NEW JERSEY'S RISING SEAS AND CHANGING COASTAL STORMS:
Report of the 2019 Science and Technical Advisory Panel

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Executive Summary

The first New Jersey Science and Technical Advisory Panel (STAP) on Sea-Level Rise and Coastal Storms was convened by Rutgers University on behalf of the NJ Climate Change Alliance in 2015, culminating in a 2016 report that identified planning options for practitioners to enhance the resilience of New Jersey's people, places, and assets to sea-level rise, coastal storms, and the resulting flood risk (Kopp et al., 2016). An innovative approach used to inform the 2016 report was the complementary convening of a panel of practitioners to offer insights on the application of the STAP science to state and local planning and decision-making. Following the same process, the same team at Rutgers University was engaged by the State of New Jersey Department of Environmental Protection to update the 2016 report based on the most current scientific information. Similar to the inaugural work, the 2019 STAP was charged with identifying and evaluating the most current science on sea-level rise projections and changing coastal storms, considering the implications for the practices and policies of local and regional stakeholders, and providing practical options for stakeholders to incorporate science into risk-based decision processes.

The 2019 STAP process recommended the following key updates to the 2016 STAP report:

1. Making available historical sea-level rise (SLR) information for New Jersey to provide a frame of reference for future projections;
2. Updating information on ice sheet dynamics;
3. Expanding consideration of tidal flooding; and
4. Expanding consideration of storm tide-related flooding.

This report integrates the 2019 key STAP updates and should be considered the most recent reference in this series.

Summary of STAP Outcomes

Sea-level rise:

Table ES-1: New Jersey Sea-Level Rise above the year 2000 (1991-2009 average) baseline (ft)*

		2030	2050	2070			2100			2150		
				Emissions								
	Chance SLR Exceeds			Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

**2010 (2001-2019 average) Observed = 0.2 ft*

Notes: All values are 19-year means of sea-level measured with respect to a 1991-2009 baseline centered on the year indicated in the top row of the table. Projections are based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Near-term projections (through 2050) exhibit only minor sensitivity to different emissions scenarios (<0.1 feet). Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global-mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low-emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLR exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLR will fall within the values in the 'Likely Range'. Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes.

The STAP has reached the following conclusions on SLR:

1. From 1911 (the start of the Atlantic City tide-gauge record) to 2019, sea-level rose 17.6 inches (1.5 feet) along the New Jersey coast, compared to a 7.6-inch (0.6 feet) total change in the global mean sea-level.
2. Over the last forty years, from 1979-2019, sea-level rose 8.2 inches (0.7 feet) along the New Jersey coast, compared to a 4.3-inch (0.4 feet) change in global mean sea-level.
3. New Jersey coastal areas are likely (at least a 66% chance) to experience SLR of 0.5 to 1.1 ft between 2000 and 2030, and 0.9 to 2.1 ft between 2000 and 2050. It is extremely unlikely (less than 5% chance) that SLR will exceed 1.3 ft by 2030 and 2.6 ft by 2050.
4. While near-term SLR projections through 2050 exhibit only minor sensitivity to different emissions scenarios (<0.1 feet), SLR projections after 2050 increasingly depend upon the pathway of future global greenhouse gas emissions.
    a. Under a high-emissions scenario, consistent with the strong, continued growth of fossil fuel consumption, coastal areas of New Jersey are likely (at least a 66% chance) to see SLR of 1.5 to 3.5 ft between 2000 and 2070, and 2.3 to 6.3 ft between 2000 and 2100. It is extremely unlikely (less than a 5% chance) that SLR will exceed 4.4 ft by 2070 and 8.8 ft by 2100.
    b. Under a moderate-emissions scenario, roughly consistent with current global policies, coastal areas of New Jersey are likely (at least a 66% chance) to see SLR of 1.4 to 3.1 ft between 2000 and 2070, and 2.0 to 5.2 ft between 2000 and 2100. It is extremely unlikely (less than a 5% chance) that SLR will exceed 3.8 ft by 2070 and 6.9 ft by 2100.
    c. Under a low-emissions scenario, consistent with the global goal of limiting warming to 2°C above early industrial (1850-1900) levels, coastal areas of New Jersey are likely (at least a 66% chance) to see SLR of 1.3 to 2.7 ft between 2000 and 2070, and 1.7 to 4.0 ft between 2000 and 2100. It is extremely unlikely (less than a 5% chance) that SLR will exceed 3.2 ft by 2070 and 5.0 ft by 2100.

In addition to the magnitude of SLR, the STAP also evaluated local rates of SLR in response to practitioner interest. SLR rates are especially important in determining whether ecological systems and habitats, such as marshes, will be able to adapt to rising seas. Left unconstrained by nearby development, these ecological systems — important for services, such as flood control — could collapse, or they could adapt to SLR by migrating inland or retaining sediment. Additionally, the rate of SLR is also an important consideration in the design and management of nature-based solutions for coastal protection (United States Army Corps of Engineers, 2015), which, depending on site-specific conditions, may reduce flood exposure as sea levels rise.

The STAP has reached the following conclusions on rates of SLR:

1. Over the last forty years, from 1979-2019, sea-level rose at an average rate of 0.2 in/yr along the New Jersey coast, compared to an average rate of 0.1 in/yr in global mean sea-level.
2. New Jersey coastal areas are *likely* (at least a 66% chance) to experience average SLR rates of 0.2 to 0.5 in/yr over 2010–2050. It is *extremely unlikely* (less than 5% chance) that average SLR rates will exceed 0.7 in/yr over 2010–2050.
3. Rates of SLR are increasingly dependent upon global greenhouse gas emissions later in the 21st century.
    a. Under a high-emissions scenario, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.3 to 1.1 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 1.7 in/yr over 2060-2100.

b. Under a moderate-emissions scenario, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.2 to 0.8 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 1.3 in/yr over 2060-2100.

c. Under a low-emissions scenario (2.0°C), coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.2 to 0.6 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 0.8 in/yr over 2060-2100.

The STAP *likely* ranges of SLR estimates are consistent with recent SLR guidance proposed by an interagency working group that included the National Oceanic and Atmospheric Administration (NOAA), the United States Army Corps of Engineers (USACE), the United States Geological Survey (USGS), and other agency and academic partners (Sweet et al., 2017).

Coastal Storms

Higher sea-levels will increase the baseline for flooding from high tides and coastal storms (i.e., tropical cyclones and extratropical cyclones) and, therefore, the impacts of coastal storms. STAP members concluded that there was no clear basis for planning guidance for New Jersey to deviate from the most recent examinations of the issues by the New York City Panel on Climate Change (Orton et al., 2019) and by the Intergovernmental Panel on Climate Change (IPCC), including the IPCC's conclusions regarding the need for further research to understand regional changes in future tropical cyclones and extratropical cyclones (Collins et al., 2019).

Tropical Cyclones

The STAP deliberations focused on three issues with respect to tropical cyclones: frequency, intensity and precipitation:

- Frequency: Most studies do not project an increase in the global frequency of tropical cyclones (*medium agreement, medium confidence*).
- Intensity: Maximum wind speeds will *likely* increase (*medium- to high-confidence*).
- Precipitation: Rate of precipitation during tropical cyclones is *likely* to increase (*high confidence*).

Changes in the frequency, intensity (wind speed), and tracks of tropical cyclones remain an area of active research, and the STAP concluded there is no definitive consensus regarding such changes specific to New Jersey.

Extratropical Cyclones

Frequency: The global frequency of extratropical cyclones is not likely to change substantially. There is some evidence for a decrease in frequency of extratropical cyclones over the North Atlantic as a whole, but not near the coast (Bengtsson et al., 2006; Chang et al., 2013; Colle et al., 2013; Zappa et al., 2013).

Changes to extratropical storm tracks in the North Atlantic are possible (Roberts et al., 2017), but have not been reliably established (Stocker et al., 2013). Changes in the frequency, intensity (wind speed), precipitation rate, and tracks of extratropical cyclones remain an area of active research, and the STAP concluded that, at this time, there is no definitive consensus regarding such changes.

Tidal Flooding

The number of days that New Jersey residents have experienced high-tide floods in the absence of an associated storm has increased in recent years. High-tide flooding can have detrimental impacts on infrastructure and community function in the absence of a major storm. Over 2007-2016, there was an average of 8 high-tide flood events in Atlantic City, NJ, with annual event totals ranging between 4 events in 2007 and 18 events in 2009. This frequency has grown from an average of less than one high-tide flood event per year in the 1950's (Sweet et al., 2018). The frequency of high tides exceeding the current high-tide flood threshold will continue to increase with sea-level rise. For example, based on the *likely* range of SLR projections, Atlantic City will experience 17-75 days per year of expected high-tide flooding per year in 2030, and 45-255 days per year of expected high-tide flooding in 2050.

Application of STAP Science

Both the STAP and the practitioner panel discussed the use of the STAP science to inform future flood levels for exposure assessment. Each panel recognized that users' planning situations will range from assessing community assets for which there is little vulnerability or consequence related to flood exposure to assessing exposures of highly consequential or vulnerable community assets. In 2016, the STAP specifically advised practitioners to use a variety of SLR estimates, given the range of future exposures and vulnerabilities that exist among people, places, and assets in New Jersey communities. It suggested that flood exposures include at least one estimate in the 'likely range' and an additional estimate that represents high-end outcomes. This report illustrates an example scenario-based planning application of the revised SLR projections. Practitioners will need to consider integrating this information into their current professional framework, recognizing different tolerances for risk and critical flood event thresholds among different community actors.

Additionally, the STAP recommends that SLR projections be revisited periodically, preferably shortly after the releases of any relevant reports from the Intergovernmental Panel on Climate Change (IPCC) or the U.S. National Climate Assessment, to assure that the estimates remain consistent with scientific advances.

Statement of Purpose

The first New Jersey Science and Technical Advisory Panel (STAP) on Sea-Level Rise and Coastal Storms was convened by Rutgers University on behalf of the New Jersey Climate Change Alliance in 2015, culminating in a 2016 report that identified planning options for practitioners to enhance the resilience of New Jersey's people, places, and assets to sea-level rise, coastal storms, and the resulting flood risk (Kopp et al., 2016). Following the same process, the same team at Rutgers University was engaged by the State of New Jersey Department of Environmental Protection to update the 2016 report based on the most current scientific information. Similar to the inaugural work, the 2019 STAP was charged with identifying and evaluating the most current science on sea-level rise projections and changing coastal storms, considering the implications for the practices and policies of local and regional stakeholders, and providing practical options for stakeholders to incorporate science into risk-based decision processes.

Dr. Robert Kopp (Rutgers University, Professor of Earth and Planetary Sciences and Director, Rutgers Institute of Earth, Ocean, and Atmospheric Sciences), chair of the 2016 STAP, again chaired the 2019 Science and Technical Advisory Panel. The 2019 panel included many of the 2016 members and was expanded to include additional experts. The STAP considered its charge with the goal of reaching consensus on the following questions:

1. How much has sea-level risen in New Jersey?
2. What is the range of future estimates of sea-level rise for New Jersey? How probable are different estimates of sea-level rise for New Jersey?
3. How are coastal storm characteristics and impacts projected to change in New Jersey and the Atlantic Basin?
4. What are the estimated changes in flood hazards for New Jersey from coastal storms and sea-level rise, and how probable are those estimates?
    a. How will different estimates of sea-level rise impact the frequency with which communities experience coastal flooding from storm events in New Jersey?
    b. How will different estimates of sea-level rise impact the frequency with which communities experience tidal flooding events in New Jersey?

5. How can efforts to apply current science recognize scientific uncertainties and the ongoing nature of scientific learning and how often should stakeholders reassess advances in scientific information for the purposes of applying the latest science into practice?
6. How can practitioners, decision-makers, and other stakeholders consider sea-level rise and changes in coastal storms in light of different planning horizons, project types, and risk tolerances?

As in the inaugural STAP process, Rutgers University also convened a meeting of resilience practitioners, chaired by Dr. Clinton Andrews (Rutgers University, Edward J. Bloustein School of Planning and Public Policy), to provide insights on barriers and opportunities for integrating the STAP's conclusions into practice. The purpose of the meeting of practitioners was to gather input on the scientists' initial recommendations for planning and decision-making. The STAP integrated the insights from the practitioner discussion in developing the findings outlined in this report.

How to Use This Document

The panel recommends that planners, engineers, elected officials, land managers and other practitioners use the guidance herein to consider community asset exposure to various levels of flooding, such as permanent inundation, tidal flooding, and extreme coastal flooding, both in the near and long-term.

Throughout the report, when describing local or regional sea-level rise (SLR), the panel refers specifically to relative sea-level rise, which is the rise in the height of the sea surface relative to the height of the land. Relative sea-level rise can be caused both by a rising sea surface and by a falling land surface (Gregory et al., 2019).

The panel uses likelihood terminology (see Table 1) and confidence terminology (see Figure 1) consistent with that of the Intergovernmental Panel on Climate Change in this report (Mastrandrea et al., 2010).

Table 1. Likelihood Scale

Likelihood Scale	
Extremely likely	At least a 95% chance
Very likely	At least a 90% chance
Likely	At least a 66% chance
Very unlikely	Less than a 10% chance
Extremely unlikely	Less than a 5% chance

Modified from Mastrandrea et al. (2010)

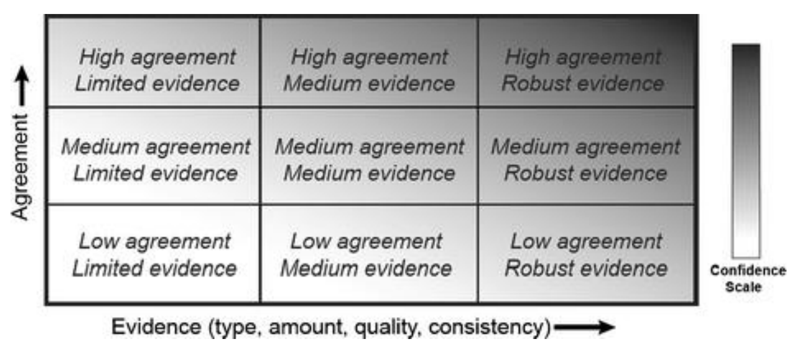

Figure 1. IPCC Fifth Assessment Report Confidence Guidance. Evidence robust when there are multiple, consistent independent lines of high-quality evidence. Confidence generally increases towards the top-right corner as suggested by darker shading. (Mastrandrea et al., 2010)

Practitioners can use the STAP panel conclusions on projected SLR estimates and probabilities in conjunction with methods to project resulting flood levels. An updated example to demonstrate one of many possible options for integrating SLR projections into practice to predict future water levels associated with permanent inundation, tidal flooding, and coastal storms is included in this report. The example is illustrative and has been provided for consideration and discussion purposes as per the STAP charge to provide practical options for stakeholders to incorporate science into risk-based decision processes. The STAP recognizes that some practitioners may desire more detailed planning methods, for example, using Geographic Information Systems to project the spatial extent of Federal Emergency Management Agency (FEMA) flood zones or equivalent hydrodynamic modeling.

Consensus Science to Support Planning for Sea-Level Rise in New Jersey

Important Assumptions and Limitations

The STAP analyzed two critical drivers of future coastal hazards facing New Jersey residents: changing local relative sea-levels and changing coastal storms. The panel considered literature prior to October 2019. The following section details the key factors, assumptions, and limitations related to the projections of future SLR and coastal storm conditions considered by the STAP.

Sea-Level Change Budget and Processes in New Jersey

Global mean sea-level (GMSL) and local relative sea-level (RSL) are determined by several factors (Gregory et al., 2019; Kopp et al., 2015). Global factors include:

1. Thermal expansion of ocean water;
2. Mass loss from glaciers, ice caps, and ice sheets; and
3. Changes in terrestrial water storage.

Additional factors relevant in New Jersey include:

1. Glacial isostatic adjustment (GIA) (the ongoing adjustment of the solid Earth to the loss of the North American ice sheet at the end of the last ice age), leading to SLR of about 0.5 in/decade across the region;
2. Vertical land motion due to natural sediment compaction and groundwater withdrawal along the Coastal Plain and in the Meadowlands, reaching up to about 0.4 in/decade along the Coastal Plain;
3. Dynamic sea-level changes due to changes in ocean circulation, temperature, and salinity, which may add as much as 1 ft/century in the U.S. Northeast under high-emissions scenarios; and
4. Gravitational, rotational and deformational effects (changes in the height of Earth's gravitational field and crust associated with the large shifts of mass from ice to the ocean), which diminish the effect of Greenland ice sheet and Arctic glacier melt and increase the effect of Antarctic ice sheet melt.

Global Mean Sea-level

Global mean sea-level (GMSL) is determined by the volume of water in the ocean. It is estimated to have risen at an average rate of 0.6 ± 0.2 in/decade (1.6 ± 0.4 mm/yr) over 1900-2015 (Dangendorf et al., 2019), with human-caused climate change being the dominant driver since at least 1970 (Oppenheimer et al., 2019). The rate of GMSL rise has been accelerating since the 1960s (Dangendorf et al., 2019). Satellite observations of GMSL, which began in 1993, confirm this acceleration. The average rate of GMSL rise over 1993-2017 was 1.2 ± 0.2 in/decade (3.1 ± 0.4 mm/yr), and increased from about 0.8 in/decade (2.1 mm/yr) at the start of this period to about 1.6 in/decade (4.1 mm/yr) today (WCRP Global Sea Level Budget Group, 2018). The three major processes contributing to GMSL change on human timescales are thermal expansion, land ice mass loss, and changes in terrestrial water storage.

Thermal expansion is the increase in the volume of seawater that occurs because of the warming of the ocean. Over 1993-2017, it was responsible for about 40% of observed GMSL rise (about 0.5 ± 0.2 in/decade [1.3 ± 0.4 mm/yr]; WCRP Global Sea Level Budget Group, 2018).

Land ice mass loss *(from ice sheets and glaciers)* increases GMSL when ice sheets and glaciers lose more mass via melting than they accumulate and when chunks of ice break off and flow into the ocean. Alpine and circumpolar glaciers are currently responsible for about 20% of observed GMSL rise (0.3 ± 0.1 in/decade [0.65 ± 0.15 mm/yr]; WCRP Global Sea Level Budget Group, 2018).

The rates at which both the Greenland ice sheet and Antarctic ice sheet are losing mass are currently increasing (e.g., Harig & Simons, 2012, 2015; Mouginot et al., 2019; Rignot et al., 2019; Shepherd et al., 2012). The Greenland ice sheet was approximately stable in the 1970s (Mouginot et al., 2019), and has been shrinking at an accelerating rate since then due to warming Arctic temperatures (contributing about 15% of observed GMSL rise (0.2 ± 0.04 in/decade [0.5 ± 0.1 mm/yr] over 1993-2017; WCRP Global Sea Level Budget Group, 2018) (Mouginot et al., 2019). The Antarctic ice sheet, whose loss is also accelerating (Rignot et al., 2019) contributed to GMSL at a rate of 0.1 ± 0.04 in/decade (0.3 ± 0.1 mm/yr) (about 8% of observed GMSL rise) from 1993-2017 (WCRP Global Sea Level Budget Group, 2018). Antarctic mass loss is currently localized near the ice sheet margins of West Antarctica. However, the marine-based sectors of the ice sheet are subject to dynamic instability (e.g., Schoof, 2007), and some evidence suggests that parts of the West Antarctic ice sheet may already be committed to long-term retreat (Joughin et al., 2014; Rignot et al., 2014). Gravitational instability of marine ice cliffs may also accelerate future mass loss of the West Antarctic Ice Sheet and some parts of the East Antarctic Ice Sheet (DeConto & Pollard, 2016). On centennial timescales, the behavior of the Antarctic ice sheet is the dominant source of uncertainty in GMSL rise projections (Kopp et al., 2014; WCRP Global Sea Level Budget Group, 2018).

Terrestrial water storage is a minor contributor to GMSL change. These changes arise from natural variability in the amount of water stored in lakes, the filling of dams (driving GMSL fall), and groundwater extraction (driving GMSL rise). The terrestrial water storage component is poorly constrained prior to the 21st century. Over 2002-2015, model-based estimates suggest a contribution of about 0.0-0.1 in/decade (0.0-0.3 mm/yr) to GMSL rise, while measurements of Earth's gravity field suggest a small terrestrial water storage-driven reduction in GMSL (WCRP Global Sea Level Budget Group, 2018).

Relative Sea-Level in New Jersey

Relative sea-level (RSL) is defined as the difference in height between the sea surface and the height of the solid Earth. The factors affecting RSL can be divided into (1) those affecting GMSL, discussed above; (2) those affecting the height of the sea surface relative to a globally uniform change; and (3) those affecting the height of the solid Earth (i.e., causing vertical land motion) (e.g., Kopp et al., 2015).

Dynamic sea-level (DSL) changes affect only the height of the sea surface. They arise from ocean-atmosphere interactions and from ocean circulation changes that alter ocean density and the distribution of mass in the ocean (Kopp et al., 2015). Dynamic sea-level exhibits rich spatiotemporal variability that is associated with both greenhouse gas forcing and internal climate modes.

Studies of observed DSL change in the early part of this decade focused on an observed regional "hotspot" of sea-level acceleration in the U.S. Northeast, beginning in about 1975 (e.g., Andres et al., 2013; Ezer & Corlett, 2012; Kopp, 2013; Sallenger et al., 2012). Drivers were variously suggested to be related to Gulf Stream variability and/or changes in alongshore wind stress (Andres et al., 2013; Ezer et al., 2013; Yin & Goddard, 2013). However, over the past decade, the Southeast US coast has experienced SLR rates of up to three times the global mean, far larger than New Jersey (e.g., Domingues et al., 2018; Valle-Levinson et al., 2017). The long timescales of internal variability hinder the identification of the causal drivers of observed decadal to multidecadal "hotspots" (Kopp et al., 2015). Most recent analyses have related DSL variability, and the differences between locations north and south of Cape Hatteras, to climate modes, including the North Atlantic

Oscillation, Atlantic Multidecadal Variability, and El Niño Southern Oscillation (e.g., McCarthy et al., 2015; Valle-Levinson et al., 2017).

Future changes in the position and strength of the Gulf Stream associated with 21st century climate changes and weakening of the Atlantic Meridional Overturning Circulation (AMOC) may significantly influence DSL along the coast of New Jersey (Yin & Goddard, 2013), with some models projecting >1 ft (30 cm) of DSL rise over the course of the century. However, the spatial pattern and amplitude of DSL change associated with AMOC weakening varies widely across climate models. The connection between future changes and observed decadal to multidecadal variability, and their underlying drivers, is currently unclear (Little et al., 2019). DSL thus remains a major contributor to uncertainty in 21st century sea-level changes in the U.S. Northeast (Kopp et al., 2014).

Gravitational, rotational and deformational (GRD) effects, arising in response to the shifting of mass between land ice, terrestrial water storage, and the ocean, affect both the height of the sea surface and the height of the solid Earth. In addition to altering the height of GMSL, the movement of mass from land ice into the ocean deforms the Earth's gravitational field and crust and alters the planet's rotation. These processes cause the regional expression of sea-level rise associated with land ice mass loss to differ, sometimes substantially, from the global mean. Near a melting ice sheet, SLR is suppressed relative to GMSL change, with an RSL fall occurring in those areas within ~2000 km of the ice sheet. Distal from a melting ice sheet, SLR is enhanced relative to GMSL. For example, along the Jersey Shore, the SLR associated with Greenland ice sheet melt is ~50% of the global mean, while that associated with West Antarctic Ice Sheet melt is ~120% of the global mean, and that associated with East Antarctic Ice Sheet melt ~105% of the global mean (Kopp et al., 2014; Mitrovica et al., 2011).

Glacial isostatic adjustment (GIA) arises from the ongoing, multimillennial response of Earth's mantle to past glaciations. Like GRD effects arising in response to contemporary changes in land ice, GIA affects both the height of the solid Earth and Earth's gravitational field and rotation (and thus the height of the sea surface). The land under the former cores of shrunken ice masses rebounds upward, lowering RSL, while land at the periphery of former ice sheets (that was raised high as a bulge while the ice sheet depressed neighboring land downwards) subsides (raising RSL). The mid-Atlantic region, which sits on the former peripheral bulge of the Laurentide Ice Sheet, is currently experiencing GIA-associated subsidence and SLR at a rate of about 0. 5-0. 6 in/decade (1.3-1.5 mm/yr) (e.g., Kopp, 2013; Kopp, Kemp, et al., 2016).

Sediment compaction affects the height of the solid Earth in areas that are located on unconsolidated sediments such as the mid-Atlantic Coastal Plain (as opposed to bedrock, such as that on which Manhattan sits). Compaction occurs naturally as a result of mass loading; since the early 20th century, it has been substantially enhanced along the Jersey Shore by groundwater withdrawal, and currently contributes about 0. 4 in/decade (1 mm/yr) of SLR (Johnson et al., 2018; Miller et al., 2013).

Tide gauge data indicate that GIA contributes 0. 5 ± 0.1 in/decade (1.3 ± 0.2 mm/yr) to SLR at the Battery (e.g., Kopp (2013); Kopp et al. (2014)), while geological data indicate that GIA and natural sediment compaction combined contribute 0.6 ± 0.04 in/decade (1.5 ± 0.1 mm/yr) along the Jersey Shore. Thus, about 20% of the approximately 0.4 in/decade (1 mm/yr) difference between the Battery and the Jersey Shore observed in the 20th and 21st centuries is attributable to natural processes, while the remaining 80% is due to local anthropogenic processes, such as groundwater withdrawal-induced compaction.

Historical Sea-Level Changes in New Jersey

Twenty thousand years ago, a giant ice sheet covered much of North America, extending as far south as northern New Jersey. Between about eighteen thousand years ago and seven thousand years ago, this giant ice sheet disappeared, and other glaciers and ice sheets around the world shrunk considerably, leading to a rapid rise in global average sea-level that was also experienced here in New Jersey. Over the last four thousand years, the dominant long-term driver of SLR in New Jersey has been the sinking of the land as part of the ongoing response to the disappearance of the North American ice sheet.

Geological data indicate that, primarily as a result of land subsidence, sea-level in New Jersey rose about 6 inches/century (1.6 ± 0.1 mm/yr) from 0-1900 CE (Kemp et al., 2013; Kopp, Kemp, et al., 2016). Rates in the 20th and 21st centuries recorded by tide gauges are significantly higher, reflecting a growing contribution from processes related to current, greenhouse gas-driven climate changes. SLR along the Jersey Shore has been consistently faster than at The Battery over this period, a difference predominantly attributed to subsidence associated with groundwater withdrawal (Figure 2b).

- From 1911 (the start of the Atlantic City tide-gauge record) to 2019, sea-level rose 17.6 inches along the New Jersey coast (average rate of 1.7 in/decade [4.2 ± 0.1 mm/yr]) in New Jersey. Sea-level rose 13.3 inches at the Battery (average rate of 1.2 in/decade [3.1 ± 0.1 mm/yr]). Comparatively, GMSL rose 7.6 inches (average rate of 0.7 in/decade [1.8 mm/yr]) (Dangendorf et al., 2019; WCRP Global Sea Level Budget Group, 2018).
- Over the last forty years, from 1979 to 2019, sea-level rose 8.2 inches along the New Jersey coast (average rate of 2.0 in/decade [5.2 ± 0.2 mm/yr]). Sea-level rose 6.5 inches at the Battery over the same period (average rate of 1.6 in/decade [4.1 ± 0.2 mm/yr]). Comparatively, GMSL rose 4.3 inches (average rate of 1.1 in/decade [2.7 mm/yr]) (Dangendorf et al., 2019; WCRP Global Sea Level Budget Group, 2018) (see Figure 2).
- Between the 19-year period centered on the year 2000 (1991-2009) and the 19-year period centered on the year 2010 (2001-2019), sea level rose by 1.5 in (3.8 cm) at The Battery, 1.7 in (4.2 cm) at Atlantic City, 2.0 in (5.2 cm) at Cape May, and 2.1 in (5.4 cm) at Sandy Hook.

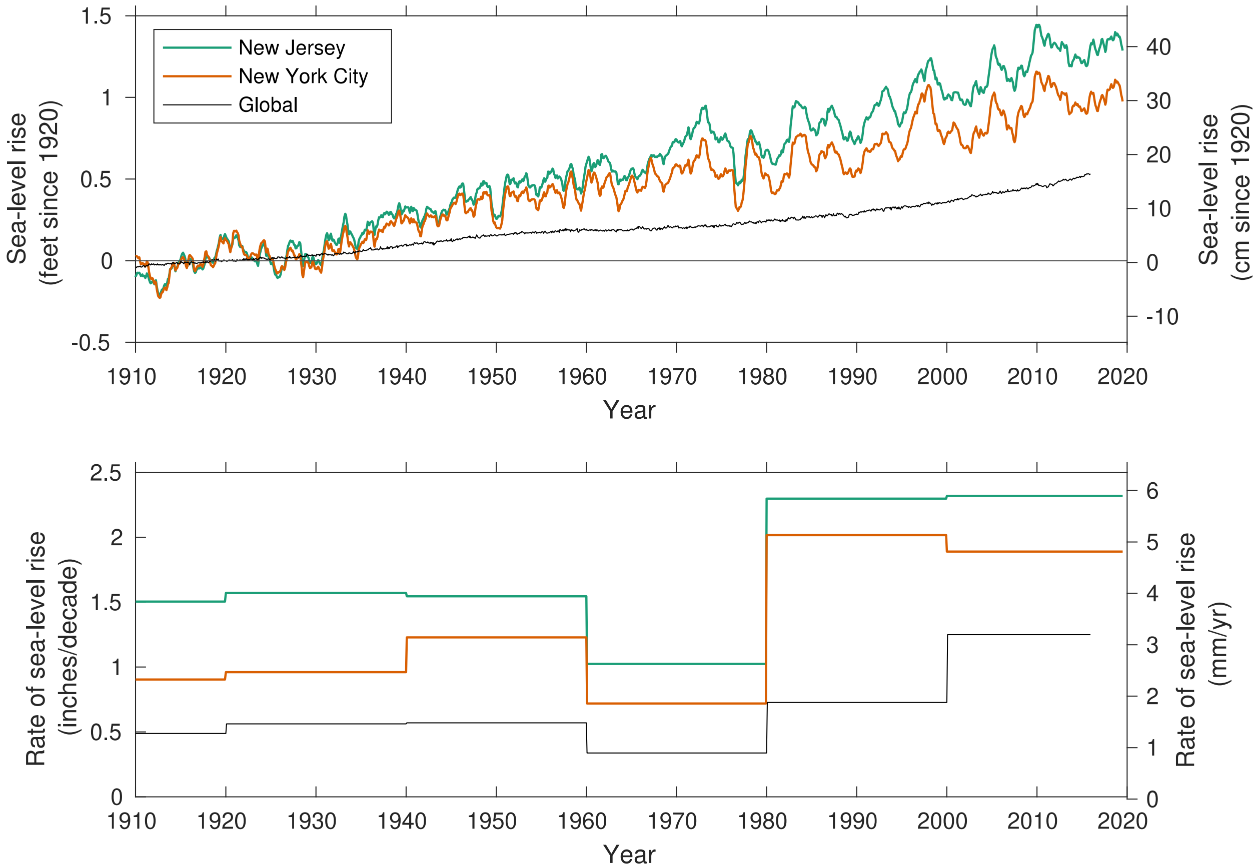

Figure 2. a) Comparison of coastal 'New Jersey' with New York, NY (The Battery). The 'New Jersey' curve is the average of Sandy Hook, Atlantic City, and Cape May. The zero sea-level datum on the upper graph is the estimated mean sea-level over 1911-1929. Individual lines represent annual averages of sea-level along the New Jersey coast and New York, NY (The Battery), based on tide gauge data. The global curve is based on Dangendorf et al. (2019). b) Comparison of coastal 'New Jersey' rate of change with New York, NY (The Battery), and global mean sea-level. Individual lines represent the rate of sea-level change over 20-year periods based on the linear trends.

Table 2. Global and New Jersey Sea-Level Budgets, 1993-2017 (in/decade [mm/yr])

	Global	New Jersey
Total observed	1.2 ± 0.1 [3.07 ± 0.37]	1.9 ± 0.1 [4.8 ± 0.2]
Global-mean thermal expansion	0.5 ± 0.2 [1.3 ± 0.4]	0.5 ± 0.2 [1.3 ± 0.4]
Glaciers	0.26 ± 0.06 [0.65 ± 0.15]	0.16 ± 0.04 [0.4 ± 0.1]
Greenland Ice Sheet	0.19 ± 0.04 [0.48 ± 0.10]	0.09 ± 0.02 [0.23 ± 0.05]
Antarctic Ice Sheet	0.10 ± 0.04 [0.25 ± 0.10]	0.12 ± 0.04 [0.3 ± 0.1]
Terrestrial water storage	(poorly constrained)	(poorly constrained)
Dynamic sea level	–	(poorly constrained)
Glacial isostatic adjustment and natural sediment compaction	–	0.6 ± 0.04 [1.5 ± 0.1]
Other subsidence	–	0.3 ± 0.1 [0.7 ± 0.2]
Total of well-characterized components	1.1 ± 0.2 [2.7 ± 0.5]	1.7 ± 0. 2 [4.4 ± 0.5]

Notes: Global budget for 1993-2017 based on WCRP Global Sea Level Budget Group (2018). New Jersey budget based on using the GRD fingerprint factors from Kopp et al. (2014) for glacier and ice sheet contributions, GIA and other natural subsidence from geological records (Kopp et al., 2016), and other subsidence from both a comparison of long-term trends and the analysis of Johnson et al. (2018). Uncertainties are one standard error.

Future Sea-Level Rise Projections

The local SLR projections of Kopp et al. (2014), used in the 2016 STAP report, are broadly consistent with the GMSL projections of the Intergovernmental Panel on Climate Change's 2013 Fifth Assessment Report (IPCC AR5) (Church et al., 2013). Since IPCC AR5, there has been increasing attention in the scientific literature to the potential instability of the polar ice sheets, particularly the Antarctic ice sheet. For example, as the 2016 STAP noted, at the time that report was written, one new study (DeConto and Pollard, 2016) "suggested that physics involving ice cliffs and ice shelves, not previously incorporated into ice sheet models, could render the Antarctic ice sheet significantly more vulnerable to melt within the current century than ice sheet models had previously indicated." Similarly, evidence has accumulated that parts of the West Antarctic Ice Sheet may already be committed to long-term collapse (e.g., Joughin et al., 2014; Rignot et al., 2014). Accordingly, in this report update, the 2019 STAP revisits the ice-sheet projections used in Kopp et al. (2014) and the 2016 STAP report.

Projections considered: The STAP deliberated upon four different studies that provide probabilistic SLR projections for sites around the world, including New Jersey. All these studies are built upon the LocalizeSL framework (https://github.com/bobkopp/LocalizeSL), first developed in Kopp et al. (2014). These studies differ in their treatment of the polar ice sheets, as well as (in some cases) the climate scenarios considered. These studies are:

1. Kopp et al. (2014) [referred to herein as K14] – This study is the framework used by the 2016 STAP. It is based upon the Representative Concentration Pathway (RCP) climate scenarios (van Vuuren et al., 2011) and yields projections of *likely* GMSL changes broadly consistent with IPCC AR5.
2. Rasmussen et al. (2018) [referred to herein as R18] – This study is entirely consistent with the framework and basic set of assumptions K14, but employs different climate scenarios. This study filters the projections of K14 based on temperature projections for 2100, so that R18 projections are (for example) for 1.5°C and 2.0°C global mean warming scenarios rather than for the RCPs.

3. Kopp et al. (2017) [referred to herein as DP16] – This study replaced the original Antarctic ice-sheet mass loss projections of K14 with those from the Antarctic ice-sheet modeling study of DeConto and Pollard (2016). The ice-sheet model used incorporated (for the first time in a continental-scale model) the gravitational instability of ice cliffs and exhibited high sensitivity to increasing atmospheric temperatures.
4. Bamber et al. (2019) [referred to herein as B19] – This study replaced the Greenland and Antarctic ice-sheet projections of K14 with projections based on a structured expert judgment (SEJ) study of ice-sheet changes associated with climate scenarios leading to 2°C and 5°C of warming by 2100, and it produced sea-level rise projections consistent with these scenarios. These sea-level rise projections were extended into local SLR projections using the LocalizeSL framework.

Structured expert judgment (SEJ) is a formal hazard analysis method that combines probabilistic expert assessments in a calibrated manner and has been widely used in a variety of fields including volcano, earthquake, and nuclear waste hazard assessments (Werner et al., 2017). Practitioners can view the ice-sheet projections from B19 as an integrated assessment of the state of the scientific literature when the study was conducted (early 2018). This study found moderately higher median contributions from the polar ice sheets than IPCC AR5 and considerable high-end risk.

SEJ is, however, not fully accepted by the ice-sheet modeling community, as it relies on the calibrated mental models of the participating experts rather than explicit physical models. Accordingly, rather than reject the IPCC AR5 projections entirely in favor of B19 or of a single ice-sheet modeling study such as that of DeConto and Pollard (2016), the STAP chose to combine the original IPCC AR5-consistent K14 methodology for SLR projection and the B19 projection methodology. To do so, it employed an approach similar to that used by Horton et al. (2018) to provide summary assessments across a broad suite of GMSL projections. This summary assessment method is described in detail below.

Climate scenarios: The 2016 STAP used the highest and lowest RCP-based SLR projections (i.e., RCP 8.5 and RCP 2.6, respectively) from K14. RCP 8.5 represents a fossil-fuel intensive growth trajectory, leading to a *likely* global mean warming of 3.2-5.4°C between the late nineteenth century and the late 21st century. RCP 2.6 represents a rapid decline in global greenhouse gas emissions, leading to net-negative carbon dioxide emissions in the last quarter of this century and a *likely* global mean warming of 0.9-2.3°C (Collins et al., 2013). The 2019 STAP has revised the 2016 climate scenario assumptions to focus upon two temperature-based scenarios – a 2°C increase in global average air temperature from early industrial (1850-1900) temperatures as the low-emissions scenario and a 5°C change high-emissions scenario – as well as a 'moderate' scenario that falls between the low and high-emissions scenarios. (Current global mean temperatures are about 1°C above early industrial levels.)

Revised low-emissions scenario: B19 use slightly different scenarios for their SEJ study, and so the STAP uses slightly different scenarios than in 2016 for this current report. In particular, the low scenario in B19 is a 2°C temperature stabilization scenario, consistent with the primary temperature target of the 2015 Paris Agreement. For consistency, we combine the B19 2°C projections with the R18 2°C projections in place of the K14 RCP 2.6 projection

High-emissions scenario: The B19 high scenario is a 5°C temperature stabilization scenario. Through 2100, it is broadly consistent with RCP 8.5, though toward the high end of climate model projections; after 2100, it stabilizes whereas RCP 8.5 continues to warm. B19 treats RCP 8.5 and their 5°C expert judgment scenario as adequately similar to combine non-ice sheet projections for RCP 8.5 with ice-sheet projections for 5°C, and the STAP agreed to use the same modeling approach for SLR projections.

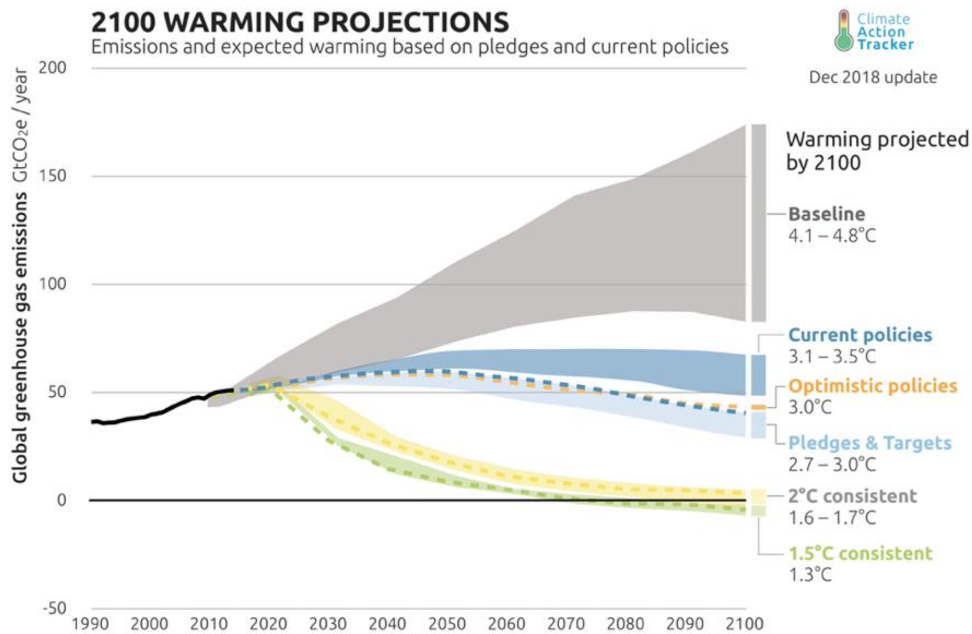

Figure 3. Policy analysis and long-term warming projections from the Global Climate Action Tracker (Potsdam Institute).

Moderate emissions scenarios: The 5°C high-emissions projection is warmer than the global-mean surface temperatures anticipated in this century if current climate policies are maintained and no large, unexpected surprises amplify the expected effects of greenhouse gas emissions. Climate Action Tracker, an independent research consortium associated with the Potsdam Institute for Climate Impact Research (Figure 3), estimates that the *likely* outcome of long-term adherence by all countries to current national policies is an average of 3.1°C - 3.5°C of warming by the end of the century. (Adherence to the pledges and targets nations have committed to under the Paris Agreement would further lower this level of warming to about 2.7°C - 3.0°C). This level of warming associated with current policies falls roughly halfway between that associated with the low-emissions 2°C scenario and that associated with the high-emissions 5°C scenario. Therefore, the STAP also provides a moderate-emissions scenario that estimates an outcome halfway between the low (2°C) the high (5°C) emissions sea-level projections as an option for users to consider in their analysis. The methodology for creating the projections associated with the moderate emissions scenario follows in the composite projection methodology section. It is important to note that, consistent with the prior 2016 report, the STAP suggests analyzing more than one climate scenario, as it is uncertain where emissions and warming will trend in the future, with uncertain global policy responses playing a significant role in long-term outcomes (Jackson et al., 2017; Riahi et al., 2017). More explicitly, assessing the likelihood of different emissions scenarios requires projecting future economic, technological, and policy developments, and the STAP therefore advises that users should exercise extreme caution if they wish to infer an associated likelihood in their assumptions about future emissions, and the associated global temperature change, when using sea-level projections.

Composite Projection Methodology: In the approach used by Horton et al. (2018) and by the 2019 STAP, summary assessments employ the lowest of considered projections for quantiles below the median, the mean of median projections, and the highest of considered projections for quantiles above the median. This approach is conservative: it implies, for example, that all the integrated studies will concur that there is at least a 66% chance that the real outcome will fall between the composite 17th and 83rd percentiles.

SLR projections through 2050 represent merged low- and high-emissions scenario projections, because differences in SLR projections between emissions scenarios are minor in the first half of the century (with low-emissions projections for 2050 being about 0.1 feet lower than high-emissions projections). Thus, to produce summary 50th percentile assessment for projections through 2050, the STAP agreed to average all median projections from the R18 2°C, B19 2°C, K14 RCP 8.5, and B19 5°C studies; to produce summary percentiles above and below the median, the STAP agreed to use the most extreme high/low percentile projections across the R18 2°C, B19 2°C, K14 RCP 8.5, and B19 5°C studies.

After 2050, the STAP projections are broken out by climate scenarios:

- For low-emissions, the STAP combines the 2°C projections of R18 and B19. The result is a composite low-emissions SLR projection.
- For high-emissions, the STAP uses the K14 RCP 8.5 projections and the B19 5°C SEJ projections. The result is a composite high-emissions SLR projection.

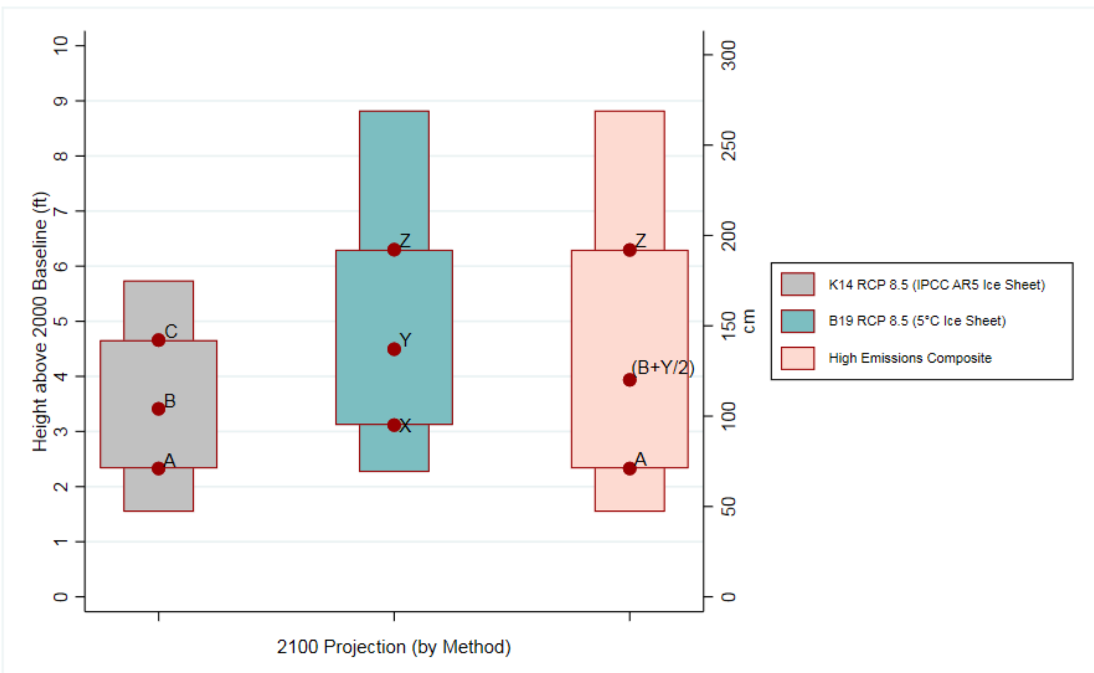

Figure 4. Composite Projection Illustration for high emissions. Gray box plots (with red outlines) represent single-study K14 high-emissions projections. Teal box plots (with red outlines) represent single-study B19 high-emissions projections. The thickest part of the K14 and B19 box plots each represents the *likely* range (17th to 83rd percentile) for the individual probabilistic models, and the narrowest part of each plot shows the *very likely* range (5th to 95th percentile) for the individual models. The red composite shows the *likely* (at least a 66% chance) and *very likely* (at least a 90% chance) ranges generated for the high-emissions composite projection as described in the text.

Figure 4 illustrates the process for creating the high-emissions composite projection. To create the projection, the STAP averages the median projections from the K14 RCP8.5 and B19 RCP8.5 studies to produce a summary median assessment, and takes the most extreme low/high percentile projections from the K14 RCP8.5 and B19 RCP8.5 studies for summary percentiles below/above the median. In other words, suppose that for a high-emissions scenario in New Jersey in a given decade, K14 projects A, B, and C, for the 17^{th}, 50^{th}, and 83^{rd} percentiles respectively, while B19 projects X, Y, Z for these same percentiles. If A is lower than X, and Z is higher than C, (as they are in the above example for 2100), the STAP high-emissions composite projection uses A as the 17^{th} percentile, ((B+Y)/2) as the 50th percentile (median), and Z as the 83rd percentile to create a *likely* range that combines results from K14 and B19. The 5th and 95th percentiles are assessed and added to the composite in a similar fashion to create the *very likely* range for the high-emissions projection. The STAP used this same process to derive the low-emissions composite projection using R18 and B19 2°C projections that represent a low warming future.

The composite approach is consistent with the use of likelihood language by the IPCC; in IPCC terminology, *likely* means a probability of *at least* two-thirds; both the K14 and B19 projections concur that there is at least a two-thirds chance that the correct value lies between A and Z, as do the R18 and B19 projections for low emissions.

Moderate Emissions Composite Projection Methodology: The full set of RCPs include two scenarios – RCP 4.5 and RCP 6.0 – in between the RCP 2.6 and 8.5 scenarios considered by the 2016 STAP. RCP 4.5 has a *likely* global mean warming of 1.7-3.3°C between the late nineteenth century and the late 21st century (Collins et al., 2013), which overlaps with but is centered below estimates of warming associated with current global policies. RCP 6.0 has quirks in its construction that make it ill-suited for comparative 21st century SLR projections. (Specifically, it exhibits temperatures below those of RCP 4.5 until the third quarter of the century.)

K14 and DP16 produce projections for RCP 4.5, while R18 computes comparable projections for a 2.5°C temperature scenario. However, B19 does not include a commensurate set of projections of future ice-sheet dynamics under moderate emissions, and instead includes only 2°C (low-emissions) and 5°C (high-emissions) scenarios. Therefore, the STAP discussed potential methodologies that would allow projections to reflect the most recent knowledge of ice-sheets under a moderate emissions scenario consistent with current global policies.

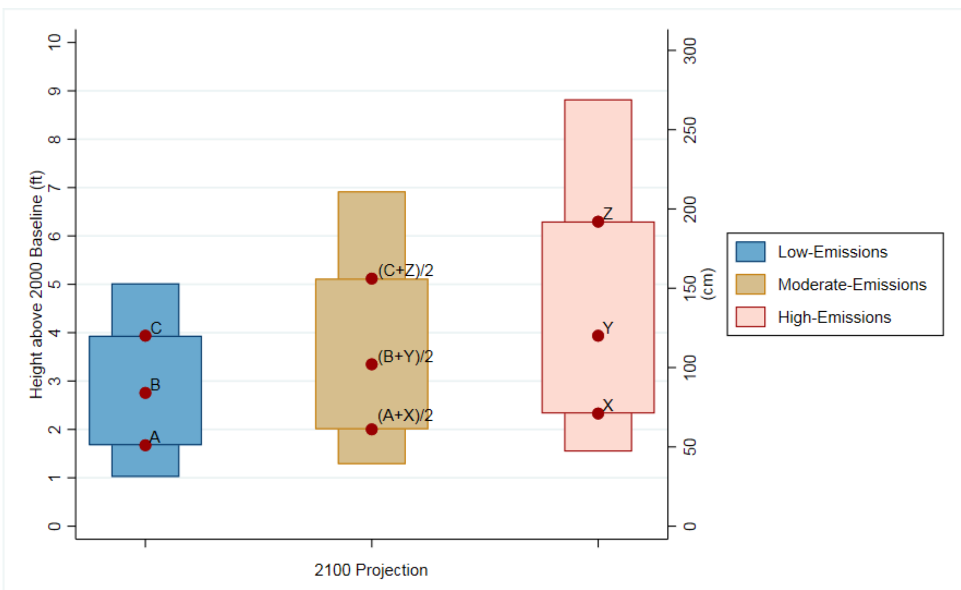

Figure 5. Interpolating a Moderate Emissions Projection. Box plots represent composite projections in 2100 for high-emissions (red) and low-emissions (blue). The thickest part of each plot represents the *likely* range (at least a 66% chance), followed by the *very likely* range (at least a 90% chance). The moderate emissions composite (gold) is generated for each decadal interval by using the midpoint between the high- and low-emissions composite projection medians [(B+Y)/2] and the midpoints between the 17th percentile [(A+X)/2] and 83rd percentile [(C+Z)/2] values of the *likely* ranges. The process is similar for the end-points of the *very likely* ranges.

For the purposes of this report, the STAP chose to interpolate a 'moderate emissions' scenario by assuming that, at each percentile, the associated projection is the average of the high and low scenario (See Figure 5). This approach is justified under the assumption that the physical uncertainties that would lead to a high or low sea-level response would be consistent across trajectories: a world that would respond to a high-emissions trajectory at the high end of SLR projections for that trajectory would most likely similarly respond at the high end for low- and moderate-emissions trajectories. The assumption that a temperature projection roughly halfway between the 2°C and 5°C scenarios would yield a sea-level outcome also halfway between is comparable to that used by Bamber et al. (2019) to compare projections associated with different scenarios.

The assumptions used by the STAP to generate a moderate emissions scenario are consistent with a moderate scenario that roughly corresponds to a warming of about 3.5°C by 2100, which would be higher than RCP 4.5 projections from prior studies. This can be confirmed when comparing the results of prior sea-level modeling for RCP 4.5 for K14 and DP16. While not a perfect approach, it is the judgment of the STAP that this is a reasonable approach in the absence of a moderate emissions scenario consistently modeled or elicited across studies, and that the interpolated 'moderate' trajectory provides a reasonable estimate of potential future SLR in New Jersey if current global climate mitigation policies are maintained but not strengthened.

Maximum Planning Horizon of 2150: The panel selected 2150 as the maximum planning horizon to accommodate both near-term and long-term asset lifecycles for infrastructure consistent with feedback from the practitioner panel. The panel selected 2030, 2050, 2070, 2100, and 2150 as periods representative of near-, mid-, and long-term projections for SLR affirmed as relevant by discussions with practitioners. Appendix A provides all decadal projections for 2010 through 2150 for practitioner reference.

2000 Baseline: Scientists measure sea-level with respect to a geodetic datum. For the U.S. National Spatial Reference System, this datum is the North American Vertical Datum of 1988 (NAVD88). NOAA measures tidal datum levels such as Mean Sea-level (MSL), Mean Higher High Water (MHHW), and Mean Lower Low Water (MLLW) in relation to the NAVD88 geodetic datum over a 19-year tidal cycle referred to as a tidal datum epoch. The current National Tidal Datum Epoch is 1983 – 2001. There are several different tidal datum levels that practitioners use within their professions to communicate flood forecasts (MLLW), coastal boundaries (for NJ, MHHW), and other information as points of reference for coastal communities and ecosystems.

For consistency with the sea-level projection literature, including most recent federal and state sea-level assessments, the baseline tidal epoch for the projections in this report is different from the National Tidal Datum Epoch. It is instead centered on the year 2000; more specifically, it is the average sea-level over 1991-2009. Based on an average rate of change over 1983-2009 of 1.8 ± 0.2 in/decade [4.6 ± 0.4 mm/yr], the 1991-2009 average for New Jersey was 1.4 ± 0.1 inches above the 1983-2001 tidal epoch, so users can adjust the STAP projection to the 1983-2001 National Tidal Datum Epoch (centered on the year 1992) by adding 1.4 inches (0.1 ft). For example, the STAP central estimate projection for 2050 is 1.4 ft above the 2000 baseline. This is equivalent to 1.5 ft above the 1983-2001 National Tidal Datum Epoch (1992). Due to atmosphere and ocean dynamics, the annual average sea-level can vary by up to 0.2 ft around the 19-year average sea-level centered in the same year.

How Much Will Sea-Level Rise in New Jersey?

Table 3. New Jersey Sea-Level Rise above the year 2000 (1991-2009 average) baseline (ft)*

	Chance SLR Exceeds	2030	2050	2070			2100			2150		
				Emissions								
				Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

**2010 (2001-2019 average) Observed = 0.2 ft*

Notes: All values are 19-year means of sea-level measured with respect to a 1991-2009 baseline centered on the year indicated in the top row of the table. Projections are based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Near-term projections (through 2050) exhibit only minor sensitivity to different emissions scenarios (<0.1 feet). Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global-mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low-emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLR exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLR will fall within the values in the 'Likely Range'. Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes.

The STAP has produced a set of probabilistic SLR projections for the years 2030 and 2050 and three sets of projections for 2070, 2100, and 2150.

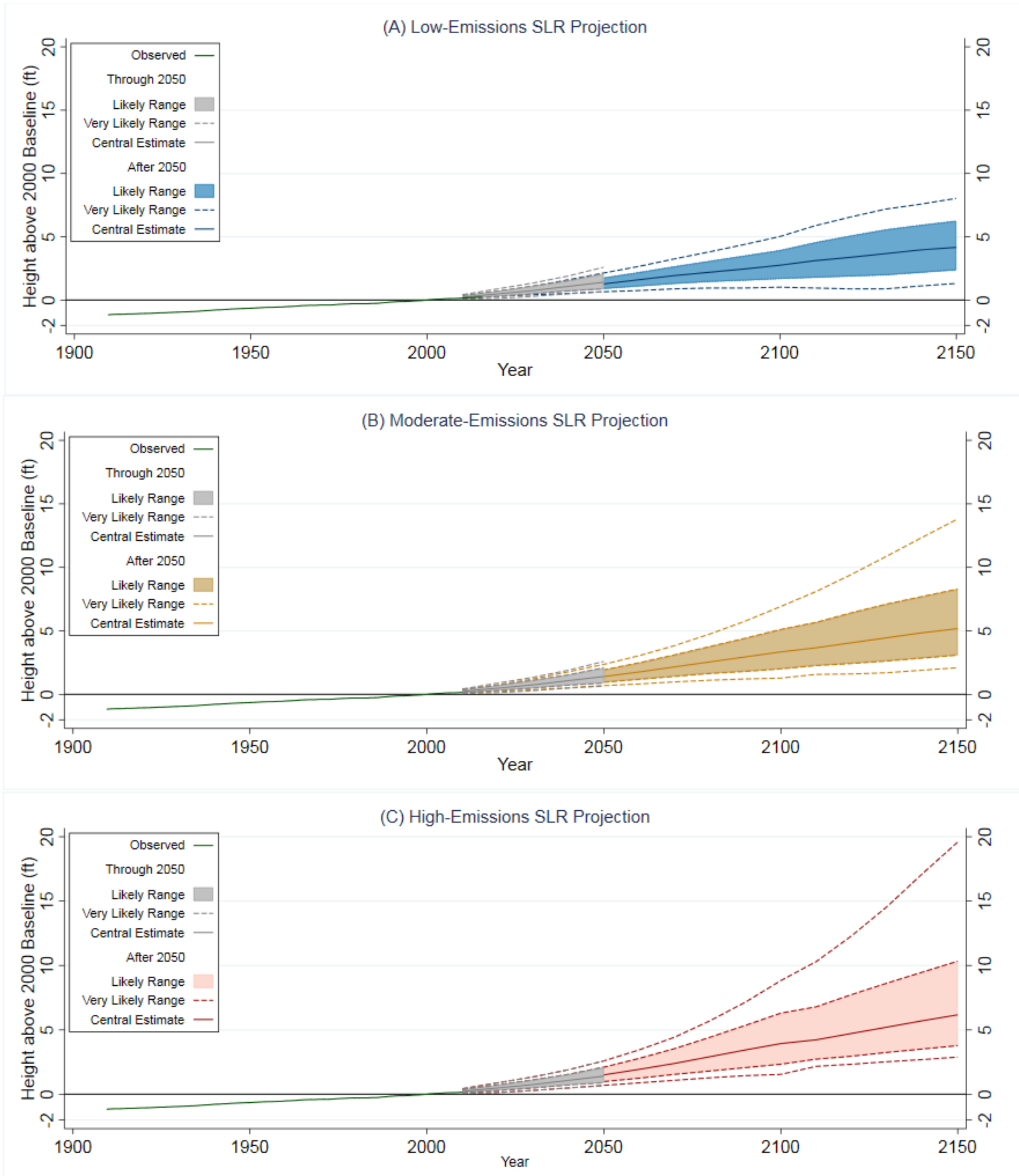

Figure 6: Time series of tide-gauge measurements (dark green) and projections for low-emissions (A), moderate emissions (B) and high-emissions scenarios (C). All Observation and SLR values are expressed as 19-year means of tide-gauge measurements and are measured with respect to a 1991-2009 (2000) baseline. Projections are 19-year averages based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Solid Lines = ~50% chance estimates; Shaded Area = *likely* range (at least a 66% chance); dotted lines denote the *very likely* range (at least a 90% chance), (Mastrandrea et al., 2010). Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes.

Considering the prior discussion of historical changes and the projections set forth by the STAP, as summarized in Figure 6 and in Table 1, the STAP has reached the following conclusions:

1. From 1911 (the start of the Atlantic City tide-gauge record) to 2019, sea-level rose 17.6 inches along the New Jersey coast, compared to a 7.2-inch total change in the global mean sea-level.
2. Over the last forty years, from 1979-2019, sea-level rose 8.2 inches along the New Jersey coast, compared to a 4.5-inch change in global mean sea-level.
3. New Jersey coastal areas are *likely* (at least a 66% chance) to experience SLR of 0.5 to 1.1 ft between 2000 and 2030, and 0.9 to 2.1 ft between 2000 and 2050. It is *extremely unlikely* (less than a 5% chance) that SLR will exceed 1.3 ft by 2030 and 2.6 ft by 2050.
4. While near-term SLR projections through 2050 exhibit only minor sensitivity to different emissions scenarios (<0.1 feet), SLR projections after 2050 increasingly depend upon the pathway of future global greenhouse gas emissions.
    a. Under a high-emissions scenario, consistent with the strong, continued growth of fossil fuel consumption, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR of 1.5 to 3.5 ft between 2000 and 2070, and 2.3 to 6.3 ft between 2000 and 2100. It is *extremely unlikely* (less than a 5% chance) that SLR will exceed 4.4 ft by 2070 and 8.8 ft by 2100.
    b. Under a moderate-emissions scenario, consistent with current global policies, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR of 1.4 to 3.1 ft between 2000 and 2070, and 2.0 to 5.2 ft between 2000 and 2100. It is *extremely unlikely* (less than a 5% chance) that SLR will exceed 3.8 ft by 2070 and 6.9 ft by 2100.
    c. Under a low-emissions scenario, consistent with the global goal of limiting warming to 2°C above early industrial (1850-1900) levels, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR of 1.3 to 2.7 ft between 2000 and 2070, and 1.7 to 4.0 ft between 2000 and 2100. It is *extremely unlikely* (less than a 5% chance) that SLR will exceed 3.2 ft by 2070 and 5.0 ft by 2100.

These results represent one consistent, scientifically justifiable way of estimating the chance of different levels of SLR. Alternative methods or new science may yield higher or lower estimates of the chance of high-end outcomes. Practitioners will need to consider if SLR values in the lower or upper part of the range best reflect their risk tolerance. For example, higher estimates may be more appropriate for long-lived, difficult to modify assets, or highly vulnerable places or people. Appendix A provides decadal projections for all emissions scenarios in both metric and imperial units.

How Fast Will Sea-Level Rise in New Jersey?

The rate of SLR is particularly important to understand in order to assess the adaptability of ecological systems, such as the capacity of coastal marshes to keep pace with SLR. Marshes provide critical functions including flood and storm protection; habitat for fisheries; and carbon and nitrogen storage, among other functions. However, the adaptability of these systems is locally dependent on other factors, including sediment accretion, accommodation space, and organic matter accumulation from plant production (Haaf et al., 2015; Kirwan & Megonigal, 2013; Schuerch et al., 2018). Globally, salt marshes have been able to adapt to a widely varying range of rates of SLR, based on available sediment, nutrients, and other local conditions (Kirwan & Megonigal, 2013; Schuerch et al., 2018). Therefore, practitioners felt that information about rates of SLR for New Jersey would be a helpful outcome of the STAP, especially related to monitoring future responses of salt marshes and other natural resources to be able to better understand adaptation thresholds and make management decisions as resources continue to degrade.

Recent National Climate Assessments find that many wetlands in the Mid-Atlantic will become stressed at a SLR rate of 0.2 to 0.25 inches/year, and will likely not survive a SLR rate of 0.4 inches/year (CCSP, 2009; Dupigny-Giroux et al., 2018). Coastal wetlands in New Jersey are already experiencing a SLR rate of 0.2 inches/year, and this is expected to continue to increase under both low and high-emissions scenarios. Over 2010-2050, average SLR rates are *likely* to be between 0.2 and 0.5 inches/year. Intensive marsh monitoring for sites in New Jersey indicates that sediment rich riverine systems, such as some coastal wetlands in the uppermost Delaware Bay, may be able to keep pace or there are available retreat pathways at the current rate of SLR. However, in Barnegat Bay, a lagoonal system which lacks in sediment supply, the marshes are not expected to keep pace at the current rate of SLR and they have limited options in terms of retreat due to extensive land development (Haaf et al., 2019). There is also increasing evidence that the sediment supply that is sustaining some (vertical) marsh accretion in the Delaware Estuary may be derived from marshes that are eroding along their seaward edge. The Delaware Estuary is currently losing about an acre of marsh per day, which may be associated with increasing rates of SLR as a result of increases in fetch that promote more erosive wave energy and increases in tidal flushing volumes that promote more erosive hydrodynamics (Kreeger, 2016; Miller et al., 2012).

Changes in SLR versus time are used to compute rates. Based on these changes, the STAP has reached the following conclusions about rates of SLR in New Jersey:

1. Over the last forty years, from 1979-2019, sea-level rose at an average rate of 0.2 in/yr along the New Jersey coast, compared to an average rate of 0.1 in/yr in global mean sea-level.
2. New Jersey coastal areas are *likely* (at least a 66% chance) to experience average SLR rates of 0.2 to 0.5 in/yr over 2010–2050. It is *extremely unlikely* (less than a 5% chance) that average SLR rates will exceed 0.7 in/yr over 2010–2050.
3. Rates of SLR are increasingly dependent upon global greenhouse gas emissions later in the 21st century.
    a. Under a high-emissions scenario, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.3 to 1.1 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 1.7 in/yr over 2060-2100.
    b. Under a moderate-emissions scenario, coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.2 to 0.8 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 1.3 in/yr over 2060-2100.
    c. Under a low-emissions scenario (2.0°C), coastal areas of New Jersey are *likely* (at least a 66% chance) to see SLR rates of 0.2 to 0.6 in/yr over 2060-2100. It is *extremely unlikely* (less than a 5% chance) that SLR rates will exceed 0.8 in/yr over 2060-2100.

The impacts on coastal areas will be highly dependent on local environmental dynamics. Nonetheless, it is important to consider SLR rate in understanding how the adaptability of natural systems will be affected, especially in the design of natural infrastructure alternatives. Decadal projections for all emissions scenarios are provided in Appendix A in both metric and imperial units.

When is Sea-Level Rise Going to Exceed X. Feet in New Jersey?

In addition to the projected *likely* range of SLR for a given year, practitioners stated that it would also be helpful to be able to communicate when a particular level of SLR is projected to occur. More specifically, practitioners must be able to respond to the question, "When is sea-level going to exceed X ft over the 2000 baseline in New Jersey?" Table 4 presents probabilities that reflect SLR exceeding stated thresholds from 1 ft through 10 ft above the 2000 baseline (Bamber et al., 2019; Kopp et al., 2014; Rasmussen et al., 2018). It is not possible to give precise probabilities in answer to such a question; disagreements among different methodologies lead the STAP to use the composite methodology described above for projecting bounds on probabilities over time. Instead, a range of probabilities for high-emissions and low-emissions scenarios is presented based on probabilities derived from different methodologies that go into calculating the summary SLR projections. This information can help practitioners communicate the strength of evidence to support incorporating a given amount of SLR over time into their decision.

Table 4. Range of Probabilities that SLR along the New Jersey coast will Exceed Stated Values in Stated Years (ft above 2000 baseline)

High-emissions (5°C)

	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
2030	23-29%									
2040	57-68%	1-4%								
2050	83-90%	10-22%	0-2%							
2060	92-97%	34-57%	3-11%	0-2%						
2070	96-99%	59-80%	13-35%	2-9%	0-3%	0-1%				
2080	98-99%	76-91%	30-60%	7-26%	1-9%	0-4%	0-2%	0-1%		
2090	98-100%	85-95%	50-77%	18-47%	5-22%	1-10%	1-6%	0-3%	0-2%	0-1%
2100	98-100%	89-97%	64-85%	32-63%	12-38%	4-20%	1-11%	1-7%	0-5%	0-3%
2110	100%	97-99%	77-94%	40-75%	15-49%	5-28%	2-16%	1-11%	1-8%	0-6%
2120	100%	98-100%	83-96%	52-83%	23-60%	9-38%	4-23%	2-15%	1-11%	1-9%
2130	100%	99-100%	88-98%	63-89%	36-71%	16-50%	7-33%	4-21%	2-15%	1-12%
2140	100%	99-100%	92-98%	72-93%	47-79%	25-60%	12-42%	6-28%	3-20%	2-15%
2150	100%	99-100%	94-99%	79-95%	57-85%	35-69%	19-52%	10-36%	5-25%	3-18%

Low-emissions (2°C)

	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
2030	5-9%									
2040	47-58%	0-1%								
2050	74-83%	3-8%								
2060	88-93%	16-27%	1-2%							
2070	93-96%	38-53%	4-8%	1%						
2080	95-97%	54-69%	11-20%	2-4%	1%					
2090	95-98%	64-78%	22-33%	5-9%	1-2%	1%				
2100	95-98%	73-85%	34-48%	10-16%	3-5%	1-2%	1%			
2110	96-98%	78-87%	47-61%	20-30%	7-11%	3-4%	1-2%	1%		
2120	97-98%	82-89%	55-68%	28-40%	11-18%	5-8%	2-3%	1%	1%	
2130	97-98%	83-91%	60-74%	36-49%	18-26%	8-12%	4-6%	2-3%	1%	0-1%
2140	97-99%	86-93%	66-80%	42-57%	23-33%	11-17%	6-8%	3-4%	2%	1%
2150	97-99%	89-94%	70-83%	46-62%	26-39%	13-21%	6-11%	4-5%	2-3%	1%

The data in Table 4 present similar information about SLR to that illustrated in Table 3 above, but in a fundamentally different way. Instead of providing a range of projected SLR for a given future year

(Table 3), Table 4 presents a range of timings for a given level of SLR. For example, under a high-emissions scenario, there is a 10-22% chance SLR will exceed 2 ft by 2050, a 59-80% chance it will do so by 2070, and an 89-97% chance it will do so by 2100. The spread in probabilities arises from different ways of assessing the sensitivity of ice-sheets to warming that serve as the basis for our composite sea-level projections (i.e., Bamber et al., 2019; Kopp et al., 2014). Under a low-emissions scenario, there is a 38-53% chance SLR will exceed 2 ft by 2070 and a 73-85% chance it will do so by 2100 (i.e., Bamber et al., 2019; Rasmussen et al., 2018).

The approach used to generate moderate-emissions projections do not lend themselves as readily to presentation in this manner, but associated probabilities would be intermediate between those for the low- and high-emissions projections. In other words, if there is an 89-97% chance that SLR will exceed 2 ft by 2100 under a high-emissions scenario, and a 73-85% chance that SLR will exceed 2 ft by 2100 under a low-emissions scenario (2°C), the probability SLR will exceed 2 ft by 2100 under a moderate-emissions scenario would fall between 73 and 97%.

How do the Consensus Sea-Level Rise Projections for New Jersey Compare with Other Regional and National Projections?

Federal climate projections rely on the study Sweet et al. (2017) available through the USACE Sea-Level Change Curve Calculator along with curves established for USACE guidance. The calculator is a tool that practitioners use to generate local SLR projections based on a tide gauge location and different assumptions about future climate impacts. Generally, the higher federal curves and scenarios are consistent with higher emissions and more extreme climatic responses to emissions (i.e., faster ice sheet melt), while the lowest curve represents a constant linear trend over time. The federal scenarios do not have associated probability estimates, whereas the projections of K14, R18, and B19 do provide probability estimates based on a variety of underlying data sources.

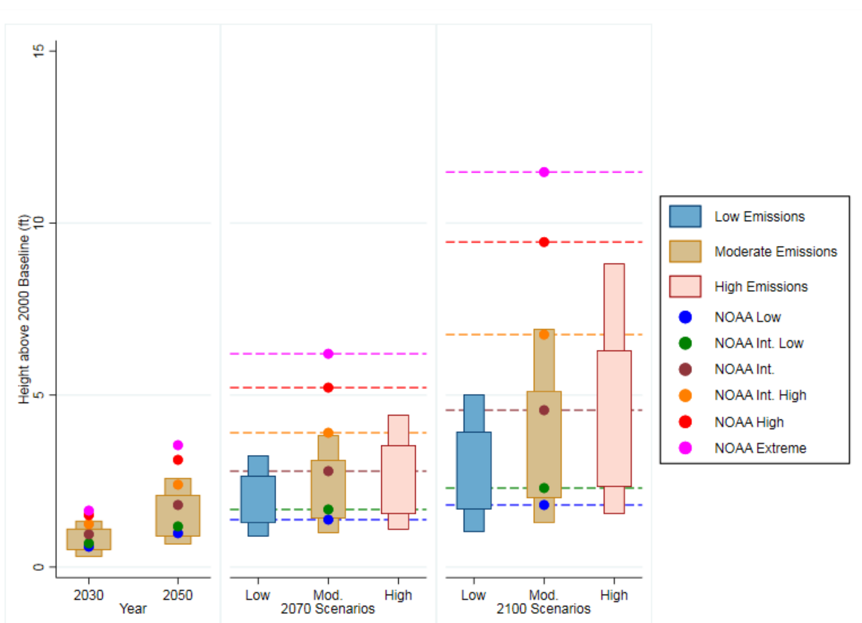

Figure 7. STAP Emissions projections compared with Federal scenario projections for Atlantic City, NJ. The thickest part of each box plot represents the *likely* range (17th to 83rd percentile), while the narrower part of the plot represents the *very likely* range (5th to 95th percentile). Dots and dashed lines denote the median SLR projection for each federal planning scenario in a given year

The STAP *likely* ranges of NJ SLR estimates are comparable to the recent SLR guidance proposed by an interagency working group that included the National Oceanic and Atmospheric Administration (NOAA), the United States Army Corps of Engineers (USACE), the United States Geological Survey (USGS), and other agency and academic partners (Sweet et al., 2017). Figure 7 presents a comparison of the NJ STAP emissions projections and the Atlantic City, NJ federal scenario projections for 2030, 2050, 2070 and 2100. When compared with the NJ STAP projections:

- For 2030 and 2050, the federal Low, Int. Low, and Intermediate scenario projections are all in the likely range; the federal Int. High scenario is unlikely, while the federal High and Extreme scenarios are extremely unlikely.
- Beyond 2050, for low-emissions projections, the federal Low and Int. Low scenarios are in the likely range, the federal Intermediate scenario is unlikely, and the federal Int. High, High and Extreme scenarios are all extremely unlikely in 2070 and 2100.
- Beyond 2050, for moderate emissions, the federal Low scenario is in the likely range in 2070 but unlikely in 2100; the federal Int. Low and Intermediate scenarios are in the likely range; the federal Int. High is extremely unlikely in 2070, but only unlikely in 2100; and the federal High and Extreme scenarios are both extremely unlikely in 2070 and 2100.
- Beyond 2050, for high-emissions, the federal low scenario is unlikely, the federal Int. Low and Intermediate scenarios are in the likely range, the federal Int. High is unlikely, and the federal High and Extreme scenarios are extremely unlikely in 2070 and 2100.

NJ practitioners preferring the federal data can compare projections and, for example, select the intermediate federal scenario to prepare for SLR that falls within the *likely* range of the NJ STAP moderate emissions projection. Despite this consistency, the STAP reminds practitioners that alternative methods or new science may yield higher or lower estimates of the probability of high-end outcomes.

Future Coastal Storms

Higher mean sea-levels will increase the baseline for flooding from coastal storms, and therefore their impacts. In addition, climate change may change the characteristics of storm systems. The STAP discussed many of the aspects of both tropical (i.e., hurricane) and extratropical (i.e., nor'easter) coastal storm systems, as well as hybrid storms such as Sandy. The STAP noted the following conclusions of the 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) that are relevant for planning in New Jersey (Collins et al., 2019):

> Tropical cyclone [TC] projections for the late 21st century are summarized as follows: 1) there is medium confidence that the proportion of TCs that reach Category 4–5 levels will increase, that the average intensity of TCs will increase (by roughly 1-10%, assuming a 2 degree global temperature rise), and that average tropical cyclone precipitation rates (for a given storm) will increase by at least 7% per degree Celsius sea surface temperature (SST) warming, owing to higher atmospheric water vapour content, 2) there is low confidence (low agreement, medium evidence) in how global TC frequency will change, although most modelling studies project some decrease in global TC frequency and 3) sea-level rise will lead to higher [water] levels for the TCs that do occur, assuming all other factors are unchanged (very high confidence).
>
> AR5 concluded that the global number of ETCs is not expected to decrease by more than a few percent due to anthropogenic change… AR5 also found a low confidence in the magnitude of regional storm track changes and the impact of such changes on

> regional surface climate (Christensen et al., 2013). A number of new studies have found links between Arctic amplification, blocking events and various types of weather extremes in NH midlatitudes in recent decades. However, the sensitivity of results to analysis technique and the generally short record with respect to internal variability means that at this stage there is low confidence in these connections. Consistent with the AR5, projected changes to NH storm tracks exhibit large differences between responses, causal mechanisms and ocean basins and so there remains low confidence in future changes in blocking and storm tracks in the NH.

STAP members concluded that there was no clear basis for planning guidance for New Jersey to deviate from the most recent examinations of the issues by the New York City Panel on Climate Change (Orton et al., 2019) and by the Intergovernmental Panel on Climate Change (IPCC), including the IPCC's conclusions regarding the need for further research to understand regional changes in future tropical cyclones and extratropical cyclones (Collins et al., 2019).

Some recent studies have focused more specifically on conditions in the region, but more work will be required to assess their conclusions. For example, while it is largely accepted that rising sea levels will increase the flood heights associated with storm surge events, models disagree on whether changes in tropical cyclone characteristics will increase the height of storm surges in the New York area above their contemporary mean sea-level (Garner et al., 2017; Lin et al., 2012). Some results suggest that the climate conditions of the late 20th and early 21st centuries have a greater propensity to generate tropical cyclones with extreme storm surges in the New York area than did conditions of the preceding millennium (Reed et al., 2015). A number of studies suggest that conditions in the future will be conducive to more intense tropical cyclones (Garner et al., 2017; Knutson et al., 2019; Marsooli et al., 2019). A recent study found that the potential changes in tropical cyclone activity may have relatively small effect on the coastal flood levels compared to the effect of SLR for high latitude regions including New Jersey (Marsooli et al., 2019). Potential changes to storm tracks could result in little change to storm surges in our region (Garner et al., 2017). Regardless of whether storm surges increase, higher sea levels will lead to higher overall water levels associated with storm surge. In addition, there is high confidence that precipitation rates during both tropical and extratropical cyclones are *likely* to increase (e.g., Bacmeister et al., 2018; Hawcroft et al., 2018; Knutson et al., 2019).

Future changes in the frequency, intensity (wind speed), precipitation rate, and tracks of extratropical storms remain an area of active research, and the STAP concluded there is no definitive consensus regarding such changes at this time. The need to better understand projected changes to coastal storms has spurred several areas of active research that could influence scientific understanding of future projections, including changes in the Gulf Stream, changes in sea surface temperatures, changes in blocking patterns, feedbacks involving latent heat release, and possible evidence of a poleward shift in storm tracks (e.g., Bhatia et al., 2018; Catalano et al., 2019; Colle et al., 2013; Emanuel, 2007; Garner et al., 2017; Harvey et al., 2015; Maloney et al., 2014; Marciano et al., 2015; Michaelis et al., 2017; Overland et al., 2015; Reed et al., 2015; Roberts et al., 2017; Woollings et al., 2012). A recent study projected a relatively small effect of climate change on extratropical cyclone storm surges in the Northeast coast, although uncertainties exist among the climate models applied in the analysis (Lin et al., 2019). The STAP cautions planners and decision-makers that ongoing and emerging research in these areas may revise current projections.

Despite lingering uncertainty pertaining to future changes to storm characteristics, such as frequency, intensity (wind speed), and tracks, it is *virtually certain* (*high confidence*) that future SLR will cause greater overall storm flood levels. Thus, it is of utmost importance to keep in mind that SLR will exacerbate future coastal storm impacts for the state of New Jersey, even if there is little or no systematic change in the frequency, intensity (wind speed), and tracks of storms.

Tidal Flooding

Certain coastal areas of New Jersey, experience tidal flooding on sunny days. The number of days that New Jersey residents have experienced these high tide floods in the absence of an associated storm has increased in recent years. High-tide flooding can have detrimental impacts on infrastructure and community function in the absence of a major storm. Over 2007-2016, there were an average of 8 high-tide flood events in Atlantic City, NJ, with annual event totals ranging between 4 events in 2007 and 18 events in 2009. This frequency has grown from an average of less than one high-tide flood event per year in the 1950s (see Figure 8) (Sweet et al., 2018).

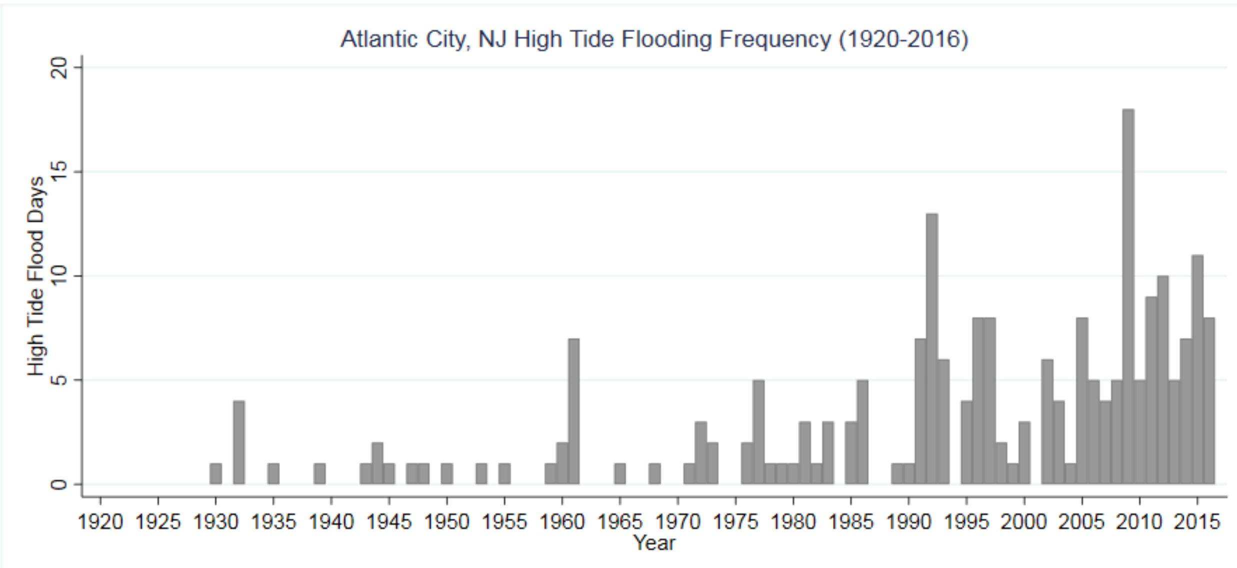

Figure 8. Historical High Tide Flood Frequency (# of flood days) for Atlantic City, NJ (Sweet et al., 2018)

Using the STAP estimates of New Jersey SLR, the STAP used a methodology consistent with Sweet et al. (2018) to calculate tidal flood frequency levels for New Jersey tide gauges corresponding to the projected sea-level changes. The high-tide flood threshold values at each of the 5 gauges suitable for New Jersey analysis are approximately 2 ft (0.56 m - 0.58 m) above MHHW in the year 2000. The high tide flood threshold values are derived using a consistent standard for high tide flooding nationwide by NOAA (Sweet et al., 2018), but are not the same as the local National Weather Service 'minor tidal flood' thresholds. Under the Sweet et al. (2018) approach, the frequency reflects that the high tide flooding threshold is exceeded at least once in a given day, but does not indicate the duration of exceedance, or multiple exceedances, for a high tide flooding event.

Table 5. Expected high-tide flooding days in Atlantic City, NJ, through 2150 for a Moderate Emissions projection

Year	Low End > 95% Chance	*Likely* Range >83% Chance	*Likely* Range ~50% chance	*Likely* Range < 17% chance	High End < 5% chance
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	75 days	110 days
2040	17 days	30 days	70 days	150 days	220 days
2050	24 days	45 days	120 days	255 days	325 days
2060	40 days	85 days	190 days	315 days	350 days
2070	55 days	120 days	265 days	350 days	**
2080	75 days	165 days	320 days	**	**
2090	85 days	200 days	345 days	**	**
2100	95 days	240 days	355 days	**	**
2110	150 days	285 days	360 days	**	**
2120	155 days	305 days	**	**	**
2130	175 days	325 days	**	**	**
2140	220 days	340 days	**	**	**
2150	255 days	350 days	**	**	**

*Notes: ** indicates high-tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

An example of the tidal flood frequencies is provided for Atlantic City, NJ, in Table 5. It is *likely* that the expected number of high tide flooding days will be between 120 and 350 by the year 2070 under a moderate emissions scenario, but this analysis does not include the year-to-year variation around the expected number of days. It is *extremely likely* (more than a 95% chance) that the expected number of high tide flooding days will exceed 55 flood days by the year 2070 under a moderate emissions scenario. By 2100, it is *likely* that high tide flooding will exceed 240 days per year, and could become a daily occurrence under a moderate emissions scenario. A table of decadal high tide flooding frequency projections for each tide gauge used in this report is included in Appendix B.

Critical Future Research Focus: Likelihood and Impacts of Compound Events

As part of the STAP deliberations, the panel discussed the state of available science and modeling with the capability to reflect combined hazards from rainfall and flooding. Such compound events occur through a combination of multiple drivers and/or hazards that contribute to societal or environmental risks (IPCC, 2019; Zscheischler et al., 2018). While flood risks are often modeled as independent precipitation, wind, and storm surge events, recent research efforts have undertaken the task of modeling compound flood events (Hendry et al., 2019; Orton et al., 2018; Orton et al., 2012; Wahl et al., 2015). Recently, Orton et al. (2018) that combined rainfall and storm tide modeling approaches to create a probabilistic flood hazard assessment for the Hudson River. Wahl et al. (2015) modeled the risk of flooding from co-occurring rainfall and storm surge on several US cities, finding that shifting weather patterns could lead to an increased likelihood for co-occurring storm surge and high precipitation events for New York City. Both the STAP members and the practitioner panel discussed the need to move toward integrated models that represent such conditions in order to plan for more comprehensive adaptation and resilience strategies.

Using the Science: Illustrating the Effects of SLR on Future Flood Exposure Assessment in New Jersey

In 2016 and, again in 2019, the STAPs and practitioner panels discussed how the STAP science can inform the assessment of future coastal flood exposures resulting from SLR. The 2016 STAP report for New Jersey (Kopp et al., 2016) outlined several approaches for assessing exposure of people, places and assets to coastal flood hazards resulting from SLR. This included an approach that, at the time was emerging, using the concept of 'SLR allowances' in Atlantic City, NJ (Buchanan et al., 2016), and an approach that is referred to as a "Total Water Level" approach (Campo & Auermuller, 2018; Eastern Research Group Inc., 2013). The latter has been advanced by practitioners at Rutgers University and is reflected on the web-based data visualization and mapping platform New Jersey Floodmapper.

While it is outside the purview of the STAP to endorse any single approach for application of STAP science for use in exposure assessment, in this section of the report, the STAP outlines a "use case" to illustrate one example of how the STAP science can be integrated into a planning and decision-making framework. For the purpose of this "use case," a fictional practitioner is created who is working in Brigantine, New Jersey, on a comprehensive land-use plan. The case is intended to simulate one of many ways in which practitioners can use the updated projections in this document, and other ancillary tools, to begin to present SLR information to other planning stakeholders and decision-makers.

In the example use case, the practitioner will ask 4 questions:

1. What tide gauge will be used as a reference?
2. What planning horizon will be used?
3. What emissions scenario will be used?
4. What SLR estimates will be used?

After answering these four questions, the practitioner will be able to summarize potential SLR impacts for consideration into the development of the comprehensive land-use plan.

Table 6, below, is provided to assist practitioners with applying the outcomes of the STAP and is applied to illustrate the Brigantine "use case."

Table 6. New Jersey Sea-Level Rise above the year 2000 (1991-2009 average) baseline (ft)*

		2030	2050	2070			2100			2150		
				Emissions								
	Chance SLR Exceeds			Low	Mod.	High	Low	Mod.	High	Low	Mod.	High
Low End	> 95% chance	0.3	0.7	0.9	1	1.1	1.0	1.3	1.5	1.3	2.1	2.9
Likely Range	> 83% chance	0.5	0.9	1.3	1.4	1.5	1.7	2.0	2.3	2.4	3.1	3.8
	~50 % chance	0.8	1.4	1.9	2.2	2.4	2.8	3.3	3.9	4.2	5.2	6.2
	<17% chance	1.1	2.1	2.7	3.1	3.5	3.9	5.1	6.3	6.3	8.3	10.3
High End	< 5% chance	1.3	2.6	3.2	3.8	4.4	5.0	6.9	8.8	8.0	13.8	19.6

**2010 (2001-2019 average) Observed = 0.2 ft*

Notes: All values are 19-year means of sea-level measured with respect to a 1991-2009 baseline centered on the year indicated in the top row of the table. Projections are based on Kopp et al. (2014), Rasmussen et al. (2018), and Bamber et al. (2019). Near-term projections (through 2050) exhibit only minor sensitivity to different emissions *scenarios (<0.1 feet). Low and high emissions scenarios correspond to global-mean warming by 2100 of 2°C and 5°C above early Industrial (1850-1900) levels, respectively, or equivalently, about 1°C and 4°C above the current global-mean temperature. Moderate (Mod.) emissions are interpolated as the midpoint between the high- and low-emissions scenarios and approximately correspond to the warming expected under current global policies. Rows correspond to different projection probabilities. There is at least a 95% chance of SLR exceeding the values in the 'Low End' row, while there is less than a 5% chance of exceeding the values in the 'High End' row. There is at least a 66% chance that SLR will fall within the values in the 'Likely Range'. Note that alternative methods may yield higher or lower estimates of the chance of low-end and high-end outcomes.*

First, the practitioner selects one of five tide gauge locations for the basis of their analysis. While the different tide-gauge locations in New Jersey will experience comparable SLR, those same locations will experience different magnitudes of flooding based on local hydrology and morphology (Pugh, 1996). The nearest tide gauge location is usually, but not always, the most suitable choice to represent local tide and flood event characteristics. Practitioners are advised to consult with local and state agencies to determine the tide gauge that best represents local conditions. In the case a tide-gauge choice is not clear, the practitioner can perform analyses for the nearest two tide-gauges and use the tide-gauge that provides more conservative (i.e., higher) water levels for planning.

2. Using a Planning Horizon

Next, the practitioner identifies the appropriate planning horizon. Practitioners can select a decade from 2020 through 2150 in order to estimate SLR impacts over the life of their decision. Practitioners may wish to analyze several decades in order to understand how the risk of flooding from different types of events increases over time. Some practitioners have suggested considering the timeframe of 20-30 years, which is the period when the public thinks about making investments in their homes and when public sector agencies complete long-range master plans for land use or transportation. However, it is important to recognize that land use, transportation, and other infrastructure decisions can have consequences lasting substantially longer than this time frame.

3. Using Emissions Scenarios

The practitioner then considers the SLR estimates. For context, the STAP indicates that SLR projections through 2050 are not dependent on assumptions about future global emissions and the commensurate change in global mean temperature. In other words, coastal communities are locked into the range of SLR that we will see by the year 2050 regardless of whether emissions increase or decrease. For planning horizons after 2050, however, practitioners are advised to estimate the sensitivity of their decision to situations where global emissions will follow a low-, moderate-, or high-emissions pathway through the end of the century.

The STAP has not assigned a likelihood that society will achieve any particular emissions outcome. To ensure that their project decisions account for a variety of future planning situations, practitioners can analyze the sensitivity of their analysis using both the moderate and high-emissions scenarios when developing adaptation strategies and assessing the risks that future flood hazards could pose to people, places, and assets in New Jersey based on current global policy. Additionally, practitioners could use the low-emissions scenario to demonstrate the potential benefits that emissions reductions actions can have on adaptive strategies toward the end of the century.

4. Using SLR Rise Estimates

Once a practitioner has selected a low, moderate and/or high-emissions scenario, they will need to select from within the range of SLR that is possible under each emissions future. Each emissions future has a low-end, *likely* range, and high-end estimate.

When considering individual assets, practitioners will want to consider that:

- Damages to community assets that are highly consequential have larger social, environmental, and economic impacts associated with their failure or impairment than those that are less consequential. For such highly consequential assets, the STAP advises that practitioners use the high-end estimate indicated in Table 6.
- Community assets for which loss or impairment would not cause significant societal losses, using a value within the *likely* range of future sea-level from Table 6 may be adequate for planning.
- While low-end projections are provided in Table 6 to illustrate the full range of *very likely* outcomes, the low-end projections are *extremely unlikely* to be sufficient for managing future exposure risk from increases in flooding.

When considering community-wide adaptation and resilience planning in which multiple assets are involved, practitioners may wish to consider SLR estimates in both the *likely* range and a high-end range in order to assess the variety of critical and non-critical assets in the community. For example, a road that has a high vulnerability may not have high consequences of failure if it only serves as access to a recreational facility. On the other hand, a pier may serve to transfer cargo for nationwide distribution and, thus, have comparatively higher consequences. In these ways, planning for resilience represents community values and necessitates transparency and community engagement.

With regard to planning for both individual assets and community-wide adaptation and resilience planning, an additional benefit of using high-end projections is that doing so accounts for additional flood attributes that are not quantified using this methodology (e.g., changes in shoreline, wave action, development patterns, etc.) and to account for uncertainty related to advances in climate science that may result in an increase in the magnitude of high-end outcomes.

OUTCOME: Summarizing SLR Impacts

In summary, a practitioner is working with decision-makers in Brigantine, NJ, on a comprehensive land-use plan. The practitioner answers the four key questions outlined above as follows:

1. **What tide gauge will be used as a reference?** The practitioner chooses to use the nearby Atlantic City tide-gauge.
2. **What planning horizon will be used?** The practitioner chooses to use a 2050 planning horizon.
3. **What emissions scenario will be used?** The practitioner analyzes their project's sensitivity to moderate and high emissions scenarios.
4. **What SLR estimates will be used?** Since this is a community-level assessment and not an exposure assessment of an individual asset, there is a mix of people, places, and assets with different levels of criticality. The practitioner chooses to analyze both a *likely* range estimate and a 'high-end' estimate for sea-level rise associated with a moderate emissions scenario.

Using the answers to these questions and the decadal SLR projection tables in Appendix A and Appendix B, the practitioner can present the following:

A. A statement about recent SLR from a 2000 baseline year which reflects consensus among STAP participants and is included in this report:

   a. From 1979-2019, sea-level rose 0.7 feet along the New Jersey coast.

B. The practitioner reviews Table A2 for the appropriate year (2050) and the commensurate columns to represent both the likely range (columns 2, 3, and 4) and 'high end' estimates (column 5) for SLR.

   a. Residents and businesses in the town are *likely* (at least a 66% chance) to experience SLR of 0.9 to 2.1 ft between 2000 and 2050, indicating that the town intends to plan for 1.4 ft, the central estimate. While it is *extremely unlikely* (less than a 5% chance) that SLR will exceed 2.6 ft by 2050, the town also wants to understand if there any critical or highly vulnerable facilities exposed in the case the unlikely occurs. (See Table 6)

   b. Looking past 2050 for long-lived investments, residents and businesses in the town are *likely* (at least a 66% chance) to experience SLR of 2.0 to 5.2 ft between 2000 and 2100, indicating that the town intends to plan for 3.3 ft, the central estimate. While it is *extremely unlikely* (less than a 5% chance) that SLR will exceed 6.9 ft by 2100, the town also wants to understand if there any contingencies needed for long-lived decisions to allow for future adaptive measures. (See Table 6)

C. The practitioner recognizes from interviews that high tide flooding is problematic in this community and will be exacerbated by SLR. The practitioner reviews Table B2 for the *likely* range (columns 2, 3, and 4) and 'high end' estimates (column 5) of high tide flooding frequency.

   a. In 2016, there were 8 high tide flooding events in Atlantic City, NJ, with annual event totals ranging between 4 high tide flood events (2007) and 18 high tide flood events (2009) over the past decade (see Figure 8) (Sweet et al., 2018). By 2050, there is approximately a 50% chance that SLR will exceed 1.4 feet, and so town residents and businesses might commensurately expect to see 120 high tide flooding days during an average year by that point in time. (See Appendix B, Table B2)

D. The practitioner recognizes that changes in SLR will not only impact communities during future tides, but also could increase the heights of **all** future flood events. Using information resources from NOAA, the practitioner decides to compute Table 7 to project how SLR would impact the following events:

   a. 100-year flood (1% AEP)

   b. Historical Sandy Storm Tide

   c. Annual Flood (99% AEP)

   d. High Tide Flooding Threshold

   e. Permanent Inundation (MHHW)

Table 7. Future Projections of Current and Historical Flood Event Heights (ft relative to 2000 MHHW)

Scenario / Year	2000	2030	2050	2070	2100
Moderate Emissions *Likely* (3.3 ft SLR by 2100)					
100-year flood (1% AEP)	4.8	5.6	6.2	7.0	8.1
Sandy Storm Tide	4.1	4.9	5.5	6.3	7.4
10-year flood (10% AEP)	3.3	4.1	4.7	5.5	6.6
Annual Flood (99% AEP)	2.5	3.3	3.9	4.7	5.8
High Tide Flooding Threshold	1.8	2.6	3.2	4.0	5.1
Permanent Inundation (MHHW)	0.0	0.8	1.4	2.2	3.3
Moderate Emissions High End (6.9 ft SLR by 2100)					
100-year flood (1% AEP)	4.8	6.1	7.4	8.6	11.7
Sandy Storm Tide	4.1	5.4	6.7	7.9	11.0
10-year flood (10% AEP)	3.3	4.6	5.9	7.1	10.2
Annual Flood (99% AEP)	2.5	3.8	5.1	6.3	9.4
High Tide Flooding Threshold	1.8	3.1	4.4	5.6	8.7
Permanent Inundation (MHHW)	0.0	1.3	2.6	3.8	6.9

Notes: All values are based on information from the Atlantic City tide gauge. Values in the table refer to total flood event height projections, given in ft. The 100-year flood (1% AEP), 10-year flood (10% AEP), and Sandy Storm Tide all derive from ***NOAA CO-OPS Extreme Water Levels*** *data. The Annual Flood (99% AEP) is generated from an empirical kernel fit provided by NOAA Co-Ops for this report. The high tide flooding threshold for Atlantic City, NJ is from Sweet et al. (2018). Note that alternative methods for measuring flood events and critical event thresholds are available from several different resources (e.g., from the* ***USACE Sea-Level Change Curve Calculator****) and may yield higher or lower estimates of future hazard exposure.*

Table 7 summarizes an example of the total flood event height projections through 2100 for two SLR scenarios in the event of permanent inundation, high tide flooding, and various coastal storm event types. Based on Table 7, the practitioner can begin to understand potential future flood events that include projected SLR. For example, the practitioner might wish to communicate the following:

1. Assuming a *likely* moderate emissions scenario, the highest of daily high tides (permanent inundation) will begin to surpass the current high tide flooding threshold (1.8 ft) between 2050 and 2070, and may be equivalent to the current 10-year flood event by 2100.
2. Assuming a *likely* moderate emissions scenario, 2050 water levels from 'nuisance' or 'sunny day' flood events (high tide flooding threshold) may be equivalent to a current 10-year flood event.
3. Assuming a *likely* moderate emissions scenario, the water level associated with an Annual Flood (99% AEP) by 2070 would surpass the Sandy Storm Tide and be roughly equivalent (0.1 ft different) to the current 100-year flood (1% AEP).

Summary

STAP members identified a consensus communication of historical observations of SLR, along with a distribution of future SLR projections for New Jersey through the year 2150. Decadal projection information is available in Appendix A for practitioner reference. STAP members concluded that there was no clear basis for deviating from the IPCC's conclusions when projecting changes in future coastal storms (i.e., tropical and extratropical cyclones) for New Jersey. They also concluded that higher sea-levels will increase the baseline for flooding from coastal storms, thus increasing their impacts. The STAP has provided an illustration for using the SLR estimates in a planning context. However, practitioners should use these SLR estimates as a consistent basis for accepted estimates and integrate this information into their preferred planning or design methods to account for unique geographic or professional considerations. The STAP recommends that practitioners and scientists review these estimates on a regular basis, not to exceed 5 years as well as after the publication of any global (i.e., IPCC) or national (i.e., National Climate Assessment) assessments related to SLR and coastal storms relevant to New Jersey.

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Appendix A: New Jersey Sea-Level Rise Appendices

Table A1. Low-emissions SLR (ft above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000			0		
2010			0.2 ft		
2020	0.1 ft	0.3 ft	0.5 ft	0.7 ft	0.9 ft
2030	0.3 ft	0.5 ft	0.8 ft	1.1 ft	1.3 ft
2040	0.5 ft	0.7 ft	1.1 ft	1.5 ft	1.9 ft
2050	0.7 ft	0.9 ft	1.4 ft	2.1 ft	2.6 ft
2060	0.8 ft	1.1 ft	1.6 ft	2.2 ft	2.7 ft
2070	0.9 ft	1.3 ft	1.9 ft	2.7 ft	3.2 ft
2080	1.0 ft	1.4 ft	2.2 ft	3.1 ft	3.8 ft
2090	1.0 ft	1.5 ft	2.5 ft	3.5 ft	4.4 ft
2100	1.0 ft	1.7 ft	2.8 ft	3.9 ft	5.0 ft
2110	1.0 ft	1.8 ft	3.1 ft	4.6 ft	5.9 ft
2120	0.9 ft	1.9 ft	3.4 ft	5.1 ft	6.6 ft
2130	0.9 ft	2.0 ft	3.7 ft	5.6 ft	7.2 ft
2140	1.1 ft	2.2 ft	4.0 ft	5.9 ft	7.6 ft
2150	1.3 ft	2.4 ft	4.2 ft	6.3 ft	8.0 ft

Table A2. Moderate-emissions SLR (ft above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000			0		
2010			0.2 ft		
2020	0.1 ft	0.3 ft	0.5 ft	0.7 ft	0.9 ft
2030	0.3 ft	0.5 ft	0.8 ft	1.1 ft	1.3 ft
2040	0.5 ft	0.7 ft	1.1 ft	1.5 ft	1.9 ft
2050	0.7 ft	0.9 ft	1.4 ft	2.1 ft	2.6 ft
2060	0.8 ft	1.2 ft	1.8 ft	2.5 ft	3.1 ft
2070	1.0 ft	1.4 ft	2.2 ft	3.1 ft	3.8 ft
2080	1.1 ft	1.6 ft	2.6 ft	3.8 ft	4.8 ft
2090	1.2 ft	1.8 ft	3.0 ft	4.4 ft	5.8 ft
2100	1.3 ft	2.0 ft	3.3 ft	5.1 ft	6.9 ft
2110	1.6 ft	2.3 ft	3.7 ft	5.7 ft	8.1 ft
2120	1.6 ft	2.4 ft	4.1 ft	6.4 ft	9.4 ft
2130	1.7 ft	2.6 ft	4.5 ft	7.1 ft	10.9 ft
2140	1.9 ft	2.9 ft	4.9 ft	7.7 ft	12.4 ft
2150	2.1 ft	3.1 ft	5.2 ft	8.3 ft	13.8 ft

Table A3. High-emissions SLR (ft above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000					
2010			0.2 ft		
2020	0.1 ft	0.3 ft	0.5 ft	0.7 ft	0.9 ft
2030	0.3 ft	0.5 ft	0.8 ft	1.1 ft	1.3 ft
2040	0.5 ft	0.7 ft	1.1 ft	1.5 ft	1.9 ft
2050	0.7 ft	0.9 ft	1.4 ft	2.1 ft	2.6 ft
2060	0.9 ft	1.2 ft	1.9 ft	2.8 ft	3.4 ft
2070	1.1 ft	1.5 ft	2.4 ft	3.5 ft	4.4 ft
2080	1.3 ft	1.8 ft	2.9 ft	4.4 ft	5.7 ft
2090	1.4 ft	2.1 ft	3.4 ft	5.3 ft	7.2 ft
2100	1.5 ft	2.3 ft	3.9 ft	6.3 ft	8.8 ft
2110	2.2 ft	2.7 ft	4.2 ft	6.8 ft	10.3 ft
2120	2.3 ft	3.0 ft	4.7 ft	7.7 ft	12.3 ft
2130	2.5 ft	3.2 ft	5.2 ft	8.6 ft	14.6 ft
2140	2.7 ft	3.5 ft	5.7 ft	9.5 ft	17.1 ft
2150	2.9 ft	3.8 ft	6.2 ft	10.3 ft	19.6 ft

Table A4. Low-emissions SLR (cm above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000			0 cm		
2010			5 cm		
2020	4 cm	9 cm	15 cm	22 cm	27 cm
2030	9 cm	15 cm	23 cm	34 cm	41 cm
2040	15 cm	22 cm	33 cm	47 cm	58 cm
2050	20 cm	27 cm	43 cm	64 cm	79 cm
2060	23 cm	33 cm	49 cm	67 cm	81 cm
2070	27 cm	39 cm	59 cm	81 cm	99 cm
2080	29 cm	44 cm	67 cm	94 cm	116 cm
2090	29 cm	47 cm	75 cm	107 cm	134 cm
2100	31 cm	51 cm	84 cm	120 cm	153 cm
2110	29 cm	54 cm	95 cm	139 cm	179 cm
2120	27 cm	57 cm	103 cm	155 cm	200 cm
2130	27 cm	60 cm	112 cm	170 cm	219 cm
2140	34 cm	66 cm	121 cm	181 cm	231 cm
2150	40 cm	72 cm	127 cm	191 cm	245 cm

Table A5. Moderate Emissions SLR (cm above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000			0 cm		
2010			5 cm		
2020	4 cm	9 cm	15 cm	22 cm	27 cm
2030	9 cm	15 cm	23 cm	34 cm	41 cm
2040	15 cm	22 cm	33 cm	47 cm	58 cm
2050	20 cm	27 cm	43 cm	64 cm	79 cm
2060	25 cm	36 cm	54 cm	76 cm	93 cm
2070	30 cm	43 cm	66 cm	95 cm	117 cm
2080	34 cm	50 cm	78 cm	115 cm	145 cm
2090	37 cm	55 cm	90 cm	135 cm	176 cm
2100	39 cm	61 cm	102 cm	156 cm	211 cm
2110	48 cm	69 cm	112 cm	173 cm	247 cm
2120	49 cm	74 cm	124 cm	196 cm	288 cm
2130	52 cm	80 cm	136 cm	217 cm	332 cm
2140	58 cm	87 cm	148 cm	235 cm	377 cm
2150	64 cm	94 cm	158 cm	253 cm	421 cm

Table A6. High-emissions Sea-Level Rise (cm above 2000 [1991 – 2009 avg.] baseline)

Year	Low End	At least a 66% chance between			High End
	Greater than a 95% chance SLR exceeds	*Greater than an 83% chance SLR exceeds*	*~50% chance SLR exceeds*	*Less than a 17% chance SLR exceeds*	*Less than a 5% chance SLR exceeds*
2000			0 cm		
2010			5 cm		
2020	4 cm	9 cm	15 cm	22 cm	27 cm
2030	9 cm	15 cm	23 cm	34 cm	41 cm
2040	15 cm	22 cm	33 cm	47 cm	58 cm
2050	20 cm	27 cm	43 cm	64 cm	79 cm
2060	27 cm	38 cm	59 cm	85 cm	105 cm
2070	33 cm	47 cm	73 cm	108 cm	135 cm
2080	39 cm	55 cm	89 cm	135 cm	174 cm
2090	44 cm	63 cm	105 cm	163 cm	218 cm
2100	47 cm	71 cm	120 cm	192 cm	269 cm
2110	66 cm	83 cm	129 cm	207 cm	314 cm
2120	71 cm	90 cm	144 cm	236 cm	375 cm
2130	77 cm	99 cm	159 cm	263 cm	444 cm
2140	82 cm	107 cm	174 cm	289 cm	522 cm
2150	88 cm	115 cm	188 cm	315 cm	597 cm

Appendix B: Tidal Flooding Projections and Frequencies

Table B1. Atlantic City, NJ High Tide Flood Days - Low-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	75 days	110 days
2040	17 days	30 days	70 days	150 days	220 days
2050	24 days	45 days	120 days	255 days	325 days
2060	35 days	70 days	155 days	270 days	330 days
2070	45 days	95 days	225 days	330 days	355 days
2080	55 days	125 days	270 days	350 days	**
2090	55 days	145 days	310 days	360 days	**
2100	60 days	170 days	335 days	**	**
2110	55 days	190 days	350 days	**	**
2120	45 days	210 days	360 days	**	**
2130	45 days	230 days	360 days	**	**
2140	75 days	265 days	**	**	**
2150	105 days	295 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B2. Atlantic City, NJ High Tide Flood Days – Moderate-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	75 days	110 days
2040	17 days	30 days	70 days	150 days	220 days
2050	24 days	45 days	120 days	255 days	325 days
2060	40 days	85 days	190 days	315 days	350 days
2070	55 days	120 days	265 days	350 days	**
2080	75 days	165 days	320 days	**	**
2090	85 days	200 days	345 days	**	**
2100	95 days	240 days	355 days	**	**
2110	150 days	285 days	360 days	**	**
2120	155 days	305 days	**	**	**
2130	175 days	325 days	**	**	**
2140	220 days	340 days	**	**	**
2150	255 days	350 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B3. Atlantic City, NJ High Tide Flood Days - High-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	>83% Chance	~50% chance	< 17% chance	< 5% chance
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	75 days	110 days
2040	17 days	30 days	70 days	150 days	220 days
2050	24 days	45 days	120 days	255 days	325 days
2060	45 days	90 days	225 days	340 days	360 days
2070	70 days	145 days	300 days	360 days	**
2080	95 days	200 days	345 days	**	**
2090	125 days	250 days	360 days	**	**
2100	145 days	290 days	**	**	**
2110	265 days	335 days	**	**	**
2120	290 days	345 days	**	**	**
2130	315 days	355 days	**	**	**
2140	330 days	360 days	**	**	**
2150	345 days	**	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B4. New York, NY (The Battery) High Tide Flood Days - Low-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	>83% Chance	~50% chance	< 17% chance	< 5% chance
2000			5 days		
2010			7 days		
2020	5 days	8 days	15 days	30 days	40 days
2030	9 days	15 days	30 days	70 days	105 days
2040	15 days	30 days	65 days	145 days	215 days
2050	21 days	40 days	115 days	255 days	320 days
2060	30 days	65 days	155 days	270 days	330 days
2070	40 days	95 days	220 days	330 days	355 days
2080	50 days	120 days	270 days	350 days	365 days
2090	50 days	140 days	310 days	360 days	**
2100	55 days	165 days	335 days	365 days	**
2110	50 days	185 days	350 days	**	**
2120	40 days	205 days	360 days	**	**
2130	40 days	230 days	360 days	**	**
2140	70 days	265 days	365 days	**	**
2150	100 days	295 days	365 days	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B5. New York, NY (The Battery) High Tide Flood Days - Moderate-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	5 days	8 days	15 days	30 days	40 days
2030	9 days	15 days	30 days	70 days	105 days
2040	15 days	30 days	65 days	145 days	215 days
2050	21 days	40 days	115 days	255 days	320 days
2060	35 days	80 days	185 days	315 days	350 days
2070	50 days	115 days	265 days	350 days	365 days
2080	70 days	160 days	320 days	360 days	**
2090	85 days	195 days	345 days	**	**
2100	95 days	235 days	355 days	**	**
2110	145 days	280 days	360 days	**	**
2120	155 days	305 days	365 days	**	**
2130	175 days	325 days	**	**	**
2140	215 days	340 days	**	**	**
2150	255 days	350 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B6. New York, NY (The Battery) High Tide Flood Days - High-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	5 days	8 days	15 days	30 days	40 days
2030	9 days	15 days	30 days	70 days	105 days
2040	15 days	30 days	65 days	145 days	215 days
2050	21 days	40 days	115 days	255 days	320 days
2060	40 days	90 days	220 days	340 days	360 days
2070	65 days	140 days	300 days	360 days	**
2080	95 days	195 days	345 days	**	**
2090	120 days	245 days	360 days	**	**
2100	140 days	290 days	365 days	**	**
2110	265 days	335 days	**	**	**
2120	290 days	345 days	**	**	**
2130	315 days	355 days	**	**	**
2140	330 days	360 days	**	**	**
2150	345 days	360 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B7. Sandy Hook, NJ High Tide Flood Days - Low-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	70 days	105 days
2040	17 days	30 days	65 days	145 days	205 days
2050	24 days	45 days	115 days	245 days	320 days
2060	35 days	65 days	150 days	265 days	325 days
2070	45 days	95 days	215 days	325 days	355 days
2080	50 days	120 days	265 days	350 days	365 days
2090	50 days	135 days	305 days	360 days	**
2100	60 days	160 days	335 days	365 days	**
2110	50 days	180 days	350 days	**	**
2120	45 days	200 days	355 days	**	**
2130	45 days	220 days	360 days	**	**
2140	70 days	260 days	365 days	**	**
2150	100 days	290 days	365 days	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B8. Sandy Hook, NJ High Tide Flood Days - Moderate-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	70 days	105 days
2040	17 days	30 days	65 days	145 days	205 days
2050	24 days	45 days	115 days	245 days	320 days
2060	40 days	80 days	180 days	310 days	350 days
2070	55 days	115 days	260 days	350 days	365 days
2080	70 days	155 days	315 days	365 days	**
2090	85 days	190 days	345 days	**	**
2100	95 days	225 days	355 days	**	**
2110	145 days	275 days	360 days	**	**
2120	150 days	300 days	365 days	**	**
2130	170 days	320 days	**	**	**
2140	205 days	340 days	**	**	**
2150	245 days	350 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B9. Sandy Hook, NJ High Tide Flood Days - High-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	6 days	9 days	17 days	30 days	45 days
2030	10 days	17 days	35 days	70 days	105 days
2040	17 days	30 days	65 days	145 days	205 days
2050	24 days	45 days	115 days	245 days	320 days
2060	45 days	90 days	215 days	335 days	360 days
2070	65 days	135 days	295 days	360 days	**
2080	95 days	190 days	345 days	**	**
2090	120 days	240 days	360 days	**	**
2100	135 days	285 days	365 days	**	**
2110	260 days	330 days	**	**	**
2120	285 days	345 days	**	**	**
2130	310 days	355 days	**	**	**
2140	330 days	360 days	**	**	**
2150	340 days	365 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B10. Cape May, NJ High Tide Flood Days - Low-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	4 days	7 days	13 days	25 days	40 days
2030	7 days	13 days	30 days	70 days	105 days
2040	13 days	25 days	65 days	150 days	220 days
2050	19 days	40 days	120 days	260 days	330 days
2060	30 days	65 days	155 days	280 days	335 days
2070	40 days	95 days	230 days	335 days	355 days
2080	45 days	125 days	280 days	355 days	365 days
2090	45 days	145 days	315 days	360 days	**
2100	55 days	170 days	340 days	365 days	**
2110	45 days	195 days	355 days	**	**
2120	40 days	215 days	360 days	**	**
2130	40 days	235 days	365 days	**	**
2140	70 days	275 days	365 days	**	**
2150	100 days	305 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B11. Cape May, NJ High Tide Flood Days - Moderate-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	4 days	7 days	13 days	25 days	40 days
2030	7 days	13 days	30 days	70 days	105 days
2040	13 days	25 days	65 days	150 days	220 days
2050	19 days	40 days	120 days	260 days	330 days
2060	35 days	80 days	195 days	320 days	355 days
2070	50 days	120 days	275 days	355 days	365 days
2080	70 days	165 days	325 days	365 days	**
2090	85 days	200 days	350 days	**	**
2100	95 days	240 days	360 days	**	**
2110	150 days	290 days	365 days	**	**
2120	155 days	310 days	365 days	**	**
2130	180 days	330 days	**	**	**
2140	220 days	345 days	**	**	**
2150	260 days	355 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B12. Cape May, NJ High Tide Flood Days - High-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	4 days	7 days	13 days	25 days	40 days
2030	7 days	13 days	30 days	70 days	105 days
2040	13 days	25 days	65 days	150 days	220 days
2050	19 days	40 days	120 days	260 days	330 days
2060	40 days	90 days	230 days	340 days	360 days
2070	65 days	145 days	305 days	360 days	**
2080	95 days	200 days	350 days	**	**
2090	125 days	255 days	360 days	**	**
2100	145 days	300 days	365 days	**	**
2110	275 days	340 days	**	**	**
2120	300 days	350 days	**	**	**
2130	320 days	355 days	**	**	**
2140	335 days	360 days	**	**	**
2150	345 days	365 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B13. Philadelphia, PA High Tide Flood Days - Low-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	3 days	5 days	8 days	15 days	25 days
2030	5 days	8 days	17 days	45 days	85 days
2040	8 days	15 days	45 days	130 days	205 days
2050	11 days	25 days	95 days	250 days	320 days
2060	17 days	45 days	140 days	265 days	325 days
2070	25 days	70 days	215 days	325 days	355 days
2080	30 days	100 days	265 days	350 days	360 days
2090	30 days	125 days	305 days	360 days	365 days
2100	35 days	155 days	335 days	360 days	**
2110	30 days	175 days	350 days	365 days	**
2120	25 days	200 days	355 days	**	**
2130	25 days	220 days	360 days	**	**
2140	45 days	260 days	360 days	**	**
2150	75 days	295 days	365 days	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B14. Philadelphia, PA High Tide Flood Days - Moderate-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	3 days	5 days	8 days	15 days	25 days
2030	5 days	8 days	17 days	45 days	85 days
2040	8 days	15 days	45 days	130 days	205 days
2050	11 days	25 days	95 days	250 days	320 days
2060	21 days	55 days	175 days	310 days	345 days
2070	35 days	95 days	260 days	350 days	360 days
2080	45 days	145 days	315 days	360 days	**
2090	60 days	185 days	345 days	365 days	**
2100	70 days	230 days	355 days	**	**
2110	130 days	280 days	360 days	**	**
2120	140 days	300 days	365 days	**	**
2130	160 days	325 days	365 days	**	**
2140	205 days	340 days	**	**	**
2150	250 days	350 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Table B15. Philadelphia, PA High Tide Flood Days - High-Emissions Scenario

Year	Low End	*Likely* Range			High End
	> 95% Chance	*>83% Chance*	*~50% chance*	*< 17% chance*	*< 5% chance*
2000			5 days		
2010			7 days		
2020	3 days	5 days	8 days	15 days	25 days
2030	5 days	8 days	17 days	45 days	85 days
2040	8 days	15 days	45 days	130 days	205 days
2050	11 days	25 days	95 days	250 days	320 days
2060	25 days	65 days	215 days	335 days	355 days
2070	45 days	125 days	300 days	360 days	365 days
2080	70 days	185 days	340 days	365 days	**
2090	100 days	245 days	355 days	**	**
2100	125 days	290 days	360 days	**	**
2110	260 days	330 days	365 days	**	**
2120	290 days	345 days	**	**	**
2130	315 days	355 days	**	**	**
2140	330 days	360 days	**	**	**
2150	340 days	360 days	**	**	**

*Notes: ** indicates at least high tide flooding expected every day of the year. Note that expected number of days of flooding per year will differ from the actual number experienced in a specific year; the expected number reflects the average that would be seen were sea-level stable at the projected level for a given year.*

Appendix C: Members of the Science and Technical Advisory Panel

LAST NAME	FIRST NAME	ORGANIZATION
Kopp	Robert	Rutgers University, Dept. of Earth and Planetary Sciences
Andrews	Clinton	Rutgers University, Edward J. Bloustein School of Planning and Public Policy
Broccoli	Anthony	Rutgers University, Dept. of Environmental Sciences
Garner	Andra	Rowan University, Dept. of Environmental Science
Kreeger	Danielle	Drexel University, Dept. of Biodiversity, Earth and Environmental Sciences
Leichenko	Robin	Rutgers University, Dept. of Geography
Lin	Ning	Princeton University, Dept. of Civil and Environmental Engineering
Little	Chris	Atmospheric and Environmental Research
Miller	John	NJ Association for Floodplain Management
Miller	Jon	Stevens Institute of Technology, Dept. of Civil, Environmental and Ocean Engineering
Miller	Kenneth	Rutgers University, Dept. of Earth and Planetary Sciences
Moss	Richard	Princeton University, Andlinger Center for Energy and the Environment
Orton	Philip	Stevens Institute of Technology, Dept. of Civil, Environmental and Ocean Engineering
Parris	Adam	New York City Mayor's Office of Resiliency
Robinson	David	Rutgers University, Dept. of Geography
Sweet	William	National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanographic Products and Services
Walker	Jennifer	Rutgers University, Dept. of Earth and Planetary Sciences
Weaver	Chris	U.S. Environmental Protection Agency
White	Kathleen	U.S. Army Corps of Engineers, Headquarters, Engineering and Construction

Appendix D: Rutgers University Technical Support Team

LAST NAME	FIRST NAME	ORGANIZATION
Auermuller	Lisa	Jacques Cousteau Coastal Education Center
Campo	Matthew	Rutgers University, Edward J. Bloustein School of Planning and Public Policy
Herb	Jeanne	Rutgers University, Edward J. Bloustein School of Planning and Public Policy
Kaplan	Marjorie	Rutgers Climate Institute