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CHAPTER 5
DELAWARE

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SUMMARY

Sea level is rising 12–16 inches per century (3–4 millimeters per year) along the coast of Delaware. Ocean beaches are eroding, prompting beach nourishment projects along most of the developed beaches. Along the shores of Delaware Bay, beaches and marshes are eroding, and some low-lying farmland is converting to marsh. These effects could become more widespread if rising global temperatures cause the rate of sea level rise to accelerate. The Intergovernmental Panel on Climate Change, for example, estimates that by the end of the next century, sea level is likely to be rising 0–3 inches per decade more rapidly than today (excluding the possible impacts of increased ice discharges from the Greenland and Antarctic ice sheets).

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

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

Each of these approaches are being pursued somewhere in Delaware. People have built dikes along the Delaware River since the late 1600s, and stone revetments are common along developed portions of the Delaware River. The federal or state government has placed sand onto the eroding recreational beaches along the Atlantic Ocean, and several communities along Delaware Bay. Few homes have been lost to erosion recently, but farms and forests are converting to marsh in low areas along Delaware Bay.

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

This report develops maps that distinguish shores that are likely to be protected from the sea from those areas that are likely to be submerged, assuming current coastal policies, development trends, and shore protection practices. Our purpose is primarily to promote the dialogue by which society decides where people will yield the right of way to the inland migration of wetlands and beaches, and where we will hold back the sea. We obtained the land use and agriculture preservation data for the state's coastal zone and floodplain boundaries for New Castle and Kent counties, and consulted with planners representing the state's three counties on how to best interpret the data given existing

statutes, regulations, and policies. The result is a statewide series of maps that uses existing data, filtered through the county governments who coordinate land use planning activities.

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

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

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

For reasons related to data quality, our study area includes lands within 16 feet (5 meters) above the tides. (We did not project the fates of secured federal installations but depicted them in red so that they stand out.)

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

Results

Map 5-1 shows our assessment of the likelihood of shore protection for the coastal zone of Delaware, and adjacent areas of Pennsylvania, New Jersey, and Maryland. Table 5-1 quantifies the area of land within approximately 3 feet (1 meter) above the tides for each of the shore protection categories by county. Table 5-2 quantifies the length of shoreline along the Atlantic Ocean, Delaware Estuary, and back barrier bays by likelihood of shore protection.

The Delaware Estuary has a long history of shore protection. Partly because of the large tide range and partly because of Dutch tradition, dikes were constructed along the Delaware River in New Castle County, Delaware, during the 1670s. By 1885, land reclamation had converted 10,000 out of 15,000 acres of the marsh in New Castle County to agricultural lands, as well as 8,000 acres in the other two counties. Since the turn of the 20th century, however, these land reclamation efforts have been reversed. In many cases, the dikes were abandoned because of reduced prices for the crops that had been grown on the reclaimed land, so that only a few of the dikes remain. Numerous efforts are under way to restore the hydrology of these lands. (See Chapter 1, Overview.)

The momentum of these environmental restoration efforts has continued. Kent County does not permit subdivisions—and generally discourages most development in the 100-year coastal floodplain, as does New Castle County south of the Chesapeake and Delaware Canal. The State is purchasing agricultural preservation easements in the coastal zone, and more than one-third of the

shore is in Prime Hook or Bombay Hook National Wildlife Refuge. More than 80 percent of the shore south of the canal is part of some form of preservation or conservation land.

Along the Atlantic Ocean, more than three-quarters of the barrier islands and spits are part of Delaware Seashore State Park, while the mainland coast is about evenly divided between Cape Henlopen State Park and intensively used resorts such as Rehoboth, Dewey Beach, and Bethany Beach. Because the major coastal highway from Ocean City (Maryland) to Rehoboth passes through the state park, shore protection may eventually be necessary; the highway is set back enough for shore protection to be unlikely along the ocean for the foreseeable future. Thus, shore protection is likely along less than half of the ocean coast. Most low-lying lands along the barrier bays are expected to be developed, however.

Conclusions

1. The 25-mile Atlantic Ocean shoreline is nearly evenly divided between lands that are likely or certain to be protected and those where shore protection is unlikely or precluded by environmental policies.
    - Resort communities that are almost certain to be protected account for 10 miles of developed coastline. An additional 2 miles are likely to be protected, including the southern portion of Cape Henlopen state park..
    - Twelve miles of the coast, including the portion of Delaware Seashore State Park beach seaward of Route 1, are unlikely to be protected.
    - Shore protection is very unlikely (i.e., no shore protection) along an additional mile of shore within Cape Henlopen state park.

2. Along the inland bays of Sussex County, the prospects for shore protection appear to be largely established along 70 percent of the 53-mile shoreline.
    - Nearly 51 percent (27 miles) of the shores of Rehoboth, Indian River, and Little Assawoman bays is already developed and therefore almost certain to be protected.
    - State conservation policies within parks and preservation areas preclude shore protection along 19 percent (10 miles) of the inland bay shore.

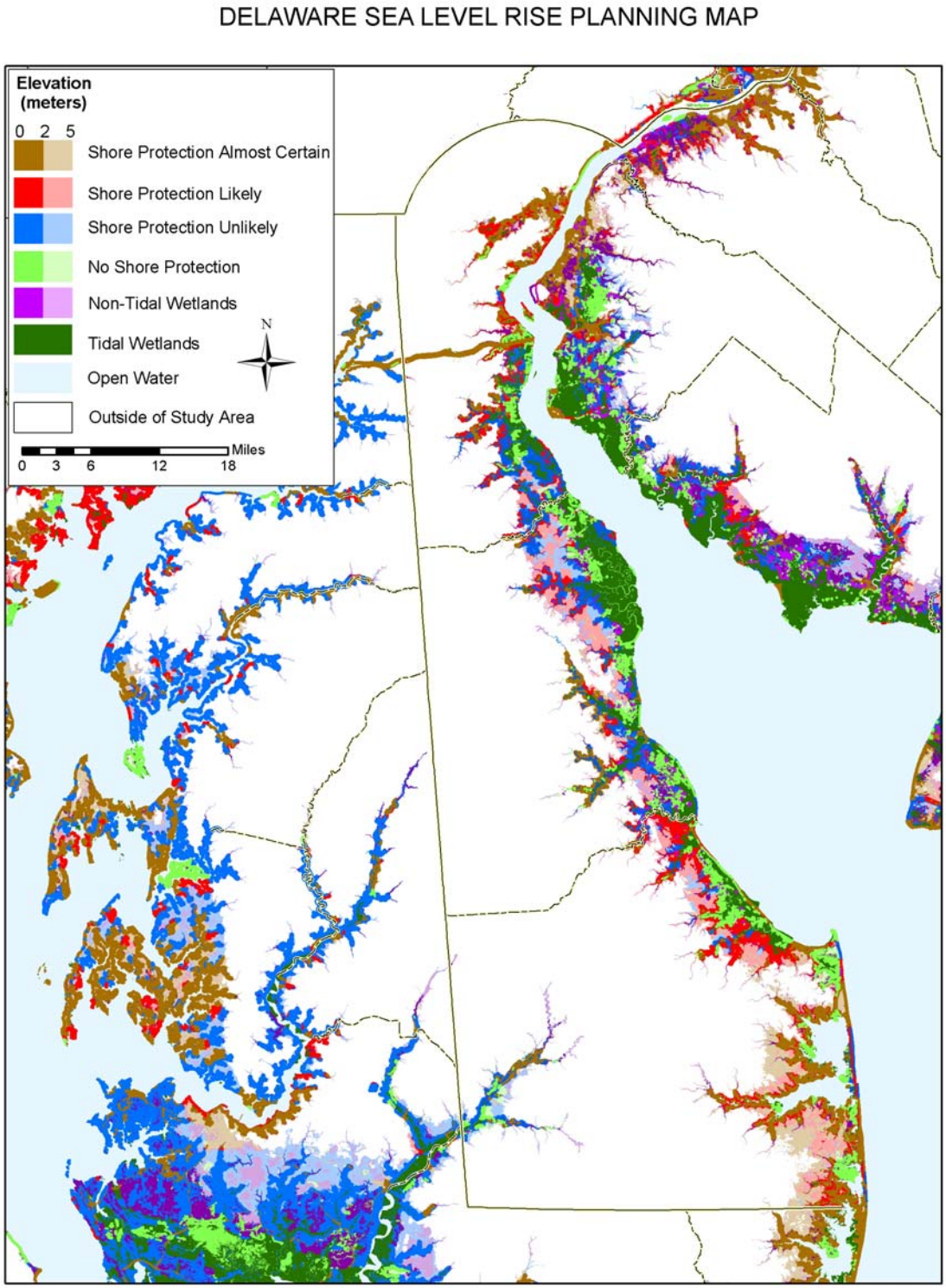
3. South of Cape Henlopen, 64 percent (12 square miles) of the land within 3 feet of the tides is likely or certain to be protected.
    - Eight square miles of land are developed and almost certain to be protected.
    - With substantial development pressures along the coast, an additional 4.2 square miles are likely to be protected.
    - Nevertheless, more than 6 square miles of dry land and nontidal wetlands within 3 feet of the tides are likely to be available for the landward migration of tidal wetlands.

4. The prospects for protection appear largely established for nearly 73 percent of the Delaware Bay shoreline; however, the prospects for landward migration of tidal wetlands are less clear.
    - Although 65 percent of Sussex County's Delaware Bay shoreline is developed and almost certain to be protected, shore protection is less than certain for nearly 90 percent of the area. within 3 feet above the tides.
    - Thirteen miles of the shore are conservation areas, including the Prime Hook and Bombay Hook National Wildlife Refuges. Although shore protection is very

unlikely, managers of these lands may continue to use engineering approaches to manage the water levels and preserve particular vegetation and animal species.

- Our options still appear to be open in the portion of Kent County and New Castle County south of the Chesapeake and Delaware Canal. Within the 100-year floodplain, the area is unlikely to be developed or protected due to regulations that prevent new development. Agriculture preservation easements also further reduce the potential for development. The regulations and easements, however, do not preclude landowners from protecting the land.
- In Kent County and Sussex County, 13.9 square miles of land less than 3 feet above of the tides are unlikely to be protected or conservation lands. An additional 7.5 square miles of nontidal wetlands exist in the area. Thus, the area of land likely to be available for wetland migration is small compared to more than 90 square miles of current tidal wetlands.

5. The portion of New Castle County north of the Chesapeake and Delaware Canal is more heavily developed than the rest of the Delaware estuary, but also contains several state preservation areas.
    - Along New Castle's 34-mile Delaware River shoreline, nearly 26 percent of the shore is either likely or almost certain to be protected.
    - An additional 13 miles of shore are part of public parks and state preservation areas that preclude shore protection.



Map 5-1. Delaware: Likelihood of Shore Protection. For each shore protection category, the darker shades represent lands that are either less than 7 feet (2 meters) above spring high water, or within 1,000 feet of the shore. The lighter shades show the rest of the study area. This map is based on data published between 1997 and 2005, and site-specific changes suggested by planners in 2005.

Table 5-1.
Area of Land within 3.3 feet (1 m) above Spring High Water by Likelihood of Shore Protection (square miles)

County	Likelihood of Shore Protection				Nontidal Wetlands	Total[a]	Elevation Error[b] (inches)	Tidal Wetlands
	Almost Certain	Likely	Unlikely	No Protection				
Atlantic Coast								
Sussex	7.8	4.2	0.5	3.2	2.4	18.8	16	15.8
Chesapeake Bay								
Sussex	0.2	0.0	0.5	0.2	0.9	1.8	16	2.6
Delaware Estuary								
Kent	1.1	1.1	5.9	4.3	5.4	17.8	16	65.1
New Castle	2.8	1.9	3.3	1.2	1.7	11.0	17	28.4
Sussex	0.9	5.1	0.8	2.6	2.1	11.6	16	26.0
Delaware	**12.8**	**12.2**	**11.0**	**11.5**	**12.4**	**61.1**		**137.9**

a. Total land includes the five categories listed plus land for which no data were available.
b. This table is based on the area of map polygons within 3.3 feet (1 meter) above the tides. Although the area of the polygons can be tabulated very precisely, the 3.3 feet (1 meter) elevation estimate is subject to the accuracy limits of the underlying elevation data. The elevation error column displays the accuracy limits (root mean square error) of the data used to identify the 1-meter elevation contour.

Table 5-2.
Shoreline Length by Major Water Body and Likelihood of Shore Protection
(miles)

County	Likelihood of Shore Protection				Nontidal Wetlands	Totals
	Almost Certain	Likely	Unlikely	No Protection		
Atlantic Ocean						
Sussex	10	2	12	1	0	25
Inland Bays						
Sussex	27	11	5	10	0.4	53
Delaware Bay	22	2	10	13	0.5	48
Kent	9	1	6	8	<0.1	24
New Castle	0.1	0.2	4	0	0.5	5
Sussex	13	0.7	0	6	0	20
Delaware River						
New Castle	7	12	2	13	0.2	34
State Total [a]	**429**	**247**	**405**	**362**	**135**	**1578**

a. Includes tributaries to the major water bodies.

INTRODUCTION

Delaware is the second smallest state in the nation, with 25 miles of shoreline along the Atlantic Ocean, 48 miles along Delaware Bay and 34 miles along the Delaware River. But when one includes the tidal inland bays, canals, creeks, and marshes, the state has more than 1500 miles of shoreline, all of which is potentially vulnerable to rising sea level.[1] Scientists estimate that sea levels rose by 3.1 mm/year over the last century at Lewes, Delaware.[2] Continuation of these historical rates would imply sea level rise of 18.6 cm between 1990 and 2050, but the potential impact of climate change increases the "best-guess" sea level rise scenario for the Mid-Atlantic during that period to 30 cm.[3] This increased rate of sea level rise will result in increased flooding and inundation of coastal lands. As a result, the management and extent of development of these lands will play a key role in the human and ecological effects of sea level rise. Both protection (through hard structures and/or beach nourishment) and abandonment of lands will impose significant costs on the state of Delaware and its people.[4]

All of Delaware's three counties have resources that are potentially vulnerable to sea level rise. Sussex County has important beach resorts and parks along the Atlantic Ocean and smaller communities and extensive wetlands along the inland bays and Delaware Bay. Kent County has only a few small communities along Delaware Bay, but it has farms, forests, and wetlands in low-lying areas. New Castle County has urban, industrial, and resort communities along the Delaware River, as well as agricultural areas that it seeks to preserve.[5] Statewide, more than 270 square miles of dry land and wetlands are below the approximately 8-foot elevation contour, and 181 square miles of dry land and wetlands are below the 2-foot contour.[6] Figure 5-1 depicts the land within approximately 20 feet (6 meters) above the ebb and flow of the tides.[7] Table 5-3 summarizes those elevations by county.

Purpose of this Study

This study develops maps that distinguish the areas likely to be protected[8] as the sea rises from the areas where shores will probably retreat naturally, either because the cost of holding back the sea is greater than the value of the land or because there is a current policy of allowing the shore to retreat. This report is part of a national effort by the U.S. EPA to encourage the long-term thinking required to deal with the impacts of sea level rise issues.

[1]The term "sea level rise" is used as a shorthand for "relative sea level rise."

[2]Titus, J.G. and V.K. Narayanan, 1995, *The Probability of Sea Level Rise*, EPA 230-R-95-008, EPA Office of Policy, Planning, and Evaluation, Washington, D.C.

[3]Ibid.

[4]For a discussion of potential national costs of sea level rise responses, see Neumann, J.E., G. Yohe, R. Nicholls, and M. Manion, 2000, *Sea Level Rise and Global Climate Change: A Review of Impacts to U.S. Coasts*, Pew Center on Global Climate Change, Arlington, VA. Additional sources that discuss sea level rise response costs specific to Delaware include Titus, J.G. et al., 1991, "Greenhouse effect and sea level rise: Potential loss of land and the cost of holding back the sea," *Coastal Management*, 19:171–204; Titus, J.G., and S.M. Greene, 1989, *An Overview of the Nationwide Impacts of Sea Level Rise*, EPA Office of Policy, Planning and Evaluation; and Yohe, G., 1990, "The cost of not holding back the sea. Toward a national sample of economic vulnerability," *Coastal Management* 18:403–431.

[5]The upper 2 miles of the Delaware Bay shore, mostly wetlands, is also in New Castle County.

[6]Titus J.G. and C. Richman, 2001, "Maps of lands vulnerable to sea level rise: Modeled elevations along the U.S. Atlantic and Gulf coasts," *Climate Research* 18:205–228.

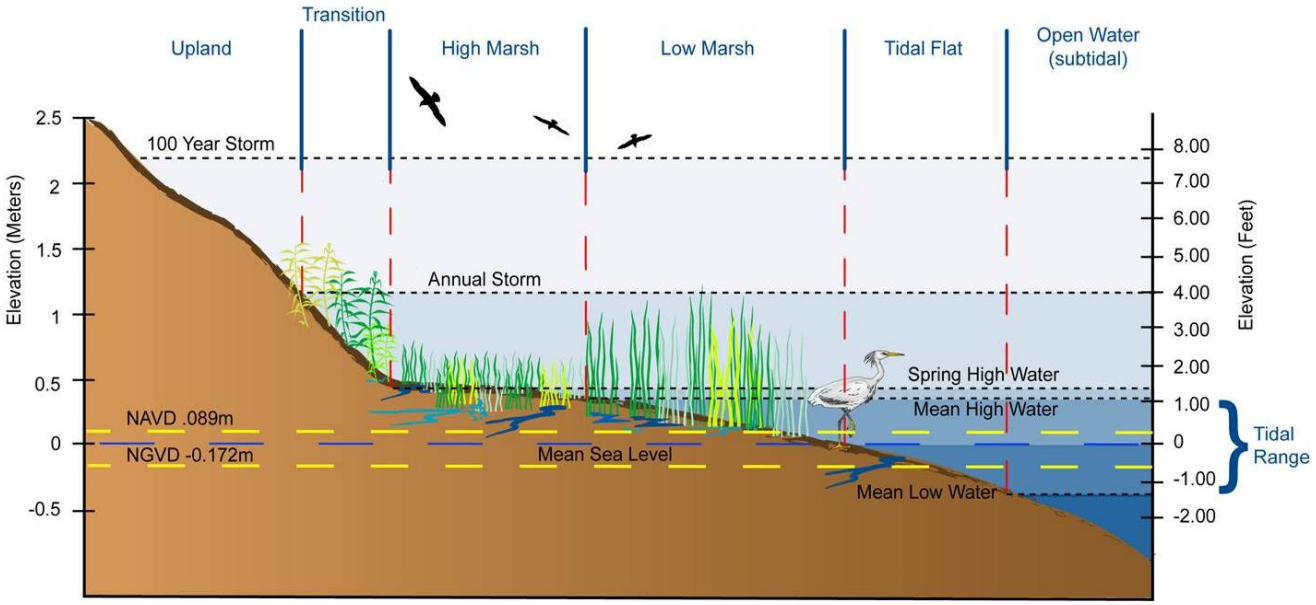
[7] See box on "Reference Elevations and Sea Level Rise" for an explanation of spring high water and sea level rise.

[8]For purposes of this study, "protect" generally means some form of human intervention that prevents dry land from being inundated or eroded. The most common measures include beach nourishment and elevating land with fill, rock revetments, bulkheads, and dikes.

BOX: TIDES, SEA LEVEL, AND REFERENCE ELEVATIONS

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

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



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

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

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

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

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

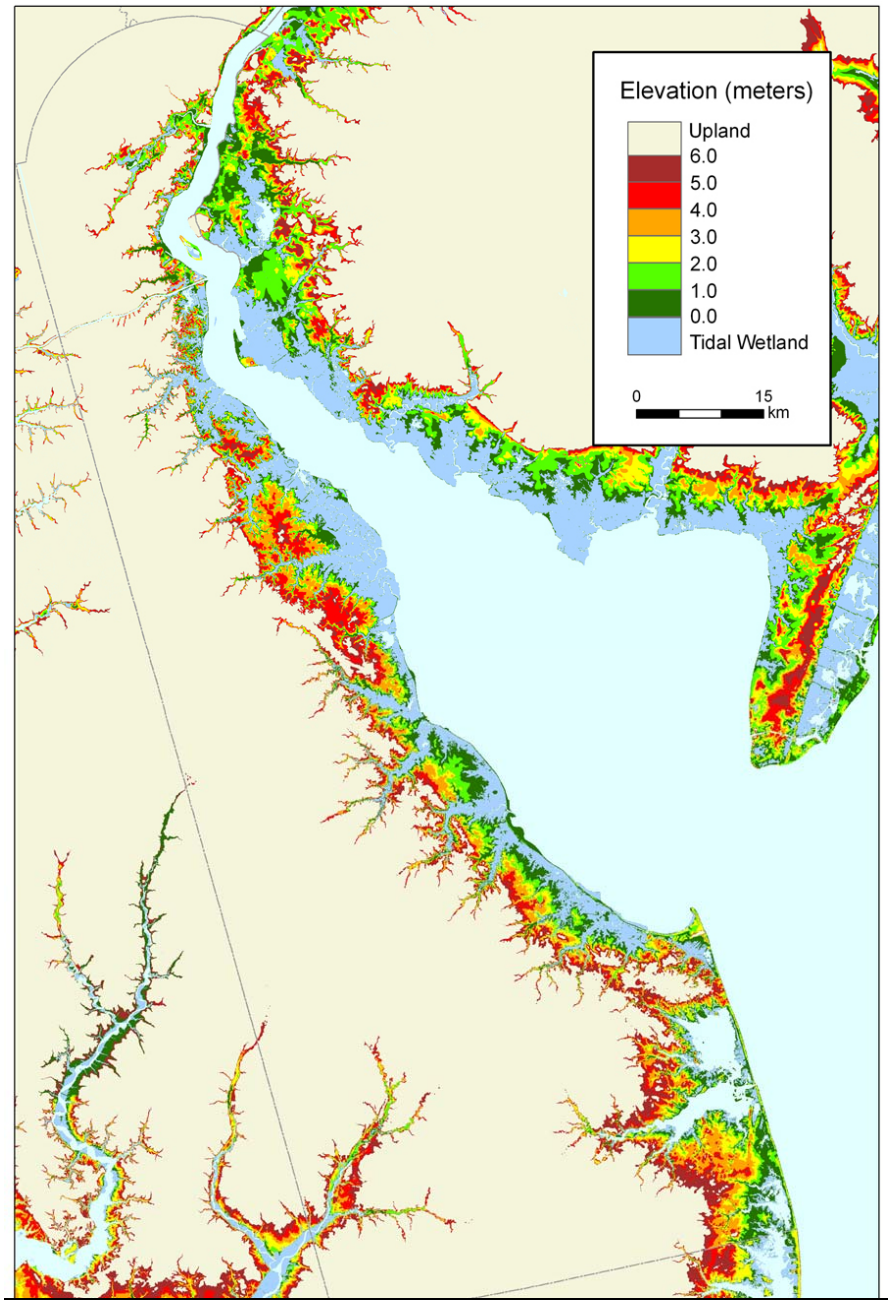


Figure 5-1. Lands Vulnerable to Sea Level Rise. Source: Titus and Wang 2008 (see Table 5-3). Elevations are relative to spring high water. Because the map has a contour interval of 1 meter (3.28 feet), we did not convert the legend from metric to the English units used in the text of this report.

TABLE 5-3. AREA OF LAND VULNERABLE TO SEA LEVEL RISE IN DELAWARE (SQUARE MILES)[a]

Jurisdiction[b]	Vulnerable land[c]	Tidal wetlands	Elevation[d]					
			0-2 feet		0-4 feet		0-8 feet	
			Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands	Dry land	Nontidal Wetlands
Sussex	66.2	44.4	17.7	4.1	32.2	6.1	62.3	9.8
Kent	77.8	65.1	8.6	4.1	14.7	6.1	30.7	9.6
New Castle	36.5	28.4	6.7	1.4	10.9	1.8	20.3	2.6
Statewide totals	**181**	**138**	**33**	**10**	**58**	**14**	**113**	**22**

[a] J.G. Titus and J. Wang. 2008. Maps of Lands Close to Sea Level along the Middle Atlantic Coast of the United States: An Elevation Data Set to Use While Waiting for LIDAR. Chapter 1 in J.G. Titus and E.M. Strange (editors) *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*. EPA 430-R-07-004, U.S. EPA, Washington, D.C.

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

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

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

Maps that illustrate the areas that might ultimately be submerged convey a sense of what is at stake, but they also leave people with the impression that submergence is beyond their control. Maps that illustrate alternative visions of the future may promote a more constructive dialogue.

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

State and local planners and others concerned about long-term consequences. Whether one is trying to ensure that a small town survives, that coastal wetlands are able to migrate inland[9], or some mix of both, the most cost-effective means of preparing for sea level rise often requires implementation several decades before developed areas are threatened.[10] For the last 25 years, EPA has attempted to accelerate the process by which coastal governments and private organizations plan for sea level rise, and evaluated whether the nation's wetland protection program will achieve its goals as sea level rises.[11] Preparing for sea level rise requires society to decide which areas will be elevated or protected with dikes and which areas will be abandoned to the sea. A key step toward such a decision is the baseline analysis of what will happen given current policies and trends. This report provides that baseline analysis.

National and international policy makers. National and international policies regarding the possible need to reduce greenhouse gas emissions require assessments of the possible impacts of sea level rise, and such an assessment depends to a large degree on the extent to which local coastal area governments will permit or

[9] In some areas, wetlands may accrete sufficient sediment to vertically increase elevation and thus avoid inundation. For further information on the potential for wetland accretion, see Reed, D.J., D.A. Bishara, D.R. Cahoon, J. Donnelly, M. Kearney, A.S. Kolker, L.L. Leonard, R.A. Orson, and J.C. Stevenson. 2008. Site-Specific Scenarios for Wetlands Accretion as Sea Level Rises in the Mid-Atlantic Region. Chapter 2A in J.G. Titus and E.M. Strange (editors) *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise*. EPA 430-R-07-004, U.S. EPA, Washington, D.C.

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

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

undertake sea level rise protection efforts.[12] Moreover, the United Nations Framework Convention on Climate Change, signed by President Bush in 1992, commits the United States to taking appropriate measures to adapt to the consequences of global warming.

Caveats

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

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

- the vulnerability of particular lands (we simply evaluate whether lands would be protected *if and when* they are threatened);
- options for protecting existing wetlands (we analyze protection only of dry land);
- which areas will receive government funded shore protection;
- whether people will hold back the sea forever, which would depend on cost factors and scientific uncertainties outside the scope of this analysis; and[13]
- whether hard structures, soft engineering, or some hybrid of the two approaches is likely in areas that will be protected, or the environmental impacts of shoreline armoring.

How to Read this Report

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

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

This chapter has separate sections in which we describe:

- *methods* by which we assess the likely sea level rise responses;

[12]Titus, J.G., et al., 1991, "Greenhouse effect and sea level rise," (see note 4). and Yohe, G., 1990 (see note 4).

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

- *state policies* that affect the management of the coastal lands;
- county-specific policies and the likely extent of future shore protection.

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

A. best estimates of the length of shoreline by likelihood of shore protection;

B. best estimates of the area of land at various elevations by likelihood of shore protection; and

C. uncertainty ranges of the amount of land at various elevations by likelihood of shore protection.

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

The final appendix (D) provides a complete list of data sources.

METHODS

This section provides detailed information on the approaches employed over the course of this study, which was initiated in 2000. Readers primarily interested in understanding our results should review the subsections on "Study Area" and "Alternative Illustrations of Results". Those who are interested in fully understanding the limitations of this effort should read all five subsections, which address:

- scope of the study area;
- methods used to develop the initial maps;
- the revised approach for displaying results;
- our approach for gathering updated information and to confirm the content of the maps and report; and
- the appropriate scale for viewing the resulting maps.

Study Area

The study area consists of dry lands that are either below the 20-foot (NGVD)[14] elevation contour or within 1,000 feet of the shore. We use the 20-foot contour as an inland boundary to be consistent with studies of neighboring states, and to ensure that the study area includes all portions of the state that might be affected by rising sea level during the foreseeable future.[15] This large study area is not meant to suggest that sea level rise would inundate all of these lands. We merely are attempting to avoid the possibility that subsequent improvements in elevation data reveal areas we omitted to be vulnerable. *Although our study area extends to the 20-foot contour, those using our results need not include the higher elevations.*[16]

Our study area also includes all dry land within 1,000 feet of tidal wetlands or open water to account for possible erosion[17] and to ensure that the study area is large enough to be seen on maps depicting a county on a single sheet of paper. We found that maps without a 1,000 foot study area along bluffs were difficult to read and did not convey the anticipated response.

Draft Maps

We began by researching state and county laws and development plans and meeting with state and county officials to determine the policies that affect sea level rise responses. The responses outlined in this study were modeled under three decision-making scenarios that are assumed to

[14] See text box.

[15] In Delaware, USGS maps generally have a 5-foot contour interval. Available maps for parts of Maryland have 20-foot contour intervals, however, and maps have 10-foot contour intervals for much of Pennsylvania, New Jersey, and Maryland. Numerous assessments have suggested that sea level could rise more than 2 meters over the next few centuries, which would bring the 100-year floodplain up to what is now the 15-foot (NGVD) contour interval.

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

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

occur within three distinct regulatory, political, and developmental climates:

Enhanced Protection Scenario (Scenario 1)— Protection of all areas that can be protected under existing state and local policies. It may bear little relation to what is practical and feasible.

Expected Protection Scenario (Scenario 2)— This scenario reflects an assessment of current as well as anticipated behavior (e.g., future development patterns) whether consistent with current policy or not. It assumes "practical" implementation of regulations and local planners' expectations. As such, it represents an assessment of the areas that are likely (or certain) to be protected from erosion, flooding, and inundation. This scenario generally excluded areas that are likely to remain sparsely developed and predominantly agricultural.

Enhanced Wetland Migration (Scenario 3)— This scenario is based on an assessment of alternative policies that would provide greater protection to natural resources (e.g., wetlands) or culturally significant resources (e.g., unique coastal populations or archeological sites). This scenario was meant to be a "reality check" on the expected protection scenario. For example, if the expected protection scenario showed that planners expected virtually an entire county to require shore protection, the logical question arises: Are there any areas where it might be feasible to allow wetlands to migrate inland, such as areas that have not yet been developed? Some lands are almost certain to be protected even if policy makers decide to promote landward migration of wetland; but areas where development is likely but not certain might be plausible candidates for a landward migration.

Through a discussion of these scenarios with the state and local planners, we developed maps using Environmental Systems Research Institute's ArcView GIS application and data available from Delaware's Office of State Planning Coordination, the University of Delaware's Spatial Analysis Laboratory, and the New Castle Department of Land Use.[18] Table 5-4 summarizes the GIS data applied in the study.

Alternative Illustration of Results

In the initial phase of this project, we used state policies combined with the judgments of county planners to specify maps for the three scenarios. We had little trouble specifying the "enhanced shore protection" and "expected shore protection" scenarios. However, some planners found it difficult to distinguish the lands where shore protection is expected regardless of environmental policy from those lands that might plausibly be available for wetland migration. Moreover, we found it difficult to define this scenario at times. As a result, we used a hypothetical approach for identifying lands that were considered likely to be protected under Scenario 2, but might be available for wetland migration (see subsequent discussion of Scenario 3 for Sussex County). Similarly, colleagues working on this project in other states found it difficult to identify areas where planners considered wetland migration to be economically and/or politically feasible.

Given the confusion, the EPA project manager (Jim Titus) modified the scenario definitions after the completion of the initial discussions with planning staff: *Enhanced wetland migration now identifies only the areas that are almost certain to be protected.* This new definition largely serves the same function; we merely change the emphasis. Lands that are likely (but not certain) to be protected are better candidates

[18]Data used include DEMs, land use/land cover (based on 1997 digital orthophotography by EarthData under contract to the State of Delaware), Delaware Department of Transportation's (DelDOT) major roads, state resource areas (publicly protected lands), state parks, and New Castle's 100-year floodplain shapefiles. All data are in (or converted to) NAD 83 (meters), Delaware State Plane projection. Data providers make no guarantee as to the accuracy or completeness of the information.

for wetland migration than lands that are almost certain to be protected. The reasons why shore protection is less than certain may have nothing to do with wetland policy, but for most purposes that does not matter. Along the ocean coast, protection may be less than certain because of moderate population densities or high costs of shore protection. Although such lands may not be suitable candidates for wetland migration, it seemed just as useful to distinguish those lands from the high density lands where shore protection is almost certain, as doing so along estuaries.

When viewing the initial study maps (which were separate maps for each scenario), it was also difficult to compare and contrast the scenarios for specific areas. As a result, we developed an approach for translating the scenarios to a single map in a way that takes the independent scenarios and combines the information into a cumulative summary. The translation between scenarios and the likelihood of shore protection is illustrated in Table 5-5. The resulting map combines the scenario information into a continuum of the likelihood of protection divided into four map colors depicted with the following scheme:

Brown: Almost certain to be protected (i.e., protected under all scenarios).

Red: Likely (but not certain) to be protected (i.e., protected under Scenarios 1 and 2 but not the enhanced wetland migration Scenario 3).

Blue: Protection unlikely (i.e., protected under the enhanced shore protection Scenario 1 but not protected under Scenarios 2 or 3).

Light Green: No shore protection under any scenario, that is, lands that are managed for a conservation objective that would be incompatible with shore protection.

We also show wetlands using dark green and sometimes purple (for nontidal wetlands). We differentiate tidal and nontidal wetlands because the effects of sea level rise are potentially very different. We differentiate nontidal wetlands from dry land because this report evaluated only whether dry land would be protected.[19]

Revised Maps

As a final check on the maps, we sent the draft of this report along with the maps to each of the counties. Doing so was important because even though we followed the decision rules and otherwise depicted the protected areas as suggested during previous meetings, textual adherence to GIS decision rules is no substitute for comparing a map to reality. This final round of meetings identified additional areas for probable shore protection.

Map Scale

Because our maps are based on decision rules and previously published data, the horizontal resolution at which one should reasonably display our maps is limited by the precision of the input data.

Most of the input data for this study were created at a scale of 1:24,000. The stakeholder and other site-specific edits were mostly based on features that were also available at a 1:24,000 scale, although a few were based on annotations to 1:100,000 scale maps. Those changes constituted less than 5 percent of the polygons; therefore they could not have deteriorated the maps to a scale worse than 1:50,000. The authors have not examined these maps at scales greater than 1:100,000.

The quality of our input data is not the primary uncertainty associated with our map boundaries. Future development and shore protection are very uncertain. Thus, the scales we suggest are simply our advice regarding the maximum scale

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

Table 5-5
Relationship between Shore Protection Scenarios and Likelihood of Shore Protection

Shore Protection Scenario		Likelihood of Shore Protection[e]			
Scenario Name	Short Name	Shore protection almost certain (brown)	Shore Protection likely (red)[f]	Shore Protection unlikely (blue)	No shore protection (light green)[7]
Enhanced Shore Protection	Scenario 1[a]	●	●	●	○
Expected Shore Protection	Scenario 2[b]	●	●	○	○
Enhanced Wetland Migration	Scenario 3[c]	●	○	○	○
Retreat	No Shore Protection [d]	○	○	○	○

Key:
● = Lands are protected
○ = Lands available for wetland migration

Notes:
a. The original definition of this scenario was: Areas that can be protected under current policies.
b. The original definition of this scenario was: Areas that are probably going to be protected.
c. The original definition of this scenario was: Same as scenario 2, but *subtract* areas that might be allowed to become submerged if wetland migration were to become a major priority for coastal zone management.
d. The initial study did not specifically identify a "No Shore Protection" scenario. This additional scenario, however, can be simply considered as the land that would not be protected under any of the other scenarios.
e. We use the term "likelihood" as a convenient shorthand. The classifications did not result from a formal assessment of probabilities. In the early rounds of many state-specific efforts, the groupings were based on shore-protection scenarios. We later reclassified the categories based on the differences between scenarios, and noticed that the differences roughly corresponded to different likelihood of shore protection.
f. This study did not attempt to characterize military lands outside of urban areas. To avoid having to define an additional map color, the maps depict these lands as red. *The GIS analysts assisting study authors, however, mostly neglected this distinction in creating GIS data sets; so most of the summary statistics include rural military lands with "shore protection likely."*
This term reflects a compromise between various considerations. The original draft maps presented to stakeholders used a variety of terms in different states, including "protection illegal," "protection contrary to public policy." None of those terms was precisely accurate, and stakeholders indicated that all of them could be misleading under some circumstances. Also "shore protection very unlikely," "protection extremely unlikely," "protection will not occur", and "protection…precluded by current policies."

at which one ought to display the maps for a given location, rather than our assessment of the accuracy of what will actually transpire in the decades ahead.

Use of Experts

This study is a hybrid between a pure data-driven assessment and an expert panel assessment. Like most assessments of shore protection, we start with the premise that lands will be protected if the cost of protection is less than the value of the resources being protected, except for where specific policies dictate otherwise. But estimating the costs and benefits of shore protection at every location would have been infeasible—and possibly involve wasted efforts for areas where the question is not close.

Instead, we adopted a simpler model: First, we identify those areas where conservation lands preclude shore protection, areas that governments have decided to revert to nature for flood mitigation or environmental reasons, and those areas that are so densely developed that no one seriously doubts the likelihood of shore protection (given current policies). Second, along estuaries we assume that residential, commercial, and other developed lands will be protected and that undeveloped lands will not be protected.[20] We rely on local planners to help us correctly use land use, planning, and zoning data—and to apply current land use policies—to identify current and project future development. Third, along ocean coasts, our premise is that current shore-protection policies generally have defined the areas where beach nourishment is almost certain, and that shore protection is likely in other areas that reach high densities. All of these aspects of the study are essentially data-driven, using a very simple model of the areas where shores are protected.

Nevertheless, we had to rely on local planners to provide facts or opinions in those cases in which the necessary data are unavailable, out of date, or provide an ambiguous result requiring a human tie-breaker. Most of the map changes provided by local planners involved cases where our data showed no development, but planners were aware of recent or imminent development. But in a small number of cases, planners reviewed our initial results, made a policy-based conjecture, and requested a map change. Judgment-based map designations constitute a very small percentage of the maps in this study.

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

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

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

TABLE 5-4. SUMMARY OF GIS DATA APPLIED IN STUDY

Data Name	Application in Study	Source/Year Published
Delaware state parks	Delineates state parks	Delaware Division of Parks and Recreation (DE DNREC)/2000
State resource areas	Delineates state-owned nature preserves	DE DNREC/1998
State agricultural preservation districts (1998)	Agricultural lands with development rights ceded to the state	Department of Agriculture/1998
State agricultural preservation districts (2004)	Agricultural lands with development rights ceded to the state	Delaware Department of Agriculture/2004
New Castle agriculture preservation	Identifies lands for which the state or county possesses development rights within New Castle County	New Castle County website/2005
Land use/land cover	Used to identify developed (residential, commercial, and industrial lands) and undeveloped lands (agricultural, range, and forest lands)	EarthData under contract to State of Delaware/1997
New Castle approved development	Identifies the location of recent development in New Castle County	New Castle County website/2005
New Castle 100-year floodplain	Delineates the 100-year floodplain in New Castle County	New Castle Department of Land Use/1996
Kent County floodplain	Delineates the 100-year floodplain in Kent County	FEMA/obtained 2005
Military lands	Used to delineate the boundaries of military-owned lands	ESRI National Atlas Federal and Indian Land/2004
Wetlands	Used to identify location of tidal and nontidal wetlands as well as open water	National Wetlands Inventory
Study area	Defines landward boundary of study area by identifying lands that are higher than 20 feet in elevation or within 1,000 feet of mean high water based on tidal wetlands data	ICF Contract to EPA/2003

Note: Additional detail on each data source is provided in appendix D.

STATE POLICIES RELATED TO SHORE PROTECTION

Existing Policies and Practices

The state's management of the coastal area is primarily based on three laws: the Coastal Zone Act (CZA), the Beach Preservation Act (BPA), and the Wetlands and Subaqueous Lands Act (WSLA).[21] The CZA prevents new industrial development in the coastal strip, the approximately 4-mile-wide strip of land parallel to the coastline.[22] The BPA gives the Department of Natural Resources and Environmental Control (DNREC) the authority to manage the state's beaches. The WLSA enables the state to manage activities in wetlands and subaqueous lands.

Beach Management

DNREC manages the beaches by issuing building permits along the coast and through beach nourishment and other management techniques that mitigate erosion. The state also controls coastal construction by requiring new structures to be set back from the coast.[23]

In 1988, DNREC prepared *Delaware's Environmental Legacy: Shaping Tomorrow's Environment Today*, which includes a discussion of the state's responses to sea level rise. The document reviews the risk of sea level rise to the state's valuable lands. The authors were particularly concerned with risks to year-round residents and the tourism industry, which had revenues of $660 million in 1985. Recommended management strategies include:

- actively regulating construction along the coastline to minimize construction impacts on the natural dune system;
- constructing devices that mitigate beach erosion, such as groins;
- nourishing beaches; and
- instituting a beach management program, which includes the reconstruction of dunes and planting of dune grass.

The *Beaches 2000* study, published in 1988, further refined the state's position on beach nourishment. This report recommended actively managing and nourishing beaches along the Atlantic Ocean as long as public benefits outweigh the public costs. Specifically, the planning group and advisory committee that prepared this report recommended the nourishment of Fenwick, South Bethany, Bethany, Dewey, and Rehoboth beaches.[24,25]

[21]For information on the CZA see Delaware Code Chapter 70 §7001 and for BPA see Chapter 68 § 6801.

[22]Throughout this report, the terms coast and coastline are used to refer to the land immediately adjacent to the Atlantic Ocean, inland bays, Delaware Bay, or the Delaware River. By contrast, we use the term oceanfront land when restricting our focus to the land area adjacent to the Atlantic Ocean.

[23]New and rebuilt structures must be constructed behind the building line, which is a line parallel to the coast that a) for land south of the tip of Cape Henlopen to the Delaware/Maryland border is 100 feet landward of the adjusted, seaward-most, 10-ft elevation contour above NGVD; b) for the land from the tip of Cape Henlopen to the southernmost limit of Primehook Beach is 100 feet landward of the adjusted seawardmost 7-ft elevation contour above NGVD; and c) for the land from the southernmost limit of Pikering Beach north to the Old Marina Canal is 75 feet landward of the adjusted seawardmost 7-ft elevation contour above NGVD; or at the landward limit of the beach, whichever is most seaward (from *Regulation Governing Beach Protection and the Use of Beaches*, Revised December 27, 1983).

[24]Although the state nourishes only beaches open to the public, private beaches have also conducted erosion management programs, including beach nourishment. Other private communities along Delaware Bay have granted public access to the beaches in return for state assistance for beach protection. Consequently, it is likely

Based on this policy, coastal beaches have been nourished several times since the late 1980s. On average, in recent years, the State has spent approximately $1.8 million annually to nourish beaches adjacent to Atlantic Ocean.[26] It is also important to note that the *Beaches 2000* study recommended that natural shoreline migration be allowed to occur at publicly owned lands along the coast.

The state's beach protection regulations require acquiring a permit before building any structure seaward of the building line that is designed to control beach erosion or protect the shore. DNREC opens the application process to public comment and reviews each application by considering potential effects on beach erosion and potential damage to the subject property. When reviewing a permit application, DNREC considers whether potential alternative means of protecting the property from storm damage exist, and determines whether permitting or denying the application—or requiring revisions to the proposed structure design—best meets the purpose of the Beach Preservation Act and regulations. When no alternatives to the statement exist, DNREC's internal policy is to approve the application. The applicant, as well as any taxpayer or agency within the state, may appeal the decision to the Secretary of DNREC and then the state's Superior Court.[27]

Wetland and Subaqueous Land Management

Additional state regulations implemented by DNREC's WSLS govern the use of all private and public subaqueous lands. The activities that require permitting because of their potential to "impair the public interest in the use of tidal or navigable waters" include "dredging, draining, filling, grading, bulkheading, mining, drilling, extraction of materials or excavation or construction of any kind, including, but not limited to, construction of a boat ramp or slip, breakwater, residences, bridge, bulkhead, culvert, dam, derrick, dock, groin, jetty, lagoon, gabion, rip-rap, launching facility, marina, mooring facility, pier, seawall, walkway or wharf."[28]

Many of the covered activities relate to erosion control and may be initiated in response to the risk posed by higher seas. Such activities are regulated under section 3.04, "Installation and Use of Shoreline Erosion Control Measures." The WSLS issues permits for preventive erosion control structures after verifying an applicant's claim that erosion is occurring. At sites where there is erosion, the WSLS recommends (in order of preference) vegetation, bio logs, riprap, and, as a last option, bulkheads. Applicants would be granted a permit, unless they are applying to control erosion and rebuild land where it has already been lost (e.g., behind a deteriorated bulkhead). In issuing the permits, the WSLS considers the potential ramifications of any project in detail.[29] If significant adverse environmental impacts are expected, that "could be offset or mitigated by appropriate actions or changes to the proposed activity by the applicant…the required mitigating measures may

that private beach communities will continue to manage erosion on their own or, if unable to do so, they will seek assistance from the state. Beaches 2000 Planning Group, *Beaches 2000: Report to the Governor*, June 21, 1988.

[25] Based on personal correspondence with Anthony Pratt, environmental program manager, Shoreline & Waterway Management Section, Division of Soil & Water Conservation, DNREC, January 31, February 24, and April 3, 2000.

[26] Additional nourishment had been conducted periodically for portions of the beach along the Delaware Bay; however, nourishment costs for these projects are not included in the cost estimate.

[27] See *Regulation Governing Beach Protection and the Use of Beaches*, revised December 27, 1983.

[28] State of Delaware, Department of Natural Resources and Environmental Control, 1991, Regulations governing the use of subaqueous lands, In accordance with 7 Del. C. §7212, p. 1. Available at: http://www.dnrec.state.de.us/water2000/Sections/Wetlands/DWRWetlands.htm, accessed October 4, 2007.

[29] Email from Christina Bosch, IEc, to Laura Herr, DNREC, "RE: DNREC regulations and EPA likelihood of shoreline protection study" September 27, 2007 and return email (summarizing conversation between Laura Herr, section director, and Melanie Tymes, Wetlands and Subaqueous Lands Section, Department of Natural Resources and Environmental Control, State of Delaware on September 27, 2007).

be included as conditions of the permit...."[30] Similarly, the WSLS attempts to avoid or mitigate any foreseen impacts to the public use of the subaqueous lands affected by the project.

The regulations, however, do not extend to property owners' management of land adjacent to wetlands. Although floodplain and setback ordinances at the county level can regulate activities within such dry land, the WSLS does not limit property owners' ability to add fill to the dry land.[31] Nor does it limit the ability of property owners to erect dikes on dry land to prevent tidal flooding of other dry land.[32]

Septic/Sewer System Regulations

The state also affects coastal land use through septic system regulations and sewer system management. Although the counties enforce septic regulations and choose where to expand sewer service, the state sets minimum requirements that the counties must implement. Several septic regulations contribute to the management of coastal properties and in some cases limit development for property subdivided after April 8, 1984. Property subdivided before that date is held to the pre-1984 septic regulations, which are substantially weaker than existing regulations. Throughout the state, properties subdivided after 1984 must meet several regulations, including:[33]

- minimum lot size of 1/2 acre for properties using septic systems (counties can require a larger minimum lot size);
- depending on the type of septic system, a separation of 20 to 36 inches between the base of the system and the water table; and
- septic systems 100 feet from both drinking wells and wetlands.

Currently, there are older developments along the coast of Sussex County that maintain cesspools rather than install more modern septic systems. Because these properties were subdivided before 1984, they are exempt from many of the current septic-related regulations. As a result, the state also faces reoccurring problems with some communities built on sandy soil. These communities typically experience one or more systems washing away during storm events. Other communities are currently serviced by holding tanks that are better able to withstand storms. In Sussex County, because of pollution problems associated with septic systems, several projects are under way to extend centralized sewer service around the inland bays, with much of the property along the oceanfront already on sewers. The State seeks to connect many of the older communities and new developments to the centralized sewer system. Consequently, developers can avoid the septic system requirements and, as a result, Sussex County may also face increased development pressures.

Public Land Management

As the green shaded area in Figure 5-2 illustrates, a large portion of the coastal area is owned by the state (e.g., park land, wildlife refuges). As developed in the *Beaches 2000* study, the state's policy is to allow natural shoreline migration in these areas. In 2007, however, the state did rebuild groins to stabilize a beach and eroding bluff to protect a historic structure.[34] Throughout the state, these public lands are highly valued, particularly the wildlife refuges that support freshwater duck species. Within these refugees, the U.S. Fish and Wildlife Service uses a system of dikes and

[30] State of Delaware, Department of Natural Resources and Environmental Control, 1991 (see note 28).

[31] Laura Herr, section director, Wetlands and Subaqueous Lands Section, Department of Natural Resources and Environmental Control, State of Delaware. As confirmed via email between Christina Bosch, IEc, and Laura Herr, DNREC, with subject: FWD: RE: DNREC regulations and EPA likelihood of shoreline protection study, on October 15, 2007.

[32] Ibid.

[33] Based on correspondence with Susan Warrington, environmental control technician, Division of Water Resources, DNREC, April 4, 2000.

[34] Noted by Anthony Pratt in his review of this report, July 26, 2007.

impoundments to modify the hydrology to maintain plant species preferable to waterfowl.[35]

Practical Assessment of Likely Actions

In this section, we summarize information obtained from Anthony Pratt of DNREC, who is knowledgeable about coastal conditions and policies that shape the state's coastal land-use planning and beach nourishment plans. He participated in the development of *Beaches 2000* and *Delaware's Environmental Legacy*, and is currently involved with the development of a federally funded beach nourishment project that will nourish publicly accessible beaches along the Delaware and Maryland coastlines. Through correspondences with Anthony Pratt, we obtained information on the state's role in shaping policies and trends relevant to sea level rise.

Meeting Notes

Environmental Program Manager and Section Administrator, Shoreline & Waterway Management Section, Division of Soil & Water Conservation, DNREC

Sea level rise is not the only process that affects property along the coastal zone. Littoral transport of sand along Delaware's ocean-facing coastline must be considered in any analysis of the coast. In Delaware, the net result is a movement of sand northward. As a product of the littoral transport, the shoreline of some areas has been eroding inland and jeopardizing coastal property.[36] As a result, the State has been actively managing against coastal erosion.

Coastal erosion poses a serious threat to the state's tourism industry, which is one of the three largest industries in the state. The tourism industry is primarily focused in Sussex County's beaches from Lewes south to Fenwick Island, with Bethany and Rehoboth beaches the most popular to the public. This area experiences significant problems from erosion—and consequently sea level rise. As a result, the State has nourished coastal beaches several times since the 1980s. A large quantity of sand resides close to the coast and provides a convenient, cost-effective source of sand for beach nourishment projects.

Unlike along the Atlantic coast, beaches and private property along the Delaware Bay face much less development pressure and do not attract significant tourism. Several of the smaller beach communities along Delaware Bay in Kent County have lower value property and structures. Because storms damaged homes in recent years, some property owners in small communities such as Kitts Hummock and Pickering Beach have abandoned their lands. In the past, however, bayfront beaches have been nourished by the state in return for public access to the land.

Through beach nourishment projects, the State has been able to maintain coastal beaches and, as a result, help protect homes adjacent to the coast. Based on the success of beach nourishment and by advocating the use of floodproofing measures that protect buildings, the State has maintained alternatives to bulkheading the coast. As a result, when reviewing bulkheading permit requests,

DNREC has, for the most part, avoided the need to permit such construction. Where no alternatives exist, however, DNREC's policy has and continues to be to accept the permit request. If the state beach nourishment efforts fail or if the State stops nourishing (which would happen if public costs outweigh public benefits), however, then the alternatives to bulkheading may no longer be feasible. As a result, DNREC would accept permit requests (i.e., the State will not seek to prevent private property owners from protecting their land if and when beach nourishment is not maintained). Therefore, the likely future response scenarios will largely depend on the degree to which landowners will seek to make the investments needed to protect their property

[35]Meeting with Wendy Carey, coastal processes specialist, Sea Grant College Program, University of Delaware, February 24, 2000. Also, documented in U.S. Fish and Wildlife Service brochures on Bombay Hook National Wildlife Refuge at http://www.fws.gov/northeast/bombayhook/BH gen broch.pdf, and Prime Hook at http://www.fws.gov/northeast/primehook/primehook.factsheet.pdf (accessed on October 15, 2007).

[36] Littoral transport results in some areas eroding whereas others accrete sediment and grow.

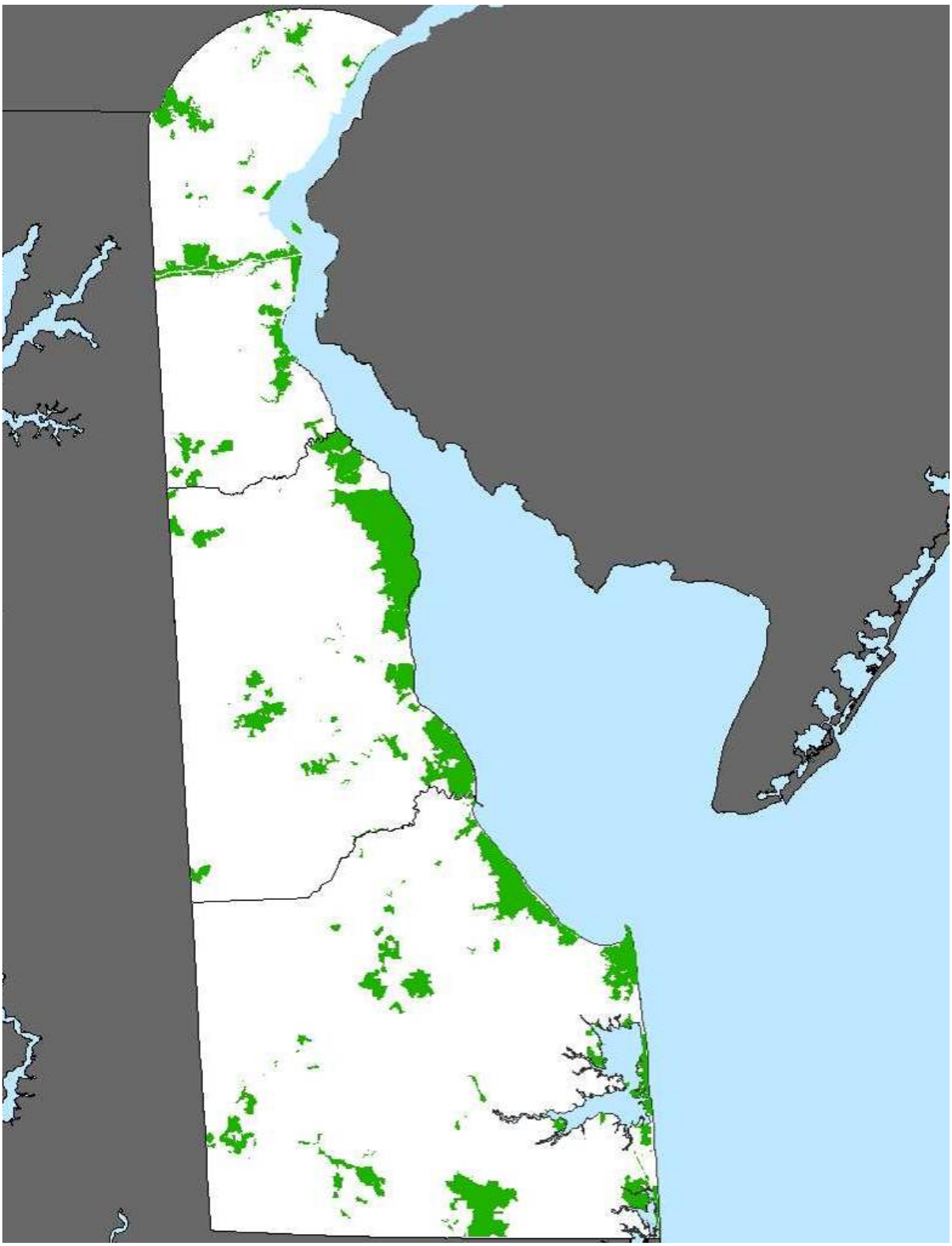


Figure 5-2. Environmental Preservation Lands in Delaware The lands shown in green are owned by the state of Delaware. As specified in the *Beaches 2000* study, beach preservation lands will be allowed to naturally migrate.

It is also important to realize that the state's public trust doctrine does not provide a feasible mechanism by which DNREC can regulate coastal management. Unlike most states, private landowners own the land down to mean low water, rather than mean high water. Consequently, DNREC accepts coastal bulkhead permit requests even in cases where it might result in the loss of the tidal zone land.

COUNTY-SPECIFIC RESPONSES TO SEA LEVEL RISE

Delaware has three counties, each with vastly different coastal land-use characteristics. Sussex has ocean beaches, a back barrier bay, and an intracoastal waterway, as well as a shoreline along Delaware Bay. Kent County is along the upper part of Delaware Bay, with a few miles of shoreline along the lower Delaware River. New Castle County's shore is entirely along the Delaware River and its tributary creeks.

Because the State will allow private property owners to protect their land, much of the likely response to sea level rise will be driven by county and municipal development decisions. Several land-use controls will shape response scenarios:

- Counties can restrict development through setback requirements.
- Through zoning and land-use plans, counties encourage development in some areas and discourage or prevent residential and commercial development on other lands.
- Counties enforce and can expand on state zoning ordinances related to septic system permits (e.g., by requiring a larger lot size than the minimum of ½ acre).

In the remaining sections of this report, we describe each county in more detail and present maps that depict the likelihood of shore protection.[37]

[37]The county governments are the basic form of government for much of the land in the state. Throughout the state, however, particularly in developed areas, municipalities have been formed. In most cases, the counties do not possess jurisdiction over municipalities' land-use decisions. Throughout this report, however, we discuss the counties in terms of both the county-controlled lands and the municipalities located in each county. Although the municipalities make land-use decisions on their own, county contacts are able to provide insight into the existing development of municipalities located along the coast.

SUSSEX COUNTY

As Delaware's only ocean-facing county, Sussex County experiences heavy residential and tourism development pressures. The *1997 Sussex County Comprehensive Plan* (adopted October 27, 1997) and the 2002 plan (adopted January 1, 2003) provide detailed information on the county's development plans. Sussex County seeks to focus future growth around existing municipalities and in designated development districts while limiting growth in more rural areas predominately characterized by agricultural lands.[38] The majority of the oceanfront land along Sussex County is zoned as a development district or existing municipality, with the exception of several scattered private and public resource areas, including state parks and wildlife refuges. Much of the ocean-facing lands are already or to soon be served by water and wastewater utilities. As a result, it is within this area that the County wishes to concentrate future growth. Based on the popularity of the area and the access to these resources, the coastal and inland bay areas will be densely developed in the near future.

Meeting Notes

Lawrence Lank, Director of County Planning & Zoning Commission of Sussex County[39]

Economic Conditions

With tourism and development pressures along the ocean-facing coastline, the land at risk of inundation is exceptionally popular and valuable. Extensive growth has occurred around the inland bays and in the vicinity of Route 1, where commercial businesses have located to meet the demands of citizens and seasonal tourists. The county has one of the lowest property tax rates in the nation because of the taxes derived from poultry feeding operations in the western portion of the state and the tourism industry located along the coast. Furthermore, it is unlikely that the County will reassess property valuations in the near future. In part, these low property taxes have contributed to a rise in development pressures.

Existing Coastal Policies and Practices

Because much of the coastal area is or will soon be serviced by centralized sewer systems, few land-use regulations exist to limit further development south of Lewes. In an effort to control pollution of land surrounding the coast and inland bays, the area is considered "environmentally sensitive." To decrease the extent to which environmentally sensitive lands are polluted, the State and County will expand drinking water and centralized wastewater management services to much of the area. Once the water and sewer services are in place, however, the County is likely to permit further development on the remaining undeveloped lands.

The land along Delaware Bay north of Lewes is characterized by less residential development and a greater proportion of natural and agricultural lands. The County seeks to limit development in natural and agricultural areas to maintain the area's rural characteristics and protect the exceptional soil quality. The County also participates in the state's agricultural preservation program, which encourages the protection of agricultural lands by temporarily or permanently acquiring development rights. This ensures that some parcels of land will not be developed for at least 10 years.

[38]Sussex County Comprehensive Plan Update, January 1 2003. Page 1.

[39]Daniel Hudgens met with Lawrence Lank in the County offices on February 25, 2000.

TABLE 5-6: ASSUMPTIONS FOR DRAFT SEA LEVEL RISE RESPONSE MAP: SUSSEX COUNTY[a]

Land Area	Protected in Scenario	Protection Likelihood	Source
The portion of Route 1 traversing the Delaware Seashore State Park	1 and 2	Likely	ESRI roads
Delaware Seashore State Park (barrier spit traversed by Route 1; excluding the road)	1	Unlikely	Delaware state parks
Public parks	None	No protection	Delaware state parks
Public preservation area	None	No protection	State resource areas
Agricultural, range, and forest lands along the Nanticoke River and Delaware Bay (north of Lewes and east of Route 1)	1	Protection unlikely	Land use/land cover[b,c]
Agricultural, range, and forest lands seaward of primary roads[d] along intracoastal waterway south of Lewes	1, 2	Protection likely	Land use/land cover[b,c]
Remaining public and private lands	1, 2 ,3	Protection almost certain	Land use/land cover

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

[b] We identify agricultural lands based on cropland, pasture, idle field, truck crop, orchard/nursery/horticulture, confined feeding operations, farmsteads/farm buildings, and other agriculture land use/land covers in data provided by EarthData, under contract to the State of Delaware.

[c] We identify range and forest lands based on herbaceous rangeland, shrub/brush rangeland, mixed rangeland, deciduous forest, coniferous forest, mixed forest, and clear-cut forest use/land covers in data provided by EarthData, under contract to the State of Delaware.

[d] Seaward of a line that starts along Route 9 in Lewes and then runs southeast along DE-1, southwest along DE-24, southeast along the MD & DEL R.R., west along DE-26, and finally southwest along DE-17. Stakeholder review for Kent County made a similar distinction for lands east and west of DE-1.

Expected Response to Sea Level Rise

Table 5-6 summarizes the county planning staff's suggested assumptions for each of the sea level rise policy scenarios, and lists the data sources we used to create maps reflecting those assumptions.

Enhanced Shore Protection (Scenario 1)

As discussed previously, the state's policies do not prevent private property owners from protecting against sea level rise.[40] Consequently, based on the enforcement of existing policies, private property could be protected, including residential, commercial, agricultural, and undeveloped lands. Most coastal land in Sussex County is privately owned and thus could be protected based on the current state policies. The only lands that would not be protected are the parks and conservation areas.[41]

Expected Shore Protection (Scenario 2)

Because approaches for protecting agriculture and other undeveloped lands (i.e., forest and

[40]The state's current policy for coastal structure permit applications is to deny permits for the construction of hard structures when alternatives exist (such as beach nourishment and floodproofing). When no alternatives exist, the State will accept permit applications.

[41]As an exception, we assume that parks on barrier spits (Delaware Seashore State Park) might be protected, given the likely protection of the state highway. Therefore these parks are considered protected under Scenario 1 but are not expected to be protected (i.e., not protected under Scenario 2 or 3).

range land) are expensive to construct and maintain (such as a pumping system to remove salt water from the crop soil), it is likely that undeveloped lands will be abandoned as sea levels rise.[42,43] Consequently, undeveloped lands are likely to be abandoned and developed lands are likely to be protected. In some areas, however, it is also likely that many of these currently undeveloped lands will be developed to satisfy residential and commercial development pressures along the coast and inland bays. As a result, one must identify the land likely to be developed in the future to identify lands expected to be protected.

Because agricultural preservation and protection of the county's rural nature are goals of the county, zoning regulations in Sussex County limit development of currently undeveloped land north of Lewes. Additionally, because centralized sewer systems are not likely to be installed north of Lewes, septic and setback regulations will also help limit further development. As a result, it is likely that the currently undeveloped lands north of Lewes will not be developed, and thus eventually abandoned

By contrast, Lawrence Lank indicates that the County will permit further development of the currently undeveloped land south of Lewes. once they are no longer economically feasible to protect.[44] Considering the development pressures in the county, it is likely that the currently undeveloped lands south of Lewes will be developed and protected in the future.[45]

It is important to note, however, that this scenario is prone to much uncertainty associated with the potential reactions of landowners. In particular, if protection methods become more cost-effective in the future, farmers on higher elevation land may be able to maintain agriculturally productive land far into the future through protection measures. Similarly, some property owners may allow wetlands to migrate inland onto portions of their property that are not located near their home.

One exception to this approach concerned the coastal highway, which runs through refuges and parks along barrier beaches between the developed areas. We assume that the areas inland from the highway are likely to be protected. Protection of the highway is almost certain, but a landward relocation is possible, as occurs routinely along the Outer Banks of North Carolina.

Enhanced Wetland Migration (Scenario 3)

The third scenario that we investigated reflects the possibility of greater environmental values in the future. Based on this scenario, we discussed with state and county officials the potential for greater protection of wetlands. Specifically, we discussed potential future efforts to ensure that property owners do not restrict wetland

[42]One reviewer, Anthony Pratt of DNREC, points out that in some cases farmers may be able to switch from conventional to salt-tolerant crops rather than abandoning the land. See peer review comments submitted by Anthony Pratt to Stephen Keach in email titled "Comments" on July 26, 2007.

[43]As sea level rise threatens agriculture lands with inundation and increased storm damage associated with salt water contamination, agriculture landowners are likely to attempt cost-effective means of protecting their lands. According to Anthony Pratt, at least one agriculture landowner in the state has already attempted to protect his property by constructing an earthen berm. Throughout the country, farmers have historically attempted to protect their land by constructing earthen banks and dikes (see Sebold, K.R., 1992, *From Marsh to Farm: The Landscape Transformation of Coastal New Jersey*, U.S. Department of Interior, National Park Service). Although these structures protect the land for a period of time, eventually storms degrade the structures and lead to the salt contamination of the soil. As a result, these threatened properties are eventually abandoned and revert back to wetlands.

[44]Anthony Pratt points out that plans for centralized sewer are subject to change. If centralized sewer service is extended to this area, the potential for further development (and consequently sea level rise protection efforts) could increase. See peer review comments submitted by Anthony Pratt to Stephen Keach in email titled "Comments" on 26 July 2007.

[45]In the development of the scenario maps, we define undeveloped lands as agricultural, range, or forest lands as identified from 1997 Land Use/Land Cover GIS data (Anderson classification codes 200 through 440). Additionally, we delineate the boundary between the land north and south of Lewes using Route 9, which bisects Lewes (i.e., land north of Lewes is considered to be land north of Route 9).

TABLE 5-7. ASSUMPTIONS FOR FINAL SEA LEVEL RISE RESPONSE MAP: SUSSEX COUNTY[a]

Land Area	Protection Likelihood	Source
Cape Henlopen State Park	Various	Hand edits based on DNREC comments
The portion of Route 1 traversing the Delaware Seashore State Park	Likely	ESRI roads
Delaware Seashore State Park (barrier spit traversed by Route 1; excluding the road)	Unlikely	Delaware state parks
Public parks	No protection	Delaware state parks
Public preservation areas	No protection	State resource areas
Developed lands	Certain	Land use/land cover[b]
Undeveloped lands seaward of primary roads along intracoastal waterway south of Lewes	Protection likely	Land use/land cover[b]
Agricultural preservation districts	Protection unlikely	State agricultural preservation districts (2004)
Remaining public and private lands along Atlantic coast	Certain	Land use/land cover
Remaining public and private lands along Delaware Bay (north of Lewes)	Likely	Land use/land cover
Remaining public and private lands along the Nanticoke River	Unlikely	Land use/land cover

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

[b] We identify developed lands based on residential, commercial, and industrial land use/land covers in data provided by EarthData, under contract to the State of Delaware. All other lands are undeveloped.

migration that could occur as sea levels rise. Although state and county officials were unable to predict how this future scenario might play out, we investigated a *hypothetical* response.

We explored the potential outcome if the State or County decided to prevent the use of protection measures (e.g., bulkheads, dikes) on currently undeveloped land located near wetlands. This could be accomplished by preventing development (and protection) of these lands or conditioning future development on the owner's agreement not to restrict wetland migration with hard structures. North of Lewes, the lack of development pressures in the area and the likelihood that property owners would not invest in costly protection efforts for undeveloped lands seem to make shore protection unlikely along the land along Delaware Bay, thus providing sufficient land for future migration. As a result, north of Lewes, the protected area expected to be protected (i.e., protected under Scenario 2) is equivalent to the protected area expected under the enhanced wetland migration scenario (Scenario 3).

South of Lewes, however, wetland migration may be restricted by home and business owners that seek to protect the land with hard structures. As with all the states in this study, developed coastal lands will almost certainly be protected—and undeveloped areas will continue to be developed. Thus, shore protection is almost certain in areas that are already developed, as well as areas inland of existing major roadways[46]

[46]Specifically, a line that starts along Rte. 9 in Lewes and then runs southeast along DE-11, southwest along DE-24, southeast along the MD & DEL R.R., west along Rte. 26, and finally southwest along Rte 17. Stakeholder review for

or inland of existing development.[47] Shore protection is not yet certain, and thus wetland migration is at least possible, in undeveloped areas seaward of existing development. Within these "potential wetland migration zones," we assume that wetlands could migrate onto currently undeveloped lands. Under this scenario, we assume that the currently undeveloped lands in the migration zones might not be developed, or that future development might be conditioned on the owner's agreement not to restrict wetland migration with hard structures.

The prospect of wetland migration in this scenario illustrates a hypothetical response that assumes that our generation will place as much value on allowing wetlands to migrate inland as sea level rises as the last generation placed on preserving the wetlands. Based on current state and county policies, however, these lands may be developed in the near future and therefore may be protected from the effects of sea level rise and wetland migration. Nevertheless, until those areas actually become developed, shore protection is not certain.

Stakeholder Review

EPA project manager Jim Titus sent the draft map to Lawrence Lank and spoke with him over the telephone on June 2, 2005. Much of his perspective was similar to that of Kent County. A considerable amount of land along Delaware Bay is in agricultural preservation—but those lands that are not part of that system will probably be developed. Unlike Kent County, development is allowed in floodplains. This difference reflects the county's Atlantic Ocean orientation, where the most valuable residential lands are all within the coastal flood plain.

Thus, he indicated, it is not correct to say that all agricultural and forest lands along Delaware Bay will probably not be protected. It would be more accurate to distinguish agricultural preservation lands, where development and shore protection are unlikely, from other lands where development has a good chance of occurring. He referred Titus to the State regarding prospects for Cape Henlopen State Park.

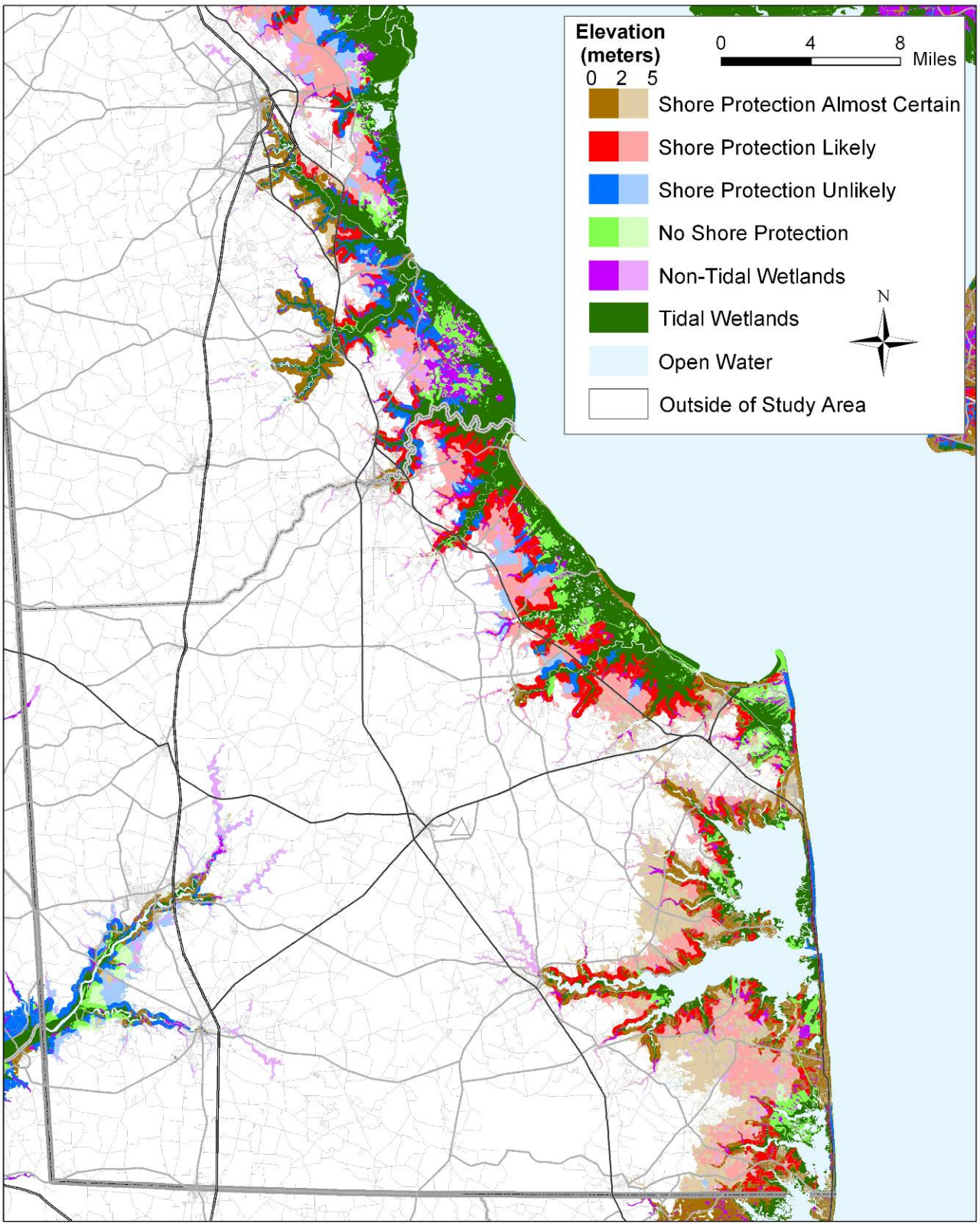
Titus spoke with Anthony Pratt of DNREC later that afternoon. Mr. Pratt explained that in 1988, a planning mechanism approved under Governor Mike Castle decided that shore erosion should be tolerated in parks along the ocean, because it is less expensive to relocate facilities inland than to hold the shoreline in place with beach nourishment. Therefore, the draft's depiction of Cape Henlopen State Park as light green is consistent with the general approach. Nevertheless, it would probably be an overstatement to say that none of the shore will be protected. There is currently a great deal of community pressure from the "Friends of Ft. Miles" to protect Battery Herring, which is 2 miles to the north. Therefore, it would be reasonable to assume that beach nourishment activities will probably be extended along the southern 2 miles. Similarly, the University of Delaware and adjacent structures would probably be protected. Otherwise, the policy would imply no shore protection.

Nevertheless, it is reasonable to assume that in the area between Battery Herring and the University of Delaware, shore protection is possible, albeit unlikely: If Battery Herring were nourished, there would most likely be some incidental nourishment of areas to the north, given the prevailing direction of alongshore transport. Similarly, nourishment of the urbanized towns such from Rehoboth to Fenwick would also indirectly nourish the state parks.

Table 5-7 illustrates the assumptions for the final maps, based on the stakeholder input. Map 5-2 depicts the results for Sussex County. The page that follows the map provides a more detailed legend that defines each of the symbols used in the statewide and county-specific maps included in this report

Kent County made a similar distinction for lands east and west of DE-1.

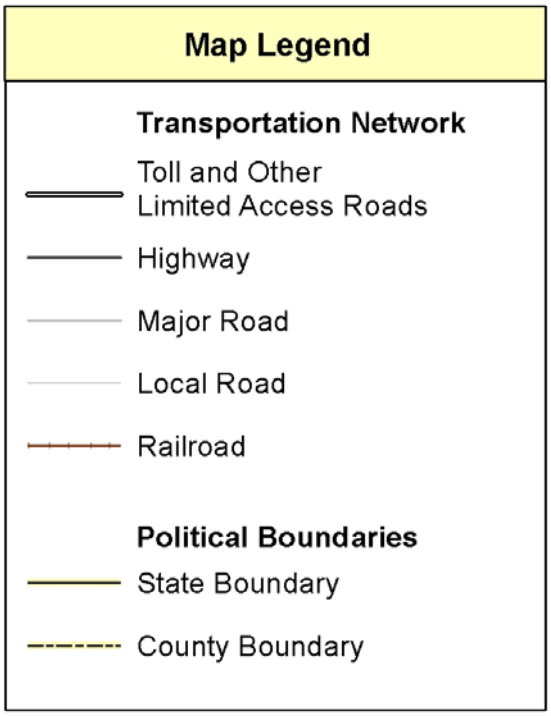
[47]Given the land use data with which we identified developed areas, polygons that do not have any land along the shore would be protected as a consequence of protecting developed areas. By "along the shore" we include any polygon with any portion within 25 meters of coastal wetlands.



Map 5-2. Sussex County: Likelihood of Shore Protection. The caption and detailed legend for this and the other county-specific maps is located on the following page.

Caption associated with Maps 5-2 through 5-4:

For each shore protection category, the darker shades represent lands that are either less than 7 feet (2 meters) above spring high water or within 1,000 feet of the shore. The lighter shades show the rest of the study area. For details about the analysis of adjacent states, see the companion chapters on New Jersey, Pennsylvania, and Maryland. This map is based on data published between 1997 and 2005. Although the map also reflects site-specific changes suggested by planners in 2005, the intended use of this map is to convey countywide prospects for shore protection, not to predict the fate of specific neighborhoods. Changes in the policies and trends we considered—or factors that we did not consider—may lead actual shore protection to deviate from the likelihoods depicted in this map.



Map 5-2 (continued). The Likelihood of Shore Protection: Statewide Results of this Study. This legend identifies the meaning for the transportation network and political boundary symbols used in the county-specific maps.

KENT COUNTY

Of Delaware's three counties, Kent County is the least developed. The county is predominately composed of wetlands, agricultural lands, the city of Dover, and Dover Air Force Base. Most of the developed areas are located in the central part of the county. The 1996 *Kent County Comprehensive Plan Update* directs the county's development around the major highways and away from the bay coast. Thus, the majority of the county's land vulnerable to sea level rise is currently and is likely to continue to be agricultural and public lands.

Meeting Notes

Michael Weyant, Service Center Coordinator, Kent County Department of Inspection and Enforcement[48]

Economic Conditions

The agriculture industry predominates along the bay, while most development in the county is located within and around the two major highways, Routes 1 and 13. Along the shoreline, most lands are agricultural or public lands (wildlife refuges and wetlands). Although the county is experiencing a steady increase in property values and development, most pressure is located in the center of the county. Thus, the coastal area remains rural in nature, with no real development pressure.

Some residential development exists along the coast; however, the only developed coastal area below the 20-foot elevation contour of significant size is Bowers Beach. This community has experienced some additional development in recent years. Other bayfront communities are much smaller, with low property values and development pressures. Small residential areas such as Pickering Beach have experienced storm damage in the past, which resulted in several homes being abandoned. There is very little pressure to develop these areas.[49]

Existing Coastal Policies and Practices

As development pressures increase, the County seeks to focus new development in the area of land around Routes 1 and 13, and away from the coastal area. Development pressures along the coast are low at this time and the farmers wish to maintain their land in agricultural production. Many have granted development rights — at least temporarily — to the State. Aside from these agricultural preservation districts, the County limits development along the bay through several other policies:

- By zoning the area as "agricultural conservation districts," potential developers must go through a lengthy process of revising zoning to build residential areas or businesses.
- The County also requires a 50-foot setback from the high-water line of tidal wetlands and a 25-foot setback from nontidal wetlands.
- Additionally, the County has no plans to expand sewer service to the bay area. Consequently, potential developers must meet state development regulations for installing septic systems (e.g., ½ acre minimum lot size).

Dover Air Force Base presents further limits to development in the coastal area. To maintain a relatively clear landing and takeoff area and to

[48]Daniel Hudgens met with Michael Weyant in the County offices on February 25, 2000.

[49]Anthony Pratt of DNREC indicated that these areas are likely to gentrify and therefore he does not believe homes would be abandoned in the future. See peer review comments submitted to Stephen Keach in email titled "Comments" on July 26, 2007.

protect homeowners from the noise of the airplanes, the County attempts to limit development in the flight paths. Development approved in these areas must meet the more costly requirements of special building codes to dampen noise within the structures. These flight paths include a significant portion of the coastal area.

Response to Sea Level Rise

Table 5-8 summarizes the county planning staff's suggested assumptions for each of the sea level rise policy scenarios, and lists the data sources we used to create maps reflecting those assumptions.

Enhanced Shore Protection (Scenario 1)

As with Sussex County, based on existing state policies, private property owners in Kent County can protect their lands. As a result, all privately owned land—including undeveloped lands—could be protected by the enforcement of existing policies. Additionally, the Dover Air Force Base air strip, which is partially within the study area, could be protected as well. A large portion of the land immediately adjacent to the bay is publicly owned land that would be abandoned (nonshaded land), while the private property at risk of inundation is located farther inland (shaded land).

Expected Shore Protection (Scenario 2)

By incorporating the assumption that it will not be feasible to protect agricultural, range, and forest lands from sea level rise, we find that much less land would be protected. Because agricultural, forest, and public lands predominate along the bay, Kent County's likely response is to abandon most vulnerable lands, including agricultural and forest lands. Based on the county's development plan and restrictive land-use regulations (e.g., septic regulations), it is not likely that these lands would be developed. Additionally, state and county officials—Anthony Pratt and Michael Weyant—deem it a possibility that property owners would eventually abandon the small developed areas such as Kitts Hummock and Pickering Beach.

TABLE 5-8: ASSUMPTIONS FOR DRAFT SEA LEVEL RISE RESPONSE MAP: KENT COUNTY[a]

Land Area	Protected in Scenario	Protection Likelihood	Source
Public parks	None	No protection	Delaware state parks
Public preservation areas	None	No protection	State resource areas
Small coastal communities, including Kitts Hummock and Pickering Beach	1	Protection unlikely	Manual GIS edit per planner input[b]
Agricultural, range, and forest lands	1	Protection unlikely	Land use/land cover[c,d]
Dover Air Force Base	1, possibly 2 and 3	Protection likely[e]	Military lands
Remaining public and private lands	1,2,3	Protection almost certain	Land use/land cover

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

[b] Michael Weyant identified Kitts Hummock and Pickering Beach as unlikely to be protected.

[c] We identify range and forest lands based on herbaceous rangeland, shrub/brush rangeland, mixed rangeland, deciduous forest, coniferous forest, mixed forest, and clear-cut forest use/land covers in data provided by EarthData, under contract to the State of Delaware.

[d] We identify agricultural lands based on cropland, pasture, idle field, truck crop, orchard/nursery/horticulture, confined feeding operations, farmsteads/farm buildings, and other agriculture land use/land covers in data provided by EarthData, under contract to the State of Delaware.

[e] Based on the nationwide approach of this study for secured installations, the maps depict these areas as red. The data we distribute assign the code "military" rather than "protection likely."

Enhanced Wetland Migration (Scenario 3)

Because county planners expect that most of Kent County's currently undeveloped lands along Delaware Bay will be abandoned as sea levels rise, coastal wetlands will generally be able to migrate inland as sea level rises. Therefore, the enhanced wetland migration scenario response is considered to be equivalent to the expected protection scenario response for Kent County. Nevertheless, there is one large red area in our map of Kent County, Dover Air Force Base. Over the last century, base managers have generally protected key military infrastructure while allowing wetlands to gradually encroach onto low areas that are otherwise unused. Delineating which areas will be protected (brown) from those areas where wetlands would probably migrate (blue) would require us, however, to speculate on the military's intentions. The nationwide approach to military lands in this study is to defer to the Department of Defense. To avoid a proliferation of map colors, our maps show secured installations as red, so that they can be distinguished from the surrounding areas.

Stakeholder Review

EPA project manager Jim Titus emailed the report and maps to Kent County Planner Kelly Crumpley, and later discussed the study over the phone.[50] The essence of his comments was that the draft maps were based on a now-outmoded way of viewing development and growth in Kent County.

For many years, the State of Delaware and the County planned for virtually all economic growth in Kent County to take place west of a line of pumping stations that is now Delaware Highway 1. Keeping development out of the area east of DE-1 had been both a matter of government policy and the general expectation, which tended to be mutually reinforcing. The policy directed public investments in infrastructure—but it never restricted development in the no-growth area through statute, regulation, or easement. As a result, recent increases in coastal property values have—in effect—shifted the development line east from DE-1 to the upper boundary of the 100-year floodplain. County regulations prevent subdivision of land within the 100-year floodplain, and the County is working with the state FEMA liaison to prevent homes from being built in the floodplain. Exceptions are rare, and primarily involve allowing intrafamily transfers when the entirety of a farm is within the floodplain. Outside of the floodplain, however, development is starting to occur and is likely to continue.

The draft maps had been based on the previous way of thinking, which implied that the Kent County coastal zone would retain a rural character. County planning staff said that our maps should be revised to reflect the new reality. East of DE-1, we should assume that development and shore protection are likely, except for conservation lands, the 100-year floodplains, and purchased agricultural preservation easements. West of DE-1, lands in the 100-year floodplain and purchased agricultural easements are unlikely to be developed. The 10-year lease agricultural lands, however, will probably be developed—and other private lands are almost certain to be developed.[51] County staff added that additional purchased agricultural easements are unlikely to cover a large amount of coastal land because of the high land values.

Along the beaches of Delaware Bay, beach nourishment projects have occurred at Pickering Beach, Kitts Hummock, Bowers, South Bowers, and state wildlife areas. Therefore, it is probably premature to assume that their shores will not be protected.

Table 5-9 summarizes the decision rules and data used by the revised maps. Map 5-3 depicts the final results for the likelihood of shore protection in Kent County.

[50]Email from Jim Titus to Kelley Crumpley, May 24, 2005 (summarizing conversation earlier that afternoon).

[51]We lacked data on the 10-year easements, so this particular insight was not incorporated into the maps.

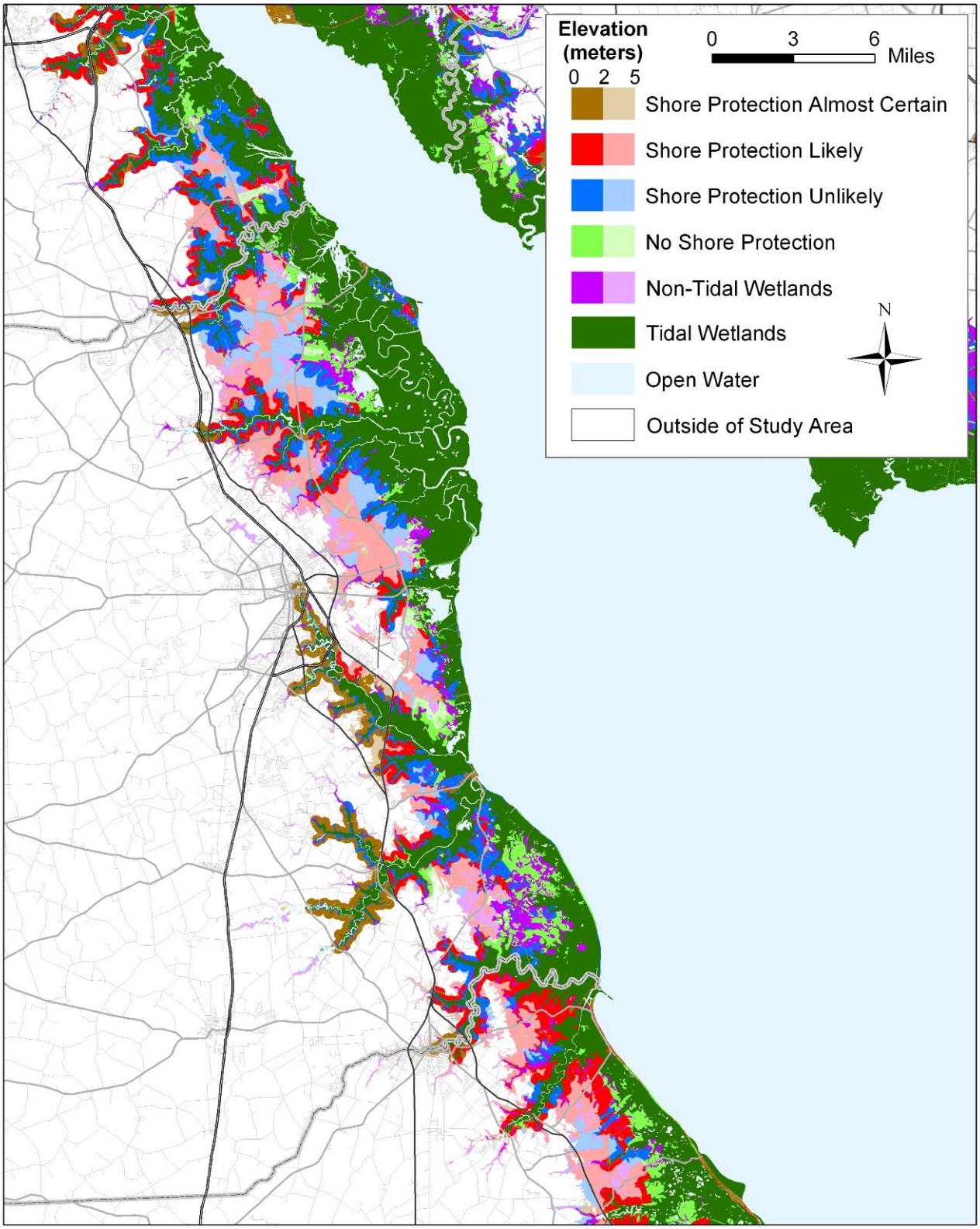
TABLE 5-9: ASSUMPTIONS FOR FINAL SEA LEVEL RISE RESPONSE MAP: KENT COUNTY[a]

Land Area	Protection Likelihood	Source
Dover Air Force Base	Protection likely[b]	Military lands
Public parks	No protection	Delaware state parks
Public preservation areas	No protection	State resource areas
Developed lands	Certain	Land use/land cover[c]
100-year floodplain	Protection unlikely	Kent County floodplain
Agricultural preservation districts	Protection unlikely	State agricultural preservation districts (2004)
Remaining public and private lands east of Route 1	Likely	Land use/land cover
Remaining public and private lands west of Route 1	Certain	Land use/land cover

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

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

[c] We identify developed lands based on residential, commercial, and industrial land use/land covers in data provided by EarthData, under contract to the State of Delaware.



Map 5-3. Kent County: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 5-2.

NEW CASTLE COUNTY

As a matter of convention, the Delaware River becomes Delaware Bay at Liston Point, an uninhabited, mostly wetland area, approximately 2 miles up the bay from the New Castle-Kent county line. Land use along the Delaware shoreline in New Castle County varies. South of the Chesapeake and Delaware Canal, the coast is relatively pristine, with a few old waterfront towns. North of New Castle, the shore is urban/industrial. Between New Castle and the canal is a combination of waterfront subdivisions, wetlands, and petrochemical plants. Development pressures along the undeveloped portions of the coast north of the C&D Canal are strong, with recent redevelopment occurring adjacent to the Christina River.

For the most part, the county is shielded from storm surges by the bell shape of the estuary. Moreover, the ground is relatively high in the north part of the county. Nevertheless, the area does experience some flooding problems. For example, the Amtrak line located along the waterfront north of Wilmington has experienced several interruptions in service caused by flooding.

Meeting Notes

Department of Land Use, New Castle County[52]

Economic Conditions

The land north of the Chesapeake and Delaware Canal is both densely developed and valuable. South of the canal, the land adjacent to the bay is mostly wetland, with agricultural and public lands inland. These areas face development pressure. Currently, the County wishes to preserve the agricultural lands in the southern parts of the county.

Existing Coastal Policies and Practices

The County uses several land-use controls as part of its efforts to prevent new development in the predominately agricultural area south of the Chesapeake and Delaware Canal. These requirements include:

- New structures must not be constructed within 50 feet of wetlands or a (rain-generated[53]) 100-year floodplain.
- The County has zoned much of the land area below and east of the municipality of Odessa for agricultural protection. Nevertheless, the County allows limited residential development through land-use regulations such as 5-acre minimum lot sizes for new construction. Moreover, the County is considering whether to provide centralized sewer service to the area. If this occurs, the minimum lot size would decrease to 1 acre (the current requirement for land north of Odessa and South of the Chesapeake and Delaware Canal), and development is likely to occur.

Additionally, many of the agricultural landowners along the bay have joined the state's Agricultural Preservation District Program. As a result, their lands cannot be developed over the next 10 years and may later be protected further through an extension of the preservation time-period or the State and County's purchase of development rights.

[52]Daniel Hudgens met with the New Castle Department of Land Use staff in the County offices on February 25, 2000.

[53]Construction is allowed in coastal floodplains, that is, areas where flooding is caused by storm surges.

TABLE 5-10: ASSUMPTIONS FOR DRAFT SEA LEVEL RISE RESPONSE MAP: NEW CASTLE COUNTY[a]

Land Area	Protected in Scenario	Protection Likelihood	Source
Fort Dupont	1,2, and 3	Certain	Delaware state parks
Public parks	None	No protection	Delaware state parks
Public preservation areas	None	No protection	State resource areas
100-year floodplain south of C&D Canal	1	Protection unlikely	New Castle 100-year floodplain
Agricultural preservation districts	1	Protection unlikely	State agricultural preservation districts (1998)
Undeveloped lands	1 and 2	Likely	Land use/land cover[b]
Developed lands	1, 2, and 3	Certain	Land use/land cover[c]

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

[b] We identify undeveloped lands based on agricultural and range and forest land use/land covers in data provided by EarthData, under contract to the State of Delaware.

[c] We identify developed lands based on residential, commercial, and industrial land use/land covers in data provided by EarthData, under contract to the State of Delaware.

Expected Response to Sea Level Rise

Table 5-10 summarizes the county planning staff's suggested assumptions for each of the sea level rise policy scenarios, and lists the data sources we used to create maps reflecting those assumptions.

Enhanced Shore Protection (Scenario 1)

As in the other counties, based on the State's policy to permit the protection of all lands, all privately owned land in New Castle could be protected under current policies. Therefore, our enhanced shore protection scenario assumes that all lands are protected conservation lands.

Expected Shore Protection (Scenario 2)

Property owner decisions to protect or abandon property depend on the costs of protection and the value of the property being protected. Planners in New Castle County expect that lands that remain undeveloped at the time of inundation will be abandoned. Most of the county's coastal zone is already developed and will almost certainly be protected. Land south of the C&D Canal, however, is an exception. Future development and shore protection are less certain, and the County's development decisions will play a key role in the likely response. Because the County bans development in the floodplain south of the canal, the likely response will be for vulnerable agricultural and forest lands in the floodplain to remain undeveloped and eventually abandoned. However, agricultural and forest lands that are within neither a 100-year floodplain nor an agricultural preservation district may be developed—and therefore protected—in the future. Development of these lands is particularly likely if the County installs a new centralized sewer system. Meanwhile, property in the agricultural preservation districts will probably remain undeveloped in the future and therefore also be abandoned to sea level rise.

One exception was Fort Dupont on Pea Patch Island, a historic site. As early as 1863, this Civil War fort was protected with a dike and drainage system.[54] There are regular boats from Fort Mott State Park in New Jersey, and from Delaware City. Therefore, we assumed this area as certain to be protected in all scenarios.

Enhanced Wetland Migration (Scenario 3)

As with the analysis of Sussex County, to define the land area protected under Scenario 3, we modified Scenario 2 by assuming that wetland migration would be allowed onto currently undeveloped parcels of lands adjacent to existing marshes. Considering the limited acreage of

[54] As of September 15, 2004, the island's shore protection history was explained at http://www.visitthefort.com/touring.html.

TABLE 5-11: ASSUMPTIONS FOR FINAL SEA LEVEL RISE RESPONSE MAP: NEW CASTLE COUNTY[a]

Land Area	Protection Likelihood	Source
Glenville	Unlikely	Hand edits based on stakeholder request
Fort Dupont	Certain	Delaware state parks
Public parks	No protection	Delaware state parks
Public preservation areas	No protection	State resource areas
Developed lands	Certain	Land use/land cover[b]
Recent and approved development	Certain	New Castle approved development
100-year floodplain south of C&D Canal	Unlikely	New Castle 100-year floodplain
Agricultural preservation districts	Unlikely	State agricultural preservation districts (2004) and New Castle agriculture preservation
Remaining public and private lands	Likely	Land use/land cover

[a] Where land areas overlap, classifications higher in the table take precedence.
[b] We identify developed lands based on residential, commercial, and industrial land use/land covers in data provided by EarthData, under contract to the State of Delaware.

coastal marshes in the county, New Castle County may wish to prevent future development from blocking the migration of these marshes. As a result, under the enhanced wetland migration scenario, currently undeveloped lands located near coastal wetlands could be abandoned. A parcel is considered to be near a wetland if any portion is less than 82 feet (25 meters) from a wetland. To allow such wetland migration, the County would have to prevent the undeveloped lands from being developed or condition future development on the owner's agreement not to restrict the inland migration of wetlands.

Under Scenario 3, the protected lands are the currently developed lands and the undeveloped lands that are neither within the 100-year floodplain, nor an agriculture preservation district, nor part of a parcel within 82 feet (25 meters) from tidal wetlands. Because the County denies permits for additional development in the 100-year floodplain, current policy already ensures that wetland migration is likely (shore protection unlikely) in most of the currently undeveloped lands onto which wetlands might migrate in the future (i.e., undeveloped floodplains south of the C&D Canal). Consequently, the expected and enhanced wetland migration scenarios are quite similar for New Castle County. The red area that differentiates these two scenarios ("protection likely") is mostly above the 10-foot (NGVD) contour (high enough to be outside the floodplain), along the shore south of the C&D Canal.

Stakeholder Review

The EPA project manager, Jim Titus, emailed the draft report and maps to Dave Culver, planning director for New Castle County, and met with him a week later.[55] The planning director confirmed that the assumptions previously suggested by his staff were reasonable, and that the resulting maps are a reasonable depiction of the areas that will be protected as sea level rises, given what we know today. Nevertheless, he suggested four improvements:

Use the County's data on approved development to identify lands that have been developed since the land use/land cover data were developed, and assume that those areas are certain to be protected.

Use the County's Agricultural Preservation Data, which is much more up to date than the State's data. Outside of floodplains, the agricultural preservation easements account for most of the private land where shores will not be protected.

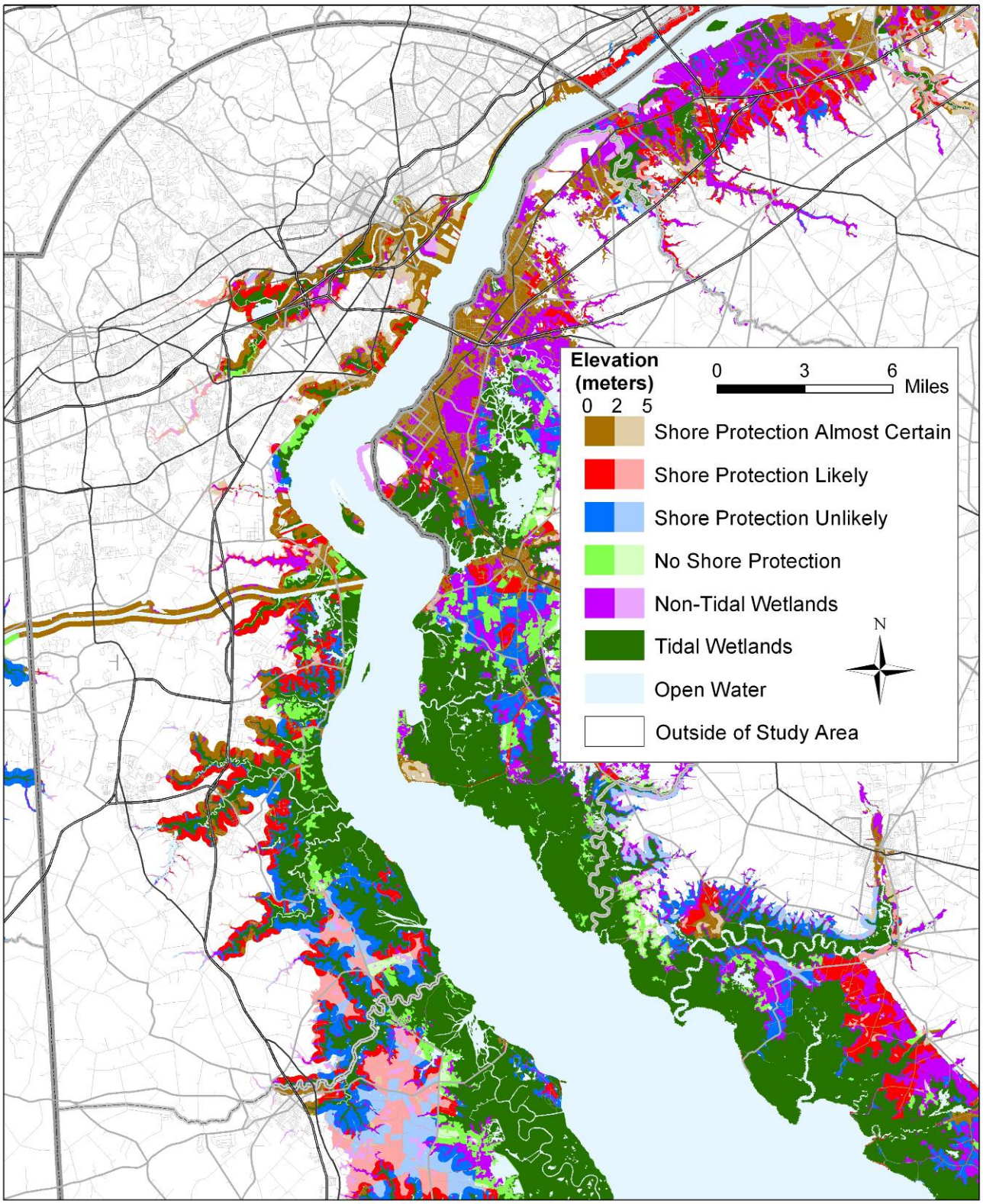
Change all but one street in Glenville from brown to blue. Because of persistent flooding, the homes in this community are being bought

[55] May 27, 2005.

out, except for those along one street. The land will be excavated to below mean spring high water and converted to tidal wetland.

Change the area east of DE-9, north of Red Lion Creek, and south of Hamburg Rd. from red to blue. This area is a buffer between industrial and residential lands. Both the corporate landowner and the County agree that such a buffer is needed here.

Table 5-11 summarizes the data and decision rules for the final maps. Map 5-4 depicts our final results at the county scale.



Map 5-4. New Castle County: Likelihood of Shore Protection. For additional details, see the legend and caption accompanying Map 5-2.

Appendix A

LENGTH OF SHORELINES BY LIKELIHOOD OF SHORE PROTECTION

Authors: John Herter and Daniel Hudgens

Table of Contents: List and description of tables included in this appendix

Notes

This appendix estimates the lengths of tidal shoreline for each of the categories of shore protection likelihood. By "shoreline" we mean the land immediately adjacent to tidal open water or tidal wetlands. We provide several alternative summaries of our tidal shoreline estimates, including shoreline length by county, type of water body, and major body of water. For information on how we created, categorized, and measured the shoreline, see Appendix 1 of this report.

Table A-1: Definitions: Water body categories used in this Appendix

Water Body Category[1]	Description
Shorelines Along Primary Water Bodies [2]	
Primary Bay	Shoreline located along a major bay such as Chesapeake Bay.
Barrier/Bayside	The side of barrier islands adjacent to the inner coastal bay.
Primary River	The portion of a major river that flows either into the Atlantic Ocean or a Primary Bay where the river is wider than one kilometer. In this case, a major river is subjectively determined but represents the most significant waterways in the region based on relative size (e.g., Potomac River, Delaware River, Nanticoke River, etc.).
Barrier Bay/Mainland	Shoreline that is located along the major county landmass and, at least partially, shielded by a barrier island.
Barrier/Oceanside	The side of barrier islands adjacent to the Atlantic Ocean.
Ocean Front	Land located immediately adjacent to the Ocean. Excludes land located along a barrier island (which is characterized as Barrier/Oceanfront).
Other Types of Shores	
Dredge and Fill	Shoreline characterized by multiple "finger" canals that run from the primary shoreline area inland and provide access to the water for the local community development.
Other/Road	A general term used for land that might not always be considered to be land. In particular, 1) dry land located at the base of causeways leading to barrier islands and 2) docks and piers that extend into the water are included in this category.
Island	A piece of land completely surrounded by water except for a barrier island. Shores along Primary Water Bodies are not included in the "Island" category.
Secondary Bay	Shoreline located along a smaller bay that is further sheltered from the wave action of a major bay or Ocean.
Secondary River	A river that is smaller in relative size than the major rivers identified as Primary River, or where the width of a major river falls below one kilometer.
Tributary[3]	Small tributaries, creeks, and inlets flowing into a Primary Water Body. The water body name reflected in the GIS data is either the actual name of the tributary or the name of the water body into which the tributary flows.

Notes:

1. With the exception of shoreline identified as "Dredge and Fill", all Water Body Categories are mutually exclusive. Dredge and Fill areas are identified separately and are associated with shoreline that would otherwise be identified as Tributary.
2. For the purpose of this study, "Primary Water Body" distinguishes larger water bodies where the more immediate effects of sea level rise are likely to occur. These areas are less protected by land barriers and offer a more favorable environment for the promotion of wave action caused by wind.
3. When categorizing the shoreline, we identify “Unclassified Tributaries” where the water body name reflects the name of the water body into which the tributary flows. For the results presented in this appendix, we combine the “Unclassified Tributaries” within the “Tributary” category and aggregate the shoreline lengths.

Table A-2: Shoreline length by County						
County	Shoreline Length (Kilometers)					
	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	Totals
Kent	80	24	314	184	128	**729**
New Castle	127	125	215	99	16	**581**
Sussex	484	249	123	299	74	**1229**
Totals	**690**	**397**	**651**	**582**	**218**	**2539**

Table A-3: Shoreline length of primary water bodies							
Water Body Category	Water Body Name	Shoreline Length (Kilometers)					
		Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	Totals
Barrier/Oceanside	Atlantic Ocean	3	0.7	16	0	0	**20**
Ocean Front	Atlantic Ocean	12	3	3	2	0	**20**
Primary Bay	Delaware Bay	35	4	17	21	0.8	**78**
Primary River	Delaware River	11	19	3	21	0.4	**54**
Barrier Bay/Mainland	Indian River Bay	18	2	0	3	0	**23**
Barrier/Bayside	Indian River Bay	2	2	0.9	0.6	0	**5**
Barrier Bay/Mainland	Little Assaswoman Bay	4	3	0	7	0	**14**
Barrier/Bayside	Little Assaswoman Bay	2	2	3	0	<0.1	**7**
Barrier Bay/Mainland	Rehoboth Bay	15	0.9		5	0.7	**21**
Barrier/Bayside	Rehoboth Bay	2	7	4	0	0	**13**
Totals		**105**	**43**	**46**	**61**	**2**	**257**

Table A-4: Shoreline lengths for all water bodies

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	Totals
Kent	Other	Delaware Bay	0.1	0	0	3	0	**4**
Kent	Primary Bay	Delaware Bay	15	2	10	12	<0.1	**40**
Kent	Secondary River	Delaware Bay	58	10	172	87	74	**400**
Kent	Tributary	Delaware Bay	0	0	0.2	0	0	**0.2**
Kent	Island	Delaware River	0.9	1	25	33	6	**65**
Kent	Tributary	Delaware River	6	11	106	44	46	**213**
Kent	Island	Secondary River	0	0	0.6	5	2	**7**
New Castle	Primary Bay	Delaware Bay	0.2	0.3	6	0	0.8	**8**
New Castle	Island	Delaware River	6	9	11	15	0.3	**40**
New Castle	Primary River	Delaware River	11	19	3	21	0.4	**54**
New Castle	Tributary	Delaware River	110	96	194	63	14	**478**
Sussex	Barrier/Oceanside	Atlantic Ocean	3	0.7	16	0	0	**20**
Sussex	Dredge and Fill	Atlantic Ocean	0	0.6	0	0	0	**0.6**
Sussex	Ocean Front	Atlantic Ocean	12	3	3	2	0	**20**
Sussex	Tributary	Atlantic Ocean	0	0	0.2	0	0	**0.2**
Sussex	Island	Delaware Bay	0.1	0	0	5	0	**5**
Sussex	Other	Delaware Bay	<0.1	0.3	0	0.3	0.3	**0.9**
Sussex	Primary Bay	Delaware Bay	20	1	0	9	0	**31**
Sussex	Secondary River	Delaware Bay	31	162	31	172	48	**444**
Sussex	Barrier Bay/Mainland	Indian River Bay	18	2	0	3	0	**23**
Sussex	Barrier/Bayside	Indian River Bay	2	2	0.9	0.6	0	**5**
Sussex	Dredge and Fill	Indian River Bay	26	0.8	0.7	0.1	0	**28**
Sussex	Island	Indian River Bay	8	0.7	2	5	0	**17**
Sussex	Tributary	Indian River Bay	102	35	0.9	9	10	**158**
Sussex	Barrier Bay/Mainland	Little Assaswoman Bay	4	3	0	7	0	**14**
Sussex	Barrier/Bayside	Little Assaswoman Bay	2	2	3	0	<0.1	**7**
Sussex	Dredge and Fill	Little Assaswoman Bay	68	<0.1	0	0	0	**68**
Sussex	Island	Little Assaswoman Bay	1	0	0	18	<0.1	**19**
Sussex	Secondary Bay	Little Assaswoman Bay	19	3	0	0	0.3	**22**
Sussex	Tributary	Little Assaswoman Bay	15	7	0.8	14	2	**39**
Sussex	Secondary River	Nanitcoke River	20	0	52	20	8	**99**

Table A-4: Shoreline lengths for all water bodies

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	Totals
Sussex	Barrier Bay/Mainland	Rehoboth Bay	15	0.9	0	5	0.7	**21**
Sussex	Barrier/Bayside	Rehoboth Bay	2	7	4	0	0	**13**
Sussex	Dredge and Fill	Rehoboth Bay	22	0.2	0.3	0	0	**23**
Sussex	Island	Rehoboth Bay	11	2	7	15	0	**35**
Sussex	Other	Rehoboth Bay	4	<0.1	0	0.5	0	**5**
Sussex	Secondary River	Rehoboth Bay	3	0	0	0	0	**3**
Sussex	Tributary	Rehoboth Bay	74	15	2	12	5	**108**
Totals			**690**	**397**	**651**	**582**	**218**	**2539**

Table A-5: Islands with roads

County	Water Body Category	Water Body Name	Shoreline Length (Kilometers)					
			Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Non-Tidal Wetlands	Totals
Kent	Island	Delaware River	0.9	0.4	19	3	2	**25**
New Castle	Island	Delaware River	0	0.6	5	10	0	**15**
Sussex	Island	Delaware Bay	0.1	0	0	5	0	**5**
Sussex	Island	Indian River Bay	3	0.7	0.7	0	0	**5**
Sussex	Island	Little Assaswoman Bay	0	0	0	16	<0.1	**16**
Sussex	Island	Rehoboth Bay	1	0.4	0	0	0	**2**
Sussex	Tributary	Little Assaswoman Bay	0	0	0	2	0	**2**
Totals			**6**	**2**	**25**	**35**	**2**	**70**

Appendix B

AREA OF LAND BY SHORE PROTECTION LIKELIHOOD

(Counties in Same Order as Discussed in the Text)

Authors: James G. Titus, Russ Jones, and Richard Streeter

The following tables were created by overlaying the shore protection planning maps developed in this report, with EPA's 30-meter digital elevation data set.

The EPA data set used the National Wetlands Inventory (NWI) to distinguish dry land, nontidal wetlands, tidal wetlands, and open water. The boundaries of that wetlands data set do not perfectly match the boundaries of the land use data used in this report. Some areas that the NWI data treated as dry land, for example, are wetlands or open water according to the land use data sets. This table treats such lands as "not considered" because our planning study did not estimate shore protection likelihood there. Most of these lands are along the shore and are as likely as not to be wetlands or open water today, even if they were still dry land when the wetlands data were created. See Appendix 2 of this report for additional details on how these tables were created.

Table B-1. Area of Land by Elevation by Shore Protection Likelihood

Delaware

Elevation above Spring High Water (m)		Area (square kilometers)							
Above	Below	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	17.1	16.0	17.3	19.1	2.6	72.2	22.2	94.4
0.5	1.0	16.0	15.6	11.1	10.6	0.7	53.9	9.8	63.8
1.0	1.5	15.4	15.7	11.0	9.9	0.3	52.4	9.2	61.6
1.5	2.0	16.1	19.0	11.4	9.6	0.3	56.3	8.9	65.2
2.0	2.5	20.4	27.1	12.4	6.3	0.1	66.4	7.9	74.3
2.5	3.0	21.9	28.0	13.1	5.9	0.1	68.9	7.8	76.7
3.0	3.5	22.3	29.9	13.0	5.2	0.1	70.5	7.9	78.4
3.5	4.0	26.2	31.2	12.5	3.8	0.0	73.8	7.6	81.4
4.0	4.5	28.2	30.1	13.3	3.8	0.0	75.5	7.5	83.0
4.5	5.0	28.8	28.6	11.9	3.6	0.0	72.9	7.4	80.2
5.0	5.5	32.3	24.9	10.1	2.7	0.0	69.9	7.3	77.2
5.5	6.0	33.3	23.9	12.0	2.4	0.0	71.5	7.5	79.0

Sussex

Elevation above Spring High Water (m)		Area (hectares)							
Above	Below	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	1191	1164	224	1000	174	3753	919	4672
0.5	1.0	1121	1230	231	549	68	3200	471	3671
1.0	1.5	1069	1240	227	483	23	3043	408	3451
1.5	2.0	1069	1251	230	480	23	3051	407	3458
2.0	2.5	1350	1521	344	262	11	3488	390	3878
2.5	3.0	1493	1611	417	216	4	3741	382	4123
3.0	3.5	1496	1597	414	216	4	3726	381	4107
3.5	4.0	1812	1379	437	192	3	3823	358	4181
4.0	4.5	2009	1266	518	193	2	3989	352	4341
4.5	5.0	2016	1266	517	193	2	3995	352	4347
5.0	5.5	2168	1175	661	177	2	4184	384	4568
5.5	6.0	2268	1077	844	146	1	4337	404	4741

Kent

Elevation above Spring High Water (m)		Area (hectares)							
Above	Below	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	161	117	913	686	47	1925	958	2883
0.5	1.0	113	159	609	418	1	1300	432	1731
1.0	1.5	113	159	609	418	1	1300	432	1731
1.5	2.0	152	424	656	389	1	1622	401	2023
2.0	2.5	229	858	676	284	0	2048	311	2359
2.5	3.0	229	858	676	284	0	2048	311	2359
3.0	3.5	291	1029	655	223	0	2198	322	2520
3.5	4.0	435	1307	579	111	0	2432	327	2758
4.0	4.5	435	1307	579	111	0	2432	327	2758
4.5	5.0	494	1169	471	89	0	2224	316	2539
5.0	5.5	682	919	245	38	0	1885	292	2177
5.5	6.0	682	919	245	38	0	1885	292	2177

New Castle

Elevation above Spring High Water (m)		Area (hectares)							
Above	Below	Shore Protection Certain	Shore Protection Likely	Shore Protection Unlikely	No Shore Protection	Not Considered	Dry Land	Non Tidal Wetlands	All Land
0.0	0.5	362	320	594	221	41	1538	347	1884
0.5	1.0	362	168	269	93	3	895	81	977
1.0	1.5	362	168	269	93	3	895	81	977
1.5	2.0	391	221	253	90	2	957	83	1040
2.0	2.5	465	333	222	85	1	1106	86	1192
2.5	3.0	465	333	222	85	1	1106	86	1192
3.0	3.5	444	367	229	84	1	1126	83	1209
3.5	4.0	373	435	238	81	1	1127	72	1199
4.0	4.5	373	435	238	81	1	1127	72	1199
4.5	5.0	373	422	202	73	1	1070	68	1138
5.0	5.5	377	391	108	50	0	926	52	978
5.5	6.0	377	391	108	50	0	926	52	978

B-2. Area of Land Vulnerable to a One Meter Rise in Sea Level (square kilometers)
By Watershed and County by Likelihood of Shore Protection

County	Likelihood of Shore Protection						Tidal Wetlands
	Certain	Likely	Unlikely	No Protection	Nontidal Wetlands	Total Nontidal Land[1]	
Atlantic Coast							
Sussex	20.2	10.8	1.2	8.3	6.1	48.7	40.9
Chesapeake Bay							
Sussex	0.6	0.0	1.3	0.5	2.2	4.6	6.6
Delaware Estuary							
Kent	2.7	2.8	15.2	11.0	13.9	46.1	168.7
New Castle	7.2	4.9	8.6	3.1	4.3	28.6	73.5
Sussex	2.3	13.1	2.1	6.7	5.5	30.1	67.5
Delaware	33.1	31.6	28.4	29.7	32.1	158.2	357.1

1. Total includes the five categories listed plus the "not considered" category.

Appendix C
ELEVATION UNCERTAINTY

Authors: James G. Titus, Russ Jones, and Richard Streeter

C-1. Low and High Estimates of the Area of Land Close to Sea Level, by County: Delaware[1]
(square kilometers)

		Meters above Spring High Water																	
		low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high	low	high
County		**0.5**		**1.0**		**1.5**		**2.0**		**2.5**		**3.0**		**3.5**		**4.0**		**4.5**		**5.0**	
		----------Cumulative (total) amount of Dry Land below a given elevation----------																	
Kent		8.8	25	22	41	35	57	48	78	66	98	86	119	107	144	129	168	154	191	178	210
New Castle		7.1	19	17	30	26	41	34	52	44	64	54	75	65	87	77	98	88	110	99	119
Sussex: Chesapeake Bay		0.5	1.6	1.4	3.3	2.7	5.2	4.3	7.1	6	11	8.5	14	12	18	15	24	20	29	26	36
Sussex: Delaware Bay		6.4	18	16	31	27	43	37	55	48	67	60	79	72	89	83	99	93	109	103	120
Sussex: Atlantic Coast		11	32	28	54	46	74	65	95	83	117	104	140	126	163	149	187	173	211	197	234
Statewide		**34**	**96**	**84**	**158**	**136**	**221**	**188**	**287**	**246**	**356**	**313**	**426**	**382**	**499**	**453**	**575**	**527**	**647**	**603**	**719**
Wetlands	Tidal	---------Cumulative (total) amount of Nontidal Wetlands below a given elevation---------																	
Kent	169	4.9	11	10	17	15	22	19	25	23	28	26	31	29	34	32	37	36	41	39	44
New Castle	74	1.8	3.8	3.5	4.8	4.3	5.8	5.1	6.7	5.8	7.6	6.7	8.4	7.5	9.2	8.3	9.9	9	11	9.7	11
Sussex: Chesapeake Bay	6.7	0.6	1.8	1.6	2.7	2.4	3.5	3.1	4.4	3.8	5.4	4.8	6.4	5.8	7.7	6.9	9.4	8.4	11	10	13
Sussex: Delaware Bay	67	2.1	4.8	4.6	6.2	5.7	7.5	6.8	8.6	8	9.6	9	11	10	11	11	12	12	13	12	13
Sussex: Atlantic Coast	41	1.7	4.9	4.2	7.5	6.6	10	8.8	12	11	14	13	16	15	17	16	18	18	20	19	21
Statewide	**357**	**11**	**27**	**24**	**38**	**34**	**48**	**43**	**56**	**52**	**64**	**59**	**72**	**67**	**80**	**75**	**87**	**82**	**95**	**90**	**102**
		Cumulative (total) amount of land below a given elevation																	
Dry Land		34	96	84	158	136	221	188	287	246	356	313	426	382	499	453	575	527	650	603	719
Nontidal Wetlands		11	27	24	38	34	48	43	56	51	64	59	72	67	80	75	87	82	95	90	102
All Land	357	402	480	465	553	527	626	588	701	655	778	730	855	806	936	885	1019	967	1102	1050	1178

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

C-2. Likelihood of Shore Protection in Delaware, High and Low Estimates of Land within One Meter above Spring High Water[1]

(square kilometers)

County	Likelihood of Shore Protection								Nontidal Wetlands		Total[2]	
	Certain		Likely		Unlikely		No Protection					
	low	high	low	high	low	high	low	high	low	high	low	high
Atlantic Coast	**13**	**26**	**6.3**	**14**	**0.8**	**1.4**	**5.9**	**9.9**	**4.2**	**7.5**	**32**	**61**
Sussex	13	26	6.3	14	0.8	1.4	5.9	9.9	4.2	7.5	32	61
Chesapeake Bay	**0.3**	**0.9**	**0**	**0**	**0.8**	**1.6**	**0.2**	**0.8**	**1.6**	**2.7**	**3**	**6**
Sussex	0.3	0.9	0	0	0.8	1.6	0.2	0.8	1.6	2.7	3	6
Delaware Estuary	**7.4**	**16**	**13**	**27**	**18**	**32**	**15**	**25**	**19**	**28**	**73**	**129**
Kent	1.9	3.5	1.5	3.8	10	19	7.7	14	10	17	32	57
New Castle	4.2	9.4	3.4	5.9	6.4	10	2.4	3.7	3.5	4.8	20	35
Sussex	1.3	3.1	7.8	17	1.1	2.8	5.3	7.6	4.6	6.2	20	37
Delaware	**21**	**43**	**19**	**41**	**20**	**36**	**22**	**36**	**24**	**38**	**108**	**196**

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.
2. Total includes the five categories listed as well as a small amount of low land the authors did not analyze.

C-3. Likelihood of Shore Protection in Delaware, High and Low Estimates of Land within Two Meters above Spring High Water[1] (square kilometers)

County	Likelihood of Shore Protection								Nontidal Wetlands		Total[2]	
	Certain		Likely		Unlikely		No Protection					
	low	high	low	high	low	high	low	high	low	high	low	high
Atlantic Coast	**31**	**47**	**18**	**28**	**1.7**	**2.3**	**12**	**15**	**8.8**	**12**	**73**	**107**
Sussex	31	47	18	28	1.7	2.3	12	15	8.8	12	73	107
Chesapeake Bay	**1.2**	**2**	**0**	**0**	**2**	**3.2**	**1.1**	**2**	**3.1**	**4.4**	**7.4**	**11**
Sussex	1.2	2	0	0	2	3.2	1.1	2	3.1	4.4	7.4	11
Delaware Estuary	**19**	**32**	**32**	**60**	**38**	**55**	**29**	**37**	**31**	**40**	**150**	**225**
Kent	4.1	7.2	4.7	15	23	33	16	21	19	25	67	102
New Castle	11	19	6.7	12	12	16	4.2	5.7	5.1	6.7	39	59
Sussex	3.8	6.2	21	33	3.5	6	8.6	10.1	6.8	8.6	44	64
Delaware	**52**	**81**	**50**	**88**	**41**	**60**	**41**	**54**	**43**	**56**	**231**	**343**

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

2. Total includes the five categories listed as well as a small amount of low land the authors did not analyze.

C-4. Area of Land by Elevation by Shore Protection Likelihood: Delaware[1]

Elevation relative to Spring High Water (m)	Area (square kilometers)													
	Dry land: likelihood of shore protection													
	Shore Protection Certain		Shore Protection Likely		Shore Protection Unlikely		No Shore Protection		Not Considered		Dry Land		Non Tidal Wetlands	
	low	high	low	high	low	high	low	high	low	high	low	high	low	high
0.5	7.9	24	7.2	23	8.3	22	9.2	24	1.4	3.2	34	96	11	27
1.0	21	42	19	41	20	35	22	36	3	3.5	84	158	24	38
1.5	36	61	35	61	30	48	32	47	3.4	3.8	136	221	34	48
2.0	52	81	50	88	41	60	41	54	3.6	4	188	287	43	56
2.5	68	103	71	116	53	74	50	60	3.9	4	246	356	51	64
3.0	89	125	98	145	66	87	56	66	4	4.1	313	426	59	72
3.5	110	150	126	176	79	99	62	69	4	4.1	381	499	67	80
4.0	133	179	157	207	91	112	67	73	4.06	4.13	453	575	75	87
4.5	160	207	188	236	104	125	71	77	4.1	4.2	527	650	82	95
5.0	188	239	218	262	118	135	75	80	4.1	4.2	603	719	90	102

1. Low and high are an uncertainty range based on the contour interval and/or stated root mean square error (RMSE) of the input elevation data. Calculations assume that half of the RMSE is random error and half is systematic error. For a discussion of these calculations, see Annex 3 of this report.

APPENDIX D: SUMMARY OF DATA SOURCES

This appendix describes data used to create the GIS-based maps accompanying this report. Data descriptions are organized by data source. Within each section we provide a brief summary of each layer obtained from that source. Summary information includes a description of how the data were developed, identifies the key elements of the data used in our analysis, and provides the date of publication.

DELAWARE DIVISION OF PARKS AND RECREATION

Delaware State Parks

Data consist of polygons representing lands managed or held by the Delaware Division of Parks and Recreation. Boundaries include state parks, nature preserves, and land protected by conservation easements. All polygons identify lands that are protected and contain significant recreational, natural, and cultural resource values. The mapscale threshold is 1:20,000 +/- 4,000. The first version of this data set was created using digitizer tablets from tax parcel maps and survey maps. Subsequent updates used digital GPS surveys with submeter accuracy, digitized survey maps, and heads-up digitizing from 1-m resolution digital orthophotography.

Key data elements: Key attributes include park name, area, perimeter, and status.

Scale: 1:24,000.

Date of publication: 2000.

State Resource Areas

Data identify lands protected by the State of Delaware and lands that might potentially be protected from further development. These lands include state parks, municipal parks, county parks, conservation easements, nature preserves, natural areas, leased lands, and fish and wildlife areas. The mapscale threshold is 1:20,000 +/- 4,000. The first version of this data set was created using digitizer tables from the DelDOT Basemap. To update the data set for the second version, Lands Preservation Office Staff reviewed each individual resource area in a four-stage revision process. Further updates used digitized survey maps and aerial photos.

Key data elements: Lands protected under the Open Space Program are represented as Protected (symbol = 77). Potentially protected lands are represented as Potential Protected (symbol = 69). Protected lands are displayed as conservation lands (light green) on the maps created for this sea level rise study. Potential Protected polygons are not displayed.

Scale: 1:24,000.

Date of publication: 1998.

DELAWARE DEPARTMENT OF AGRICULTURE

State Agricultural Preservation Districts

Data identify agricultural lands purchased as easements through the Delaware Agricultural Preservation Program. These data include only those lands where the state has obtained a permanent easement.

Key data elements: Each parcel has an unique identifier and includes the place name.

Scale: Unable to identify documentation. A visual inspection showed that the boundaries of this layer match with the 1:24,000 state resources areas and that the density of vertices is similar to 1:24,000 data layers. However, no information was available to document whether the maps are accurate to such a scale under National Mapping Standards.

Date of publication: 1998 and 2004

EARTH DATA INTERNATIONAL FOR THE STATE OF DELAWARE

Land Use/Land Cover

Data provide land use and land cover information, as interpreted from 1997 digital orthophotography, for all counties in Delaware. EarthData International created the dataset under contract with the State of Delaware.

Key data elements: The Anderson et al. Land Use Classification System is used to classify land use and land cover. Exhibit D-1summarizes these codes and their descriptions.

Scale: 1:24,000.

Date of publication: 1997.

NEW CASTLE COUNTY

New Castle 100-Year Floodplain

New Castle County's Department of Land Use provided GIS data that identify the county's 100-year floodplain.

Scale: 1:24,000.

Date of publication: 1996.

New Castle Agriculture Preservation

Data obtained from NCC eParcelView Map at http://dmz-arcims02.co.new-castle.de.us/website/nccparcelmap2/viewer.htm. Data identify the state and county's agricultural preservation lands. Data compiled by Delaware Department of Agriculture, 2003, and New Castle County Department of Land Use.

Key data elements: Data identify name of parcel and via the field "First_Type" identify permanent holdings (AGPM) from easements that last only 10 years (AGTY). For this study, we use only those lands that are identified as permanent holdings.

Scale: Unable to identify documentation. A visual inspection showed that the boundaries of this layer match with the 1:24,000 state resources areas and that the density of vertices is similar to

Exhibit D-1. LAND USE CODES AND DESCRIPTIONS

Land Cover Code	Description
111	Single Family Dwellings
112	Multi Family Dwellings
114	Mobile home Parks/Courts
120	Commercial
121	Retail Sales/Wholesale/Professional Services
122	Vehicle Related Activities
123	Junk/Salvage Yards
125	Warehouses and Temporary Storage
129	Other Commercial
130	Industrial
140	Transportation/Communication
141	Highways/Roads/Access roads/Freeways/Interstate
142	Parking Lots
143	Railroads
144	Airports
145	Communication - antennas
146	Marinas/Port Facilities/Docks
149	Other Transportation/Communication
150	Utilities
160	Mixed Urban or Built-up Land
170	Other Urban or Built-up Land
180	Institutional/Governmental
190	Recreational
210	Cropland and Pasture
211	Cropland
212	Pasture
213	Idle Fields
214	Plowed, Unvegetated Fields
215	Truck Crops
220	Orchard/Nurseries/Horticulture
230	Confined Feeding Operations/Feedlots/Holding
240	Farmsteads and Farm Related Bldgs.
290	Other Agriculture
310	Herbaceous Rangeland
320	Shrub/Brush Rangeland
330	Mixed Rangeland
410	Deciduous Forest
420	Evergreen Forest
430	Mixed Forest
440	Clear-cut
510	Waterways/Streams/Canals
520	Natural Lakes and Ponds
530	Man-made Reservoirs and Impoundments
540	Bays and Coves
590	Others
600	Wetlands
720	Beaches and River Banks
730	Inland Natural Sandy Areas
750	Extraction
760	Transitional (incl. Cleared, filled, and graded areas)

1:24,000 data layers. However, no information was available to document whether the maps are accurate to such a scale under National Mapping Standards

Date obtained: June 2005.

New Castle Approved Development

Data obtained from NCC eParcelView Map at http://dmz-arcims02.co.new-castle.de.us/website/nccparcelmap2/viewer.htm. Data include both proposed and recently recorded major land development plans. New Castle County developed the data and updates the information monthly.

Key data elements: Data identify the land parcel name and indicate whether the development is approved or the decision is pending.

Scale: Unable to identify documentation. A visual inspection showed that the boundaries of this layer are similar to 1:24,000 data. However, no information was available to document whether the maps are accurate to such a scale under National Mapping Standards

Date obtained: June 2005.

ESRI NATIONAL ATLAS

The National Atlas data identify federal land and are distributed as part of the ESRI data CDs. The data were used to identify the location of Dover Air Force Base.

Scale: 1:2,000,000.

Date of publication: 2004.

FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

FEMA created floodplain data that identify the boundaries of the 100-year floodplain. These data were obtained through ESRI's website at http://www.esri.com/data/download/fema/index.html. Used in this study to identify the floodplain within Kent County.

Key data elements: For this study, we identify land within the 100-year floodplain as polygons where the field "Zone" identifies the land area as "A," "AE," or "VE."

Scale: 1:24,000.

Date obtained: June 2005.

ICF CONSULTING CONTRACT TO EPA (2003)

Study Area

Defines landward-boundary of study area by identifying lands that are higher than 20 feet in elevation or within 1,000 feet of mean high water based on tidal wetlands data. Data collected by the U.S. Geological Survey and stored in 1:24,000 maps that ICF Incorporated compiled into a single digital product, under contract to EPA.

Key data elements: Each polygon is categorized as "within" or "outside" the study area. Polygons outside the study area (lands higher than 20 feet in elevation and more than 1000 feet from mean high water) are displayed as white polygons. Polygons within the study area are displayed as clear polygons.

Date of publication: 2003.

Wetlands

Data identify tidal and nontidal wetlands as well as open water. Data are a reprojection of the U.S. Fish and Wildlife Service's (FWS) National Wetlands Inventory (NWI) data, which are based on U.S. Geological Survey maps (1:24,000). ICF Incorporated compiled the maps into a single digital product, under contract to EPA.

Key data elements: Each polygon is assigned a classification that identifies it according to the FWS hierarchical wetlands classification system. The reprojected dataset stores this classification information in an "attribute" field. Wetlands are identified as tidal or nontidal based on the first two characters of the classification code. Tidal wetlands include those classification codes beginning with "M1" and "E2" whereas nontidal codes begin with "PS," "PF," "PE," "R1," "R2," "L2," and "PU," with the exception of any code that includes "OW," which indicates open water.

Date of publication: Ranges from February 1971 to December 1992.