.5 3	1.9 3.6	2.5 4.2	3.1 4.9	3.7 5.5	4.3 6.2						
Fredericksburg	0	0 <0.01	<0.01 0.01	<0.01 0.01	<0.01 0.01	0.01 0.01	0.01 0.01	0.01 0.01	0.01 0.01	0.01 0.01	0.01 0.01						
King George	13	0 0.5	0.3 1	0.6 1.5	1 2	1.3 2.4	1.7 2.8	2.1 3.3	2.5 3.7	2.9 4.1	3.3 4.6						
Spotsylvania	0.1	0 0.02	0.01 0.03	0.02 0.05	0.03 0.06	0.04 0.06	0.05 0.07	0.06 0.08	0.06 0.08	0.07 0.09	0.08 0.12						
Caroline	6.3	0 0.1	0.03 0.1	0.1 0.2	0.1 0.3	0.2 0.5	0.2 0.7	0.3 0.9	0.5 1.1	0.7 1.3	0.9 1.5						
Northern Neck	57	0 2.5	1.2 4.8	2.9 7.3	4.7 9.8	6.4 14	8.1 18	10 22	14 26	18 30	22 34						
Westmoreland	14	0 0.5	0.3 1	0.6 1.5	1 2.2	1.3 3.9	1.7 5.6	2.5 7.2	4.1 8.9	5.7 10.6	7.3 12						
Richmond	22	0 0.9	0.4 1.7	1 2.5	1.6 3.3	2.2 3.9	2.8 4.5	3.4 5.1	4 5.7	4.5 6.3	5.1 6.9						
Northumberland	11	0 0.5	0.3 1.1	0.6 1.6	1 2.2	1.4 3.7	1.8 5.1	2.4 6.6	3.8 8	5.2 9.6	6.6 11						
Lancaster	9.8	<0.01 0.5	0.3 1.1	0.7 1.6	1.1 2.1	1.4 2.5	1.8 2.8	2.2 3.2	2.5 3.5	2.8 3.8	3.2 4.2						
Middle Peninsula	165	2.6 12	9.5 26	19 40	31 54	44 66	55 78	67 90	79 98	90 106	98 113						

Essex	28	0	0.8	0.4	1.5	0.9	2.3	1.5	2.9	2	3.4	2.5	3.9	3	4.4	3.5	4.8	3.9	5.3	4.4	5.9
King and Queen	22	0	0.9	0.5	1.7	1.1	2.5	1.6	3.1	2.2	3.5	2.8	4	3.2	4.4	3.6	4.8	4	5.3	4.4	5.8
King William	36	0	0.4	0.2	0.7	0.5	1.1	0.7	1.4	0.9	1.7	1.2	2	1.5	2.3	1.8	2.6	2	2.9	2.3	3.3
Middlesex	9.7	<0.01	0.7	0.4	1.4	0.8	2.1	1.4	2.8	1.9	3.1	2.4	3.5	2.8	3.8	3.2	4.1	3.5	4.5	3.8	4.8
Gloucester	44	1.4	5.5	4.5	12	9.1	19	15	25	20	28	25	31	27	34	30	36	33	37	34	38
Mathews	27	1.2	3.8	3.5	8.6	6.7	14	11	19	16	26	22	34	29	41	37	46	44	51	48	55
Hampton Roads	329	12	42	38	74	64	96	84	127	104	167	127	205	164	245	202	285	242	326	279	391
James City	33	<0.01	0.8	0.4	1.5	0.9	2.2	1.4	2.8	1.9	3.3	2.5	3.7	2.9	4.2	3.3	4.6	3.8	5.1	4.2	5.6
York	17	0.19	0.9	0.7	2.7	1.9	4.9	3.7	6.7	5.6	7.4	6.9	8	7.6	8.7	8.2	9.1	8.8	9.5	9.2	9.9
Newport News	15	0.1	0.3	0.3	0.7	0.5	1	0.9	1.3	1.2	1.4	1.35	1.42	1.4	1.5	1.4	1.5	1.5	1.6	1.6	1.7
Poquoson	24	0.02	0.1	0.1	0.4	0.3	0.8	0.6	1.1	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Hampton	14	0.06	0.2	0.2	0.4	0.3	0.6	0.5	0.9	0.7	1.5	1.1	2.2	1.8	2.9	2.5	4	3.3	5.1	4.4	6.2
Surry	11	0	0.6	0.3	1.3	0.8	1.9	1.2	2.4	1.7	2.5	2.1	2.7	2.4	2.9	2.6	3	2.7	3.2	2.9	3.4
Isle of Wight	29	<0.01	0.3	0.2	0.6	0.4	0.9	0.6	1.4	0.8	2.2	1	3.1	1.5	4	2.4	4.8	3.2	5.7	4	7.3
Norfolk	4.7	0.1	0.3	0.2	0.5	0.4	0.8	0.7	1.1	0.9	1.3	1.1	1.5	1.3	1.7	1.5	1.7	1.7	1.7	1.7	1.7
Virginia Beach	112	4.2	14	13	25	22	33	29	41	37	46	43	50	48	53	51	56	54	57	56	59
Suffolk	26	0.03	0.2	0.1	0.3	0.2	0.4	0.3	0.8	0.4	1.3	0.5	1.8	1	2.3	1.4	3.1	2.1	6.8	2.9	33
Portsmouth	3.7	2.4	7.7	6.8	8.9	8.9	9.2	9.1	9.5	9.3	9.9	9.6	10	10	11	10	11	10.7	11	10.9	11
Chesapeake	40	4.5	17	15	32	28	40	36	58	44	89	56	120	86	152	116	186	149	217	180	251
Other Jurisdictions	85	0	5.5	3.2	11	6.9	16	10	20	14	22	18	24	20	26	22	28	24	30	26	33
Charles City	22	0	1.9	1.1	3.7	2.4	5.6	3.6	6.8	4.9	7.4	6.2	8	6.9	8.6	7.5	9.2	8.1	9.8	8.6	11
Chesterfield	11	0	0.4	0.2	0.7	0.4	1.1	0.7	1.2	0.9	1.2	1.1	1.2	1.17	1.24	1.2	1.3	1.2	1.3	1.2	1.3
Henrico	4.2	0	0.04	0.02	0.08	0.05	0.12	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.3	0.2	0.3	0.2	0.4	0.3	0.4
Hopewell	0.7	0	0.1	0.1	0.2	0.1	0.3	0.2	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.36	0.4	0.37	0.41	0.38	0.42
New Kent	34	0	2.3	1.3	4.5	2.9	6.8	4.4	8.1	6	8.7	7.6	9.3	8.2	9.8	8.8	10.4	9.3	11	9.9	12
Prince George	11	0	0.8	0.5	1.5	1	2.3	1.5	3.1	2	3.9	2.6	4.7	3.3	5.5	4	6.3	4.8	7.1	5.5	7.5
Williamsburg	0.4	0	0.02	0.01	0.03	0.02	0.05	0.03	0.06	0.04	0.07	0.05	0.08	0.06	0.1	0.07	0.11	0.09	0.12	0.1	0.14

Statewide	1619	21	86	72	167	134	240	197	317	260	389	320	459	387	529	455	594	523	657	583	745
	Cumulative (total) amount of land below a given elevation																				
Dry Land		54	236	189	479	362	751	585	1029	816	1362	1060	1707	1368	2051	1708	2332	2028	2582	2283	2830
Nontidal Wetlands		21	86	72	167	134	240	197	317	260	389	320	459	387	529	455	594	523	657	583	745
All Land	1619	1694	1941	1881	2265	2115	2611	2401	2965	2694	3370	2999	3785	3374	4199	3782	4545	4170	4858	4486	5193

C-2. Likelihood of Shore Protection in Virginia, High and Low Estimates of the Land within One Meter above Spring High Water¹
(square kilometers)

Jurisdiction	Likelihood of Shore Protection										Total ²	
	Certain		Likely		Unlikely		No Protection		Nontidal Wetlands			
	low	high	low	high	low	high	low	high	low	high	low	high
Eastern Shore	8.6	18	12	27	19	42	16	20	20	48	76	159
Accomack	7.6	16	7.7	18	13	33	7	9.8	19	45	56	123
Northampton	1	2.5	3.9	9.2	5.1	9.5	9.2	11	1	3.4	21	36
Northern Virginia	1.2	4.1	0.3	1	0.4	1.3	0.2	0.7	0.2	0.7	2.3	8
Arlington	0.1	0.4	0.02	0.08	<0.01	0.01	0	0	0	0	0.1	0.5
Alexandria	0.2	0.7	0	0	0.1	0.2	0	0	0.02	0.07	0.3	0.9
Fairfax	0.6	2.1	0.2	0.7	0.3	0.9	0.03	0.12	0.1	0.4	1.2	4.3
Prince William	0.3	0.9	0.1	0.2	0.1	0.2	0.1	0.6	0.1	0.3	0.6	2.3
Rappahannock Area	0.8	3	0.8	3	0.7	2.5	0.1	0.4	0.6	2.2	3.2	11
Stafford	0.3	1.2	0.2	0.9	0.2	0.6	0.01	0.05	0.3	1	1	3.8
Fredericksburg	0.03	0.09	0	0	0	0	0.01	0.04	<0.01	0.01	0.04	0.14
King George	0.4	1.6	0.6	2.1	0.3	1.2	0.1	0.3	0.3	1	1.7	6.4
Spotsylvania	0.03	0.08	0.01	0.02	0.02	0.07	0	0	0.01	0.03	0.1	0.2
Caroline	0.01	0.02	0.02	0.07	0.2	0.7	0	0	0.03	0.12	0.3	1
Northern Neck	5	19	2.4	9.3	3	11	0.4	1.5	1.2	4.8	12	48
Westmoreland	0.7	2.6	0.5	1.8	1.2	4.4	0.03	0.12	0.3	1	2.7	10
Richmond	0.6	2.2	0.3	1	1.4	5.1	0.1	0.6	0.4	1.7	2.9	11
Northumberland	1.4	5.9	1	3.9	0.2	1	0	0	0.3	1.1	3.1	13
Lancaster	2.3	8.9	0.7	2.7	0.3	0.9	0.2	0.8	0.3	1.1	3.9	15
Middle Peninsula	6.7	18	12	32	14	37	0.1	0.2	9.5	26	43	115
Essex	0.2	0.6	0.3	1.3	1.5	5.4	0	0	0.4	1.5	2.4	8.9
King and Queen	0.02	0.07	0.4	1.5	1.2	4	0	0	0.5	1.7	2.2	7.4
King William	0.1	0.5	0.1	0.4	0.6	2.1	0	0	0.2	0.7	1.2	3.9
Middlesex	0.7	2.2	0.5	1.8	0.7	2.5	0	0	0.4	1.4	2.4	8.2
Gloucester	2.3	6	6.4	16	4.3	10.2	0.1	0.2	4.5	12	18	45
Mathews	3.4	8.7	4.3	11	5.3	12.4	0	0	3.5	8.6	17	42
Hampton Roads	45	121	12	31	21	46	0.6	1.5	38	74	116	274
James City	1.3	4	0.2	0.8	0.6	2.3	<0.01	<0.01	0.4	1.5	2.6	8.6
York	3.6	9.8	0.9	2.7	0.1	0.2	0.2	0.4	0.7	2.7	5.5	16
Newport News	2.6	3.9	3.5	7	0.02	0.03	0	0	0.3	0.7	6.4	12
Poquoson City	4	8.6	0	0	0.1	0.1	0	0	0.1	0.4	4.1	9.2
Hampton City	3.4	12	1.8	5.7	<0.01	<0.01	0	0	0.2	0.4	5.4	19
Surry	0.1	0.3	0.1	0.2	0.4	1.6	0.1	0.5	0.3	1.3	1.1	4
Isle of Wight	1.1	3.5	0.4	1.2	0.4	1	0.2	0.5	0.2	0.6	2.3	6.7
Norfolk City	5.2	17	0.02	0.04	0	0	0	0	0.2	0.5	5.4	18
Virginia Beach	10	27	1.8	4	18	37	0.02	0.03	13	25	44	94

Suffolk City	2.4	4.7	0.7	2.4	0	<0.01	0	0	0.1	0.3	3.3	7.4
Portsmouth	3.2	9.1	0.3	0.5	<0.01	<0.01	0.02	0.05	6.8	8.9	10	19
Chesapeake	7.2	20	2.3	6.7	1.2	3.7	0	0	15	32	26	63
Virginia³	67	184	39	104	57	140	17	25	69	156	253	616

4. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.
5. Total includes the five categories listed as well as a small amount of low land that the authors did not analyze.
6. Excludes the Richmond Regional and Crater Planning Districts, as well as three jurisdictions from the Hampton Roads Planning District: Southampton County and the cities of Franklin and Williamsburg.

C-3. Likelihood of Shore Protection in Virginia, High and Low Estimates of the Land within Two Meters above Spring High Water
(square kilometers)

Jurisdiction	Likelihood of Shore Protection								Nontidal Wetlands		Total ²	
	Certain		Likely		Unlikely		No Protection					
	low	high	low	high	low	high	low	high	low	high	low	high
Eastern Shore	22	34	36	58	54	85	21	24	63	101	200	305
Accomack	19	28	24	38	43	68	11	12	58	92	156	242
Northampton	3.4	5.9	12	20	12	17	11	11	4.7	8.1	43	63
Northern Virginia	4	8.4	1	2.1	1.3	2.5	0.7	1.3	0.7	1.4	7.7	16
Arlington	0.4	1.1	0.1	0.2	0.01	0.02	0	0	0	0	0.5	1.3
Alexandria	0.7	1.4	0	0.02	0.2	0.3	0	0	0.06	0.11	0.9	1.8
Fairfax	2.1	4.1	0.7	1.4	0.9	1.8	0.1	0.2	0.4	0.7	4.2	8.3
Prince William	0.9	1.9	0.2	0.5	0.2	0.4	0.5	1	0.3	0.6	2.2	4.5
Rappahannock Area	2.9	6.3	2.9	6.3	2.5	5.1	0.4	0.9	2.1	4.3	11	23
Stafford	1.2	2.4	0.8	1.8	0.6	1.1	0.05	0.09	1	1.9	3.7	7.3
Fredericksburg	0.1	0.2	0	<0.01	0	0	0.04	0.08	<0.01	0.01	0.1	0.3
King George	1.6	3.5	2	4.3	1.1	2.4	0.3	0.7	1	2	6.2	13.4
Spotsylvania	0.1	0.2	0.02	0.04	0.06	0.12	0	0	0.03	0.06	0.2	0.4
Caroline	0.02	0.04	0.1	0.2	0.7	1.4	0	0	0.1	0.3	1	2.1
Northern Neck	19	41	9.1	20	11	24	1.4	3	4.7	9.8	47	102
Westmoreland	2.5	6.1	1.8	4.2	4.3	9.9	0.1	0.3	1	2.2	10	23
Richmond	2.1	4.5	0.9	2	5	11	0.5	1.2	1.6	3.3	10	22
Northumberland	5.6	13	3.7	8.1	0.9	2	0	0	1	2.2	12	26
Lancaster	8.9	18	2.7	5.5	0.9	1.7	0.8	1.6	1.1	2.1	15	30
Middle Peninsula	23	41	40	70	42	76	0.2	0.3	31	54	139	244
Essex	0.6	1.3	1.2	2.5	5.2	11	0	0	1.5	2.9	8.6	18
King and Queen	0.1	0.3	1.5	2.9	3.9	8.5	0	0	1.6	3.1	7.2	15
King William	0.5	1	0.4	1.4	2.1	5.7	0	0	0.7	1.4	3.8	9.7
Middlesex	2.7	5.3	1.8	3.6	2.4	5	0	0	1.4	2.8	8.7	17
Gloucester	7.5	13	20	34	12	20	0.2	0.3	15	25	55	92
Mathews	12	21	15	26	16	26	0	0	11	19	55	92
Hampton Roads	160	280	40	72	61	113	1.5	2.5	84	127	348	596
James City	3.9	7.6	0.8	1.5	2.3	4.9	<0.01	0.01	1.4	2.8	8.5	17
York	13	22	2.6	5.1	0.2	0.3	0.4	0.6	3.7	6.7	20	34
Newport News	4.2	5.2	8.6	13	0.03	0.03	0	0	0.9	1.3	14	19
Poquoson City	11	16	0	0	0.11	0.11	0	0	0.6	1.1	12	17
Hampton City	17	32	7.9	14	<0.01	<0.01	0	0	0.5	0.9	26	46
Surry	0.3	0.6	0.2	0.4	1.6	3.2	0.5	1	1.2	2.4	3.9	7.7
Isle of Wight	3.4	7.5	1.2	2.4	1	2	0.4	0.8	0.6	1.4	6.6	14
Norfolk City	24	42	0.04	0.06	0	<0.01	0	0	0.7	1.1	25	44
Virginia Beach	39	69	5.2	8.7	49	85	0.03	0.03	29	41	123	204
Suffolk City	5.1	9.3	2.3	5.9	<0.01	0.01	0	<0.01	0.3	0.8	7.7	16
Portsmouth	12	21	0.5	0.8	<0.01	<0.01	0.07	0.1	9.1	9.5	22	31

Chesapeake	27	48	10	21	6.9	17	0	0	36	58	81	145
Virginia³	232	411	129	228	173	307	25	32	186	297	753	1286

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

2. Total includes the five categories listed as well as a small amount of low land that the authors did not analyze.

3. Excludes the Richmond Regional and Crater Planning Districts, as well as three jurisdictions from the Hampton Roads Planning District: Southampton County and the cities of Franklin and Williamsburg.

C-4. Area of Land by Elevation by Shore Protection Likelihood, High and Low Estimates: Virginia¹

Elevation relative to Spring High Water (m)	Area (square kilometers)															
	Dry land: likelihood of shore protection										Dry Land		Non Tidal Wetlands		All Land	
	Shore Protection Certain		Shore Protection Likely		Shore Protection Unlikely		No Shore Protection		Not Considered							
low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	
0.5	20	82	11	49	16	71	6	20	0.9	14	54	236	21	86	75	322
1.0	67	184	39	104	57	140	17	25	9	26	189	479	72	167	262	646
1.5	137	296	78	165	107	223	23	28	18	38	362	751	134	240	496	992
2.0	232	411	129	228	173	307	26	32	26	52	585	1029	197	317	782	1346
2.5	329	571	181	298	243	393	28	34	35	66	816	1362	260	389	1075	1751
3.0	442	737	232	377	312	476	31	37	43	80	1060	1707	320	459	1380	2166
3.5	591	902	299	456	387	558	33	39	55	94	1366	2049	386	529	1752	2578
4.0	757	1024	377	527	470	632	35	41	69	108	1708	2332	455	594	2163	2926
4.5	905	1139	454	588	550	689	37	43	82	122	2028	2582	523	657	2551	3239
5.0	1020	1251	517	648	612	747	40	46	95	138	2283	2830	583	745	2867	3574

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

References (metadata)

- Intergovernmental Panel on Climate Change, 2001, *Climate Change 2001: The Scientific Basis*, Technical Summary of Working Group 1. Cambridge University Press, New York and London.
- Titus, J.G., and V.K. Narayanan, 1995, *The Probability of Sea level Rise*, EPA Office of Policy, Planning, and Evaluation, EPA 230-R-95-008. Washington, D.C.: U.S. EPA.
- U.S. Environmental Protection Agency, 1989, *The Potential Effects of Global Climate Change on the United States: Report to Congress*. Office of Policy, Planning, and Evaluation
- Titus, J.G. and J. Wang, 2008. Maps of Lands Close to Sea Level along the Middle Atlantic Coast of the United States: An Elevation Data Set to Use While Waiting for LIDAR, Chapter 1 in J.G. Titus and E.M. Strange (eds.), *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.
- Titus, J.G. and E.M. Strange (eds.) 2008. *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.
- Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson, 2008, Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region. In J.G. Titus and L. Strange (eds.) *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.
- Titus, J.G., 1998, "Rising seas, coastal erosion and the takings clause: How to save wetlands and beaches without hurting property owners," *Maryland Law Review* 57:1279–1399.
- Hoffman, J.S., D. Keyes, and J.G. Titus 1983, *Projecting Future Sea Level Rise*. Washington, DC : U.S. Environmental Protection Agency.
- Barth, M.C. and J.G. Titus, editors. 1984. *Greenhouse Effect and Sea Level Rise: A Challenge for this Generation*, Van Nostrand Reinhold, New York.
- Titus, J.G., et al., 1991, "Greenhouse effect and sea level rise: The cost of holding back the sea," *Coastal Management* 19:171–204; Yohe, G., 1990, "The cost of not holding back the sea: Toward a national sample of economic vulnerability," *Coastal Management* 18:403–431.
- Trono, K.L., 2003, *An Analysis of the Current Shoreline Management Framework in Virginia: Focus on the Need for Improved Agency*.
- Hardaway, C.S., L.M. Varnell, D.A. Milligan, G.R. Thomas, and C.H. Hobbs, 2001, *Chesapeake Bay Dune Systems: Evolution and Status*, Virginia Institute of Marine Science.
- Virginia Public Beach Board, 2000, *20 Years of Coastal Management*, Board on Conservation and Development of Public Beaches, Richmond, VA.
- Nuckols, W.H., P. Johnston, D. Hudgens, and J.G. Titus. 2010. "Maryland." In James G. Titus and Daniel Hudgens (editors). *The Likelihood of Shore Protection along the Atlantic Coast of*

the United States. Volume 1: Mid-Atlantic. Report to the U.S. Environmental Protection Agency. Washington, D.C.

J.G. Titus. 2010. "District of Columbia." In James G. Titus and Daniel Hudgens (editors). *The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic.* Report to the U.S. Environmental Protection Agency. Washington, D.C.

Titus, J.G. and D. Hudgens (ed) 2010. *The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 1: Mid-Atlantic.* Report to the U.S. Environmental Protection Agency. Washington, D.C.

Titus, J.G. and D. Cacula. 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. In J.G. Titus and E.M. Strange (eds.). *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.

Jones, R. and J Wang. 2008 Interpolating Elevations: Proposed Method for Conducting Overlay Analysis of GIS Data on Coastal Elevations, Shore Protection, and Wetland Accretion. In J.G. Titus and E.M. Strange (eds.). *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*, EPA 430R07004, Washington, DC: U.S. EPA.