Appendix F. Chesapeake Bay

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In 1607, a group of English settlers landed three ships near the mouth of North America's largest estuary, and established Jamestown, the first permanent town in what eventually became the United States of America. Jamestown was the capital of Virginia until 1699, when a fire destroyed the statehouse. Rising sea level was probably also a contributing factor in the decision to move the capital to Williamsburg[110], because it was making the Jamestown peninsula less habitable than it had been during the previous century (Blanton, 2000). Because the James River was brackish, groundwater was the only reliable source of freshwater. But the low elevations on Jamestown limited the thickness of the freshwater table — especially during droughts. As Figure F.1 shows, a 10 cm rise in sea level can reduce the thickness of the freshwater table by 4 meters on a low-lying island where the freshwater lens floats atop the salt water.

Rising sea level has continued to alter Jamestown. Two hundred years ago, the isthmus that connected the peninsula to the mainland eroded, creating Jamestown Island (Johnson

110 Geologist Carl Hobbs contributed this idea as part of the stakeholder review process for the report. Carl Hobbs. (2007). Stakeholder Review Process. Stakeholder Comments.

and Hobbs, 1994 p. 11). Shore erosion also threatened the location of the historic town itself, until a stone revetment was constructed (Johnson and Hobbs, 1994, p. 11). As the sea rose, the shallow valleys between the ridges on the island became freshwater marsh, and then tidal marsh (Johnson and Hobbs, 1994, p. 9). Maps from the 17th century show agriculture on lands that today are salt marsh. Having converted mainland to island, the rising sea will eventually convert the island to open water, unless the National Park Service continues to protect it from the rising water.

Other shorelines along Chesapeake Bay have also been retreating over the last four centuries. Several bay island fishing villages have had to relocate to the mainland as the islands on which they were located eroded away (Leatherman, 1992). Low-lying farms on the eastern shores are converting to marsh, while the marshes in wildlife refuges convert to open water. As sea level rises, the risk of flooding is increasing from Poquoson, Virginia, to Fells Point (Baltimore) Maryland.

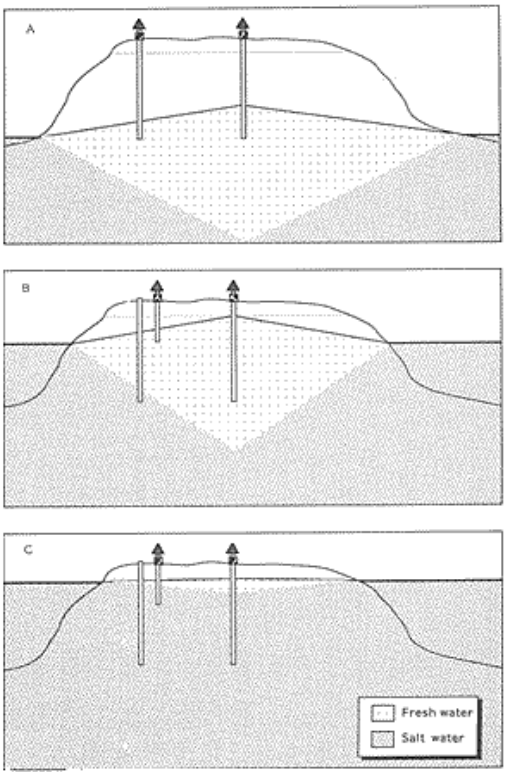


Figure F.1 Impact of sea-level rise on an island freshwater table. *(*A) The freshwater table extends below sea level 40 cm for every 1 cm by which it extends above sea level. (B) For islands with substantial elevation, a 1 meter rise in sea level simply shifts the entire water table up 1 meter, and the only problem is that a few wells will have to be replaced with shallower wells. (C) However, for very low islands the water table cannot rise because of runoff, evaporation, and transpiration. A rise in sea level would thus narrow the water table by 40 cm for every 1 cm that the sea level rises, effectively eliminating groundwater supplies for the lowest islands.

This appendix examines the sensitivity of Chesapeake Bay and some of its tributaries to rising sea level. We first examine coastal elevations and vulnerable habitat (Section F.1) and then summarize policies related to the impacts of sea-level rise (F.2). Finally, we briefly discuss new estimates of the population that resides in the areas most vulnerable to sea-level rise (F.3). Sections F.2 and F.3 start with Hampton Roads and then proceed clockwise around the Bay to Virginia's Middle Peninsula and Northern Neck, then up the

Potomac River to Washington DC, then up Maryland's Western Shore, around to the Upper Eastern Shore, and finally down to the Lower Eastern Shore. The discussions for Virginia are largely organized by planning district; the Maryland discussions are organized by major section of shore.

F.1 IMPACTS ON THE PHYSICAL ENVIRONMENT

F.1.1 Hampton Roads

Hampton Roads is the southernmost coastal planning district in Virginia. Extending from the North Carolina border to the York River, the region has 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.

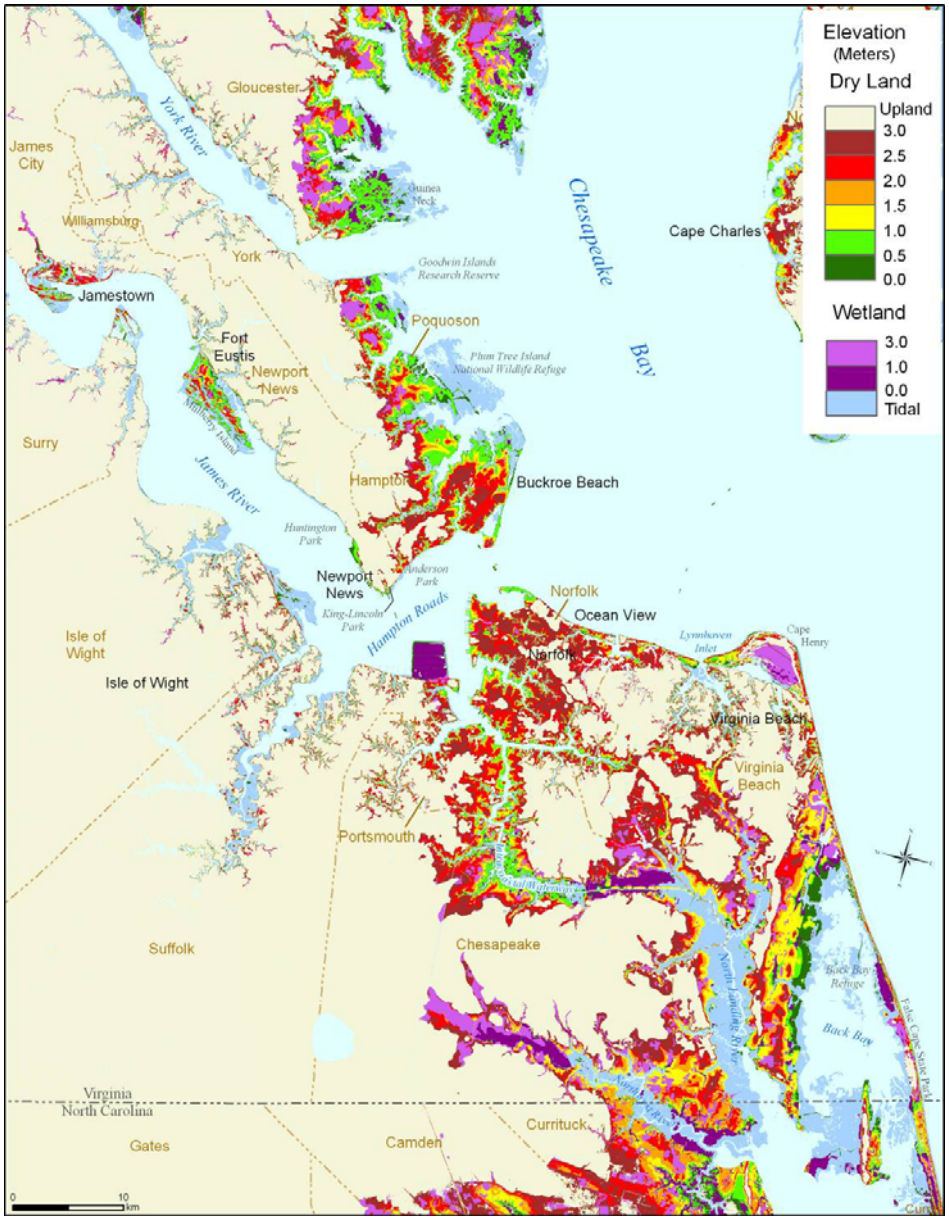
Elevations

Figure F.2 shows the elevations of lands close to sea level in the Hampton Roads area (see also Table F.1). 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. Most of Virginia Beach's very low land is either along the back-barrier bays near the North Carolina border, or along the North Landing River. The lightly developed southern half of this city is mostly within 3 meters above mean 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[111]. Hampton and Newport News have substantial areas between the 1.5- and 3-meter contours, with a few areas within 1 meter above the tides.

The town of Poquoson is extensively developed and probably the community that is most vulnerable to rising water levels (see Figures F.3 and F.4). Although the city's corporate limits include some high ground, the town is approximately 50% wetland and almost all residential lands are less than 3 meters above the tides; several neighborhoods are vulnerable to even minor surges in Chesapeake Bay. The localities located farther up the James and York rivers have less low land. An important exception is historic Jamestown Island, which has been gradually submerged by the rising tides since the colony was established 400 years ago.

111 The intracoastal waterway includes the North Landing River which flows into Currituck Sound (NC), the southern branch of the Elizabeth River, which flows into Chesapeake Bay, and an East-West canal that connects these two rivers.



12379

12380 **Figure F.2** Hampton Roads: Elevations relative to spring high water.

Table F.1 Low and high estimates for the area of dry and wet land close to sea level, Hampton Roads, Virginia (square kilometers).

	Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
		Low	High	Low	High	Low	High	Low	High	Low	High
Locality	Cumulative (total) amount of Dry Land below a given elevation										
Virginia Beach		9.3	33.0	30.3	68.7	93.6	163.2	184.7	272.9	378.1	418.2
Chesapeake		3.5	11.9	10.8	30.6	44.6	86.6	100.4	204.5	353.0	429.7
Norfolk		1.9	5.8	5.2	17.1	24.0	42.4	52.4	91.2	121.7	128.2
Portsmouth		1.2	3.9	3.5	9.6	12.8	22.0	26.7	45.0	62.6	69.9
Suffolk		0.7	4.3	3.1	7.1	7.5	15.2	13.0	31.0	47.3	73.3
Isle of Wight		0.2	3.4	2.1	6.2	6.0	12.8	10.1	21.6	26.8	42.0
Surry		0.0	1.4	0.7	2.7	2.7	5.3	4.6	7.1	8.1	11.2
James City		0.1	3.8	2.2	7.2	7.0	14.2	11.8	22.1	26.7	38.7
York		1.4	6.0	4.8	13.1	16.3	27.7	28.3	37.3	44.3	51.3
Newport News		2.2	6.9	6.1	11.0	12.9	17.9	19.3	24.8	34.9	42.3
Poquoson		1.4	4.5	4.1	8.8	10.9	16.3	16.4	16.6	16.7	16.7
Hampton		1.9	5.9	5.3	18.1	25.4	45.3	51.2	73.8	94.7	102.4
Total		**23.8**	**90.8**	**78.2**	**200.2**	**263.6**	**468.9**	**519.0**	**847.9**	**1214.9**	**1423.8**
	Cumulative (total) amount of wetlands below a given elevation										
Virginia Beach	111.9	4.2	14.5	13.3	24.9	29.1	40.9	43.5	49.6	56.5	59.3
Chesapeake	39.7	4.5	16.6	15.4	32.1	36.4	58.3	55.7	120.2	180.3	250.8
Norfolk	4.7	0.1	0.3	0.2	0.5	0.7	1.1	1.1	1.5	1.7	1.7
Portsmouth	3.7	2.4	7.7	6.8	8.9	9.1	9.5	9.6	10.3	10.9	11.2
Suffolk	26.4	0.0	0.2	0.1	0.3	0.3	0.8	0.5	1.8	2.9	33.1
Isle of Wight	28.6	0.0	0.3	0.2	0.6	0.6	1.4	1.0	3.1	4.0	7.3
Surry	11.5	0.0	0.6	0.3	1.3	1.2	2.4	2.1	2.7	2.9	3.4
James City	32.8	0.0	0.8	0.4	1.5	1.4	2.8	2.5	3.7	4.2	5.6
York	17.0	0.2	0.9	0.7	2.7	3.7	6.7	6.9	8.0	9.2	9.9
Newport News	15.1	0.1	0.3	0.3	0.7	0.9	1.3	1.4	1.4	1.6	1.7
Poquoson	23.7	0.0	0.1	0.1	0.4	0.6	1.1	1.1	1.1	1.1	1.1
Hampton	14.3	0.1	0.2	0.2	0.4	0.5	0.9	1.1	2.2	4.4	6.2
Total	**329.4**	**11.7**	**42.4**	**38.0**	**74.2**	**84.5**	**127.1**	**126.5**	**205.4**	**279.5**	**391.1**
Dry and Nontidal wetland		35	133	116	274	348	596	645	1053	1494	1815
All Land	329	365	463	446	604	677	925	975	1383	1824	2144

Source: Titus and Cacela, 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. Section 1.3 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea-level Rise, J.G. Titus and E. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC.The low and high estimates are based on the on the contour interval and/or stated root mean square error (RMSE) of the data used to calculate elevations.

Figures F.3 and F.4 Poquoson, Virginia. Homes Close to Sea Level. (a) The water levels in the roadside ditches rise and fall with the tides. A bulkhead is on one side of the ditch, while marsh grasses have colonized the other side (October 2002). (b) A home being elevated after Hurricane Isabel (October 2004).

Vulnerable Habitat

Sandy beaches with dune systems comprise the Chesapeake Bay shoreline of the City of Virginia Beach and Norfolk, from Cape Henry to the mouth of the James River (Hardaway, *et al.*, 2005). Overall trends in the last century show the dunes east of the Lynnhaven inlet advancing into the Bay. West from the inlet, erosion, beach nourishment, and fill operations as well as condominium development and shoreline armoring have affected the accretion and erosion patterns (Hardaway, *et al.*, 2005). Along the shores of Norfolk, the rate of erosion is generally low, and beach accretion occurs along much of the shore (Berman *et al.*, 2002). Most of the shore along Chesapeake Bay is protected by groins and breakwaters, and hence relatively stable (Hardaway *et al.*, 2005, p.9). On the other side of the James River, the Bay shoreline is dominated by marshes, many of which are eroding.

Along the bay shores of the Hampton Roads planning district, current sea-level trends or a modest acceleration (e.g. current rate plus 2mm/yr) are unlikely to substantially

12402 diminish beach habitat, compared to the existing impact from human activities.
12403 Urbanization and foot traffic impair beach habitat compared with a pristine
12404 environment[112]. Nevertheless, the commitment to maintain the existing beaches make
12405 further habitat degradation unlikely because the beaches will continue to exist, unless
12406 sea-level rise accelerates enough to cause officials to rethink that commitment.
12407
12408 Other tidal habitat is more vulnerable. Approximately one quarter of the tidal wetlands in
12409 the area is within Poquoson's Plum Tree Island National Wildlife Refuge (see Table
12410 F.1)[113]. Unlike most mid-Atlantic wetlands, these wetlands appear to be unable to keep
12411 pace with the current rate of sea-level rise (Reed *et al.*, 2008). This refuge has very
12412 limited human access because unexploded ordnance remains on the island from its prior
12413 use as a bombing range. The relative isolation of the area has made it a haven for over
12414 100 different species of birds, including northern harrier (*Circus cyaneus*), black duck
12415 (*Anas rubripes*), sedge wren (*Cistothorus platensis*), sharp-tailed sparrow (*Ammodramus*
12416 *caudacutus*), bald eagle, peregrine falcon (*Falco peregrinus*), black-necked stilts
12417 (*Himantopus mexicanus*), and little blue heron (*Egretta caerulea*). In addition to the salt
12418 marsh, the refuge has substantial forested dune hummocks (CPCP, 1999). A variety of
12419 mammals (muskrats, red fox, and white-tailed deer) use the higher ground of the refuge.
12420 Endangered sea turtles, primarily the loggerhead, use the nearshore waters. Oyster, clams,

112 A possible exception is Grandview Beach Nature Preserve in Hampton. The preserve has over two miles of beach shoreline on Chesapeake Bay and is home to a population of northeastern beach tiger beetles (Cicindela dorsalis dorsalis), federally listed as threatened (USFWS, 1994). U.S. Fish and Wildlife Service. 1994. Northeastern Beach Tiger Beetle (Cicindela dorsalis dorsalis) Recovery Plan. Hadley Massachusetts. 60 pp. page 6.
113 The refuge has the vast majority of Poquoson's tidal wetlands.

and blue crabs inhabit the shallow waters and mudflats, and striped bass, mullet, spot, and white perch have been found in the nearshore waters and marsh (USFWS, date unkown).

The wetlands in York County appear able to keep pace with the current rate of sea-level rise; but assuming that they are typical of most wetlands on the western side of Chesapeake Bay, they would become marginal with a modest acceleration and be lost if sea-level rise accelerates to 1 cm/yr (Reed *et al.*, 2008). Bald eagles currently nest in the Goodwin Islands National Estuarine Research Reserve (Watts and Markham, 2003).This reserve includes intertidal flats, 300 acres of eelgrass and widgeon grass (VIMS, date unknown), and salt marshes dominated by salt marsh cordgrass (*Spartina alterniflora*) and salt meadow hay (*Spartina patens*). Even if the wetlands keep pace with rising sea level, the habitat just above the wetlands could be lost as it converts to marsh. This habitat includes forested wetland ridges, dominated by estuarine scrub/shrub vegetation, and ridges with oak and pine black gum (*Nyssa sylvatica*), and cottonwood (*Populus deltoides*) (VIMS, date unknown).

F.1.2 York River to Potomac River

Elevations

Two planning districts lie between the York and Potomac rivers. The Middle Peninsula Planning District includes the land between the York and Rappahannock rivers. The Northern Neck is between the Rappahannock and Potomac rivers.

As Figure F.5 shows, the Middle Peninsula includes Mathews and Middlesex counties, which are along Chesapeake Bay. Gloucester County is between the York River and Mobjack Bay, with very little of the county actually on Chesapeake Bay. Gloucester is the most developed county, while the remainder of the Middle Peninsula consists of a mix of rural areas and seasonally occupied coastal homes.

The Northern Neck planning district is primarily rural, with approximately one-third of the land area currently farm land. Major developed areas lie along the shores of Chesapeake Bay and the Potomac River, while the Rappahannock River banks remain largely undeveloped, especially upstream from Lancaster County.

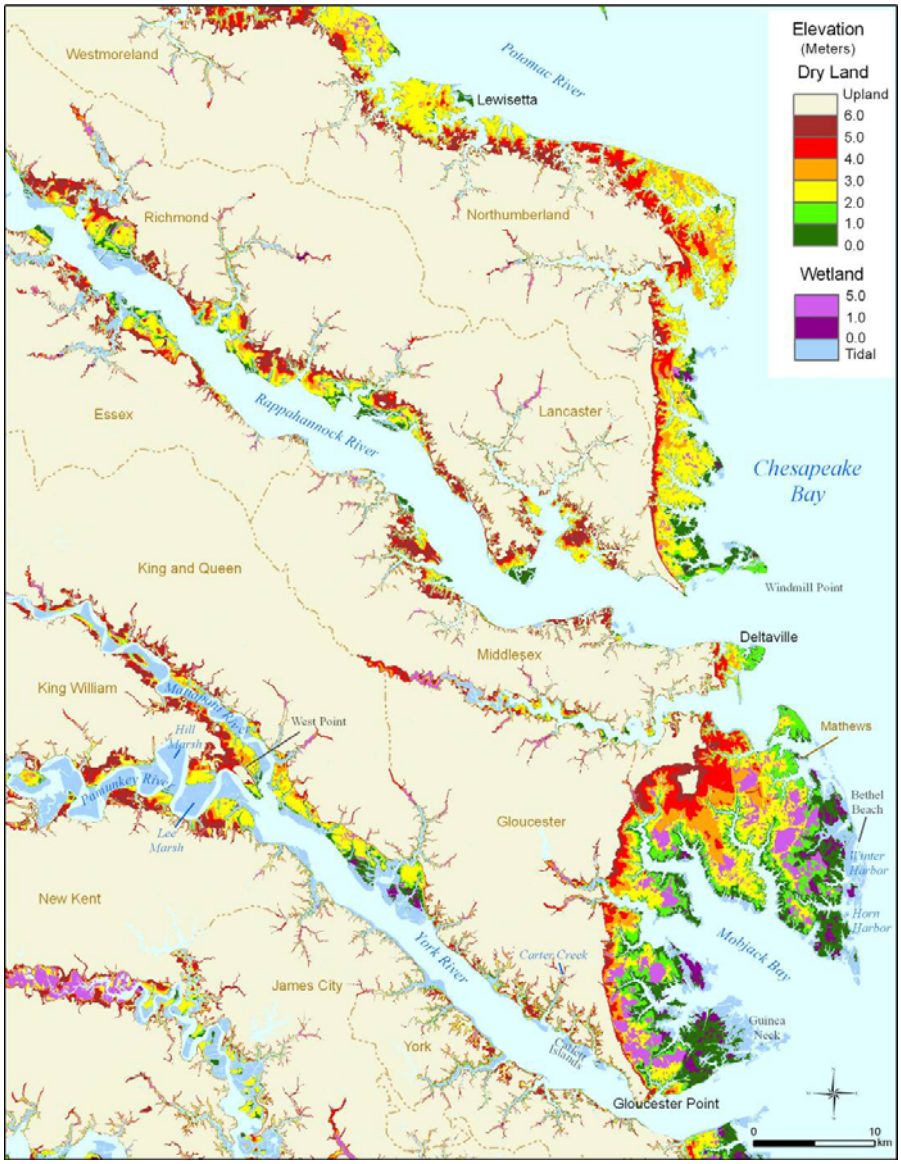


Figure F.5 Middle Peninsula and Northern Neck: Elevations relative to spring high water. Contour interval is 1 meter because data quality is insufficient to display 50 cm at this scale.

Figure F.5 and Table F.2 report elevations relative to spring high water for the two planning districts. Gloucester County has between 13 and 33 square kilometers of dry

land within 1 meter above the coastal wetlands. Most of that land is on the Guinea Neck. The long-established communities on this neck may be the most vulnerable to rising sea level along the Western Shore of Chesapeake Bay.

The vast majority of Mathews County is less than 6 meters above spring high water, as Figure F.5 shows. For the most part, the very low dry land in this county tends to be undeveloped forests lying just inland of the tidal wetlands. Its most vulnerable development is in the southernmost neck, between Horn Harbor and Mobjack Bay, approximately 1–1.5 meters above spring high water. The other counties have relatively little low land. In spite of its name, for example, Deltaville (Middlesex) is generally 4 meters above sea level and not vulnerable to inundation.

For the most part, the Northern Neck has rolling hills with relatively few low spots. Many coastal homes are along bluffs, some of which are eroding. The available topographic data suggest that within the Northern Neck planning district, Lancaster County has the most dry land located below 2 meters (between 14 and 28 square kilometers)[114].

114 The available topographic data does not allow a meaningful estimate of the land within one meter above the tides. See Map 1.1 in Chapter 1.

Table F.2 Low and high estimates for the area of dry and wet land close to sea level Chesapeake Bay, Middle Peninsula and Northern Neck Areas, Virginia (square kilometers).

	Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
		Low	High	Low	High	Low	High	Low	High	Low	High
Locality	Cumulative (total) amount of Dry Land below a given elevation										
Gloucester		4.1	16.0	13.2	32.9	40.5	66.9	66.9	84.2	96.4	110.8
Mathews		4.7	14.8	13.4	33.1	43.9	73.1	78.6	96.8	114.7	120.7
Middlesex		0.2	3.4	2.0	6.8	7.3	14.4	13.1	22.8	28.1	38.9
King William		0.0	1.6	0.9	3.2	3.1	8.4	5.4	17.7	22.7	36.1
King and Queen		0.0	2.9	1.7	5.7	5.5	11.9	9.6	19.0	22.7	32.9
Essex		0.0	3.8	2.0	7.3	7.1	15.5	12.3	27.9	34.2	52.8
Lancaster		0.1	7.0	3.6	13.8	13.8	28.0	24.0	41.5	48.4	67.9
Northumberland		0.0	5.9	2.8	11.5	11.0	24.1	19.2	63.8	84.5	140.9
Richmond		0.0	4.6	2.4	8.9	8.7	18.5	15.0	31.6	38.2	56.5
Caroline		0.0	0.4	0.3	0.9	0.9	1.8	1.5	2.8	3.4	5.2
Spotsylvania		0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.5	0.5	0.8
Fredericksburg		0.0	0.1	0.0	0.1	0.1	0.2	0.2	0.3	0.4	0.5
Total		**9.2**	**60.5**	**42.4**	**124.2**	**142.1**	**263.2**	**246.0**	**409.0**	**494.2**	**664.0**
	Cumulative (total) amount of wetlands below a given elevation										
Gloucester	43.5	1.4	5.5	4.5	11.9	14.7	24.8	24.6	30.8	34.4	38.5
Mathews	27.0	1.2	3.8	3.5	8.6	11.4	19.0	21.6	33.6	48.1	55.1
Middlesex	9.7	0.0	0.7	0.4	1.4	1.4	2.8	2.4	3.5	3.8	4.8
King William	35.6	0.0	0.4	0.2	0.7	0.7	1.4	1.2	2.0	2.3	3.3
King and Queen	21.6	0.0	0.9	0.5	1.7	1.6	3.1	2.8	4.0	4.4	5.8
Essex	27.5	0.0	0.8	0.4	1.5	1.5	2.9	2.5	3.9	4.4	5.9
Lancaster	9.8	0.0	0.5	0.3	1.1	1.1	2.1	1.8	2.8	3.2	4.2
Northumberland	11.4	0.0	0.5	0.3	1.1	1.0	2.2	1.8	5.1	6.6	10.8
Richmond	21.7	0.0	0.9	0.4	1.7	1.6	3.3	2.8	4.5	5.1	6.9
Caroline	6.3	0.0	0.1	0.0	0.1	0.1	0.3	0.2	0.7	0.9	1.5
Spotsylvania	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Fredericksburg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**214.3**	**2.6**	**14.1**	**10.5**	**29.7**	**35.1**	**62.0**	**61.7**	**90.9**	**113.5**	**136.9**
Dry and Nontidal wetland		12	75	53	154	177	325	308	500	608	801
All Land	214	226	289	267	368	392	539	522	714	822	1015

Source: Titus and Cacela, 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. Section 1.3 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea-Level Rise, J.G. Titus and E. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC. The low and high estimates are based on the on the contour interval and/or stated root mean square error (RMSE) of the data used to calculate elevations. For additional details, see Chapter 1.

Vulnerable Habitat

Like the marshes of Poquoson to the south, the marshes of the Guinea Neck and adjacent islands are not keeping pace with the current rates of sea-level rise (Reed *et al.*, 2008). For more than three decades, scientists have documented their migration onto farms and

forests (Moore, 1976). Thus, the continued survival of these marshes depends on land use and shore protection decisions. As a general rule, loss of marsh can eliminate nesting and forage habitat for birds and fish, and reduce the food supply of invertebrates such as crabs and shrimp, as well as the birds that feed on these species[115].

Upstream from the Guinea Neck, sea-level rise is evident in the York River's tributaries, not because wetlands are converting to open water but because the composition of wetlands is changing. Along the Pamunkey and Mattaponi rivers, dead trees reveal that tidal hardwood marshes are converting to brackish or freshwater marsh[116]. Tidal hardwood marshes provide nesting sites for piscivorous species such as ospreys, bald eagles, and double-crested cormorants (Robbins and Blom, 1996). The freshwater marshes also host a variety of migratory and breeding birds.

Some scientists are concerned about the implications of a shift from high marsh to low marsh. In a study of the Lee and Hill marshes in the lower Pamunkey River, the authors posit that brackish marshes, due to their locations at transitions between tidal freshwater and oligohaline marshes, may face greater risk than marshes with more extreme, nontransitional salinities. If sea-level rise were to convert 100 hectares of high marsh big cordgrass (*Spartina cynasuroides*) to low marsh arrow arum (*Peltandra virginica*), the authors estimate a reduction in the number of breeding red-winged blackbirds that currently depend on the big cordgrass portions of the marshes (Paxton and Watts, 2002). However, the change to an arrow arum-dominated marsh may increase bird density and

115 See Chapter 4.
116 Written communication from Gary Fleming, Vegetation ecologist for the Virginia Natural Heritage Program, cited in Shellenbarger Jones and Bosch, 2007a.

diversity during winter, particularly for waterfowl and shorebirds. Arrow arum dies back in winter, creating an open mud flat that provides birds with improved access to invertebrate prey (Paxton and Watts, 2002, pp 25-26).

In Mathews County, Bethel Beach (a natural area preserve separating Winter Harbor from Chesapeake Bay) is currently migrating inland over an extensive salt marsh area (Shellenbarger Jones and Bosch, 2008a). The beach is currently undergoing high erosion (Berman *et al.*, 2000), and is home to a population of the Northeastern beach tiger beetle (federally listed as threatened) and a nesting site for least terns, which scour shallow nests in the sand. In the overwash zone extending toward the marsh, a rare plant is present, the sea-beach knotweed (*Polygonum glaucum*). The marsh is also one of few Chesapeake Bay nesting sites for northern harriers (*Circus cyaneus*), hawks that commonly nest in more northern areas (VA DCR, 1999). As long as the shore is able to migrate, these habitats will remain intact; but eventually, overwash and inundation of the marsh could reduce the sea-beach knotweed and the northeastern beach tiger beetle population, as well as the nesting area for least terns and northern harriers (Shellenbarger Jones and Bosch, 2008a).

F.1.3 The Potomac River

Elevations

Virginia Side. The available topographic data do not allow a meaningful estimate of the land within 1 meter above the tides; but it does suggest that the counties along the Potomac River have between 24 and 53 square kilometers of dry land (and between 4 and

8 square kilometers of nontidal wetlands) below 2 meters (Table F.3). Although Westmoreland and King George County have the greatest amount of low land (a combined area of between 14 and 33 square kilometers below 2 meters), the low areas are well distributed, as shown in Figure F.6. Many coastal homes are along bluffs, some of which are eroding.

The most low-lying community on the Virginia side of the Potomac River is Lewisetta in Northumberland County. Lewisetta appears to be the only community along the Potomac River vulnerable to tidal inundation with a 50–100 cm rise in sea level. Water in some ditches 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. Somewhat higher, Old Town Alexandria and Belle Haven (Fairfax County) both flood occasionally from high levels in the Potomac River. But outside a small number of communities, shore erosion–not inundation–will almost certainly be the primary factor forcing people to choose between shore protection and land loss.

Table F.3 Low and high estimates for the area of dry and wet land close to sea level, Potomac River (square kilometers).

		Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
			Low	High	Low	High	Low	High	Low	High	Low	High
Locality	**State**	Cumulative (total) amount of Dry Land below a given elevation										
Westmoreland	VA		0.0	4.7	2.4	9.3	9.0	21.2	15.5	53.0	69.2	112.3
King George	VA		0.0	2.7	1.5	5.4	5.2	11.4	9.0	21.9	27.3	42.8
Stafford	VA		0.0	1.4	0.8	2.7	2.7	5.4	4.6	8.1	9.5	13.5
Prince William	VA		0.0	1.0	0.5	2.0	1.9	3.9	3.3	5.5	6.4	8.8
Fairfax	VA		0.0	2.0	1.1	3.9	3.8	7.6	6.6	10.7	12.4	18.1
Alexandria	VA		0.0	0.4	0.3	0.9	0.9	1.7	1.5	2.5	2.9	4.0
Arlington	VA		0.0	0.2	0.1	0.5	0.5	1.3	0.8	2.6	3.4	5.0
DC			1.6	3.0	2.8	4.4	5.5	7.4	8.9	11.1	15.9	17.7
Prince George's	MD		0.1	1.1	0.5	2.2	1.6	4.0	3.2	5.4	6.6	9.9
Charles	MD		0.7	10.9	4.6	19.4	14.1	38.4	28.3	64.0	74.2	96.0
St. Mary's	MD		1.6	12.0	5.6	19.8	14.9	39.2	27.9	70.1	81.2	99.8
Total			**4.1**	**39.5**	**20.1**	**70.4**	**60.0**	**141.5**	**109.5**	**255.1**	**308.9**	**428.1**
		Cumulative (total) amount of wetlands below a given elevation										
Westmoreland	VA	14.4	0.0	0.5	0.3	1.0	1.0	2.2	1.7	5.6	7.3	12.0
King George	VA	13.5	0.0	0.5	0.3	1.0	1.0	2.0	1.7	2.8	3.3	4.6
Stafford	VA	6.8	0.0	0.5	0.3	1.0	1.0	1.9	1.7	2.6	3.0	3.9
Prince William	VA	5.1	0.0	0.2	0.1	0.3	0.3	0.6	0.5	0.7	0.8	0.9
Fairfax	VA	4.9	0.0	0.2	0.1	0.4	0.4	0.7	0.6	0.9	1.1	1.4
Alexandria	VA	0.2	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Arlington	VA	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DC		0.5	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.3	0.3
Prince George's	MD	1.6	0.0	0.3	0.1	0.5	0.4	0.8	0.7	0.9	1.2	2.1
Charles	MD	22.9	0.1	3.6	1.4	6.2	4.6	11.3	9.0	15.9	17.8	22.2
St. Mary's	MD	11.7	0.3	1.8	0.8	3.3	2.4	7.1	4.9	12.9	15.4	22.5
Total		**81.5**	**0.5**	**7.6**	**3.5**	**13.9**	**11.1**	**26.8**	**21.0**	**42.7**	**50.1**	**70.1**
Dry and Nontidal wetland			5	47	24	84	71	168	130	298	359	498
All Land		82	86	129	105	166	153	250	212	379	441	580

Source: Titus and Cacela, 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. Section 1.3 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea-level Rise, J.G. Titus and E. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC. The low and high estimates are based on the on the contour interval and/or stated root mean square error (RMSE) of the data used to calculate elevations. For further details, see Chapter 1.

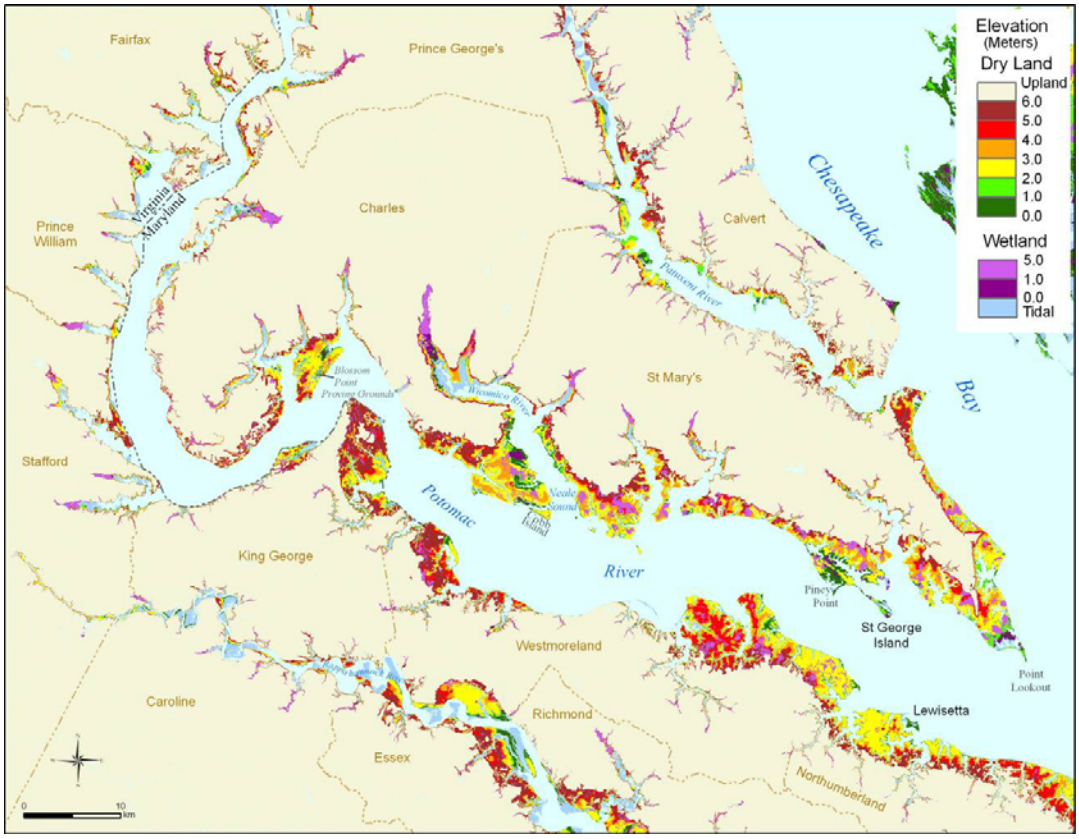
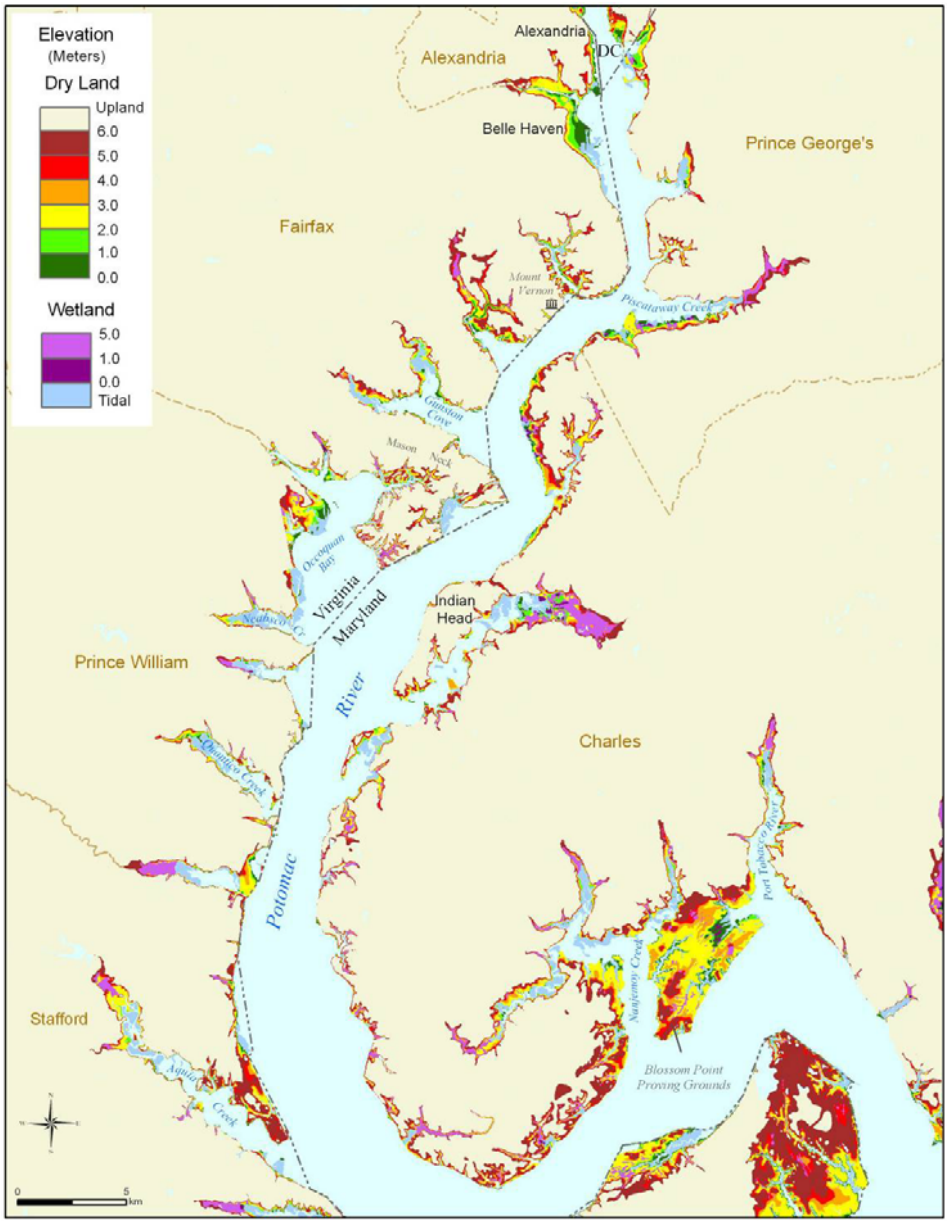


Figure F.6 Lower Potomac. Elevations relative to spring high water.



12544

12545 **Figure F. 7** Upper Tidal Potomac. Elevations relative to spring high water.

Maryland Side. Over the last several years, the Maryland Department of Natural Resources and other state agencies have collected LIDAR data for most of the state. In the near future it will be possible to provide a very precise estimate of the amount of land close to sea level along the Maryland side of the Potomac River. Although such an estimate was not available as this report was written, a rough estimate of the land within 1 meter above the tides is possible because the DNR provided EPA with spot elevation data. Table F.3 suggests that the Maryland side of the Potomac River has between 11 and 41 square kilometers of dry land and between 2 and 10 square kilometers of nontidal wetlands within 1 meter above spring high water. As Figure F.6 shows, the land within about 1 meter above the tides is concentrated around St. George Island and Piney Point in St. Mary's County, and along the Wicomico River and along Neal Sound opposite Cobb Island in Charles County. Substantial areas are within three meters of spring high water, including the southern 5 to 6 kilometers of St. Mary's County, almost all of Cobb and St. George Islands, and most of Blossom Point Proving Grounds. Relatively steep bluffs, however, are also common. Comparing the area of land close to sea level on the Maryland side to the 1300 km of shoreline along the River and its tributaries, the one-meter contour is, on average, less than 20 meters inland of the shore[117]. The inundation of low-lying lands is very unlikely to be a serious problem along the Maryland side of the Potomac River if sea level rises one meter.

Vulnerable Habitat

117 The total shoreline length of the Potomac and its tributaries is approximately 1300 km and 29 square kilometers are within one meter of the tides (Jones and Wang 2008).

The Lower Potomac River includes a diverse mix of land uses and habitat types. The implications of sea-level rise vary from one place to the next, depending on the land use, habitat type, and current or anticipated shoreline protection measures. The following description highlights key resources and impacts, but broad characterization of environmental implications is difficult and subject to exceptions.

Freshwater tidal marshes in the Lower Potomac are found in the upper reaches of tidal tributaries. For example, freshwater tidal marshes in the Caledon Natural Area and Chotank Preserve (in Virginia) provide habitat for catfish, perch, sunfish, and carp, and support numerous turtles, including the red-eared palm slider, its close relative the yellow-belly palm slider, painted turtles, and snapping turtles. Green heron and great blue heron feed on fish and invertebrates in the marshes. Local ponds attract numerous waterfowl, including Canada geese, tundra swan, and many duck species. Other major freshwater marshes are found on Virginia's Crow's Nest Peninsula and in Maryland's Zekiah Swamp Environmental Area. In general, freshwater tidal marshes in the Lower Potomac are keeping pace with sea-level rise through sediment and peat accumulation, and are expected to continue to do so, even under higher sea-level rise scenarios (Reed *et al.*, 2008).

Brackish tidal marshes are a major feature of the downstream portions of the region's rivers. For instance, major brackish marshes are found throughout Maryland's Nanjemoy Peninsula. In general, these marshes are keeping pace with sea-level rise today, but are considered marginal under moderate sea-level rise rate increases and are likely to be lost

if sea level accelerates by 2 mm/yr or more (Reed *et al.*, 2008). Loss of brackish tidal marshes would eliminate nesting, foraging, roosting, and stopover areas for migrating birds. Significant concentrations of migrating waterfowl forage and overwinter in these marshes in fall and winter. Rails, coots, and migrant shorebirds are transient species that feed on fish and invertebrates in and around the marshes and tidal creeks. The rich food resources of the tidal marshes also support rare bird species such as bald eagle and northern harrier (White, 1989). Fish species common in the brackish waters of the region include resident marsh species such as killifishes, anchovies, silversides, blennies, gobies, and hogchoker. Striped bass and white perch move in and out of marshes year-round. Anadromous fishes, including herrings and shad, as well as marine transients such as Atlantic menhaden and drum species, are present in late spring and early fall (White, 1989).

Unnourished *beaches and tidal flats* of the Lower Potomac are likely to erode as sea levels rise. Impacts on beaches are highly dependent on the nature of shoreline protection measures selected for a specific area. For example, at the mouth of the Wicomico River in Maryland are the developed areas of Wicomico Beach and Cobb Island. Assuming that the shores of Cobb Island continue to be protected, sea-level rise is likely to eliminate most of the island's remaining beaches and tidal flats. Likewise, at the mouth of Aquia Creek, north of Virginia's Crow's Nest Peninsula, shoreline protection could eliminate the beaches. The remainder of the county shoreline north of Aquia Creek is also primarily sandy beach; without nourishment, these beaches are likely to be eliminated in areas where armoring restricts shoreline retreat. Beach habitats often contain a high

diversity and abundance of species ranging from microscopic organisms to filter-feeding bivalves and deposit-feeders such as fiddler crabs and mud snails. In turn, numerous predators feed on these invertebrates, including predatory snails (such as the oyster drill), blue crab, and a variety of fishes and birds[118].

Finally, where the *cliffs and bluffs* along the Lower Potomac are not protected (*e.g.*, Westmoreland State Park, Caledon Natural Area), natural erosional processes will generally continue, helping to maintain the beaches below.

Above Indian Head, the Potomac River is fresh. Tidal wetlands are generally expected to keep pace with rising sea level in these areas (see Chapter 3). Nevertheless, the Dyke Marsh Preserve faces an uncertain future. Its freshwater tidal marsh is one of the last major remnants of the original freshwater tidal marshes of the Upper Potomac River (Johnston, 2000, p. 242). The marsh proper is dominated by common freshwater tidal marsh plants, and an adjacent embayment contains one of the largest mudflats along the Upper Potomac (Johnston, 2000, p. 228). A recent survey found 62 species of fish, nine species of amphibians, seven species of turtles, two species of lizards, three species of snakes, 34 species of mammals, and 76 species of birds in Dyke Marsh (Engelhardt *et al.*, 2005, p 4). The rare least bittern and the federally listed bald eagle breed in the marsh; it also hosts the only known breeding population of marsh wrens in the upper tidal Potomac (Johnston, 2000, p 248). Many of the fish species present (*e.g.*, striped bass, American shad, yellow perch, blueback herring) are important for commercial and recreational

118 For general information on the fauna of soft-sediment habitats see Chapter 6 in Bertness, 1999.

fisheries in the area (Mangold, 2004). A recent analysis of conditions at Dyke Marsh Preserve concluded that further study of the marsh's response to sea-level rise is needed to predict impacts and formulate restoration plans (Engelhardt *et al.*, 2005, p. 7).

Parklands on the Mason Neck Peninsula will be managed for conservation, but shoreline protection on adjacent lands may result in marsh loss and reduced abundance of key bird species. For instance, the Mason Neck National Wildlife Refuge hosts seven nesting bald eagle pairs and up to 100 bald eagles during winter. The refuge also has one of the largest great blue heron colonies in Virginia and provides nesting areas for hawks and waterfowl, as well as a stopover for migratory birds. Many of the resident and migratory birds are of high conservation priority. Studies in marshes of Virginia's Eastern Shore have found a direct relationship between marsh area and the abundance of bird species in the marsh (Watts, 1993).

Apart from conservation lands, much of the Upper Potomac shorefront is either beach and mudflat or is heavily developed. On the Virginia side, much of the Prince William County shoreline is developed with sandy beach (NOAA, 2005). On the Maryland side the beach at the Indian Head Naval Surface Warfare Center is likely to erode without nourishment, although plans are unclear. In developed parts of Maryland and D.C., narrow shoreline areas are likely to erode in front of hard structures.

F.1.4 Washington, D.C.

Elevations

As Figure F.11 shows, the Potomac River originally covered the area occupied today by East Potomac Park, Hains Point, Washington Channel, the Tidal Basin, and the Reflecting Pool. The plan was to put the president's residence just northeast of the mouth of Tiber Creek, which was near what is now 17th and Constitution; thus the White House grounds originally had a tidal shoreline (Figure F.8). To improve navigation between Georgetown and Bladensburg, George Washington and Pierre L'Enfant envisioned what became the Washington City Canal from Tiber Creek to the approximate vicinity of what later became the Washington Navy Yard. The canal eventually ran east from the Potomac River along what is now Constitution Avenue, with a lock at 6th Street, and a connection to James Creek, which flowed into the Anacostia[119].

119 For a brief history of the canal, see e.g. the web page for the Washington Canal Park: http://www.washingtoncanalpark.org/history.html (cited July 22, 2005).

Figure F.8 During the Presidency of John Tyler, the White House had waterfront property. Source: White House Historical Association (permission pending)

The White House and especially the Capitol were built on high ground immune from flooding, but much of the land between the two was quite low (Figures F.9 and F.10).

During the following decades, soil erosion from upstream farming led to the creation of wide mudflats below Georgetown. A large dredge-and-fill operation later excavated Washington Channel from the mudflats, and the extra material was used to create the shores of the Tidal Basin and the dry land on which the Lincoln Memorial, Jefferson Memorial, East Potomac Park, and Hains Point sit today (Bryan, 1914). These areas were bulkheaded from the start, because it was most efficient to construct a retaining wall and place material on one side of the wall. The canals were filled and replaced with drain pipes (see e.g. Farquhar, 2000).

Figure F.9 View of the City of Washington from Across the Anacostia River. The White House and Capitol are on high ground. The Potomac River is in the rear ground on left and right sides. Source: Library of Congress, "View of the City of Washington...from Arlington House..." Black and white lithograph by Fitz Hugh Lane after P. Anderson. Published by T. Moore's Lithography, Boston. Copyrighted 1838 by P. Anderson.

Figure F.10 City of Washington from Arlington House, looking east. A canal runs along the north side of the mall, which is very low-lying. The Potomac River occupies what later became Washington Channel, the Tidal Basin, and East Potomac Park. Source: Library of Congress, "City of Washington From beyond the Navy Yard." Color aquatint by William James Bennett after George Cooke. Published 1834 by Lewis P. Clover of New York.

Figure F.12 shows lands close to sea level, based largely on topographic information provided by the District of Columbia. Within the downtown area, most of the lowest land is the area filled during the 1870s, such as Hains Point and the location of the former Tiber and James Creeks, as well as the Washington City Canal that joined them. The largest low area is the former Naval Air Station, now part of Bolling AFB, just south of the mouth of the Anacostia River. A dike protects this area. Most of the low land between I-295 and the Anacostia River was open water when the District of Columbia was originally planned (compare Figures F.11 and F.12). The District of Columbia has between 2.8 and 4.1 square kilometers of land below 1 meter, an area roughly half the size of Rock Creek Park (NPS, 2008).

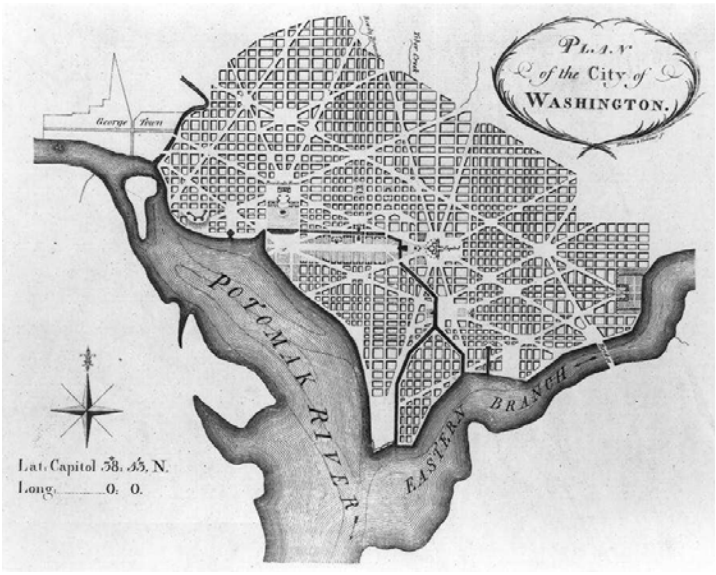
Vulnerable Habitat

The Upper Potomac River features a variety of sensitive wetland habitats potentially vulnerable to sea-level rise. Several major areas are managed for conservation or are the target of restoration efforts, making ultimate impacts uncertain.

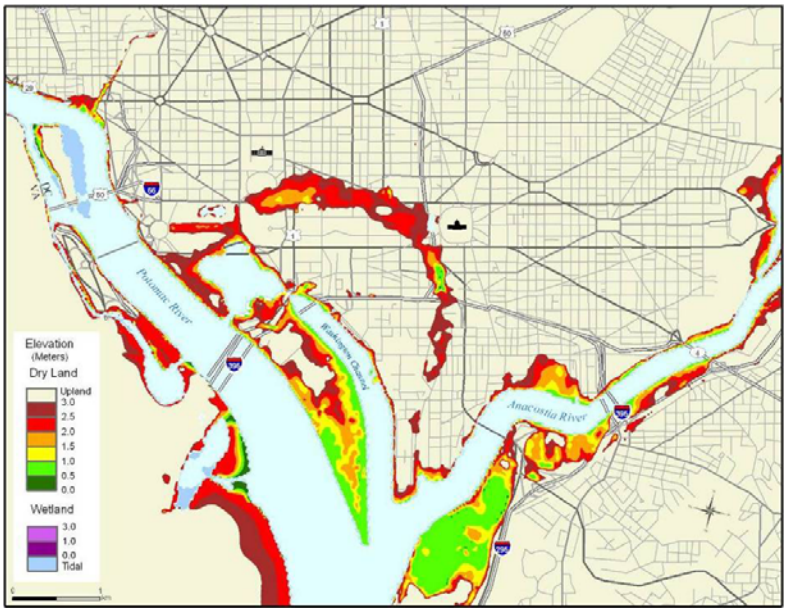
The wetlands around the Anacostia River are an example. Local organizations have been working to reverse historical modifications and restore some of the wetlands around several heavily altered lakes. Restoration of the 32-acre Kenilworth Marsh was completed in 1993; restoration of the Kingman Lake marshes began in 2000 (USGS, date

unknown). Other efforts to restore the river include conversion of some seawalls and bulkheads to woodland buffers. Given the planned buffers, marshes would be allowed to migrate in parts of Kingman Island; but shoreline armoring would also be required to protect the golf course. Monitoring of the restored habitats demonstrates that these marshes can be very productive. A recent survey identified 177 bird species in the marshes, including shorebirds, gulls, terns, passerines, and raptors as well as marsh nesting species such as marsh wren and swamp sparrow (Paul *et al.*, 2004, p. 11).

Roosevelt Island is another area where sea-level rise effects are uncertain. Fish in the Roosevelt Island marsh provide food for herons, egrets, and other marsh birds (NPS, not dated). The ability of the tidal marshes of the island to keep pace with sea-level rise will depend on the supply of sediment, and increased inundation of the swamp forest could result in crown dieback and tree mortality (Lippson and Lippson, 2006, p 218).



12733 **Figure F.11** L'Enfant's Plan for the City of Washington.
12734 Source: Library of Congress.
12735



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12737 **Figure F.12** Elevations of lands close to sea level in Washington, D.C.

12738

12739 **F.1.5 Western Shore: Potomac River to Susquehanna River**

12740 **Elevations**

12741 The Western Shore counties have relatively little low land, unlike the low counties across
12742 the Bay. As Figure F.13 shows, the Deal/Shady Side peninsula (Anne Arundel) and
12743 Aberdeen Proving Grounds (Harford) are the only areas with substantial amounts of land
12744 within 1 to 2 meters above spring high water. The block closest to the water, however, is
12745 similarly low in many of the older communities, including parts of Baltimore, downtown
12746 Annapolis, North Beach, and Chesapeake Beach.

12747

Table F.4 suggests that the Maryland localities along the Western Shore (including the Patuxent River) have between 28 and 73 square kilometers of dry land within 1 meter above the tides. Most the low land is in Harford, Anne Arundel, and Baltimore Counties (all of whose planning departments provided EPA with local elevation data)[120]. Hurricane Isabel flooded many areas between 1 and 3 meters above spring high water, including downtown Annapolis, North Beach, Chesapeake Beach, and Fells Point. (See box: Baltimore)

Between the Potomac and the Patuxent Rivers, the bay shore is usually a sandy beach in front of a bank less than three meters high. Cliffs and bluffs up to 35 meters above the water dominate the shores of Calvert County. The shores north of Calvert County tend to be beaches — but these beaches become narrower as one proceeds north, where the wave climate is milder.

Vulnerable Habitat

A range of sea-level rise impacts are possible along the western shore of Chesapeake Bay, including potential loss of key habitats. First, partial or complete marsh loss is expected in many areas. Along the bay shorelines, marshes are expected to be marginal with mid-range increases in sea-level rise, and to be lost with high-range increases in sea-level rise. The ability to migrate is likely to determine coastal marsh survival as well as the survival of the crustaceans, mollusks, turtles, and birds that depend on the marshes. In upper reaches of tributaries, however, marsh accretion should be sufficient to counter sea-level rise (Reed *et al.*, 2008). Several key locations warrant attention:

120 The Harford data, however, did not include the Aberdeen Proving Grounds.

- In the upper Patuxent River, marsh areas have achieved minimal migration despite inundation. In the Jug Bay Sanctuary, marsh inundation is causing vegetation changes, compounding stress on local bird species (Shellenbarger Jones and Bosch, 2008b).
- Cove Point Marsh in Calvert County is a 150-acre freshwater, barrier-beach marsh. Numerous state-defined rare plant species are present, including American frog's-bit (*Limnobium spongia*), silver plumegrass (*Erianthus alopecuroides*), various ferns, and unique wetland communities (Steury, 2002, p 16 and 21), as well as populations of the Northeastern beach tiger beetle, the Puritan tiger beetle (both federally listed as threatened), and the rare leaf beetle *Glyptina maritima*. The marsh is continuing to migrate, but will soon hit the northern edge of local residential development.
- Saltwater intrusions may shift the fauna dependent on nontidal wetlands in Shady Side, particularly freshwater fish.
- The potential loss of the wide mudflats at Hart-Miller Island would eliminate major foraging and nesting areas for sandpipers, plovers, and terns, as well as several high conservation priority species such as the swamp sparrow (*Melospiza georgiana*), spotted sandpiper (*Actitis macularia*), and willow flycatcher (*Empidonax traillii*).
- Given the extent of development and shoreline armoring in Anne Arundel and Baltimore City/County, both intertidal areas and wetlands are likely to be lost with even a modest acceleration in sea level rise.

Beach loss, particularly in St. Mary's, Calvert, and Anne Arundel counties along Chesapeake Bay, may occur in areas without nourishment. The widespread presence of shoreline protection can interfere with longshore transport and prevent inland retreat of beach areas. In general, beach loss will lead to habitat loss for resident insects (including the Northeastern beach tiger beetle, federally listed as threatened) and other invertebrates, as well as forage loss for larger predators such as shorebirds (Lippson and Lippson, 2006)[121].

The Calvert County cliffs represent unique habitat that could be degraded by sea-level rise; however, the cliffs are not likely to be lost entirely. The Puritan tiger beetle and Northeastern beach tiger beetle, both federally listed, are present in the area. In particular, the Puritan tiger beetle depends on natural, moderate cliff erosion for habitat, both as larvae and as adults. While natural erosion processes are allowed to continue in the protected cliff areas in the southern portion of the county, shoreline protections in the more northern developed areas are increasing erosion rates (Wilcock *et al.*, 1998). If erosion occurs at rates high enough to shear off areas to a depth below larvae burrows, Puritan tiger beetles could be eliminated. In addition, in the northern areas where the cliffs are stabilized, the rocky and sandy toes to the cliffs will be lost to inundation, along with the invertebrate community (*e.g.*, burrowing amphipods and hermit crabs) that resides there.

121 For more detail on beach habitats and the species that occur in the mid-Atlantic region, see Shellenbarger Jones, 2008.

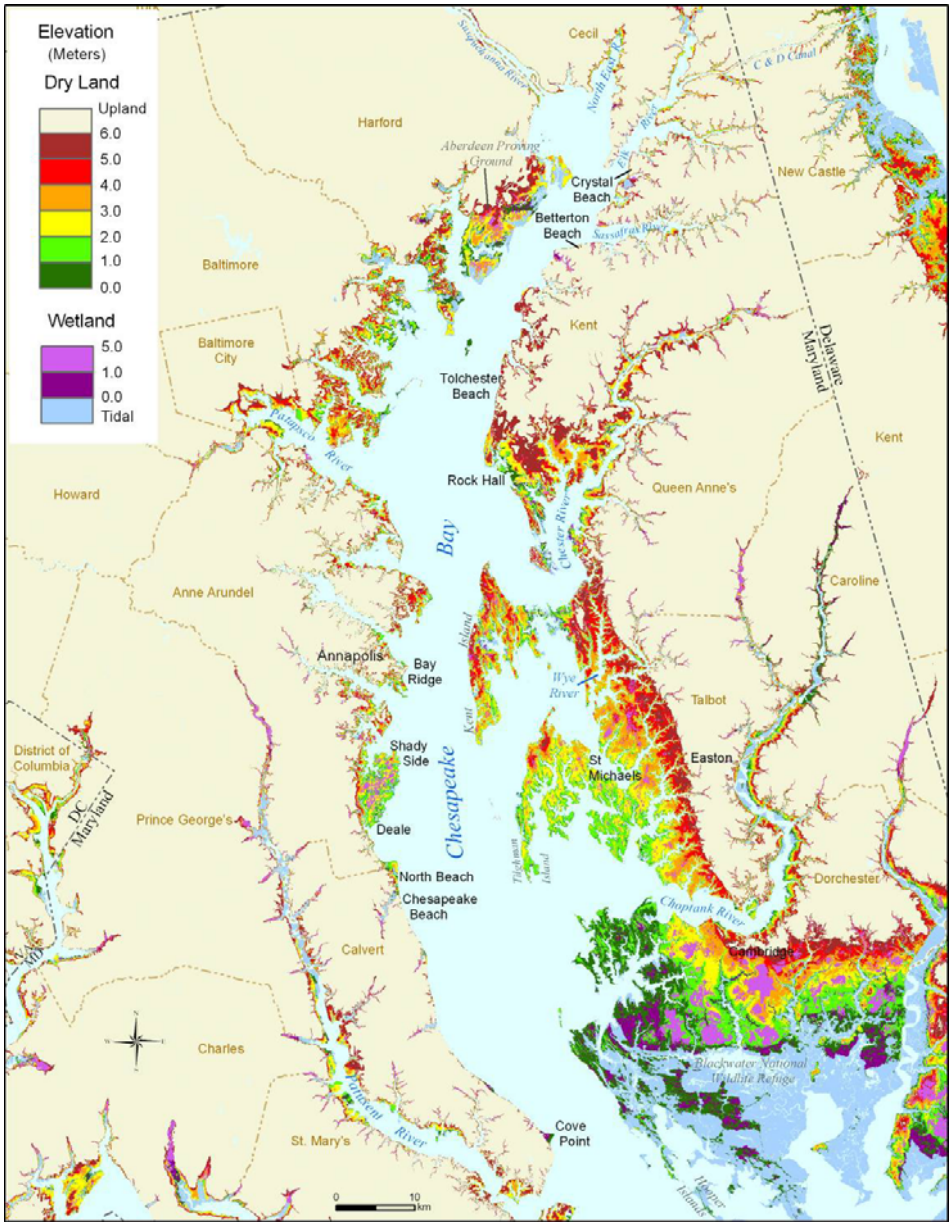
Other effects on nearshore communities may be observed. In the upper Patuxent River, the spread of SAV more tolerant of deeper depths and higher turbidity (*e.g.*, *Hydrilla*) may be accompanied by a decrease in larger fish, though its spread may be tempered by changes in salinity (Shellenbarger Jones, 2008).

F.1.6 Eastern Shore: Susquehanna River to Choptank River

Elevations

One hundred years ago, residents of the Baltimore-Washington-Annapolis area who wanted to go to the beach did not usually travel to Ocean City or Rehoboth on weekends. They went to bay beaches such as Bay Ridge (AAC, 2007) and resorts on the Eastern Shore such as Betterton Beach and Tolchester.

As Figure F.13 shows, the Eastern Shore above Rock Hall is dominated by bluffs and steep slopes rising to above 6 meters. Tolchester Beach, Betterton Beach, (Figures F.14 to F.16) and Crystal Beach (Figure 4.9, Chapter 4) are typical in that regard. From Rock Hall south to around the middle of Kent Island, all of the land within a few kilometers of the Chesapeake Bay or its major tributaries is within 6 meters above spring high water; with some areas less than 3 meters above the tides. Between Kent Island and the Choptank River, large areas are less than 3 meters above the tides.



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12836 **Figure F.13** Upper Chesapeake Bay. Elevations relative to spring high water.

Table F.4 Low and high estimates for the area of dry and wet land close to sea level, Chesapeake Bay, Maryland Western Shore (square kilometers).

	Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
		Low	High	Low	High	Low	High	Low	High	Low	High
Locality	Cumulative (total) amount of Dry Land below a given elevation										
Prince George's		0.0	1.1	0.4	1.7	1.3	3.2	2.3	5.3	6.5	10.8
Charles		0.0	0.7	0.3	1.2	0.9	2.0	1.7	2.5	2.7	3.3
St. Mary's		0.8	3.8	2.5	8.0	8.8	18.8	18.2	30.6	38.5	48.4
Calvert		0.4	3.9	1.7	5.8	4.6	10.1	7.6	17.3	21.2	35.7
Anne Arundel		1.7	7.2	6.7	14.6	20.2	38.7	43.5	59.1	80.5	94.3
Howard		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3
Baltimore City		0.2	2.1	0.9	3.9	2.7	7.5	5.7	11.9	14.1	21.0
Baltimore		2.3	6.6	7.3	13.0	20.8	27.0	37.0	45.8	74.5	80.7
Harford		0.7	17.3	7.6	25.1	21.7	40.3	34.2	57.1	65.5	78.2
Total		**6.1**	**42.7**	**27.5**	**73.4**	**81.1**	**147.8**	**150.3**	**229.7**	**303.7**	**372.7**
	Cumulative (total) amount of wetlands below a given elevation										
Prince George's	12.3	0.0	0.5	0.2	0.9	0.7	1.8	1.3	2.9	3.5	5.1
Charles	1.3	0.0	0.2	0.1	0.2	0.2	0.4	0.3	0.4	0.5	0.6
St. Mary's	7.0	0.3	1.0	0.8	2.0	2.2	3.9	3.9	5.9	7.5	8.8
Calvert	14.6	0.1	0.9	0.4	1.3	1.1	2.2	1.7	3.8	4.7	7.5
Anne Arundel	12.1	0.2	0.7	0.6	1.6	3.1	8.1	9.5	12.4	15.3	17.1
Howard	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1
Baltimore City	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1
Baltimore	10.5	0.1	0.3	0.3	0.7	1.0	1.3	1.5	1.7	2.2	2.3
Harford	29.4	0.2	2.5	1.2	3.8	3.3	6.2	5.2	9.0	10.2	12.0
Total	**87.3**	**0.8**	**6.2**	**3.7**	**10.5**	**11.6**	**24.0**	**23.5**	**36.4**	**43.9**	**53.6**
Dry and Nontidal wetland		7	49	31	84	93	172	174	266	348	426
All Land	87	94	136	119	171	180	259	261	353	435	514

Source: Titus and Cacela, 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. Section 1.3 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea-level Rise, J.G. Titus and E. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC. The low and high estimates are based on the on the contour interval and/or stated root mean square error (RMSE) of the data used to calculate elevations. For more details, see Chapter 1.

Vulnerable Habitat

Above Kent Island. The environmental implications of sea-level rise effects in the upper Chesapeake Bay are likely to be relatively limited. The Susquehanna River provides a large (though variable) influx of sediment to upper Chesapeake Bay, as well as almost half of Chesapeake Bay's freshwater input (CBP, not dated). This sediment generally is retained above the Chesapeake Bay Bridge and provides material for accretion in the tidal wetlands of the region (CBP, 2002). The other Upper Chesapeake Bay tributaries

characteristically have large sediment loads as well, and currently receive sufficient sediment to maintain wetlands and their ecological function. As such, Upper Chesapeake Bay will continue to provide spawning and nursery habitat for crabs and fish, as well as nesting and foraging habitat for migratory and residential birds, including bald eagles and large numbers of waterfowl. Likewise, while some of the beaches may require nourishment for retention, the general lack of shoreline protections will minimize interferences with longshore sediment transport. Hence, beaches are likely to remain intact throughout much of the region.

Two areas in the Upper Bay — Eastern Neck and Elk Neck — appear most vulnerable to sea-level rise effects. First, Eastern Neck Wildlife Refuge lies at the southern tip of Maryland's Kent County. Ongoing shoreline protection efforts seek to reduce erosion of habitats supporting many migratory waterfowl and residential birds, as well as turtles, invertebrates, and the Delmarva fox squirrel (*Sciurus niger cinereus*), federally listed as endangered. In many marsh locations, stands of invasive *Phragmites australis* are the only areas retaining sediment (Shellenbarger Jones and Bosch, 2008c). Local managers have observed *P. australis* migrating upland into forested areas as inundation at marsh edges increases, although widespread marsh migration of other species has not been observed (Shellenbarger Jones and Bosch, 2008c). The three-square bulrush marshes (*Scirpus americanus*) on Eastern Neck have been largely inundated, as have the black needle rush marshes (*Juncus roemerianus*) on Smith Island and other locations, likely causes of reductions in black duck counts (Shellenbarger Jones and Bosch, 2008c).

Likewise, loss of upland to open water is decreasing habitat for bald eagle and the Delmarva fox squirrel.

Other sea-level rise impacts are possible in Cecil County, in and around the Northeast and Elk Rivers. The headwaters of the rivers are tidal freshwater wetlands and tidal flats, spawning and nursery areas for striped bass and a nursery area for alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), hickory shad (*Alosa mediocris*) and white perch, as well as a wintering and breeding area for waterfowl (USFWS, 1980). Accretion is expected to be sufficient in some areas due to the large sediment inputs in the Upper Bay. However, significant armoring in the developed headwaters could interfere with sediment transport. Where accretion rates are not sufficient, wetland migration would be difficult due to the upland elevation adjacent to the shorelines. These conditions increase the chances of large tidal fresh marsh losses.

Other sensitive Cecil County habitats exist. The cliffs at Elk Neck State Park and the Sassafras River Natural Resource Management Area will be left to erode naturally. The cliff swallows and Puritan tiger beetle (federally listed as threatened) will continue to use the unique habitat. Around Grove Point, Puritan tiger beetle populations may be impacted because shoreline stabilization may result in loss of beach areas.

Finally, marsh loss is possible in and around the Aberdeen Proving Ground in Harford County. The Proving Ground is primarily within 5 meters of sea level and contains a large concentration of tidal wetlands (20,000 acres). The prospects for future shore

protection are poorly understood here, as well as along other secured installations along Chesapeake Bay and its tributaries. The wetlands may accrete sufficient sediment to meet moderate sea-level rise rates, but higher rates would result in loss of the tidal marshes and associated ecological functions. In particular, the large bird populations (*e.g.*, bald eagles, great blue herons, double-crested cormorants) that migrate through and nest in these marshes would be affected (MD DNR, not dated).

Kent Island to Choptank River. The central eastern shore region of Chesapeake Bay contains diverse habitats, and sea-level rise holds equally diverse implications, varying greatly between sub-regions. Large expanses of marsh and tidal flats are likely to be lost, affecting shellfish, fish, and waterfowl populations. Several subregions merit consideration:

- The Chester River forms the northern border of Queen Anne's County. Marshes along the river will be marginal with moderate sea-level rise rate increases, and topography will preclude migration in many areas (Reed *et al.*, 2008). Birds that breed or feed in the Chester River marshes (*e.g.*, Virginia rail, American black duck, great blue and green herons, osprey) will be negatively affected by the habitat and prey loss (Robbins and Blom, 1996).
- Large tidal flats exist at the mouth of the Chester River (Tiner, 1995). Unless sedimentation increases significantly tidal flats are likely to be inundated if sea-level rise accelerates. Loss of tidal flats may result in a decline in the resident invertebrates and fish that use the shallow waters as well as the birds that feed on the flats (*e.g.*, great blue and green herons) (Shellenbarger Jones and Bosch,

2008d; Robbins and Blom, 1996). Effects may extend to commercial and recreational fish species that spawn or feed in the area, including king and Spanish mackerel, cobia, red drum, flounder, and bluefish (NOAA, not dated).

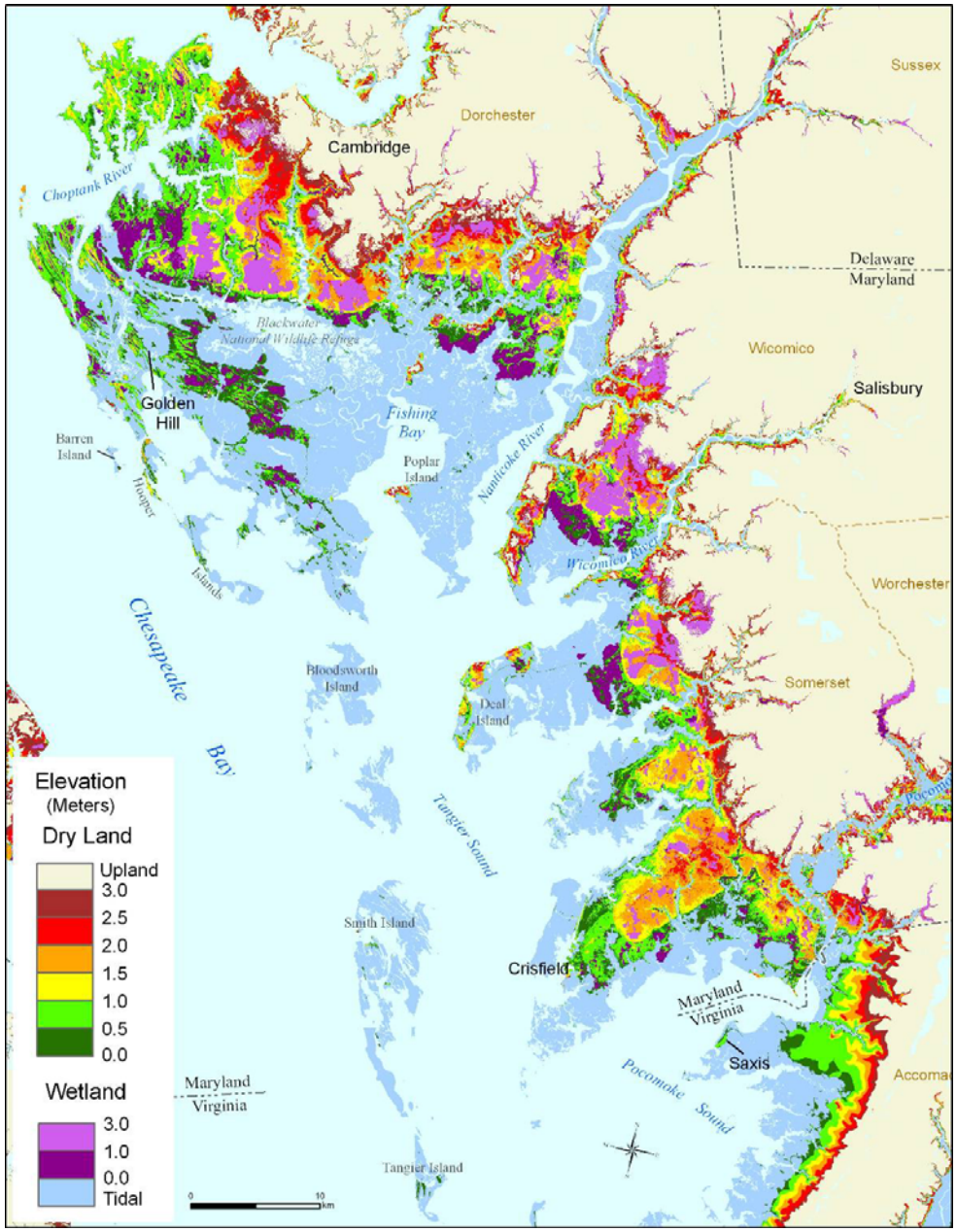
- The Eastern Bay side of nearby Kent Island has several tidal creeks, extensive tidal flats, and wetlands. If shores are protected in this area, the marshes and tidal flats are likely to be lost (although some marsh may convert to tidal flat). Increasing water depths are likely to reduce — and eventually eliminate — the remaining SAV (largely a mix of *Ruppia maritima* and *Zannichellia palustris*); a landward migration onto existing flats and marshes will depend on sediment type and choice of shoreline structure (Shellenbarger Jones and Bosch, 2008). The loss of tidal wetlands and probable loss of SAV would cause losses to fish and birds (see Chester River discussion). Additionally, large shellfish beds in Eastern Bay may be affected by the habitat changes, with uncertain consequences.
- Portions of the Wye River shore are being developed. If these shores are protected and the marshes and tidal flats in these areas are lost, the juvenile fish nurseries will be affected and species that feed in the marshes and SAV (*e.g.*, wading birds, striped bass, blue gill, blue crabs, oysters, and soft-shell clams) will lose an important food source (MD DNR, 2004, p. 19).

Certain key marsh areas are likely to be retained. The upper reaches of tributaries, including the Chester and Choptank rivers, are likely to retain current marshes and the associated ecological services. Likewise, Poplar Island will provide a large, isolated marsh and tidal flat area. In addition, the marshes of the Wye Island Natural Resource

Management Area support a large waterfowl population, with a wintering waterfowl count of 20,000 birds such as mallard, canvasback, and ruddy ducks and Canada geese (MD DNR, 2004, p 18). Maryland DNR will manage Wye Island to protect its biological diversity and structural integrity, such that detrimental effects from sea-level rise acceleration are minimized (MD DNR, 2004, p 12).

Beach loss is also possible in some areas. The Chesapeake Bay shore of Kent Island historically had narrow sandy beaches with some pebbles along low bluffs, as well as some wider beaches and dune areas (*e.g.*, Terrapin Park). As development continues, however, privately owned shores are gradually being replaced with stone revetments. The beaches will be unable to migrate inland, leading to habitat loss for the various resident invertebrates, including tiger beetles, sand fleas, and numerous crab species. Shorebirds that rely on beaches for forage and nesting will face more limited resources (Lippson and Lippson, 2006). Likewise, on the bay side of Tilghman Island, the high erosion rates will tend to encourage shoreline protection measures, particularly following construction of waterfront homes (MDNR, date unknown). Beach loss, combined with anticipated marsh loss in the area, will eliminate the worms, snails, amphipods, sand fleas, and other invertebrates that live in the beach and intertidal areas and reduce forage for their predators (*e.g.*, oystercatchers, sandpipers, plovers, and glossy ibises).

Figures F.14 to F.16 Tolchester. 1883-2003. F.14 shows the Tolchester resort as seen from a steamship docked at the end of the peer. F.15 shows the beach looking north during 1883, before the steamship pier was constructed. F.16 shows the same beach today. Also, see Chapter 4,Figure 4.9 for a picture of bluffs overlooking Crystal Beach.



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12967 **Figure F.17** Lower Eastern Shore: Lands close to sea level.

Table F.5 Low and high estimates for the area of dry and wet land close to sea level, Chesapeake Bay Eastern Shore (square kilometers).

		Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
			Low	High	Low	High	Low	High	Low	High	Low	High
Locality	**State**	Cumulative (total) amount of Dry Land below a given elevation										
Cecil	MD		0.2	2.5	1.0	5.2	3.7	11.6	7.8	20.0	24.3	37.9
Kent	MD		0.2	8.4	4.8	15.9	16.3	32.9	28.8	56.1	71.4	105.2
Queen Anne's	MD		0.6	4.1	5.3	11.9	24.2	35.0	51.6	68.2	125.2	142.6
Caroline	MD		0.7	3.2	2.2	6.1	6.9	12.5	13.2	19.7	25.9	32.9
Talbot	MD		2.2	7.8	11.1	23.7	64.0	98.7	148.7	175.1	265.6	279.4
Sussex	DE		0.5	1.6	1.4	3.3	4.3	7.1	8.5	13.8	26.0	36.3
Dorchester	MD		30.1	120.0	150.4	214.9	281.9	312.9	358.4	386.2	461.6	474.0
Wicomico	MD		5.0	14.9	18.3	28.6	47.1	58.5	76.0	86.2	133.2	141.6
Somerset	MD		17.1	58.4	70.5	100.7	167.8	193.4	215.1	232.5	326.5	344.6
Worcester	MD		0.7	2.7	3.1	5.8	10.6	16.5	23.6	28.4	46.1	53.4
Accomack	VA		5.8	18.4	16.8	40.4	53.3	87.5	94.2	110.4	129.5	138.1
Northampton	VA		2.3	7.2	6.5	15.8	20.8	34.5	39.9	62.8	98.7	123.7
Total			**65.3**	**249.1**	**291.4**	**472.4**	**701.0**	**901.2**	**1065.8**	**1259.5**	**1734.0**	**1909.7**
		Cumulative (total) amount of wetlands below a given elevation										
Cecil	MD	12.6	0.0	0.2	0.0	0.7	0.4	1.7	1.2	2.8	3.5	5.5
Kent	MD	18.3	0.1	1.1	0.9	2.6	3.3	5.4	5.2	7.9	9.7	14.4
Queen Anne's	MD	21.4	0.2	1.1	1.5	3.0	4.9	6.5	7.9	9.6	14.6	17.9
Caroline	MD	14.4	0.3	1.4	0.7	2.6	2.5	5.3	4.4	7.5	8.0	11.7
Talbot	MD	26.1	0.1	0.3	0.5	1.0	2.5	4.2	6.8	8.5	17.9	19.6
Sussex	DE	6.7	0.6	1.8	1.6	2.7	3.1	4.4	4.8	6.4	10.1	13.1
Dorchester	MD	424.8	14.9	45.8	53.4	70.1	94.4	104.0	113.8	120.6	140.1	142.5
Wicomico	MD	67.0	5.4	9.9	10.7	13.5	24.2	29.2	37.0	44.4	67.0	70.2
Somerset	MD	265.4	6.6	15.7	17.3	21.3	34.8	39.8	45.1	51.5	80.6	90.1
Worcester	MD	23.7	0.3	0.9	1.0	1.6	2.7	4.0	6.3	8.8	18.2	20.8
Accomack	VA	156.4	5.3	16.7	15.3	34.6	44.8	71.8	76.5	88.2	103.2	111.1
Northampton	VA	25.5	0.1	0.4	0.4	1.2	1.9	3.7	4.2	6.2	8.8	10.1
Total		**1062.4**	**33.8**	**95.3**	**103.3**	**155.0**	**219.5**	**279.9**	**313.0**	**362.4**	**481.7**	**526.9**
Dry and Nontidal wetland			99	344	395	627	921	1181	1379	1622	2216	2437
All Land		1062	1162	1407	1457	1690	1983	2244	2441	2684	3278	3499

Source: Titus and Cacela, 2008. Uncertainty Ranges Associated with EPA's Estimates of the Area of Land Close to Sea Level. Section 1.3 in: Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea-level Rise, J.G. Titus and E. Strange (eds.). EPA 430R07004. U.S. EPA, Washington, DC. The low and high estimates are based on the on the contour interval and/or stated root mean square error (RMSE) of the data used to calculate elevations. For more details, see Chapter 1.

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F.1.7 The Lower Eastern Shore: Choptank River to Cape Charles

Between the Choptank River and Ocohannock Creek along the eastern shore of Chesapeake Bay lies the nation's fifth largest concentration of land close to sea level (see Figure F.17). These four counties have approximately 256 to 385 square kilometers of dry land within 1 meter above the tides (see Table F.5). Water levels in roadside ditches rise and fall with the tides in the areas west of Golden Hill in Dorchester County and several necks in Somerset County. Many farms abut tidal wetlands, which are gradually encroaching onto those farms. Some landowners have responded by inserting makeshift tide gates over culverts, decreasing their own flooding but increasing it elsewhere. Throughout Hoopers Island, as well as the mainland nearby, one finds numerous abandoned driveways that once led to a home but are now ridges flooded at high tide, surrounded by low marsh or open water more recently abandoned homes surrounded by marsh, and dead trees still standing in areas where marsh has invaded a forest.

Elevations

Approximately halfway between Crisfield on the Eastern Shore and the mouth of the Potomac River on the Western Shore, are the last two inhabited islands in Chesapeake Bay unconnected by bridges to the mainland: Smith (Maryland) and Tangier (Virginia). Both islands are entirely below the USGS 5-foot contour.

Along the eastern shore of Northampton County, by contrast, elevations are higher, often with bluffs of a few meters. Nevertheless, several blocks of homes in the Town of Cape Charles are within 2 meters above spring high water.

Vulnerable Habitat

On the lower Eastern Shore of Chesapeake Bay in Maryland, habitats vulnerable to sea-level rise are diverse and include beaches, various types of tidal marsh, nontidal marshes, and upland pine forests.

Narrow sandy beaches exist along discrete segments of shoreline throughout the region, particularly in Somerset County. Given the gradual slope of the shoreline, these habitats could accommodate moderate sea-level rise by migrating upslope, assuming no armoring or other barriers exist. Many of the beaches provide critical nesting habitat for the diamondback terrapin (*Malaclemys terrapin*), and proximity of these nesting beaches to nearby marshes provides habitat for new hatchlings. Maryland lists the terrapin as a Species of Concern and it is protected across much of its geographic range (although it is commercially and recreationally harvested for food in Maryland). Because of increasing shoreline protection in areas to the north, the lower Eastern Shore region is responsible for supporting a growing portion of the diamondback terrapin population (Schweizer and Henry, 2004). Erosion control and shoreline stabilizing practices block access to the beach, forcing females to travel around the obstructions, or to deposit their eggs below the high tide line. Loss of prime nesting beaches remains a major threat to the diamondback terrapin population in Chesapeake Bay (see text box) (MD DTTF, 2001).

Of the 87,000 hectares of tidal marsh in the Chesapeake Bay, a majority is located in the three-county lower Eastern Shore region (Darmondy and Foss, 1979). The marshes are critical nursery grounds for commercially important fisheries (*e.g.*, crabs and rockfish); critical feeding grounds for migratory waterfowl; and home to furbearers (*e.g.*, muskrat and nutria). Tidal marshes will persist as sea level rises so long as they build vertically through accumulation of mineral and/or organic matter and as long as there are no shoreline barriers to migration[122]. The ability to build vertically in response to sea-level rise differs among the three tidal marsh types:

- Submerged Upland Tidal Marsh: Submerged upland tidal marsh is the predominant marsh type in the lower Eastern Shore region, with the majority located in Dorchester and Somerset counties (Darmondy and Foss, 1979). The drainage system in these marshes is poor, and limited tidal exchange and sediment influx means that vertical marsh development occurs primarily through the accumulation of plant organic matter. As a result, accretion rates in these marshes are typically less than the rate of sea-level rise (Stevenson and Kearney, 2001). In addition, studies in Blackwater NWR demonstrate that local land surface adjustments (*e.g.*, from groundwater withdrawal) can effectively increase sea-level rise, leading to more severe wetland loss (Stevenson *et al.*, 2001). The accretion deficits in these marshes lead not only to decreased marsh area and increased open water, but also to a change in the proportion of high and low marsh habitats.

122 Barriers to transgression are relatively few in Dorchester and Wicomico counties, being mostly associated with developed shorelines in the vicinity of towns and cities, although eroding shorelines on marsh islands are being more frequently stabilized to slow island loss (Kearney and Stevenson, 1991).

- Estuarine Meander Tidal Marsh: In estuarine meander tidal marshes, the dominant vegetation consists of cattails (*Typha* spp.), *Spartina cynosuroides*, and pickerel weed (*Pontederia cordata*), while more saline areas consist of the same species found in submerged upland marshes (*e.g.*, *Scirpus olneyi*, *Spartina patens*, and *Spartina alterniflora*). These marshes have better drainage and a greater influx of mineral sediments, especially during extreme high tides when the entire marsh surface is inundated with sediment-laden river waters. Accretion rates typically exceed the rate of sea-level rise (Kearney and Ward, 1986); therefore, these marshes are more capable of surviving future sea-level rise than submerged upland marshes, and will migrate upriver as sea level rises.
- Freshwater Tidal Marsh: Accretion rates in freshwater tidal marshes are relatively high because of the abundant source of riverine sediment (Kearney *et al.*, 1988). These marshes will tolerate the greatest increases in the rate of sea-level rise. However, the areal extent of tidal freshwater marshes will decrease once the entire river is influenced by tides and the turbidity maxima continue to migrate up the estuary. Salt water will intrude into the lower reaches of the tidal freshwater marsh zone, and that marsh will likely convert to estuarine marsh.

Freshwater riparian wetlands and swamps exist beyond the extent of tidal influence, in the upper reaches of the rivers. These habitats have unique ecological value for a wide array of plant and animal species, and function as freshwater reservoirs through the interaction of groundwater discharge/recharge processes and surface runoff. As sea level

rises, tidal influences, and eventually salt water, will intrude into these habitats and convert them to tidal and estuarine habitats.

As submerged upland marshes migrate upslope, they encroach upon pine forests located immediately inland, causing inundation, saturation, and salinization of forest soils, and eventually tree mortality. For example, in the Beaverdam Creek area of Blackwater NWR, tidal marsh has transgressed > 100 m into the pine forest since about 1940, where trees of the leading edge of the forest are dead and decomposing (Guntenspergen and Cahoon, 2005). This forested area is habitat for the Federally endangered Delmarva Fox Squirrel.

Areas of Virginia's Eastern Shore are uniquely vulnerable to sea-level rise. Large portions of Northampton and Accomack counties (184.8 and 208.2 square miles, respectively) lie near sea level (Titus and Wang, 2008). Because most of the land in the two counties is undeveloped or agricultural, the area also has a high potential for wetland creation relative to other Virginia shorelines.

Most notably, the bay side of northern Accomack County is primarily tidal salt marsh, with low-lying lands (less than 2 feet above the wetlands) extending several miles inland. The county as a whole contains nearly a fifth of the state's dry land within 2 feet of mean spring high water. (Titus and Cacela 2008). Unprotected marshes are already migrating inland in response to sea-level rise, creating new wetlands in agricultural areas at a rate of 40 acres per year. Given the anticipated lack of shoreline protection and insufficient

sediment input, the seaward boundaries of these tidal wetlands are likely to continue retreating (Reed *et al.*, 2008). The upland elevations are higher in southern than northern Accomack County (see Figure E.2), however, making wetland migration more difficult.

The salt marshes of Accomack County support a variety of species, including rare bird species such as the seaside sparrow, sharp-tailed sparrow, and peregrine falcon (VA DCR, date unknown). Growth and survival of these species may be reduced where shores are hardened, unless alternative suitable habitat is available nearby. Furthermore, long-term tidal flooding will decrease the ability of nekton (*i.e.*, free-swimming finfish and decapod crustaceans such as shrimps and crabs) to access coastal marshes. As the accessible area declines, a decrease in nekton production may occur.

The bay side of Northampton County is most notable for its beach/dune systems, including some wide sandy beaches near the town of Cape Charles (Varnell and Hardaway, 2005). Estuarine beach/dune systems occur in areas of stability and sand accretion (such as the mouths of tidal creeks), in front of older dune features (such as washovers or spits), and against structures like jetties and groins (Hardaway *et al.*, 2004). Beach nourishment to protect public beaches is likely. The beaches and associated maritime forests provide habitat for a variety of species, most notably neo-tropical songbirds and the federally listed threatened northeastern beach tiger beetle (Varnell and Hardaway, 2005, p 5).

F.2 BAYWIDE POLICY CONTEXT

Chesapeake Bay's watershed has tidal shores in Virginia, Maryland, the District of Columbia, and Delaware. Because the shores of the District and Delaware account for a small portion of the total, the policy context depends primarily on Virginia and Maryland This section focuses mainly on the coastal policies of these two states that focus on the Bay, but we also include some policies that apply to both ocean and bay.

Coastal management officials of Maryland have cooperated with EPA since the 1980s in efforts to learn the ramifications of accelerated sea-level rise for their activities (AP, 1985). Increased erosion from sea-level rise was one of the factors cited for the state's decision in 1985 to shift its erosion control strategy at Ocean City from groins to beach nourishment (AP, 1985). The state also developed a planning document for rising sea level (Johnson, 2000), and sea-level rise was a key factor motivating Maryland to become the second mid-Atlantic state to obtain LIDAR elevation data for the entire coastal floodplain.

Neither Maryland nor Virginia has adopted an explicit policy to address the consequences of rising sea level. Nevertheless, the policies designed to protect wetlands, beaches, and private shorefront property are collectively an implicit policy. Both states prevent new buildings within 100 feet of most tidal shores; Maryland also limits the density of new development in most areas to one home per 20 acres within 1,000 feet (300 meters) of the shore. Virginia allows most forms of shore protection. Maryland encourages shore

protection[123], but discourages new bulkheads in favor of revetments or nonstructural measures (MD DNR, 2006a). Both states have programs to inform property owners of nonstructural options, although obtaining permits for structural options is easier (NRC, 2007; Johnson and Luscher, 2004). Both states work with the federal government to obtain federal funds for beach nourishment along their respective ocean resorts (Ocean City and Virginia Beach); Virginia also assists local governments in efforts to nourish public beaches along Chesapeake Bay and its tributaries. Summaries of these land use, wetlands, and beach nourishment policies follow.

F.2.1 Land use

The primary state policies related to land use are Maryland's Chesapeake Bay Critical Area Protection Act, Virginia's Chesapeake Bay Preservation Act, and Virginia's Coastal Primary Sand Dunes & Beaches Act.

Maryland Chesapeake Bay Critical Area Protection Act. The Maryland General Assembly enacted the Chesapeake Bay Critical Area Protection Act in 1984 to reverse the deterioration of the Bay[124]. The law seeks to control development in the coastal zone and preserve a healthy Bay ecosystem. The jurisdictional boundary of the Critical Area includes all waters of Chesapeake Bay, adjacent wetlands[125], dry land within 1,000 feet

123 Code of Maryland Regulations§ 27.01.04.02.02-03
124 Chesapeake Bay Critical Areas Protection Act, Maryland Code Natural Resources §8-1807.
125 I.e. all state and private wetlands designated under Natural Resources Article, Title 9 (now Title 16 of the Environment Article).

of open water[126], and in some cases dry land within 1,000 feet inland of wetlands that are hydraulically connected to the Bay[127].

The act created a Critical Areas Commission to set criteria and approve local plans[128]. The commission recognizes three land use management sub-districts within the Critical Area: intensely developed areas (IDAs), limited development areas (LDAs), and resource conservation areas (RCAs)[129]. Within the RCAs, new development is limited to an average density of one home per 20 acres[130], and the regulations encourage communities to "consider cluster development, transfer of development rights, maximum lot size provisions, and/or additional means to maintain the land area necessary to support the protective uses"[131] The program limits future intense development activities to lands within the IDAs, and permits some additional low-intensity development in the LDAs. However, the statute allows up to 5% of the RCAs in a county to be converted to an IDA[132].

The three categories were originally delineated based on the land uses of 1985. Areas that were dominated by either agriculture, forest, or other open space, as well as residential areas with densities less than 1 home in 5 acres, were defined as RCAs[133]. Thus, the greatest preservation occurs in the areas that had little development when the act was

126 Maryland Code Natural Resources §8-1807(c)(1)(i)(2).
127 Lands more than 1000 feet from open water may be excluded if and only if highly functional wetlands are between the land and the open water. Maryland Code Natural Resources §8-1807(c)(1)(i)(2) and §8-1807(a)(2).
128 Maryland Code Natural Resources §8-1808.
129 Code of Maryland Regulations §27.01.02.02(A).
130 Code of Maryland Regulations §27.01.02.05(C)(4).
131 Code of Maryland Regulations §27.01.02.05(C)(4).
132 Code of Maryland Regulations §27.01.02.06.
133 Code of Maryland Regulations §27.01.02.05.

passed, typically lands that are far from population centers and major transportation corridors — particularly along tributaries (as opposed to the Bay itself).

The Critical Areas Program also established a 100-foot natural buffer adjacent to tidal waters[134]. No new development activities, with the exception of those supporting water-dependent facilities, are allowed within the buffer[135]. By limiting development in the buffer, the program prevents additional infrastructure from being located in the areas most vulnerable to sea-level rise. In some cases, the 100-foot buffer provides a first line of defense against coastal erosion and flooding induced by sea-level rise. But the regulations also encourage property owners to halt shore erosion[136]. Nonstructural measures are preferred, followed by structural measures[137], with an eroding shore the least preferable (Titus, 1998).

Virginia Chesapeake Bay Preservation Act. The Chesapeake Bay Preservation Act[138] seeks to limit runoff into the Bay by creating a class of land known as Chesapeake Bay Preservation Areas. The act also created the Chesapeake Bay Local Assistance Board to implement[139] and enforce[140] its provisions. Although the act defers most site-specific development decisions to local governments[141], it lays out the broad framework for the

134 Code of Maryland Regulations §27.01.00.01 (C)(1).
135 Code of Maryland Regulations §27.01.00.01 (C)(2).
136 Code of Maryland Regulations§ 27.01.04.02. 02
137 Code of Maryland Regulations§ 27.01.04.02. 03.
138 Code 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+TOC10010000021000000000000.
139 Code VA §10.1-2102.
140 Code VA §10.1-2104.
141 Code VA §10.1-2109.

preservation areas[142] and provides the Board with rulemaking authority to set overall criteria[143]. The Board has issued regulations[144] defining the programs that local governments must develop to comply with the act[145].

All localities must create maps that define the locations of the preservation areas, which are subdivided into resource management areas[146] and resource protection areas (RPAs)[147]. RPAs include areas flooded by the tides, as well as a 100-foot buffer inland of the tidal shores and wetlands[148]. 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-foot buffer if necessary to preserve the owner's right to build; but any building must still be at least 50 feet from the shore[149]. 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.

142 Code VA §10.1-2107(B).
143 Code VA §10.1-2107(A).
144 Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et. seq.).
145 9 Virginia Administrative Code §10-20-50.
146 The 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 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.
147 9 Virginia Administrative Code §10-20-70.
148 9 Virginia Administrative Code §10-20-80 (B).
149 9 Virginia Administrative Code §10-20-130 (4).

Virginia Coastal Primary Sand Dunes & 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 Northumberland (Hardaway *et al.*, 2001); all but Hampton and Accomack have done so. The act 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.

F.2.2 Wetlands and erosion control permits

Virginia. 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" (VA Code 28.2-1302). It 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, localities create a wetlands board consisting of five to seven citizen volunteers. The jurisdiction of these local boards extends from mean low water (the Marine Resources Commission has jurisdiction over bottom lands seaward of mean low water) to mean high water where no emergent vegetation exists, and slightly above spring high water[150] where marsh is

150 The Act grants jurisdiction to an elevation equal to 1.5 times the mean tide range, above mean low water.

present. The board grants or denies permits for shoreline alterations within their jurisdiction (Trono, 2003).

The Virginia 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 non-vegetated wetlands by type and describe the consequences of use of these wetlands types" (Section 28.2-1301). 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.

The Virginia Coastal Program's web page recently posted a fairly detailed analysis of the process for issuing permits for erosion control structures (Trono, 2003), which is designed to avoid destruction of wetlands or other adverse environmental impacts. The focus of the regulations and the review processes, however, is on avoiding immediate damage to the environment. The long-term impact on the environment from preventing the landward migration of tidal habitats is not considered.

Maryland. The Wetlands and Riparian Rights Act151 gives the owner of land bounding on navigable water the right to protect their property from the effects of shore erosion. For example, property owners who erect an erosion control structure in Maryland can

151 Maryland Environmental Code §16-101 to §16-503.

obtain a permit to fill vegetated wetlands152 and fill beaches and tidal waters up to 10 feet seaward of mean high water153. In addition, Maryland's statute allows anyone whose property has eroded to fill wetlands and other tidal waters to reclaim any land that the owner has lost since the early 1970s154. (The Corps of Engineers has delegated most wetland permit approval to the state155.) The state encourages the "living shorelines" approach to halting erosion (e.g., marsh planting and beach nourishment) over hard structures and revetments over bulkheads156. Few new bulkheads are built for erosion control, and existing bulkheads are often replaced with revetments.

Shore protection structures tend to be initially constructed landward of mean high water, but neither the state of Virginia nor Maryland[157] 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 replacement bulkheads within state waters, although Maryland encourages revetments.

F.2.3 Beach nourishment and other shore protection activities

Virginia. Until 2003, the Board on Conservation and Development of Public Beaches promoted maintenance, access, and development along the public beaches of Virginia.

152 See MD. CODE ANN., ENVIR. § 16-201 (1996); Maryland General Permit, previous note, app. at I-24, I-31. Along sheltered waters, the state encourages property owners to control erosion by planting vegetation. For this purpose, one can fill up to 35 feet seaward of mean high water. See MD. CODE ANN., ENVIR. § 16-202(a)(3)(iii) (Supp. 1997). Along Chesapeake Bay and other waters with significant waves, hard structures are generally employed.
153 MD. CODE ANN., ENVIR. § 16-202(a)(2).
154 MD. CODE ANN., ENVIR. § 16-201.
155 See Baltimore Dist., U.S. Army Corps of Engineers, Dep't of the Army, Maryland State Programmatic General Permit §§ 1-5 (May 6, 1996) [hereinafter Maryland General Permit].
156 Maryland General Permit at 56, section IV(A)(1)(g).
157 The 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.

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 (VA PBB, 2000). 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% of the funding for beach nourishment at Virginia Beach, with the local and federal shares being 67% and 30% respectively (VA PBB, 2000).

Virginia has made a greater effort than Maryland to promote beach nourishment (and public use of beaches) along Chesapeake Bay and its tributaries. Norfolk's four guarded beaches serve 160,000 visitors each summer (VA PBB, 2000). When shore erosion threatened property, the tourist economy, and local recreation, the Beach Board helped the city construct a series of breakwaters with beachfill and a terminal groin at a cost of $5 million (VA PBB, 2000). 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 severe erosion problems. Throughout the 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.

Maryland's primary effort to protect shores along the Bay is through the Department of Natural Resource's Shore Erosion Control Program. The program provides both financial and technical assistance to Maryland property owners to resolve erosion problems through both structural and nonstructural shore erosion control projects. The state program has focused on nonstructural projects using bioengineering methods for shoreline restoration.

Although beach nourishment has historically been less common along Maryland's bay shores than those of Virginia, the Department of Natural Resources has been involved in several small-scale beach restoration efforts. The most significant beach nourishment project along the Bay has been a small recreational beach at North Beach (which despite its name has replaced most of the beach with a boardwalk and revetment). Many parks and small recreational communities have also received beach nourishment, including Sandy Point, and Point Lookout state parks on the western shore, the historic resort community of Bay Ridge, Terrapin Beach State Park, and Clairborne Landing and the Choptank River Fishing Pier in Talbot County.

The state has also used dredge spoils to restore Poplar and Smith islands. The Maryland Port Administration's Poplar Island Restoration Project is using dredge materials from the Port of Baltimore to restore the island to its approximate footprint in the mid-1800s (USACE, 2005). The Port and the Corps of Engineers are currently working at Smith Island to combat erosion through a program to place dredged material on portions of the island (USACE, 2001). Preliminary examinations are under way to see if dredged materials can be used to restore other Chesapeake Bay islands such as James and Barren Islands (Federal Register, 2006), or to protect valuable environmental resources such as the eroding lands of the USFWS Blackwater National Wildlife Refuge (USACE, 2005 and USFWS, 2008).

The preceding discussion presents a simplification of the policy context. Many of the counties have coastal policies that may further alter coastal development — and citizens sometimes intervene to prompt *ad hoc* policy adjustments. (Appendix E discusses a proposed development along the Blackwater River that was cancelled as a result of citizen opposition.)

F.3 DEVELOPMENT AND SHORE PROTECTION

Chapter 5 describes the basis for ongoing studies that are analyzing land use plans, land use data, and coastal policies to create maps depicting the areas where shores may be protected and where wetlands may migrate inland. Because the maps from those studies have not yet been finalized, this section describes some of the existing and evolving

conditions that may influence decisions related to future shore protection and wetland migration

F.3.1 Hampton Roads

Hampton Roads is the southernmost coastal planning district in Virginia. Extending from the North Carolina border to the York River, the region has 16 localities whose combined population is over 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.

Norfolk is home to the central business district of the Hampton Roads region. Although the city's population dropped during the 1990s, the local government is taking measures to redevelop and revitalize the urban core. One example of such a measure has been the successful revitalization of the Ocean View area along the northern shore of Norfolk. Newport News has similar development to Norfolk along its southern shores, with bluffs giving rise to less dense residential areas further 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 Mulberry Island in northern Newport News.

Outside of the urban core, localities are more rural in nature. These 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 within three meters above sea level.

Virginia Beach has sandy shores along both the Atlantic Ocean and the mouth of Chesapeake Bay. Dunes dominate the bay shore, but much of the developed ocean shore is protected by a seawall (Figures F.18a and b), and periodic beach nourishment has occurred since the mid-1950s (Hardaway *et al.*, 2005). As the state's only ocean resort, this city has a combination of high-rise condominiums and hotels, low-rise motels, restaurants and shops, and single-family homes with high property values. The northern two thirds of the city's ocean coast is heavily developed; the southern third is within a state park or Back Bay National Wildlife Refuge.

Along Chesapeake Bay, by contrast, the Virginia Beach shore has substantial dunes, with homes set well back from the shore in some areas. Although the ground is relatively high, beach nourishment has been required on the bay beaches at Ocean Park (Hardaway *et al.*, 2005). Norfolk has maintained its beaches along Chesapeake Bay mostly with breakwaters and groins. Shores along other bodies of water are being armored. Of Norfolk's 167 miles of shoreline, 70 miles have been hardened (Berman *et al.*, 2002).

Figures F.18 Virginia Beach. (a) Homes set well back behind the dunes along the north-facing Chesapeake Bay shoreline. (b) Seawalls along the east-facing Atlantic beaches (October 1998).

Outside of the urban core of Hampton Roads, many lands are still rural and shore protection is not widespread.. Since 1979, Virginia Beach has had a "Green Line"[158] south of which the city tries to maintain the rural agricultural way of life. Because development has continued, Virginia Beach has also established a "Rural Area Line," which coincides with the Green Line in the eastern part of the city and runs 3 miles south

158 "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 this 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, at 19.

of it in the western portion. Below the Rural Area Line, the city strongly discourages development and encourages rural legacy and conservation easements (VBCP, 2003). In effect, the city's plan to preserve rural areas will serve to preserve the coastal environment as sea level rises throughout the coming century and beyond. To the west, by contrast, the City of Chesapeake is encouraging development in the rural areas, particularly along major corridors. Comprehensive plans in the more rural counties such as Isle of Wight and James City tend to focus less on preserving open space and more on encouraging growth in designated areas (IWCP, 2001 and JCCP, 2003). Therefore, these more remote areas may present the best opportunity for long-range planning to minimize coastal hazards and preserve the ability of ecosystems to migrate inland.

F.3.2 York River to Potomac River

Gloucester County's land use policies also have a strong conservation ethic. A large portion of the necks along Mobjack Bay has a conservation zoning that allows 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 wetlands159. The County also seeks to maintain coastal ecosystems important for crabbing and fishing. As a result, wetlands and beaches along Mobjack Bay may be able to migrate inland as sea level rises.

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

Gloucester County also has a suburban country side zoning, which allows for low density residential development, including clustered sub-developments160 along part of the Guinea Neck and along the York River between Carter Creek and the Catlett islands. These developments often leave some open space that might convert to wetlands as sea level rises even if the development itself is protected. The county plan anticipates development along most of the York River. Nevertheless, a number of areas are off-limits to development. For example, the Catlett islands are part of the Chesapeake Bay National Estuarine Research Reserve in Virginia, managed as a conservation area161.

Along the Northern Neck, shoreline armoring is already very common, especially along Chesapeake Bay and the Rappahannock Rivers shores of Lancaster County. (See Figure F. 19.) Above Lancaster County, however, development is relatively sparse along the Rappahannock River. Development is proceeding along the Potomac River, by contrast.

160 Definition 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….Cluster development is encouraged in order to protect environmental and scenic resources."

161 See the Research Reserve's web page at http://www.vims.edu/cbnerr/about/index.htm; accessed on May 12, 2007.Virginia Institute of Marine Science. (date unknown). "About Chesapeake Bay National Estuarine Research Reserve in Virginia." http://www.vims.edu/cbnerr/about/index.htm. Accessed May 12, 2007.

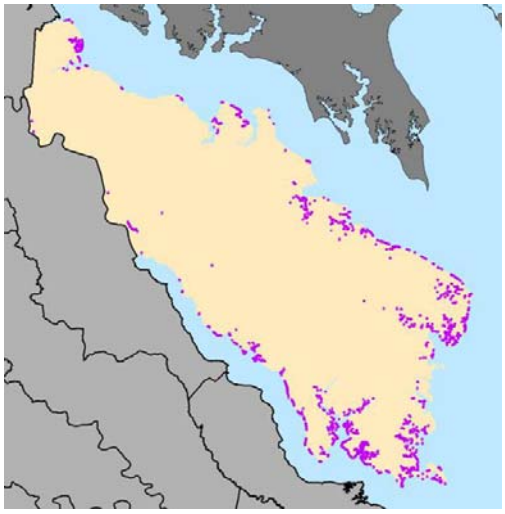

Figure F. 19 Location of shoreline armoring within the Northern Neck. Each dot indicates the presence of a bulkhead or revetment within about 1,000 feet. Therefore, the armoring is not necessarily as continuous as the map might appear to imply. The dots that appear to be inland are actually along tidal creeks. Source: Northern Neck Planning District.

F.3.3 Potomac River

West of Chesapeake Bay, the southwestern shoreline of the Potomac River is the border between Maryland and Virginia[162]. As a result, 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. Moreover, most efforts to control erosion along the Virginia shore take place partly in Maryland (or DC) and thus could potentially be subject to Maryland (or DC) policies[163].

Development is proceeding along approximately two-thirds of the Potomac River shore. Nevertheless, most shores in Charles County (Maryland) are in the resource conservation

162 See Maryland v. Virginia, 540 US (2003), slip opinion at 2.

163 The Virginia Shore across from the District of Columbia is mostly owned by the federal government, which would be exempt from DC policies.

area defined by the state's Critical Areas Act (and hence limited to one home per 20 acres) (MD DNR, 2007). A significant portion of Prince George's County's shoreline along the Potomac and its tributaries are owned by the National Park Service and other conservation entities that seek to preserve the coastal environment (MD DNR, 2000).

In Northern Virginia, parks also account for a significant portion of the shore. In Outside the park lands, several developers have set development back from low-lying marsh areas to avoid problems associated with flooding and poor drainage, or created developments with lot sizes greater than 10 acres. In Stafford County, the CSX railroad line follows the river for several miles, and is set back to allow shores to erode, but not so far back as to allow for development between the railroad and the shore[164].

F.3.4 Washington DC

The low land vulnerable to sea level rise in the District of Columbia includes portions of the downtown area, the monuments, Columbia Island, and the military lands along the Potomac River south of the mouth of the Anacostia. These facilities are unlikely to be given up to rising sea level; city officials are currently discussing the flood control infrastructure necessary to avoid portions of the downtown area from being classified as part of the 100-year floodplain. Nevertheless, natural areas in the city account a substantial portion of the city's shore, such as Roosevelt Island and the shores of the Potomac River within C&O National Historic Park.

164 Personal communication with Mark Remsberg, Community Development, King George County, December 17, 2004.

As part of the city's efforts to restore the Anacostia River, District officials plan have proposed a series of environmental protection buffers along the Anacostia River with widths between 50 and 300 feet. Bulkheads are being removed except where they are needed for navigation, in favor of natural shores in the upper part of the river and bioengineered "living shorelines" in the lower portion (see Figure F.20) (DCOP, 2003).

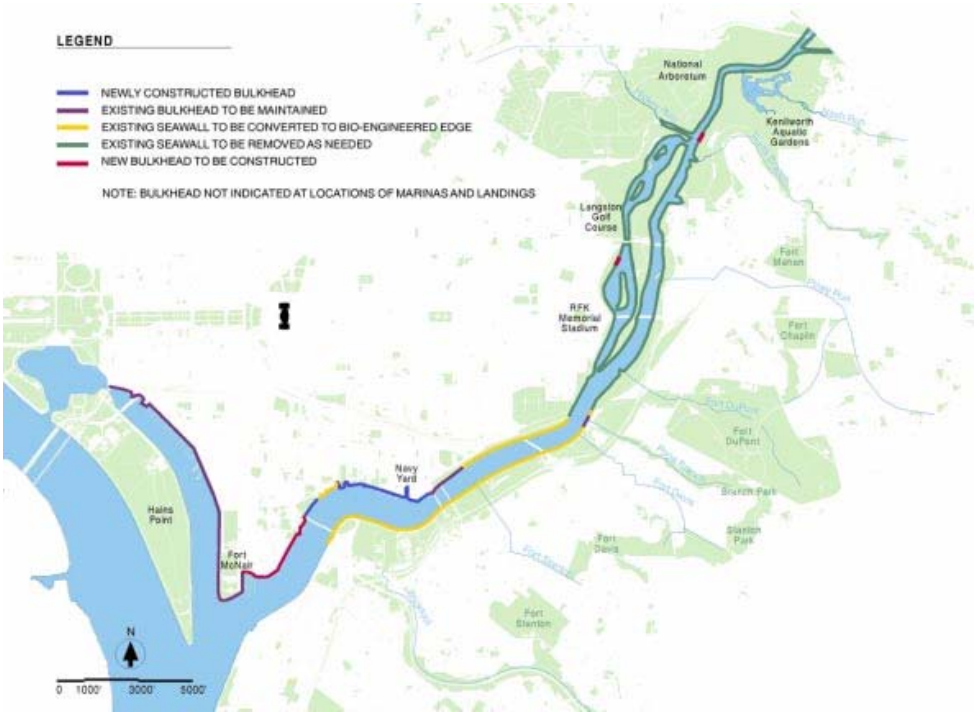

Figure F.20 District of Columbia Plans to restore natural shores along Anacostia River.
Source: DCOP, 2003.

F.3.5 Western Shore: Potomac River to Susquehanna River

Compared with the Potomac River, Maryland's Critical Areas Act is unlikely to preserve a major portion of the Western Shore, which was largely developed before the act was

passed. Stone revetments are common along the mostly developed shores of Anne Arundel and Baltimore counties. .Yet the Western Shore also has one of the only shore protection policies in the nation that prohibits shore protection along an estuary, even when the prohibition means that homes will be lost. Calvert County's erosion policy is designed to preserve unique cliff areas that border Chesapeake Bay. They are a unique visual landmark and provide habitat to plants and wildlife, including endangered species.

The County allows erosion control structures in certain developed areas to protect property interests, but also bans structures in other areas to protect endangered species and the unique landscape. Cliffs in Calvert County are separated into three categories according to the priority for preservation of the land:

- Category 1 provides the greatest environmental protection. No shore protection is allowed and new development must be set back from the cliff edge by 300 feet.
- Category 2 allows limited shoreline armoring. Shore protection is allowed solely to protect built before 1997. A 200-foot setback for new development is also required.
- Category 3 comprises all remaining cliff areas on the Chesapeake Bay. Shore protection is allowed[165].

Although a county policy prohibiting shore protection would appear to run counter to the state law granting riparian owner the right to shore protection, to date no legal challenges to the cliff policy have been made. The state has accepted the County's policy, which is

[165] Personal communication from Dr. David Brownlee to William Nuckols and Daniel Hudgens, December 14, 2000.

embodied in the County's critical areas plan submitted to the state under the Critical Areas Act.

Recognizing the potential environmental implications, living shoreline protection is becoming increasingly commonplace along the Western Shore.

F.3.6 Eastern Shore: Susquehanna River to Choptank River (Cecil, Kent, Queen Anne's, Caroline, and Talbot counties)

The decline of the bay beach resort has coincided with a decline in public demand for a bay beach. For those who have built or purchased homes near the ocean during the last few decades, one of the most important reasons for purchasing a home has been the amenity that one can walk to the beach — an amenity that would be lost if the beach were to disappear. Hence substantial expenditures have been devoted to beach nourishment to avoid having to choose between losing the beach and losing the first row of homes. Along Chesapeake Bay, by contrast, recent coastal development has not placed a high value on the beach. The new bayfront subdivisions often provide no public access to the beach, and as shores erode, people erect shore-protection structures that eventually eliminate the beach (Titus, 1998). Some traditional access points have been closed (Titus, 1998). Maintaining a beach remains important to some of the older bay resort communities where residents have long had a public beach — but even communities with "beach" in the name are seeing their beaches replaced with shore protection structures[166].

166 E.g. Chesapeake Beach, North Beach, Tolchester Beach all have more armored shores than beach.

Maryland's Critical Areas Act, however, is likely to restrict the extent of additional development along the Eastern Shore of Chesapeake Bay to a greater extent than along the Western Shore. The resource conservation areas where development is discouraged include half of the Chesapeake Bay shoreline between the Susquehanna and Choptank rivers. Among the major tributaries, most of the Sassafras, Chester, and Choptank rivers is similarly preserved; the Act did not prevent development along most of the Wye, Elk, and North East rivers. Existing development is most concentrated in the northern areas near I-95, Kent Island, and the various necks near Easton and St. Michaels. .

Extrapolating the recent bayfront model for development along Chesapeake Bay would lead one to expect beaches to be replaced with shoreline armoring. However, if bay beaches were to come back into vogue, then efforts to maintain them might involve either beach nourishment or allowing shores to erode naturally. Scientists are starting to recognize environmental value to bay beaches[167] and homeowners are starting to place value on environmental quality.

F.3.7 The Lower Eastern Shore: The Choptank River to Cape Charles

Along Chesapeake Bay, islands are threatened by a combination of erosion and inundation. Wetlands are taking over portions of Hoopers and Deal Islands, but shore erosion is the more serious threat. During the middle of the 19th century, watermen who made their living by fishing Chesapeake Bay made their homes on various islands in this region. Today, Bloodsworth and Lower Hoopers islands are uninhabitable marsh, and the

167 E.g., see Nordstrom, 1997 and NRC, 2007. Nordstrum "Estuarine Beaches". National Research Council. "Mitigating Shoreline Erosion".

erosion of Barren and Poplar islands led people to move their homes to the mainland. Smith Island is now several islands, and it has a declining population. Hoopers and Deal islands are becoming gentrified. Virtually all of the beaches along Chesapeake Bay are eroding. Shore erosion of beaches and clay shores along the Chester, Nanticoke, and Chester rivers is less — but enough to induce shoreline armoring along most developed portions.

The lower Eastern shore has a history of abandoning lowlands to shore erosion and rising sea level to a greater extent than other parts of the state.

Today Smith and Tangier are the only inhabited islands without a bridge connection to the mainland. Government officials at all levels are pursuing efforts to prevent the loss of these lands, partly because of their unique cultural status and — in the case of Tangier — a town government that works hard to ensure that the state continues to reinvest in schools and infrastructure. The Corps of Engineers has several planned projects for halting shore erosion, but to date, serious efforts to elevate the land are not under way. The replacement of traditional lifestyles with gentrified second homes may increase the resources available to preserve these islands.

The mainland of Somerset County vulnerable to sea-level rise is mostly along three necks. Until recently, a key indicator of the cost-effectiveness of shore protection was the availability of a sewer line[168]. As sea level rises, homes without sewer may be condemned as septic systems fail. The incorporated town of Crisfield, in the

168 The mounds systems have made it possible to inhabit low areas with high water tables.

13562 southernmost neck, has long had sewer service, which has been recently expanded to
13563 nearby areas. The town itself is largely encircled by an aging dike. Deal Island, no longer
13564 the thriving fishing port of centuries gone by, still has moderate density housing on most
13565 of the dry land.
13566
13567 Wicomico County's low-lying areas are along both the Wicomico and Nanticoke Rivers.
13568 Unlike Somerset, Wicomico has a large urban/suburban population, with the Eastern
13569 Shore's largest city, Salisbury. Planners accept the general principals of the state's
13570 Critical Areas Act, which discourages development along the shore.
13571
13572 Much of coastal Dorchester County is already part of Blackwater Wildlife Refuge. The
13573 very low land south of Cambridge that is not already part of the refuge is farmland. A
13574 development of approximately 1000 acres was recently proposed and approved along
13575 Egypt Road south of Cambridge; but as a result of citizen opposition it was later
13576 cancelled and the state plans to buy most of the property. The County plan does not
13577 anticipate development in most of the low-lying lands west of Cambridge. On the higher
13578 ground along the Choptank River, by contrast, many waterfront parcels are being
13579 developed.
13580
13581

BOX F.1: The Diamondback Terrapin, *Malaclemys Terrapin*

The diamondback terrapin, *Malaclemys terrapin*, comprising seven subspecies, is the only turtle that is fully adapted to life in the brackish salt marshes of estuarine embayments, lagoons, and impoundments (Ernst and Barbour, 1972). Its range extends from Massachusetts to Texas in the narrowest of coastal strips along the Atlantic and Gulf coasts of the United States (Palmer and Cordes, 1988). Extreme fishing pressure on the species resulted in population crashes over much of their range so that by 1920 the catch in Chesapeake Bay had fallen to less than 900 pounds. The Great Depression put a halt to the fishery, and during the mid-20th century, populations began to recover (CBP, 2006). Although a modest fishery has been reestablished in some areas, stringent harvest regulations are in place in several states. In some instances, States have listed the species as endangered (Rhode Island), threatened (Massachusetts), or as a "species of concern" (Georgia, Delaware, New Jersey, Louisiana, North Carolina, and Virginia). In Maryland, the status of the northern diamondback subpopulation is under review (MD DNR, 2006b).

Effects of Sea-level Rise

The prospect of sea-level rise, along with land subsidence at many coastal locations, increasing human habitation of the shore zone and shoreline stabilization, places the habitat of terrapins at increasing risk. Because human infrastructure (*i.e.*, roadways, buildings, and impervious surfaces) leaves tidal salt marshes with little or no room to transgress inland, the ecosystem that terrapins depend on may be lost with concomitant extirpation of the species.

F.4 POPULATION OF LANDS CLOSE TO SEA LEVEL

F.4.1 Chesapeake Western Shore

Table F.6 estimates the population of lands close to sea level for each of the localities along the Western Shore of Chesapeake Bay or its tributaries. The greatest concentration of people living close to sea level is in the various localities around Hampton Roads. The uncertainty range reflects the lack of precision in the elevation data. Although Maryland now has LIDAR for most of the state, when our elevation data set was assembled it was unavailable; as Figure 1.1 shows (Chapter 1), we had better elevation data in the Hampton Roads area than most of the Western Shore.

Table F.6 Population of lands close to sea level: Western Shore.

Locality	Low and high estimates of population below a given elevation (thousands)					
	50cm		**1m**		**2m**	
	Low	**High**	**Low**	**High**	**Low**	**High**
Hampton Roads						
Chesapeake	3.4	13.9	3.4	19.8	12.5	50.2
Hampton	6.1	19.7	6.1	35.6	19.0	98.5
Isle of Wight	0.0	0.3	0.0	0.3	0.0	0.4
James City County	0.0	0.1	0.0	0.5	0.0	0.7
Newport News	4.1	6.8	4.1	7.7	6.8	17.9
Norfolk	9.2	30.6	9.2	40.1	29.8	166.8
Poquoson	0.5	5.1	0.5	8.4	4.9	11.6
Portsmouth	1.1	8.5	1.1	12.3	8.3	45.4
Suffolk	0.0	0.8	0.0	1.2	0.0	1.9
Surry	0.0	0.0	0.0	0.0	0.0	0.006
Virginia Beach	4.8	28.4	4.8	47.8	25.2	168.8
York	1.8	4.5	1.8	5.5	4.3	10.3
Total	**30.9**	**118.7**	**30.9**	**179.2**	**110.6**	**572.6**
Northern Neck/Middle Peninsula)						
Essex	0.0	0.2	0.0	0.2	0.0	0.4
Gloucester[a]	0.2	2.7	0.2	3.3	2.7	5.2
King and Queen	0.0	0.0	0.0	0.1	0.0	0.2
King William	0.0	0.3	0.0	0.9	0.0	1.3
Lancaster	0.0	0.6	0.0	0.6	0.1	1.6
Mathews	0.0	1.3	0.0	1.8	1.3	4.2
Middlesex	0.0	0.1	0.0	0.2	0.1	0.4
Northumberland[b]	0.0	0.1	0.0	0.1	0.0	2.8
Richmond County	0.0	0.0	0.0	0.1	0.0	0.2
Total	**0.2**	**5.3**	**0.2**	**7.3**	**4.2**	**16.3**

Table F.6 Population of lands close to sea level: Western Shore (cont.).

Locality	Low and high estimates of population below a given elevation (thousands)					
	50cm		1m		2m	
	Low	**High**	**Low**	**High**	**Low**	**High**
Maryland						
Anne Arundel	0.0	2.9	0.0	10.2	2.8	21.2
Baltimore City	0.0	0.3	0.0	1.5	0.0	6.3
Baltimore County	*	*	*	*	*	*
Calvert	0.0	1.3	0.0	1.8	1.0	3.3
Charles[2]	0.0	0.1	0.0	1.2	0.0	1.8
Harford	0.0	0.9	0.0	1.0	0.9	2.9
Prince George's[b]	0.0	0.3	0.0	0.5	0.1	1.6
St. Mary's[b]	0.0	1.3	0.0	2.7	0.8	5.6
Total	**0.0**	**7.1**	**0.0**	**18.9**	**5.6**	**42.7**

* Data unavailable.
a. Figures are for the entire county. County is split between Chesapeake and Delaware Bay Watersheds.
b. Figures are for the entire county. County is split between Chesapeake and Potomac River Watersheds.

F.4.2 Potomac River

Table F.7 estimates the population of lands close to sea level along for each of the counties along the Potomac River and the District of Columbia. The absence of good elevation data makes these estimates very uncertain. Because Lewisetta is below the USGS "5-ft" contour, the low estimate for Northumberland should include the population of that community for the 2-meter case. The "high estimates" are also partly an artifact of our data limitations. In Fairfax County, for example, the NOAA analysis found 1647 people living in Census blocks that are entirely below the lowest topographic contour (the 10-ft contour). However, tens of thousands of people live in Census blocks with some land below that contour, and hence the high estimate of 6000 people.

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Table F.7 Population of lands close to sea level: Potomac River.

County	Low and high estimates of population below a given elevation (thousands)					
	50cm		1m		2m	
	Low	**High**	**Low**	**High**	**Low**	**High**
District of Columbia	0.0	0.2	0.0	0.2	0.2	5.6
Maryland						
Charles[a]	0.0	0.1	0.0	1.2	0.0	1.8
Prince George's[a]	0.0	0.3	0.0	0.5	0.1	1.6
St. Mary's[a]	0.0	1.3	0.0	2.7	0.8	5.6
Virginia						
Alexandria	0.0	3.1	0.0	7.6	0.0	11.0
Arlington	0.0	0.0	0.0	1.6	0.0	2.5
Fairfax	0.0	6.1	0.0	9.5	0.0	10.2
King George	0.0	0.4	0.0	0.4	0.0	0.4
Northumberland[a]	0.0	0.1	0.0	0.1	0.0	2.8
Prince William	0.0	2.2	0.0	2.4	0.0	2.5
Stafford	0.0	0.0	0.0	0.1	0.0	0.2
Westmoreland	0.0	0.4	0.0	0.8	0.0	2.2
Total	**0.0**	**14.2**	**0.0**	**27.1**	**1.1**	**46.3**

a. Figures are for the entire county. County is split between Chesapeake and Potomac River Watersheds.

13605
13606

13607 The District of Columbia was able to provide better elevation data than Maryland and
13608 Virginia (See Figure 1.1 in Chapter 1). Approximately 200 people live in low-lying areas
13609 near Georgetown that are potentially vulnerable to sea-level rise.

13610

13611 **F.4.3 Chesapeake Bay Eastern Shore**

13612 Table F.8 estimates the population of lands close to sea level for each of the counties
13613 along the Eastern Shore of Chesapeake Bay or its tributaries. Somerset, Dorchester, and
13614 Accomack counties have the largest populations living within one meter above spring
13615 high water[169]. These three counties have islands that have long been populated by
13616 watermen (Smith, Hoopers, and Tangier, respectively), as well as low-lying towns such

[169] Worcester and Sussex Counties have substantial populations living in low lying areas along the Atlantic Coast. Their small areas close to sea level in the Chesapeake Bay watershed are lightly populated.

as Crisfield, Toddville, and Chesconessex. The uncertainty range reflects the lack of precision in the elevation data. Thus, the Maryland calculations are more accurate.

Table F.8 Population of lands close to sea level: Eastern Shore.

County	Low and high estimates of population below a given elevation (thousands)					
	50cm		1m		2m	
	Low	**High**	**Low**	**High**	**Low**	**High**
Delaware						
Sussex[1]	1.1	7.2	1.1	9.5	7.1	17.0
Maryland						
Caroline	0.3	0.6	0.3	0.6	0.4	0.9
Cecil	0.0	0.3	0.0	0.7	0.2	1.3
Dorchester	0.0	0.6	0.7	2.0	3.5	4.2
Kent	0.0	0.5	0.0	1.0	0.0	1.7
Queen Anne's	0.0	0.1	0.1	0.2	0.7	2.2
Somerset	1.2	3.8	4.5	6.2	8.1	9.7
Talbot	0.0	0.1	0.1	0.3	0.9	1.7
Wicomico	0.1	0.1	0.1	0.4	0.9	1.2
Worcester[2]	0.0	1.1	0.6	3.2	6.4	12.6
Virginia						
Accomack[2]	0.8	7.0	0.8	7.6	6.9	9.3
Northampton[2]	0.0	0.3	0.0	0.6	0.2	1.1
Total	**7.3**	**30.7**	**12.3**	**45.1**	**42.5**	**86.0**

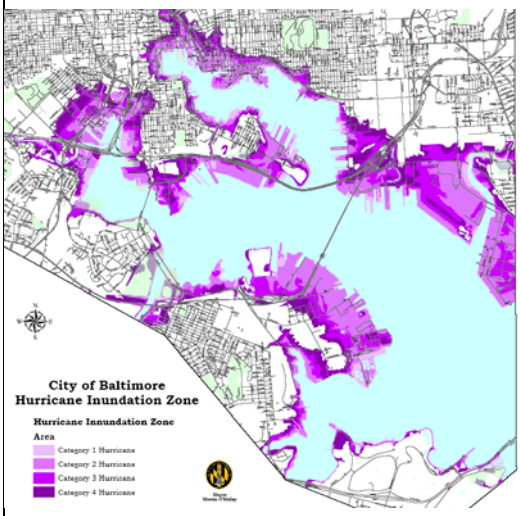
[1] Figures are for the entire county. County is split between Chesapeake and Delaware Bay Watersheds.
[2] Figures are for the entire county. County is split between Chesapeake and Atlantic Coast Watersheds.

13620

BOX F.2: Planning for Sea-level Rise in Baltimore

Only 3.2% of the City of Baltimore's 210 square kilometers of land is currently within the coastal floodplain. This land, however, includes popular tourist destinations such as Inner Harbor and the Fells Point Historic District, as well as industrial areas, some of which are being redeveloped into mixed use developments with residential, commercial, and retail land uses. The map below depicts the areas that the city expects to be flooded by category 1, 2, 3 and 4 hurricanes, which roughly correspond to water levels of 1.75 meters (6 feet), 3 meters (10 feet), 4.2 meters (14 feet), and 5.5 meters (18 feet) above NAVD. Approximately 250 homes are vulnerable to a category 1, while 700 homes could be flooded by a category 2 hurricane. As Hurricane Isabel passed in September 2003, water levels in Baltimore Harbor generally reached approximately 8 feet above NAVD, flooding streets and basements, but resulting in only 16 flood insurance claims.

The city's All Hazards Plan explicitly includes rising sea level as one of the factors to be considered in land use and infrastructure planning.[170] The All Hazards Plan has as an objective to "develop up-to-date research about hazards" and a strategy under that objective to "study the threat, possible mitigation and policy changes for sea-level rise." As a first step toward accurate mapping of possible sea-level rise scenarios the city is exploring options for acquiring LIDAR. Policies developed for floodplain management foreshadow the broad methods the city is likely to use in its response.



Map: Inundation Zone under Category 1, 2, 3, and 4 hurricanes.

Property values are high, and there is a long-standing practice of armoring shores to facilitate port-related activities and more recently, protect waterfront structures from shore erosion. In most areas, there is not enough room between the harbor and waterfront buildings to fit a dike. Even where there is room, the loss of waterfront views would be unacceptable in tourist and residential areas. In addition, storm sewers, which drain by gravity into the harbor, would have to be fit with pumping systems.

Fells Point Historic District

This historic community has 60 acres within the 100-year flood plain. Fells Point is a Federal Historic District and pending approval as a Local Historic District. The row houses here were built predominantly in the early to mid-19th century and cannot be easily elevated. Elevating brick and stone structures is always more difficult than elevating a wood frame structure. But because row houses are, by definition, attached to each other, elevating them one at a time is not feasible. Many of these homes have basements, which already flood. FEMA regulations do not permit basements in new construction in the floodplain and treats existing basements as requiring mitigation. Possible mitigation for basements includes relocation of utilities, reinforcement of walls, and filling.

In theory, homes could be remodeled to add stairways and doors to convert what is now the second floor to a first floor and convert the first floors to basements. But doing so would reduce the livable space. Moreover, federal and local preservation laws, as well as community sensibilities, preclude adding third stories to these homes. Elevating streets is also problematic because below-grade utilities need to be elevated. In the last decade only one street was elevated specifically to reduce flooding.

FEMA Flood Hazard Mapping and Sea-level Rise

Baltimore City is a participating jurisdiction in the National Flood Insurance Program (NFIP) through its regulation of development in the floodplain and through overall floodplain management. The city is currently funded through the Cooperative Technical Partnership (CTP) to update its flood maps. Federal flood mapping policies require that Flood Insurance Rate Maps (FIRMs) be based on existing conditions. At the time the mapping agreement was created (2005), FEMA would not allow use of the CTP funds to include additional mapping of sea-level rise or the mapping of projected future BFE. As a result, the city will be permitting new structures with effective functional lifespan of 50 to 100 years but elevated only to current flood elevations. One strategy to surmount this limitation is to add "freeboard," or additional elevation to the effective BFE. Baltimore already requires one additional foot of freeboard.

The City of Baltimore is concerned, however, that 1 to 2 additional feet of freeboard is inequitable and inefficient. If flood levels will be, for example, 1 meter higher than the flood maps currently assume, then lands just outside the current flood boundary are also potentially vulnerable. If the city were to add 1 meter of freeboard to property in the floodplain, without addressing adjacent properties outside the floodplain, then adjacent property owners would have divergent requirements that city officials would find difficult to justify.

Infrastructure
Baltimore has two regional sewerage plants. One of them, the Patapsco Wastewater Treatment Plant, sits on ground that is less than two meters above mean sea level and floods occasionally. The facility itself is elevated and currently drains by gravity into the Patapsco River. With a significant rise in sea level, however, pumping will be needed and possibly additional protections against storms. Numerous streets, with associated conduits and utility piping, are within the existing tidal floodplain and would potentially be impacted by sea-level rise.

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