Global sea level rise (SLR) has been a persistent trend for decades. It is expected to continue beyond the end of this century, which will cause significant impacts in the United States (US). Over eight million people live in areas at risk to coastal flooding, and many of the nation's assets related to military readiness, energy, commerce, and ecosystems are already located at or near the ocean.

Past trends provide valuable evidence in preparing for future environmental change but, by themselves, are insufficient for assessing the risks associated with an uncertain future. For example, a number of recent studies project an increase in the rate and magnitude of global SLR. The US Congress recognizes the need to consider future trends in the Global Change Research Act (USGCRA), which calls for a National Climate Assessment (NCA) every four years. This report provides a synthesis of the scientific literature on global SLR at the request of a federal advisory committee charged with developing the next NCA. This report also provides a set of four global mean SLR scenarios to describe future conditions for the purpose of assessing potential vulnerabilities and impacts.

A wide range of estimates for future global mean SLR are scattered throughout the scientific literature and other high profile assessments, such as previous reports of the NCA and the Intergovernmental Panel on Climate Change (IPCC). Aside from this report, there is currently no coordinated, interagency effort in the US to identify agreed upon global mean SLR estimates for the purpose of coastal planning, policy, and management. This is an important gap because identifying global mean SLR estimates is a critical step in assessing coastal impacts and vulnerabilities. At present, coastal managers are left to identify global SLR estimates through their own interpretation of the scientific literature or the advice of experts on an ad-hoc basis. Yet, for a great majority of the US coastline, relative sea level (RSL)[1] has been rising over the past 60 years, consistent with the global trend.

[1] Relative sea level – The height of the sea with respect to a specific point on land.

Scenario Planning

Scenarios do not predict future changes, but describe future potential conditions in a manner that supports decision-making under conditions of uncertainty. Scenarios are used to develop and test decisions under a variety of plausible futures. This approach strengthens an organization's ability to recognize, adapt to, and take advantage of changes over time. Using a common set of scenarios across different regions and sectors to frame the range of uncertainties surrounding future environmental conditions is a relatively new and evolving initiative of the NCA. This report provides scenarios to help assessment experts and their stakeholders analyze the vulnerabilities and impacts associated with possible, uncertain futures.

Probabilistic projections of future conditions are another form of scenarios not used in this report because this method remains an area of active research. No widely accepted method is currently available for producing probabilistic projections of sea level rise at actionable scales (i.e. regional and local). Coastal management decisions based solely on a most probable or likely outcome can lead to vulnerable assets resulting from inaction or maladaptation. Given the range of uncertainty in future global SLR, using multiple scenarios encourages experts and decision makers to consider multiple future conditions and to develop multiple response options. Scenario planning offers an opportunity to initiate actions now that may reduce future impacts and vulnerabilities. Thus, specific probabilities or likelihoods are not assigned to individual scenarios in this report, and none of these scenarios should be used in isolation.

Global Mean SLR Scenarios

> We have very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100.

In recent decades, the dominant contributors to global sea level rise have been ocean warming (i.e. thermal expansion) and ice sheet loss. The relative magnitude of each of these factors in the future remains highly uncertain. Many previous studies, including the IPCC, assume thermal expansion to be the dominant contributor. However, the National Research Council (NRC) recently reports that advances in satellite measurements indicate ice sheet loss as a greater contribution to global SLR than thermal expansion over the period of 1993 to 2008. Our scenarios are based on four estimates of global SLR by 2100 that reflect different degrees of ocean warming and ice sheet loss (Table ES-1 and Figure ES 1).

Table ES-1. Global SLR Scenarios

Scenario	SLR by 2100 (m)*	SLR by 2100 (ft)*
Highest	2.0	6.6
Intermediate-High	1.2	3.9
Intermediate-Low	0.5	1.6
Lowest	0.2	0.7

* Using mean sea level in 1992 as a starting point.

Key Uncertainties on Global SLR

At this stage, the greatest uncertainty surrounding estimates of future global SLR is the rate and magnitude of ice sheet loss, primarily from Greenland and West Antarctica. Our Highest Scenario of global SLR by 2100 is derived from a combination of estimated ocean warming from the IPCC AR4 global SLR projections and a calculation of the maximum possible glacier and ice sheet loss by the end of the century. The Highest Scenario should be considered in situations where there is little tolerance for risk (e.g. new infrastructure with a long anticipated life cycle such as a power plant).

Our Intermediate-High Scenario is based on an average of the high end of semi-empirical, global SLR projections. Semi-empirical projections utilize statistical relationships between observed global sea level change, including recent ice sheet loss, and air temperature. Our Intermediate-Low Scenario is based on the upper end of IPCC Fourth Assessment Report (AR4) global SLR projections resulting from climate models using the B1 emissions scenario. The Intermediate-High Scenario allows experts and decision makers to assess risk from limited ice sheet loss. The Intermediate Low Scenario allows experts and decision makers to assess risk primarily from ocean warming.

The Lowest Scenario is based on a linear extrapolation of the historical SLR rate derived from tide gauge records beginning in 1900 (1.7 mm/yr). Global sea level has risen 0.2 meters (8 inches) over this period of record, and we anticipate at least 8 inches by 2100. The rate of global mean SLR derived from satellite altimetry (1992 to 2010) has been substantially higher (3.2 mm/yr), approaching twice the rate of the longer historical record from tide gauges. However, the 18-year altimeter record is insufficient in duration for projecting century-scale global SLR. Trends derived from shorter records are less reliable as projections because they are affected by interannual and decadal climate and oceanographic patterns that are superimposed upon the long-term rise of global sea level. The Lowest Scenario should be considered where there is a great tolerance for risk.

There is a highly significant correlation between observations of global mean SLR and increasing global mean temperature, and the IPCC and more recent studies anticipate that global mean sea level will continue to rise even if warming ceases. Our Intermediate-Low and Lowest Scenarios are optimistic scenarios of future environmental change assuming rates of ice sheet loss and ocean warming slightly higher or similar to recent observations.

RSL is highly variable over time and along different parts of the US coast. Changes in vertical land movement and ocean dynamics may be applied with different degrees of confidence based on available regional or local data. For example, changes in RSL observed over multiples decades in the Pacific Ocean basin demonstrate that regional-to-global-scale climate factors can cause ocean basin-scale patterns that may persist for a few decades. In the Pacific Northwest, upward vertical land movement reduces RSL on the coast of Alaska and parts of Washington and Oregon.

In the Mississippi River Delta, coastal subsidence increases RSL. As such, individual regions should expect a set of additional processes beyond global SLR that may influence estimates of regional and local sea level change. To provide the level of detail required for sound coastal assessments, regional and local experts, including the NCA chapter authors, are needed to evaluate regional and local ocean dynamics and vertical land movement and make specific adjustments to global scenarios.

SLR and Coastal Flooding

It is certain that higher mean sea levels increase the frequency, magnitude, and duration of flooding associated with a given storm, which often have disproportionately high impacts in most coastal regions. Extreme weather events will continue to be the primary driver of the highest water levels. However, a consensus has not yet been reached on how the frequency and magnitude of storms may change in coastal regions of the US. The greatest coastal damage generally occurs when high waves and storm surge occur during high tide. In many locations along the US coast, small increases in sea level over the past few decades already have increased the height of storm surge and wind-waves. Thus, considering the impact of different weather events combined with scenarios of SLR is crucial in developing hazard profiles for emergency planning and vulnerability, impact, and adaptation assessments.

Conclusion

Based on a large body of science, we identify four scenarios of global mean SLR ranging from 0.2 meters (8 inches) to 2.0 meters (6.6 feet) by 2100. These scenarios provide a set of plausible trajectories of global mean SLR for use in assessing vulnerability, impacts, and adaptation strategies. None of these scenarios should be used in isolation, and experts and coastal managers should factor in locally and regionally specific information on climatic, physical, ecological, and biological processes and on the culture and economy of coastal communities. Scientific observations at the local and regional scale are essential to action, and long-term coastal management actions (e.g. coastal habitat restoration) are sensitive to near-term rates and amounts of SLR. However, global phenomena, such as SLR, also affect decisions at the local scale, especially over longer time horizons. Thousands of structures along the US coast are over fifty years old, including vital storm and waste water systems. Thus, coastal vulnerability, impact, and adaptation assessments require an understanding of the long-term, global, and regional drivers of environmental change.

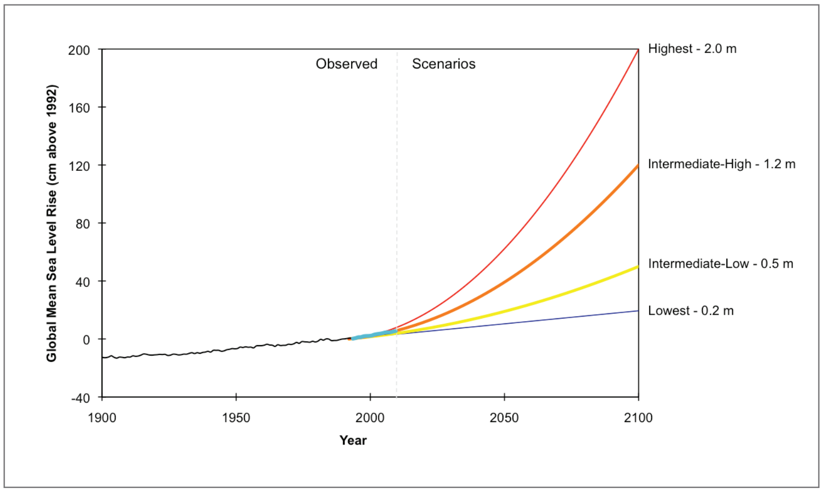

Figure ES 1. Global mean sea level rise scenarios. Present Mean Sea Level (MSL) for the US coasts is determined from the National Tidal Datum Epoch (NTDE) provided by NOAA. The NTDE is calculated using tide gauge observations from 1983 – 2001. Therefore, we use 1992, the mid-point of the NTDE, as a starting point for the projected curves. The Intermediate-High Scenario is an average of the high end of ranges of global mean SLR reported by several studies using semi-empirical approaches. The Intermediate Low Scenario is the global mean SLR projection from the IPCC AR4 at the 95% confidence interval.