



SEA LEVEL RISE IMPACTS

IN THE DELAWARE ESTUARY OF PENNSYLVANIA

PREPARED FOR:

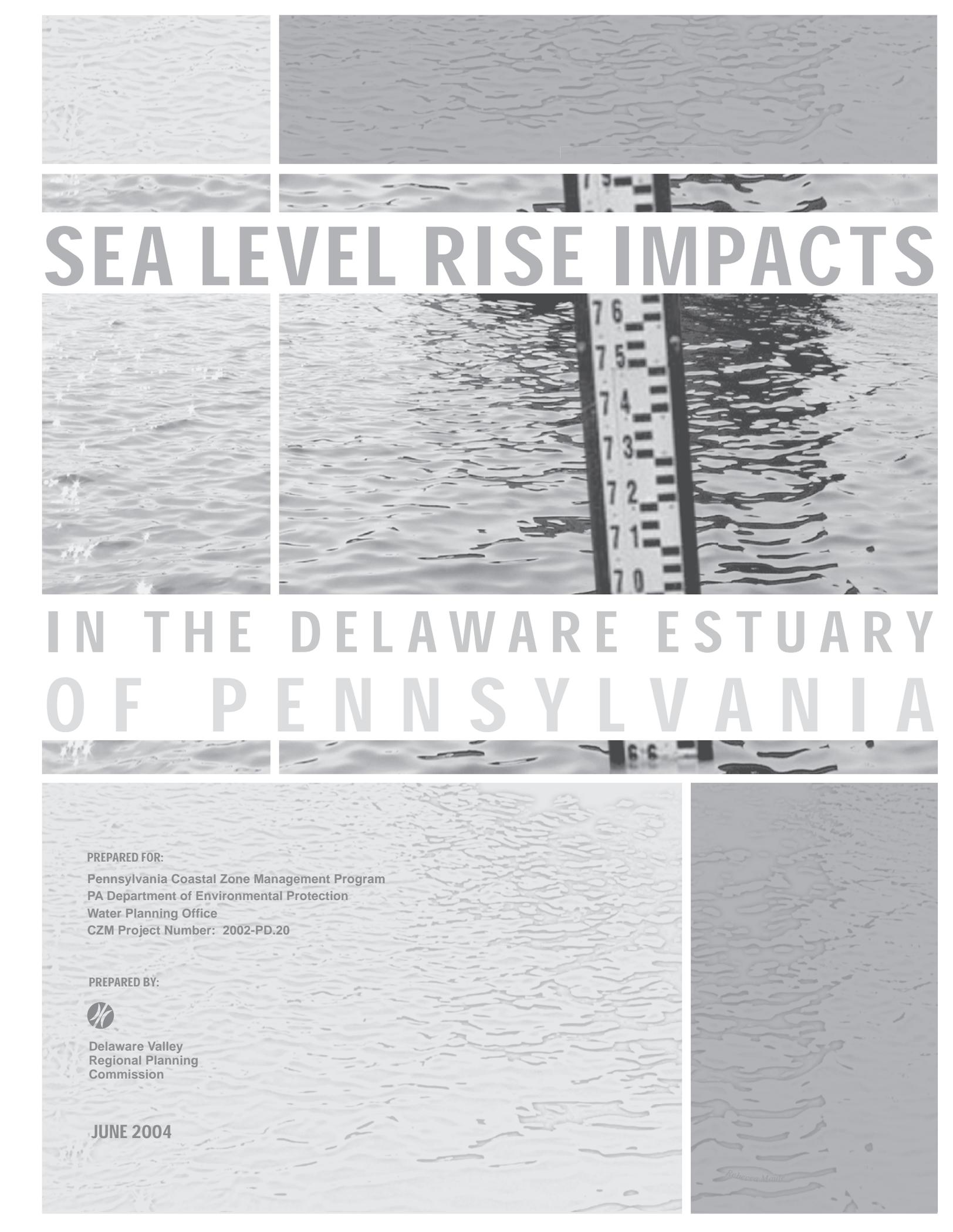
Pennsylvania Coastal Zone Management Program
PA Department of Environmental Protection
Water Planning Office
CZM Project Number: 2002-PD.20

PREPARED BY:



Delaware Valley
Regional Planning
Commission

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Rebecca Mault

Created in 1965, the Delaware Valley Regional Planning Commission (DVRPC) is an interstate, intercounty and intercity agency that provides continuing, comprehensive and coordinated planning to shape a vision for the future growth of the Delaware Valley region. The region includes Bucks, Chester, Delaware, and Montgomery counties, as well as the City of Philadelphia, in Pennsylvania; and Burlington, Camden, Gloucester and Mercer counties in New Jersey. DVRPC provides technical assistance and services; conducts high priority studies that respond to the requests and demands of member state and local governments; fosters cooperation among various constituents to forge a consensus on diverse regional issues; determines and meets the needs of the private sector; and practices public outreach efforts to promote two-way communication and public awareness of regional issues and the Commission.



Our logo is adapted from the official DVRPC seal, and is designed as a stylized image of the Delaware Valley. The outer ring symbolizes the region as a whole, while the diagonal bar signifies the Delaware River. The two adjoining crescents represent the Commonwealth of Pennsylvania and the State of New Jersey.

This project was financed, in part, through a Federal Coastal Zone Management Grant, administered by the Pennsylvania Department of Environmental Protection (DEP). Funding was also provided by the National Oceanic and Atmospheric Administration (NOAA), United States Department of Commerce under Award Number: **NA17OZ2349**. The views expressed herein are those of the author(s) and do not necessarily reflect those of the U.S. Department of Commerce, NOAA, the PA DEP nor any of their sub-agencies.



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INTRODUCTION

This study supplements work performed by the Delaware Valley Regional Planning Commission (DVRPC) investigating anticipated responses to sea level rise in the Delaware Estuary of Pennsylvania (Linn 2004). That study, sponsored by the U.S. Environmental Protection Agency, attempts to distinguish areas likely to be protected from erosion and inundation as seas rise from areas where shores will be left to retreat naturally. The study also considers the impacts of sea level rise on future waterfront development plans and efforts to enhance public access to the coastal zone in the Delaware Valley. The impacts of sea level rise on the ecological resources of the Pennsylvania Delaware Estuary—and policies now in place to protect those resources—are also examined by the study. The Pennsylvania Coastal Zone Management (PA CZM) program, which seeks to protect and enhance the natural resources of Pennsylvania’s coastal zones and create a synergistic relationship between environmental protection and economic and community well-being, sponsored this effort to examine some of these same issues in more detail as well as others not directly addressed by the EPA funded study. This study will examine the potential impacts of sea level rise on five critical PA CZM focus areas: (1) wetlands; (2) salinity; (3) water quality; (4) public access; and (5) hazardous waste sites.

The study area for this analysis is the same as that used for the EPA-funded study, which includes all land below the USGS 20-foot (1929 NGVD) contour. This region is roughly equivalent to the CZM program boundary, but not identical. We chose to use the 20-foot contour as the boundary for this study because low elevation lands are most likely to be impacted by rising seas. The Pennsylvania coastal zone study area, as defined by the 20-foot contour, is approximately 180 km² and contains 58 km² of open water. The study area is comprised of portions of Delaware, Bucks and Philadelphia counties, including portions of nineteen municipalities, and the City of Philadelphia. **Map 1** depicts the study area extent along with the CZM program boundary.

Sea Level Rise in the Delaware Estuary

During the past century, global sea level rose about 15 cm (six inches). Sea level along the shores of the Delaware Estuary rose about 30 cm (one foot) during the same period due to both globally rising seas and subsidence in the Mid-Atlantic region. The International Panel on Climate Change predicts that global sea level will rise by as much as 90 centimeters (three feet) during the twenty-first century. Presumably, the local rise in this area will continue to be approximately 1.5 mm/yr greater than the global average due to land subsidence in the Mid-Atlantic region.

Forecasting beyond 2100 is more difficult due to uncertainties about the continuing build up of greenhouse gases in the atmosphere and the many uncertainties related to the behavior of glaciers; but assuming “business-as-usual” conditions, sea level will continue to rise, and if polar ice sheets begin to disintegrate, the rate at which seas

are rising will accelerate more rapidly. Accordingly, a rise of up to three meters (ten feet) in the next 200 years is a distinct possibility, and a larger rise cannot be ruled out.

For the purpose of examining the impacts of sea level rise, it is important to understand that Pennsylvania's coast is influenced by relatively large tidal fluctuations. The tide range in the Delaware River and Bay ranges from 1.8 to 2.4 meters. Since "sea level" on USGS topographic maps—which is measured relative to the National Geodetic Vertical Datum of 1929—is 0.4 m below the mean tide level in the Delaware River, a tide range of 2 meters means that most lands up to an elevation of 1.4 meters are already submerged at mean spring high water. These are Pennsylvania's tidal wetlands (see **Figure 1**). The estuary's tide range also means that a 1.6 meter sea level rise would inundate all lands below the USGS 10-foot contour (3 meters) at high tide, assuming that no measures to hold back the sea are implemented.

Compared to many other coastal states, Pennsylvania has a relatively small amount of extremely low-lying land: six square kilometers of land (mostly tidal wetlands) lie below 1.5 meters and an additional seven square kilometers of nontidal wetlands and 25 square kilometers of dry land lie between 1.5 and 2.5 meters. Florida, by contrast, has more than 12,000 square kilometers of land below 1.5 meters in elevation (Titus and Richman 2001). Thus, with forecasts indicating a sea level rise of about one meter in the next 100 to 150 years, rising seas threaten to inundate a relatively small portion of Pennsylvania's coastal counties during the next century. However, the impacts of sea level rise go beyond inundation to include increased erosion, increased flooding, and the migration of the salt line further up tidal rivers and streams. Also, since the state has a large amount of heavily developed land below six meters (20 feet) in elevation, sea level rise poses a particularly serious long-term threat for Pennsylvania.

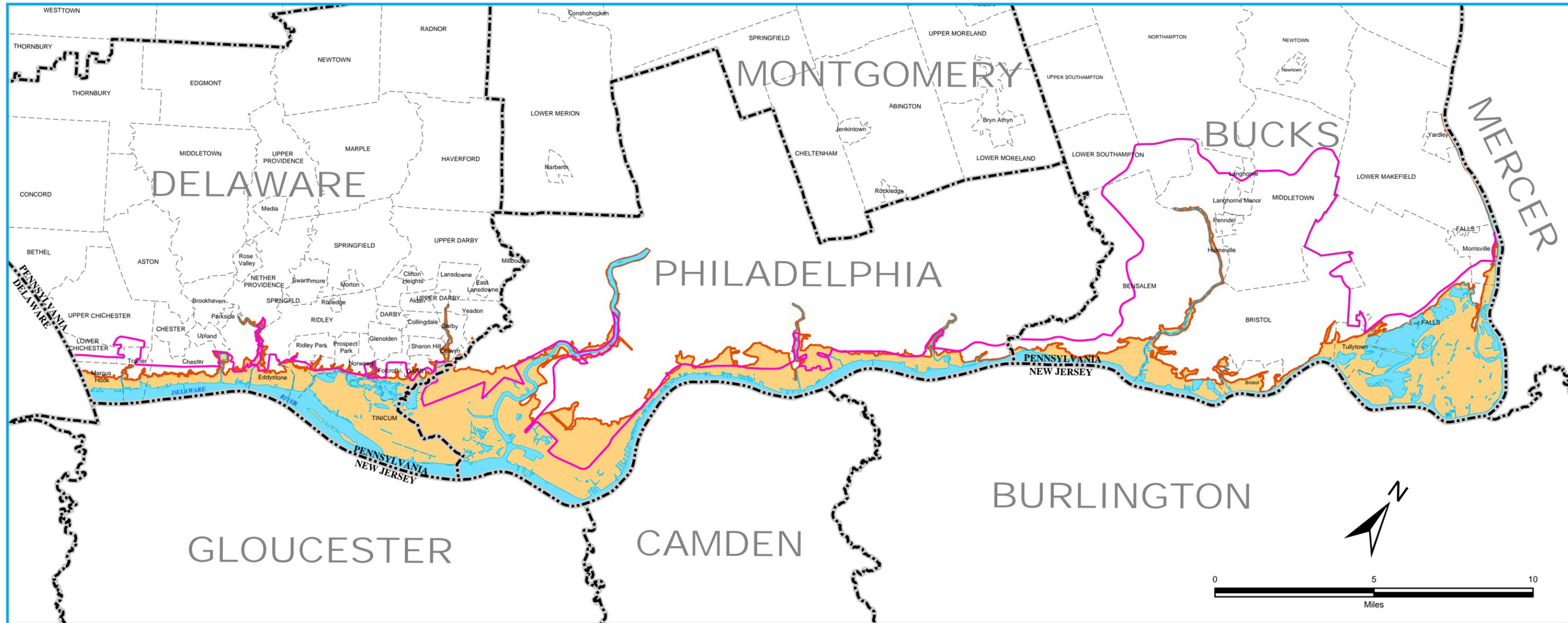
CZM Sea Level Rise Study

MAP 1: Delaware Estuary Coastal Zone Study Area

- Open Water
- Pennsylvania Coastal Zone Study Area
- 20-Foot Contour / Study Area Boundary
- Coastal Zone Management Boundary



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WETLANDS

Preserving, protecting, and, where possible, enhancing or restoring, tidal and nontidal coastal wetlands are key policies of the Pennsylvania CZM program. This section will assess the potential impacts of future sea level rise on wetlands in the Pennsylvania Delaware Estuary coastal zone.

In most wetland inventories, “tidal wetlands” are synonymous with “coastal wetlands.” Moreover, most coastal wetlands are saltwater wetlands. However, in Pennsylvania’s Delaware Estuary, most tidal wetlands are freshwater. For this study the term “coastal wetlands” will refer to all wetlands within the study area, including both tidal and nontidal, as well as saltwater and freshwater wetlands. The terms “tidal” and “nontidal” will be used specifically to differentiate between these two types of wetlands.

Wetlands, which are relatively abundant along the entire Atlantic and Gulf coasts of the United States, are a critical ecological resource; supporting both terrestrial and aquatic animals and boasting biological productivities far greater than those found on dry land. Wetlands also play a vital role in maintaining water quality by cleaning ground and surface water. The ecological importance of wetlands, however, has not always been appreciated. For over three centuries, people drained and filled marshes and swamps to create dry land for agriculture and urban development. Dams and navigation channels have prevented fresh water, nutrients, and sediment from reaching wetlands, resulting in their conversion to open water. Marshes have often been used as city dumps and as disposal sites for hazardous wastes and channel dredging. As a result, nationwide coastal and noncoastal wetlands decreased from approximately 221 million acres at the beginning of European settlement to about 105 million acres by the late 1980s (Dahl 1990).

In the 1960s, an important shift occurred in the way the public, and consequently the Federal Government, viewed wetland ecosystems. In 1972, the U.S. Congress added Section 404 to the federal Clean Water Act, which strengthened the requirement that anyone wishing to fill a tidal coastal wetland obtain a permit from the Army Corps of Engineers, and added the requirement of approval by the Environmental Protection Agency. Several coastal states subsequently enacted legislation to sharply curtail destruction of coastal wetlands. In the decade following the passage of Section 404, tidal coastal wetland loss declined from 1000 to 20 acres per year in Maryland, from 3100 to 50 acres per year in New Jersey, and from 444 to 20 acres per year in Delaware (Titus 1988).

The history of wetlands in Pennsylvania’s Delaware Estuary has followed national trends. Although historical data is not available to quantitatively chronicle coastal wetland loss in Pennsylvania over time, the shoreline of the estuary has been filled, extended seaward and bulkheaded many times over to accommodate industry,

commercial development, housing, port related activities and navigation.¹ Coastal wetlands have also been preferred locations for landfills, hazardous waste disposal, and the deposition of dredge spoils. As of 2002, southeastern Pennsylvania had 1,466 acres of tidal wetlands. Nontidal wetlands within the project study area, i.e., the “coastal zone”, totaled 1,664 acres.² Tidal and nontidal wetlands currently occupy approximately 7% of the land and water surface of the study area. **Maps 2-A through 2-C** depict the spatial extent of coastal wetlands within the study area.

Wetland Loss and Sea Level Rise

Although the nationwide and local loss of coastal wetlands due to draining, dredging, filling, and leveling has slowed drastically over the past three decades, during the next century, conversion of tidal coastal wetlands to open water due to sea level rise will become a serious threat to the nation’s coastal wetland ecosystems. Most tidal wetlands lie less than one meter above sea level. Accordingly, a one-meter rise in sea level could eliminate a sizable portion of our tidal coastal wetlands. However, such a rise does not mean that tidal wetlands would disappear entirely. Two compensating factors will work to offset the loss of tidal wetlands: (1) a rise in sea level would flood areas that are now dry land, creating new wetlands; and (2) wetlands can grow upward by accumulating sediment and organic material, a process known as wetland accretion.

While these processes will create new wetlands, their potential to stave off tidal coastal wetland loss in Pennsylvania may be limited. Wetland migration along Pennsylvania’s coast will in many cases be blocked by development just inland of existing wetlands. It is unlikely that much of the built-up coast will be readily abandoned to allow wetland migration. As for wetland accretion, while it has kept pace with the amount of sea level rise over the past hundred years (approximately 2.7 mm/yr in the Delaware Estuary), it is not likely to keep pace with the accelerated rate expected during the next century, which could easily be as high as 1 cm per year in the Mid-Atlantic region (Armentano et al. 1988).

Natural Impacts of Sea Level Rise on Wetlands

Tidal wetlands extend seaward to roughly the elevation that is flooded at mean tide, and landward to roughly the area that is flooded by spring tide (the highest astronomical tide every 15 days). As stated above, because the Delaware Estuary has a tide range of roughly two meters and because NGVD sea level is approximately 0.4 meters below the mean tide in the Delaware Estuary, tidal wetlands occupy elevations between 0.4 meters and 1.4 meters above NGVD sea level. See **Figure 1: Tides and Wetlands in the Delaware Estuary**. For purposes of description, this wetland zone is

¹ Because most of Pennsylvania’s tidal wetlands are freshwater tidal wetlands, not saltwater, they have historically been grouped with nontidal wetlands in statewide inventories, and their loss over time cannot be documented separate from nontidal wetlands.

² Acreage figures are from the *Pennsylvania Coastal Zone Wetlands Status Report*, Pennsylvania Department of Environmental Protection, Coastal Zone Management Program, 2002.

then divided into “low marsh” and “high marsh”. Tidal wetlands flooded once or twice daily support low marsh vegetation, while areas flooded less frequently support high marsh species. Transition “wetlands” (which are not technically wetlands) can be found above the high marsh, in areas flooded less frequently than twice a month.

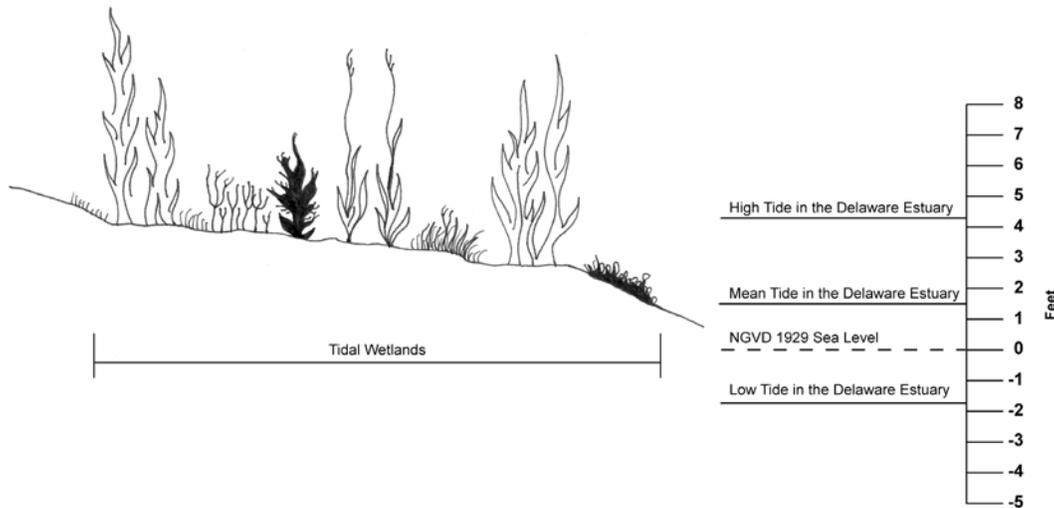


Figure 1. Tides and Wetlands in the Delaware Estuary

The natural impact of a rising sea is to cause tidal wetlands (marsh) to migrate upward and inland. As sea level rise increases the frequency and/or duration of tidal flooding throughout a wetland, the low marsh gradually becomes open water; portions of the high marsh become low marsh; and upland areas immediately above the former spring tide level (transition wetlands), become high marsh. The rate at which this occurs depends upon both local topography and the rate of wetland accretion. Ignoring wetland accretion for now, the net change in total marsh acreage depends upon the slope of the marsh and the adjacent upland area. If the land has a constant slope throughout the marsh and upland, then the area lost to marsh drowning will be equal to the area gained by the landward encroachment of spring high tides. In most areas, however, the slope above the marsh is steeper than the marsh; so a rise in sea level causes a net loss of marsh acreage.

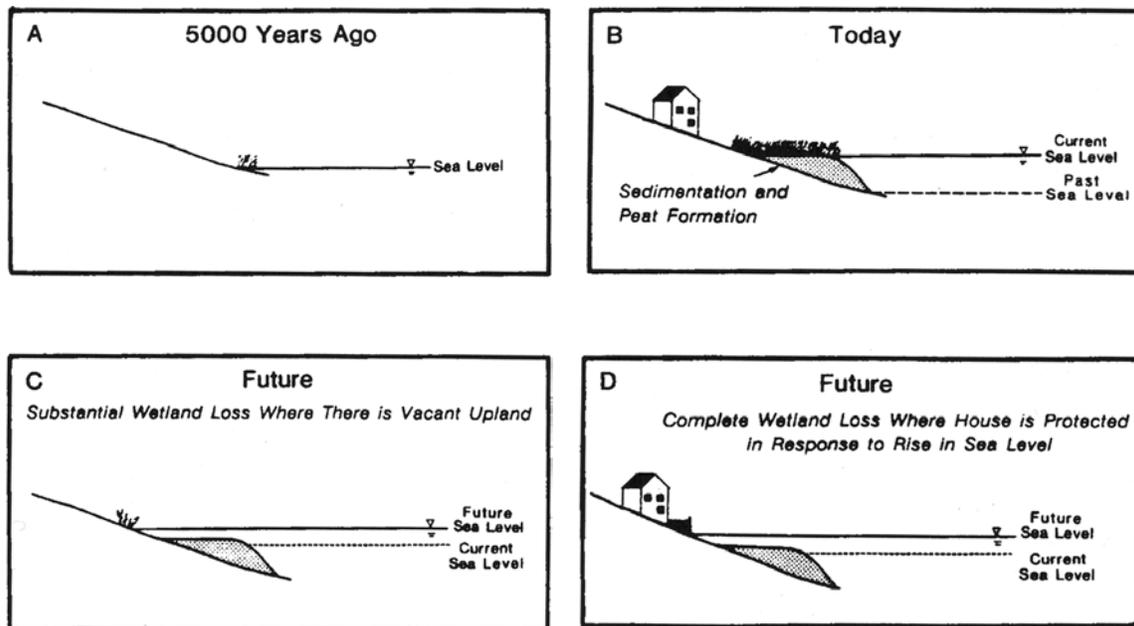
Figure 2: Impact of Sea Level Rise on a Marsh illustrates why there is so much more land at marsh elevation than just above the marsh and why the slope above the marsh is steeper than the marsh. Wetlands can grow upward fast enough to keep pace with the slow rise in sea level that most areas have experienced in the past. Thus, areas that might have been covered with two or three meters of water (or more) have wetlands instead (**Figures 2-A, 2-B**). This is also the reason why the existing marsh profile is relatively flat when compared to adjacent upland areas. If sea level rise accelerates only slightly over the current rate, tidal wetlands may have sufficient sediment to keep pace with sea level, and absent human interference, the total wetland area will actually grow. However, if the rate of rise in the Delaware Estuary increases from its current rate of

approximately 3 mm per year to 10 mm per year, the sea will be rising much more rapidly than the demonstrated ability of wetlands to grow upward in most areas (Armentano et al, 1988). Such a rapid rise coupled with a comparatively steeper upland profile along most of Pennsylvania's coast, will negate the increase in wetland acreage of the last few thousand years (**Figure 2-C**).

Human Interference with Nature's Response to Sea Level Rise

The presence of development in upland areas will in many cases prevent wetland migration. Seawalls, bulkheads and other forms of shoreline armoring, built to protect existing and future development, will block wetland migration, substantially increasing the loss of wetlands beyond what would occur naturally (**Figure 2-D**). In the Delaware Estuary, the impacts could be so severe that all tidal coastal wetlands may be lost.

Although environmental regulations in Pennsylvania generally prevent or discourage people from filling in or building on wetlands, they have not prevented people from building structures, and protecting those structures, just inland of wetlands. As the final box in **Figure 2** shows, wetlands can be completely squeezed out between an advancing sea and bulkheads erected inland of existing wetlands. Because the Pennsylvania coastal zone is heavily developed, wetlands in this region will have few opportunities for inland migration, barring changes in future development patterns.

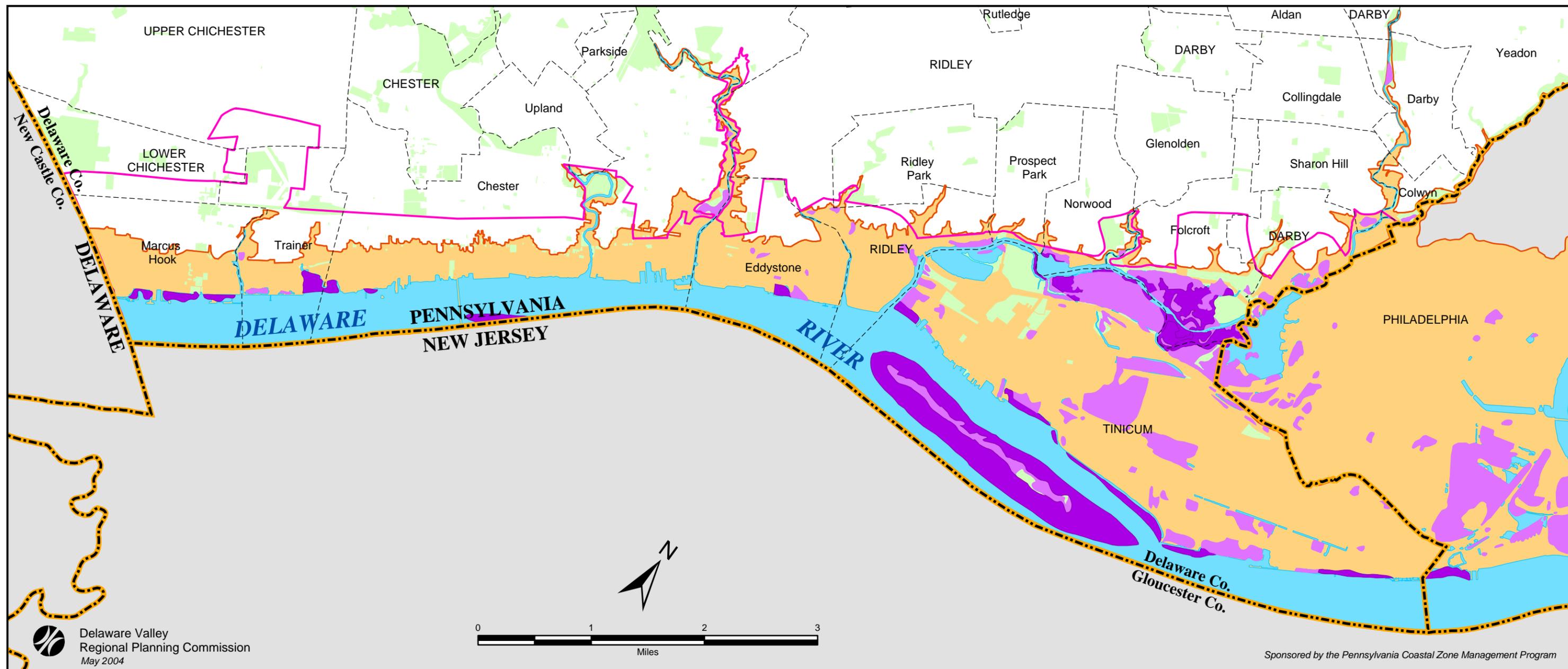


Source: Titus (1988)

Figure 2. Impact of Sea Level Rise on a Marsh

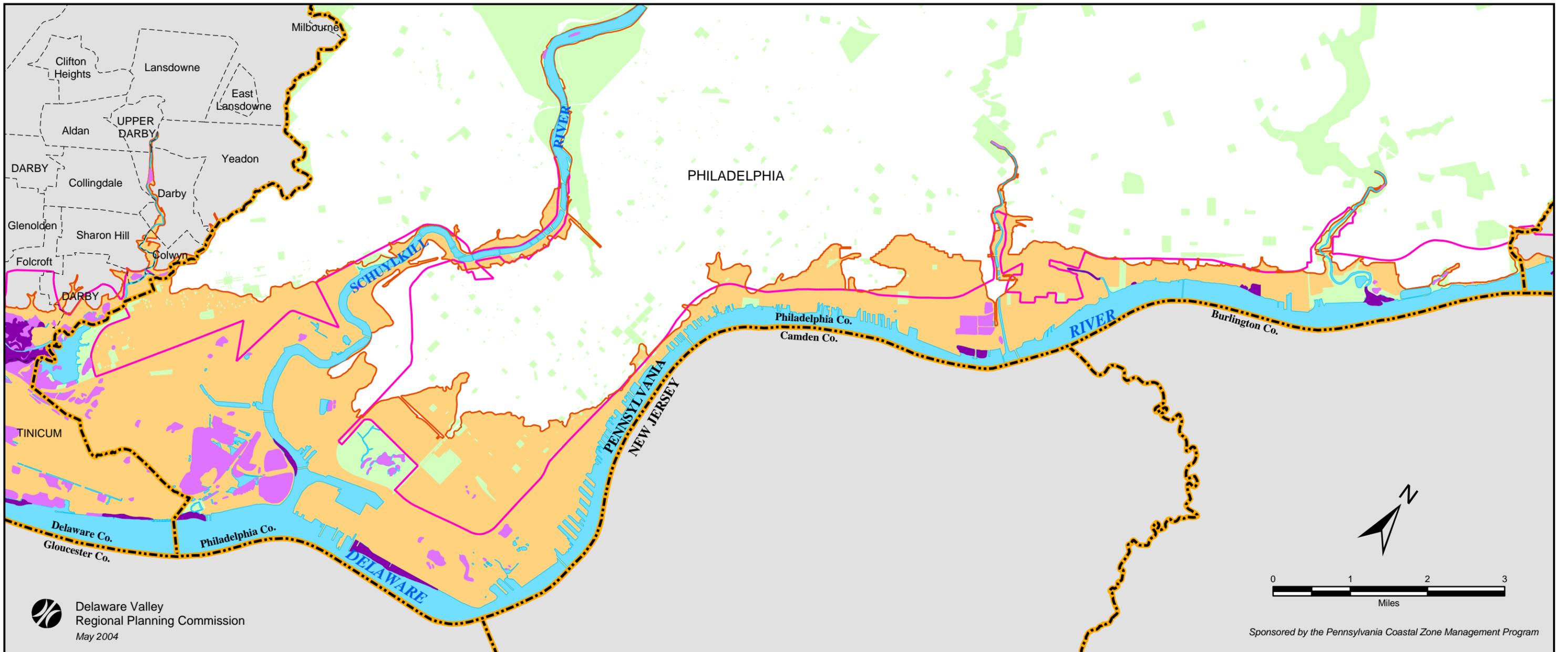
MAP 2-A DELAWARE COUNTY COASTAL WETLANDS

- Tidal Wetlands
- Non-tidal Wetlands
- Protected Open Space
- Coastal Zone Study Area
- Coastal Zone Management Boundary



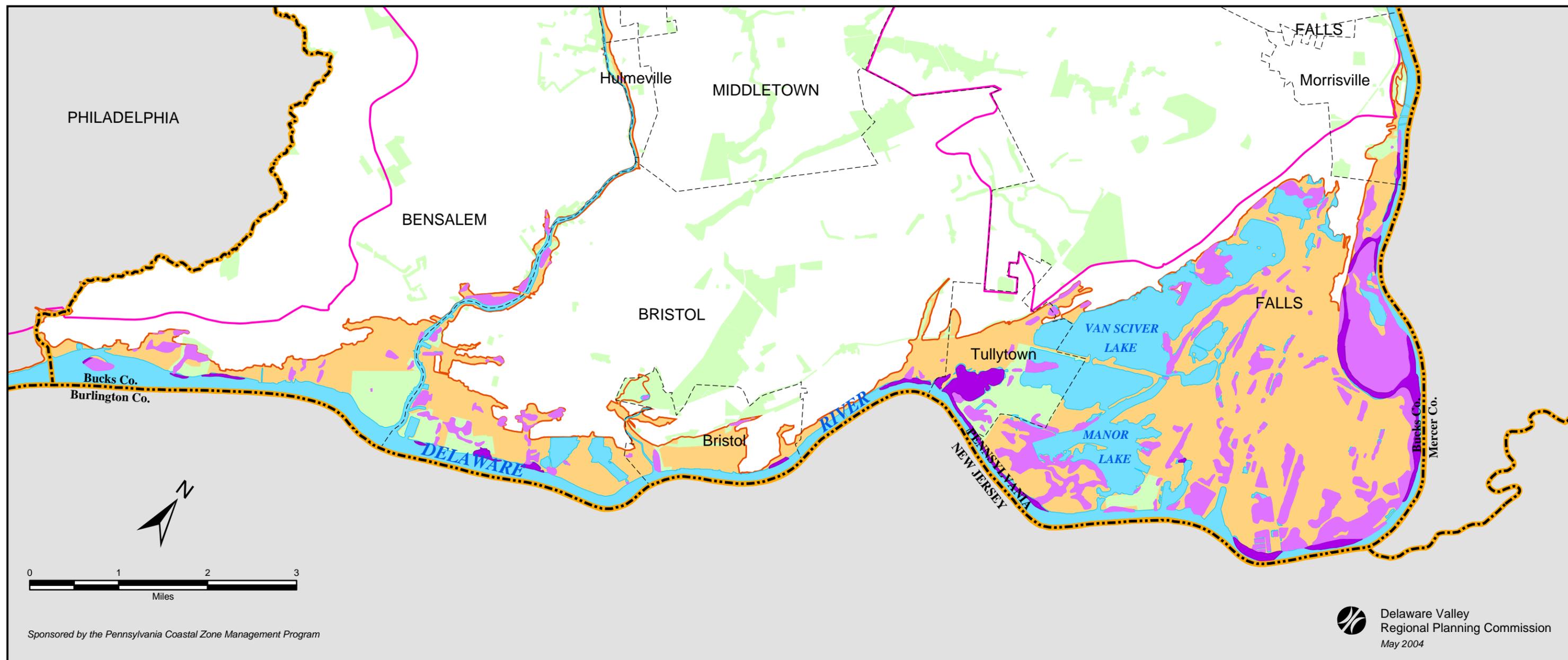
MAP 2-B PHILADELPHIA COUNTY COASTAL WETLANDS

- Tidal Wetlands
- Non-tidal Wetlands
- Protected Open Space
- Coastal Zone Study Area
- Coastal Zone Management Boundary



MAP 2-C BUCKS COUNTY COASTAL WETLANDS

- Tidal Wetlands
- Non-tidal Wetlands
- Protected Open Space
- Coastal Zone Study Area
- Coastal Zone Management Boundary



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The point at which development will prevent new wetlands from forming depends on the extent to which development is set back from tidal coastal wetlands. Along much of Pennsylvania's coast, there is little separation between existing development and tidal wetlands. In Maryland, by contrast, the Chesapeake Bay Critical Areas Act forbids most new development within 1,000 feet of existing tidal wetlands in order to enable some degree of wetland migration. Pennsylvania has no such law, and existing development is in many cases much closer than 1,000 feet away from tidal wetlands areas.

Wetland Loss in the Delaware Estuary as a Result of Sea Level Rise

Studies have been performed to estimate the effects of sea level rise on tidal coastal wetlands in Charleston, South Carolina and Tuckerton, New Jersey (Kana et al. 1988). The researchers who conducted the study surveyed those areas and developed average cross-sections for each region. Using the average cross-section and a representative rate of wetland accretion, Kana et al. estimated net wetland losses by 2075 for both an 87 cm (low scenario) and 159 cm (high scenario) sea level rise. For both sites, their study assumed an annual average wetland accretion rate of 5 mm.³ For the Charleston site the study also calculated the combined impacts of sea level rise and future development on wetland loss.

In New Jersey, 4% and 82% of coastal wetland acreage would be lost with the low- and high-rise scenarios respectively. The small loss in the low scenario is due to the fact that most of the wetlands in the New Jersey study area are high marsh. Accordingly, the low scenario simply resulted in the conversion of high marsh to low marsh, without converting much wetland acreage to open water.

In the Charleston study, the low- and high-rise scenarios eliminate 49% and 80% of the wetland area respectively. That study also considered the combined impacts of development and sea level rise. Since development in Charleston is prohibited in transition wetlands by law (the area extending 75 cm above the high marsh), protecting development in the low-rise scenario would not increase the loss of marsh through 2075 (although it would increase the loss of "transition wetlands"). For the high scenario, however, protecting development with bulkheads, dikes and other forms of shoreline armoring would result in a 90% loss of wetlands, a significant increase over the "no protection" scenario.

Creating detailed estimates of wetland loss in the Delaware Estuary will require studies similar to the ones performed by Kana et al. in New Jersey and South Carolina. To date, no such studies have been performed. However, nationwide estimates by region for wetland losses as a result of sea level rise have been developed. These estimates shed some light on the fate of Pennsylvania's coastal wetlands. According to conclusions drawn by Titus (1988) based on modeling work done by Armentano et al. (1988), the

³ Actual wetland accretion rates can vary widely from site to site. The U.S. Geological Service (USGS) is now studying wetland accretion at 12 sites along the Atlantic and Gulf coasts to obtain a better understanding of wetland accretion processes and rates. See http://www.nrel.colostate.edu/brd_global_change/proj_43_wetland_elev.html.

Mid-Atlantic region (CN, NY, NJ, DE, MD, VA) would lose approximately 286,000 out of 733,000 acres of existing tidal coastal wetlands, and would gain 194,000 acres of new wetlands, if sea level rose 87 cm, resulting in a net loss of 92,000 acres. A rise of 159 cm would eliminate all 733,000 acres of existing tidal wetlands and create 108,000 acres of new wetlands, resulting in a net loss of 625,000 acres. The wetland gains in these calculations assume that upland areas are not developed or that development is removed and that wetland accretion rates remain constant. Presumably, the presence of existing or future development in upland areas would result in a higher net loss of wetlands for both scenarios.

Considering that most upland areas in Pennsylvania are developed, the impact of sea level rises similar to those considered by Armentano et al. would likely be at least as severe as those forecasted for the region as a whole. However, the regional numbers cited above are part of a nationwide assessment based on dozens of assumptions. The authors of the study state that their estimates should not be considered as statistically valid estimates of wetland loss for particular U.S. coastal regions. Nevertheless, the estimates support the simple hypothesis that a one to two meter rise in sea level would destroy most existing—and create little new—tidal wetlands in the Delaware Estuary.

The estimates of “coastal wetland” loss made by Armentano et al. and Titus pertain specifically to tidal wetlands. The study area for this project also contains significant nontidal wetland acreage. A one-meter rise in sea level would likely convert many of the nontidal wetlands in the coastal zone to tidal wetlands, followed by a subsequent conversion to open water. However, it is beyond the scope of this study to make accurate predictions regarding the magnitude of such conversions. Forecasting these impacts will require more detailed study based on field observations and accurate topographic data.⁴ Rising seas could also impact tidal and nontidal wetlands by increasing their salinity and converting them from freshwater to saline wetlands. The section on salinity discusses how these changes could impact the estuary’s wetland ecosystems.

Preventing Future Wetland Losses

Future losses of wetlands from sea level rise in the Delaware Estuary could be reduced by (1) slowing the rate of sea level rise by reducing greenhouse gas emissions, (2) enhancing wetlands’ ability to keep pace with sea level rise, (3) decreasing human interference with natural process by which wetlands adapt to sea level rise, or (4) holding back the sea while maintaining coastal wetlands artificially.

Although reducing greenhouse gas emissions to sustainable levels is the most effective way to avoid sea level rise, it is the most difficult to contemplate in the near term. Moreover, even if greenhouse gas emissions were reduced to sustainable levels

⁴ Many coastal states now use Light Detection and Ranging (LIDAR) sensors mounted on aircraft to map shorelines and create detailed, accurate elevation models. Such data could be used to study the potential impacts of sea level rise on nontidal wetlands in the coastal zone. For more information see the NOAA Coastal Services Center at www.csc.noaa.gov/crs/.

immediately, a “lag effect” associated with previous emissions would still cause sea level to rise. A detailed discussion of global climate change science and politics is beyond the scope of this paper, but it is important to remain aware of the root cause of the current acceleration of sea level rise and to remember that it is largely the result of the burning of fossil fuels and the release of greenhouse gases by industrial societies.

Increasing the “growth rate” of wetlands could enable them to survive rising seas. It is possible to enhance the rate of wetland accretion by spraying sediment onto a wetland in a manner that imitates natural flooding. Although this technology has been demonstrated to work in site-specific applications, it is not now, nor will it be in the foreseeable future, cost-effective on large scales.

The primary adaptation of wetlands to rising sea level is landward migration. To allow migration, however, communities must either prevent development of areas upland of existing wetlands, or remove structures at a later date if and when the sea rises. Preventing the development of upland areas would require either purchasing undeveloped land adjacent to coastal marshes or instituting regulations that curtail the right to build on this property. The former option would be costly to taxpayers, while the latter option would be costly to property owners and would face legal challenges that might result in requirements for compensation. Making room for coastal wetland migration may be costly, but it will probably be the most important method for insuring the survival of coastal wetlands as seas rise. With that said, it should be noted that the economics of protecting or purchasing land for wetland migration in Pennsylvania are probably not favorable when compared to other larger, less developed low-lying areas such as those found in southwestern New Jersey or the coastal estuaries of North Carolina.

Finally, it might be possible to hold back the sea and maintain wetlands artificially. For small amounts of sea level rise, tidal gates might be installed that open during low tide but close during high tide, thereby preventing saltwater intrusion and lowering average water levels. For larger rises, levees and pumping systems could be installed to maintain wetland water levels below sea level. Although these measures would be expensive, they would also help to protect developed areas from the sea.

Planning for Wetland Loss in Pennsylvania’s Delaware Estuary

As stated, the most effective way to insure the survival of tidal coastal wetlands is to allow them to migrate inland. While the presence of development in Pennsylvania leads to the conclusion that wetland migration is unlikely along most of Pennsylvania’s coast, the transformation of the region’s waterfronts that is just now beginning offers the opportunity to address wetland loss at an early stage. The transition of the region’s waterfront districts from centers of heavy industry to mixed-use communities that emphasize public access and open areas along the water will complement efforts to create a buffer between development and rising seas. The replacement of abandoned factories and derelict properties with open space areas along the water’s edge would obviate the need for expensive shoreline armoring schemes. Moreover, an un-armored shoreline will

mean that wetlands can migrate inland where conditions are favorable. Of course, wetland migration will need to be balanced with demands for active recreation spaces and continuous public access along the shoreline. Potential future land use changes along the region's waterfronts and their relationship to rising seas are discussed in more detail in the Public Access section.

SALINITY

Salinity in all estuaries ranges from that of seawater (at the mouth) to that of fresh water (near the head of tide). The salinity at a particular point varies over the course of a year, depending primarily on the amount of fresh water flowing into the estuary. The “salt line” or “salt front” is defined as the point where the seven-day chloride concentration averages 250 milligrams per liter. This concentration is based on drinking water quality standards originally established by the U.S. Public Health Service. The salt line migrates naturally depending on rainfall patterns. During periods of drought, the reduction in freshwater flowing down the river causes the salt line to migrate upstream. When rainfall is abundant, the salt line migrates toward the sea. The upstream migration of the salt line increases salinity at water intakes, results in the infiltration of salty water into groundwater supplies and damages freshwater aquatic ecosystems.

Sea level rise will promote the upstream migration of the salt line in the Delaware Estuary, assuming other factors remain constant. In this respect the impact of sea level rise is similar to the impact of reduced flows during a drought. The former increases the saltwater force, whereas the latter decreases the freshwater force. This section will review the impacts of sea level rise on salinity in the Delaware Estuary and the potential policy responses.

Management of Salinity in the Delaware Estuary

The water resources of the Delaware River Basin are under the regulatory control of the Delaware River Basin Commission (DRBC), a regional federal-interstate agency established in 1961 to represent the federal government and the states that share the Basin. DRBC has long considered the implications of droughts on water management and the migration of the salt line. DRBC tracks the levels of both sodium and chloride ions in the estuary. To prevent the damaging effects associated with increased salinity and to protect public health, DRBC also seeks to keep the chloride and sodium concentrations at river mile 98—the DRBC salinity control point—below 180 mg/l and 100 mg/l, respectively. These limits were designed primarily to protect public groundwater supplies pumped from aquifers upstream of mile 98, which have a good hydraulic connection with the estuary. The estuary supplies over one-half of the water entering these aquifers. DRBC has estimated that as long as the river mile 98 objective is met, sodium levels in most wells tapping the aquifers will remain below 50 mg/l, the drinking water standard. Likewise, sodium concentrations at Philadelphia’s Baxter water intake, near Torresdale at river mile 110, will remain below 30 mg/l.

Fresh water flow opposes salt water migrating upstream. The highest saltiness in the estuary occurs during droughts when fresh water flow is low. DRBC keeps salinity from reaching unacceptable levels both by limiting consumptive uses of water and by releasing water from reservoirs during periods of low stream flow. When reservoir

releases are needed for salinity control in the estuary, DRBC directs the U.S. Army Corps of Engineers to release water from impoundments in the Delaware River watershed.

DRBC is responsible for tracking and controlling salinity in the estuary as it migrates in response to changes in freshwater flow. In the mid-1980s DRBC conducted a joint study with EPA to evaluate the impacts of greenhouse warming and changes in sea level on salinity in the Delaware River and adjacent aquifers in New Jersey (Hull and Titus 1986). Although the study is now eighteen years old, it is the only study of its kind that examines the impact of rising seas on salinity in a freshwater estuary.

Impacts of Sea Level Rise on Salinity

In their study, Hull and Titus reasoned that the magnitude of future sea level rise is uncertain. Accordingly, they studied a wide range of rise scenarios so that their results were likely to encompass the actual situation. The range they chose was based on then current EPA sea level rise estimates. They examined the impacts of a 2.4-foot and an 8.2-foot rise over 1965 sea level at Lewes, Delaware. Hull and Titus chose 1965 as their base year because that was the year of DRBC's "drought of record." During the 1965 drought, the seven-day average salt front migrated to river mile 102, its farthest recorded upstream migration. Employing a mathematical model developed by DRBC, Hull and Titus determined how each sea level rise scenarios would impact the salt front given a recurrence of the 1965 drought.

The study determined that a 2.4-foot rise would increase the maximum "thirty-day" average chloride levels at river mile 98, the salinity control point, from approximately 135 mg/l to 305 mg/l. The thirty-day average location of the salt front (250 mg/l) would advance to river mile 100, compared with mile 93 for the 1965 drought. The maximum thirty-day chlorinity for an 8.2-foot rise would increase to approximately 1,560 mg/l at river mile 98 and the thirty-day average salt front would advance to river mile 117, well above Philadelphia's Baxter water intake. The salt front for shorter time spans would migrate some distance beyond the thirty-day average, extending five to ten miles further upriver, as it did in 1965 when the seven-day average salt front reached river mile 102.

Implications

According to Hull and Titus, "a rise in sea level of several feet would substantially exacerbate today's salinity problems in the Delaware Estuary. The upper estuary above the Schuylkill River in Philadelphia, now a source of fresh water for both municipalities and industries, would become too salty for most uses, necessitating a switch to alternative supplies – at great expense." The Baxter water intake would be subject to occasional invasions of sea salts, which would sometimes leave the water unacceptable for the City's many water customers. Industries using fresh water from the upper estuary would find brackish water at their intakes during dry periods. Industries

using brackish water from the middle and lower reaches of the estuary would experience higher salinities than those for which their systems were designed, which would damage pipes, tanks, and machinery, and increase water-treatment costs. In some cases these industries would have to shift permanently to alternative water supplies.

Salinity increases would also impact the natural oyster beds found in the less saline portions of the estuary. These beds are managed by the oyster industry to provide seed oysters for planting in leased growing areas in more seaward, saline areas of the bay. Because of their location in less saline water, the seed-oyster beds provide havens for the young oysters from some of their natural enemies that require higher salinities for survival. Increased salinity in this stretch of the bay would benefit oyster predators and competitors. The oyster beds could shift up the estuary, but shifting the beds upstream would reduce yields both because the estuary is much narrower above the bay and because the beds would be closer to upstream sources of pollution.

The magnitude of salinity increase found in model simulations would also be expected to produce major changes in the ecology of the Delaware Estuary. There would be an up-estuary advance of marine and estuarine species and a retreat of freshwater species. Some species now thriving in the relatively clean waters of the lower estuary would migrate into the more polluted areas of the upper estuary, closer to wastewater outfalls and other hazards. Watercraft now using the freshwater reaches of the upper estuary would be subject to problems caused by marine fouling organisms. These marine organisms could also infest water systems that take water from the tidal river in reaches now free of this problem.

Finally, although not a critical issue for Pennsylvania, saltwater may contaminate southern New Jersey's drinking water aquifers. According to Titus and Hull, these aquifers already face saltwater intrusion issues that will be aggravated by rising salinity. Some aquifers now heavily used would become too salty for drinking water and would have to be abandoned altogether or limited to agricultural and industrial use.

To mitigate future salinity increases, Hull and Titus emphasize two techniques: releasing fresh water from reservoirs and decreasing consumptive water use during droughts. According to Hull and Titus, additional reservoir storage of approximately 110 thousand acre feet could offset the salinity increase caused by a one-foot rise in sea level. The proposed future reservoir storage listed in DRBC's long-range comprehensive plan at the time of the Hull and Titus study was 592 thousand acre-feet. The current DRBC comprehensive plan highlights proposed reservoir projects with a combined long-term storage of 525 thousand acre-feet. However, the status of these projects is listed as "de-authorized" or "inactive" (DRBC 2001). Limiting consumptive water uses during times of low flow has also historically been one of DRBC's tools for combating increased salinity. However, the continual growth of per capita water use and population may limit the long-term ability of conservation measures to reduce consumption from current levels.

Current Status

The work of Hull and Titus demonstrates that rising sea level would increase salinity in the estuary. The magnitude of increase and the resulting migration of the salt front would be significant enough to negatively impact drinking water intakes, industrial process water intakes, groundwater supplies, recreational uses, and the health of aquatic ecosystems. Assuming that sea level rise is unavoidable, these consequences will need to be addressed. However, more study is needed. Newer studies based on the latest sea level rise estimates and more detailed mathematical modeling of changes in the cross-sectional geometry and width of the estuary would provide more up-to-date estimates of the impact of sea level rise on salinity upon which to base future management policies.

Preventing the salt line from migrating beyond its current range during times of drought due to rising seas will require augmenting low river flows and/or reducing consumptive uses. While greater reservoir storage is an obvious means of addressing increased salinity, reservoir construction has fallen out of favor as a dominant water management strategy for the basin, due to a wide range of serious environmental drawbacks associated with reservoirs. Given that (1) there is no single simplistic solution to increased salinity; (2) that solutions to this problem may themselves have environmental repercussions; and (3) that salinity is simultaneously a water supply and a water quality issue, future policies to address salinity will best be formed within the context of the nearly completed *Water Resources Plan for the Delaware River Basin*. The Plan offers an integrated approach for addressing water resource issues in the basin: asserting that “water supply and water quality cannot be managed separately and that ground water and surface water are two aspects of the same resource, separated in time and space, but fundamentally interrelated.” The Plan states that all aspects of “the water resource” should be considered in decision-making, and conversely, that a wide range of decisions—not just those traditionally associated with water management—can affect the water resource. Due to the nature of salinity issues, state and regional agencies should utilize the integrated water resource management framework outlined by the *Water Resources Plan* to anticipate and develop solutions to salinity problems brought on by rising seas.⁵

⁵ A public review draft of the *Water Resource Plan for the Delaware River Basin* was published in January, 2004 and is available at <http://www.state.nj.us/drbc/basinplan.htm>. Public comments on the plan have been solicited and are now under review.

WATER QUALITY

The loss of wetlands and increased salinity will impact water quality in the Delaware Estuary. As concluded in the wetlands section above, a rise in sea level of one to two meters will likely destroy nearly all of the tidal wetlands as well as many of the nontidal wetlands found in Pennsylvania's coastal zone. The destruction of wetlands, which store, cleanse, and purify surface water and stormwater runoff and which provide critical habitat for numerous aquatic and terrestrial species, will adversely affect water quality in the estuary. Rising seas will also lead to an upriver migration of the salt line, which will jeopardize drinking water supplies, threaten aquatic ecosystems, and convert freshwater wetlands to brackish water. At the same time, the inundation, erosion and flooding of former industrial parcels and hazardous waste sites has the potential to wash more pollutants into estuary waters. This section will review these impacts in more detail. Before doing so, however, it will be useful to highlight the potential impacts of climate change more broadly on water quality.

Climate Change and Water Quality

Within the climate change milieu, sea level rise is not typically seen as the most significant threat to water quality. The potential effects of climate change on water quality typically include increased evaporation and lower river flows; more frequent and/or more intense precipitation events; and warmer water temperatures. In areas where river flows decrease due to increased evaporation, pollution concentrations will rise because there will be less water to dilute the pollutants. To keep pollution concentrations in waterways from increasing, sewage treatment plants and other water pollution controls may have to be upgraded—which could cost billions of dollars per year. Increased frequency of severe rainstorms, on the other hand, could increase the amount of pollutants that run off from farms, lawns, and streets into rivers, lakes, and bays.

The amount of dissolved oxygen in the water could also be reduced by climate change, effectively suffocating fish and other aquatic life in some areas. Higher water temperatures decrease the solubility of oxygen in water and hasten the rate at which organic pollutants degrade, thereby creating a "biochemical oxygen demand" (BOD). Lower oxygen solubility and higher BOD will reduce the availability of dissolved oxygen, which is critical to the health of aquatic organisms. One study estimated that throughout the southeastern United States, warmer water temperatures could push dissolved oxygen levels in most rivers below the 5 ppm necessary to sustain most fish (U.S. EPA, 2004).

Changing climate could also impair water quality in rivers and estuaries by reducing the flexibility of the existing water management system. An increase in the frequency or severity of summer droughts (a possible regional effect of climate change) would limit the ability of reservoir managers to balance competing ecological and human

use demands. These resource pressures would in turn be intensified by the need to release water from reservoirs during droughts to control salinity.

Sea Level Rise and Water Quality

While climate change will impact water quality throughout the state, the impacts of sea level rise on water quality will be felt primarily in the Delaware Estuary. These impacts include wetland destruction, increased salinity, and the washing of land-based pollutants into estuary waters.

Water Quality and Wetlands

As highlighted earlier, a one-meter rise in sea level, which is possible in the Delaware Estuary by 2100, could destroy most existing tidal wetlands and a large portion of the coastal zone's nontidal wetlands. While new wetland formation could take place, existing development and shoreline armoring will constrain the ability of coastal wetlands to migrate in Pennsylvania.

The destruction of coastal wetlands will impact the estuary negatively because of the many ecological functions wetlands perform. Wetlands store floodwater, improve water quality and promote biological productivity. Wetland vegetation acts as a natural sponge, storing water and slowly releasing it. This process slows water's momentum, dissipates erosive energy, reduces flood heights, and allows for groundwater recharge. Wetlands' storage capacity allows sediments, excess nutrients and pollutants from fertilizer, manure, leaking septic tanks, municipal sewage, etc. to settle and drop to the bottom of the wetland. Once absorbed, biological and chemical processes carried out by the plants and microorganisms living in the wetland filter pollutants and excess nutrients. By the time water leaves a wetland, most of the water's nutrient and pollutant load is removed. Because of the nutrient-rich environment found in most wetlands, they are also among the most biologically productive ecosystems in the world, comparable to tropical rain forests and coral reefs in their productivity and the diversity of species they support (U.S. EPA 2001).

The impact of wetland loss on water quality in Pennsylvania's waters depends, however, not just upon the loss of wetlands in Pennsylvania, but also upon the net loss of wetlands throughout the entire estuary. Estimates by Titus (1988) indicating a substantial loss of wetlands due to sea level rise for the Mid-Atlantic region, suggest significant wetland losses for the Delaware Estuary region as a whole. However, greater opportunities for wetland migration in parts of New Jersey and Delaware may partially offset the overall impact of wetland loss in the estuary. Even so, if new wetlands are created down-estuary, they may not directly benefit Pennsylvania's waters. In summary, predicting the impacts of wetland loss on water quality in the estuary will require more detailed studies that model both wetland destruction and new wetland formation as seas rise.

Salinity Increase and Water Quality

Salinity is a significant water quality issue for the Delaware Estuary. As discussed previously, sea level rise could substantially increase the salinity of the Delaware Estuary in the next century. A repeat of the 1960s' drought would send the salt line 10 to 25 miles further upriver given a two to eight foot rise in sea level. A 2.4-foot rise in sea level would jeopardize the City of Philadelphia's drinking water supply by raising sodium concentrations above 50 ppm (the drinking water standard) for 15 percent of the tidal cycles at the Baxter water intake. An 8.2-foot rise would raise sodium concentrations above 50 ppm during 50 percent of the tidal cycles (Hull and Titus 1986).

Increases in salinity would make the estuary's waters too salty for many industrial users, damaging their pipes, tanks and machinery. Industrial users may have to switch to alternate supplies. Higher salinities could also threaten the oyster seed beds in the Delaware Bay and produce major changes in the ecology of the estuary. Estuarine and marine species would migrate up-estuary, while freshwater species would be forced to retreat. Such a migration would bring freshwater species into contact with the more polluted waters of the upper estuary near Pennsylvania's coast. Finally, salinity may contaminate New Jersey's groundwater supply.

Flooding and Erosion

More frequent floods, an expanded floodplain and the landward retreat of shorelines all have the potential to increase the amount of land-based pollutants washed into the estuary. Given the 6-8 foot tidal range in the estuary, a five foot rise in sea level would expand the floodplain to roughly coincide with the study area boundary. Such an expansion has the potential to wash additional land-based pollutants into estuary waters. Significant portions of the study area are occupied by existing or former industrial sites, which are potential sources of pollution and contamination. While the level of contamination varies widely from site to site—from the highly toxic water and soil contamination found at superfund sites, to the basic debris, grease, oil, tires, scrap metal, etc., associated with all industrial operations—these sites are all potential sources of pollutants that could be washed into estuary waters.

In addition to flooding, inundation and erosion have the potential to increase the amount of pollutants that enter the estuary. The inundation and erosion of polluted lands or toxic soils could wash a wide range of contaminants, including heavy metals, volatile organic compounds, solvents and petrochemicals, into estuary waters. The potential of sea level rise to bring hazardous wastes and toxic substances into estuary waters, and potential responses to this threat, are discussed in more detail in the Hazardous Waste section below.

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PUBLIC ACCESS

Providing public access to the waters of the coastal zone has been a priority of the PA CZM program since its inception in 1980. The PA CZM program has contributed funds to numerous waterfront public access sites in the Delaware Estuary coastal zone including Market Square Memorial Park, Barry Bridge Park, Little Tinicum Island, and Leedom Estates Park in Delaware County; the Tinicum-Fort Mifflin Trail, the Kensington & Tacony Trail, Fairmount Waterworks, Schuylkill River Park, Bartram's Garden, Penn's Landing, Lardner's Point Park, and Pleasant Hill Park in Philadelphia; and James Armstrong Memorial Park, Neshaminy State Park, Bristol Lions Park, Radcliffe Street Access Area, Pennsbury Manor, and the Morrisville dike walkway in Bucks County among others. In 1997 the CZM program funded a public access study, *Planning for Public Access to Pennsylvania's Coasts: An Inventory of Existing Conditions*. That study was designed to serve as the basis for developing plans and policies to guide future coastal public access decision-making in Pennsylvania.

The CZM-funded public access study inventoried existing public access sites and highlighted salient public access issues in both the Delaware Estuary and Lake Erie coastal zones. The study stressed that most of southeastern Pennsylvania's coastal waterfront was inaccessible to the public because of competing uses by industry, port activities and utilities. At the same time, recreational users had created a strong demand for quality coastal public access sites that was not being met. Since the conclusion of that study, some significant new public access projects have been fully implemented, such as the 1.2-mile Schuylkill River Park Trail running from Locust St. to the Fairmount Water Works along the eastern bank of the Schuylkill River, while others are in various stages of planning, acquisition, design and construction, including the K&T and Tinicum-Fort Mifflin trails. This section will consider the impact of sea level rise on both existing public access sites and plans to create new public access facilities in the coastal zone.

Public Access and Sea Level Rise

Giving the public access to the region's waterfronts and transforming waterfronts into public amenities has become a priority for all of southeastern Pennsylvania. The past decade has seen a wellspring of interest in creating public open spaces along the water's edge and in utilizing these sites for a wide range of passive recreational activities. As a testament to this desire, Philadelphia's Mayor John Street recently pledged \$235 million of City funds to transform Philadelphia's waterfronts from derelict industrial backwaters to paragons of the public realm.⁶ Although this transformation is far from complete, it has begun to take shape. Numerous planning documents, including the *Comprehensive Plan for the North Delaware Riverfront* and the *Tidal Schuylkill River Master Plan*, have laid out strategies to revitalize the region's waterfronts. Creating public access along the water's edge has become a hallmark of these, and indeed, nearly

⁶ Young, Earni, "Mayor has eye on developing waterfront," *Philadelphia Inquirer*, March 17, 2004.

all, visions for revitalizing waterfront communities in southeastern Pennsylvania and across the nation.

This section will focus specifically on public access sites along the shores of the region's tidal waters, including the tidal Delaware and Schuylkill rivers and the numerous tidal creeks and streams that flow into the estuary. Public sites in the coastal zone that are not on tidally influenced waters are not inventoried (with the exception of the Delaware Canal). There are currently 46 publicly owned access sites along tidally influenced waters in the Delaware Estuary coastal zone (see **Maps 3-A through 3-C**). The sites range in size from the 1200-acre John Heinz National Wildlife Refuge to 0.4-acre McClurg Park in Chester City. These public access sites also differ in the amount of water frontage they contain. Many of the sites are situated so that most of the site space runs perpendicular to the water. Such sites contain little riverfront property. For example, Governor Printz Park, a 5-acre park in Tinticum Township, contains only 200 feet of river frontage. Conversely, the recently acquired K&T Trail right-of-way in northeastern Philadelphia has over 9,000 feet of river frontage. Of the 46 sites that offer access to the waters of the coastal zone, 27 are located along the Delaware River, five are located along the Schuylkill River, six are located along the Darby Creek, and four are located along the Chester Creek. The remaining sites are located on Marcus Hook Creek, Ridley Creek, Pennypack Creek, and the Delaware Canal.

All of the region's coastal public access sites will be subject to inundation, erosion, and flooding as seas rise. In some cases, sea level rise may convert large portions of public access sites to open water. The John Heinz NWR and Little Tinticum Island, which possess significant tidal wetland acreage, are particularly at risk. Although large-scale inundation does not directly threaten upland sites (at least not in the next 100 years), sea level rise poses important questions for the management of all public access sites. Should sites be armored? Should they be allowed to erode? Should they facilitate wetland migration?

The management of public access sites and how they respond to sea level rise will depend upon their current use, size, water frontage, and neighboring land uses. For example, a small, active recreation site surrounded by developed land uses which are likely to be protected from shoreline erosion and inundation, would probably be protected as well. Market Square Memorial Park and Penn Treaty Park are examples of such sites. Likewise, it may be necessary to armor linear public access sites, such as the K&T Trail, whose purpose is to provide a continuous right-of-way along the water's edge, but which extend only a small distance inland of the shoreline. If such sites are not armored, they could become fragmented, thereby breaking up the continuous right-of-way, or be consumed entirely by erosion. Conversely, armoring parks that feature natural shorelines would negate the ecological and aesthetic benefits that soft edges, small wetlands and riparian vegetation provides. Armoring would also extinguish the possibility of future wetland migration.

MAP 3-A DELAWARE COUNTY COASTAL ZONE PUBLIC ACCESS FACILITIES

-  Public Access Facilities
-  Coastal Zone Study Area
-  Protected Open Space
-  Coastal Zone Management Boundary

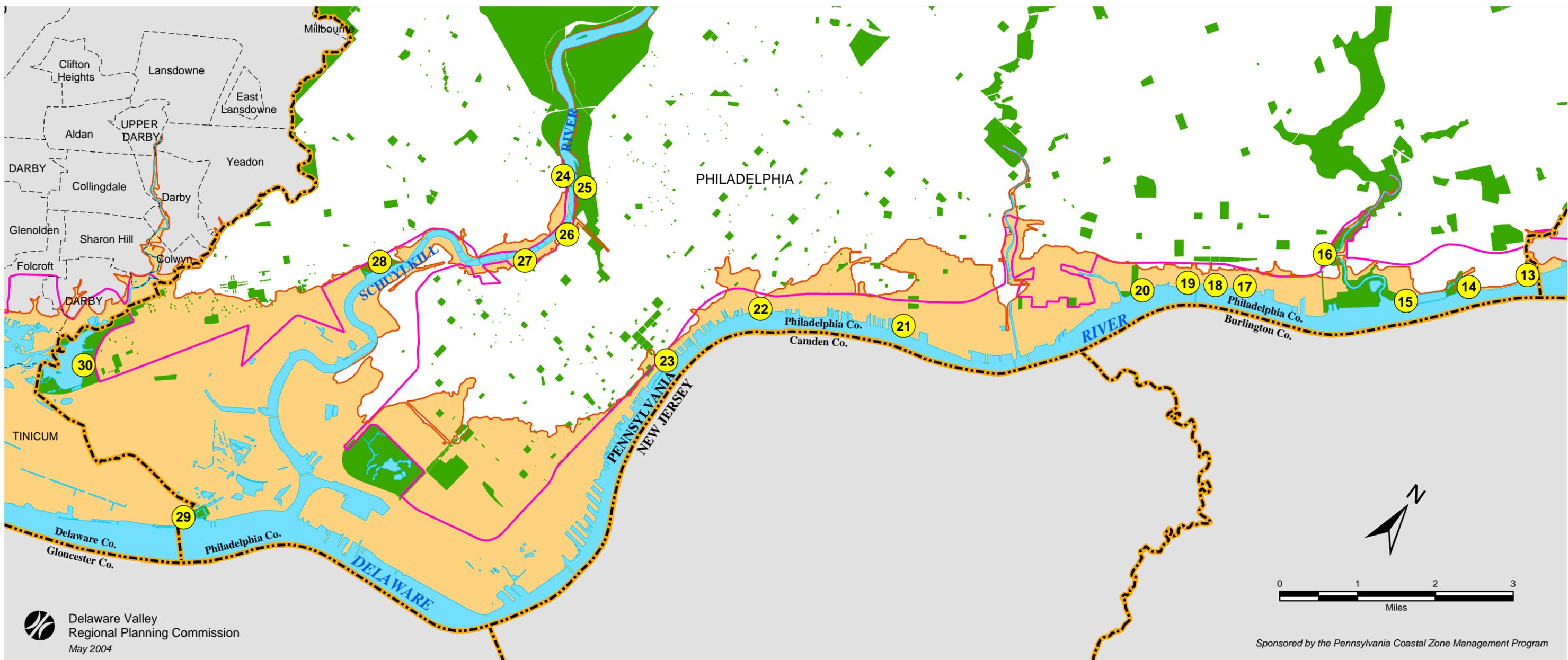
COASTAL ZONE EXISTING PUBLIC ACCESS FACILITIES			
#	Facility Name	Municipality	Size (Acres)
30	John Heinz National Wildlife Refuge	Philadelphia/Tinicum	1200
31	Montgomery Park Recreation Area	Folcroft	4
32	Winona Avenue Park	Norwood	50
33	Morton Mortonson House	Norwood	14.5
35	Morton Homestead	Prospect Park	5
34	Leedom Estates Park	Ridley	17
36	Little Tinicum Island	Tinicum	157
37	Governor Printz Park	Tinicum	5
38	Sun Village Park	Chester City	22
39	Ethel Waters Park	Chester City	0.5
40	McClurg Park	Chester City	0.4
41	YMCA Parcel	Chester City	2
42	Deshong Estate	Chester City	18
43	Barry Bridge Park	Chester City	17.5
44	Wharf at Rivertown	Chester City	N/A
45	Henry Johnson Park	Trainer	27.7
46	Market Square Memorial Park	Marcus Hook	3



MAP 3-B PHILADELPHIA COUNTY COASTAL ZONE PUBLIC ACCESS FACILITIES

-  Public Access Facilities
-  Coastal Zone Study Area
-  Protected Open Space
-  Coastal Zone Management Boundary

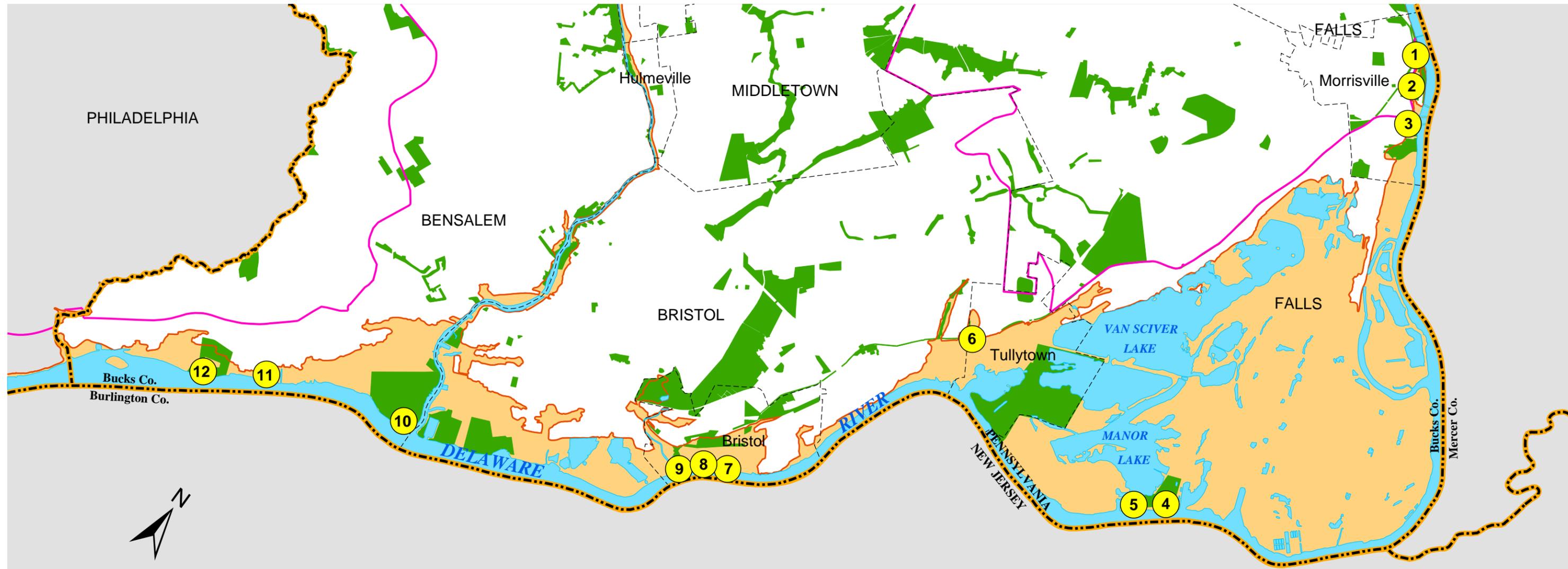
COASTAL ZONE PUBLIC ACCESS FACILITIES			
#	Facility Name	Municipality	Size (Acres)
13	Glen Foerd on the Delaware	Philadelphia	18.2
14	Pleasant Hill Park	Philadelphia	3
15	Foot of Pennypack Avenue	Philadelphia	1
16	Pennypack Park	Philadelphia	54.4
17	Tacony Boat Launch Area	Philadelphia	3.7
18	Kensington & Tacony Trail	Philadelphia	1.8 miles
19	Lardner's Point Park	Philadelphia	6
20	Frankford Arsenal Boat Area	Philadelphia	21.6
21	Foot of Alleghany Avenue	Philadelphia	1
22	Penn Treaty Park	Philadelphia	2
23	Penn's Landing	Philadelphia	219
24	Fairmount Dam Fishway Ladder	Philadelphia	N/A
25	Schuylkill River Park Trail	Philadelphia	1.2 miles
26	Fairmount Waterworks	Philadelphia	2
27	Schuylkill River Park	Philadelphia	6
28	Bartram's Garden	Philadelphia	45
29	Fort Mifflin	Philadelphia	49.8
30	John Heinz National Wildlife Refuge	Philadelphia/Tinicum	1200



MAP 3-C BUCKS COUNTY COASTAL ZONE PUBLIC ACCESS FACILITIES

COASTAL ZONE EXISTING ACCESS FACILITIES			
#	Facility Name	Municipality	Size (Acres)
1	Dike Walkway	Morrisville	0.34 miles
2	Williamson Park	Morrisville	34.4
3	Philadelphia Avenue Area	Morrisville	N/A
4	Pennsbury Manor	Falls	525
5	Falls Township Waterfront Park	Falls	43
6	Delaware Canal State Park	Bristol to Morrisville	10 miles
7	Radcliffe Street Del Rur Access Area	Bristol	0.5
8	Bristol Lions Park	Bristol	1.5
9	Bristol Marsh Nature Preserve	Bristol	16.5
10	Neshaminy State Park	Bensalem/Bristol	330
11	Delaware River Access Area	Bensalem	8
12	Delaware River Parcel	Bensalem	101

- 1 Public Access Facilities
- Coastal Zone Study Area
- Protected Open Space
- Coastal Zone Management Boundary



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The region will need to consider sea level rise as it works to expand public access to the area's waterfronts. Certainly, sea level rise can be a strong argument in favor of public access along the water's edge. Undeveloped public lands could provide a buffer zone that would protect against rising seas while obviating the need for expensive shoreline armoring projects. If open space buffers are significantly wide, they could buy considerable time before communities would need to armor their shores. However, if public access zones exist as narrow rights-of-way, eroding shorelines could jeopardize their continuity, and consequently they may require shoreline armoring themselves. In this case, sea level rise will jeopardize the very benefits that future public access areas aim to provide. With numerous public and private groups now working to transform and revitalize southeastern Pennsylvania's waterfronts, now is the time to begin planning for rising seas. Projects that aim to give the public access to the waterfront, such as the K&T Trail and the East Coast Greenway, must address rising seas in their planning and implementation to prepare for the potential effects of erosion and inundation.

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HAZARDOUS WASTE SITES

There are a variety of hazardous waste and contaminated sites in the coastal zone that may be impacted by sea level rise. Erosion, flooding and inundation all have the potential to wash hazardous wastes into the waters of the estuary. Flooding in particular has the greatest potential to impact hazardous waste sites. This section first discusses the dangers associated with waste sites in floodplains and the federal regulations that exist to mitigate those dangers. It then identifies regionally significant hazardous sites in the coastal zone and assesses their vulnerability to rising seas. Finally, it presents the conclusion that compliance with existing regulations could prevent serious problems with operating sites but not with closed or abandoned sites.

Regulations for Siting Hazardous Waste Facilities

The Resource Conservation and Recovery Act (RCRA) of 1976 and subsequent amendments created a legal mechanism for the management of hazardous wastes. EPA implemented RCRA through a series of regulations and guidelines; a significant part of the regulations restrict waste disposal in environmentally sensitive areas. The following RCRA regulations pertain to hazardous waste facilities in floodplains:

Floodplains: [B 264.18(b)] Hazardous waste surface impoundments, waste, piles, land treatment units, and landfills preferably should not be located in a 100-year floodplain. Facilities so located must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by a 100-year flood. However, in accordance with 264.18(b)(1)(i) if the owner or operator demonstrates that, in the event of a flood, the waste would be removed to a safe area before flood waters reached the facility, special design and operating procedures to prevent washout are not required. This option may not be viable for many existing surface impoundments, waste piles, land treatment units, and landfills. Accordingly, the Agency is promulgating a second exemption, defining narrow circumstances in which existing facilities, not designed and operated to prevent washout, may be located in a 100-year floodplain with the owner or operator making the demonstration cited above in 264.18(b)(1)(ii). These circumstances are where the owner or operator demonstrates that a washout would cause no adverse effects on human health or development. (CFR, 1982, *Federal Register*, vol. 47(143): 32290-32291.)

EPA did not prohibit the operation of facilities in the 100-year floodplain, both because of the potential economic impacts of such a requirement and because of the availability of techniques to protect the facilities from floods. However, the regulations do strongly discourage siting hazardous waste facilities in floodplains, and EPA requires that the lowest floor of all buildings, including the basement, be either elevated to the 100-year flood elevation or be flood-proofed so that the structure is watertight and capable of withstanding the forces exerted by floodwaters during a 100-year storm.

Although the siting of hazardous waste facilities is now strongly discouraged and heavily regulated, many hazardous waste sites were historically located within or near the floodplain (i.e. the coastal zone study area) prior to the enactment of RCRA. Chemical processing facilities, refineries, manufacturing facilities and energy producers have historically located within the coastal zone because it is flat and near water and transportation routes. The industrial, largely non-residential character of the coastal zone has also attracted commercial hazardous waste handlers and processors. As a result, active hazardous waste facilities as well as numerous abandoned and contaminated sites are now present in the coastal zone.

Pennsylvania's coastal zone contains superfund sites, hazardous waste transfer, storage and recovery facilities, landfills, active and derelict industrial properties, and Brownfield sites, many of which are located partly or wholly in the floodplain. Map 4 depicts regionally significant hazardous waste and contaminated sites including Superfund National Priority List (NPL) sites, permitted hazardous waste storage, transfer and recovery facilities, and existing and closed landfills. Four active NPL superfund sites, four deleted NPL sites, one proposed NPL site, and one "removed" NPL site; eight permitted hazardous waste transfer, storage, and recovery facilities; and two active (Tullytown and GROWS) and one closed (Money Island) solid waste landfills are located in or near the coastal zone. Two hazardous waste facilities and one NPL site lie just beyond the study area boundary, but are included on the map because they either lie within Pennsylvania's CZM Boundary or close to a tidal creek or stream. In addition to these sites, the coastal zone is home to dozens of former and current industrial operations that utilize or possess heavy metals, petrochemicals, volatile organic compounds, solvents and other toxic substances. These sites will need to prepare for sea level rise. Current areas of industrial land use are also shown on **Map 4: Delaware Estuary Coastal Zone Hazardous Waste Sites**.⁷

Impacts of Sea Level Rise on Hazardous Waste Sites

The coastal zone is already a potentially volatile location for hazardous waste sites because proximity to the river and low elevations potentially place them in the path of floodwaters. Floodwaters can float hazardous waste storage tanks off their foundations; carry the hazardous contents of waste ponds downstream; and erode waste piles, berms, landfills, or other types of waste management structures. Sea level rise will exacerbate these risks and create new ones.

⁷ The industrial land uses shown on Map 4 are meant to give an indication of the extent and spatial distribution of industrial activities in the coastal zone. However, not all industrial operations use, create or store hazardous materials. Conversely, former industrial sites which may be contaminated, i.e. Brownfields, may no longer be classified as industrial land uses (i.e., they may be classified as vacant) and may not show up on the map.

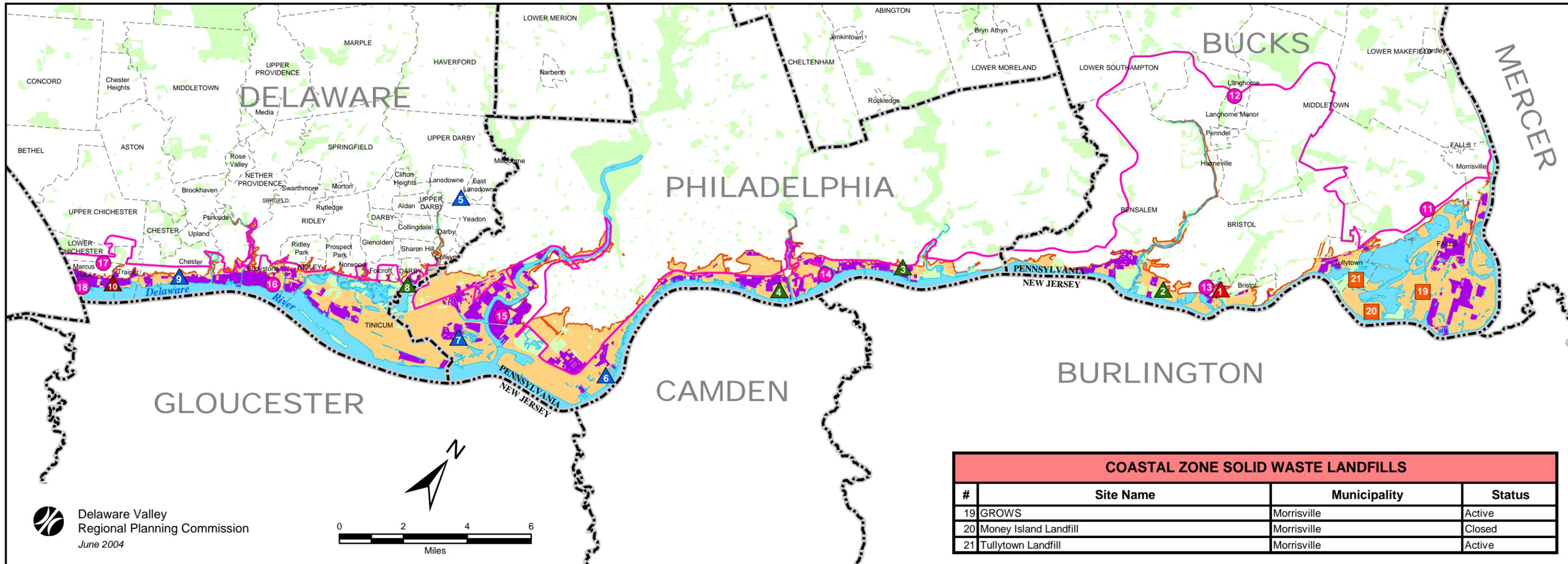
MAP 4 DELAWARE ESTUARY COASTAL ZONE HAZARDOUS WASTE SITES

-  SUPERFUND NPL SITE (DELETED)
-  SUPERFUND NPL SITE (FINAL)
-  SUPERFUND NPL SITE (REMOVED)
-  SUPERFUND NPL SITE (PENDING)
-  HAZARDOUS WASTE FACILITIES
-  SOLID WASTE LANDFILL
-  INDUSTRIAL LAND USE
-  PROTECTED OPEN SPACE
-  COASTAL ZONE STUDY AREA
-  COASTAL ZONE MANAGEMENT BOUNDARY

Sponsored by the Pennsylvania Coastal Zone Management Program

COASTAL ZONE SUPERFUND NATIONAL PRIORITY LIST SITES			
#	Site Name	Municipality	NPL Status
1	Rohm and Haas Co Landfill	Bristol	Removed
2	Croydon TCE	Croydon	Final
3	Metal Banks	Philadelphia	Final
4	Franklin Slag Pile (MDC)	Philadelphia	Final
5	Austin Avenue Radiation Site	Delaware County	Deleted
6	Publicker Industries, Inc.	Philadelphia	Deleted
7	Enterprise Avenue	Philadelphia	Deleted
8	Lower Darby Creek Area	Darby	Final
9	Wade (ABM)	Chester City	Deleted
10	East Tenth Street	Marcus Hook	Proposed

COASTAL ZONE HAZARDOUS WASTE FACILITIES			
#	Site Name	Municipality	Status
11	Safety - Kleen	Falls	Permitted
12	Betz Laboratories, Inc.	Langhorne	Permitted
13	Rohm and Haas Company	Bristol	Permitted
14	Sunoco, Inc. - Frankford Plant	Philadelphia	Permitted
15	Sun Company (R&M)	Philadelphia	Permitted
16	Boeing Defense and Space Group, Helicopters Division	Ridley	Permitted
17	Marcus Hook Processing, Inc.	Marcus Hook	Permitted
18	Sun Refining & Marketing Company	Marcus Hook	Permitted



COASTAL ZONE SOLID WASTE LANDFILLS			
#	Site Name	Municipality	Status
19	GROWS	Morrisville	Active
20	Money Island Landfill	Morrisville	Closed
21	Tullytown Landfill	Morrisville	Active

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The impacts of sea level rise on hazardous waste sites can be classified into increased flooding, shoreline retreat, and changes in water tables. Flooding is likely to be the most important factor. A rise in sea level would bring new sites into floodplains and result in more severe flood levels for those already in floodplains. Furthermore, the risks from damaging storm waves would increase as deeper water allowed these waves to penetrate further inland.

Shoreline retreat could also threaten hazardous waste sites. As discussed in previous sections, sea level rise results in both inundation and erosion; a rise of one foot could result in a shoreline retreat from a few feet along steep coasts to several miles along low-lying marshland. Significant shoreline retreat might leave a waste site under water or in the surf zone subject to constant wave attack. Operating sites, especially factories for which the waste site is a small portion of the entire operation, would generally protect themselves from an encroaching shoreline. Abandoned sites, however, would not be guaranteed the same protection.

Finally, changing water tables could threaten wastes stored in surface impoundments and landfills. Higher water tables could threaten containment vessels by exerting additional hydrostatic pressure. Furthermore, saltwater can permeate clay liners that are impervious to freshwater. As a result, the risk of wastes leaching through the liners would increase.

Although existing EPA and DEP regulations do not address changing water tables, the regulations would protect the public from the risks associated with shoreline retreat and flooding for active sites, provided that flood maps are redrawn in a timely fashion and the regulations are enforced. However, if the status of the changing floodplain is not monitored and mapped in a timely fashion, facilities will either not be prepared for flooding events, or they will be forced to play “catch-up” in their efforts to remain in compliance with the regulations (if and when the maps are finally updated). Facilities which were floodproofed to withstand existing conditions will probably have to spend more to upgrade their flood-proofing than they would if they had originally built their flood protection works to accommodate the amount of sea level rise expected to occur throughout their operating lifetime. Furthermore, other sites may have chosen to locate farther inland had they realized that their chosen site would someday be in a floodplain (Flynn et al. 1984).

Conclusions

The flood mitigation measures in place at hazardous waste facilities vary widely in their flood mitigation effectiveness. Accordingly, serious health and environmental problems may result from the flooding of some active facilities, even in the absence of sea level rise. Furthermore, flood mitigation measures generally will not, in their present condition and configuration, provide protection against flooding associated with a large rise in base sea level.

The need to anticipate sea level rise and the ability to prepare for larger floods varies according to the operating status of hazardous waste sites. Owners and operators of proposed facilities should consider whether the prospect of increased flooding justifies changing the planned location. Proposed facilities may also minimize flood mitigation investments in the long run by designing for the flood levels to be experienced over the project's lifetime rather than those currently to be expected.

Currently operational facilities will remain secure, and the public will be protected from increased exposure to wastes, so long as flood maps are redrawn and facilities are retrofitted with the additional required flood mitigation measures. If hazardous waste facilities upon which the expanding floodplain encroaches cannot prove that they can quickly remove wastes before a flood and/or withstand a washout, the facility should relocate outside of the floodplain.

Operating facilities scheduled to close would not be protected by existing regulations. To address this inadequacy, closure plans required by federal and state agencies should go beyond the level of protection required of currently operating facilities and incorporate measures to protect these sites from the inundation, erosion, and flooding that could occur in the next century.

Inactive facilities, particularly those that were improperly closed or that do not have an identifiable owner or operator, may already present environmental hazards. These hazards would be aggravated by a rising sea. Identification and decontamination of these sites may pose the most troublesome of the problems discussed here. While operating hazardous waste facilities can adapt to rising seas and changing floodplains by moving or restructuring their operations, contaminated areas of the coastal zone will have to be cleaned up before rising waters encroach upon them to avoid polluting estuary waters.

Proven flood mitigation measures exist to address the risks that could be created by sea level rise. Environmental programs should be expanded in order to address this challenge explicitly.

CONCLUSION

A three- to four-foot rise in sea level in the Delaware Estuary during the next 100 years will have a wide range of impacts on the coastal zone. Rising seas will inundate almost all existing tidal wetlands. While new tidal wetlands could form in areas that are now dry land, existing development and shoreline armoring will severely limit opportunities for wetland migration. The conversion of waterfront industrial and abandoned properties to open space, however, could provide additional areas for wetland migration. Such a conversion would also obviate the need for expensive shoreline armoring projects to protect development. Meanwhile, the fate of nontidal wetlands in the coastal zone is less clear—some may be inundated while others could become tidal. Overall, current research supports the conclusion that Pennsylvania will experience a significant net loss of wetlands within the coastal zone as seas rise.

Sea level rise will promote the up-estuary migration of the salt line in the Delaware River. During times of drought, rising seas will exacerbate what is already a serious problem—salinity—for the management of the Delaware Valley's water resources. The region will need to prepare for potential salt water contamination of water intakes and aquifers. At the same time, significant ecological shifts in the estuary will take place. The region will need to find ways to effectively manage its water supply during times of drought to avoid the worst consequences of increased salinity. The emerging integrated water resources management paradigm conceived by the Delaware River Basin Commission needs to incorporate sea level rise into its management framework to confront the salinity challenge.

Hazardous waste sites in the coastal zone pose a looming threat to the waters of the estuary. Existing federal, state, and local regulations are designed to insure that operating hazardous waste facilities do not release their hazardous contents during flooding events. However, as seas rise and the floodplain expands, floodplain maps will need to be redrawn and regulations enforced, so that facilities remain prepared for an expanded flooding threat. Contaminated closed or abandoned facilities and facilities that are now closing pose a greater management challenge for the region. As seas rise, the threat of flooding, inundation and erosion will steadily increase. If contaminated sites are not cleaned up in a timely fashion, they will likely pollute estuary waters with heavy metals, petrochemicals, volatile organic compounds, solvents and other toxic substances. Plans need to be made to ensure that contaminated sites are mitigated before seas and floodwaters encroach upon them and procedures for closing facilities should be revised to address both current and expected future flood heights.

Public access to the shores of the coastal zone has become an increasingly high profile issue in southeastern Pennsylvania in recent years. Much of the area has historically been dominated by industrial, commercial and other private enterprises that discourage open access to the waterfront. The decline of the region's industrial economy has opened the door to new visions of the waterfront that aim to reclaim it for the benefit of the public sphere. Not only will the creation of new public spaces along the water's

edge be a boon to the region, it will also better equip communities to adapt to sea level rise. Linear open spaces along the waterfront would act as buffers between developed areas and encroaching seas and allow additional opportunities for wetland migration. Creating larger open space nodes would keep permanent structures and other at-risk facilities out of the expanding floodplain and allow for more flexible management responses to rising seas. However, sea level rise will also be a challenge for efforts to increase public access. Erosion and inundation could break up the continuity of new public access rights-of-way that parallel the shoreline or eliminate them altogether. To protect investments in public access, communities may have to invest further resources in shoreline armoring. Although rising seas will need to be considered by groups working to expand public access, sea level rise is a strong argument in favor of continuous public access and larger open space nodes along all of our region's tidal waterfronts.

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DELAWARE VALLEY REGIONAL PLANNING COMMISSION

Publication Abstract

Title: *Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania*

Date Published: June 2004
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Geographic Area Covered: The Pennsylvania Coastal Zone as defined by the shoreline of the Delaware River and the 20-foot contour in Bucks, Delaware and Philadelphia counties in Pennsylvania.

Key Words: Sea level rise, coastal zone, Delaware Estuary, Pennsylvania, Mid-Atlantic, wetlands, coastal wetlands, wetland migration, salinity, water quality, public access, shoreline armoring, hazardous waste sites.

ABSTRACT

This publication investigates the potential impacts of sea level rise on wetlands, salinity, water quality, public access, and hazardous waste sites in Pennsylvania's coastal zone. The study area for this analysis includes all land below the USGS 20-foot (1929) NGVD contour. The study concludes that a three- to four-foot rise in sea level during the next 100 years will have a wide range of impacts. Rising seas will inundate almost all of Pennsylvania's 1,500 acres of tidal wetlands. The salt line in the Delaware River will migrate further upstream, threatening Philadelphia's drinking water supply. The pollutants found in contaminated sites may be released into estuary waters. Efforts to increase public access to the waterfront may be jeopardized by rising waters. However, more open spaces on the waterfront would provide opportunities for wetland migration and could eliminate the need for expensive and environmentally destructive shoreline armoring schemes.

For More Information Contact:

Delaware Valley Regional Planning Commission
The Bourse Building – 8th Floor
111 South Independence Mall East
Philadelphia, PA 19106-2582
Phone: 215-592-1800
Fax: 215-592-9125
Internet: www.dvrpc.org

Staff Contacts:

Christopher Linn, Environmental Planner

Direct Phone:

215-238-2873

Email

clinn@dvrpc.org



Delaware Valley Regional Planning Commission

**The Bourse Building
111 South Independence Mall East
Philadelphia, PA 19106-2582
215.592.1800
www.dvrpc.org**

