Sea Level Rise Projections for Monroe County, Florida (FINAL)

Monroe County Roadway Inundation Analysis
Monroe County, Florida
Project # 6783193178

Prepared for:

Monroe County

102050 Overseas Hwy, Ste. 246, Key Largo, FL 33037

January 9, 2020

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Table of contents

List of figures

List of tables

1.0 Introduction

The purpose of this technical brief is to outline climate change projections for sea level rise (SLR) in support of the Monroe County Roadway Inundation Study. Climate change projections discussed herein are based primarily on The Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group's Unified Sea Level Rise Projection for Southeast Florida (Compact, 2015), which in turn draws from studies by the National Oceanic and Atmospheric Administration (NOAA) (NOAA, 2012), the United States Army Corps of Engineers (USACE, 2013), the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (IPCC, 2013) and other studies. Compact (2015) is currently being updated to account for additional scientific understanding of SLR mechanisms and will focus on a revised set of timelines. The below discussion includes more recent SLR projections from NOAA (NOAA, 2017), which may also be considered as part of the Compact report update (targeted completion by the end of 2019). Also discussed are projections from the Coastal Assessment Regional Scenario Working Group (CARSWG, 2016), which is part of the Department of Defense (DoD) led Strategic Environmental Research and Development Program (SERDP).

It is well established in the scientific community that no single climate model produces an ideal simulation of all climate variables and their various statistics. A single projection represents only one of many possible realizations of the future climate and is not robust as it does not capture the primary sources of climate projections uncertainty. As each global climate model (GCM) provides a slightly different conceptualization of the earth-atmosphere system, the IPCC and others recommend using a multi-model ensemble approach (i.e., a collection of various climate projections). Ensembles often include multiple greenhouse gas (GHG) emissions scenarios, as it is unknown what future GHG emissions will be.

In order to account for multiple possible future emissions scenarios, the IPCC developed four Representative Concentration Pathways (RCP) as part of a new initiative for the AR5 (Taylor et al. 2012). RCP 2.6, 4.5, 6.0 and 8.5 reflect various levels of climate change mitigation efforts (RCP 2.6, resulting in an increase of 2.6 W/m^2 in radiative forcing to the global climate system) and business-as-usual GHG emissions continuing (RCP 8.5, an increase of 8.5 W/m^2). Climate models from the IPCC's Third and Fourth Assessment Reports followed the Special Report on Emissions Scenarios (SRES) suite of scenarios. A comparison of the respective radiative forcing of various scenarios from both RCP and SRES is shown in Figure 2-1. The SLR projections discussed in this technical brief follow a range of emissions scenarios as detailed in the respective sections.

2.0 Sea Level Rise

Global SLR is driven by the thermal expansion of the ocean as it warms as well as the addition of water from melting icecaps and glaciers. SLR in any specific location is additionally influenced by other processes such as changes in ocean circulation and land subsidence or rebound. The projected slowing of the Gulf Stream is expected to contribute significantly to SLR on the east coast of the United States, while changes in Earth's gravitational field due to the redistribution of mass from melting ice are also a factor. Church et al (2013) discusses the regional variation of projected SLR, summarized in Figure 2-2. This map shows that the east coast of North America will likely experience higher SLR relative to the global mean, with southern Florida's relative deviation being on the order of 10-20% higher.

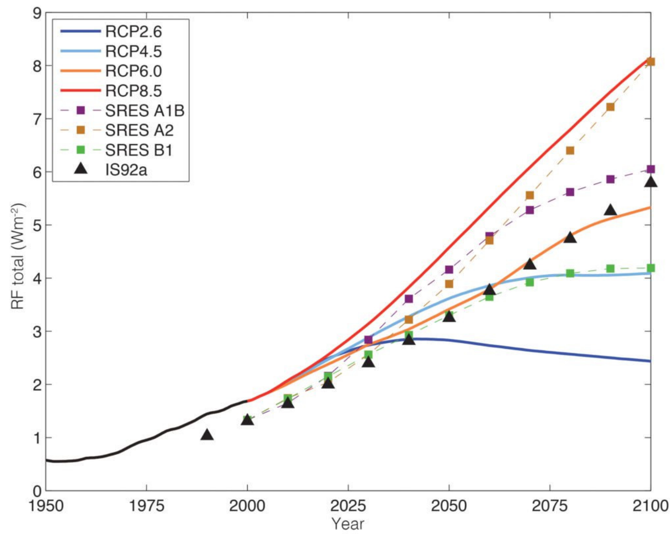

Figure 2-1 Radiative forcing (RF) of respective RCP and SRES GHG emissions scenarios, relative to pre-industrial levels. (Source: Figure 1.15 from Cubasch et al, 2013)

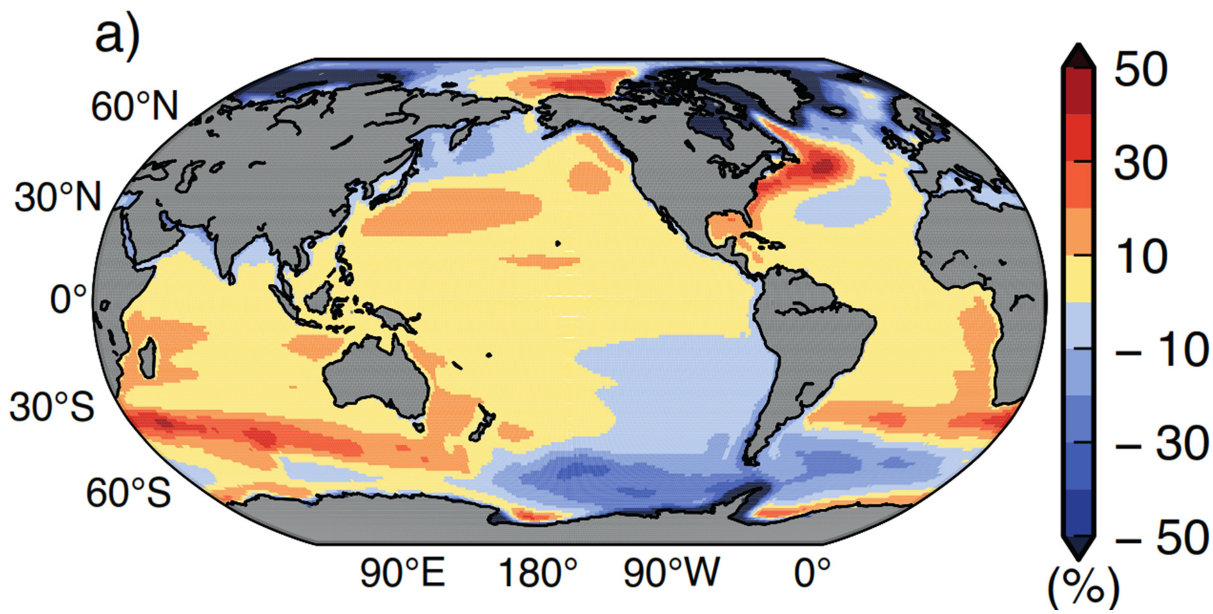

Figure 2-2 Percent deviation of regional sea level rise projections from mean global projections (between 1986-2005 and 2081-2100), representative of all RCP scenarios (Source: Figure 13.21 in Church et al., 2013)

Observations of mean sea levels have shown an accelerating upward trend in recent decades. The average rate of increase since 1900 has been about 1.7 mm/year (0.067 in/year) (based on tide gauges) while the rate from 1992-2010 was found to be 3.2 mm/yr (0.126 in/year) (based on satellite altimetry) (NOAA, 2012). If the acceleration continues at this observed pace, SLR will amount to approximately 26 inches by 2100 (Nerem et al, 2018).

The following sub-sections outline various SLR projections for Monroe County, FL (often using Key West as the reference point, which can be considered representative for all of Monroe County) and respectively take into consideration some or all of these processes.

2.2 Summary of Compact (2015) Sea Level Rise Projections

In development of Compact (2015), SLR projections were reviewed and considered for inclusion based on comprehensiveness of the respective data and models, scientific credibility and regional applicability.

The report recommends using three SLR curves for planning purposes: the median projections from the IPCC AR5 RCP 8.5 scenario , the USACE (2013) High Curve, and the NOAA (2012) High Curve. These three sources and their respective projections are summarized in the following subsections. The projected SLR values recommended by Compact (2015) are presented in Table 2-1.

Table 2-1: Compact (2015) Sea Level Rise Projection Summary for Monroe County, FL

Scenario	Relative SLR Projection (inches)		
	2030	2060	2100
IPCC Median	6	14	31
USACE High	10	26	61
NOAA High	12	34	81

*Relative to 1992 mean sea level

Compact (2015) recommends that most infrastructure planning decisions should use SLR values that fall between the IPCC Median and USACE High projections, particularly up to 2060. The NOAA High projections are intended as the uppermost boundary for longer term planning for critical infrastructure and infrastructure with a low tolerance for risk.

2.2.1 IPCC AR5

The GCMs used in IPCC Fifth Assessment Report (AR5) follow the RCP scenarios discussed previously. The models attempt to consider a comprehensive list of SLR mechanisms including glacial, Greenland ice-sheet and Antarctic ice-sheet melting, rapid dynamics of the respective ice-sheets, thermal expansion, and changes in land water storage. A summary of the AR5's projected likely global mean SLR ranges (5th and 95th percentiles of ensemble projections) are present in Table 2-2 (from Church et al., 2013).

Table 2-2 IPCC AR5 Global Mean Sea Level Rise Projection Summary

IPCC AR5 Scenario	SLR Projections (inches)			
	2046 - 2065		2081 - 2100	
	5%	95%	5%	95%
RCP 2.6	6.7	12.6	10.2	21.7
RCP 4.5	7.5	13.0	12.6	24.8
RCP 6.0	7.1	12.6	13.0	24.8
RCP 8.5	8.7	15.0	17.7	32.3
RCP 8.5 (2100)	-	-	20.5	38.6

*Relative to 1986-2005 mean sea level

2.2.2 USACE 2013

USACE (2013) SLR projections are primarily based on National Research Council curves I and III (see NRC, 1987 for full details), modified to account for more recent SLR rates (i.e., 1.7 mm/year) and a start date of 1992. USACE (2013) categorizes their projections into high, intermediate and low scenarios, as outlined below.

- High: based on NRC (1987) Curve III (roughly corresponding to global mean SLR of 1.5 m), corrected for local vertical land movement and accounts for potential rapid ice loss from Antarctica and Greenland, in addition to thermal expansion.
- Intermediate: based on NRC (1987) Curve I (roughly corresponding to global mean SLR of 1.0 m), corrected for local vertical land movement as well as moderate ice melt rates and thermal expansion.
- Low: based on a linear extrapolation of the long-term historical SLR rate since 1900 (per NOAA, 2012).

Table 2-3 provides a summary of the various USACE (2013) projections, while Figure 2-3 shows a comparison of USACE (2013) and NOAA (2012) projections (from http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html).

Table 2-3: USACE (2013) Sea Level Rise Projection Summary for Monroe County, FL

USACE 2013 Scenario	Relative SLR Projection (inches)								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Low	2.5	3.4	4.2	5.2	6.0	6.8	7.8	8.6	9.5
Intermediate	3.4	4.9	6.7	8.8	10.9	13.3	16.1	18.8	22.0
High	6.0	9.8	14.5	20.0	26.5	34.0	42.2	51.4	61.4

*Relative to 1992 mean sea level

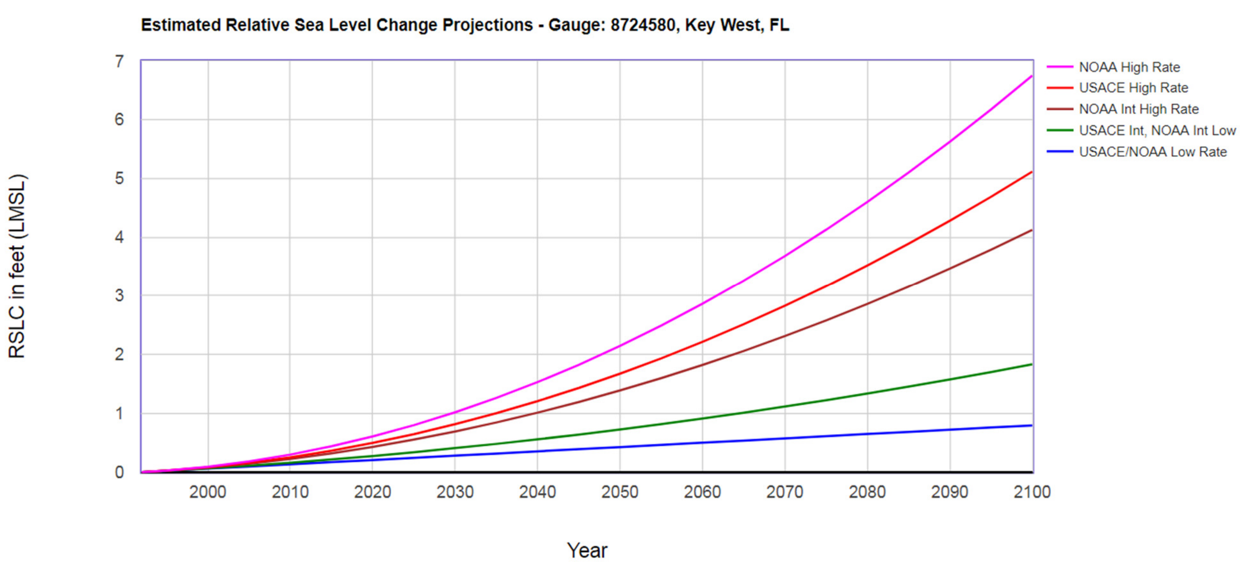

Figure 2-3 USACE (2013) and NOAA (2012) relative sea level change (RSLC) projections for Key West, representative of all Monroe County, FL (Source: http://www.corpsclimate.us/ccaceslcurves.cfm)

2.2.3 NOAA 2012

NOAA (2012) was one of the first coordinated, inter-agency efforts in in the U.S. to identify agreed upon global mean SLR projections for planning and policy purposes. The four scenarios (listed below and with respective projections in Table 2-4) are based on different degrees of ocean warming as well as glacier and ice sheet loss by 2100, as discussed below.

- High: based on ocean warming projections from IPCC AR4 and maximum possible glacier and ice sheet loss (as understood at the time),
- Intermediate-High: based on an average of high-end semi-empirical, global SLR projections,
- Intermediate-Low: based on upper end of IPCC AR4 global SLR projections using B1 emissions scenario (comparable to RCP 4.5 and RCP 6.0),
- Low: based on a linear extrapolation of the long-term historical SLR rate since 1900 (i.e., 1.7 mm/yr).

Table 2-4: NOAA (2012) Sea Level Rise Projection Summary for Monroe County, FL

NOAA 2012 Scenario	Relative SLR Projections (inches)								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low	2.5	3.4	4.2	5.2	6.0	6.8	7.8	8.6	9.5
Int Low	3.4	4.9	6.7	8.8	10.9	13.3	16.1	18.8	22.0
Int High	5.2	8.3	12.1	16.7	21.8	27.7	34.3	41.6	49.6
High	7.3	12.2	18.4	25.8	34.3	44.2	55.2	67.6	81.0

*Relative to 1992 mean sea level

Since the publication of AR5 in 2013 there have been some notable advances in scientific understanding, particularly related to ice-sheet dynamics and contributions to SLR. For instance, DeConto and Pollard (2016) found that mechanisms by which marine-terminated ice-cliffs in Antarctic collapse give Antarctica the potential to contribute more than 1 m (3.3 ft) global mean SLR by 2100 (and more than 15 m (50 ft) by 2500) under business-as-usual GHG emissions. A recent study published in the Proceedings of the National Academy of Sciences (Bamber et al., 2019) indicates that new understanding and uncertainty in ice-sheet dynamics suggest that global mean SLR may exceed 6 ft by the end of the century, under a business-as-usual GHG scenario. Robel et al. (2019) also found that the potential for Antarctic ice-sheet collapse widens the range of possible future-scenarios (i.e., uncertainty) while making worst-case scenarios more likely.

2.3 Other Sea Level Rise Projections

2.3.1 CARSWG 2016

The Coastal Assessment Regional Scenario Working Group (CARSWG), part of DoD's SERDP, is a multi-agency research group consisting of representatives from NOAA, USACE, the Office of the Oceanographer of the Navy, and the South Florida Water Management District, with contributions from various other government agencies and academia. Their 2016 report "Regional Sea Level Scenarios for Coastal Risk Management" provides regionalized SLR projections for nearly 1,800 DoD sites worldwide, including those located in Monroe County. The projections are based on five scenarios ranging from 0.2 to 2.0 m by 2100 (relative to 1992 mean sea level) and many of the projected values are based on (and identical to) NOAA

(2012), as shown in Table 2-5. The below Monroe County projections can be considered within the context of the global prevue of CARSWG (2016), which may allow for insight into comparable situations from diverse geographic regions, including potential adaptation measures. (Such a comparison is outside of the scope of the current study but is noted here for completeness.)

Table 2-5: CARSWG (2016) Sea Level Rise Projection Summary for Monroe County, FL

CARSWG Scenario	Relative SLR Projections (inches)								
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Lowest	2.5	3.4	4.2	5.2	6.0	6.8	7.8	8.6	9.5
Low	3.4	4.9	6.7	8.8	10.9	13.4	16.1	19.0	22.0
Medium	4.7	7.3	10.6	14.4	18.7	23.6	29.0	35.2	41.6
High	6.0	9.7	14.5	20.0	26.5	34.0	42.1	51.4	61.3
Highest	7.3	12.2	18.4	25.8	34.3	44.2	55.2	67.6	81.0

*Relative to 1992 mean sea level

2.3.2 NOAA 2017

NOAA (2017) updated their 2012 report by assessing the most up-to-date scientific literature on upper-end global mean SLR projections including recent observations and modeling related to rapid ices sheet melting. Based on this review, NOAA developed a new 'extreme' upper-bound scenario for global mean SLR of 2.5 m (8.2 ft or 98.4 in) by 2100, which is 0.5 m higher than NOAA's previous (2012) upper-bound. Similarly, the lower-bound estimate was revised upward from 0.1 m (4 in) to 0.3 m (1 ft) by 2100. This 0.3-2.5 m range was then discretized into 0.5 m increments and aligned with emissions-based scenarios and GCM projections, as listed in the right-most column of Table 2-6. SLR projections specific to Monroe County are also presented in Table 2-6 with the exception of the Low scenario.

Table 2-6: NOAA (2017) Sea Level Rise Projection Summary for Monroe County, FL

NOAA 2017 Scenario	Relative SLR Projection (inches)					Global Mean SLR
	2020	**2040**	**2060**	**2080**	**2100**	**2100**
Intermediate Low	4.0	8.3	13.0	17.3	21.2	19.7 in (0.5 m)
Intermediate	5.5	12.2	21.2	32.6	46.1	39.4 in (1.0 m)
Intermediate High	6.7	16.6	30.7	50.0	73.7	59.1 in (1.5 m)
High	8.3	20.9	40.6	68.9	102.7	78.7 in (2.0 m)
Extreme	8.6	23.6	48.5	82.3	125.2	98.4 in (2.5 m)

*Relative to 2000 mean sea level
**Values are marginally lower (3% or less) for Miami Beach

3.0 Recommendations

As the Compact's updated projections, released December 2019, consider the results of recent studies focusing on SLR projections (e.g., DeConto and Pollard, 2016; Bamber et al., 2019; Robel et al., 2019), which tend to indicate an increased likelihood of more extreme changes (see Section 2.2.1), Wood recommends basing SLR projections primarily on NOAA (2017), which is reflected in the 2019 Compact projections and incorporates a broader range of uncertainty with higher extreme values, with consideration for the latest IPCC Median projections. The values in Table 3-1 and Figure 3-1 are based on

NOAA (2017) projections relative to 2000 mean sea levels and were sourced from the USACE Sea-Level Change Curve Calculator (Version 2019.21 available at http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html), while the IPCC Median values were adapted from a preliminary release of Compact (2019) projections (full report not available as of 09-January-2020).

Table 3-1: Recommended Sea Level Rise Projections for Monroe County, FL.

Scenario	SLR Projections (inches)						
	2025	2030	2035	2040	2045	2060	2100
IPCC Median (per Compact, 2019)	6	8	9	10	12	17	32
NOAA 2017 Int-High	9	12	14	17	20	31	74
NOAA 2017 High	11	14	18	21	25	41	103

*Relative to 2000 mean sea level

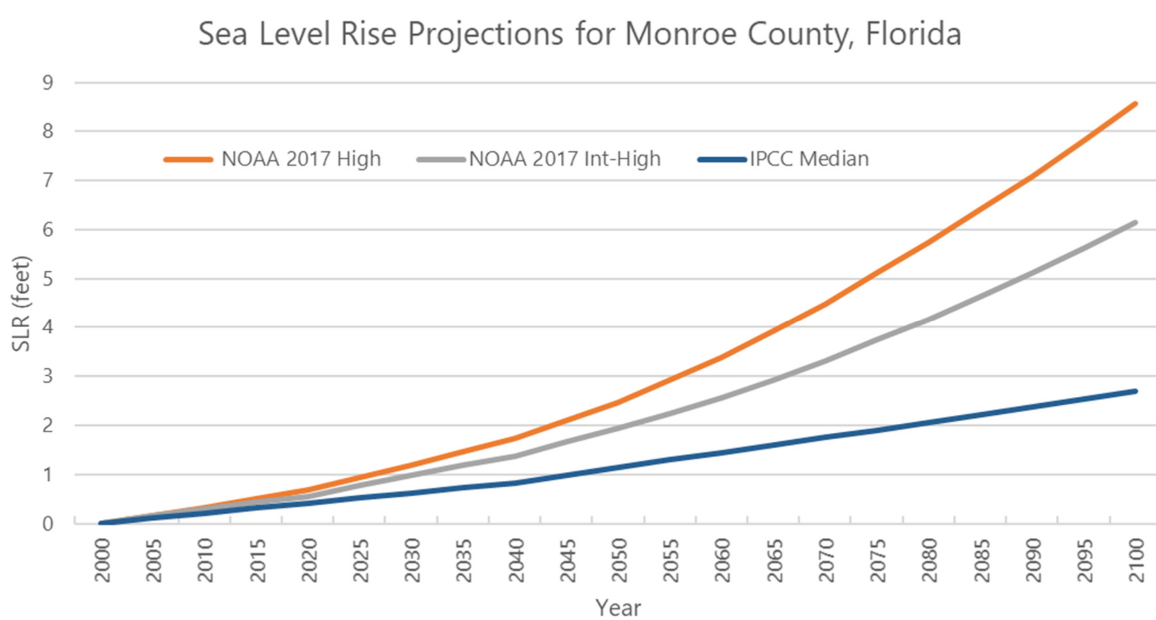

Figure 3-1 Recommended SLR projections for Monroe County, FL (relative to 2000 mean sea level)

NOAA (2017) indicates that increases to mean sea level lead to proportional increases in high tidal levels (including Mean High Water and Mean Higher High Water) and worsen the impacts of storm surge, high tides, and wave action.

The guidance provided by Compact (2015 and 2019) for selecting a scenario on which to base planning and design decisions is largely applicable to the above projections and similar to NOAA (2017) guidance. When deciding which of the projected values to use as the basis for design and planning, NOAA (2017) recommends selecting a scientifically plausible upper-bound (or worst-case) scenario as a "guide for overall system risk and long-term adaptation strategies," while using a more mid-range scenario as the baseline for shorter term planning (e.g., initial adaptation plans for the next two decades). This should be considered along with the consequences of failure/disruption of the asset or system in question, which must be balanced with the cost and benefit of potential adaptation measures. It is rarely possible (or advisable) to plan and design for the worst-case scenario. The most notable exceptions to this being nuclear facilities and dams, where the consequences of failure could be catastrophic.

While keeping in mind the considerations discussed immediately above, in general for relatively short-term projections (2025 to 2045) the focus should be on the IPCC Median to NOAA 2017 Int-High scenarios (i.e., 9 to 14 inches by 2035), with a focus on IPCC Median for low risk or adaptable projects with relatively short design lives. This is consistent with the Compact (2015 and 2019) guidance for applying projections between the IPCC Median and USACE High for similar situations. Medium term projections (2060) for projects with longer design lives or moderate risks should also focus on the IPCC Median to NOAA 2017 Int-High scenarios with additional consideration for the High scenario for more critical infrastructure (i.e., 17 to 31 inches but potentially up to 41 inches). Long-term projections (2100) for planning of future, long-lived and highly critical infrastructure should focus on the NOAA 2017 Int-High to High scenarios (74 to 103 inches), while acknowledging there is a small risk of the Extreme scenario shown in Section 2.3.2.

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