Appendix D. Delaware Estuary

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Much of this report examines the difference between protecting the current boundary between dry land and wetlands and allowing that boundary to retreat. At one time, there was a third option: *advance* the shore seaward by converting marsh to dry land. Environmental policies ended that practice in the United States. But the methods and results of preventing dry land from becoming wet have many similarities with creating dry land from water: Just as we can prevent land from becoming water by elevating land and beaches with fill material, at one time people converted water to land by filling wetlands and shallow waters[83]. Just as we can prevent dry lands from becoming wetlands by building dikes inland of the existing wetlands, at one time people created farmland by building dikes seaward of the marsh.

Nowhere in the United States was more marsh converted to dry land than along the Delaware River and Delaware Bay. (See Box D.1) Although most of the dikes used to

83 E.g., See discussion about filling of the Potomac River in Washington D.C. in Appendix F.

reclaim land from the sea have been dismantled, some still persist. Even where the dikes have been dismantled, their effects are still noticeable.

This report uses the term "Delaware Estuary" as shorthand for referring to both the Delaware Bay and the tidal portions of the Delaware River. From the head-of-tide at Trenton to Commodore Barry Bridge near the Delaware–Pennsylvania border, the river is generally fresh. This chapter examines the coastal elevations and environmental vulnerability. We divide the discussion between land above and below the Commodore Barry Bridge over the Delaware River, which roughly defines the boundary between fresh and brackish water.

BOX D.1: Land Reclamation in the Delaware Estuary

Nowhere in the United States was more marsh converted to dry land than along the Delaware River and Delaware Bay. A Dutch governor of New Jersey diked the marsh on Burlington Island. In 1680, after the English governor had possession of the island, observers commented that the marsh farm had achieved greater yields of grain than nearby farms created by clearing woodland (Danckaerts, 1913). Shortly after, an English governor ordered the construction of dikes to facilitate construction of a highway through the marsh in New Castle County (Sebold, 1992).

Colonial (and later state) governments in New Jersey chartered and authorized "meadow companies" to build dikes and take ownership of the reclaimed lands. During the middle of the 19th century, the state agriculture department extolled the virtues of reclaimed land for growing salt hay.[1] By 1866, 20,000 acres of New Jersey's marshes had been reclaimed from Delaware Bay, mostly in Salem and Cumberland counties (State Geologist, 1866), and by 1892, more than 15,000 acres had been reclaimed in Salem County alone (Vermeule, 1984). In 1885, the U.S. Department of Agriculture cited land reclamation in Cumberland County, New Jersey, as among the most impressive in the nation.[2] On the other side of the river, 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 Delaware's other two counties (Nesbit, 1885). In Pennsylvania, most of the reclaimed land was just south of the mouth of the Schuylkill along the Delaware River, near the present location of Philadelphia International Airport.

During the 20th century, these land reclamation efforts were reversed. In many cases, lower prices for salt hay led farmers to abandon the dikes (DDFW, 2007).In some cases, where dikes remain, rising sea level has limited the ability of dikes to drain the land, and the land behind the dike has converted to marsh (see Box D.4 on Gibbstown Levee). Efforts are under way to restore the hydrology of many lands that were formerly diked (DDFW, 2007). The momentum of these environmental restoration efforts has extended inland in both Delaware and New Jersey. Much of the formerly diked lands are now part of conservation areas.

Notes:

1. "In 1857 the Cape May County, New Jersey, had 58,824 acres of marsh, of which 1,918 acres were improved through reclamation and 17,223 acres were used as meadow. The [state geologist] encouraged reclamation because once landowners shut off the tidal waters using banks and sluices, the marshes would become fresh and capable of improvement for cultivation. The state geologist asserted that unimproved salt marsh could be made profitable by improving it just enough to grow salt hay; all one had to do was dig ditches and open salt holes to allow the flow of the tide to escape." (State of New Jersey, 1885)
2. "The superiority of diked land over poor upland is nowhere better illustrated than along the Maurice River, in New Jersey. There the banked meadows, some of which have been in cultivation, without manure, for generations, are wonderfully fertile, and the upland immediately adjoining is only able to produce scrub oak and stunted pine" (State of New Jersey, 1885)

D.1 THE NATURAL ENVIRONMENT

D.1.1 Delaware Bay and the Lower Delaware River

D.1.1.1 Coastal Elevations

Figure D.1 depicts the elevations of lands close to sea level. Salem County in New Jersey and Kent County in Delaware have the most dry land within 2 meters of spring high water. Salem County has between 54 and 84 square kilometers of dry land below 2 meters, and Kent County has between 48 and 78 square kilometers (see Table D.1). Approximately 90–186 square kilometers of dry land lie within 1 meter above the tides along the shores of the Delaware Estuary south of the Pennsylvania/Delaware and Salem/Gloucester County, New Jersey, border. Within this area, a similar area of nontidal wetlands exists, with 71–131 square kilometers.

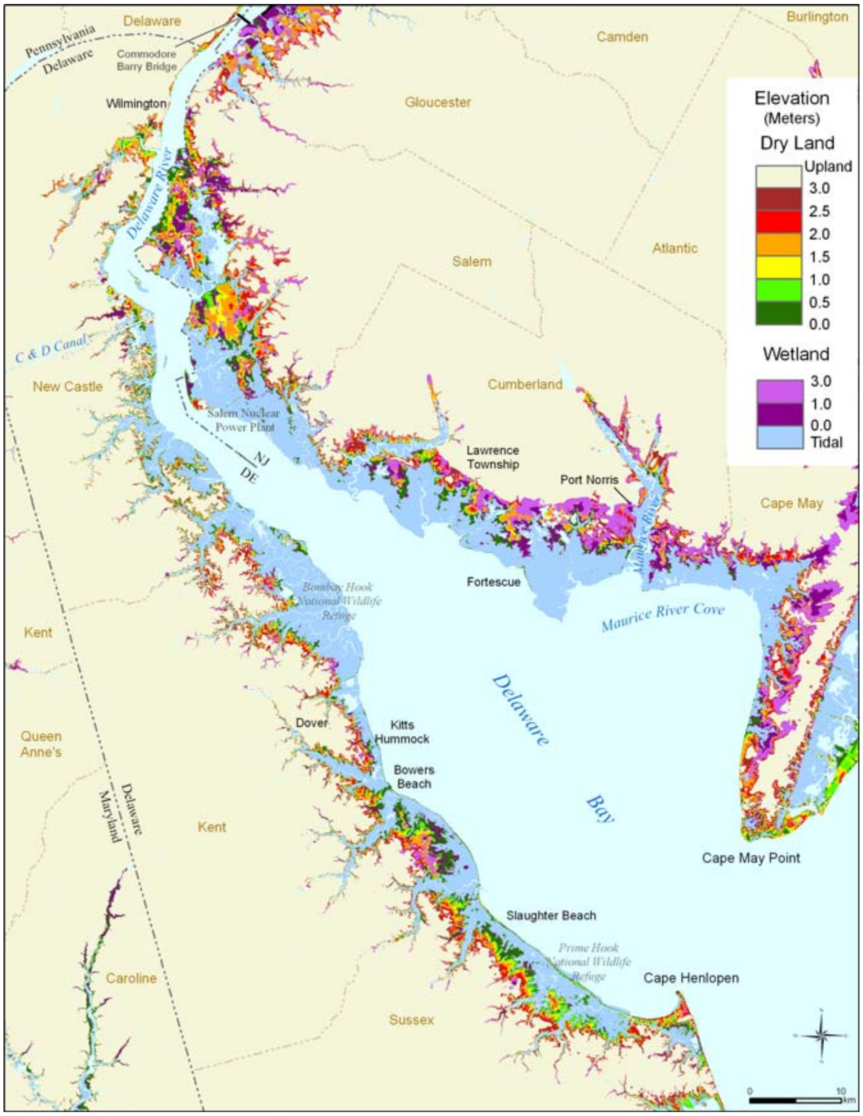

Figure D.1 Delaware Bay: Elevations relative to spring high water.

Table D.1 Low and high estimates for the area of dry and wet land close to sea level, Delaware Estuary (square kilometers).

Elevations above spring high water:		Tidal	50 cm		1 meter		2 meters		3 meters		5 meters	
			Low	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Locality	**State**	Cumulative (total) amount of dry land below a given elevation										
Sussex	DE		6.4	18.2	15.8	30.8	37.3	55.2	60.0	78.6	103.3	119.7
Kent	DE		8.8	24.8	21.9	40.6	47.9	77.6	86.1	119.2	177.8	209.9
New Castle	DE		7.1	19.0	16.8	29.9	34.4	52.2	54.2	75.0	99.0	119.0
Delaware	PA		0.4	6.1	4.0	12.1	11.5	18.0	17.2	20.7	22.2	25.9
Philadelphia[1]	PA		3.6	6.1	6.8	12.4	20.0	24.8	31.6	36.8	51.5	54.8
Bucks	PA		0.0	4.4	0.2	8.5	5.3	18.0	11.9	27.4	25.3	42.1
Mercer	NJ		0.0	0.1	0.0	0.1	0.1	0.2	0.2	0.4	0.3	0.4
Burlington	NJ		0.1	4.3	0.4	8.4	5.3	16.4	11.0	24.5	22.5	42.2
Camden	NJ		0.0	3.8	0.1	7.3	4.3	14.8	9.5	22.4	20.4	34.5
Gloucester	NJ		0.2	9.2	6.1	18.4	17.7	33.3	29.6	46.5	53.5	69.3
Salem	NJ		5.9	26.9	21.3	48.7	53.8	84.4	83.9	114.0	135.5	160.3
Cumberland	NJ		3.0	15.8	12.1	28.9	30.3	53.2	49.5	76.9	90.8	114.3
Cape May	NJ		0.4	3.5	2.5	7.5	8.6	19.9	20.9	36.9	55.5	68.0
Total			**35.9**	**142.0**	**108.0**	**253.7**	**276.5**	**468.0**	**465.7**	**679.2**	**857.7**	**1060.4**
		Cumulative (total) amount of wetlands below a given elevation										
Sussex	DE	67.4	2.1	4.8	4.6	6.2	6.8	8.6	9.0	10.6	12.3	13.3
Kent	DE	168.7	4.9	11.4	10.4	16.6	19.0	24.6	25.9	30.9	38.8	43.5
New Castle	DE	73.5	1.8	3.8	3.5	4.8	5.1	6.7	6.7	8.4	9.7	11.1
Delaware	PA	3.6	0.1	0.8	0.6	1.7	1.6	2.2	2.2	2.3	2.3	2.3
Philadelphia	PA	0.6	0.5	0.6	0.6	0.9	1.2	1.4	1.6	1.7	1.9	1.9
Bucks	PA	1.9	0.0	0.9	0.1	1.9	1.2	4.1	2.9	6.3	6.2	8.2
Mercer	NJ	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Burlington	NJ	5.4	0.0	0.6	0.0	1.2	0.7	2.3	1.5	3.4	3.1	5.8
Camden	NJ	1.5	0.0	0.3	0.1	0.7	0.5	1.3	0.9	1.9	1.8	2.7
Gloucester	NJ	18.0	0.2	8.8	5.9	17.4	16.8	25.9	25.0	28.8	30.4	33.5
Salem	NJ	110.1	9.6	25.1	22.3	35.8	38.2	49.0	48.9	55.4	60.3	67.6
Cumberland	NJ	212.6	4.7	23.6	18.1	42.1	43.6	65.5	63.5	80.6	89.8	103.2
Cape May	NJ	48.3	4.3	14.7	12.2	25.1	28.2	40.3	41.5	51.2	58.6	63.7
Total		**713.5**	**28.3**	**95.5**	**78.5**	**154.2**	**163.0**	**231.8**	**229.7**	**281.6**	**315.1**	**356.8**
Dry and nontidal wetland			64	237	187	408	440	700	695	961	1173	1417
All land		713	778	951	900	1121	1153	1413	1409	1674	1886	2131

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

1. This number includes Philadelphia's 2.4 square kilometers of dry land below spring high water, of which 0.87, 0.26, 0.054, and 0.005 are at least 0.5, 1, 2, and 3 meters below spring high water, respectively. Most of this land is near Philadelphia International Airport.

Nontidal wetlands account for more than half of the land below 1 meter on the New Jersey side, but only one quarter on the Delaware side.

D.1.1.2 Vulnerable Habitats

On both sides of Delaware Bay, most shores are either tidal wetlands or sandy beaches with tidal wetlands immediately behind them. In effect, the sandy beach ridges are similar to the barrier islands along the Atlantic, only on a smaller scale. Several substantial communities with wide sandy beaches on one side and marsh on the other side are along Delaware Bay — especially on the Delaware side of the bay. Shoreline erosion has been a more immediate threat to these communities. Nevertheless, Bowers Beach, Slaughter Beach, and Fortescue are all within 2 meters above spring high water.

Delaware Bay is home to hundreds of species of ecological, commercial, and recreational value (Dove and Nyman, 1995). Unlike other estuaries in the Mid-Atlantic, the tidal range is greater than the ocean tidal range, generally about 2 meters. Beaches account for 52% of the bay's shore, with marsh and eroding peat accounting for most of the remainder (Lathrop, et al., 2006). We briefly discuss the possible loss of Delaware Bay's tidal marshes and beaches.

Tidal Marsh

Like most large estuaries, Delaware Bay has freshwater, brackish, and salt marshes. The bay's low marsh is dominated by smooth cordgrass, *Spartina alterniflora*, whereas high marsh is dominated by salt hay, *Spartina patens (*Kreeger and Newell, 2000). High marsh habitat is less common than low marsh, and likely to be more vulnerable. Among the many bird species that rely on high marsh are black rail and the coastal plain swamp sparrow (*Melospiza Georgiana nigrescens*), which has nearly its entire breeding distribution in Delaware Estuary[84].

In some areas, dikes have been removed to restore tidal flow and natural marsh habitat and biota, but in some areas invasion by common reed (*Phragmites australis)* has been a problem (Able et al., 2000; Weinstein, et al. 2000).

Habitat Change as Sea Level Rises

Can Marshes Keep Pace with Rising Sea Level? The net gain or loss of tidal marshes as sea level rises depends on tide range, the ability of the wetlands to keep pace with rising sea level, and their ability to migrate inland. With a 2 meter daily tide range, it would take almost a 1 meter rise to submerge all the existing low marsh, or to convert high marsh into low marsh.

In much of Delaware Bay, however, tidal marshes appear to be at the low end of their potential elevation range, increasing their vulnerability (Kearney et al., 2002). Recent research indicates that 50 to 60% of Delaware Bay’s tidal marsh has been degraded, primarily because the surface of the marshes is not rising as fast as the sea (Kearney et al., 2002). One possible reason is that channel deepening projects and consumptive withdrawals of fresh water have changed the sediment supply to the marshes (Kreeger et

84 Kevin Kalasz, Delaware Natural Heritage Program, Division of Fish and Wildlife in written communication to EPA, 5/14/07.

al., 2007). Marshes are also eroding at their seaward edges; for example, the mouth of the Maurice River near Port Norris, New Jersey. But the wetlands along Bombay Hook National Wildlife Refuge on the Delaware side, and between Fortescue and the Salem Nuclear Power Plant on the New Jersey side, are already marginal and would mostly be lost from even a sea-level rise acceleration of 2 mm/year.

Can Wetlands Migrate Inland as Sea Level Rises? Along Delaware Bay, most of the shore is undeveloped. If these lands do not receive shore protection, they would be available for potential wetland migration. Each acre of land submerged, however, would not necessarily correspond to an acre of increased wetland habitat: Landward migration of tidal wetlands may occur at the expense of existing nontidal wetlands along much of the shore. Moreover, no one has established that the tidal inundation of the freshwater wetlands would lead to creation of salt marsh; in many areas such inundation converts the wetlands to open water instead.

Implications of Habitat Change. The loss of tidal marsh as sea level rises would harm species that depend on these habitats for food, and shelter, including invertebrates, finfish, and a variety of bird species. Great blue herons, black duck, blue and green-winged teal, Northern harrier, osprey, rails, red winged blackbirds, widgeon, and shovelers all use the salt marshes in Delaware Bay. Blue crab, killifish, mummichog, perch, weakfish, flounder, bay anchovy, silverside, herring, and rockfish rely on tidal marshes for feeding on the mussels, fiddler crabs, and other invertebrates and for protection from predators (Dove and Nyman, 1995).

Invertebrates associated with cordgrass stands in the low intertidal zone include grass shrimp, ribbed mussel, coffee-bean snail, and fiddler crabs (Kreamer 1995). Blue crab, sea turtles, and shorebirds are among the many species that prey on ribbed mussels; fiddler crabs are an important food source for bay anchovy and various species of shorebirds (Kreamer, 1995). Wading birds such as the glossy ibis feed on marsh invertebrates (Dove & Nyman, 1995). Waterfowl, particularly dabbling ducks, use low marsh areas as a wintering ground.

Beaches

Habitat Change. Sandy beaches and foreshores account for 54% of the Delaware and New Jersey shores of Delaware Bay. Table D.2 shows additional estimates of the status of the bay's shoreline, with an emphasis on the vulnerability of beach habitat. As sea level rises, beaches can be lost if either shores are armored or if the land behind the existing beach has too little sand to sustain a beach as the shore retreats (Nordstrom, 2005). As shown in Table D.2, so far, only 4 (Delaware) and 6 (New Jersey) percent of the natural shores have been replaced with shoreline armoring. Another 15 (Delaware) and 4 (New Jersey) percent of the shore is developed. Although conservation areas encompass 58% of Delaware Bay's shores, they include only 32% of beaches that are optimal or suitable habitat for horseshoe crabs.

BOX D.2: Horseshoe Crabs, Limulus polyphemus, and Estuarine Beaches

The Atlantic horseshoe crab (*Limulus polyphemus)*, an ancient species that has survived virtually unchanged for more than 350 million years enters estuaries each spring to spawn along sandy beaches. The species has experienced recent population declines, apparently due to over harvesting as well as habitat loss and degradation (Berkson and Shuster, 1999).

Population Status and Sea-Level Rise

In Delaware Bay, as elsewhere along its range, horseshoe crabs depend on narrow sandy beaches and the alluvial and sand bar deposits at the mouths of tidal creeks for essential spawning habitat. A product of wave energy, tides, shoreline configuration, and over longer periods, sea-level rise, the narrow sandy beaches utilized by horseshoe crabs are diminishing at sometimes alarming rates due to beach erosion as a product of land subsidence and sea level increases (Nordstrom 1989; Titus et al. 1991). At Maurice Cove in Delaware Bay, for example, portions of the shoreline have eroded at a rate of 4.3 m per year between 1842 and 1992 (Weinstein and Weishar 2002); an estimate by Chase (1979) suggests that the shoreline retreated 150 m landward in a 32-year period, exposing ancient peat deposits that are believed to be suboptimal spawning habitat (Botton et al. 1988). As human infrastructure along the coast leaves estuarine beaches little or no room to transgress inland as sea level rises, there will likely be concomitant loss of horseshoe crab spawning habitat. Kraft et al. (1992) estimated this loss, concomitant with wetland “drowning” as > 90% in Delaware Bay (~ 33,000 ha).

Horseshoe Crab Spawning and Shorebird Migrations

Each spring, horseshoe crab spawning coincides with the arrival of hundreds of thousands of shorebirds migrating from South America to their sub-Arctic nesting areas. While in Delaware Bay, shorebirds feed extensively on horseshoe crab eggs to increase their depleted body mass before continuing their migration (Castro and Myers 1993; Clark 1996). Individual birds may increase their body weight by nearly one-third before leaving the area. How shorebirds might be affected by horseshoe crab population decline is uncertain (Smith et al., 2006).

Table D.2 The shores of Delaware Bay: Habitat type and conservation status of shores suitable for horseshoe crabs.

Shoreline length	Delaware		New Jersey		NJ+DE
…by Habitat Type (percent of bay shoreline)[1]	km	%	km	%	%
Beach	68	74	62	42	54
Armored Shore	3.7	4	8.3	6	5
Organic	20	22	78	53	41
Total Shoreline	91	100	148	100	100
… by Existing Development					
Development[1]	13	15	5.7	3.8	8
…by Suitability for Horseshoe Crab (percent of Bay shoreline)					
Optimal Habitat[2]	31.3	34	26.0	18	24
Suitable Habitat[2]	10.5	12	5.1	3.5	6.6
Less Suitable Habitat[2]	29.0	32	49.0	33	33
Unsuitable Habitat[2]	20.0	22	67.0	46	37
…Within Conservations Lands by Suitability for Horseshoe Crab (percent of equally suitable lands)					
Optimal Habitat[3]	12.9	41	9.6	37	39
Optimal and Suitable Habitat[3]	13.6	33	9.8	32	32
Optimal, Suitable, and Less Suitable Habitat[3]	32.2	46	43.3	54	50
All Shores[3]	44.7	49	92.7	63	58

[1] Delaware and New Jersey results from Lathrop et al., 2006.
[2] Delaware and New Jersey results from Lathrop et al., 2006 at p.16 Table 9. "Unsuitable" includes both "avoided" and "disturbed."
[3] From Lathrop et al. at p.18 Table 1. Lathrop et al. report results for the categories separately, while we aggregate the categories.

Beach nourishment has been relatively common along the developed beach communities on the Delaware side of the bay. Although beach nourishment can diminish the quality of habitat for horseshoe crabs, nourished beaches are more beneficial than an armored shore. But many Delaware Bay beaches have a relatively thin layer of sand. Although these small beaches have enough sand to protect the marshes immediately inland from wave action, it is uncertain whether some beaches would survive accelerated sea-level rise even without shoreline armoring. In a few cases, Delaware has already nourished beaches with the primary purpose of restoring horseshoe crab habitat (Smith, 2006).

Implications of Habitat Change. Delaware Bay is a major stopover area for six species of migratory shorebirds, including most of the Western Hemisphere population of red knot[85]. On their annual migrations from South America to the Arctic, nearly a million shorebirds move through Delaware Bay, where they feed heavily on invertebrates in tidal mudflats, and particularly on horseshoe crab eggs on the bay's sandy beaches and foreshores (Walls, 2002). The Delaware Estuary is home to the largest spawning population of horseshoe crabs in the world. Although these animals can lay eggs in tidal marshes, their preferred nesting sites are the mid- and high intertidal zones of sandy beaches.

A sea-level rise modeling study estimated that a 2 foot rise in relative sea level over the next century could reduce shorebird foraging areas in Delaware Bay by 57% or more by 2100 (Galbraith et al., 2002). If these foraging habitats are lost and prey species such as horseshoe crab decline, there are likely to be substantial reductions in the numbers of shorebirds supported by the bay (Galbraith et al., 2002). In fact, since 1991 there has been a dramatic decline in horseshoe crabs in Delaware Bay and a corresponding decline in shorebird numbers (NJDEP, date unkown).

Numerous other animals, including diamondback terrapins, and Kemp's and Ridley sea turtles, rely on the sandy beaches of Delaware Bay to lay eggs or forage on invertebrates such as amphipods and clams. When tides are high, numerous fish also forage along the

85 For example, see discussion of migratory shorebirds in Delaware Bay at http://www.state.nj.us/dep/fgw/ensp/shorebird_mig.htm, accessed 1/23/08.

submerged sandy beaches, such as killifish, mummichog, rockfish, perch, herring, silverside, and bay anchovy (Dove and Nyman, 1995).

BOX D.3: Finfish and Tidal Salt Marshes

Tidal salt marshes are among the most productive habitats in the world (Teal, 1986). In addition to directly benefiting resident salt marsh species, marsh-associated organic matter is incorporated into food webs supporting marine transient fish production in open waters. Marine transients are adapted to life on a "coastal conveyor belt," often spawning far out on the continental shelf and producing estuarine dependent young that are recruited into coastal embayments year-round (Deegan, 2000).

Tidal salt marshes serve two critical functions for young finfish (Boesch and Turner, 1984). First, abundant food and the warm shallow waters of the marsh are conducive to rapid growth of both resident and temporary inhabitants. Combined with the low abundance of large predators, marshes and their drainage systems may serve as shelters from predation. Rapid growth and the ability to deposit energy reserves from the rich marsh diet prepare young fish for the rigors of migration and/or overwintering (Weinstein, et al., 2005; Litvin and Weinstein, 2008).

Effects of Sea-Level Rise

Because intertidal and shallow subtidal waters of estuarine wetlands are "epicenters" of material exchange, primary (plant) and secondary (animal) production, and serve as primary nurseries for the young of many fish and shellfish species (Childers et al., 2000; Weinstein, 1979; Deegan et al., 2000) , the prospect of sea-level rise, sometimes concomitant with land subsidence, human habitation of the shore zone and shoreline stabilization place these critical resources at risk. Such ecological hotspots could be lost as a result of sea-level rise because human presence in the landscape leaves tidal wetlands little or no room to migrate inland. Because of lack of a well-defined drainage system, small bands of intertidal marsh located seaward of armored shorelines have little ecological value in the production of these taxa (Weinstein et al., 2005; Weinstein, 1983).

D.1.2 Delaware River: Above the Commodore Barry Bridge

Figure D.2 shows coastal elevations along the tidal freshwater portion of the Delaware River, with a contour interval of 1 meter. Figure D.3 focuses on Philadelphia with a contour interval of 50 centimeters, based on the 2-foot contour elevation data the City provided EPA. Approximately half of Pennsylvania's low land is in Philadelphia, which has between 6.8 and 12.4 square kilometers within 1 meter above spring high water, of which 3.6 to 6.1 square kilometers are below 50 centimeters (Table D.1). Because of the long history of dike construction, Philadelphia has 2.4 square kilometers of dry land below spring high water, including about 24 hectares that are more than 1 meter below spring high water, mostly near Philadelphia International Airport.

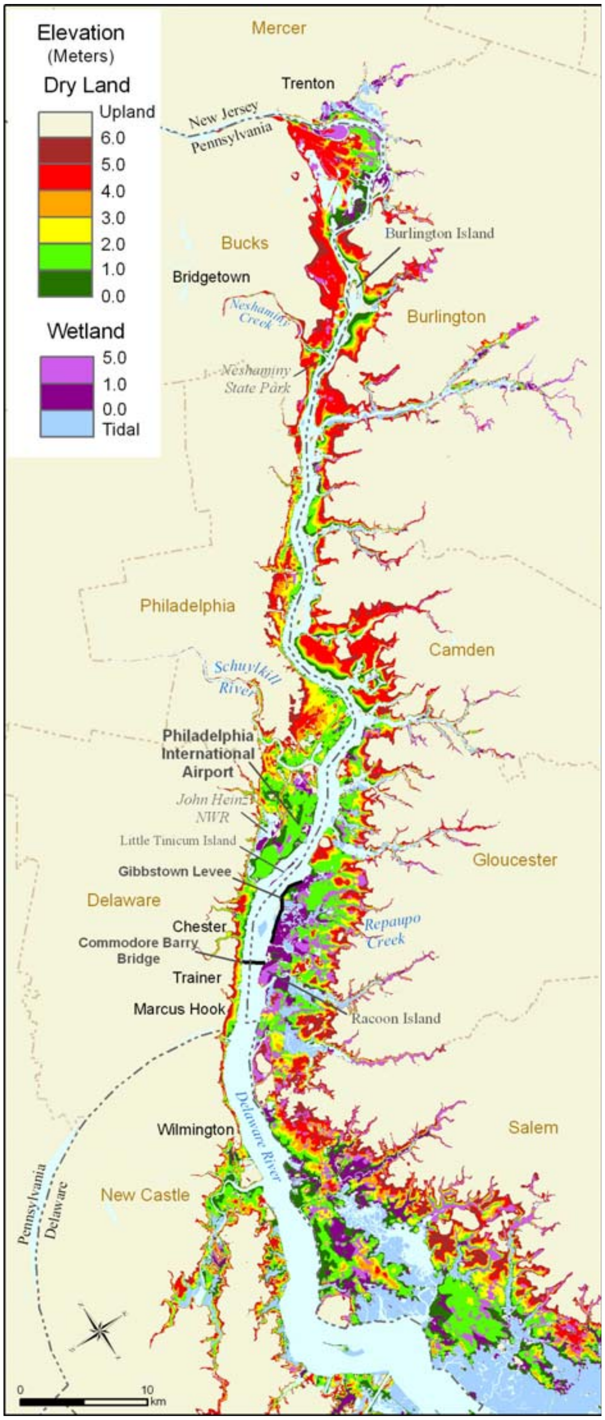

Figure D.2 Delaware River: Elevations relative to spring high water.

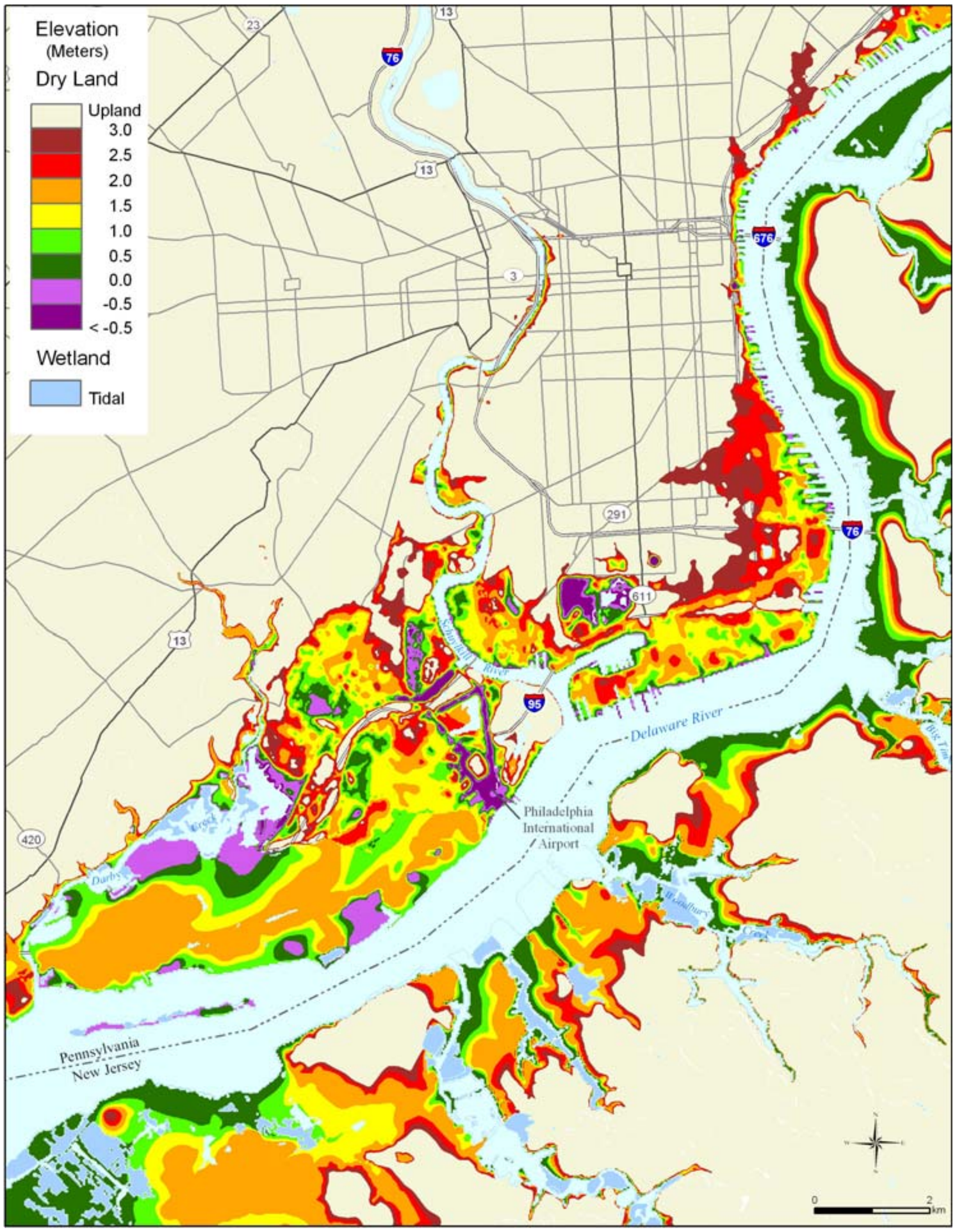

Figure D.3 Philadelphia: Elevation relative to spring high water.

New Jersey's lowest land along the Delaware River is in Gloucester County, behind a dike known as the Gibbstown Levee[86]. "The Gibbstown Levee runs 4.5 miles along the Delaware River in Logan Township and Greenwich Township in Gloucester County, NJ. It protects the 21-square-mile Repaupo Creek watershed inhabited by approximately 6,700 residents."(USACE, 2004). Several square miles are below the 00-foot (NGVD) contour shown on the USGS 7.5 minute map of the area. Most of this low area is some form of freshwater wetland, but there are also a few homes and a trailer park along Floodgate Road below the 00-foot contour (which is 20–25 centimeters below sea level; see Chapter 1 box on "Tides, Wetlands, and Reference Elevations"). This dike once served a function similar to the dikes in Cumberland County, preventing tidal inundation and lowering the water table to a level below mean sea level. When the dike was built 300 years ago (USACE, not dated), the tides were 3 feet lower; and hence the combination dike and tide gate was able to keep the water levels low enough to permit cultivation. But rising sea level has left this land barely above low tide, so that many lands do not completely drain during low tide. Hence, they are now nontidal wetlands. Parts of Raccoon Island near the entrance to the Commodore Barry Bridge, for example, are below mean sea level.

86 Dikes are often mistakenly called levees, just as groins are mistakenly called jetties. A levee is built to protect an area from surging river levels; a dike is built to protect low lands from tidal inundation or storm surges.

D.2 DEVELOPMENT AND SHORE PROTECTION

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

D.2.1 Delaware Bay and Lower Delaware River

Policies that may be relevant for adapting to sea-level rise in New Jersey include policies related to the Coastal Facilities Review Act (CAFRA), the State Plan, an unusually strong public trust doctrine, and strong preference for beach nourishment along the Atlantic Ocean over hard structures or shoreline retreat. The first three of these policies are discussed here, and the fourth is discussed in Appendix C (New Jersey Shore). The policy context for shore protection in Delaware is discussed in Appendix E.

CAFRA sometimes limits development in the coastal zone, primarily to reduce runoff of pollution into the state's waters (State of New Jersey, 2001). Like Maryland's Critical Areas Act (see Appendix E), this statute may indirectly reduce the need for shore protection by ensuring that homes are set back farther from the shore than would otherwise be the case.

The New Jersey State Plan provides a statewide vision of where growth should be encouraged, tolerated, and discouraged — but local government has the final say. In most areas, lands are divided into five planning areas:

1. Metropolitan areas
2. Suburban areas
3. Fringe areas
4. Rural areas, where the rural character ought to be maintained
5. Land with valuable ecosystems, geologic features, or wildlife habitat, including coastal wetlands and barrier spits/islands (State of New Jersey, 2001).

The state encourages development in planning areas 1 and 2, as well as areas in planning area 3 that are either already developed or part of a well-designed new development. The state discourages development in most portions of planning areas 4 and 5 (State of New Jersey, 2001). However, even these areas include developed enclaves, known as "centers" where development is recognized as a reality (State of New Jersey, 2001). Most developed barrier islands are part of a center within planning area 5, for example. The preservation of rural and natural landscapes in planning areas 4 and 5 is likely to afford opportunities for wetlands to migrate inland as sea level rises.

The public trust doctrine in New Jersey has two unusual aspects. First, the public has an easement along the dry beach between mean high water and the vegetation line. Although other states have gradually acquired these easements in most recreational communities, few states have general access along the dry beach[87]. As a result, people are entitled to walk along river and bay beaches, where public demand for access would not have otherwise been sufficient for governments to acquire such universal access. The laws of Delaware and Pennsylvania, by contrast, grant less public access along the shore. In most states, the public owns the land below mean high water. In these two states, the public owns the land below mean low water. The public has an easement along the wet beach between mean low and mean high water, but only for navigation, fishing, and hunting — not for recreation.

Even more remarkably, the New Jersey Supreme Court has held that the public is entitled to perpendicular access to the beach[88]. The holding does not mean that someone can indiscriminately walk across any landowner's property to get to the water (which would be an unconstitutional taking), but it does require governments to take prudent measures to ensure that public access to the water accompanies new subdivisions[89]. As sea level rises, the unusual public access to all New Jersey shores is likely to support a greater public demand for ensuring the continued survival of estuarine beaches than would be the case if the public had no access to those beaches (Titus, 1998).

New Jersey policies to manage stormwater may also facilitate the migration of wetlands. The State's stormwater management regulations limit new development within 300 feet of the shore along the majority of Delaware Bay (NJDEP, DWM, April 2004). Although encroachment into the protection area is allowed under certain circumstances, the

87 See Chapter 7 for additional details.
88 Matthews v Bay Head Improvement Association, 471 A.2d 355. Supreme Court of NJ (1984).
89 Federal law requires similar access before an area is eligible for beach nourishment.

functional value and overall condition of the protection area must be maintained to the maximum extent practicable. The establishment of this protection area will help preserve areas suitable for the inland migration of the extensive wetlands located in the area. Of the 147 square kilometers of land within approximately 1 meter above the tides on the New Jersey side (Salem, Cumberland, and Cape May counties), 82 square kilometers are nontidal wetlands (Jones and Wang, 2008).

In Cumberland County, salt marsh has been reclaimed for agricultural purposes for more than 200 years (Sebold, 1992; State of New Jersey, various years). Over the last few decades, many of those dikes have been dismantled. Some have failed during storms. Others have been purchased by conservation programs seeking to restore wetlands, most notably PSE&G in its efforts to offset possible environmental effects of a nuclear power plant. Although the trend is for dike removal, the fact that diked farms have been part of the landscape for centuries leads one to the logical inference that dikes may be used to hold back a rising sea once again. In fact, dikes may be more effective at protecting currently arable dry land than protecting former marsh, because drained wetlands often subside. Cumberland County has relatively little coastal development, yet the trend in coastal communities that have not become part of a conservation program has been for a gradual retreat from the shore. Several small settlements along Delaware Bay are gradually being abandoned.

Delaware On the Delaware side, dry land accounts for 80 of the 104 square kilometers of land within approximately 1 meter of the tides (Jones and Wang, 2008). 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.[90] Because the 100-year floodplain for storm surge extends about 2 meters above spring high water, this is likely to be more effective at allowing wetlands to migrate inland than limiting development within a fixed width of a few hundred feet. Nevertheless, if sea level continues to rise, this buffer would not last forever.

Preservation easements and land purchases have also contributed to a major conservation buffer that will almost certainly allow wetlands to migrate inland as sea level rises. The State is purchasing agricultural preservation easements in the coastal zone, and a significant portion of the shore is in Prime Hook or Bombay Hook National Wildlife Refuge. More than 80% of the shore south of the canal is part of some form of preservation or conservation land.

Whether wetland migration on the New Jersey side of Delaware Bay is more sustainable than along the Delaware side would partly depend on whether the Delaware county floodplain regulations or the New Jersey State Plan is more effective at discouraging development in the coastal floodplain.

[90] See Kent County Ordinances Section 7.3 and New Castle Ordincance 40.10.313

D.2.2 Delaware River: Freshwater Portion

D.2.2.1 Policy Context[91]

Pennsylvania is the only state in the nation along tidal water without an ocean coast[92]. The resulting lack of barrier islands and communities vulnerable to coastal erosion and life-threatening hurricanes has often led observers to ignore the impact of sea-level rise on Pennsylvania (USGS, not dated). To be sure: Pennsylvania's sensitivity to sea-level rise is different than other states. Floods in the tidal Delaware River are as likely to be caused by extreme rainfall as storm surges. The Delaware River is usually fresh along almost all of the Pennsylvania shore. Because Philadelphia relies on freshwater intakes in the tidal river, the most important impact may be the impact of salinity increases from rising sea level on the city's water supply.

Pennsylvania has no policies that directly address the issue of sea-level rise[93]. The lack of an ocean coast implies that Pennsylvania has less need for the types of policies that have been motivated by hazards along the ocean. Nevertheless, the state has several coastal policies that might form the initial basis for a response to sea level rises, including state policies on tidal wetlands and floodplains, public access, and redeveloping the shore in response to the decline of water-dependent industries.

Tidal Wetlands and Floodplains

91 This section only addresses the Pennsylvania side of the river because Appendix C addressed the policy context for shore protection in New Jersey.
92 This statement also applies to the District of Columbia.
93 But Philadelphia's flood regulations consider sea level rise.

Pennsylvania's Dam Safety and Waterway Management Rules and Regulations[94] require permits for construction in the 100-year floodplain or wetlands[95]. The regulations do not explicitly indicate whether landowners have a right to protect property from erosion or rising water level. A permit for a bulkhead or revetment seaward of the high-water mark can be awarded only if the project will not have a "significant adverse impact" on the "aerial extent of a wetland" or on a "wetland's values and functions." A bulkhead seaward of the high-water mark, however, eliminates the tidal wetlands on the landward side. If such long-term impacts were viewed as "significant," permits for bulkheads could not be awarded except where the shore was already armored. But the State has not viewed the elimination of mudflats or beaches as "significant" for purposes of these regulations; hence it is possible to obtain a permit for a bulkhead.

The rules do not restrict construction of bulkheads or revetments landward of the high water mark. But they do prohibit permits for any "encroachment located in, along, across or projecting into a wetland, unless the applicant affirmatively demonstrates that…the … encroachment will not have an adverse impact on the wetland…"[96] Therefore, shoreline armoring can eliminate coastal wetlands (or at least prevent their inland expansion[97]) as sea level rises by preventing their landward migration.

94 These regulations were issued pursuant to the Dam Safety and Encroachment Act of 1978. Laws of Pennsylvania, The Dam Safety and Encroachments Act of November 26, 1978, P.L. 1375, No. 325.
95 See Chapter 5.
96 Pennsylvania Code, Chapter 105. Dam Safety and Waterway Management, Pennsylvania Department of Environmental Protection, 1997. Subchapter 105.18b.
97 This assessment concludes that most tidal wetlands in Pennsylvania can keep pace with projected rates of sea level rise. But that finding does not address erosion of wetlands at their seaward boundary. Even though wetlands can keep vertical pace with the rising water level, narrow fringing wetlands along rivers can be eliminated by shoreline armoring as their seaward boundaries erode and their landward migration is prevented. Moreover, even where the seaward boundary keeps pace, preventing an expansion of wetlands might be viewed as significant.

Like the shore protection regulations, Pennsylvania's Chapter 105 floodplains regulations consider only existing floodplains, not the floodplains that would result as the sea rises.

Public Access

Public Access is for recreation is an objective of the Pennsylvania Coastal Zone Management (PA CZM) program. This policy, coupled with ongoing redevelopment trends in Pennsylvania, may tend to ensure that future development includes access along the shore. If the public access is created by setting development back from the shore, it may tend to also make a gradual retreat possible. Even if shores are armored, however, public access need not be eliminated by responses to sea level rise if keeping public access if a policy goal of the authority awarding the permit for shore protection (Titus 1998).

Development and Redevelopment

Industrial, commercial, residential, recreational, wooded, vacant, transportation, and environmental land uses all occupy portions of Pennsylvania's 100-kilometer coast. Generally speaking, however, the Pennsylvania coastal zone is consistently and heavily developed. Only about 18% of the coastal area is classified as undeveloped (DVRPC, 2000). Much of the shoreline was filled or modified with bulkheads, docks, wharfs, piers, riprap shorelines, and other hard structures over the past two centuries (DVRPC, 2000). The existing armoring enhances the vulnerability of remaining environmentally valuable areas with natural shorelines such as mudflats and tidal wetlands.

The Pennsylvania coast is moving from an industrial to a post-industrial landscape. Historically, the river's edge was a favorable location for the region's extensive manufacturing and industrial enterprises. The coastal zone is still dominated by manufacturing and industrial land uses, but a steady decline in the industrial economy over the past 60 years has led to the abandonment of many industrial and manufacturing facilities. Some of these facilities sit empty and idle; others have been adapted for uses that are not water dependent.

A majority of the Delaware River shore is classified as developed, but sizable expanses, especially near the water, are blighted and stressed (DVRPC, 2003). Because of the decaying industrial base, many residential areas along the Delaware River have depressed property values, declining population, high vacancy rates, physical deterioration, and high levels of poverty and crime (DVRPC, 2003). These trends are part of a larger regional pattern of sprawl, disinvestment in older communities, and urban decline. Many—perhaps most—of the refineries, chemical processing plants, and other manufacturing facilities that operate profitably today may close in the next 50 to 100 years as the U.S. economy continues to shift away from a manufacturing and industrial base. Regardless of whether the manufacturing decline continues at its current pace, the coastal area has passed its industrial prime and many facilities have long since been abandoned (PDEP, 2006).

New paradigms of waterfront development have emerged that offer fresh visions for southeastern Pennsylvania's waterfront. In late 2001, Philadelphia released the Comprehensive Redevelopment Plan for the North Delaware Riverfront—a 25-year redevelopment vision for a distressed 10-mile stretch of waterfront led by the design firm Field Operations. Delaware County, meanwhile, developed its Coastal Zone Compendium of Waterfront Provisions (1998) to guide revitalization efforts along its coast. Likewise, Bucks County just finished a national search for a design firm to create a comprehensive plan outlining the revitalization of its waterfront. Meanwhile, the Schuylkill River Development Corporation produced the Tidal Schuylkill River Master Plan.

All of these plans and visions share common elements. They view the region's waterfronts as valuable public amenities that can be capitalized on, and they view the estuary as something for the region to embrace, not to turn its back on. They emphasize public access along the water's edge, the creation of greenways and trails, open spaces, and the restoration of natural shorelines and wetlands where appropriate. Revitalization strategies also aim to take advantage of the quality of life benefits to be had from public access and an attractive, ecologically healthy waterfront by constructing vibrant, mixed-use communities within the coastal zone (DRCC, 2006).

D.2.2.2 Responses to Sea Level Rise

Pennsylvania

The greatest opportunity to plan for sea-level rise in Pennsylvania may lie in the ongoing redevelopment of the industrial areas along the Delaware River and other navigable waters. State and local government has the opportunity to decide whether the public will have access, and whether wetlands, beaches, and mudflats will be restored or eliminated as sea level rises.

Given the transitional state of Pennsylvania's coastal area and the visions that have been proposed, much of what is along the shore today will probably not be there in 50 or 100 years. Although these areas will generally be developed, the reintroduction of public access, natural shorelines, and open spaces along the water's edge will be a key element of revitalization efforts (PDEP, 2006). Redevelopment may not be designed to allow ecosystems to migrate inland, but in some cases the redevelopment may be landward of today's shore, preserving public access, natural shores, and an opportunity for a limited landward migration of intertidal shores.

In Delaware County,[98] the John Heinz National Wildlife Refuge, which is separated from the river by Philadelphia International Airport, is the largest protected, intact tidal wetland ecosystem in the Pennsylvania coastal zone[99]. Little Tinicum Island, which is

98 A small part of this refuge is in Philadelphia.
99 The remainder of Delaware County's coastal wetlands mostly consists of smaller tidal wetlands along the river's shore and some larger nontidal wetlands in and around the Philadelphia airport.

located in the river channel across from the airport, is publicly owned and surrounded by mudflats or sandy beaches on all sides.

In Bucks County, a portion of Neshaminy State Park up the Neshaminy Creek away from the river contains forested wetlands and is managed by the state for conservation purposes. The Nature Conservancy owns or leases approximately 18 acres of marshy ground just to the southwest of Bristol Borough (TNC, undated). The Nature Conservancy has an explicit policy of allowing wetlands to migrate inland.

New Jersey

The State Plan contemplates a substantial degree of agricultural and environmental preservation along the Delaware River and its tidal tributaries in Salem and lower Gloucester County. An agricultural easement program in Gloucester County is reinforcing that expectation. Although farmers in the past built dikes for agriculture, regulatory authorities may not allow any new dikes. In this case, wetlands may be able to migrate inland along parts of the Salem and Gloucester shores as sea level rises.

BOX D.4: The Gibbstown Levee

The Gibbstown Levee once served a function similar to the dikes in Cumberland County, preventing tidal inundation and lowering the water table to a level below mean sea level. When the dike was built 300 years ago (USACE, undated), the tides were 3 feet lower and the combination dike and tide gate kept the water levels low enough to permit cultivation. But rising sea level and land subsidence have left this land barely above low tide, and many lands drain too slowly to completely drain during low tide. Hence, farmland has converted to nontidal wetland.

By keeping the creek a meter or so lower than it would be if it rose and fell with the tides, the levee improves drainage during rainstorms for Greenwich Township. Nevertheless, it is less effective today than when the sea was 50–100 centimeters lower. During extreme rainfall, the area can flood fairly easily because the tide gates have to be closed most of the day. Heavy rain during a storm surge is even more problematic because for practical purposes there is no low tide to afford the opportunity to get normal drainage by opening the tide gate. Evacuations were necessary during hurricane Floyd when part of this dike collapsed as a storm tide brought water levels of more than 10 feet above mean low water (NCDC, 1999).

Officials in Greenwich Township are concerned that the dikes in Gloucester County are in danger of failing. “The Gibbstown Levee was repaired in many places in 1962 by the Corps of Engineers under Public Law 84-99.”(USACOE, 2004) Part of the problem appears to be that most of these dikes are the responsibility of meadow companies originally chartered in colonial times. These companies were authorized to create productive agricultural lands from tidal marshes. Although harvests of salt hay once yielded more than enough revenue to maintain the dikes, this type of farming became less profitable during the first half of the 20th century. Moreover, as sea level has continued to rise, the land protected by the dikes has mostly reverted to marsh. Revenues from these lands, if any, are insufficient to cover the cost of maintaining the dikes (DiMuzio, 2006). As a result, the dikes are deteriorating, leading officials to fear a possible catastrophic dike failure during storm, or an increase in flood insurance rates (DELO, 2006).The officials hope to obtain federal funding (DELO, 2006).

Even if these dikes and their associated tide gates are fortified, the dry land will gradually be submerged unless pumping facilities are installed, because much of the area is barely above low tide even today. Although freshwater marshes in general seem likely to be able to keep pace with rising sea level, wetlands behind dikes do not always fare as well as those exposed to normal tidal currents. Over longer periods of time, increases in salinity of the Delaware River resulting from rising sea level and reduced river flows during droughts could enable saltwater to invade these fresh marshes, which would convert them to open water ponds.

Pumping facilities may not be sufficient for a daily pumping of all the very low lands protected by the dikes. Rather, the primary impact of the dikes would be to prevent flooding from storm surges and ordinary tides. For the isolated settlements along Marsh Dike Road and elsewhere, elevating homes and land surfaces may be cost-effective; although property values are less than along the barrier islands, sources for fill material are closer. Gibbstown, Bridgetown, and other more populated communities could be encircled with a ring dike with a pumping system that drains only the densely developed area; or they too may find it cost-effective to elevate land as the sea rises.

The industrial northeastern half of Gloucester County’s riverfront and almost all of Camden and Burlington’s riverfront are on high ground, generally more than 5 feet above the tides. In the industrial and commercial areas, most of the shoreline there is already bulkheaded, to provide the vertical shore that facilitates docking — but the effect is also to stop coastal erosion. The eventual fate of existing dikes, which protect lightly developed areas, is unclear (see Box D.4 on the Gibbstown Levee).

D.3 POPULATION OF LANDS CLOSE TO SEA LEVEL

Table D.3 provides the likely range for the population of lands close to sea level for each of the counties along the Delaware Estuary. Philadelphia provided the best elevation data, and hence the uncertainty range is least. The table suggests that between 1000 and 3500 people live on land within 50 cm above spring high water. Approximately 600 people live in Census blocks that are entirely within 1 meter above the tides.

Several shorefront communities along the Delaware side of the estuary include populations living close to sea level. The results for Cape May and Sussex County largely reflect the population of land along the Atlantic Ocean and associated coastal bays, rather than Delaware Bay. The elevation data was too coarse to identify population within 50 cm above spring high water in New Jersey, but a few thousand people live on land within 2 meters above the tides in Salem and Gloucester counties in such towns as Pennville and Gibbstown.

Table D.3 Population of lands close to sea level: Delaware Estuary.

	Low and high estimates of population below a given elevation (thousands)					
	50cm		**1m**		**2m**	
County	**Low**	**High**	**Low**	**High**	**Low**	**High**
Delaware						
Kent[1]	*	*	*	*	*	*
New Castle	0.2	4.1	0.2	7.4	2.3	12.3
Sussex[2]	1.1	7.2	1.1	9.5	7.1	17.0
New Jersey						
Burlington[3]	0.0	23.7	0.0	27.6	2.6	46.2
Cape May[3]	2.1	30.5	17.3	44.2	38.9	56.9
Cumberland	0.0	3.0	0.0	3.6	0.4	6.6
Gloucester[1]	0.0	11.9	0.0	15.1	2.1	18.2
Salem	0.0	15.3	0.0	19.7	9.3	26.5
Pennsylvania						
Bucks	0.0	4.8	0.0	6.4	0.0	18.4
Delaware	0.0	12.9	0.0	13.4	1.7	15.6
Philadelphia	1.0	3.5	2.9	7.3	9.4	16.4
Total	**4.4**	**117.0**	**21.6**	**154.1**	**73.8**	**234.1**

* Data unavailable.
[1] Figures are for the entire county. County is split between Chesapeake and Delaware Bay Watersheds.
[2] Figures are for the entire county. County is split between Chesapeake, Atlantic Coast, and Delaware Bay Watersheds.
[3] Figures are for the entire county. County is split between Delaware River and New Jersey Shore Watersheds.

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