SEA LEVEL

Draft – April 2017

1. OVERVIEW

Sea level rise and the increasing frequency of nuisance flooding are stressors to human activities, infrastructure, and natural habitat along Narragansett Bay's shoreline and adjacent floodplains. The National Oceanic and Atmospheric Administration (NOAA) tide gauges in Narragansett Bay have measured increases of mean sea levels of 9 inches (22.9 centimeters) from 1930 to 2015 at Newport and 6.6 inches (16.8 centimeters) from 1938 to 2015 at Providence. Sea level has been rising approximately 1 inch (2.5 centimeters) per decade, and the rate is predicted to accelerate. NOAA's most recent worst-case projection for relative sea level rise in the northeastern U.S. coastal region is an increase of 9.8 feet (3 meters) by 2100 (NOAA 2017).

2. INTRODUCTION

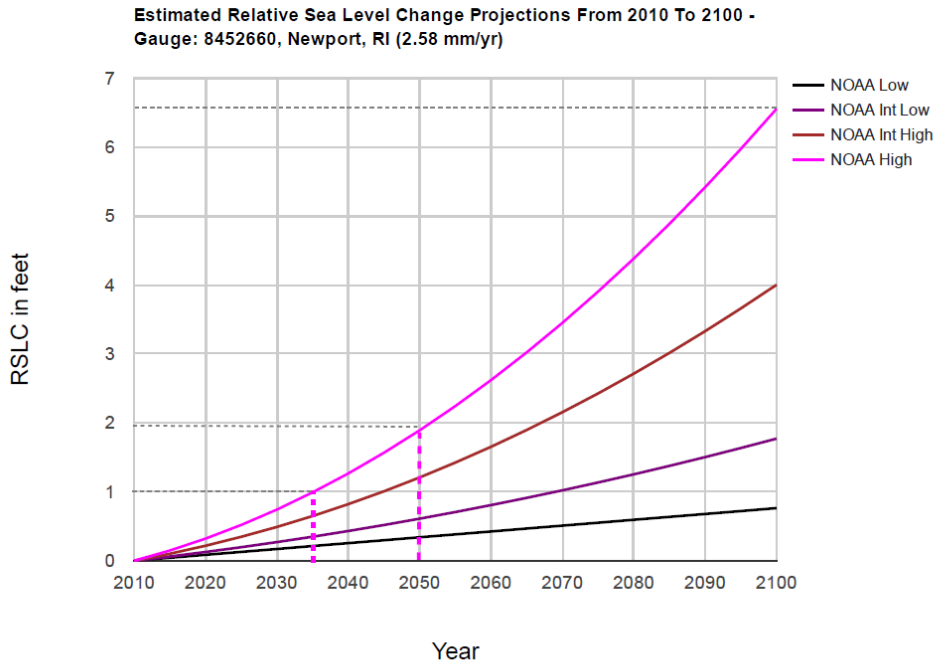
Sea level is the height of the sea with respect to a standardized reference elevation, or datum. Sea levels are rising at an accelerating rate along most of the world's coastlines (IPCC 2013). At the global scale, sea level is rising because of two main processes: (1) seawater is becoming warmer, causing the seawater to expand in volume, and (2) glaciers and the polar ice sheets are melting, causing more water to enter the ocean. The global change in sea level is termed eustatic sea level rise. Carbon dioxide and other greenhouse gases in the atmosphere cause warming of the atmosphere and oceans, and contribute to sea level rise. The average annual temperature of Narragansett Bay's estuarine waters increased 1.4–1.6°C (2.5–2.9°F) from 1960 to 2010 (see "Temperature" chapter). As there is a time lag in sea level rise in response to climate change, sea levels are expected to increase for hundreds of years into the future regardless of steps taken to curb global greenhouse gas emissions (IPCC 2007).

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 and 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 slowly as a result of past glacial activity. Subsidence 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 8.8 millimeters (0.35 inch) 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, Yin et al. 2009). As 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) has formally adopted NOAA's sea level rise projections for Newport, Rhode Island (Parris et al 2012.) In 2015, NOAA Sea Level Rise Curves suggested that relative sea level rise at Newport would be a maximum of approximately 1.0 foot in 2035 and 2.0 feet in 2050 (Figure 1).

Figure 1. NOAA's Curves for Projections of Coastal Flooding in Newport tide gauge by 2100.



Source: U.S Army Corp. Sea Level Rise Curves

However, in January 2017 NOAA updated its scenarios of global mean sea level (GMSL) rise, integrating regional factors that contribute to sea level changes along the U.S. coast (NOAA 2017). The updated scenarios account for (1) shifts in oceanographic factors such as circulation patterns, (2) changes in Earth's gravitational field and rotation, and (3) vertical movement (subsidence or uplift). Although in 2015 NOAA estimated a maximum of approximately 6.6 feet (2 meters) of sea level rise at Newport by 2100 (Figure 1), the updated estimated maximum for the northeastern U.S. coastal region is substantially greater: 9.8 feet (3 meters).

Numerous other sources have also estimated future 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 ago, estimates were higher, ranging from 1.6 feet (0.49 meter) to 6.6 feet (2 meters) (Rahmstorf et al. 2007, Horton et al. 2008, Pfeffer et al. 2008, Allison et al. 2009, Richardson et al. 2009). As evidenced by NOAA's 2017 report, the most recent scientific observations indicate an even greater expected increase in sea level rise by the end of this century.

3. METHODS

A. Historical 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 (NOAA 2013), 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. Local tidal measurements should not be transferred to other places, which may have different oceanographic or geomorphic characteristics. NOAA uses monthly mean sea level data to characterize linear trends, average seasonal cycles, and interannual variations.

Long-term datasets from NOAA stations can be used to analyze historical sea level rise trends and to develop projections for future sea level rise. The Narragansett Bay Estuary Program used NOAA Tides and Currents data to identify water levels and sea level trends for tide gauge stations in Narragansett Bay. Table 1 summarizes the types of information for each tide gauge station and provides definitions used throughout this chapter.

Table 1. Definitions of selected terms used this chapter.

Term		**Definition**
Tidal Datum		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.
National Tidal Datum Epoch	(NTDE)	An epoch is a 19-year tidal cycle used to calculate datums. The present National Tidal Datum Epoch (NTDE) is 1983 through 2001.
Station Datum	(STND)	A fixed base elevation at a tide station to which all water level measurements refer. It is unique to each station.
Mean Sea Level	(MSL)	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. It is the reference datum for calculating sea level trends.
Mean Higher High Water	(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.
Mean Lower Low Water	(MLLW)	The average of all the lower low water heights observed over the National Tidal Datum Epoch.

Source: NOAA

The following are the tide datums for gauges with historical trends in Narragansett Bay:

a) Newport tide gauge
   Current mean sea level: 3.63 feet (1.11 meters)
   Mean Higher High Water: 5.74 feet (1.75 meters)
   Mean Lower Low Water: 1.89 feet (0.58 meters)
   Source: NOAA Tides and Currents: Datums for Newport, RI # 8452660

b) Providence tide gauge
   Current mean sea level: 5.74 feet (1.75 meters)
   Mean Higher High Water: 8.33 feet (2.5 meters
   Mean Lower Low Water: 3.49 feet (1.06 meters)
   Source: NOAA Tides & Currents: Datums for Providence, RI # 8454000

In Narragansett Bay, historical trends are available for two active tide gauges: Newport (station #8452660) and Providence (station #8454000), where mean sea levels have been measured since 1930 and 1938 respectively.

NOAA does not provide sea level trends for any other tide gauge stations in Narragansett Bay, such as the Fall River tide gauge station in Mount Hope Bay, because records for those stations cover much shorter time periods.

To analyze global trends in sea level, the Narragansett Bay Estuary Program used measurements collected since 1993 using satellite radar altimeters (sealevel.colorado.edu). The measurements were monitored continuously against a network of tide gauges, and estimates were revised approximately every two months to improve the quality of data.

B. Projected Sea Level Rise

For this report, the Narragansett Bay Estuary Program used a summary of current sea level rise projections with the understanding that the science will continue to develop and projections will be modified over time. The primary source for current projections affecting Narragansett Bay was the recent NOAA forecast for global mean sea level (GMSL) and regional relative mean sea level rise (NOAA 2017).

There is high uncertainty regarding the rate of ice sheet breakup and melting. However, increasing evidence in the scientific literature indicates that the rate of ice sheet disintegration and melting is much greater than previously anticipated. Beyond an unknown threshold, a collapse of the polar ice sheets, especially in Greenland, will be inevitable and irreversible. Total loss of the Greenland ice sheet would raise global sea levels by approximately 24 feet (7 meters) (Overpeck et. al. 2006, DeConto and Pollard 2016, Hansen et. al. 2016).

C. Visualization of Sea Level Rise Scenarios

Government agencies have developed a number of online map viewers 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 the incomparability of the data and different spatial and time scales among viewers, we chose to focus on information from two well-established sources, STORMTOOLS and the Sea Level Affecting Marshes Model, and did not attempt to reconcile data from different national and state sea level rise viewers. The following are relevant data and tools sea level projections in Narragansett Bay.

i. Sea Level Rise Impacts on the Landscape

At the state level, STORMTOOLS was developed by the University of Rhode Island for the CRMC to aid state and local adaptation planning efforts. 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 Island that would be affected by different amounts of sea level rise (1–7 feet, 0.3–2.1 meters) with or without storm surge (predictions for 25-, 50-, and 100-year return interval storms) at a 95 percent confidence level.

We used the Rhode Island e911 Exposure Assessment in STORMTOOLS to identify buildings exposed to flooding in 21 coastal communities. The e911 database contains location data for all structures in the state with known street addresses.

ii. Sea Level Rise Impacts on Estuarine Habitats

The Sea Level Affecting Marshes Model (SLAMM) was completed for Rhode Island in 2015 (CRMC 2015). It focuses specifically on salt marsh vulnerability to sea level rise. A series of maps depict areas of salt marsh, parcel by parcel, that will persist or be lost under scenarios of 1, 3, or 5 feet (0.3, 0.9, or

1.5 meters) of sea level rise. SLAMM also predicts areas where marshes may migrate landward in response to the different sea level rise scenarios (CRMC 2015).

D. Nuisance Flooding

Nuisance flooding is defined as a water level that exceeds the National Weather Service's local threshold (water.weather.gov/ahps) for minor flooding impacts, established for emergency preparedness (Sweet et al. 2014, 2015, 2016). Nuisance flooding is measured based on NOAA tide gauges (tidesandcurrents.noaa.gov).

For Providence, nuisance flooding is 2.16 feet (0.66 meter) above Mean Higher High Water (MHHW) (Sweet el al. 2014). This is the level at which buildings and infrastructure will be flooded by MHHW. The Providence tide gauge is the only station in Narragansett Bay with an established threshold for nuisance flooding. The thresholds in other areas of the Narragansett Bay watershed may be different.

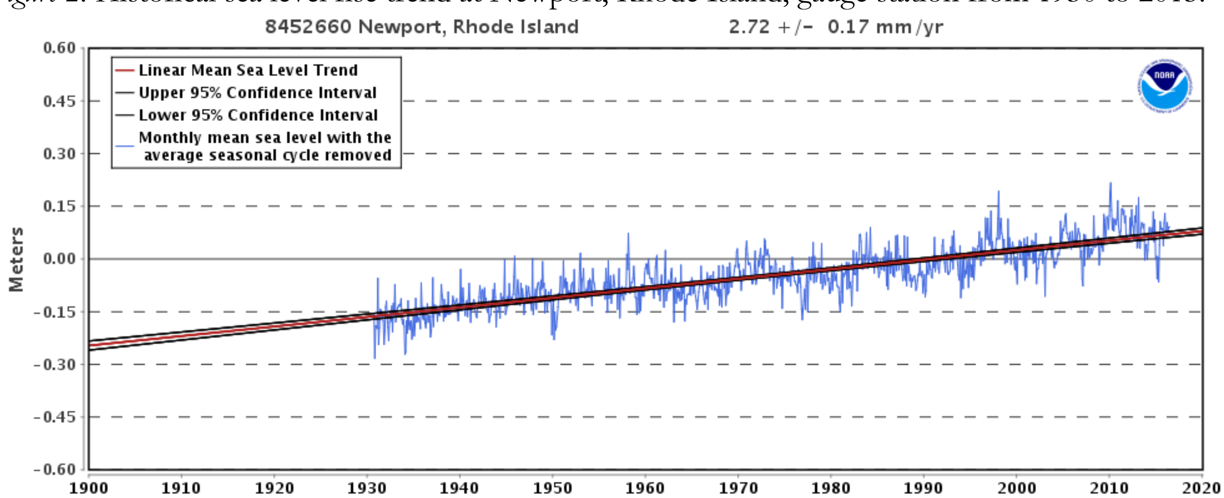
The Narragansett Bay Estuary Program used NOAA's Inundation Analysis Tool (IA) (NOAA 2013) to calculate the number of nuisance flooding events for which the threshold (above 0.66m of MHHW) exceeded at the Providence tide gauge. The IA tool allows the user to set a specific water level (for example, the minor or moderate flooding threshold) and a specific date range. The IA tool plots the number of events represented by the duration of inundation versus elevation above MHHW; for the purpose of this report, we chose between January 1, 2016 and December 31, 2016, to determine the most recent nuisance flooding events at Providence tide gauge.

4. STATUS, TRENDS, AND PROJECTIONS

A. Trends of Sea Level Rise

The long-term historical rate of relative sea level rise at the Newport tide gauge, averaged over the 1930 to 2015 period, was approximately 1.1 inches (2.7 centimeters) per decade. Sea level rose a total of more than 9 inches over the 85-year period (Figure 2). At that rate, sea level would rise 10.7 inches (0.27 meter) over 100 years.

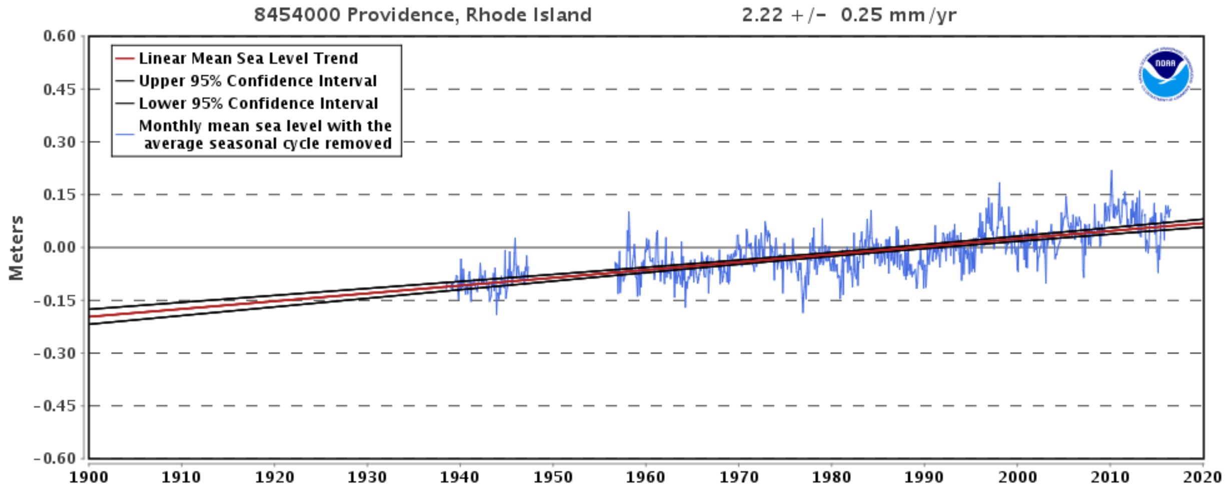
Figure 2. Historical sea level rise trend at Newport, Rhode Island, gauge station from 1930 to 2015.



Source: NOAA Tides and Currents – Mean Sea Level Trend for Newport, RI #8452660

At the Providence tide gauge, based on monthly mean sea level data from 1938 to 2015, relative sea level increased by approximately 0.9 inch (2.2 centimeters) per decade for a total of 6.6 inches (16.9 centimeters) over the 76-year period. At that rate, sea level would rise 8.9 inches (22.6 centimeters) over 100 years (Figure 3).

Figure 3. Historical sea level rise trend at Providence, Rhode Island, gauge station from 1938 to 2015.



Source: NOAA Tides and Currents – Mean Sea Level Trend for Providence, RI # 8454000

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. Table 2 summarizes sea level trends reported by different sources and at varying geographical and temporal scales. Recent rates for both relative sea level rise (for Newport and Providence) and global sea level rise appear to have accelerated over the past several decades, when compared to the longer-term rates (Table 2). However, caution is advisable when citing short-term data sets (less than 30 years) because of inherently large regression errors and anomalous oceanographic events such as the 2009–2010 slowdown in the Atlantic Meridional Overturning Circulation that caused a temporary surge in sea level rise (Goddard et al. 2015).

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 sea level rise.

Scale	Source	Timeline for Calculating Sea Level Trends													Rate	
		1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020	mm/ yr	inch/ decade
Newport	***NOAA (2015)***				***1930-2015***										***2.72***	***1.1***
Providence	***NOAA (2015)***				***1938-2015***										***2.22***	***0.9***
Newport	PSMSL[1]									1985-2014					4.2	1.7
Newport	Carey et al[1]									1984-2011					4.1	1.6
Global	IPCC[2]	1901-2010													1.7	0.7
Global	IPCC[2]										1993-2010				3.2	1.3
Global	Satellite altimetry[3]										1993-2016				3.4	1.3
Global	Hay et al[4]	1901-1990													1.2	0.5
Regional	Engelhart et al[4]	1901-1990													1.8	0.7

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 4.17 ±0.79 centimeters (approximately 1.7 inches) per decade. The PSMSL analysis used the NOAA (2015) data from Newport but included only a portion of the complete record. Carey et al. (2014) also calculated relative sea level rise using a portion of the NOAA (2015) data for Newport with similar results.
2. The Intergovernmental Panel on Climate Change (IPCC) estimated a global or eustatic mean rate of sea level rise of 1.7 centimeters (0.7 inches) per decade between 1901 and 2010 for a total sea level rise of 0.19 meter (7.3 inches) (IPCC 2013). Between 1993 and 2010, the rate was higher at 3.2 centimeters (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 3.4±0.4 centimeters (approximately 1.3 inches) per decade (Nerem et al. 2010) (Figure 4).
4. An analysis of global sea level rise that corrected for spatial bias in the tide gauge records calculated a rate of 1.2 centimeters (0.5 inches) per decade from 1901 to 1990 (Hay et al. 2015). Along the U.S. East Coast, the rate was 1.8 centimeters (0.7 inches) per decade during the same period (Engelhart et al. 2009).

Figure 4. Global mean sea level based on satellite data (1993–2016).

Source: NASA Satellite sea level observations. Credit: Jet Propulsion Laboratory (JPL) and California Institute of Technology.

B. Projected Sea Level Rise

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 was increased to 2.5 meters (8.2 feet) (NOAA 2017). The revised projections incorporated the growing evidence of accelerated ice loss from Antarctica and Greenland. Six GMSL rise scenarios for 2050 and 2100 are shown in Table 3.

Table 3. Revised projections for global mean sea level (GMSL) rise from 2000–2050 and 2000–2100.

GMSL Scenarios	GMSL Rise (2000–2050)		GMSL Rise (2000–2100)	
Low	0.16 meters	0.5 feet	0.3 meters	1.0 feet
Intermediate-Low	0.24	0.8	0.5	1.6
Intermediate	0.34	1.1	1.0	3.3
Intermediate-High	0.44	1.4	1.5	4.9
High	0.54	1.8	2.0	6.6
Extreme	0.63	2.1	2.5	8.2

Source: NOAA 2017

Along the U.S. Atlantic coast from Virginia northward, including Narragansett Bay, relative sea level rise is projected to be higher than the global average (NOAA 2017). NOAA estimated that under the Intermediate-High, High, and Extreme scenarios the Northeast region will experience relative sea level rise that exceeds GMSL rise by 0.3–1.0 meter (1–3 feet) by 2100. Based on that estimate, approximately 2.8–3.5 meters (9.2–11.2 feet) of sea level rise would occur in the Northeast by 2100 under the Extreme scenario.

C. Visualization of Sea Level Rise Scenarios

i. Sea Level Rise Impacts on the Landscape

Table 4 shows the total number of buildings exposed to flooding based on scenarios of 1, 2, or 7 feet of sea level rise, as well as during a 25-year storm. The results cover only the Rhode Island portion of the Narragansett Bay Estuary Program's study area; data for the Massachusetts portion were unavailable. A 25-year storm was estimated to add a surge of 6.3 feet (see: Storm surge height vs return period based on NACCS estimates).

Table 4. Number of buildings exposed to flooding under sea level rise scenarios of 1, 2, and 7 feet (+25-year storm) for towns within the Narragansett Bay Estuary Program's study area.

Study Area	SLR 1 ft	SLR 2 ft	SLR 7 ft	SLR 1 ft + 25-year storm	SLR 2 ft + 25-year storm	SLR 7 ft + 25-year storm
Narragansett Bay	23	100	3,918	10,757	12,563	21,718
Little Narragansett Bay and Southwest Coastal Ponds[1]	21	114	1,799	2,947	3,402	5,271

[1] Includes the towns of Westerly, Charlestown and South Kingstown

Source: Rhode Island "e911" Exposure Assessment

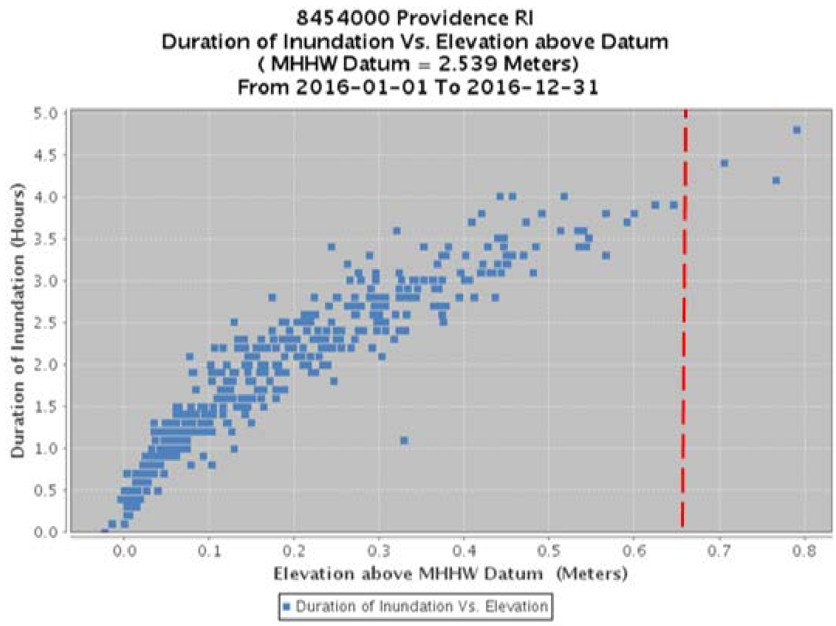
ii. Sea Level Rise Impacts on Estuarine Habitats

Results from SLAMM for coastal areas in Rhode Island showed a 13 percent, 52 percent and 87 percent loss of salt marsh for scenarios of 1, 3, and 5 feet of sea level rise, respectively (CRMC 2015). A similar analysis is currently being conducted for coastal areas in Massachusetts.

D. Status of Nuisance Flooding

At the Providence tide gauge station, NOAA's Inundation Analysis Tool (IA) showed a total of 3 tidal inundation events in 2016 (Figure 6). The observed nuisance flood events ranged from 0.7–0.8 meter (2.3–2.6 feet) above MHHW and were within the near-term tidal flood-frequency outlook projected in the *2015 State of U.S "Nuisance" Tidal Flooding* report (Sweet et al. 2016). 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 5. Elevation and duration of inundation events in 2016 at Providence tide gauge station. Red dashed line indicates nuisance flooding threshold as defined for this station by Sweet et al. (2016).



Source: NOAA, 2016

5. DISCUSSION

Tide gauge data show that sea level has risen more than an inch per decade since 1930 in Narragansett Bay, and this pace appears to be accelerating in recent decades (Carey et al. 2014, PSML 2014; Table 4). Over the last 85 years, local sea levels have increased by 10 inches, and further increases of up to 10 feet or more are projected by the end of the century (NOAA 2017).

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 sea level rise. A report by the Rhode Island Executive Climate Change Coordinating Council states that sea level rise along this section of the North American coastline will likely be 8 to 11 inches (20 to 28 centimeters) greater than the global average sea level rise by 2100 (EC4 2016). In 2017, NOAA published a report that projected sea level rise in the northeastern U.S. would be 11 to 20 inches (30 to 50 centimeters) above the extreme scenario for global mean sea level rise of 8.2 feet.

Sea level rise will have very significant ecological and socio-economic implications in Narragansett Bay given the extensive urbanization and development along the Bay's coastline in Rhode Island and Massachusetts, which is approximately 560 miles long according to geospatial analysis by the Estuary Program. Coastal infrastructure, residential homes, commercial enterprises, beaches, tourism, water quality (surface and groundwater), and habitats are already impacted by inundation. Approximately 6, 13, and 20 square miles (15.5, 33.7, and 51.8 square kilometers) of coastal Rhode Island would be flooded permanently with sea level rise of 1, 3, and 5 feet (0.3, 0.9, 1.5 meters), respectively (Rhode Island EC4 2016).

Continued population growth and increased urban development in the watershed (see "Population" and "Land Use" chapters) will exacerbate the impacts of sea level rise. According to the results of Rhode Island's e911 building assessment of coastal towns around Narragansett Bay, 100 buildings will be flooded when the sea rises 2 feet (0.61 meter) as projected by 2050, and 12,500 buildings will be exposed to flooding when that amount of sea level rise combines with approximately 6.3 feet (1.9 meters) of storm surge estimated for a 25-year storm (Table 4). Similarly, a recent socio-economic analysis concluded that 20 to nearly 7,000 people in residential units would be affected by sea level rise of 1 to 7 feet (0.3 to 2.1 meters), respectively, based on the estimate that approximately 70–73 percent of the residential units located within sea level rise inundation zones are occupied (Rhode Island Statewide Planning Program 2015).

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). Wastewater treatment facilities (WWTF) are also threatened by sea level rise. The Rhode Island Department of Environmental Management completed a vulnerability study for the major municipal WWTFs, which treat approximately 120 million gallons of sewage per day. With sea level rise of 1 to 5 feet (0.3 to 1.5 meters), two-thirds of the 15 coastal WWTFs will experience flooding, compromising water quality and raising public health concerns (RIDEM, in press): 6 facilities will be predominantly inundated (including Westerly in Little Narragansett Bay), 4 will be partially inundated, and 5 will not be affected by sea level rise.

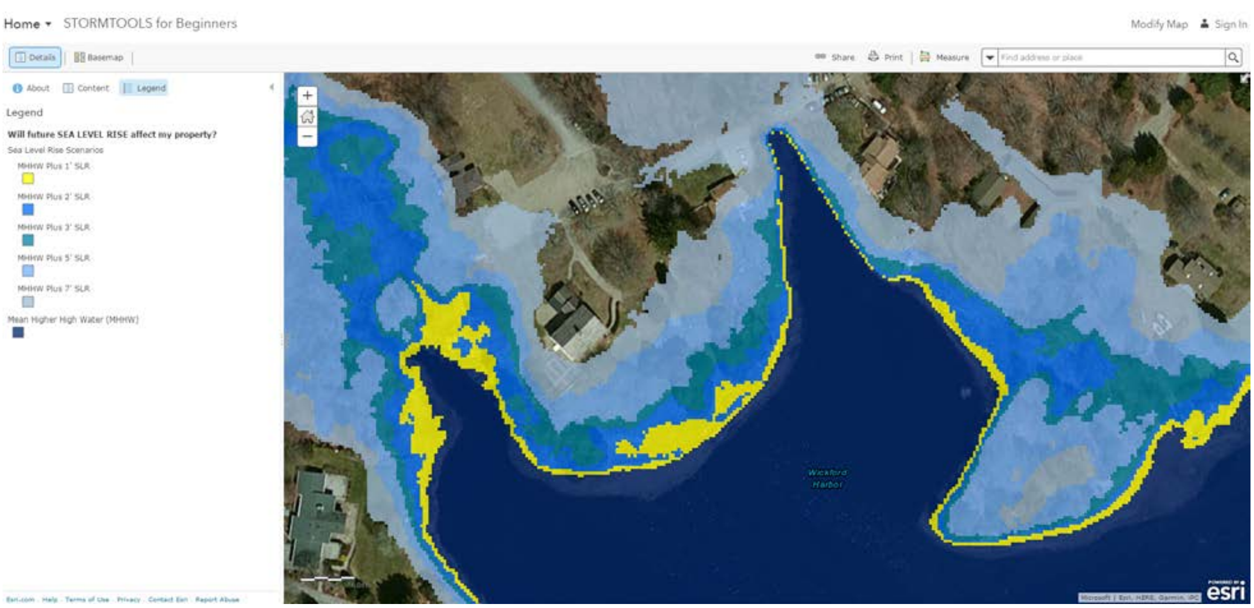
Of the approximately 3,370 acres of salt marsh in Narragansett Bay, 440 to nearly 3,000 acres in Rhode Island are projected to be lost if sea level rises 1 to 5 feet (0.3 to 1.5 meters) (CRMC 2015; see "Salt Marsh" chapter). Frequent flooding and some loss of Narragansett Bay's wetlands is already occurring, as these coastal wetlands, particularly salt marsh, cannot gain sufficient elevation to keep up with sea level rise (CRMC 2015, Raposa et al. 2017). The CRMC expects that total statewide losses of existing coastal wetlands may be 13 percent, 52 percent, and 87 percent under 1, 3, and 5 feet of rise, respectively. If sea level rises 1 foot by 2100, formation of new wetlands is projected to add 38 percent to the total wetland area, whereas that number would fall to only 5 percent with 3 feet of sea level rise, assuming that presently developed shorelines will block wetland migration. However, allowing wetlands to migrate onto currently developed areas would result in 51 percent to 80 percent of new coastal wetlands under the same sea level rise scenarios (CRMC 2015). Those estimates do not include the coastal and estuarine areas in Massachusetts along the Taunton, Cole, Lee, and Palmer Rivers, which have extensive areas of brackish and salt marsh habitat.

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 strong 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 study quantifying the economic benefits of coastal wetlands in reducing property damage from storm events and flooding in the northeastern U.S. estimated for the coastal areas of Rhode Island and Massachusetts that relative savings in property damages from wetlands is $300,000 and $6,300,000, respectively, compared between present and wetland-loss scenarios (Narayan et al. 2016).

With higher sea levels, local flooding thresholds can be reached more easily during average high tides (Dahl et al. 2017). High tide flooding, as measured locally by NOAA tide gauges, is described as “nuisance”, “sunny-day”, or “recurrent”. Nuisance flooding has been found to be increasing more rapidly along the East and Gulf Coasts of the U.S. (Sweet et al. 2014). Such flooding is increasingly common, even with little or no storm surge (Sweet et al. 2014). However, the frequency of nuisance flooding in the Northeast region will increase 25-fold by the year 2045 due to sea level rise (Dahl et al. 2017).

Sea level rise scenarios and flooding events for nuisance flooding and nuisance storms can be visualized using user-friendly map viewers, illustrating areas that are projected to be affected under different scenarios (Figure 4). Rhode Island is actively planning for future sea level rise. The CRMC accounts for sea level rise in Section 145 of the Rhode Island Coastal Resource Management Plan, and many tools—such as STORMTOOLS, SLAMM, and e911—are available for planners, businesses, and homeowners to understand the future effects of sea level rise. Tools developed at the national scale can also be used to visualize the extent of sea level rise along the U.S coastline, such as [NOAA’s Sea Level Rise Viewer](#).

Figure 4. Example of STORMTOOLS viewer for a section of Narragansett Bay’s coastal area (Wickford Harbor)



Source: STORMTOOLS for Beginners

6. DATA GAPS AND RESEARCH NEEDS

Because of the growing awareness and concern at state and local levels regarding sea level rise in this region, it is important to prioritize bi-state efforts to collect and use data that can be used to create models for the entire Narragansett Bay, as opposed to state-focused efforts. STORMTOOLS, which has the best resolution (at the parcel level) for sea level rise scenarios and other capabilities, should be completed for the entire Bay, including Mount Hope Bay and other Massachusetts areas. Improving collaboration and coordination across state lines to analyze data and develop predictions and models for sea level rise and nuisance flooding for the entire Narragansett Bay is imperative to identify issues at the full scale.

Once this information is developed for the entire Bay, it will be valuable for continued research into impacts on the Bay's watershed and estuarine areas. For example, an inventory of onsite wastewater infrastructure, at the parcel level, is needed to identify "hot spots" or areas of high potential risk to water quality in response to sea level rise, nuisance flooding, and storms. There are also gaps in building- or parcel-scale data on onsite wastewater infrastructure that will be burdened by increased frequency of inundation. An inventory of storm water infrastructure is needed, as nuisance flooding will continue to affect the effectiveness of storm water systems, leaving storm drains and other infrastructure—including those designed as green infrastructure—vulnerable, and failing, with consequences for water quality from pathogens and nutrients. Models should be developed to estimate the potential risks to public health, habitat, and wildlife from wastewater treatment plant facilities, onsite wastewater treatment systems, and stormwater infrastructure compromised by sea level rise and flooding. Analyzing potential impacts of sea level rise on ground water and drinking water supplies in coastal areas and floodplains is also important, perhaps employing study methods similar to a recent effort on Cape Cod (Walter et al. 2016).

Continued research into salt marsh migration is needed to determine current migration rates and patterns, the factors that affect those rates, and methods that can enhance salt marsh migration. In addition, identification and prioritization of parcels along the entire coast of Narragansett Bay suitable for salt marsh migration—open space, agricultural fields and other areas with no artificial barriers—would enable state officials and landowners to promote salt marsh restoration and protection actions. Likewise, 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 bird, mammal, and amphibian migration grounds, submerged aquatic vegetation, freshwater wetlands (palustrine and lacustrine), shellfish habitat, fish passage habitat (diadromous and anadromous fish), and fish species and assemblages.

An analysis of the entire Bay should be conducted to determine specific locations for installation of additional tide gauges. For example, sea level trends derived from the Newport, Providence, or Fall River NOAA gauges may not represent trends in the shallow embayments of the Bay, such as Greenwich Bay, Wickford Harbor, and the Warren, Barrington, and Palmer Rivers. Many of those embayments have high population densities and intense shoreline development, and it is important to have locally reliable water level data for hydrodynamic modeling and flooding projections. Enhanced bathymetry data would assist in enhancing the resolution and certainty of the hydrodynamic models that are used to predict flooding potential with sea level rise and storm surge.

Because of the information and geographic data gap in the Massachusetts section of the Bay, sea level rise analysis is needed for Mount Hope Bay using the Fall River tide gauge, which has NOAA water level gauge records since 1955. This is especially important since the Taunton River watershed has low topography relative to other watersheds in the Narragansett Bay watershed, where scenarios of sea level rise are showing serious implications for low-lying areas (see NOAA's Sea Level Map Viewer: Shallow Coastal Flooding Areas).

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