Technical Report for the Delaware Estuary and Basin

2022

Partnership for the DELAWARE ESTUARY

A publication of the Partnership for the Delaware Estuary and the Delaware Estuary Program

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The Partnership for the Delaware Estuary, host of the Delaware Estuary Program, leads collaborative, science–based efforts to improve the Delaware River and Bay, which covers portions of Delaware, New Jersey, and Pennsylvania.

2.6 Sea Level

Description of Indicator

Sea level is an indicator of climate change as it is impacted by increasing global air temperatures in a variety of ways, such as the addition of water to the oceans by ice-mass loss and by thermal expansion. Relative sea level is also affected by other factors, such as isostatic rebound and subsidence due to groundwater and oil withdrawals. Rising sea levels are a major threat to global coastal communities and estuarine habitats because of increased high tide flooding, infiltration of saline water into groundwater systems, and upstream progression of the salt front which can impact drinking water intakes (see Chapter 3). The long-term rate of global sea level rise from 1900 to 2018 is about 1.6 cm per decade, but more recent rates (1993–2018) indicate global mean sea level is increasing at 3.4 cm per decade (Frederikse et al. 2020).

Mean sea levels within the Estuary were obtained from the Permanent Service for Mean Sea Level database for three locations: (1) Philadelphia, Pennsylvania (Station ID: 135), (2) Cape May, New Jersey (Station ID: 1153), and (3) Lewes, Delaware (Station ID: 224) (Fig 2.1). Sea level data are annual means calculated from monthly means with gaps of up to 3 months filled using linear interpolation. Recent publications were also reviewed to identify historical trends in tidal range, connections to mean sea level, and projected changes.

Past Trends

Within the Delaware Estuary, both the long-term and recent sea level trends are positive and significant at the 95% confidence level (Table 2.7). Over the past 120 years, sea level at Philadelphia has been rising at a rate of 3.07 cm per decade (Fig 2.13). From 1992 to 2021, sea level at Philadelphia has increased at a rate of 4.7 cm per decade, indicating that the rate of sea-level rise is increasing in the Delaware Estuary, as it is globally. At the mouth of Delaware Bay, sea level has risen at an average rate of 5.7 cm per decade over the past 30 years, for a total of about 17 cm (7 inches). These high rates of sea-level rise are exacerbated by geologic contributions of around 2 cm per decade (Kopp 2013). Sea-level rise has contributed to increasing salinity throughout much of the estuary (Ross et al. 2015).

Table 2.7 Sea level trends in the Delaware Estuary. P-values are in parentheses and significant trends are bold (95% confidence).

Station	Sea level trends (cm per decade)	
	1901-2021	1992-2021
Philadelphia, PA	**3.07 (< 1e^{-4})**	**4.7 (0.00025)**
Cape May, NJ	-	**5.8 (3.9e^{-08})**
Lewes, DE	-	**5.6 (1.1e^{-07})**

Tidal amplitudes and overall tidal ranges in the Estuary have also varied historically, in part due to sea-level rise (Ross et al. 2017). Anomalies in the highest astronomical tide at tide gauges throughout the Estuary have been positively correlated with anomalies in mean sea level (Devlin et al. 2019). Channel deepening has also influenced tidal range, causing it to more than double over the first half of the 20th century in the upper estuary, between Philadelphia and Trenton (DiLorenzo et al. 1993; Pareja-Roman et al. 2020).

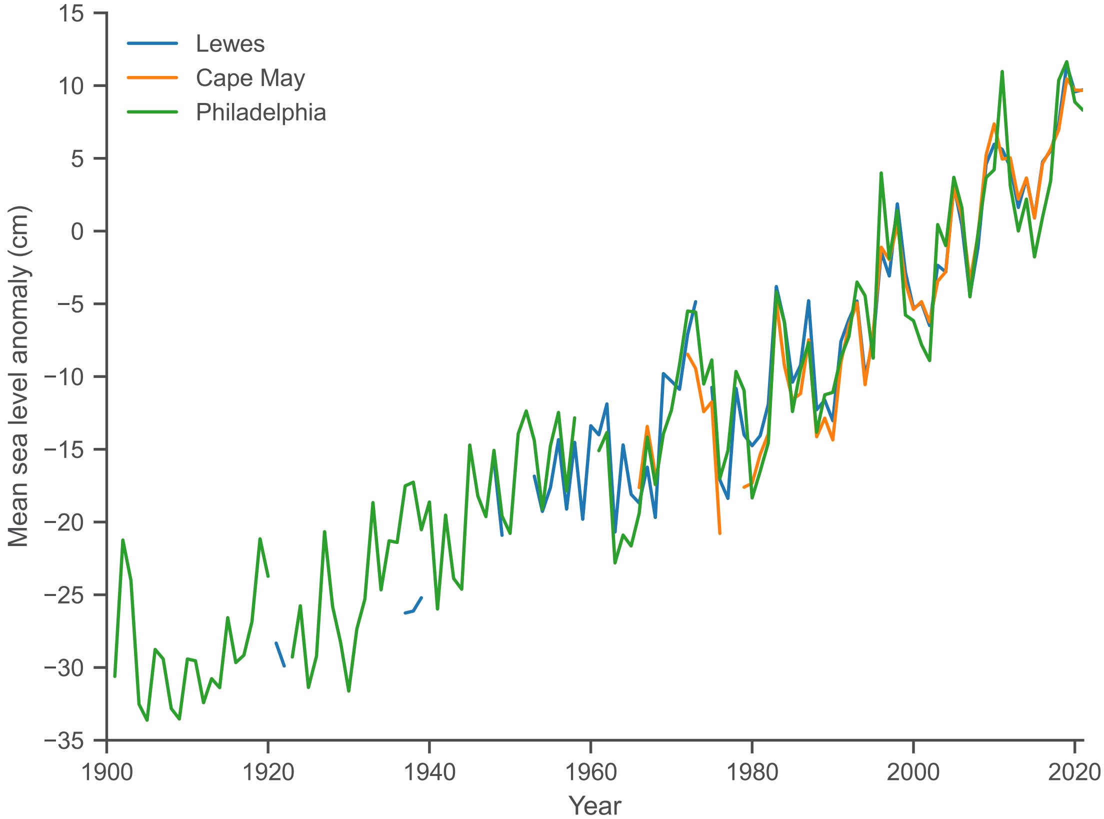

Figure 2.13 Annual mean sea level anomalies with respect to the 1991-2020 means.

Increases in tidal range have increased the frequency of "nuisance flooding" during high tides at Philadelphia (Li et al. 2021). The water level height when nuisance flooding occurs is based on the mean high high water level at each station, which is about 1.9 ft (0.58 meters) above sea level for the locations discussed here (Sweet et al. 2022). At Philadelphia, nuisance flooding events have been increasing over the past 20 years with a peak of 15 instances in 2011 alone (National Ocean Service). The monitoring stations at Lewes, Delaware, and Cape May, New Jersey, have also experienced increases in high tide flooding events since the 1980s (National Ocean Service).

Future Predictions

Mean sea level along the contiguous United States is predicted to increase by 30 cm by the year 2050 (Sweet et al. 2022). Based on the RCP8.5 low and high probability scenarios, sea level in Delaware Bay is projected to increase between 52 cm and 153 cm by the year 2100 when compared to mean sea level observed in the year 2000 (Callahan et al. 2017). In the near term, rising mean sea level and an increase in tidal range associated with a regular 18.6-year tidal cycle are projected to result in a substantial increase in nuisance flooding in the 2030s and moderate flooding in the 2050s (Thompson et al. 2021).

The positive historical correlation between tidal range and mean sea level suggests that future sea level rise is likely to continue to cause increased tidal range beyond the expected cyclical increase in the 2030s. Model simulations agree with this hypothesis; Lee et al. (2017) projected that 1 m of sea-level rise would cause mean tidal range in the upper Estuary to increase by 25 cm, with smaller increases in the Bay. However, Lee et al. (2017) found that the simulations were sensitive to the treatment of shorelines in the model. Sea-level rise increased tidal range when the coast was modeled like a hardened shoreline; if instead low-lying coastal land was inundated as the sea level rose, the model tidal range decreased.

Saltwater intrusion is likely to increase in the Delaware Estuary as a result of sea-level rise (Ross et al. 2015). Such salinity increases are projected to negatively impact industry, including electricity generation (Shirazi et al. 2019), and reduce the large tidal-fresh portion of the estuary, which harbors important and unique species.

Actions and Needs

Coastal communities across the United States are already feeling the impacts of rising sea levels. Adaptations currently used to prevent or reduce flooding due to rising sea levels range from sandbags to living shorelines to higher seawalls, even including elevating structures. However, future predicted sea levels compounded with increasing storm intensities will likely be devastating to coastal communities, regardless of adaptations (see Climate Feature 2). For example, the heights of peak storm tides of cool-season storms, like Nor'easters, are predicted to increase in counties along the Delaware River by the late 21st century because of more intense storms tracking further inland (Pringle et al. 2021). With a projected additional increase in sea level of over 1 meter along the Delaware River, tropical and cool-season storms will become more damaging and far reaching. The Delaware Estuary and Basin is already starting to experience unprecedented storms and their impacts. After landfall in Louisiana as a category 4 storm, Hurricane Ida stalled over the northeastern US in September 2021, causing flash flood events and a storm surge of up to a meter above normal tides (Beven II et al. 2022). Increases in tidal range due to sea-level rise and periods of higher range in the 2030s and 2050s will exacerbate due to flooding storms, particularly in the upper Estuary; detailed projections of these changes and adaptations to cope with regular flooding are urgently needed.

Severe flooding may occur when multiple flood types, such as pluvial flooding (directly due to heavy local precipitation), fluvial flooding (due overflowing river banks), and coastal flooding (due to high tides and storm surge), happen simultaneously. Such compound flooding is likely to increase in the future in many parts of the world, including the Delaware Estuary, as a result of heavy precipitation, higher sea-levels, and stronger storms. Most of the United States is expected to see increases in flooded area from 2020 to 2050 (Bates et al. 2021) that will disproportionately impact Black communities (Wing et al. 2022). Coastal areas, including the Delaware Estuary, are expected to be hardest hit, and the effects by the end of the century under high emissions are projected to be dramatic. Specifically, a severe compound pluvial and storm surge flood, which is when 100-year extreme rainfall occurs simultaneously with 100-year extreme sea level, is projected to change from an occurrence every 270 years to every 7 years on average throughout the Delaware Estuary, a 36-fold increase in likelihood (Gori et al. 2022).

Summary

Changes on decadal to century time scales in sea level and tidal range are indicators of climate change and can have drastic impacts on coastal communities along the Delaware Bay and within the tidal reach of the lower Delaware River. At Philadelphia, the rate of sea level rise has increased and is correlated with increases in tidal range. These and future projected increases will impact other climate change indicators, such as flooding events, particularly within communities already impacted by nuisance flooding (see Climate Feature 2), changes in coastal habitats (see Chapter 6), and movement of the salt front (see Chapter 3). Without an appreciable reduction in GHG emissions, in addition to adaptations to modern increases in sea level, communities and habitats along the Delaware Bay and River will likely experience severe negative impacts.