SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CA

DRAFT APPENDIX J
CLIMATE

JANUARY 2024

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO

US Army Corps of Engineers

PORT OF SAN FRANCISCO

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Acronyms and Abbreviations

Acronym	Definition
AR	Assessment Report
AR	Atmospheric Rivers
CCC	California Coastal Commission
CCSF	City and County of San Francisco
CO-OPS	Center for Operational Oceanographic Products and Services
ENSO	El Niño Southern Oscillation
EP	Engineer Pamphlet
ER	Engineer Regulation
ETC	Extratropical Cyclones
GCM	Global Circulation Models
GHCN	Global Historical Climatology Network
HUC	Hydrologic Unit Code
IPCC	Intergovernmental Panel on Climate Change
MSL	Mean Sea Level
NAVD	National Vertical Datum
NCA	National Climate Assessment
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OPC	Ocean Protection Council
PDO	Pacific Decadal Oscillation

POSF	Port of San Francisco
RCP	Representative Concentration Pathways
SFPUC	San Francisco Public Utilities Commission
SFWCFS	San Francisco Waterfront Coastal Flood Study
SLC	Sea Level Change
SLR	Sea Level Rise
SSP	Shared Socioeconomic Pathways
USACE	U.S. Army Corps of Engineers
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
VAT	Vulnerability Assessment Tool
WMO	World Meteorological Organization

1. Introduction

1.1 Purpose

The United States Army Corps of Engineers (USACE) Civil Works Program and its water resources infrastructure – built and natural, structural, and nonstructural – represent a tremendous Federal investment that supports regional and national economic development, public health and safety, and national ecosystem restoration goals. The hydrologic and coastal processes underlying this coastal storm flood risk management project are very sensitive to changes in climate and weather. The assumptions of stationary climatic baselines and a fixed range of natural variability as captured in the historical hydrologic record are no longer appropriate for long-term project planning in some locations (USACE, 2017). Therefore, USACE has a compelling need to understand and adapt to climate change and weather variability and to continue providing authorized performance despite changing conditions.

USACE maintains guidance and regulations for incorporating climate change information in coastal and inland hydrologic analyses in accordance with the USACE overarching climate change adaptation policy. The objective is to enhance climate preparedness and resilience by incorporating relevant information about observed and expected climate change. For example, Engineer Pamphlet (EP) 1100-2-1 (USACE, 2019a), Engineering Regulations (ER) 1100-2-8162 (USACE, 2019b), and USACE Sea Level Change Calculator (USACE, 2020) provide guidance for incorporating sea level change (SLC) within coastal storm flood risk studies. In addition, if SLC will affect inland project hydrology, Engineering and Construction Bulletin (ECB) 2018-14 requires sea level change analysis for the inland hydrology analyses (USACE, 2022).

The goal of the climate change analysis is to describe the observed present and possible future climate threats, vulnerabilities, and impacts of climate change specific to the study. This includes consideration of both past (observed) changes as well as potential future (projected) changes to relevant meteorological and hydrologic variables. Projections of specific climatic changes and their associated impacts to local-scale project coastal dynamics and hydrology that may occur in the future can be highly uncertain, requiring guidance on their interpretation and use for plan formulation and the recommended plan.

This appendix provides background on the climate change drivers and projections relevant to the San Francisco Waterfront Coastal Flood Study (SFWCFS) area using a 100-year planning horizon. This information informs plan formulation and is used to support analysis presented elsewhere within the study documentation. As climate change projections will continue to evolve as the study progresses, the climate assessment may require updates after the recommended plan has been finalized.

2. Climate Overview

San Francisco is situated in the mid-latitudes between the 37th and 38th north parallels with a Mediterranean climate as classified under the Köppen climate classification system (Figure J-1). The most distinct feature of Mediterranean climates is a single rainy season. In the San Francisco Bay Area, about 75% of the annual average rainfall occurs between November and March (Figure J-2), with drought conditions prevailing each summer. San Francisco's variation of the Mediterranean climate type includes cool (mild) summers, cool (mild) winters, and summer fog. San Francisco's precipitation, temperature, and tide stations have some of the longest periods of record among all recording stations in the country.

A high-pressure system known as the Pacific High blocks storms from reaching the San Francisco Bay Area (Bay Area) in summer months. During winter months, the system moves south and allows storm systems to move in. Mid-latitude storms that impact the region generally originate from the south as narrow bands of subtropical moisture (atmospheric rivers) or from the north as extratropical cyclones. Precipitation in the Bay Area can occur from either storm type, or a combination of the two. When atmospheric rivers and extratropical cyclones occur together, a rapid pressure drop can occur (i.e., explosive cyclogenesis) creating bomb cyclone conditions with low atmospheric pressure, heavy precipitation, high windspeeds, and large waves (Sanders & Gyakum, 1980; Zhang et al., 2019; Zhu & Newell, 1994).

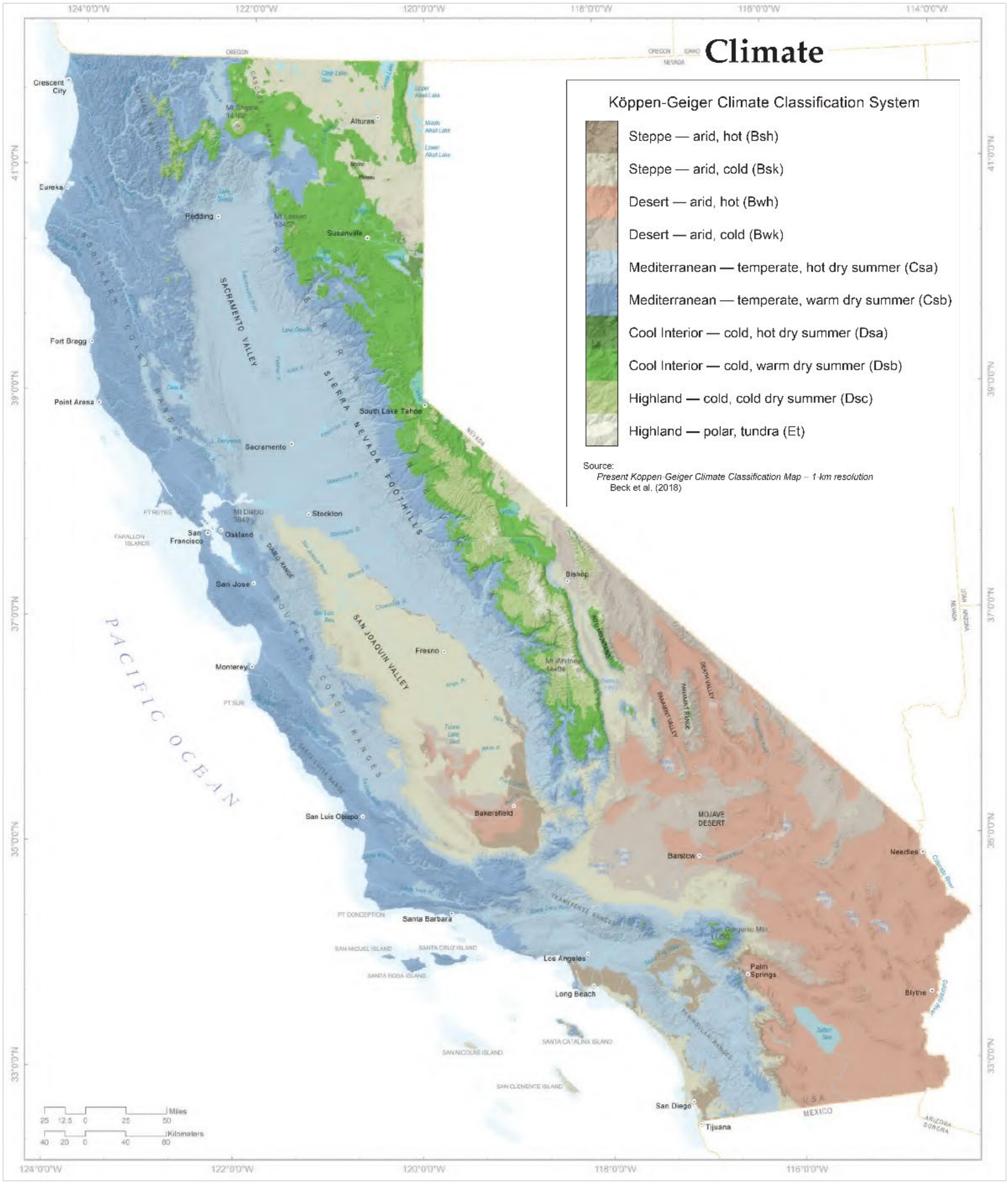
2.1 Temperature

Temperature data from 1920 to the present is available for the San Francisco downtown weather station. Temperatures over the 100-year historical period have ranged from a minimum of 27°F to a maximum of 106°F. 2017 was San Francisco's hottest summer on record, coinciding with the second hottest year on record in the US, and the fourth hottest year on record globally. Average temperatures calculated from 100 years of data from San Francisco downtown weather station are presented in **Table J-1**, and **Figure J-2** shows a climograph of precipitation and temperature norms for NOAA's most recent averaging period (1981-2010). However, the 10 warmest years on record globally have all occurred after 2010 (**Figure J-3**). Since 1970, average annual temperatures have increased by 2.9 degrees F (NCEI, 2020).

Table J-1: Average Temperatures at San Francisco Downtown Weather Station

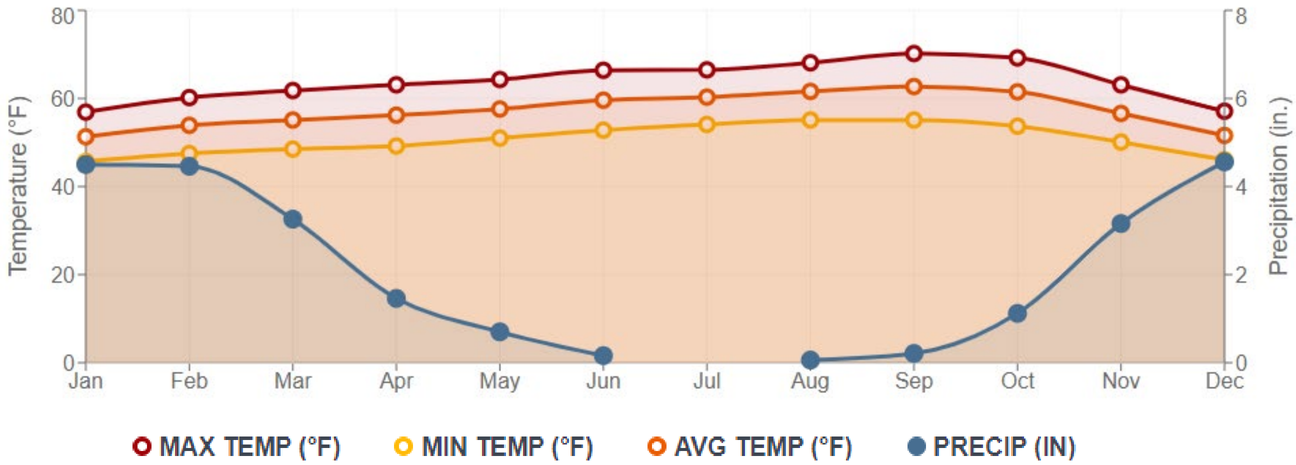
Value	Temperature
Average daily minimum	51°F
Average daily maximum	64°F
Average annual minimum	38°F
Average annual maximum	93°F

Source: Weather Station GHCND: USW00023272



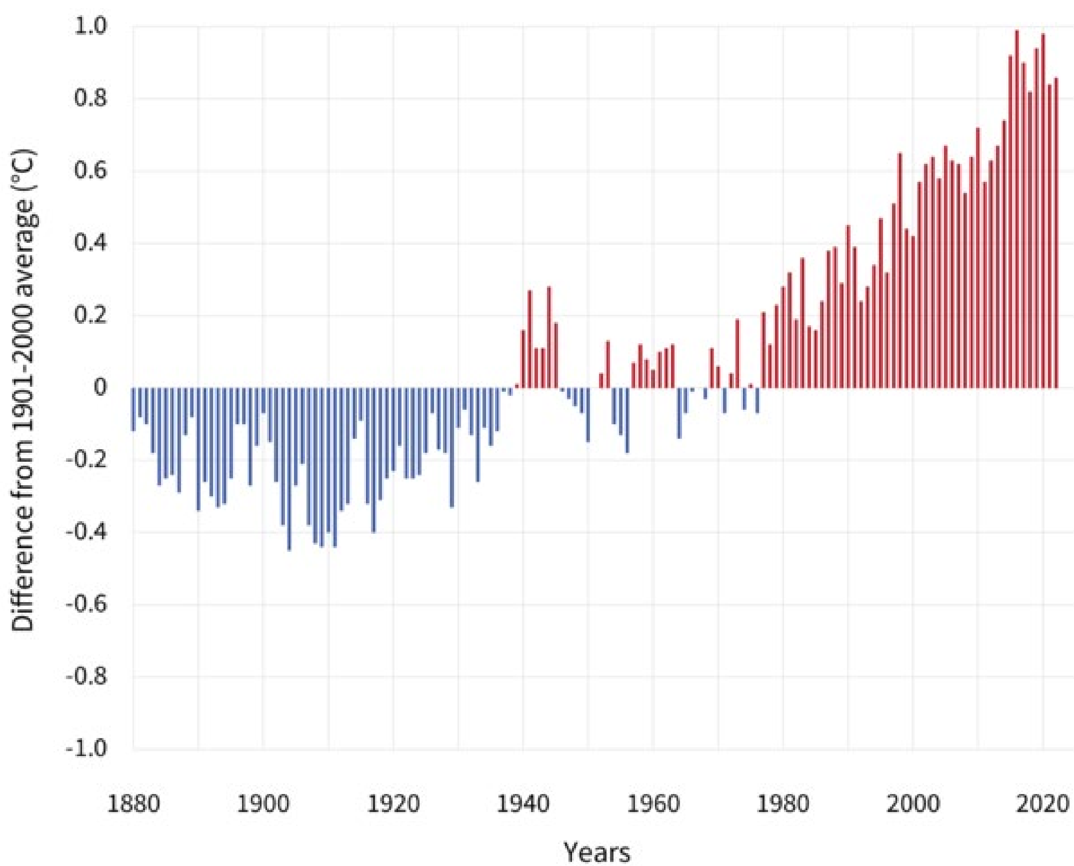
Source: California Department of Fish and Game (2003)

Figure J-1. Modified Köppen climates for California from the Atlas of Biodiversity for California



Source: NOAA (n.d.-a)

Figure J-2: Climograph for San Francisco Downtown Station GHCND: USW00023272 based on NOAA 30-year Climate Norms (1981-2010)



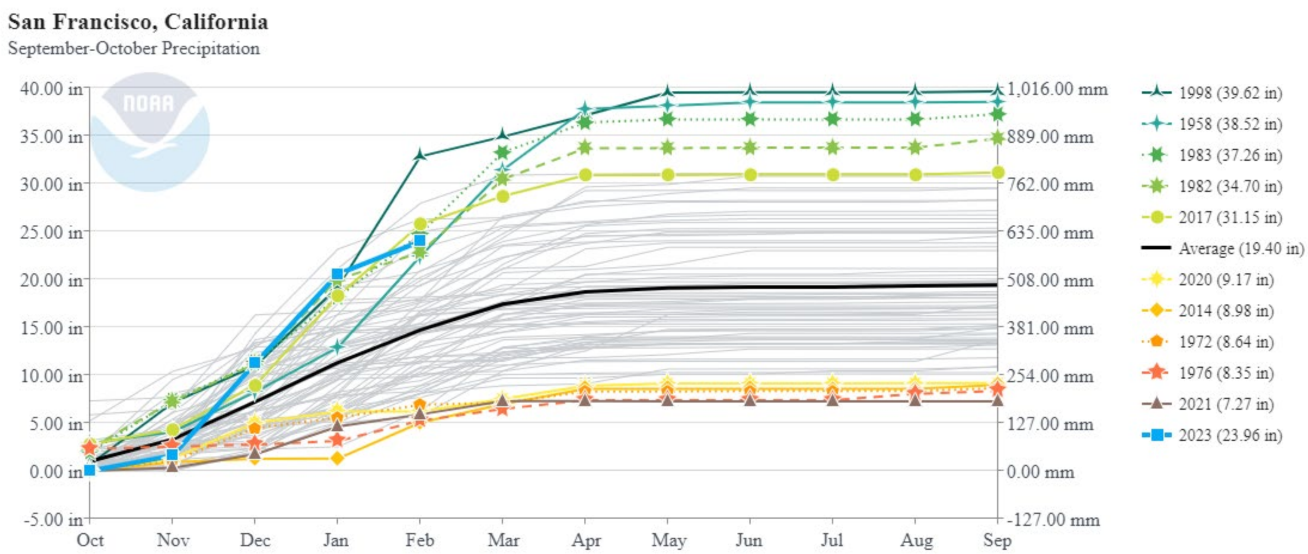
Source: NCEI, 2023

Yearly surface temperature compared to the 20th-century average from 1880–2022. Blue bars indicate cooler-than-average years; red bars show warmer-than-average years. NOAA Climate.gov graph, based on data from the National Centers for Environmental Information.

Figure J-3: Global Average Surface Temperatures (1880-2022)

2.2 Precipitation

Precipitation data from 1920 to the present is available for the San Francisco downtown weather station. The Bay Area's cumulative annual precipitation amounts vary widely, with an average annual precipitation of about 22 inches (**Figure J-4)**. Variability from year to year is impacted by the El Niño Southern Oscillation (ENSO), though its impacts on precipitation can be difficult to generalize. In years with high El Niño indices, including 1982-1983 and 1997-1998, which had the strongest El Niño indices on record, the region experienced unusually high precipitation totals. Years when coastal water levels have reached their highest observed levels have also coincided with high El Niño indices. However, the La Niña winter of 2023 brought record rainfall for San Francisco, with 18 inches of rain falling over 21 days (Mak et al., 2023a, 2023b). The winter of 2023 brought widespread rain and record snowfall throughout California, filling reservoirs, and providing reprieve from years of extreme and prolonged drought.



Source: NOAA (2023b)

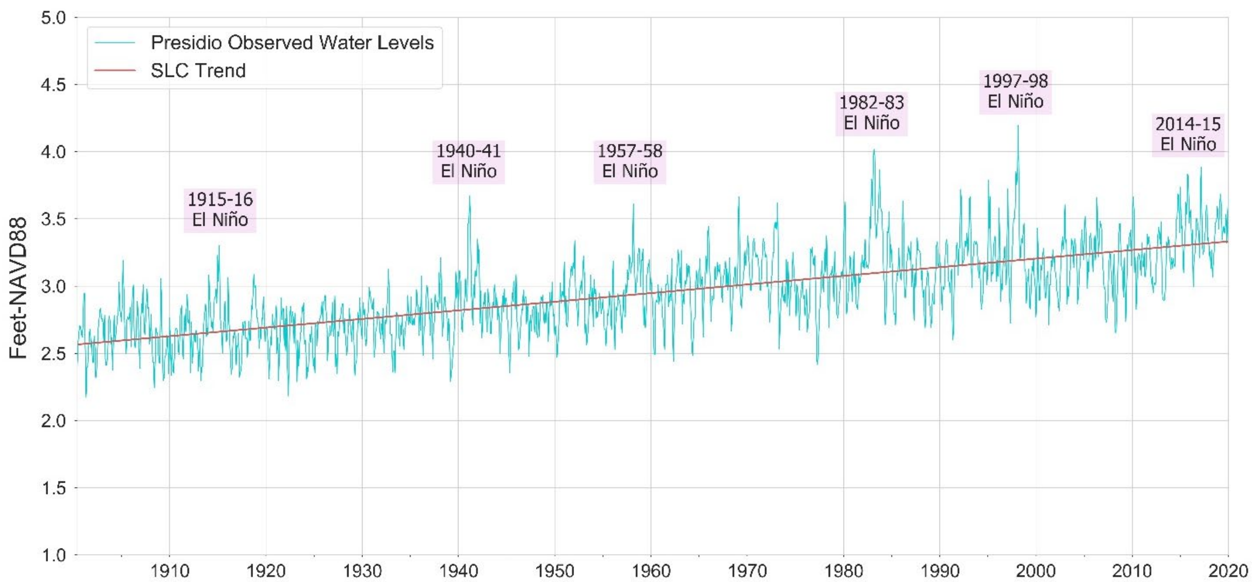
The five highest and lowest water year totals and the current year-to-date total are highlighted.

Figure J-4: Cumulative Precipitation Totals by Water Year for San Francisco (1948-2023)

2.3 San Francisco Bay Water Levels

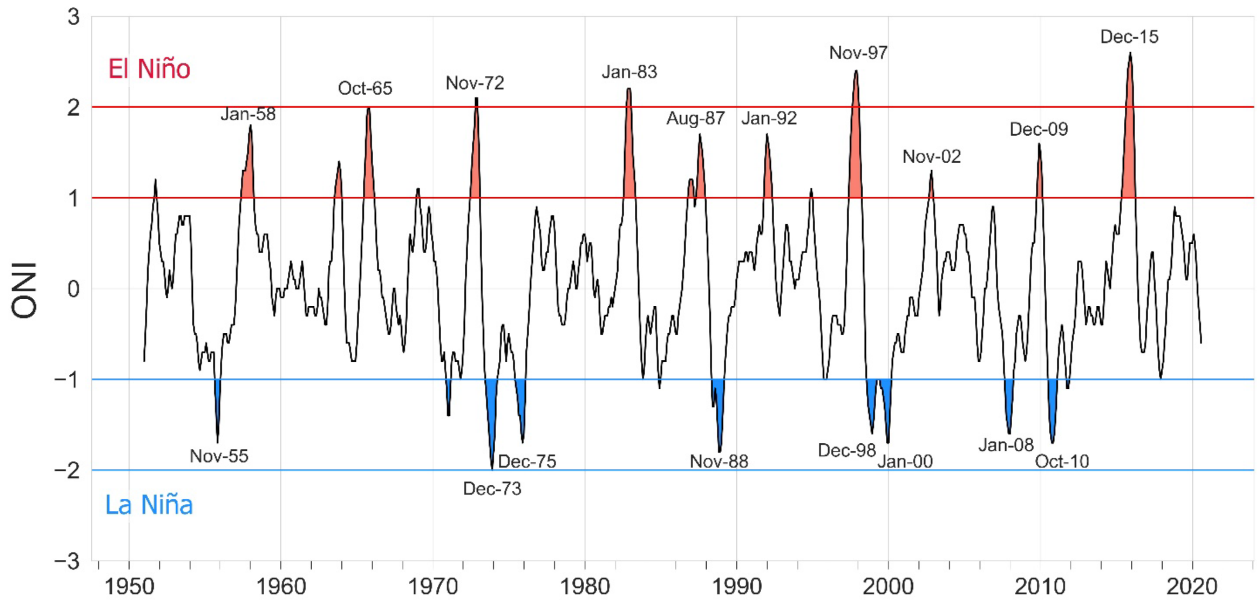
The Presidio tide gage, located along the San Francisco shoreline near the Golden Gate Bridge, was established in 1853. The tide gate represents the longest running series of tidal observations in the Americas. The tides are mixed semidiurnal, with two highs and two lows of unequal heights observed each day. *Sub-Appendix B.1.1 Coastal Extreme Water Levels and High Tide Flooding*, provides a detailed analysis of the observed water levels (CH2M/Arcadis Team, 2023).

Figure J-5 presents the long-term time series of Presidio water level observations, relative to mean sea level. An increasing trend is observed over time, associated with sea level rise. The largest observed water levels generally occur during El Niño years, as noted on **Figure J-5**. **Figure J-6** presents the Oceanic Niño Index which measures the relative strength of the El Niño and La Niña conditions. The strength of El Niño and La Niña conditions, as measured by the Oceanic Niño Index, is also observed to increase over time.



Source: (NOAA, 2020)

Figure J-5: San Francisco Presidio Tide Gage Sea Level Record (Relative to Mean Sea Level)



Source: (NOAA, 2023c)

Figure J-6: Oceanic Niño Index

2.4 Inland Hydrology

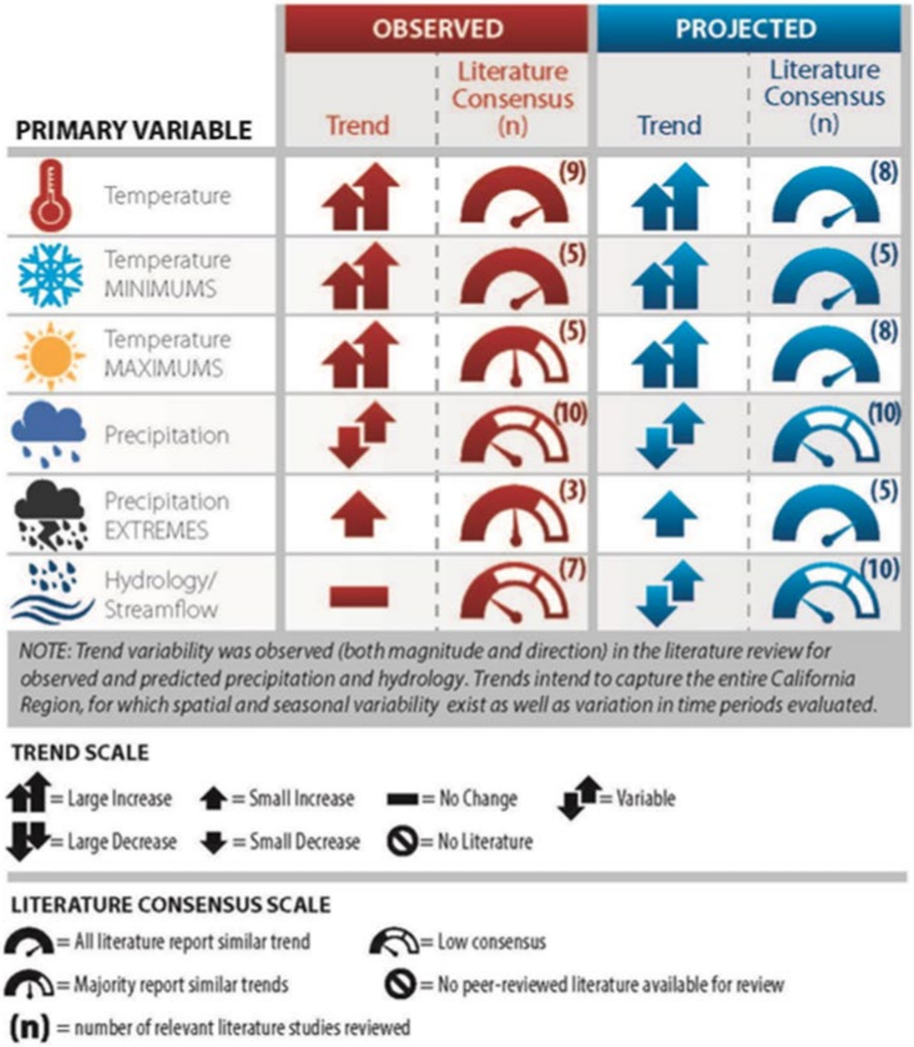
There are two large watersheds in the study area, the Islais Creek and Mission Creek watersheds. However, both creeks were placed underground and their associated floodplains and marsh and mudflat areas near the creek mouths were filled for development in the 1800s and 1900s. Both creeks retain a remnant inlet near the Bay, but there are no active measurements of creek flows by the USGS or the city.

The nearest USGS streamflow gage with available data is on Colma Creek in South San Francisco. However, Colma Creek's watershed and contributing areas are not representative of San Francisco's watersheds; therefore, analysis of Colma Creek's streamflows was not completed to inform this study.

Figure J-7 presents the USGS Hydrologic Units for California Region 18. The SFWCFS study area is located within the San Francisco Bay Hydrologic Unit Code (HUC) 1805. For the California Region, there is substantial trend variability (in both magnitude and direction) expected in annual precipitation and streamflow **(Figure J-8**).

Source: (USACE, 2015)

Figure J-7: Hydrologic Unit Map for California – Region 18



Source: (USACE, 2015)

Figure J-8: Observed and Projected Climate Trends

3. Literature Review and Data Sources

3.1 Literature Review

This literature review provides overarching context of the global, national, state, and local climate data, research, and guidance available.

3.2 Global Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC prepares comprehensive climate Assessment Reports about of the state of scientific, technical, and socioeconomic knowledge on climate change, its impacts, and future risks. These reports provide the global foundation for most national and local climate assessments, including the United States (U.S.) National Climate Assessment (NCA) developed through the U.S. Global Change Research Program (USGCRP).

IPCC released the Sixth Assessment Report (AR6) in March 2023 (IPCC, 2023b), which includes the finding of Working Group 1 on the Physical Science Basis (IPCC, 2021), Working Group 2 on Impacts, Adaptation, and Vulnerability (IPCC, 2023a), and Working Group 3 on Mitigation of Climate Change (IPCC, 2022). Due to the relatively recent release of AR6, the State of California and USACE sea level rise projections used within the SFWCFS rely on previous IPCC reports from 2014 (Fifth Assessment Report, AR5) and 2007 (Fourth Assessment Report, AR4), respectively, for their scientific basis (IPCC, 2007b, 2014).

Over time, IPCC has revised its approach for estimating how the climate may change. Future projections rely on an array of global climate models that simulate complex physical processes with assumptions regarding future population growth and how global actors will limit or reduce greenhouse gas emissions over time. No direct, simple comparison is available to translate projections across reports, but the following provides a summary for AR5 and AR6.

The climate scenarios in AR5 are based on a set of four greenhouse gas concentration trajectories or Representative Concentration Pathways (RCPs) (IPCC, 2014):

- RCP 8.5 assumes anthropogenic global greenhouse gas emissions continue to rise over the next century (i.e., there are no significant efforts to limit or reduce emissions),
- RCP 6.0 assumes anthropogenic global greenhouse gas emissions peak in 2080 and then decline,
- RCP 4.5 assumes anthropogenic global greenhouse gas emissions peak in 2040 and then decline,
- RCP 2.6 assumes stringent emissions reductions, with anthropogenic global emissions declining by about 70 percent between 2015 and 2050, to zero by 2080, and below zero thereafter (i.e., humans would absorb more greenhouse gases from the atmosphere than they emit).

The climate scenarios in AR6 build upon the framework presented in AR5, while separating the physical science and socio-economic assumptions to provide greater flexibility. AR6 relies on Shared Socioeconomic Pathways (SSPs) that provide additional quantitative data on population growth, urbanization, and gross domestic product per capita to define a larger suite of potential climate pathways. SSP5-8.5 most closely resembles RCP 8.5, while SSP2-4.5 most closely resembles RCP 4.5.

Through the Paris Agreement in 2015, global communities agreed to implement best available efforts to limit global warming to 1.5 degrees C by 2100. This temperature threshold was chosen to reduce the likelihood of surpassing tipping points that could lead to irrevocable change (IPCC, 2018). However, the world is poised to pass the 1.5

degree C threshold before 2026 (WMO, 2022). At present, there is optimism that global commitments and actions may result in global temperatures rising by 2 to 3 degrees C by 2100 (IPCC, 2023b), which is generally similar to RCP 4.5 / SSP2-4.5. However, global greenhouse gas emissions continue to increase, and global temperatures have already risen by 1.1 to 1.3 degree C compared to pre-industrial conditions (1850-1900) (IPCC, 2023b). This suggests that it is not feasible to limit global temperature increases to 1.5 degrees by 2100 without drastic actions (e.g., net negative emissions before 2030).

3.3 National Climate Projections

USGCRP has a congressional mandate to produce an updated climate assessment every four years. The assessment reviews the science of climate change and variability and its impacts across the U.S., now and in the future. The Fourth National Climate Assessment (NCA4) was published in two volumes, the Climate Science Special Report (USGCRP, 2017) and the Impacts, Risks, and Adaptation in the U.S. (USGCRP, 2018). The Fifth National Climate Assessment (NCA5) is in progress, with an anticipated publication date in late 2023.

NCA4 relies on IPCC AR5 and National sea level rise projections developed by NOAA, USGS, EPA, and Rutgers University (Sweet et al., 2017). NCA5 relies on the latest IPCC AR6 and U.S. based sea level rise projections that consider geographic differences across the country developed by the Federal Interagency Sea Level Rise Task Force (Sweet et al., 2022). The Federal Interagency Sea Level Rise Task Force includes subject matter experts from eight Federal agencies, Rutgers University, and the Florida International University Institute of Environment.

3.4 Local Climate Projections

In 2018, the State of California recommended using sea level rise projections associated with RCP8.5 and RCP2.6 from Sweet et al. (2017) for planning and design (CCC, 2018; OPC & CNRA, 2018). RCP8.5 was selected because, at the time, worldwide greenhouse gas emissions continued to follow (or exceed) this trajectory; and RCP2.6 was selected because, although challenging to achieve at the global scale, it aligns with California's ambitious greenhouse gas reduction efforts. The state is in the process of revising its sea level rise recommendations for consistency with the Federal Interagency Sea Level Rise Task Force 2022 report (Sweet et al., 2022), with an estimated publication date in 2023.

The City and County of San Francisco (CCSF) largely adopted the State of California guidance for sea level rise, using the RCP8.5 as an upper bound, but increasing the lower bound projection to RCP4.5 instead of RCP2.6. RCP4.5 was considered a more realistic lower bound assumption for planning and design due to the significant number of global variables outside of San Francisco's control required to meet the RCP 2.6 target (CPC, 2020).

San Francisco agencies have embarked on multiple research and planning efforts related to better understanding climate change and the associated impacts, such as the

Sea Level Rise Action Plan (CCSF, 2016), Sea Level Rise Vulnerability and Consequences Assessment (CCSF, 2020), and the Islais Creek Mobility Adaptation Study (San Francisco Planning, 2021). San Francisco agencies also participated in two recently completed research efforts: the San Francisco Extreme Precipitation Study in collaboration with Lawrence Berkeley National Laboratory and Pathways Climate Institute (Mak et al., 2023a, 2023b; Patricola et al., 2022) and the Shallow Groundwater Response to Sea Level Rise Study in collaboration with the Pathways Climate Institute and the San Francisco Estuary Institute (May et al., 2022).

The Port also led a multi-hazard risk assessment along the Embarcadero and northern waterfront that considered combined hazards associated with earthquakes, sea level rise, coastal flooding, and a high groundwater table (Port of San Francisco, 2020b, 2020c, 2020a).

3.5 Weather and Tide Gage Stations

San Francisco and the larger Bay Area region have several weather and tide gage stations that are part of the Global Historical Climatology Network (GHCN) and the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS). The GHCN San Francisco downtown weather station and the NOAA CO-OPS Presidio tide gage are the stations closest to the study area, and both stations have over 100 years of observational record (**Figure J-9**). These stations provide historical records of sufficient length to analyze precipitation trends and examine extreme coastal water levels.

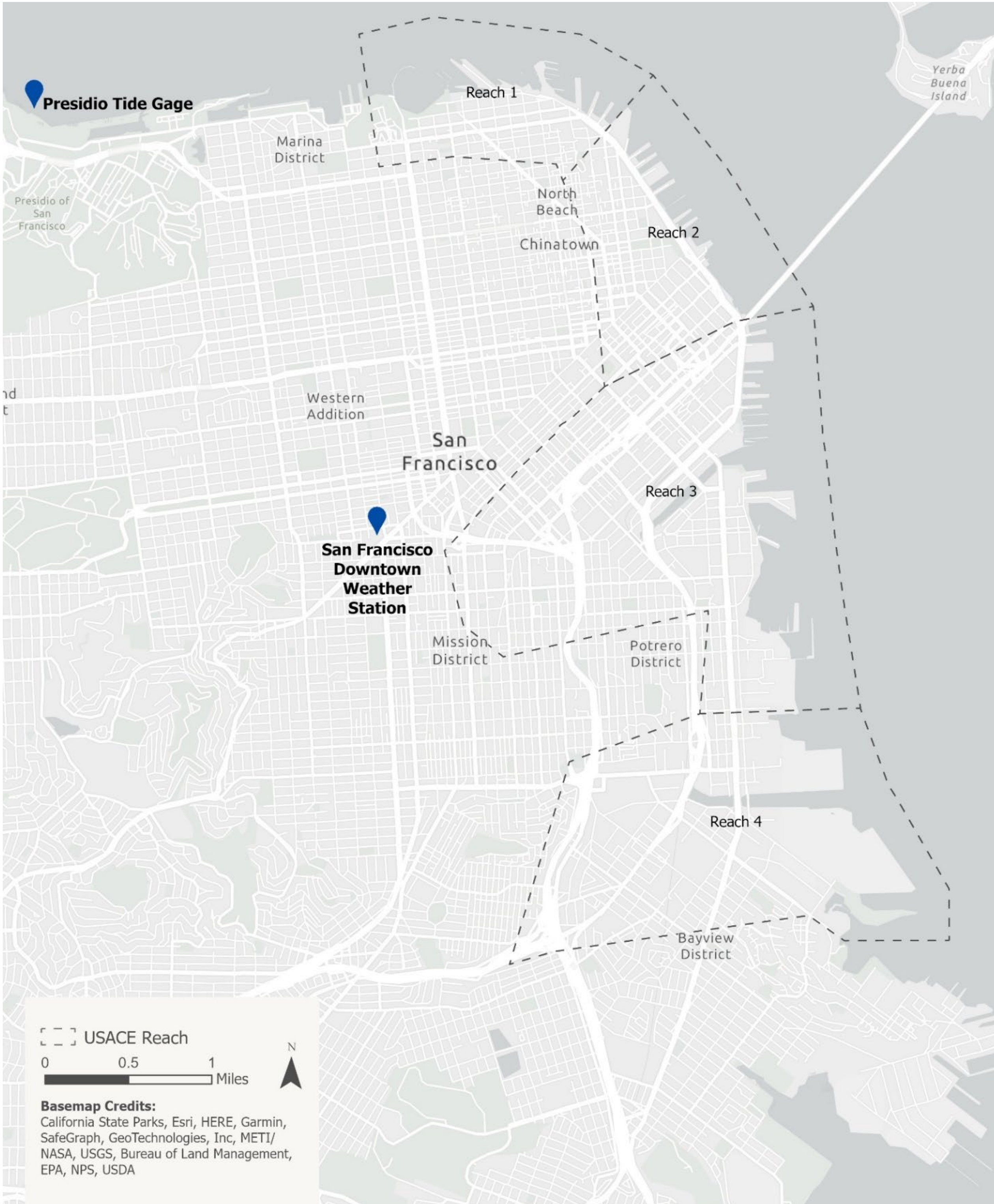


Figure J-9: NOAA Presidio Tide Gage and GHCN San Francisco Downtown Weather Station

3.6 San Francisco Downtown Weather Station

The San Francisco downtown weather station is in Hayes Valley near the city center, with over 100-years of data for several standard climate variables, including air temperature, precipitation, and wind (**Table J-2**).

Table J-2: Weather Station Details

Name	San Francisco Downtown, CA US
Network ID	GHCND: USW00023272
Latitude	37.7705°
Longitude	-122.4269°
Elevation	45.7 meters
Start Date	1921-01-01
End Date	On going
Data Coverage	100%

Source: https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00023272/detail

3.7 Presidio Tide Gage

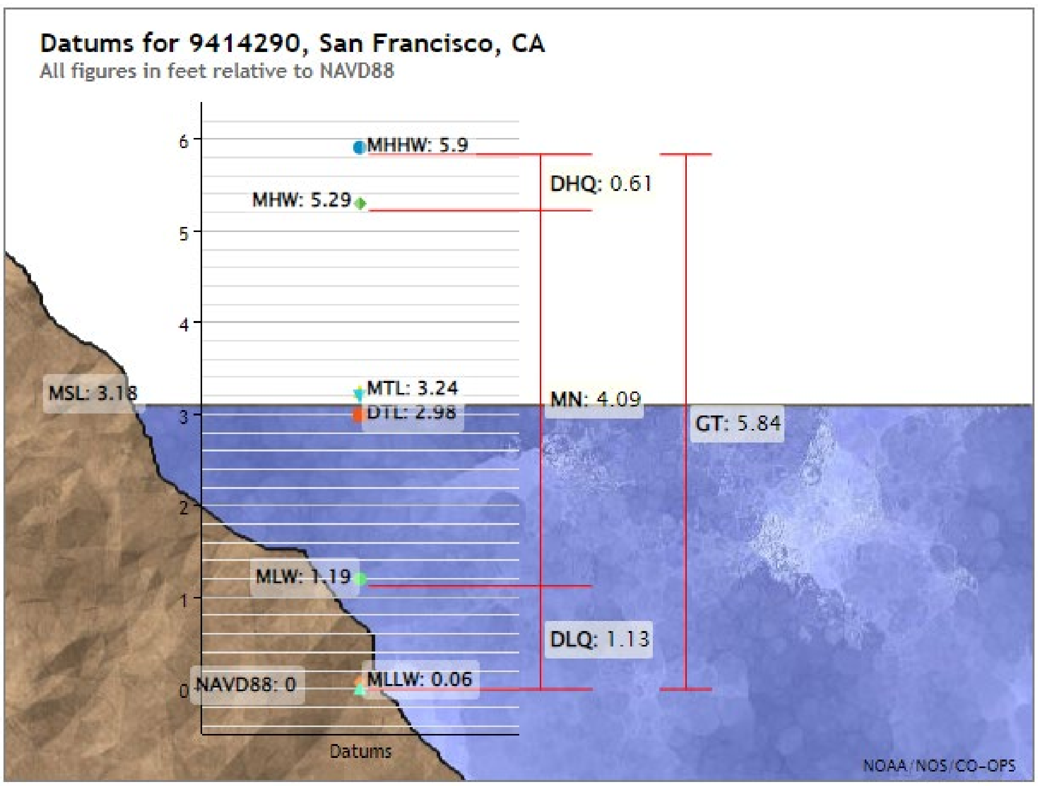
The Presidio tide gage (NOAA CO-OPS gage #9414290, **Table J-3** and **Figure J-10**) is located off the San Francisco shoreline near the Golden Gate Bridge. It was established in 1853 and is tied to a geodetic datum. Data from this gage is used to examine historical high tides, historical extreme coastal water elevations, observed changes in sea level, and comparisons to existing stormwater infrastructure elevations. A detailed assessment of the tide gage data is included in the Coastal Storms Report (Sub Appendix B.1.1.

Table J-3. Presidio Tide Gage Details

Name	Presidio, San Francisco CA
Station ID	9414290
Established	June 30, 1854
Time Meridian	0° E
Present Installation	Sep 1, 1988
Water Level Max (ref	2.82 feet Jan 27, 1983

MHHW)	
Water Level Min (ref MLLW)	-2.82 feet Dec 17, 1933
Mean Range	4.09 feet
Diurnal Range	5.84 feet
Latitude	37.8067°
Longitude	-122.4650°
NOAA Chart #	18649
Met Site Elevation	8.8 feet above MSL

Source: NOAA (2020b)



Source: NOAA (2023a)

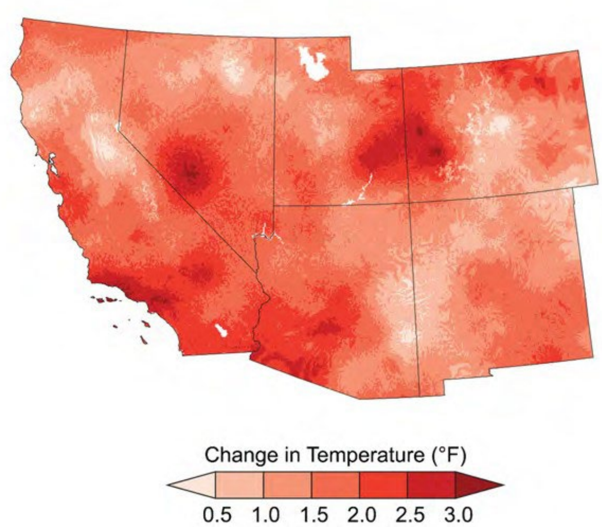
Figure J-10: Presidio Tide Gage Datums

4. Temperature

In addition to being a key indicator of climate change, air temperature is a key factor in decisions made by builders, insurers, energy companies, and regulators (Vose et al., 2017). Higher air temperatures are also associated with an increase in the intensity of extreme precipitation events (Easterling et al., 2017).

4.1 Observed Temperature Trends

The average annual temperature of the contiguous United States rose by approximately 1.2 to 1.8 degrees F over the twentieth century (i.e., from 1900 to 2000). The largest increases are observed in the Southwest (including California), Alaska, and the Northern Great Plains NCA regions. The Southwest NCA region experienced an increase in annual average, minimum, and maximum temperatures of 1.6°F between recent measurements (1986-2016) and the first half of the last century (1901-1960) (Vose et al., 2017). **Figure J-11** shows the spatial variation of temperature increases across the Southwest region. Since 1970, average annual temperatures have increased by 2.9 degrees F (NCEI, 2020).

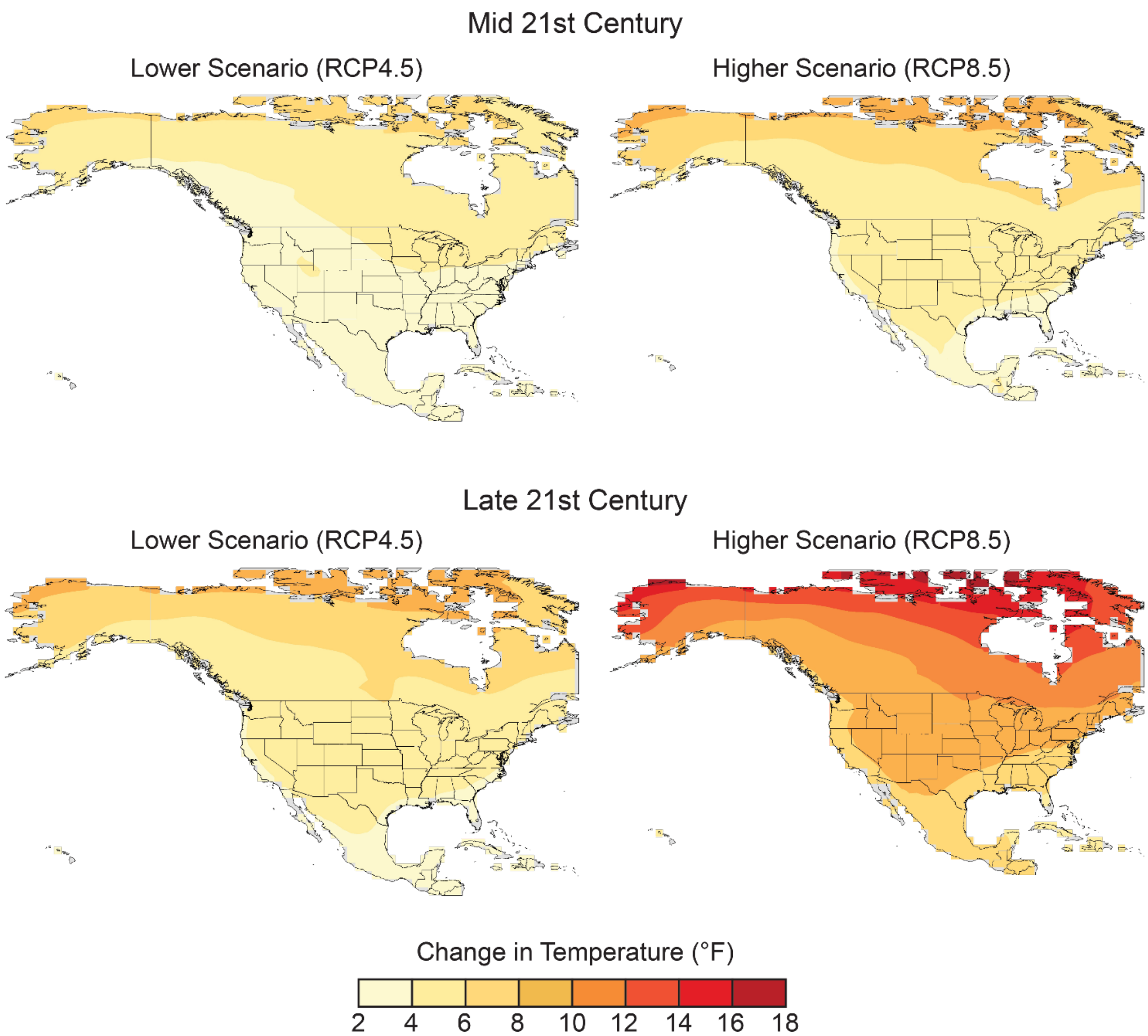


Source: Gonzalez et al. (2018)

Figure J-11: Southwest Region Temperature Increase from 1901-1960 to 1986-2016

4.2 Projected Temperature Trends

Temperatures are expected to increase throughout the United States under all emissions scenarios (Hayhoe et al., 2018) (**Figure J-12**). In general, northern latitudes and inland areas will experience greater increases in temperatures than coastal areas. Extreme temperatures (e.g., coldest and warmest daily temperatures) are also expected to increase in most areas by mid-century (Vose et al., 2017), which is consistent with the observed trends exhibited in the non-stationarity analysis.



Source: Vose et al. (2017)

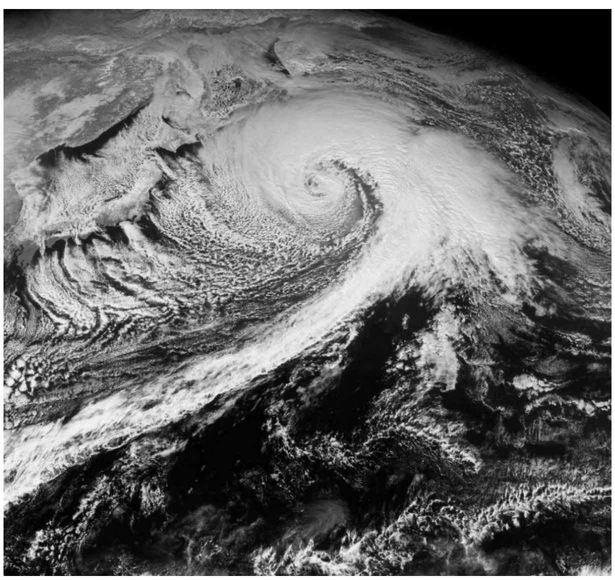
Figure J-12: Projected Change (°F) in Annual Average Temperature in Mid- and Late- 21st Century under RCP4.5 and RCP8.5Precipitation

4.3 Overview of Bay Area Storms

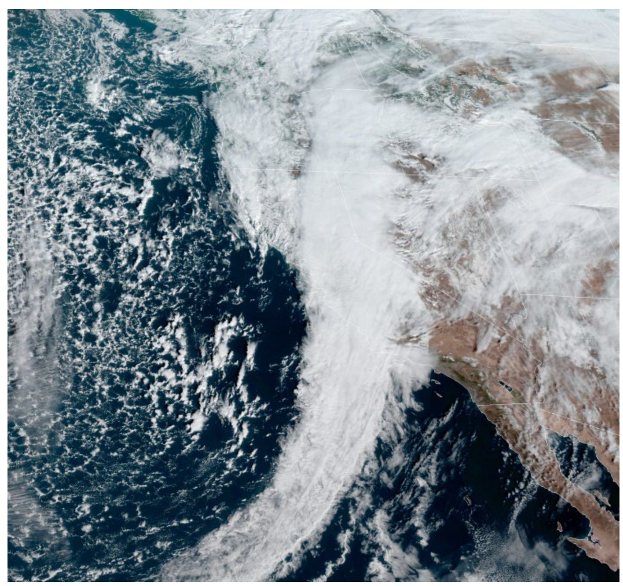
The Bay Area has a Mediterranean climate, with about 75% of its annual average rainfall between November and March, and little to no rainfall occurring in the summer. This region oscillates between extremes, with periods of below average annual rainfall (e.g., drought conditions) interspersed with years with above average annual rainfall. Two storm types bring rainfall to the Bay Area:

- ***Extratropical cyclones (ETCs)*** develop offshore and can bring cloudiness and mild showers to severe gales, thunderstorms, blizzards, and heavy rain; and
- ***Atmospheric rivers (ARs)*** originate in the tropics and can bring light beneficial rain to torrential downpours and high winds.

Each storm type can occur on its own, or they can occur in combination. A single AR event can also co-occur with a series of back-to-back extratropical cyclones. ARs and ETCs on the more hazardous end of the spectrum are associated with an increased risk of flooding in low-lying areas throughout the Bay Area. Approximately 90% of the storms that impact the west coast are either ETCs or ARs combined with ETCs (Zhang et al., 2019). Climate change is projected to increase the intensity of these storms by up to 37% by 2100 (Patricola et al., 2022).



a) Northwest Pacific Extratropical Cyclone and Atmospheric River, January 15, 2013



b) Atmospheric River Satellite Image, January 28, 2021

Source: NOAA

Figure J-13: Satellite Imagery of Bay Area Storm Types

4.3.1 Atmospheric Rivers

First coined by Newell and Zhu in the 1990s, ARs have captured considerable media attention over the last decade (Newell et al., 1992; Zhu & Newell, 1994). ARs are often described as long and narrow atmospheric conveyor belts that, on average, span ~500 miles wide and thousands of miles long (**Figure J-13b**). They are found in the lower atmosphere (within 2 – 9 km, or 1.2 – 5.6 miles, high) and transport water vapor moisture from the tropics to the subtropics.

The most recognizable AR, named the “Pineapple Express,” brings warm, moist air from Hawaii to the west coast of the U.S. and Canada. When ARs carrying water vapor from the tropics make landfall along the California coast, precipitation can be sustained over a span of hours to days with varying intensity (Cordeira et al., 2019; Dettinger et al., 2011; Lamjiri et al., 2018; Ralph et al., 2012).

Landfalling ARs account for 30%–50% of precipitation and snowpack along the western US (Cordeira et al., 2019; Polade et al., 2017) and are associated with severe flooding events in California and other western states (Cordeira et al., 2019; Das et al., 2013; Dettinger et al., 2009; Dettinger et al., 2011; Easterling et al., 2017; Polade et al., 2017).

4.3.2 Extratropical Cyclones

Within the Earth’s middle latitudes, cyclones are called mid-latitude cyclones or ETCs (Booth et al., 2017; Colle et al., 2015; Dacre, 2020). ETCs generally travel from west to east, vary in size and strength, with a low-pressure core and high rotating windspeeds that can resemble a hurricane when viewed via satellite imagery (Figure J-13a) (Catto, 2016). However, hurricanes and ETCs have many differentiating features, including their frequency of occurrence, duration, vertical wind and temperature profile, and their direction of movement.

ETCs can produce mild cloudy days with light showers to a myriad of extreme weather conditions including heavy precipitation, thunderstorms, coastal storm surge, high winds, and tornadoes. These cyclones form along weather fronts, producing rapid changes in temperature and dew point. Multiple ETCs may pass over the same area in sequence within a short period of time (e.g., days to weeks) (Dacre, 2020).

The most damaging storms for the Bay Area have resulted from the co-occurrence of a large and rapidly intensifying ETC and an AR off the California coastline (May et al., 2019). ETCs can intensify ARs with stronger winds, and ARs with strong water vapor transport can provide favorable conditions for rapid ETC intensification (i.e., explosive cyclogenesis) (Zhang et al., 2019, p. 20). Explosive cyclogenesis occurs when the central pressure within the ETC drops rapidly – by at least 24 millibars in 24 hours – creating a condition referred to as a “bomb cyclone” with extreme rainfall and high winds (Sanders & Gyakum, 1980; Zhu & Newell, 1994). In addition, ARs can feed off the warm water vapor or moisture from the ETCs, which can help to lift the ARs higher in the atmosphere and result in increased rain (Zhang et al., 2019).

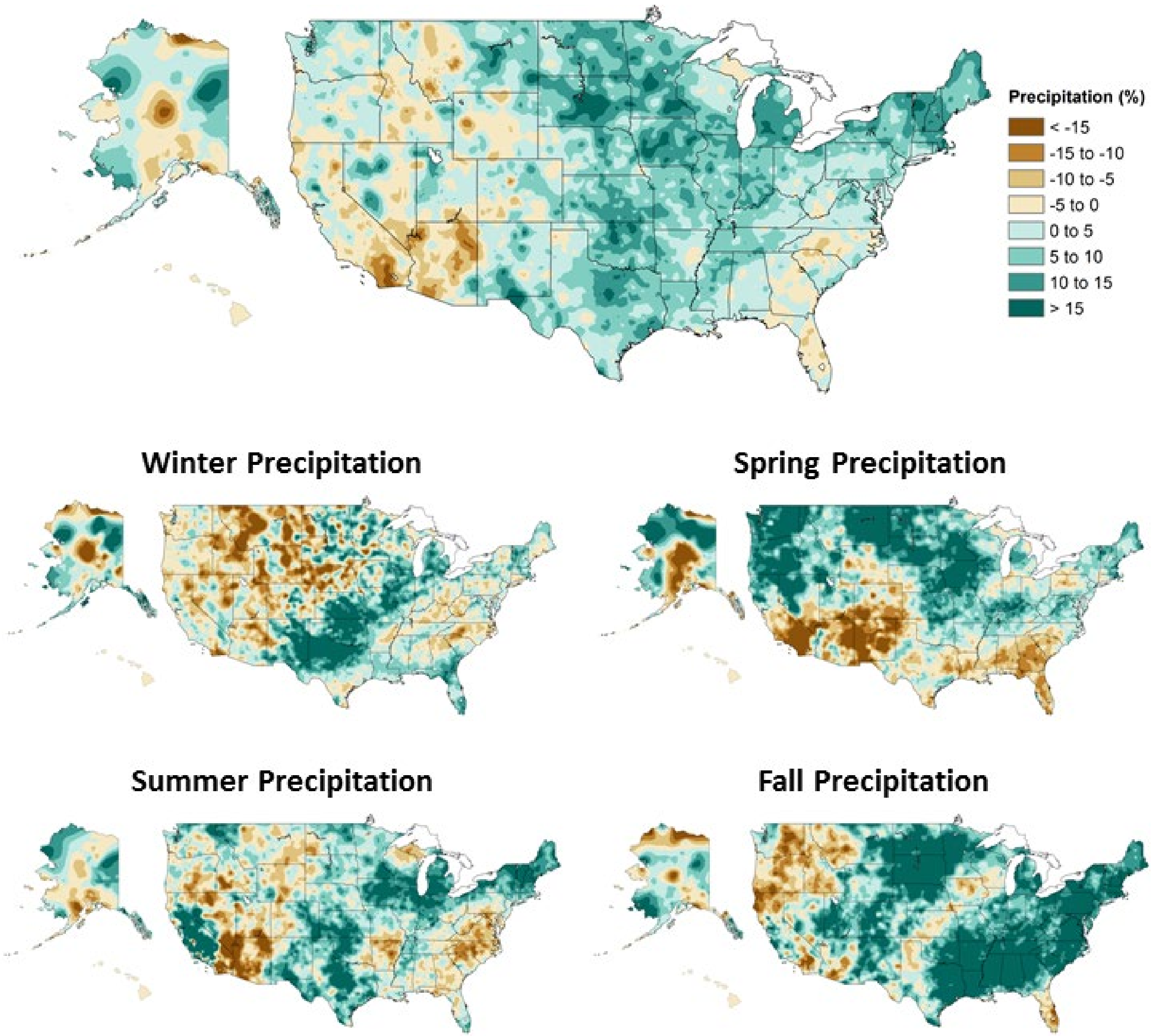
4.4 Observed Precipitation Trends

The U.S. maintains a network of weather stations, and the observational record provides insight into how precipitation has changed over time.

4.4.1 National and Regional Observations

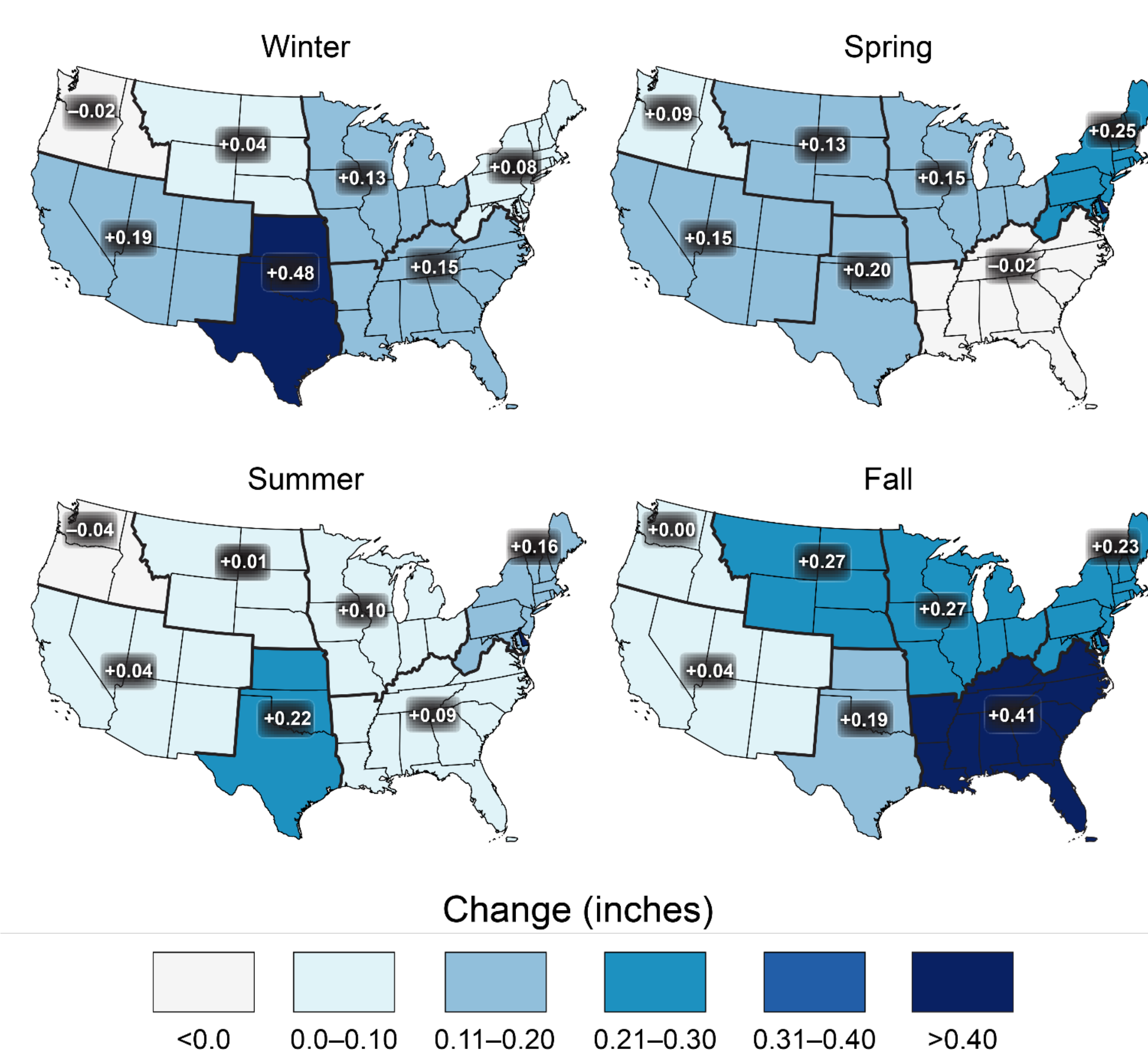
Annual and seasonal precipitation have changed throughout the U.S. over the past century. The more recent period (1986-2015) is about 4% wetter on average across the country compared to the first half of the last century (1901-1960) (Easterling et al., 2017). However, the degree of change varies greatly by geography and by season (**Figure J-14**).

Extreme precipitation trends have also shown increases. **Figure J-15** shows a general increasing trend in the 20-year return period, 24-hour precipitation event. The greatest changes in California are observed in the winter and spring, which coincides with the typical rainy season.



Source: (Easterling et al., 2017)

Figure J-14: Annual and Seasonal Precipitation Percent Change from 1901-1960 to 1986-2015



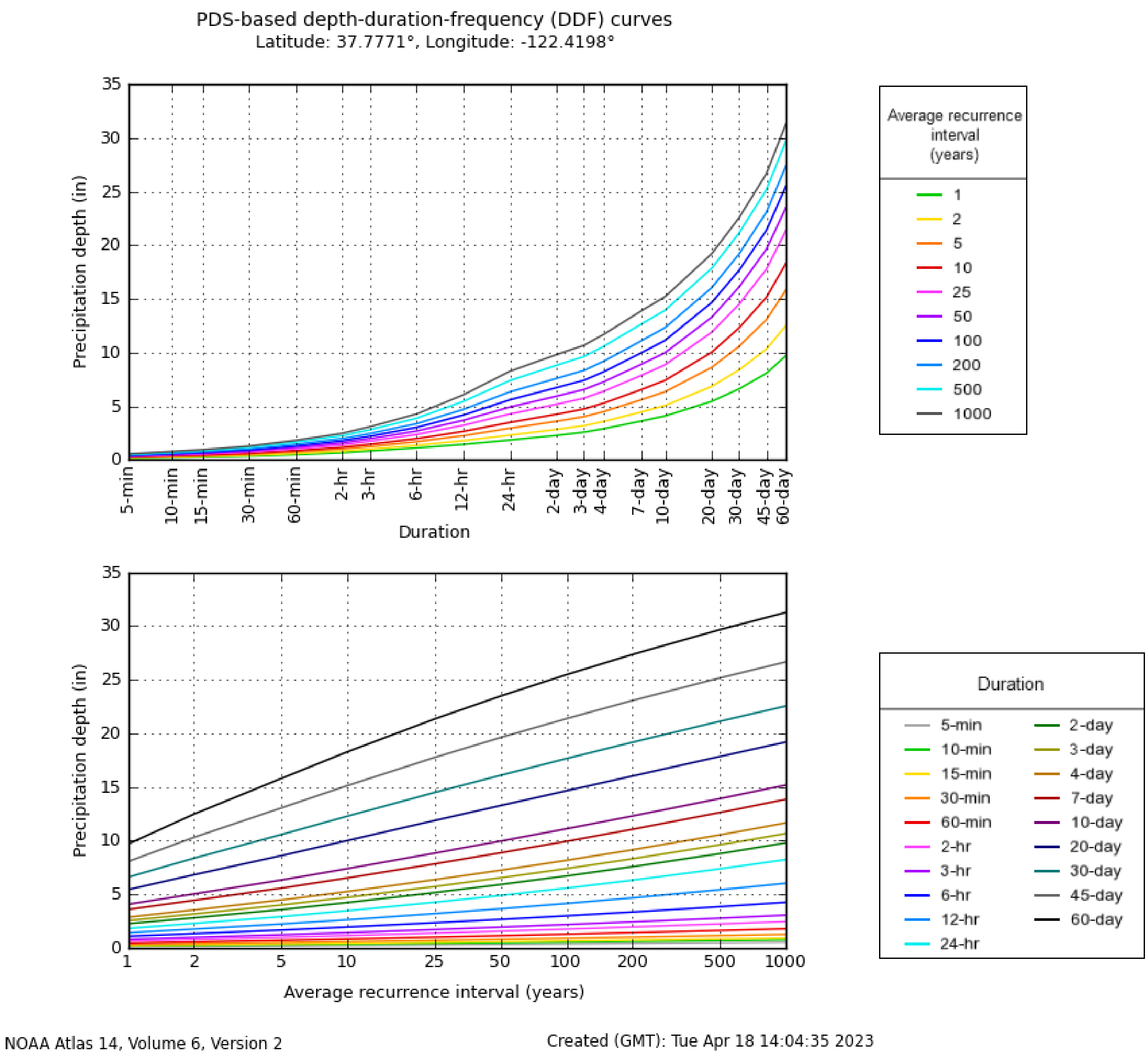
Source: Easterling et al., (2017)

Figure J-15: Observed Change in Daily, 20-year Return Level Precipitation

4.4.2 Local Observations

NOAA Atlas 14 is the most used data source for precipitation frequency estimates, with gridded estimates of precipitation intensity, duration, and frequency (IDF) across the U.S. (Finzi Hart et al., 2022). NOAA Atlas 14 precipitation estimates for California were last updated in 2014, relying solely on historical observations. Many utilities and other infrastructure owners and operators rely on NOAA Atlas estimates to inform infrastructure planning and design throughout the Bay Area. However, storms occurring today already bear the hallmarks of climate change and are increasing in intensity and severity when compared with historical observations (Cordeira et al., 2019; Dettinger et al., 2009; Lamjiri et al., 2018; Patricola et al., 2022).

Figure J-16 shows the NOAA Atlas 14 intensity, frequency, and duration curves for San Francisco.



Source: NOAA (2014)

Figure J-16: NOAA Atlas 14 Intensity, Duration, Frequency Estimates for San Francisco

4.4.3 Recent Storms and Compound Events

A recent study by Mak et al. (2023a, 2023b) identified 15 extreme storms that impacted San Francisco and the Bay Area, six of which were selected to model to assess how the storms could change under a warmer climate. Details on the 15 extreme storms and their selection is available in May et al. (2019). The largest storms, with heavy precipitation, high winds, and elevated Bay water levels generally occurred during strong El Niño years. However, as the Bay Area experienced prolonged La Nina conditions in winter 2021/2022 and 2022/2023, the Bay Area also experienced two extreme wet winters.

In October 2021, an extreme storm series impacted the Bay Area bringing more than 15 inches of rainfall to portions of Northern California. In the following year, the 2022/2023 winter brought a series of back-to-back ARs, ETCs, and bomb cyclones, becoming one of the wettest years on record.

October 2021 Bomb Cyclone

In October 2021, a large AR (the Pineapple Express) collided with a series of ETCs and brought heavy rainfall, flooding, and damaging storm conditions from the central California coast and up into Canada. The first and third ETCs in the series underwent explosive cyclogenesis and became bomb cyclones.

As categorized by the Center for Western Weather and Water Extremes (CW3E), the first ETC to collide with the Pineapple express produced AR 4 conditions in southwestern Oregon and AR 2 to AR 3 conditions were observed elsewhere along the coast from the Bay Area to the Olympic Peninsula (CW3E, 2021). The third ETC to collide with the Pineapple Express reached AR 5 conditions over California, near Point Reyes, due to the combination of maximum IVT values (> 1000 kg/m/sec) and AR duration (> 48 hours) (Ralph et al., 2019). This was the strongest October storm system to make landfall in the Bay Area in the previous 40 years, and the most powerful bomb cyclone recorded in the Northeastern Pacific. Intense rainfall on October 24th caused flooding in the Bay Area and triggered multiple landslides in Northern California. Portions of Northern California received more than 15 inches of total precipitation from the consecutive storms.

Winter 2022-2023 Consecutive and Compounding ARs and ETCs

Early weather predictions for the 2022-2023 wet winter season suggested California would experience low precipitation accumulations relative to average conditions, consistent with La Niña. However, this winter season started out as one of the wettest winters on record, breaking a 152-year-old record for the second wettest 10-day period since 1871. The wettest 10-days on record occurred in 1862.

Between December 26, 2022 and January 16, 2023, the Bay Area was hit with nine consecutive ARs, some that co-occurred with ETCs, and one that became a powerful bomb cyclone on January 5, 2023. In San Francisco, 18 inches of rain fell over the 21 days, representing 75% of the total average annual rainfall. The Bay Area experienced widespread flooding, power outages, mudslides, downed trees, and disruption to daily life.

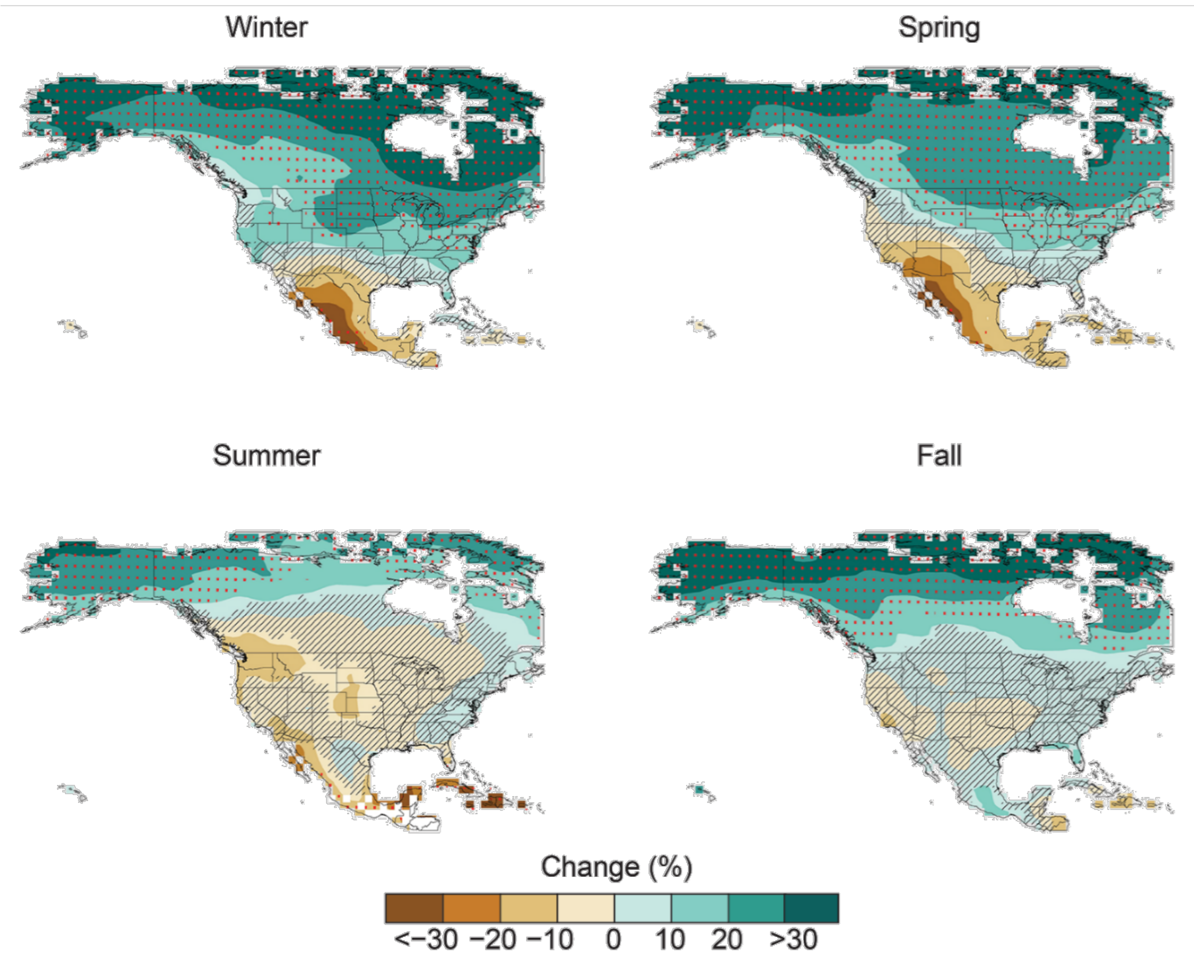
In parallel to these historic rain events along the coast, concomitant record-breaking snowfall was recorded across the state's mountain ranges, even down to the Southern California mountains east of Los Angeles and San Diego.

Although the October 2021 storms led to widespread flooding, damage and disruption, the shorter duration of the events did little to provide relief for California's extreme drought conditions. However, the back-to-back series of storms in winter 2022/2023, and the continued rainfall and snowfall that occurred through March 2023, replenished most reservoirs, and provided some reprieve from the prolonged drought.

4.5 Projected Precipitation Trends

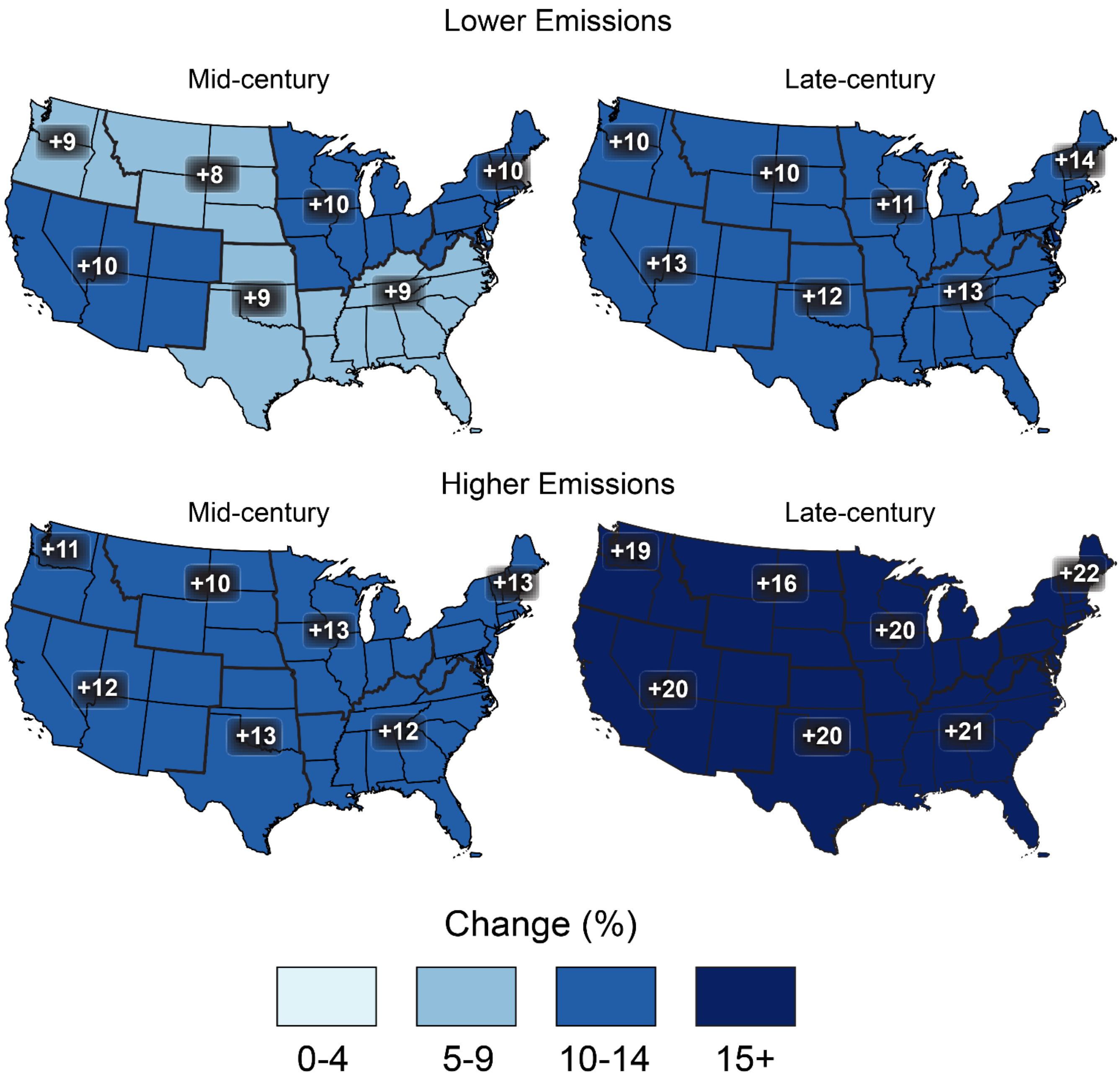
4.5.1 National Climate Projections

Changes in seasonal average precipitation is projected to vary by region across the country (**Figure J-17**). Extreme precipitation is expected to increase throughout all NCA regions (**Figure J-18**) (Easterling et al., 2017). For much of California, although average annual precipitation totals are not necessarily projected to increase, the frequency and intensity of atmospheric rivers are expected to increase. California, and the Bay Area region, are projected to experience more prolonged periods of extreme drought interspersed with more extreme wet years.



Source: Easterling et al. (2017)

Figure J-17: Projected Change (%) in Average Seasonal Precipitation between 2070-2099 and 1976-2005



Source: Easterling et al. (2017)

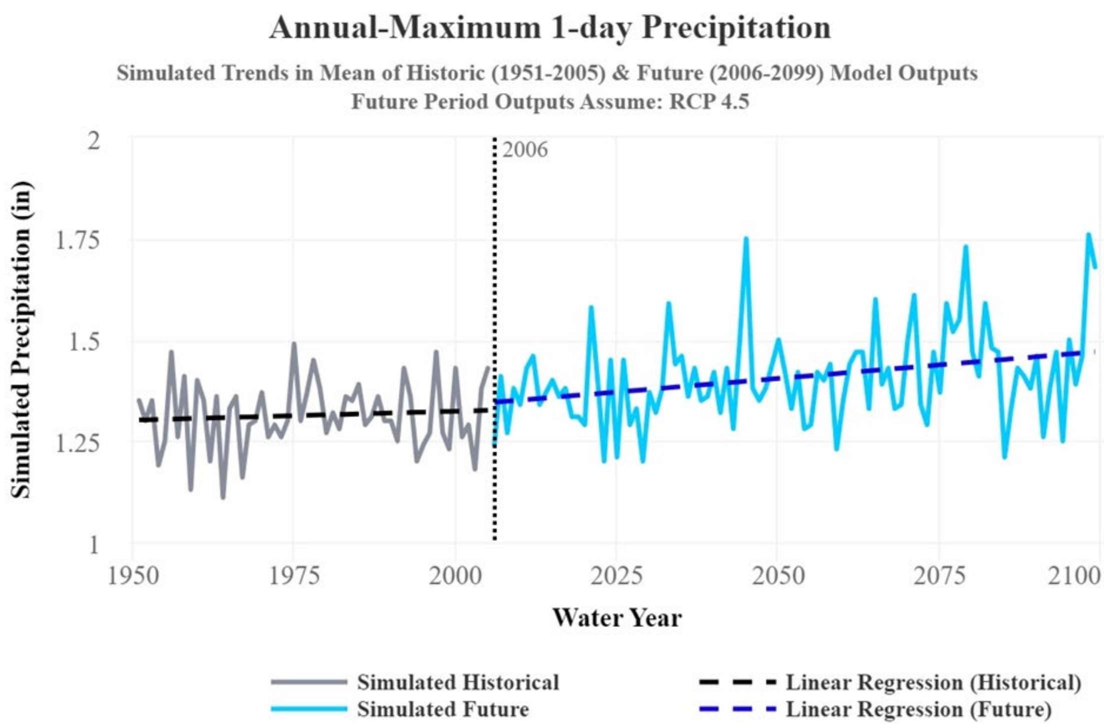
Figure J-18: Projected Change (%) in Daily, 20-year Extreme Precipitation for Mid- and Late- 21st century for RCP4.5 and RCP8.5

4.5.2 Local Climate Projections

USACE developed the Climate Hydrology Assessment Tool to enhance climate preparedness and resilience (USACE, 2023). The tool aids in assessing hydrologic-based climate change impacts, including evaluating past (observed) and potential future (projected) changes to relevant hydrologic inputs such as precipitation.

Figure J-19 displays the observed and projected trends for the annual-maximum 1-day precipitation, based on 93 different climate change hydrologic simulations for the period of 1950-2099 and assuming the RCP4.5 climate scenario (USACE, 2023). Year-to-year variability in the projected trend is expected, consistent with observations.

Several San Francisco departments partnered with Lawrence Berkeley National Laboratory and Pathways Climate Institute to conduct a regional climate modeling to better understand how Bay Area storms could change under a warming climate. In the Bay Area, where the highly variable and complex topography (i.e., combinations of low-lying areas surrounded by steep hills) influences both temporal and spatial differences in local precipitation, global climate models fall short. The grid resolution of global climate models (e.g., 100 to 500 km) often results in the entire Bay Area being captured within one model grid. Current state-of-the-art climate models are approaching resolutions of 25 km, which can broadly represent west coast atmospheric rivers. However, even at 25 km, the models cannot adequately capture the complex topographic differences across the Bay Area that lead to highly variable precipitation rates.



Source: Climate Hydrology Assessment Tool (USACE, 2023)

Figure J-19: Observed and Projected Annual Maximum 1-day Precipitation

San Francisco's regional climate study combined state-of-the-art climate modeling methods with a physical understanding of regional storms and storm types to produce high-resolution extreme precipitation projections and the associated stakeholder-requested data products. The research and data products, including updated intensity-duration-frequency (IDF) curves that incorporate projections through the end of the century, are anticipated to inform infrastructure planning and design throughout the Bay Area.

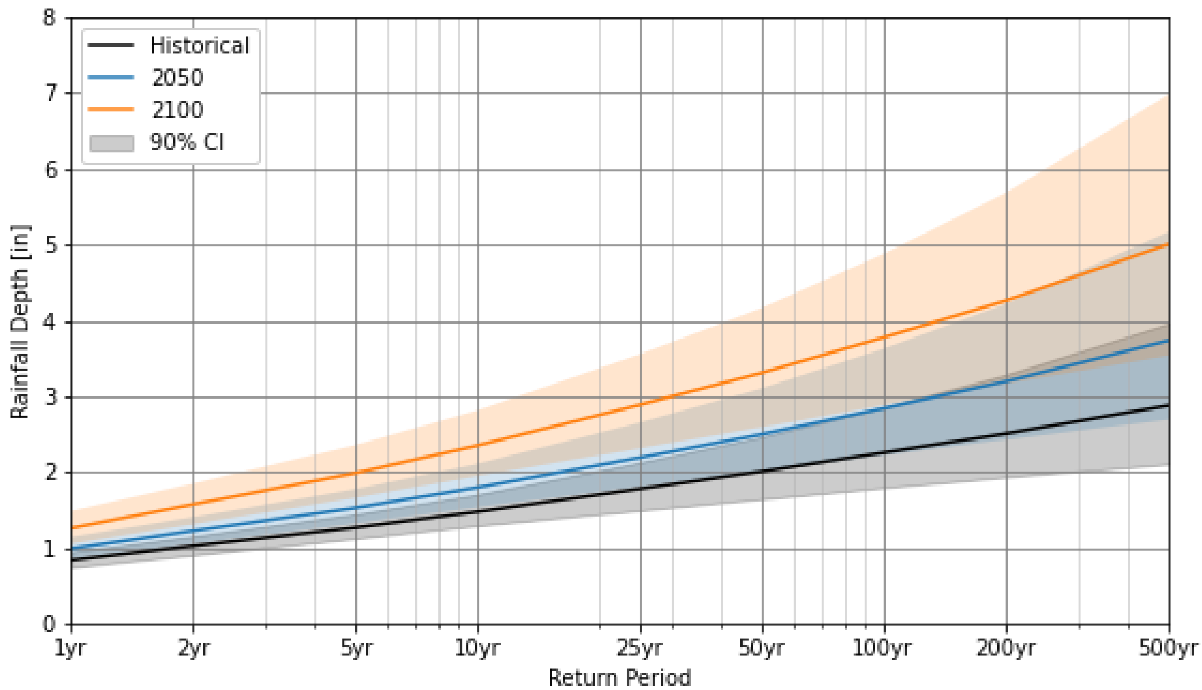
The key study findings include:

- Storm duration could increase between 9 – 24% by 2050 and from 18 – 55% by the end of century, both relative to historic conditions.
- Storm-total precipitation could increase by up to 17% by 2050 and 37% by 2100 relative to historical conditions (Patricola et al., 2022).
- Rainfall intensity within the short durations (e.g., 3 hours or less, **Table J-4** and **Figure J-20**) is increasing faster than longer durations (e.g., 24-hour or more, **Table J-5** and **Figure J-21**), which has implications for stormwater conveyance and flash flooding.

Table J-4: Historical and Future Precipitation Intensity for 5-year and 100-year Frequency, 3-hour Duration with 90% Confidence Interval

Source: Mak et al. (2023a, 2023b)

Historical (Atlas 14)		+0%	+0%
	90% CI	*-11% to 14%*	*-20% to 27%*
2050		+20%	+26%
	90% CI	*+12 to +30%*	*+16 to 35%*
2100		+56%	+67%
	90% CI	*+38 to +75%*	*+47% to +87%*



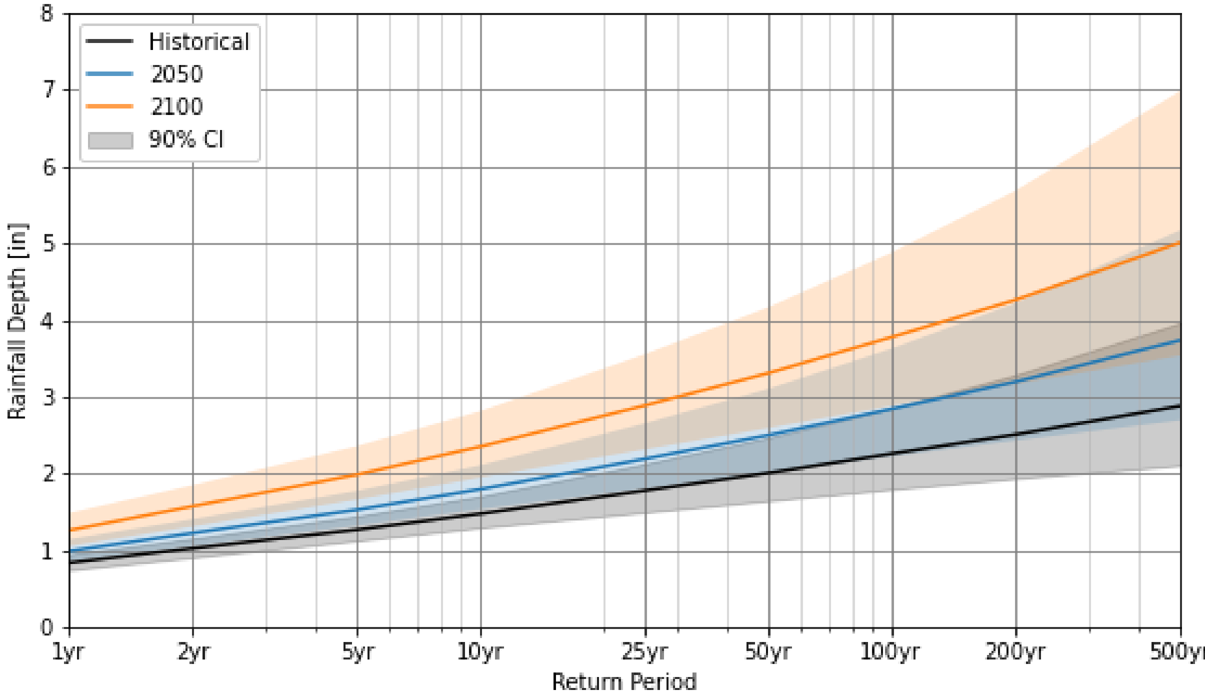
Source: Mak et al. (2023a, 2023b)

Figure J-20: Historical and Future Return Period versus Rainfall Depth for 3-hour Durations

Table J-5. Historical and Future Precipitation Intensity for 5-year and 100-year Frequency, 24-hour Duration with 90% Confidence Interval

Source: Mak et al. (2023a, 2023b)

Historical (Atlas 14)		+0%	+0%
	90% CI	*-10 to +13%*	*-17 to +23%*
2050		+17%	+22%
	90% CI	*+7 to +27%*	*+12 to 32%*
2100		+41%	+51%
	90% CI	*+26 to +57%*	*+35 to +67%*



Source: Mak et al. (2023a, 2023b)

Figure J-21: Historical and Future Return Period versus Rainfall Depth for 24-hour Duration

5. Sea Level Change

5.1 Overview of San Francisco Bay Water Levels

The *Sub-Appendix B.1.1 Coastal Extreme Water Levels and High Tide Flooding*, provides a robust description of the cycles and processes (e.g., tidal, oceanic, and atmospheric) that drive regular variations in Bay water levels (CH2M/Arcadis Team, 2023). In summary, the tidal, oceanic, and atmospheric processes that drive natural climate variability in Bay water levels are:

- **Astronomical tidal cycles**, which can be predicted with relative certainty, including:
  - A mixed semidiurnal tidal cycle, with two high tides and two low tides occurring each day, with each of the four tides reaching different elevations (Conomos, 1979).
  - A 14-day spring-neap cycle, with the highest energy (and largest tidal range) occurring during spring tides during the new and full moon, and the lowest energy (and smallest tidal range) occurring during neap tides when the sun and moon are at right angles to each other.
- **Oceanic cycles and processes** that alter the astronomical tides from their predicted state:
  - An annual cycle in which water levels are generally lower in the spring and early summer and higher in the early fall through winter. The decrease in water levels in the spring is referred to as the “spring drop” (USGS, 1999).
  - The El Niño / La Niña cycle (El Niño-Southern Oscillation, ENSO), where every 2 to 7 years the equatorial trade winds relax, or even reverse, and warm surface water moves back along the Equator towards South America (Park et al., 2012; USGS, 1999). The El Niño / La Niña cycles can influence water levels for several months at time.
  - The Pacific Decadal Oscillation (PDO) is a long-term (e.g., 20 – 30 years) ocean fluctuation of sea surface temperatures in the Pacific Ocean. When the PDO drives warmer waters along the west coast North America (and colder waters in Alaska), water levels along the west coast are often elevated. The reverse happens when the PDO shifts, returning warmer waters to Alaska and colder waters to the Pacific Coast. These shifts in the PDO may mask or accelerate localized sea level trends for long periods. For example, the rate of SLC was observed to be depressed along the Pacific coast of North America between the mid-1970s and 2003 when colder water conditions prevailed along the Pacific coast (Bromirski et al., 2011; NRC, 2012). More recently, this trend has reversed and SLC has increased along the Pacific coast (Fasullo & Nerem, 2018). Assessing

ocean cycles and their influence on global SLC trends remains an area of active research (Nerem et al., 2020).

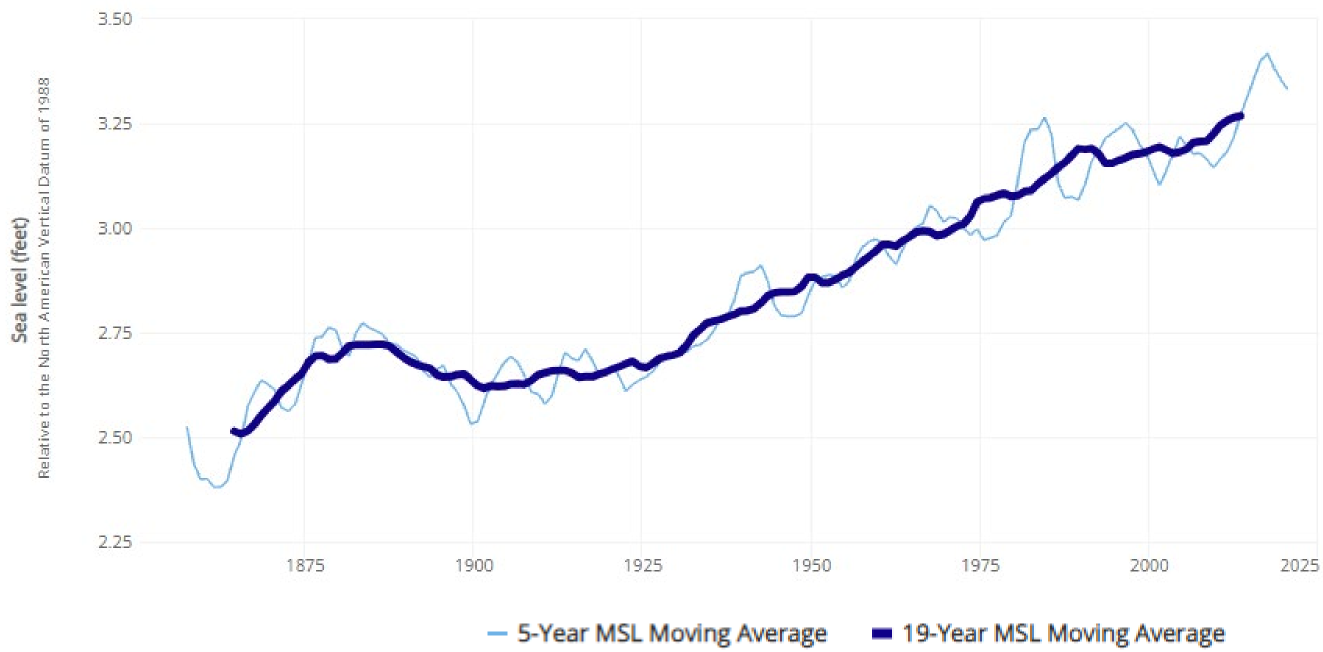
- **Atmospheric processes** (e.g., the weather), including extreme storm events, that influence the combination of tidal and oceanic cycles noted above:
    - California winter storms typically bring high rainfall, low atmospheric pressure, and strong winds. The low atmospheric pressure of storm systems allows ocean waters to expand, and unusually low-pressure systems can result in a sea level increase of up to 10 inches (USGS, 1999). Along the California coast, during El Niño winters, strong storm-related winds from the south combine with the Coriolis effect to push surface ocean waters toward the coast and into San Francisco Bay, raising sea level an additional 10 to 12 inches (USGS, 1999). These storm-induced water level increases are generally short lived, with most Bay Area storm systems lasting approximately 3 to 7 days (May et al., 2019). If these storm-induced water level increases are removed from the long-term San Francisco Presidio (Presidio) tide gage data, the remaining data would better represent the tidal and oceanic factors noted above that drive variations in Bay water levels, including the factors that drive high tide flooding – the temporary inundation of low-lying inland areas during exceptionally high tides in the absence of an extreme storm event.

Source: Flickr User Dave R (CC BY-NC 2.0), February 17, 2016.

Figure J-22: Shoreline Overtopping near the Agricultural Building, San Francisco, CA

5.2 Observed Sea Level Trends

The Presidio tide gage recorded a rise in sea level of approximately 9 inches between 1854 and 2016 (Gonzalez et al., 2018). The USACE Sea Level Tracker provides historic mean sea level (MSL) 5-year and 19-year moving averages (**Figure J-23**). Both the 5-year and 19-year moving averages show an upward trend over time, overprinted by natural climate variability based on tidal, oceanic, and atmospheric cycles as described in **Section J-6.1**.



Source: (USACE, 2020)

Figure J-23: Sea Level Data and Projections for Presidio Tide Gage (9414290)

5.3 Projected Sea Level Trends

National and Regional Sea Level Rise Projections

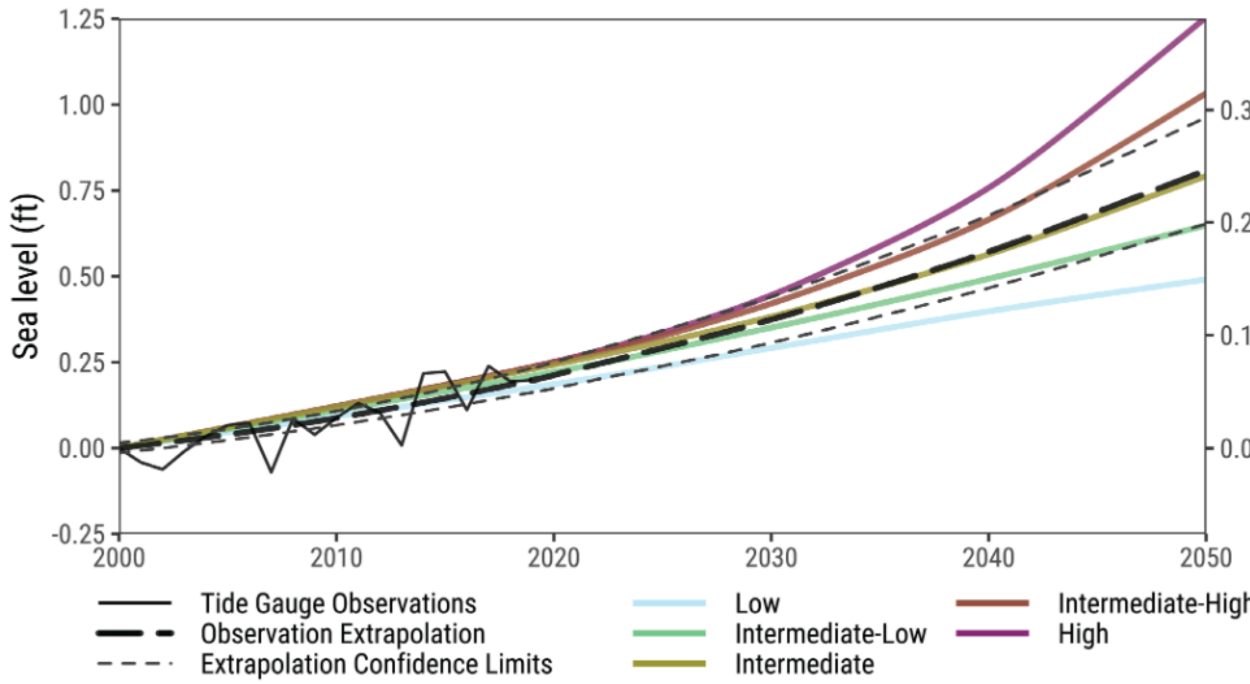
As described in **Section J-3.1**, IPCC produces regular updates to the state of scientific, technical, and socio-economic knowledge on climate change, its impacts, and future risks at a global scale. The most recent updates for sea level rise science were released in 2021 from Working Group 1 on the Physical Science Basis (IPCC, 2021). The Federal Sea Level Rise Task Force, comprised of subject matter experts from eight Federal agencies, including USACE, and academic experts from Rutgers University and Florida International University Institute of Environment relied on these findings to develop regional U.S. based sea level rise projections (Sweet et al., 2022).

A significant scientific contribution of Sweet et al. (2022) is detailed analysis of tide gage and satellite observations, and the extrapolation of this information from 2020 to 2050 (**Figure J-24**). This analysis and extrapolation is made possible due to the increased number and length of available tide gage and satellite altimetry records. Extrapolations beyond 2050 were not developed, as it is assumed that processes not fully represented in the observations from 1970 – 2020 could become dominant (Sweet et al., 2022).

Figure J-24 presents the observation extrapolation of mean sea level for California and southern Oregon (the Southwest Region in Sweet et al. (2022), which is not exactly aligned with the NCA regions), which highlights that the current trajectory of sea levels along the California coast is aligned with the 2022 Southwest Intermediate scenario.

Figure J-25 presents the USACE Low, Intermediate, and High SLC scenarios used within the SFWCFS relative to the 2022 SLC scenarios from Sweet et al. (2022). Future updates to the observation extrapolations by the Federal Sea Level Rise Task Force will be instrumental is assessment the climate trajectory post 2050.

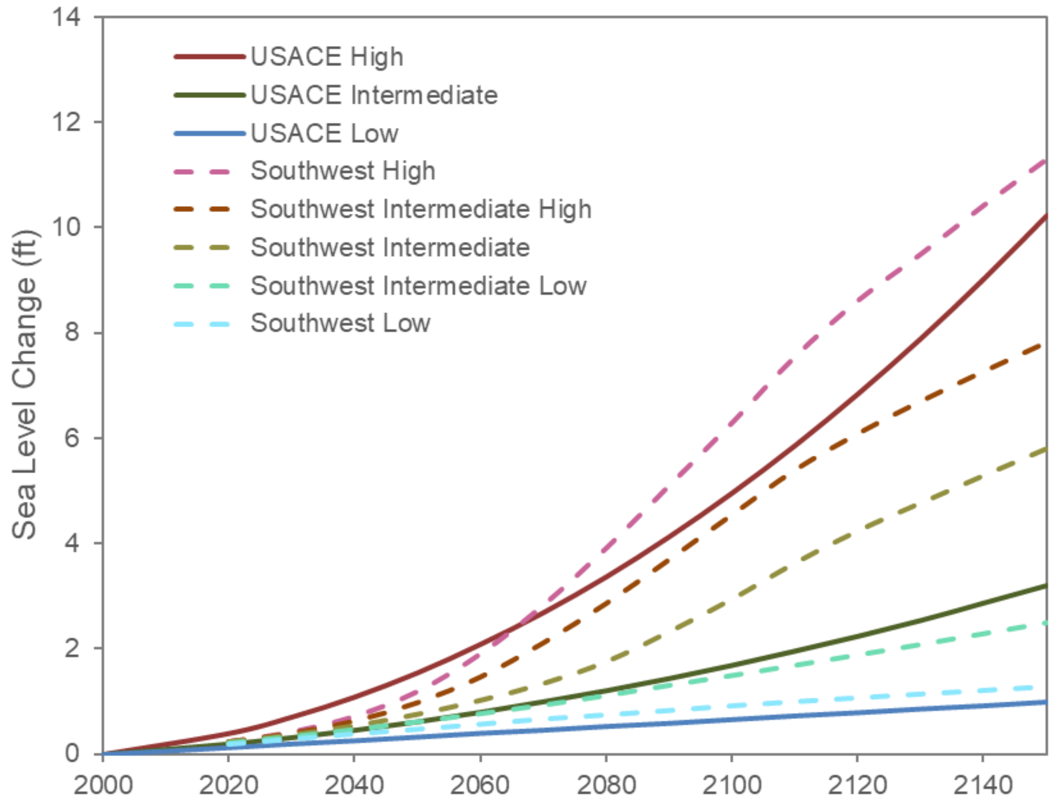
The USACE Low, Intermediate, and High SLC scenarios are based on IPCC (2007b, 2007a) and NRC (2012), as recommended in EP 1100-2-1 and ER 1100-2-8162 (USACE, 2019a, 2019b).



Source: Sweet et al. (2022), Collini et al. (2022)

Average annual water levels from tide gages are overlaid for context. The extrapolation confidence limits represent the 17th and 83rd percentile confidence interval for the observation-based extrapolations.

Figure J-24: Southwest Region (California and Southern Oregon) Sea Level Rise Scenarios and Observation-based Extrapolations



Source: (Sweet et al., 2022; USACE, 2020)

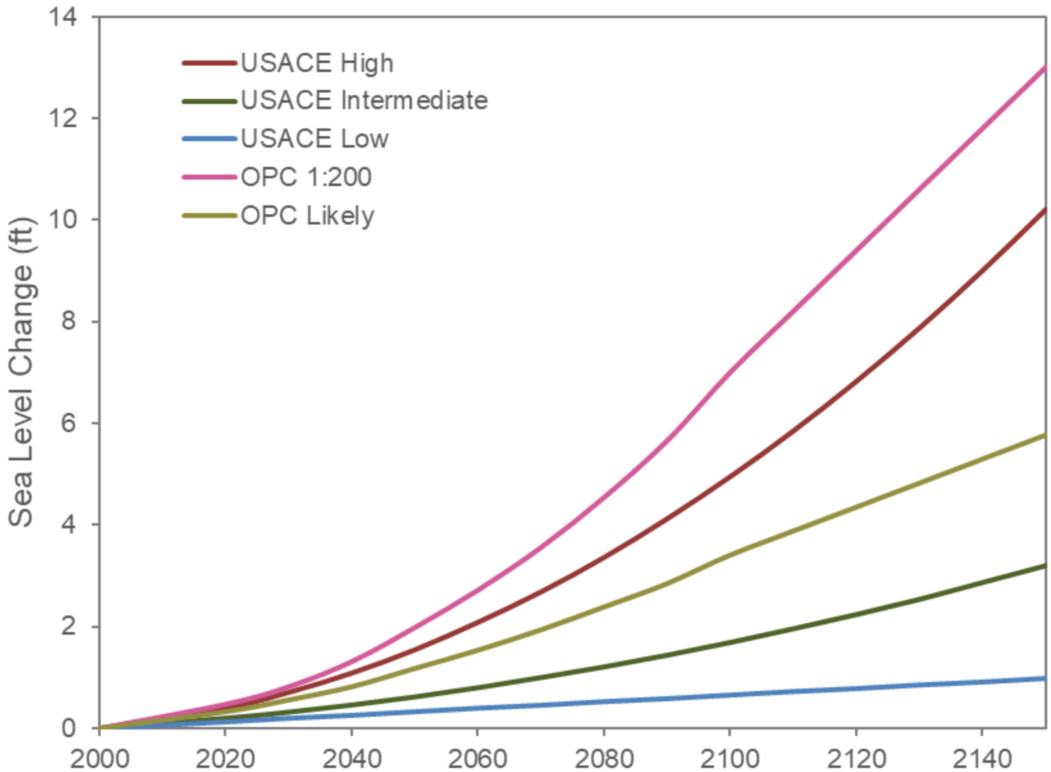
All projections are baselined to the year 2000 for the purposes of illustration. Inputs for analysis were developed in accordance with USACE requirements, detailed in the Coastal Storms Report within Appendix B.1.

Figure J-25: USACE and the Southwest Region Sea Level Rise Scenarios

5.3.1 State and Local Sea Level Rise Scenarios

The State of California adopted sea level rise scenarios in 2018 based on IPCC (2014) and the Federal companion U.S. based sea level rise scenarios in Sweet et al. (2017). The state is in the process of updating its guidance to reflect the recommendations in Sweet et al. (2022), with an anticipated release date in 2023.

The City of San Francisco adopted the state scenario, and recommended the use of the higher end values associated with RCP8.5 for projects directly along the shoreline (CPC, 2020). This approach led to the selection of the Ocean Protection Council (OPC) Likely values, which has a 17% chance of being exceeded based on a Bayesian probability analysis of the suite of global climate models (Kopp et al., 2014), and the 1-in-200 value, which has a 0.5% chance of being exceeded using the same probabilistic approach. **Figure J-26** presents the OPC Likely and 1-in-200 SLC scenarios alongside the three USACE SLC scenarios used within the SFWCFS.



Source: OPC & CNRA (2018), USACE (2020)

All projections are baselined to the year 2000 for the purposes of illustration. Inputs for analysis were developed in accordance with USACE requirements, detailed in the Coastal Storms Report within Appendix B.1.

Figure J-26: USACE and the State of California Sea Level Rise Scenarios

5.4 Shallow Groundwater Response to Sea Level Rise

The unconfined shallow groundwater table in low-lying coastal areas, such as San Francisco, will rise as sea levels rise (Befus et al., 2020; May, 2020; May et al., 2022; Plane et al., 2019). Therefore, it is important to understand the elevation (or depth below ground) of existing shallow groundwater table, as well as how it may rise as sea levels rise over the next century and beyond.

5.4.1 Local Observations

May et al. (2022) used multiple data sets to map the existing highest annual shallow groundwater table, which generally occurs in response to precipitation events, and its likely response to sea level rise in Alameda, Marin, San Francisco, and San Mateo Counties. The mapped highest annual shallow groundwater table was based on historical depth to groundwater measurements collected after wet winters between 2000 and 2020. This study did consider the high groundwater table elevations that occurred in response to back-to-back AR and ETC events that occurred in the winter of

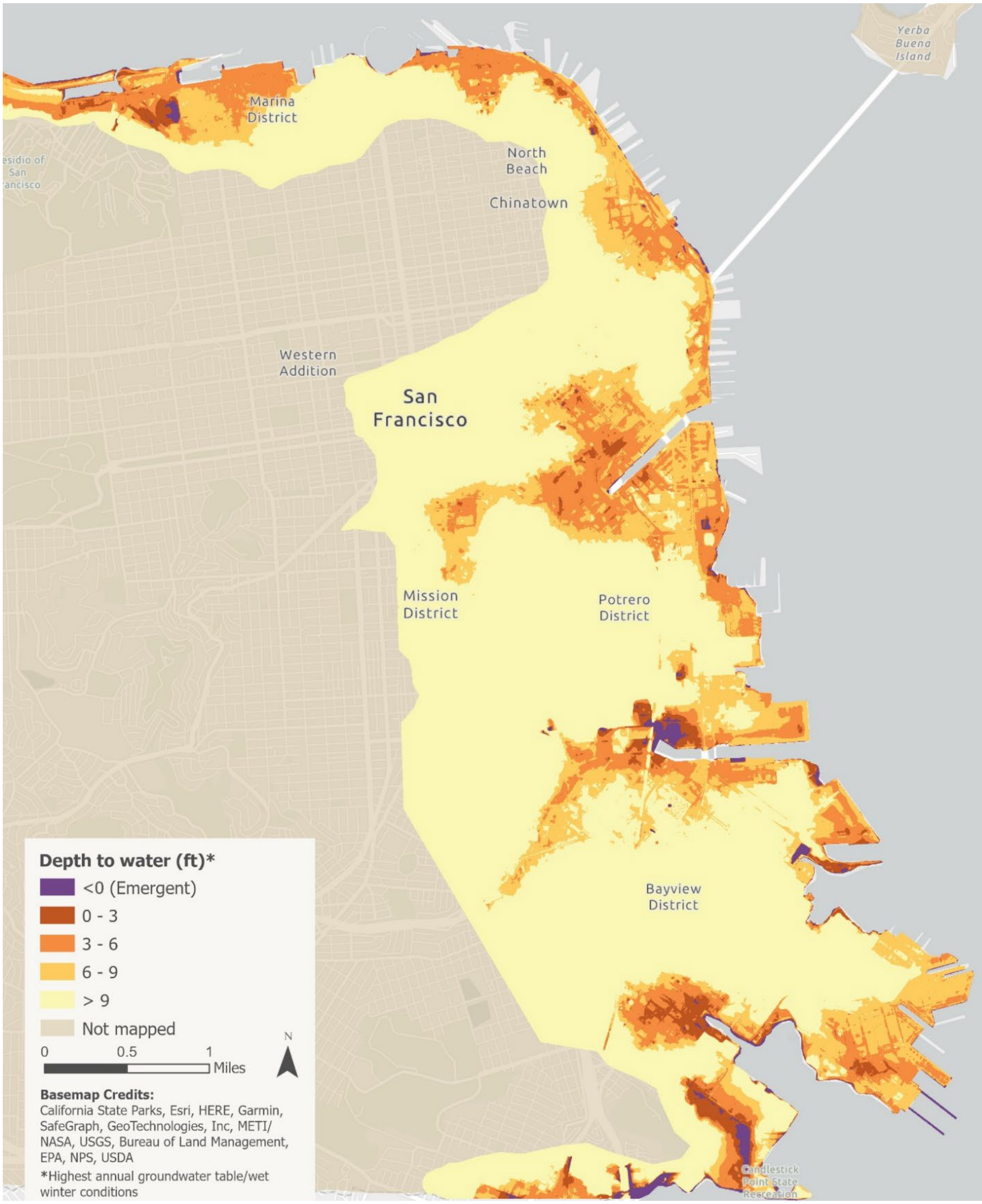
2022/2023 described in **Section J-4.4.3.2**; therefore, the results from this study may underestimate the highest of the existing highest annual shallow groundwater table.

Figure J-27 presents the existing highest annual shallow groundwater table for San Francisco. The areas with groundwater within zero to nine feet of the existing groundwater surface are generally areas that were filled for development between the 1800s and mid-1900s. This includes areas along the northern waterfront that were filled behind the Embarcadero seawall, and the floodplains, marshplains, and mudflats of the historic Islais and Mission Creeks.

5.4.2 Future Projections

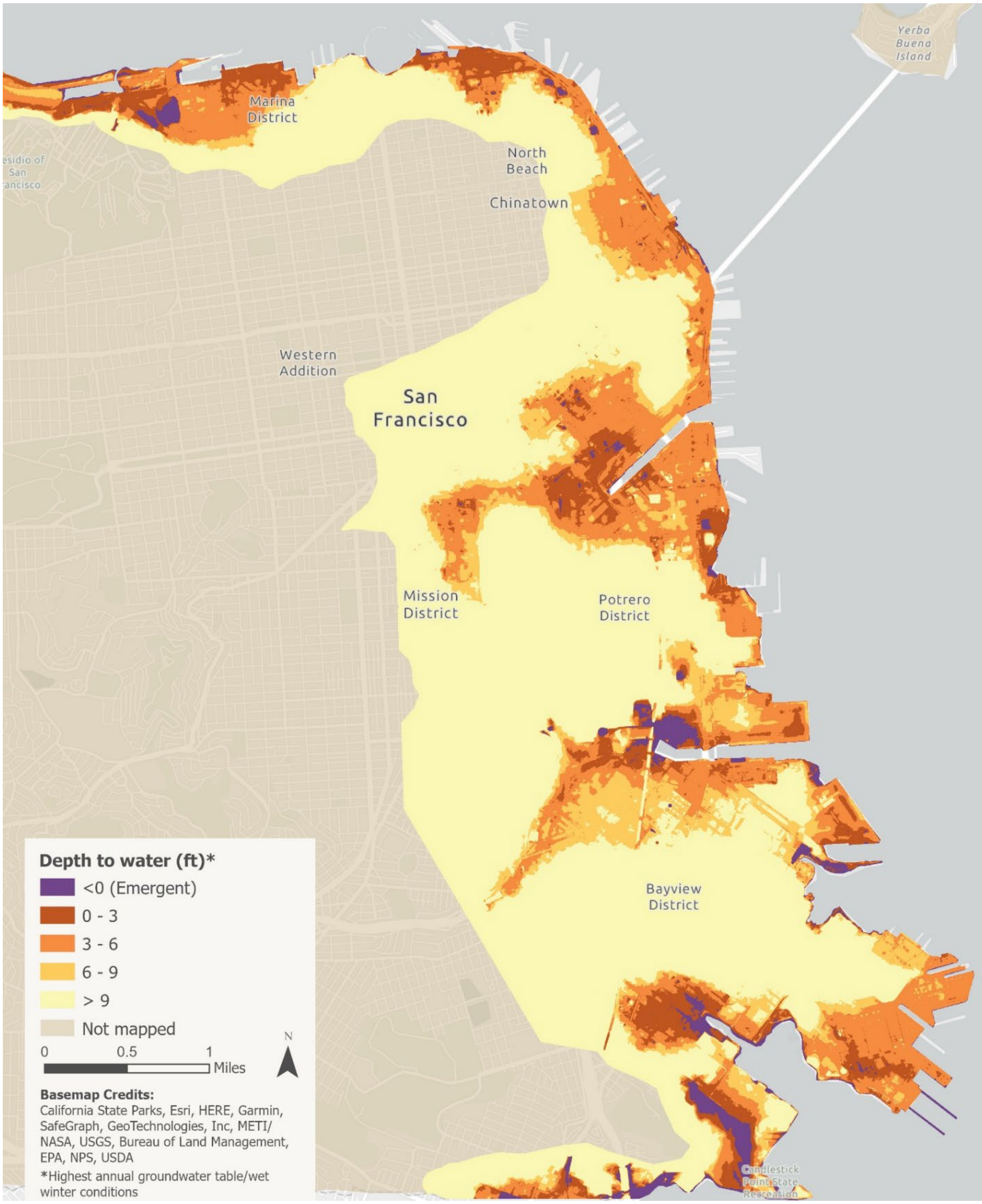
Figure J-28, **Figure J-29**, and **Figure J-30** represent the shallow groundwater surface with 24, 36-, and 108-inches of SLC. As sea levels rise, the groundwater surface will rise closer to the ground surface along the Bay shoreline. Areas shown in purple are likely to have emergent groundwater, poor drainage, and ponding during and after heavy rainfall events.

Figure J-30 presents the worst-case scenario, showing both areas that could be inundated with 108 inches of SLC by Bay floodwaters overtopping the shoreline, and inland areas that are likely to have emergent groundwater with 108 inches of SLR. With this scenario, all areas filled for development are projected to have emergent groundwater, and areas of emergent groundwater are likely to extend farther inland of areas directly inundated by Bay floodwaters.



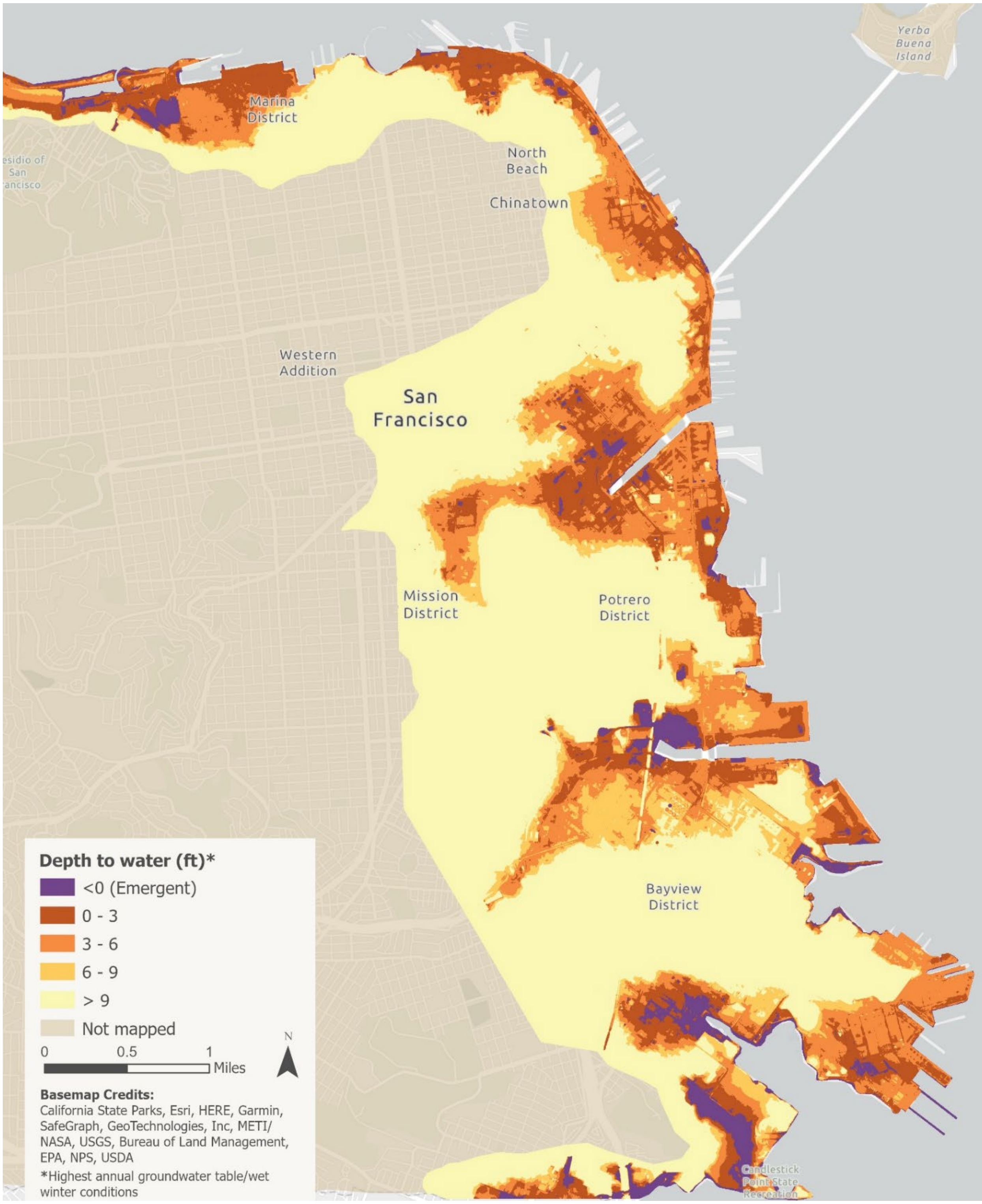
Source: May et al. (2022)

Figure J-27: Depth to Groundwater in San Francisco, Existing (2000 – 2020) Conditions



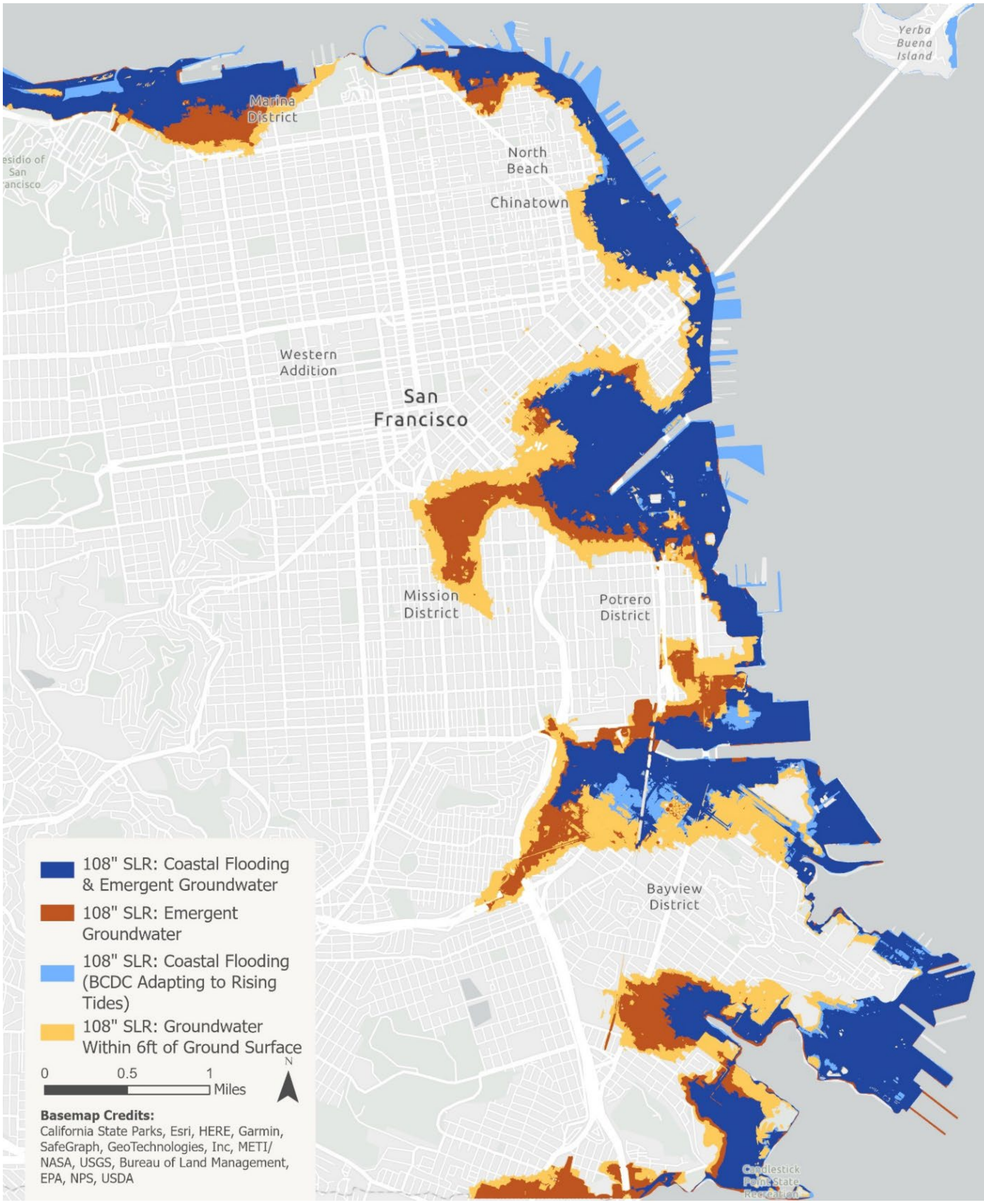
Source: May et al. (2022)

Figure J-28: Future Groundwater Conditions, 24 Inches of Sea Level Rise Scenario



Source: May et al. (2022)

Figure J-29: Future Groundwater Conditions, 36 Inches of Sea Level Rise Scenario



Source: May et al. (2022), Vandever et al. (2017)

Figure J-30: Future Groundwater Conditions, 108 Inches of Sea Level Rise Scenario

6. Inland Hydrology

6.1 Historic Creeks

San Francisco's two natural drainage channels, Mission Creek and Islais Creek were filled and highly modified over the past 150 years. Before European settlers arrived, Mission Creek ran from approximately Mission Dolores in the Mission District through what was once a much broader and extensive Mission Bay with about 500-acres of tidal marsh. The shoreline areas were occupied by the Sitlintac and Chutchui villages until the late 1850s.

Starting in the mid-1800s, Mission Creek was gradually converted to a channel and placed underground, and Mission Bay was filled to accommodate growth and development in the city and region. Much of today's Mission Bay neighborhood is served by a municipal separated storm sewer system (known as an MS4), such that stormwater runoff collects in a network of pipes separate from sanitary sewage and is discharged directly to the Bay.

Islais Creek is the largest watershed in San Francisco. Once a major freshwater source for the Ohlone and later Western settlers, the natural creek ran from the upper reaches of Glen Canyon down to the Bay where the remnant Islais Creek channel is today. Debris from the 1906 earthquake was used to fill much of the creek's floodplains and marshplains. Today, most of the watershed flows are conveyed within the combined sewer system network, with large culverts running beneath Alemany Boulevard.

6.2 Watersheds

USACE maintains a Vulnerability Assessment Tool (VAT) that provides a comparison of the climate change vulnerability for a specific watershed relative to other watersheds across the continental U.S. (USACE, 2016). The VAT facilitates a screening level assessment of how vulnerable a given watershed is to the impacts of climate change and assigns a climate vulnerability score to a range of USACE sectors (e.g., flood risk reduction, ecosystem restoration, recreation, navigation, water supply, and emergency management). The assessment is completed for two 30-year epochs of time centered at 2050 (2035 – 2064) and 2085 (2070 – 2099). Within each future epoch the global circulation models (GCMs) are sorted by cumulative runoff projections and divided into two equal-sized groups. The group with the smaller cumulative runoff projections are used to calculate vulnerability scores for the "Dry" scenarios, and the group with the larger cumulative runoff projections are used for the "Wet" scenarios. In combination, the Wet and Dry scenarios represent the range in current climate projections, reflective of the inherent uncertainties of climate projections.

Results of the VAT assessment are provided in **Table J-6**, **Table J-7**, and **Table J-8**. **Table J-6** shows the vulnerability of selected USACE business sectors in the San Francisco HUC. Vulnerability to climate change is quantified using the multi-criteria Weighted Ordered Weighted Average (WOWA) procedure. While all WOWA scores range between 0 and 100, the scores are best interpreted as a relative scale of vulnerability versus an absolute measurement. Thus, for a given USACE business sector, comparing WOWA scores between epochs convey changing vulnerability. However, the WOWA scores cannot be compared between two USACE business sectors, due to differences in the underlying indicator values, their definitions, and assigned weights in WOWA calculations.

Overall, the WOWA scores show that there is relatively high vulnerability in the San Francisco Bay Watershed in each of the USACE business sectors in each of the five Epoch-Scenarios. The exception is the Flood Risk Reduction business sector. The WOWA score is near median value for US watersheds for the Base, Dry 2050, and Dry 2085 scenarios. However, the vulnerability increases by 27% and 33% for the Wet 2050 and Wet 2085 scenarios, respectively. This result is notable as the indicators for the Flood Risk Reduction business sector linked to inland flooding versus coastal flood hazards.

To gain insight on the changes on the Flood Risk Reduction business sector, corresponding data on the constituent indicators have been examined. **Table J-7** and **Table J-8** present information on the constituent indicators used to represent watershed vulnerability related to USACE Flood Risk Reduction Business sector and changes in these indicators between selected scenarios, respectively. Specifically, in **Table J-8**, the changes in WOWA component values are reported for each scenario relative to that of the Base scenario. The vulnerability increases for the Wet 2050 and Wet 2085 scenarios correspond primarily to relative increases in flood magnification indicator values (568C and 568L).

Table J-6: Projected Vulnerability of San Francisco Bay HUC-4 Watershed with Respect Various USACE Sectors

	Base	2050 Dry		2050 Wet		2085 Dry		2085 Wet	
USACE Business Sector	WOWA Score	WOWA Score	% increase of Base	WOWA Score	% increase of Base	WOWA Score	% increase of Base	WOWA Score	% increase of Base
Ecosystem Restoration	74.7	75.7	1%	77.3	3%	76.2	2%	79.1	6%
Emergency Management	68.6	66.0	-4%	66.4	-3%	65.0	-5%	67.1	-2%
Flood Risk Reduction	49.2	52.1	6%	62.4	27%	51.0	4%	65.2	33%
Navigation	73.8	74.8	1%	79.2	7%	74.9	2%	81.0	10%
Recreation	72.2	73.3	2%	76.3	6%	74.4	3%	77.8	8%
Regulatory	75.9	77.1	2%	78.1	3%	77.3	2%	78.9	4%

Source: USACE (2016)

Table J-7: Component Indicators for Vulnerability Score (WOWA): Flood Risk Reduction Sector

Indicator Short Name	Indicator Name	Indicator Description	Data Sources	Projection	Last Updated
568C FLOOD MAGNIFICATION	Flood magnification factor (cumulative)	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM(s) output	Sep-14
568L FLOOD MAGNIFICATION	Flood magnification factor (local)	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM(s) output	Sep-14
590 URBAN 500YRFLOODPLAIN AREA	Acres of urban area within 500-year floodplain	Acres of urban area within the 500-year floodplain.	(1) FEMA - 500 year Flood Zones (2) EPA - Integrated Climate and Land Use Scenarios (ICLUS)	Using ICLUS data	Jan-11
175C ANNUAL COV	Annual CV of unregulated runoff (cumulative)	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM(s) output	Sep-14
277 RUNOFF PRECIP	% change in runoff divided by % change in precipitation	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014) using method of Sankarasubramanian and Vogel 2001 WRR 37(6)1771-1781	Using GCM(s) output	Feb-15
571C 10PERC EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; cumulative)	Flood runoff: monthly runoff that is exceeded 10% of the time, including upstream	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM(s) output	Sep-14

Indicator Short Name	Indicator Name	Indicator Description	Data Sources	Projection	Last Updated
		freshwater inputs (cumulative).			
571L 10PERC EXCEEDANCE	Flood flow (monthly flow exceeded 10% of time; local)	Flood runoff: monthly runoff that is exceeded 10% of the time, excluding upstream freshwater inputs (local).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM(s) output	Sep-14

Source: USACE (2016)

Table J-8: Component of Flood Risk Reduction Indicators on Vulnerability Score (San Francisco Bay HUC-4 Watershed)

Indicator	Base	2050 Dry		2050 Wet		2085 Dry		2085 Wet	
	WOWA Score	WOWA Score	% increase of Base	WOWA Score	% increase of Base	WOWA Score	% increase of Base	WOWA Score	% increase of Base
277 RUNOFF PRECIP	4.3	4.6	8%	3.0	-30%	4.6	9%	3.0	-29%
568L FLOOD MAGNIFICATION	2.7	2.7	-1%	15.1	460%	2.8	5%	15.9	490%
568C FLOOD MAGNIFICATION	12.6	8.1	-35%	29.8	137%	13.2	5%	31.4	149%
590 URBAN 500YRFLOODPLAIN AREA	21.8	22.8	5%	9.3	-57%	22.0	1%	9.3	-57%
175C ANNUAL COV	7.8	13.9	79%	5.2	-33%	8.3	7%	5.6	-29%
TOTALS	49.2	52.1	6%	62.4	27%	51.0	4%	65.2	33%

Source: USACE (2016)

6.3 Urban Stormwater

The San Francisco Public Utilities Commission (SFPUC) operates and maintains a combined sewer system to manage wastewater and stormwater flows throughout most of San Francisco. Major infrastructure in the network includes three treatment plants, 26 pump stations, 1,900 miles of pipe, and 36 combined sewer discharge outfalls. The major system components and the current watersheds as delineated by SFPUC are shown in **Figure J-31.** The combined sewer system collects both wastewater and stormwater in the same network of pipes. During dry weather, the wastewater flows are treated at the Southeast Treatment Plant near Islais Creek and discharged to the Bay, and the Oceanside Plant near Ocean Beach and discharges to the Pacific Ocean. The Southeast Treatment plant serves approximately two-thirds of the city. During wet weather, a third treatment (the Northpoint Wet Weather Facility near Pier 39) is operated to provide additional treatment capacity for the combined wastewater and stormwater flows. During large storms, the volume of stormwater can exceed the capacity of the system resulting in combined sewer outflows from one or more of the 36 combined sewer discharge outfalls (**Figure J-32**). As sea levels rise, the discharge capacity of the combined sewer discharge outfalls will decrease, and may result in increased inland stormwater flooding (CCSF, 2020; SFPUC, 2015).

Figure J-31: San Francisco Watersheds and Major Stormwater and Wastewater Transport and Treatment Facilities.

Source: (SFPUC, 2020)

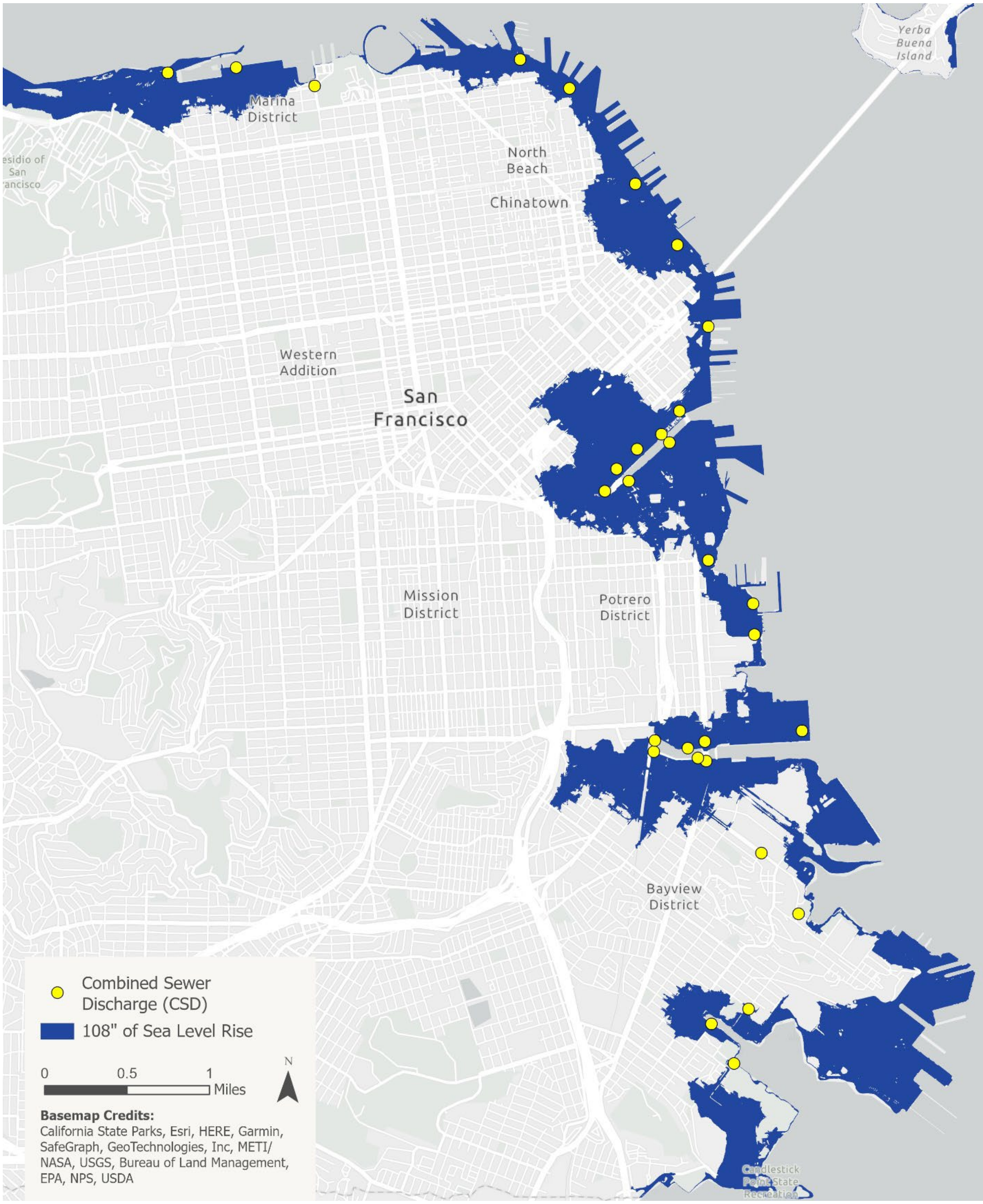


Figure J-32: Location of Combined Sewer Outfalls on the Bay Shoreline

Source: CCSF (2020), Vandever et al. (2017)

7. References

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