Climate Change Stressor Indicators

CHAPTER 3:
SEA LEVEL


Photo: High tide in the Barrington River, Barrington, RI (James Tobey)
BACKGROUND

- In recent decades, sea level has been rising at an increasingly rapid pace in Narragansett Bay. The change in sea level affects ecosystem condition, including salt marshes and seagrasses, and it influences other stressors including population, land use, and wastewater infrastructure. Temperature influences the rate of sea level rise.

KEY FINDINGS

- **Status and Trends:** Sea level rose nine inches at the tide gauge in Newport from 1930 to 2015 and 6.6 inches at Providence from 1938 to 2015. Three nuisance flooding events occurred at Providence in 2016.

- **Projections:** NOAA projects that sea level could rise as much as eleven feet at Newport by 2100. Along Rhode Island’s coastline in Narragansett Bay, approximately seventeen square miles of land and 3,765 buildings would be inundated under a seven-foot sea level rise scenario. Over 10,000 people live today within this area along Rhode Island’s coastal areas of Narragansett Bay. Narragansett Bay salt marshes are converting to unvegetated tidal flats and open water, and the rate of this marsh loss is projected to increase with rising rates of sea level. The frequency of nuisance flooding in the Northeast region is projected to increase 25-fold by the year 2045 due to sea level rise.
**Introduction**

Sea level is the height of the sea with respect to a standardized reference elevation, or datum. Sea levels are rising at an accelerating rate along most of the world’s coastlines (IPCC 2013). At the global scale, sea level is rising because of two main processes: (1) seawater is becoming warmer, causing the seawater to expand in volume, and (2) glaciers and the polar ice sheets are melting, causing more water to enter the ocean. The driving force behind those processes is the emissions of carbon dioxide and other greenhouse gases into the atmosphere, where they trap heat and cause the air and ocean to become warmer (see introduction to “Climate Change Stressor Indicators” section in this report). The global change in sea level is termed “eustatic or absolute sea level rise.” As there is a time lag in sea level rise in response to climate change, sea levels are expected to continue rising long into the future regardless of steps taken to climate change, sea levels are expected to continue rising long into the future regardless of steps taken to curb global greenhouse gas emissions (IPCC 2007). Other factors, such as changes in ocean circulation patterns, also have important influences on sea level.

In addition to eustatic sea level rise, other processes can augment or reduce the amount of sea level rise that occurs in a particular place. For example, vertical movement of landmasses—whether they are subsiding or uplifting due to geological processes—can affect the amount of sea level rise observed on a local or regional scale. The combination of eustatic sea level rise with subsidence- or uplift-related changes in sea level is termed “relative sea level rise” (Rovere et al. 2016). The New England coast is subsiding (sinking) slowly, and this effectively increases the local rate of sea level rise. At the Newport, Rhode Island, tide gauge, the land along the coastline moved downward at a rate of 0.35 inch (8.8 millimeters) per decade between 1930 and 2006 (NOAA 2013).

Changes in ocean circulation can affect sea level on a regional scale and are a source of uncertainty in regional projections of sea level rise. The Intergovernmental Panel on Climate Change (IPCC) predicts that ocean circulation in the North Atlantic Ocean is likely to slow down by 2100 because of shifts in salinity and temperature of the Arctic Ocean and North Atlantic Ocean (IPCC 2007 and Yin et al. 2009). As a result, sea level is rising faster along the coast from Cape Hatteras, North Carolina, to the Canadian Maritime Provinces compared to other parts of the world (Sallenger et al. 2012).

The Rhode Island Coastal Resources Management Council (CRMC) formally adopted a set of sea level rise projections published in 2012 by the National Oceanic and Atmospheric Administration (NOAA) for Newport (Parris et al. 2012). Based on those projections (Sea Level Rise Curves), relative sea level at Newport was projected to increase by a maximum of approximately one foot (0.3 meter) by 2035, two feet (0.61 meter) by 2050, and 6.6 feet (two meters) by 2100. However, as discussed later in this chapter (see Projected Sea Level Rise), NOAA recently increased its projections quite dramatically (Sweet et al. 2017), based in large part on projected increases in melting of the Greenland and Antarctic ice sheets.

There is increasing evidence in the scientific literature indicating that the rate of ice sheet disintegration and melting may be much greater than previously anticipated. Beyond an unknown threshold of greenhouse gas emissions, the collapse of the polar ice sheets, especially in Greenland and Antarctica, will be inevitable and irreversible (Overpeck et al. 2006, DeConto and Pollard 2016, Hansen et al. 2016).

In this chapter, the Estuary Program presents the most recent research and findings from numerous sources that have calculated sea level trends and future projections at global, regional, and local scales, and are relevant to Narragansett Bay. The Estuary Program focused on providing a comprehensive summary of the literature currently available, including studies that have estimated impacts on habitat, people, and infrastructure. In addition, the Estuary Program calculated the number of buildings and total population along Rhode Island’s coastline in Narragansett Bay that may be affected under different sea level rise scenarios. The many factors that cause sea level rise are dynamic and have their own drivers and stressors, and new research and updated projections regarding sea level rise, and emerging research and updated projections regarding sea level rise and nuisance flooding are expected to continue.

**Methods**

**STATUS AND TRENDS OF SEA LEVEL RISE**

NOAA maintains a network of tide gauge stations for monitoring water levels and rates of sea level rise. Most stations provide readings every six minutes, making it possible to monitor real-time tide elevations and inundation threats. Sea level is measured in relation to a tidal datum, or height, which is a standard elevation defined for each station (Table 1). NOAA uses monthly mean sea level data from the tide gauge measurements to characterize linear trends, average seasonal cycles, and interannual variations.
Long-term datasets from NOAA stations can be used to analyze relative mean sea level rise trends and to develop projections for future sea level rise. From NOAA Tides and Currents, the Estuary Program gathered information about water levels and relative mean sea level trends for two tide gauge stations in Narragansett Bay, both in Rhode Island: Newport (station #8452660) and Providence (station #8454000). At Newport and Providence, NOAA has monitored mean sea levels since 1930 and 1938 respectively. While there is a tide gauge station in Fall River, Massachusetts, NOAA does not provide sea level trends for that station because the record of data collection is too short (tide gauge station was established in 1955). Table 1 summarizes the types of information available for each tide gauge station and provides definitions used throughout this chapter.

**PROJECTIONS OF SEA LEVEL RISE**

In this chapter, the Estuary Program summarized the most current sea level rise projections relevant to Narragansett Bay with the understanding that the science will continue to develop and projections will be modified over time. The primary source for projections affecting Narragansett Bay was the recent NOAA report on global mean sea level (GMSL) rise and regional relative mean sea level rise (Sweet et al. 2017). The data for projections were obtained directly from the database that accompanies the NOAA technical report (Sweet et al. 2017).

**Visualization of Sea Level Rise Scenarios**

Government agencies have developed sea level rise geospatial models and user-friendly online tools that are helpful for visualizing and evaluating the potential impacts of sea level rise (e.g., https://www.climate.gov/maps-data/dataset/sea-level-rise-map-viewer). Because of data limitations at the Bay scale, including incomparability of methods and varying spatial and time scales among models, the Estuary Program did not attempt to reconcile data from different national and state sea level rise data sources, rather, the Estuary Program built upon information from two well-established sources, STORMTOOLS and the Sea Level Affecting Marshes Model (SLAMM), both developed and completed for the statewide coastal areas of Rhode Island.

**Sea Level Rise Impacts on the Landscape**

The University of Rhode Island developed STORMTOOLS for the CRMC to aid state and local adaptation planning efforts statewide. The STORMTOOLS maps have very high resolution for the Rhode Island sections of Narragansett Bay. This mapping tool allows the user to identify coastal areas of Rhode

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**Table 1. Definitions of selected terms used in this chapter.**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Datum</td>
<td>A tidal datum is a standard elevation defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels and should not be extended into areas having differing oceanographic characteristics without substantiating measurements.</td>
</tr>
<tr>
<td>National Tidal Datum Epoch</td>
<td>(NTDE) An epoch is a nineteen-year tidal cycle used to calculate datums. The present National Tidal Datum Epoch (NTDE) is 1983 through 2001.</td>
</tr>
<tr>
<td>Station Datum</td>
<td>(STND) A fixed base elevation at a tide station to which all water level measurements refer. It is unique to each station.</td>
</tr>
<tr>
<td>Mean Sea Level</td>
<td>(MSL) The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. It is the reference datum for calculating sea level trends.</td>
</tr>
<tr>
<td>Mean Higher High Water</td>
<td>(MHHW) The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. It is the reference datum for determining frequency and duration of nuisance flooding.</td>
</tr>
<tr>
<td></td>
<td>• Newport tide gauge: MHHW is 5.74 feet (1.75 meters).</td>
</tr>
<tr>
<td></td>
<td>• Providence tide gauge: MHHW is 8.33 feet (2.5 meters).</td>
</tr>
<tr>
<td>Mean Lower Low Water</td>
<td>(MLLW) The average of all the lower low water heights observed over the National Tidal Datum Epoch.</td>
</tr>
<tr>
<td></td>
<td>• Newport tide gauge: MLLW is 1.89 feet (0.58 meters).</td>
</tr>
<tr>
<td></td>
<td>• Providence tide gauge: MLLW is 3.49 feet (1.06 meters).</td>
</tr>
</tbody>
</table>

*Source: NOAA Tidal Datums Website (2013); NOAA Datums for Newport, RI, and Providence, RI (2017).*
While data on sea level rise scenarios derived from STORMTOOLS have been used widely in Rhode Island to analyze impacts on people and infrastructure at the state and local level, the same group that developed STORMTOOLS and other state and local partners, the Estuary Program focused only on the coastline around Narragansett Bay. Readily available data from these other efforts were in tabular form, typically covering the entire state or towns rather than only the Narragansett Bay Watershed, and were not geospatial. Thus, the Estuary Program performed a geospatial analysis that covered only the portions of Rhode Island that lie in the Narragansett Bay Watershed, excluding areas of the state and portions of towns that fall outside of the Watershed. For this reason, the results of this cursory analysis represent only areas in Rhode Island and not the portions of the Narragansett Bay Watershed in Massachusetts, such as Mount Hope Bay.

The Estuary Program used the Derived Inundations Surfaces data available in RIGIS, which are the data outputs of sea level rise scenarios from STORMTOOLS, to calculate vulnerable coastal areas in the Rhode Island portion of Narragansett Bay under sea level rise scenarios of one, three, and seven feet. The following analyses were performed by the Estuary Program to calculate the number of buildings and the total number of residents (based on Census 2010 data) that would be exposed to inundation under each sea level rise scenario.

- **Number of Buildings (Rhode Island Portion of Watershed Only):** The Estuary Program performed spatial analyses of Rhode Island e911 Exposure Assessment data similar to those conducted by the developers of STORMTOOLS. The e911 geo-spatial dataset contains locations for all buildings in the state with known street addresses; this dataset represents buildings that have been identified from 2006 through 2017.

- **Total Population Residing in the Watershed (Rhode Island Portion of Watershed Only):** The estimated number of residents affected by the sea level rise scenarios was calculated using population data from dasymetric analysis (see “Population” chapter), which identifies population distribution on a finer spatial scale than towns or census blocks. This approach enabled the Estuary Program to identify more accurately where people live within the Watershed boundaries, as opposed to state, municipal, or census block boundaries. (Information about impacts of sea level rise scenarios at the state and municipal level are available from the State of Rhode Island, Division of Planning.)

### Sea Level Rise Impacts on Estuarine Habitats

The CRMC produced a report in 2015 that assessed the vulnerability of Rhode Island’s salt marshes to sea level rise based on results from the Sea Level Affecting Marshes Model (SLAMM) (CRMC, 2015). The report included a series of maps depicting areas of salt marsh, parcel by parcel, that were projected to persist or be lost under scenarios of one, three, or five feet (0.3, 0.9, or 1.5 meters) of sea level rise. These three scenarios for sea level rise were chosen because CRMC had adopted in 2008 projections of three to five feet of sea level rise by 2100 based on the latest peer-reviewed science and research (CRMC 2015).

Similarly, the Massachusetts Office of Coastal Zone Management (MA CZM) recently completed modeling using SLAMM for salt marsh habitat along the Massachusetts coastline of Narragansett Bay, including Mount Hope Bay (Marc Carullo, presentation at the Narragansett Bay Estuary Program’s Steering Committee Meeting, June 2017). Massachusetts used scenarios of 0.8, 2.3, 4.5, and 7.1 feet (0.25, 0.7, 1.37, and 2.16 meters) of sea level rise, which were based on National Climate Assessment (Parris et al. 2012) projected scenarios for sea level rise by 2100; 4.5 feet was the intermediate-high projection.

Comparing the SLAMM modeling conducted by both states, the main similarities and differences include the following: 1) Both states used National Wetland Inventory (NWI) data to classify wetlands in the model (see “Salt Marsh” chapter). 2) Both mapped and calculated areas of potential losses and gains of salt marsh, such as through conversion from upland or other vegetated wetland to salt marsh in response to sea level rise. 3) The Massachusetts SLAMM results also include projected changes in wetland classes, such as changes from infrequently flooded marsh to regularly flooded marsh. 4) The Rhode Island SLAMM report includes results from two modes for projecting marsh migration: (a) including all undeveloped and developed (e.g., roads) lands as potential marsh migration corridors or (b) including only undeveloped lands; modeling in Massachusetts included only the latter (CRMC 2015 and Marc Carullo, proceedings for Estuary Program Steering Committee Meeting, June 2017).
Data, results, and the final report of the Massachusetts SLAMM modeling effort were not available at the time this chapter was completed.

**STATUS OF NUISANCE FLOODING**

Nuisance flooding is defined as a water level that exceeds the National Weather Service’s local threshold for minor flooding impacts established for emergency preparedness (Sweet et al. 2014, 2015, 2016); it is also defined as flooding that causes public inconveniences.

Nuisance flooding is measured based on NOAA tide gauges (tidesandcurrents.noaa.gov). At the Providence tide gauge station, an event of nuisance flooding is defined as occurring when the tide elevation is 2.16 feet (0.66 meter) above Mean Higher High Water (MHHW). This is the level at which buildings and infrastructure will be flooded. The Providence tide gauge is the only station in Narragansett Bay with an established threshold for nuisance flooding. Nuisance flooding may occur at different water levels in other areas of the Narragansett Bay Watershed.

The Estuary Program used NOAA’s Inundation Analysis Tool (IA) (NOAA 2013) to determine how many times the threshold for nuisance flooding was exceeded at the Providence tide gauge in 2016. The IA tool allows the user to set a specific water level, such as the minor or moderate flooding threshold, and a specific date range. For each inundation event, the IA tool plots the duration of inundation versus elevation above MHHW.

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Climate Change Stressors

Sea Level

Figure 2. Historical sea level rise trend at Providence, Rhode Island, tide gauge station from 1938 to 2015. Source: NOAA Tides and Currents – Mean Sea Level Trend for Providence, RI # 8454000.

Table 2. Sea level trends by geographical scale and source. Note that some of the data presented are relative sea level rise, and others are global or eustatic sea level rise.

<table>
<thead>
<tr>
<th>Spatial Scale</th>
<th>Source</th>
<th>Time Scale for Calculating Sea Level Trends By Sources</th>
<th>Rate of Trends mm/ yr</th>
<th>inch/ decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newport</td>
<td>NOAA (2015)</td>
<td>1930-2015</td>
<td>2.72</td>
<td>1.1</td>
</tr>
<tr>
<td>Providence</td>
<td>NOAA (2015)</td>
<td>1938-2015</td>
<td>2.22</td>
<td>0.9</td>
</tr>
<tr>
<td>Newport</td>
<td>FSMSL1</td>
<td>1985-2014</td>
<td>4.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Newport</td>
<td>Carey et al</td>
<td>1984-2011</td>
<td>4.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Global</td>
<td>IPCC2</td>
<td>1993-2010</td>
<td>1.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Global</td>
<td>IPCC3</td>
<td>1993-2010</td>
<td>3.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Global</td>
<td>Satellite altimetry</td>
<td>1993-2016</td>
<td>3.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Global</td>
<td>Hay et al4</td>
<td>1991-1990</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Regional</td>
<td>Engelhart et al4</td>
<td>1991-1990</td>
<td>1.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Source:
1. Permanent Service for Mean Sea Level (PSMSL) collects and analyses relative sea level data from a global network of tide gauges. For Newport, the mean annual rate of sea level rise trend from the last thirty years (1985–2014) was approximately 1.7 inches (4.3 centimeters) per decade. The PSMSL analysis used the NOAA (2015) data from Newport but included only a portion of the complete record. Carey et al. (2017a) also calculated relative sea level rise using a portion of the NOAA (2015) data for Newport (1984–2011) with similar results.
2. The Intergovernmental Panel on Climate Change (IPCC) estimated a global or eustatic mean rate of sea level rise of 0.7 inches (1.8 centimeters) per decade between 1901 and 2010 for a total sea level rise of 7.3 inches (1.9 meter) (IPCC 2013). Between 1993 and 2010, the rate was higher at 1.3 inches per decade (IPCC 2013).
3. Using satellite altimetry, the Global Mean Sea Level (GMSL) trend (1993–2016) generated from the Integrated Multi-Mission Ocean Altimeter Data for Climate Research (GMSL dataset) was approximately 1.3 inches (3.3 centimeters) per decade (Nerem et al. 2010).
4. An analysis of global sea level rise that corrected for spatial bias in the tide gauge records calculated a rate of 0.5 inches (1.3 centimeters) per decade (from 1901 to 1990) (Hay et al. 2015). Along the U.S. East Coast, the rate was 0.7 inches (1.8 centimeters) per decade during the same period (Engelhart et al. 2009).
Atlantic Meridional Overturning Circulation in 2009 and 2010, which caused a temporary surge in sea level rise (Goddard et al. 2015). Globally, proxy and instrumental sea level data indicate a transition in the late nineteenth century and the early twentieth century from relatively low mean rates of sea level rise over the previous two millennia to higher rates of rise (IPCC 2013). It is likely that the rate of global mean sea level rise has continued to increase since the early twentieth century, and other studies are consistent with the NOAA sea level trends.

**PROJECTED SEA LEVEL RISE**

Two decades ago, the IPCC estimated that global mean sea level would rise between 0.6 foot (0.18 meter) and 1.9 feet (0.58 meter) by 2100. A decade later, estimates were higher, ranging from 1.6 feet (0.49 meter) to 6.6 feet (two meters) by 2100 (Rahmstorf et al. 2007, Horton et al. 2008, Pfeffer et al. 2008, Allison et al. 2009, Richardson et al. 2009). These projections are based on various scenarios of greenhouse gas emissions and the effects on these emissions on global temperature.

In January 2017, NOAA released revised projections for global sea level rise scenarios. The extreme scenario for global mean sea level (GMSL) rise from 2000 to 2100 is 8.2 feet (2.5 meters) (Sweet and colleagues 2017), which is 1.6 feet (0.5 meters) higher than the upper-bound scenario published by NOAA in 2012 (Parris et al. 2012). The revised projections incorporated the growing evidence of accelerated ice loss from Antarctica and Greenland, and other factors. Six GMSL rise scenarios are shown in Table 3.

Along the U.S. Atlantic coast from Virginia northward, including Narragansett Bay, relative sea level rise is projected to be faster than GMSL rise. Sweet and colleagues (2017) estimated that under the Intermediate-High, High, and Extreme scenarios, the Northeast region would experience relative sea level rise that exceeds GMSL rise by one to three feet (0.3 to 1.0 meter) by 2100.

For the Newport tide gauge station, NOAA has provided projections of relative sea level rise to 2100 (Sweet et al. 2017), including three sub-scenarios (Low, Medium, High) for each scenario. Under the Extreme scenario of GMSL rise (8.2 feet; 2.5 meters), the relative sea level rise at Newport under the Medium sub-scenario (50th percentile) is 0.92 foot (0.28 meter) from 2000 to 2020 and 11.15 feet (3.40 meters) from 2000 to 2100 (Table 4). Figure 3 shows the relative sea level change at the Newport tide gauge, in each of the six GMSL rise scenarios (Low to Extreme) as well as the relative sea level rise caused by vertical land movement (VML) only.

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**Table 3.** NOAA’s revised projections for global mean sea level (GMSL) rise from 2000 to 2100.

<table>
<thead>
<tr>
<th>GMSL Scenarios</th>
<th>GMSL Rise (2000–2100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0.3 meters</td>
</tr>
<tr>
<td>Intermediate-Low</td>
<td>0.5</td>
</tr>
<tr>
<td>Intermediate</td>
<td>1.0</td>
</tr>
<tr>
<td>Intermediate-High</td>
<td>1.5</td>
</tr>
<tr>
<td>High</td>
<td>2.0</td>
</tr>
<tr>
<td>Extreme</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Source: Sweet et al. (2017)

**Table 4.** NOAA’s sub-scenarios of projected relative sea level rise (in feet) at Newport, Rhode Island, under the Extreme scenario of 8.2 feet (2.5 meters) of global mean sea level rise by 2100.

<table>
<thead>
<tr>
<th>Sub-scenarios$^{(1)}$</th>
<th>2000-2020</th>
<th>2000-2050</th>
<th>2000-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>17th percentile</td>
<td>0.45</td>
<td>2.2</td>
</tr>
<tr>
<td>Medium</td>
<td>50th percentile</td>
<td>0.92</td>
<td>3.41</td>
</tr>
<tr>
<td>High$^{(2)}$</td>
<td>83rd percentile</td>
<td>1.02</td>
<td>3.71</td>
</tr>
</tbody>
</table>

$^{(1)}$ For each GMSL rise scenario, there is a low, medium, and high sub-scenario, corresponding to the 17th, 50th, and 83rd percentile of the climate-related sea level projections consistent with the GMSL scenario.

$^{(2)}$ Shown in Figure 4 for the Sweet et al. (2017) extreme scenario.

Source: Sweet et al. (2017) and the database that accompanies that NOAA technical report.
Figure 3. NOAA projections for relative sea level rise through 2100 at the Newport, Rhode Island, tide gauge station for the Intermediate GMSL scenario (1 meter) under six different climate change scenarios. 66 Percentile Confidence Range for the Intermediate Scenario is shown. Vertical Land Movement (VML): 0.00322 feet/year, as shown in the lowest curve. All values expressed in feet. Lines shown are the result of interpolation between values plotted. (Revised July 18th, 2017, http://www.corpsclimate.us/ccaceslcurves.cfm) Data Sources: Sweet et al. (2017). Charts: U.S. Army Corps of Engineers Sea Level Change Curve Calculator.

Table 5. Estimates of the land area, number of buildings, and population along Rhode Island’s coastline in Narragansett Bay that will be affected by sea level rise scenarios of one, three, and seven feet above MHHW.

<table>
<thead>
<tr>
<th>Sea Level Rise Scenarios</th>
<th>SLR 1 ft</th>
<th>SLR 3 ft</th>
<th>SLR 7 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area in Square Miles (Acres)(^{(3)})</td>
<td>3.2 (2,025)</td>
<td>7.2 (4,623)</td>
<td>17.2 (10,956)</td>
</tr>
<tr>
<td>Number of Buildings(^{(2)})</td>
<td>14</td>
<td>283</td>
<td>3,765</td>
</tr>
<tr>
<td>Population(^{(2)})</td>
<td>267</td>
<td>1,667</td>
<td>10,274</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Also includes a few areas in Massachusetts around the Palmer River, inherent from STORMTOOLS
\(^{(2)}\) Location of buildings from e911 database as of February 2017
\(^{(3)}\) Based on 2010 population from dasymetric analysis (see “Population” chapter)

Data: RIGIS. 2015 NACCS-Derived Inundation Surfaces for Rhode Island Incorporating the Effects of Both Storm Surge and Tide and Rhode Island E 9-1-1 Uniform Telephone System.
Figure 4. Map of select focus areas in the Rhode Island portion of the Narragansett Bay Watershed showing areas predicted to be inundated by one, three, or seven feet of sea level rise based on STORMTOOLS (developed for Rhode Island only). Red indicates areas where people live and that are projected to be inundated with seven feet of sea level rise. A total of 10,274 people (see Table 5) live in those areas, based on dasymetric analysis (see “Population” chapter).
Figure 5. SLAMM model results for Barrington, Rhode Island, showing potential areas of salt marsh losses and salt marsh migration with five feet of sea level rise. Source: CRMC (2015)
Visualization of Sea Level Rise Scenarios

Sea Level Rise Impacts on the Landscape

The estimated land area and number of buildings in the Rhode Island part of Narragansett Bay that would be flooded under three different sea level rise scenarios, not considering storm surge, are shown in Table 5. The number of buildings includes current structures of all types, such as residential, educational, and commercial. A map of areas and population distribution affected by sea level rise scenarios is presented in Figure 4. Across the coastal areas of Rhode Island along Narragansett Bay, the estimated impacts of sea level rise in the three scenarios chosen for this analysis should be considered underestimates if development and population continue to increase within the land areas projected to be exposed to permanent flooding.

Sea Level Rise Impacts on Estuarine Habitats

Results from SLAMM for Rhode Island suggest that under scenarios of one, three, or five feet of sea level rise, the state could lose 13, 52, or 87 percent of its existing salt marshes, respectively. SLAMM results also indicate locations where marshes may, hypothetically, migrate landward in response to sea level rise. However, given that rates of sea level rise are projected to accelerate, perhaps quite dramatically, it is likely that the process of landward migration by marshes could be impeded by rapid sea level rise, similar to the marsh platform being unable to keep pace with sea level and becoming submerged. In addition, development such as seawalls, bulkheads, and roads in urban and suburban areas that are common in the Narragansett Bay Watershed, along with relatively steep upland slopes in some areas, will impede landward marsh migration. Field research and modeling are needed to better understand the landward marsh migration process under regimes of accelerated sea level rise, while also pursuing efforts to preserve upland areas that could serve as suitable migration corridors assuming that salt marshes will maintain some capacity to move landward. The SLAMM model is a useful tool for identifying these corridors where upland slopes are slight and free of obstructions. Figure 5 is an example of SLAMM results for Barrington, Rhode Island, including potential areas of salt marsh losses and salt marsh migration in a scenario of five feet of sea level rise.

As discussed above in the Methods section, SLAMM results for Massachusetts were not available at the time this chapter was completed, but a final report and data summaries were in production.

STATUS OF NUISANCE FLOODING

At the Providence tide gauge station, NOAA’s Inundation Analysis Tool (IA) showed a total of three nuisance tidal inundation events in 2016 (Figure 6). The observed nuisance flood events ranged from 2.3 to 2.6 feet (0.7 to 0.8 meter) above MHHW. Tidal inundation events such as those observed in 2016 are expected to become increasingly common, consistent with the view that today’s flood tide will become tomorrow’s high tide.

Figure 6. Elevation and duration of inundation events in 2016 at Providence tide gauge station. Red dashed line indicates the threshold for nuisance flooding as defined for this station by Sweet et al. (2016). Source: NOAA (2016)

Discussion

Tide gauge data show that sea level in Narragansett Bay has risen approximately an inch per decade since 1930, and the pace appears to have accelerated in recent decades (Table 2; PSML 2014, Carey et al. 2017a). Over the last 85 years, sea level at Providence has increased by nine inches, and further increases of up to eleven feet are projected for Narragansett Bay by the end of the century under an extreme scenario of accelerated sea level rise (Figure 3; Sweet et al. 2017). That projection is approximately five feet higher than what was projected in 2012 (Figure 7; Parris et al. 2012).

It is documented that sea level rise is accelerating globally and that from Cape Hatteras, North Carolina, to the Canadian Maritime Provinces the rate of relative sea level rise is greater than the global average rate of sea level rise. NOAA projects that by 2100 sea level rise in the northeastern United States could be eleven to twenty inches greater than the 8.2-foot rise projected for global mean sea level (Sweet et al. 2017).
Approximately three, seven, or seventeen square miles of land in Rhode Island around Narragansett Bay would be flooded permanently with sea level rise of one, three, or seven feet, respectively (Table 5). With the potential for nearly 11,000 acres of permanently flooded land in low-lying areas of the Rhode Island coast, not even considering scenarios with storm surge, there are very significant socio-economic and ecological implications given the extensive urbanization and development along the coastline. The Rhode Island Statewide Planning Program has begun to integrate sea level rise and climate change into its comprehensive planning process by using STORMTOOLS to calculate socioeconomic indicators for different sea level rise scenarios (Rhode Island Statewide Planning 2015).

If population continues to grow as expected in these coastal areas, leading to an increase in urban development (see “Population” and “Land Use” chapters), the impacts of sea level rise and nuisance flooding will be exacerbated. Based on geospatial analysis and calculations by the Estuary Program for areas of Rhode Island in the Narragansett Bay Watershed, approximately 283 buildings would be permanently flooded when the sea rises three feet, and 3,765 buildings would be flooded with seven feet of sea level rise (Table 5). Similarly, between 267 and 10,274 people who currently reside in these coastal areas of Narragansett Bay will be affected by sea levels rising one to seven feet, respectively (Figure 4). Those magnitudes of sea level rise are projected to occur by approximately 2050 and 2080, respectively, under the extreme sea level rise scenario (Sweet et al. 2017). Because these calculations do not include the Massachusetts portion of Narragansett Bay, except for some areas around the Palmer River, the impacts for the entire Narragansett Bay are expected to be even greater than these estimates.

Roads, stormwater and wastewater infrastructure, residential homes, commercial enterprises, beaches, tourism, water quality (surface and groundwater), and habitats are already being impacted by tidal inundation, especially during extreme high tides, causing nuisance flooding in low-lying areas around the Bay. With higher sea levels, local flooding thresholds can be reached more easily during average high tides (Dahl et al. 2017). Nuisance flooding, even with little or no storm surge, is increasingly common along the East and Gulf Coasts of the United States (Sweet et al. 2014). The frequency of nuisance flooding in the Northeast region is projected to increase 25-fold by the year 2045 due to sea level rise (Dahl et al. 2017).

Figure 7. NOAA projections for relative sea level rise from 2010 to 2100 at Newport, Rhode Island, under a range of climate change scenarios. Projections published in 2012 (Parris et al. 2012). See Figure 3 for updated NOAA projections published in 2017. Source: USACE Sea Level Rise Curves.
Figure 8. Example of STORMTOOLS viewer for a section of Narragansett Bay’s coastal area (Wickford Harbor). Source: STORMTOOLS for Beginners
Many of the buildings subject to flooding are served by onsite wastewater treatment systems, and the combination of elevated groundwater levels driven by sea level rise and overland flooding will put those systems at high risk of failing (Walter et al. 2016). Areas with failed septic systems pose a high risk of water quality degradation along the coast (see “Wastewater Infrastructure” chapter). Likewise, wastewater treatment facilities (WWTF) are also threatened by sea level rise. The Rhode Island Department of Environmental Management (RIDEM) completed a vulnerability study for the major municipal WWTFs, which treat approximately 120 million gallons of sewage per day. With sea level rise of one to five feet, two-thirds of the fifteen coastal WWTFs in the state will experience flooding, compromising water quality and raising public health concerns (RIDEM and Woodard & Curran 2017). Of the facilities located in the Narragansett Bay Watershed, five facilities will be predominantly inundated, four will be partially inundated, and five will not be affected by sea level rise of five feet.

Coastal and estuarine natural habitats are also threatened by higher sea levels. Of the approximately 3,320 acres of salt marsh in Narragansett Bay, a significant proportion may be submerged or lost if sea level rises one to five feet (CRMC 2015; see “Salt Marsh” chapter). Frequent flooding and conversion of some Narragansett Bay salt marshes to mudflats and open water is already occurring, as these coastal wetlands cannot gain sufficient elevation to keep up with sea level rise (CRMC 2015, Raposa et al. 2017). This trend of salt marshes being stressed by sea level rise, among other factors, and becoming wetter has been reported elsewhere in southern New England (Smith 2015, Carey et al. 2017b, Watson et al. 2017). The CRMC, based on SLAMM modeling, expects that total statewide losses of existing coastal wetlands may be 13 percent, 52 percent, or 87 percent under one, three, or five feet of sea level rise, respectively. The SLAMM study also suggested, hypothetically, that if wetlands were able to migrate landward onto currently developed and undeveloped areas the amount of coastal wetlands could increase (CRMC 2015). However, while some coastal areas are currently protected as open space and might potentially be suitable for wetland migration, very few significant natural lands remain unreserved along the Bay’s shoreline (see “Open Space” chapter). The CRMC’s results cover Rhode Island only; results for Massachusetts are forthcoming from the Massachusetts Office of Coastal Zone Management.

The loss of coastal wetlands would mean a loss of the protection they provide to the coast as an important natural barrier to storm surge. There is evidence that reefs and wetlands help protect coastlines by reducing wave energy (Shepard et al. 2011, Ferrario et al. 2014, Narayan et al. 2016). A recent study estimated that during Hurricane Sandy the presence of wetlands reduced statewide property damages by $300,000 in Rhode Island and $6,300,000 in Massachusetts, and that on average where wetlands were present they reduced damages by more than ten percent (Narayan et al. 2016).

Seagrass habitats are also threatened by higher sea levels, especially in Narragansett Bay where there is some evidence of slow recovery (see “Seagrasses” chapter). Sea level rise is expected to change the tidal regime and water depth of Narragansett Bay, affecting the distribution of seagrasses (Short and Neckles 1999, Saunders et al. 2013, USEPA 2016). When sea level rises by 1.6 feet, which is projected to occur by 2030 (Sweet et al. 2017), the increase in water depth could reduce seagrass growth in existing seagrass beds by 30 to 40 percent (Short and Neckles 1999), impairing further restoration and recovery efforts, although seagrass can migrate to shallower areas—if conditions are appropriate—as upland areas are submerged (see “Seagrasses” chapter).

The research, findings, predictions, and implications of sea level rise should be considered in planning actions, as many of the Estuary Program’s partners are already doing. The states of Rhode Island and Massachusetts are actively planning for future sea level rise. The Rhode Island CRMC accounts for sea level rise in Section 145 of the Rhode Island Coastal Resource Management Plan, and many tools—such as STORMTOOLS (Figure 8) and SLAMM—are available for planners, businesses, and homeowners to understand the future effects of sea level rise.

**Data Gaps and Research Needs**

- The STORMTOOLS model should be expanded to include the Massachusetts portion of Narragansett Bay to identify and evaluate high-risk areas.
- An analysis of the potential impacts of sea level rise on groundwater, drinking water supplies, floodplains, and individual wastewater treatment systems is needed (Walter et al. 2016).
- Data and research are needed to evaluate the effects of sea level rise on other ecological systems at the landscape and seascape level, such as the impacts on bird, mammal, and amphibian migration and breeding habitat, submerged aquatic vegetation, freshwater wetlands (palustrine and lacustrine), estuarine beaches and shores, shellfish habitat, and fish passage habitat (diadromous and anadromous fish).
• A sea level rise trend analysis is needed for Mount Hope Bay using data from the Fall River tide gauge, which NOAA has operated since 1955. This analysis is especially important because of the low elevations of the Taunton River watershed.

• Enhanced bathymetry data would improve the resolution of the hydrodynamic models that are used to predict flooding potential from sea level rise and storm surge.

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Climate Change Stressors

Sea Level


