SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CALIFORNIA

APPENDIX J
CHANGING HYDROLOGIC AND METEOROLOGICAL CONDITIONS

JULY 2026

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
°F	degree(s) Fahrenheit
AR	atmospheric river
Bay	San Francisco Bay
Bay Area	San Francisco Bay Area
BCSD	Bias Correction and Spatial Disaggregation
CCSF	City and County of San Francisco
CFRM	Coastal Flood Risk Management
CMIP5	Coupled Model Intercomparison Project Phase 5
CO-OPS	Center for Operational Oceanographic Products and Services
CW3E	Center for Western Weather and Water Extremes
ECB	Engineering and Construction Bulletin
ENSO	El Niño Southern Oscillation
EP	Engineer Pamphlet
EPA	U.S. Environmental Protection Agency
ER	Engineer Regulation
ETC	extratropical cyclone
FEMA	Federal Emergency Management Agency
GCM	global circulation model
GHCN	Global Historical Climatology Network
HUC	Hydrologic Unit Code
ICLUS	Integrated Climate and Land Use Scenario

Acronym	Definition
IDF	intensity, duration, and frequency
IPCC	Intergovernmental Panel on Climate Change
IVT	Integrated Water Vapor Transport
kg/m/s	kilogram(s) per meter per second
km	kilometer(s)
MS4	municipal separated storm sewer system
MSL	mean sea level
NCA	National Climate Assessment
NOAA	National Oceanic and Atmospheric Administration
OPC	Ocean Protection Council
PDO	Pacific Decadal Oscillation
RCP	Representative Concentration Pathway
RSLC	relative sea level change
SFPUC	San Francisco Public Utilities Commission
SFWCFS	San Francisco Waterfront Coastal Flood Study
SSP	Shared Socioeconomic Pathway
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VAT	Vulnerability Assessment Tool
VIC	Variable Infiltration Capacity
WMO	World Meteorological Organization
WOWA	Weighted Ordered Weighted Average
WRR	Water Resources Research

1.0 Introduction

The U.S. 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 study are very sensitive to changes in climate and weather. The assumptions of stationary climatic baselines and a fixed range of natural variability, as documented 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 changing meteorological conditions and to continue providing authorized performance despite changing conditions.

1.1 Purpose

USACE maintains guidance and regulations for incorporating changing hydrologic and meteorological condition information in coastal and inland hydrologic analyses in accordance with USACE policy. The objective is to enhance preparedness and resilience by incorporating relevant information about observed and expected changing conditions. For example, the following resources provide guidance for incorporating relative sea level change (RSLC) in USACE Civil Works activities:

- *Engineer Pamphlet (EP) 1100-2-1, Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation* (USACE 2019a)
- *Engineering Regulations (ER) 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs* (USACE 2019b)
- *Sea-Level Change Curve Calculator* (USACE 2020)

In addition, if RSLC will affect inland project hydrology, *Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects,* requires RSLC analysis for the inland hydrology analyses (USACE 2022).

The goal of this appendix is to describe the observed present and possible future threats, vulnerabilities, and impacts of changing hydrologic and meteorological conditions specific to the San Francisco Waterfront Coastal Flood Study (SFWCFS). This includes consideration of both past (observed) changes, as well as potential future (projected) changes to relevant meteorological and hydrologic variables. Projections of specific physical 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 drivers and projections relevant to the 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.

2.0 Climate Overview

San Francisco is situated in the mid-latitudes between the 37^{th} and 38^{th} northern 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. Based on the historical record, about 75% of the annual average rainfall in the San Francisco Bay Area (Bay Area) occurs between November and March (Figure J-2), with drought conditions prevailing each summer, based on historical records.

San Francisco's historical 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 historical periods of record among all recording stations in the country.

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

2.1 Temperature

Temperature data from 1920 to the present are available for the San Francisco downtown weather station. Temperatures over the 100-year historical period have ranged from a minimum of 27 degrees Fahrenheit (°F) to a maximum of 106°F. As of 2025, 2017 was San Francisco's hottest summer on record.

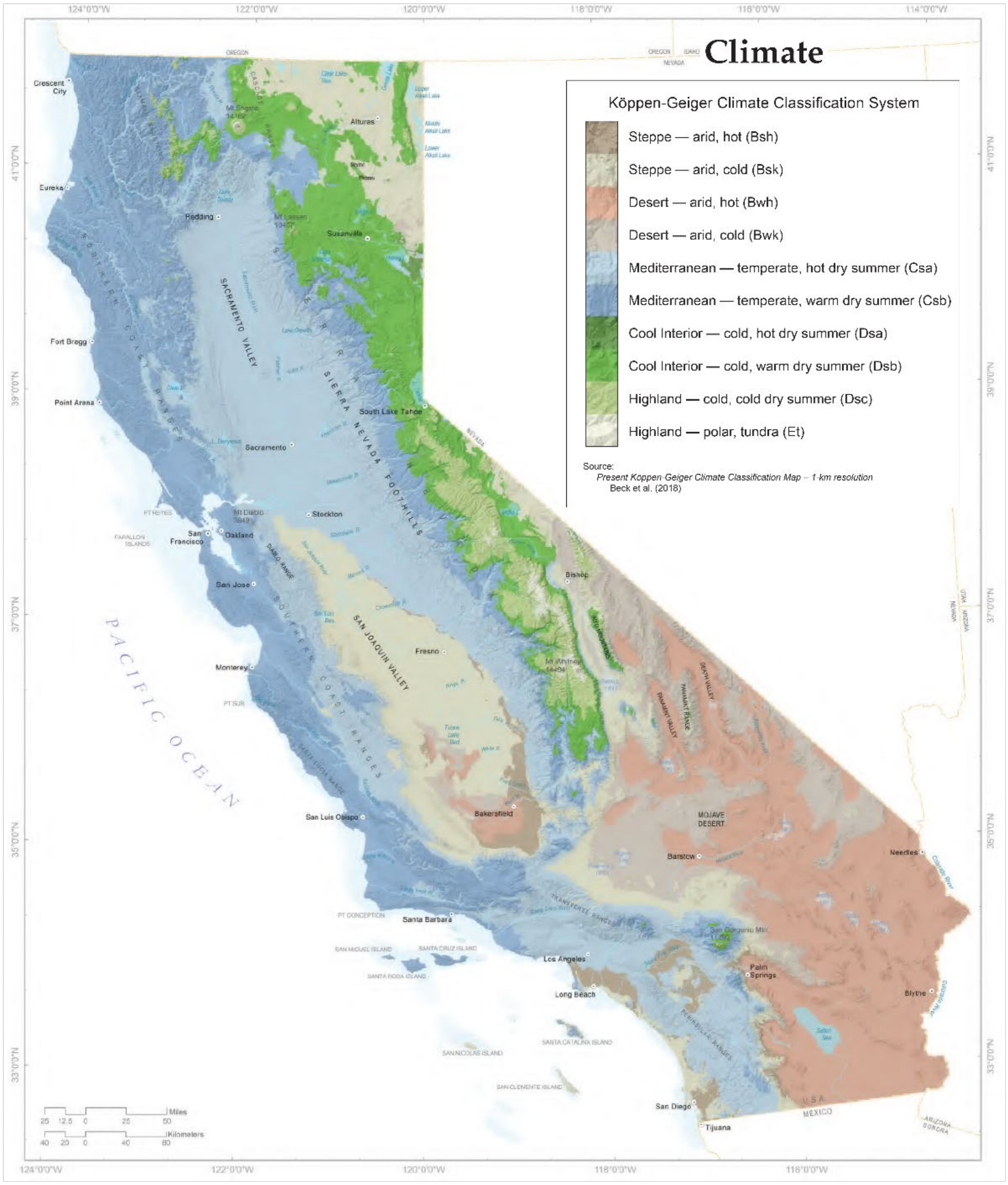
Average temperatures calculated from 100 years of data from San Francisco downtown weather station are presented in **Table J-1**, and **Figure J-2** shows a climograph of precipitation and temperature norms for National Oceanic and Atmospheric Administration's (NOAA's) most recent averaging period (1981-2010). 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°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

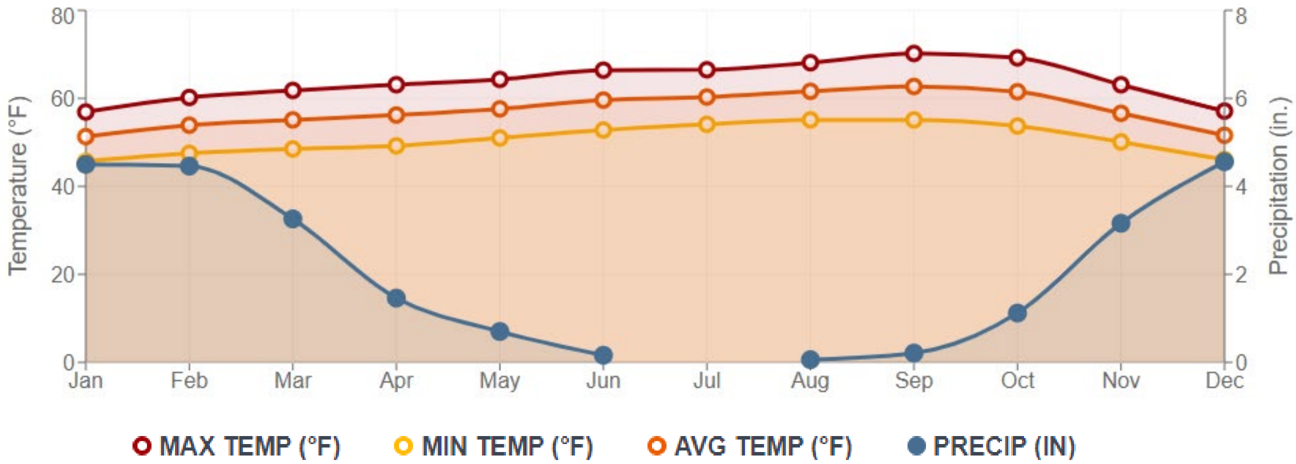
Value	Temperature
Average annual maximum	93°F

Source: (NCEI 2023c) Weather Station GHCND: USW00023272



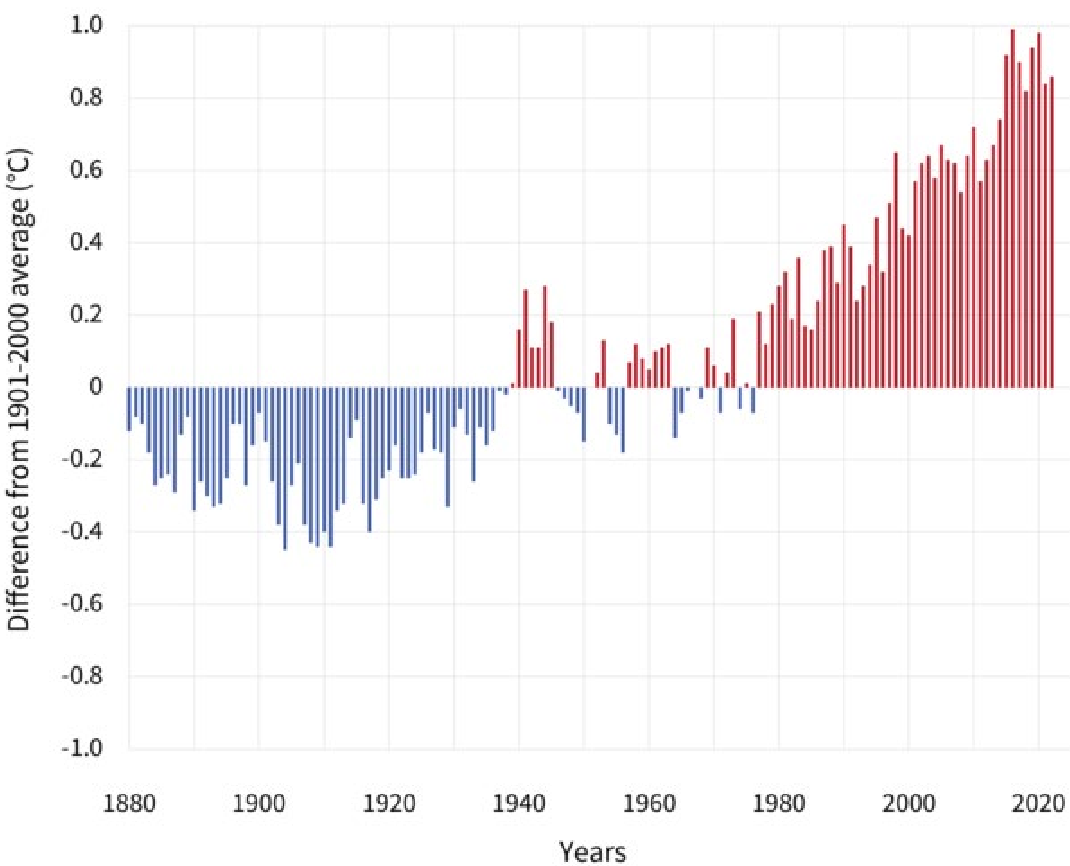
Source: (California Department of Fish and Game 2003)

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



Source: (NCEI 2023)

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



Source: (NOAA 2023b)
Annual 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

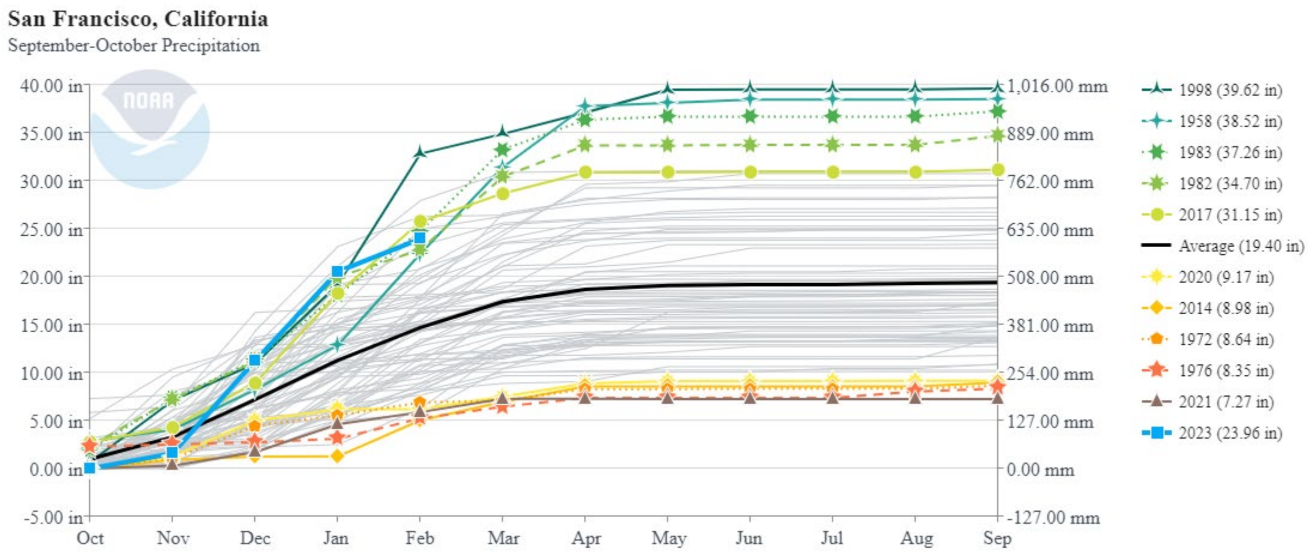
Precipitation data from 1920 to the present are available for the San Francisco downtown weather station. The Bay Area's cumulative annual precipitation amounts vary widely, with an average annual precipitation of about 22 inches (**Figure J-4)**. Variability from year to year is impacted by the El Niño 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 so far 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.

A high-level rainfall-tide analysis was completed as part of the interior drainage assessment. The analysis was done primarily to determine the dependence of rainfall and tidal conditions for the study area. This was done by comparing rainfall totals over various time intervals to the peak tidal elevation for that day. The two variables were found to be independent of each other.

Coincident timing of the rainfall and peak tidal conditions was also evaluated. It was found that large rainfall events can occur near a higher tide for the day; however, there were also cases when the peak rainfall occurred near the lower tide for the day, as well. The impacts of compound flooding and consecutive events were not assessed.

The analysis was done looking at large daily events because runoff travels quickly through the city. For more information on the rainfall-tide analysis completed for the interior drainage assessment, as well as the San Francisco Bay (Bay) conditions evaluated and sensitivity to those conditions, see *Annex B.1.4 Hydrology and Hydraulics Interior Drainage Analysis*. Due to the complexity of the city scape and combined sewer system, these more detailed analyses may be required during the design phase.



Source: (NOAA 2023b)

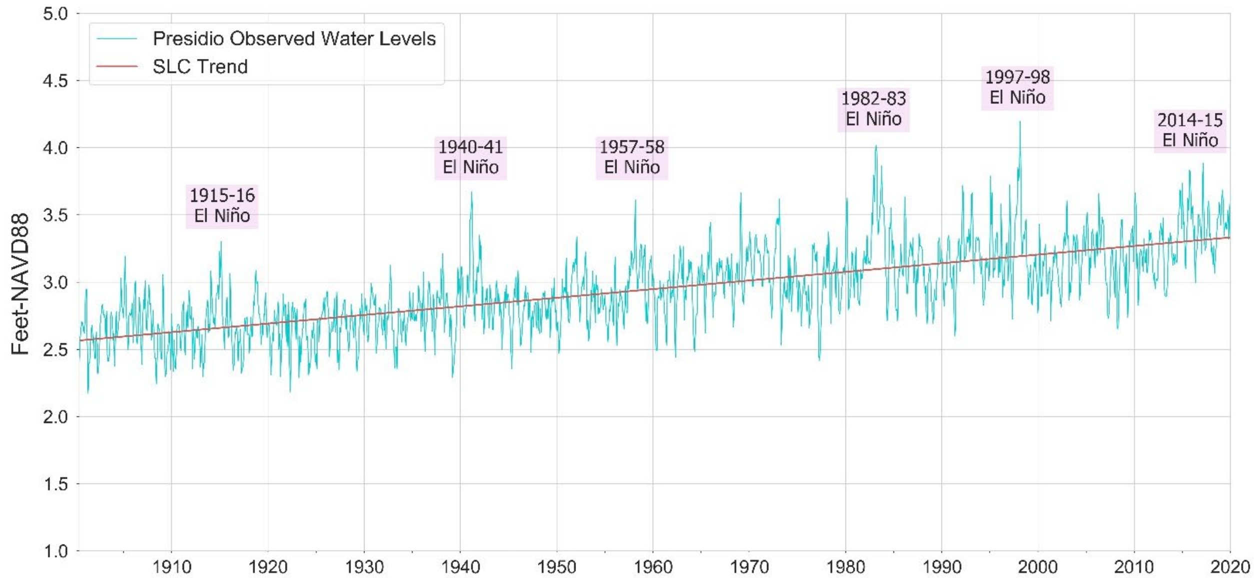
The five highest and lowest water year totals and the year-to-date total through 2023 are highlighted in shades of green and yellow/orange, respectively.

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

2.3 San Francisco Bay Water Levels

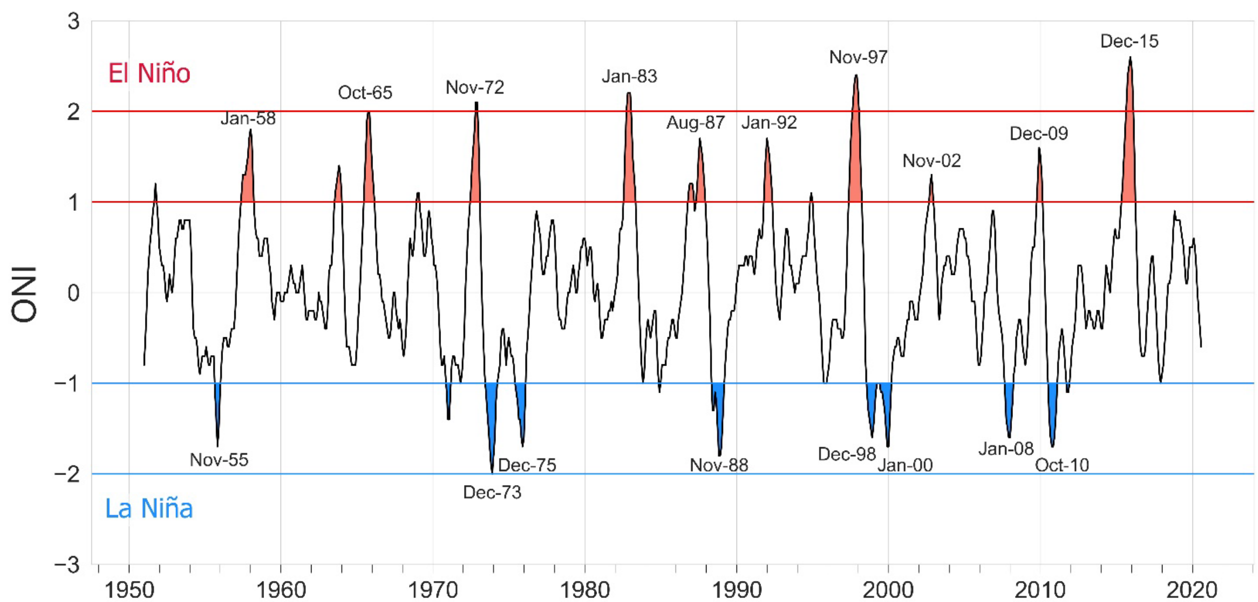
The Presidio tide gage, located along the San Francisco shoreline near the Golden Gate Bridge, was established in 1853. The tide gate represents the longest running series of tidal observations in the Americas. The tides are mixed semidiurnal, with two highs and two lows of unequal heights observed each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

Figure J-5 presents the long-term time series of Presidio water level observations, relative to mean sea level (MSL). An increasing trend is observed over time, associated with RSLC. The highest 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 Niño 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

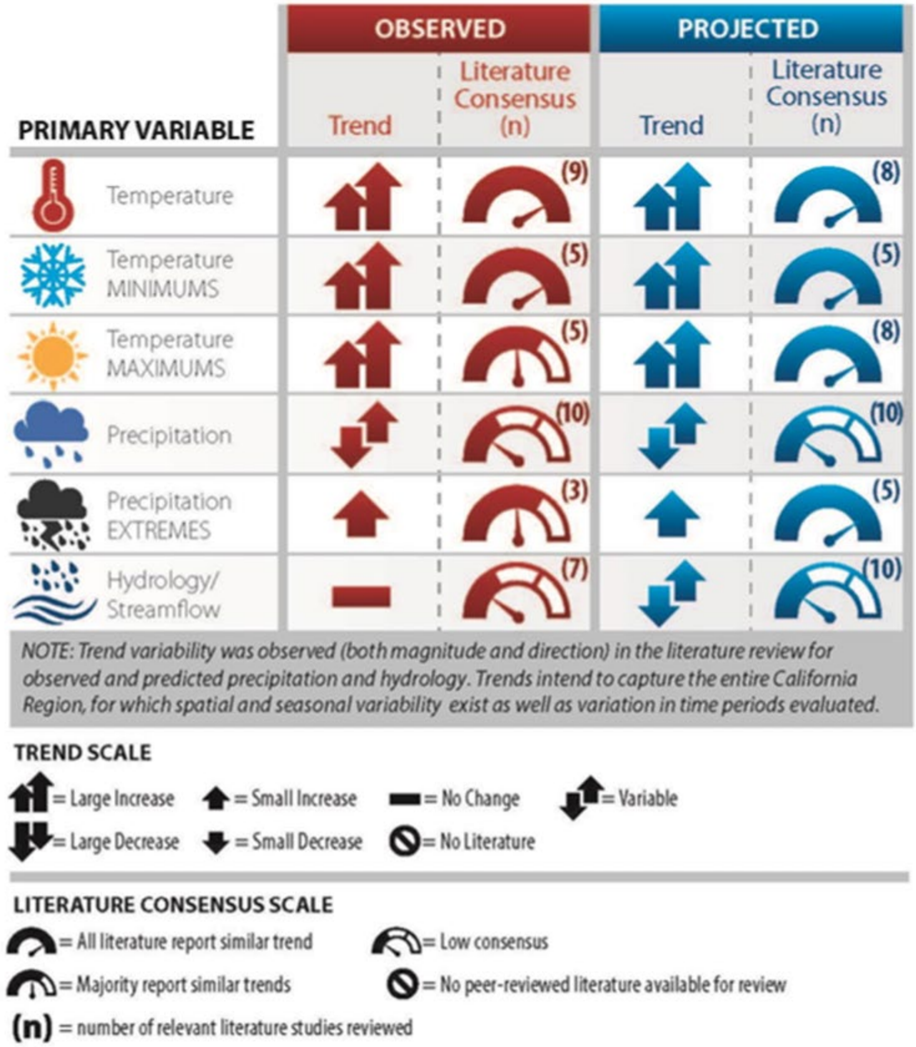
There are two large watersheds in the study area: the Islais Creek and Mission Creek watersheds. However, both creeks were placed underground, and their associated floodplains and marsh and mudflat areas near the creek mouths were filled for development in the 1800s and 1900s. Both creeks retain a remnant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

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 Unit Codes (HUCs) for California Region 18. The SFWCFS study area is located within the San Francisco Bay HUC 1805. For California Region 18, there is substantial trend variability in both magnitude and direction related to both observed and projected future annual precipitation and streamflow **(Figure J-8**).

Source: (USACE 2015)

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



Source: (USACE 2015)

Figure J-8: Observed and Projected Climate Trends

3.0 Data Sources

3.1 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 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 more than 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.

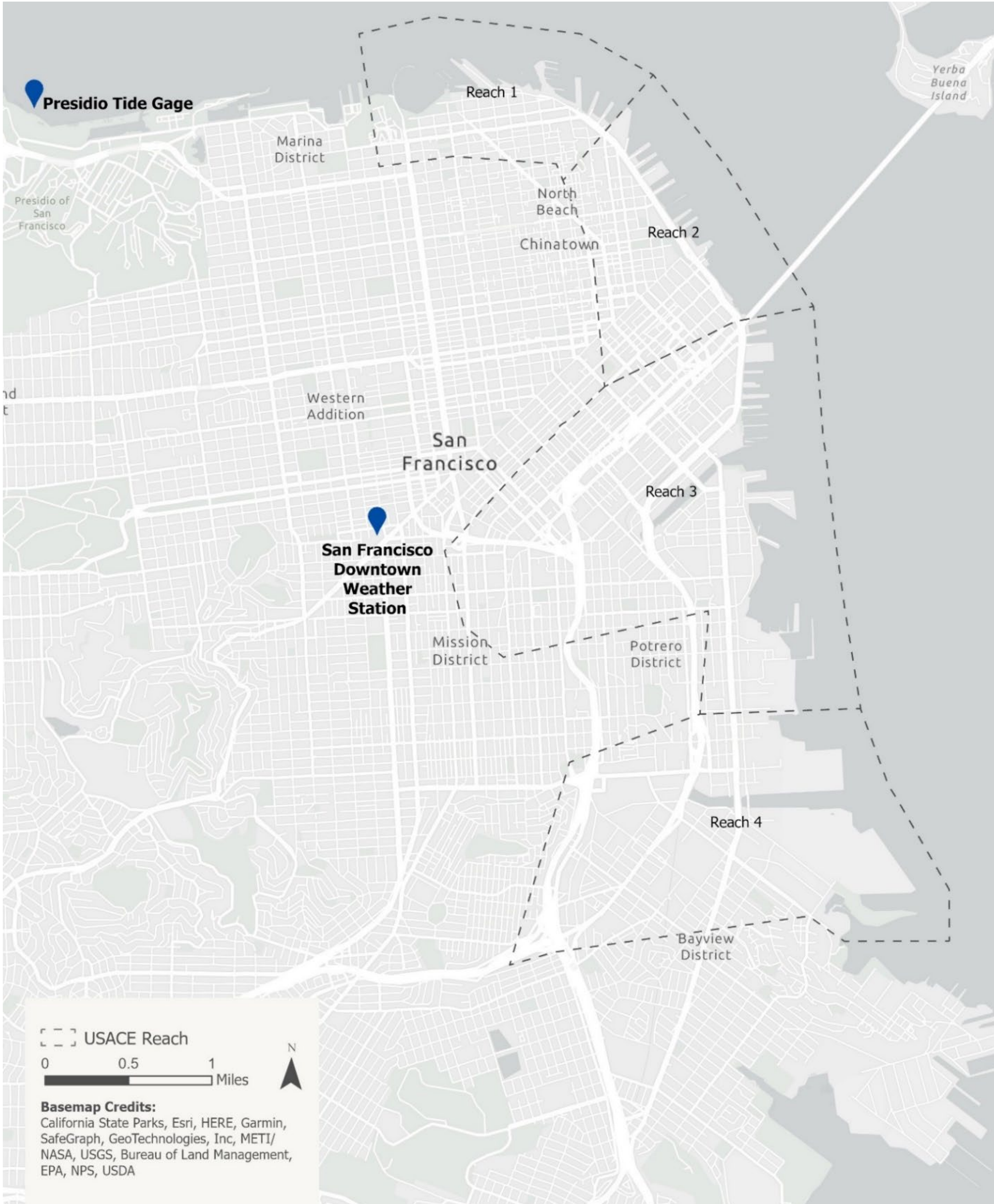


Figure J-9: NOAA Presidio Tide Gage and GHCN San Francisco Downtown Weather Station

3.2 San Francisco Downtown Weather Station

The San Francisco downtown weather station is in Hayes Valley near the city center, with more than 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	Ongoing
Data Coverage	100%

Source: (NCEI 2020)

° = degree(s)

ID = identification

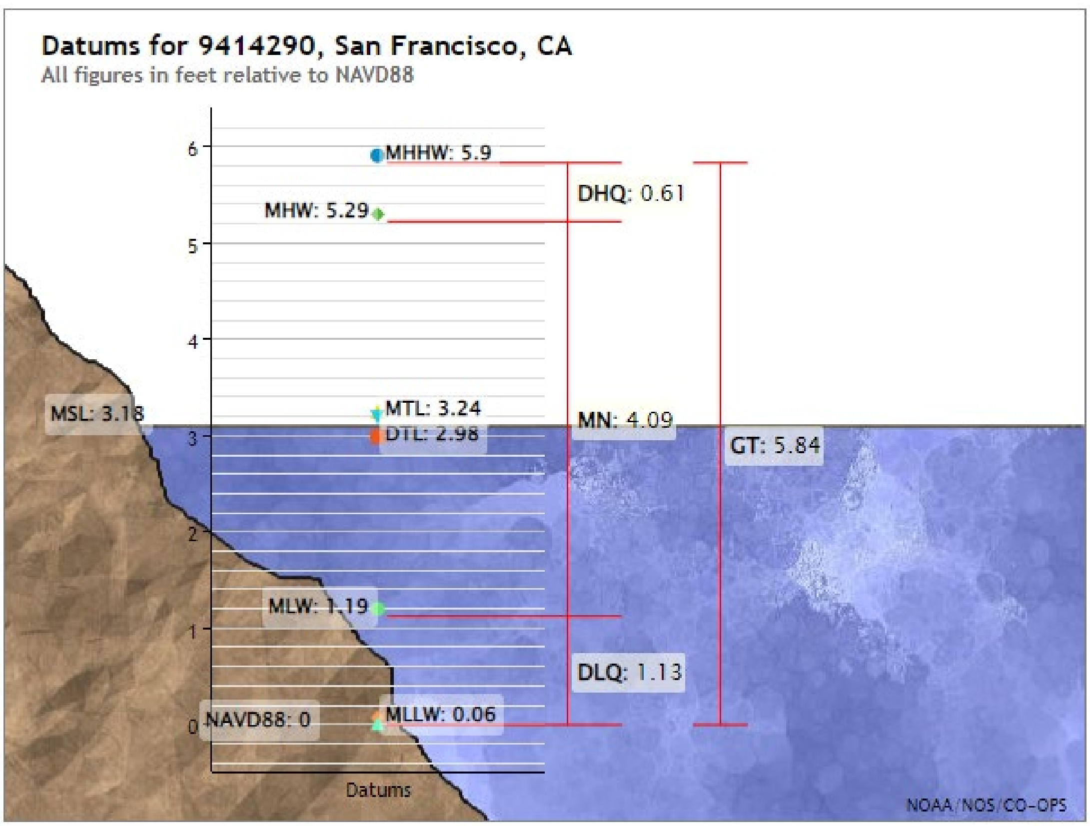
3.3 Presidio Tide Gage

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 are 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 *Annex B.1.1 Coastal Extreme Water Levels and High Tide Flooding*.

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 MHHW)	2.82 feet Jan 27, 1983
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 2020)



Source: (NOAA 2023a)

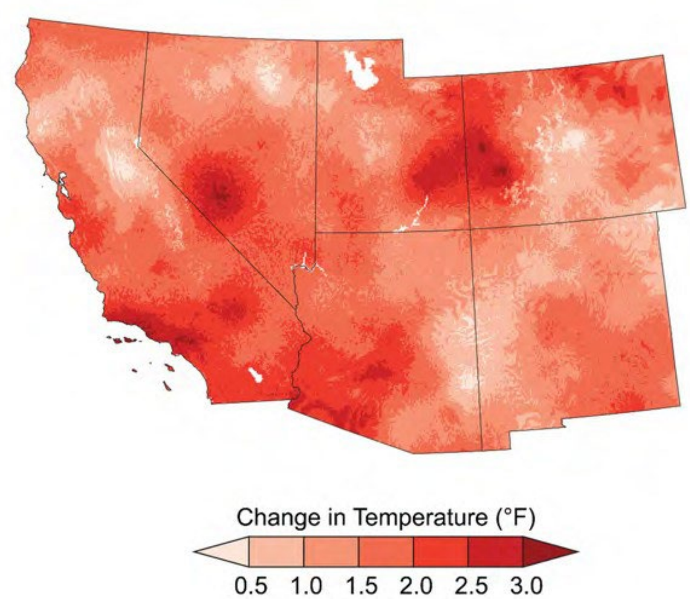
Figure J-10: Presidio Tide Gage Datums

4.0 Temperature

In addition to being a main indicator of changing conditions, air temperature is an important 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°F during the 20th century (that is, from 1900 to 2000). The largest increases are observed in the Southwest (including California), Alaska, and the Northern Great Plains National Climate Assessment (NCA) regions. The Southwest NCA region experienced an increase in annual average, minimum, and maximum temperatures of 1.6°F between historical 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. From 1970 to 2020, average annual temperatures have increased by 2.9°F (NCEI 2020).

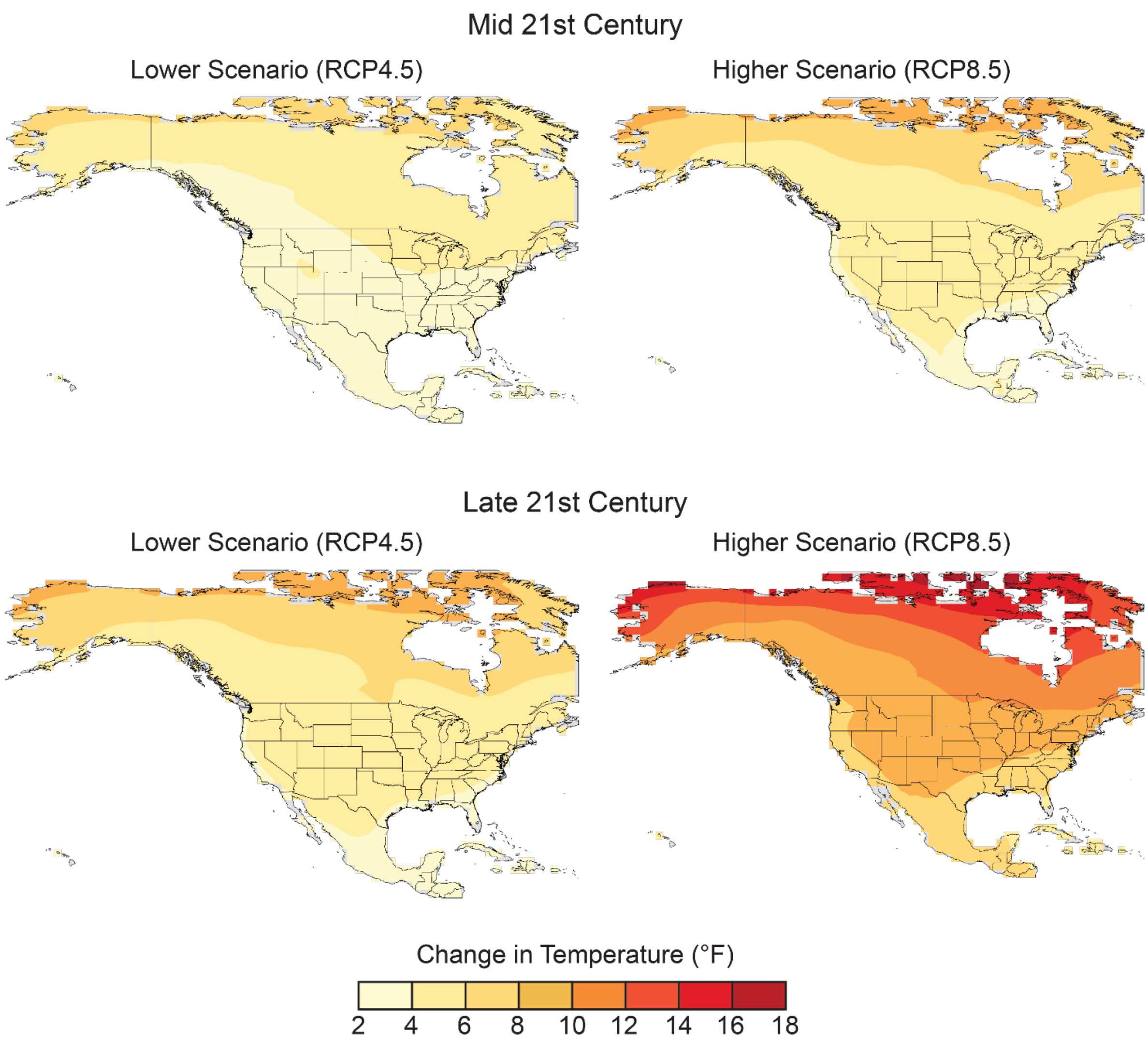


Source: (Gonzalez et al. 2018)

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 (for example, 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 nonstationarity 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 RCP8.5 Precipitation

5.0 Precipitation

This section discusses precipitation as relevant to the study area.

5.1 Overview of Bay Area Storms

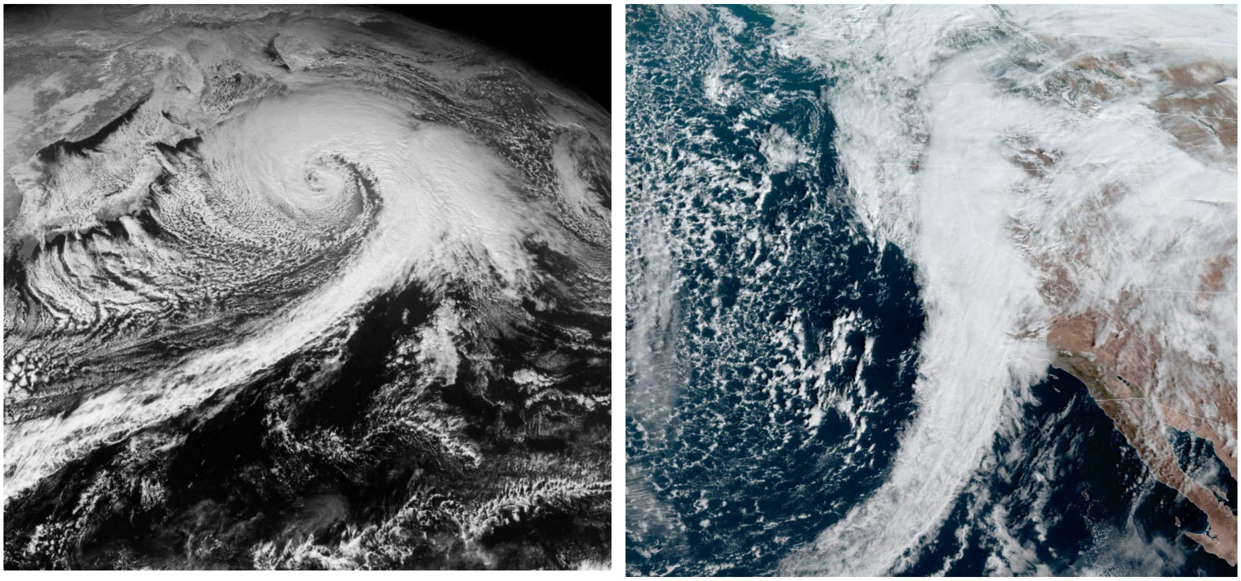
The Bay Area has a Mediterranean climate, with about 75% of its annual average rainfall between November and March, and little to no rainfall occurring in the summer (NCEI 2023). This region oscillates between extremes, with periods of below average annual rainfall (for example, drought conditions) interspersed 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.
- ***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 ETCs. 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 Pacific coast are either ETCs or ARs combined with ETCs (Zhang et al. 2019). Changing meteorological conditions are projected to increase the intensity of these storms by up to 37% by 2100 (Patricola et al. 2022).

A joint probability analysis between heavy precipitation and high coastal water levels was not completed for this feasibility study. In addition, the impacts of compound flooding and consecutive events were not assessed. However, these analyses may be required during the design phase.



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

b) Atmospheric River Satellite Image, January 28, 2021

Source: (NOAA 2013, 2021)

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

5.1.1 Atmospheric Rivers

First coined by Newell and Zhu in the 1990s, ARs have captured considerable media attention (Newell et al. 1992; Zhu and Newell, 1994). ARs are often described as long and narrow atmospheric conveyor belts that, on average, span approximately 500 miles wide and thousands of miles long (**Figure J-13b**). They are found in the lower atmosphere (within 2 to 9 kilometers [km], or 1.2 to 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 Pacific 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 to 50% of precipitation and snowpack along the western United States. (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).

5.1.2 Extratropical Cyclones

Within the Earth's middle latitudes, cyclones are called midlatitude 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 with 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 profiles, 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 (for example, 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 (that is, explosive cyclogenesis) (Zhang et al. 2019).

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 and Gyakum 1980; Zhu and 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).

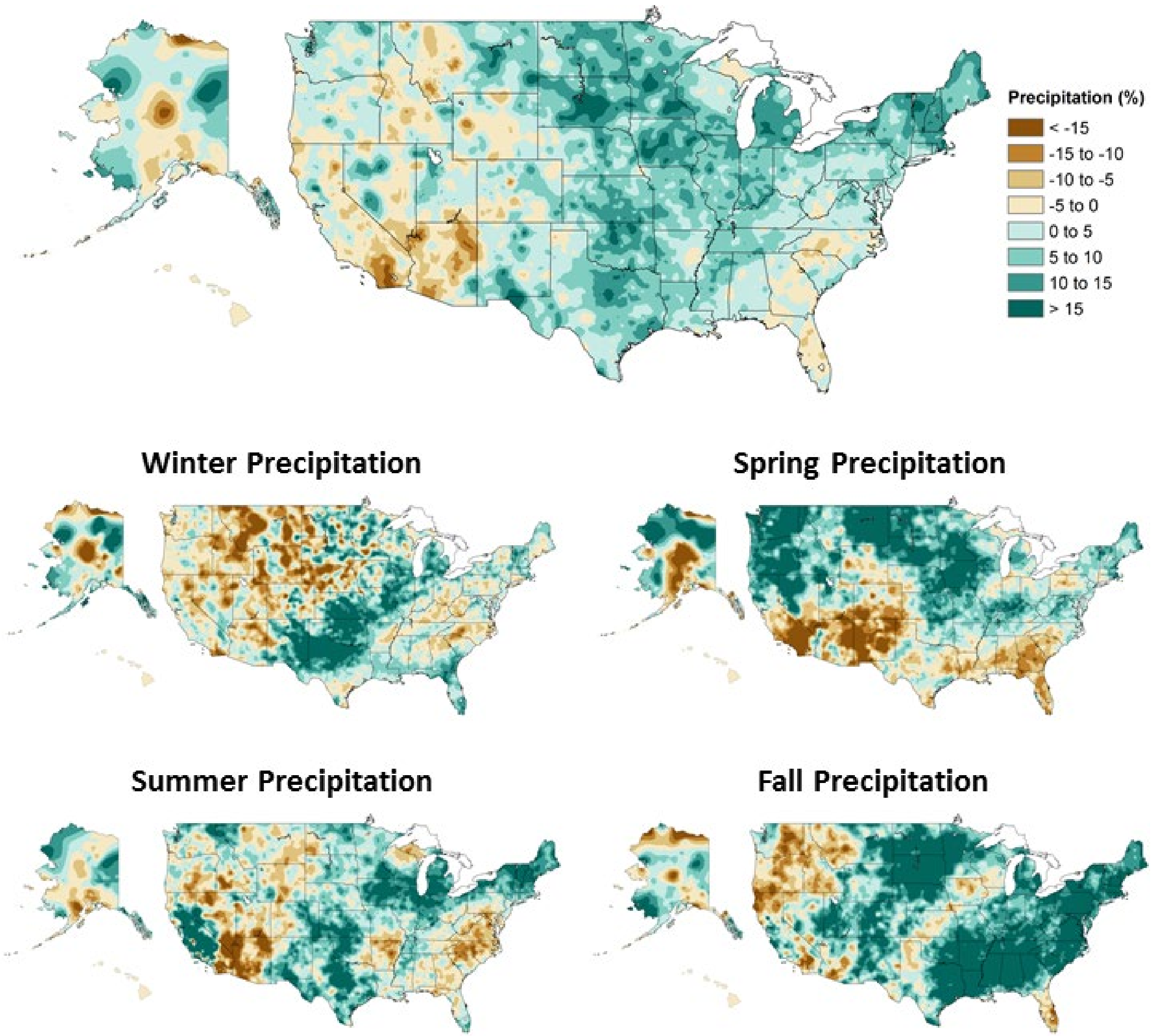
5.2 Observed Precipitation Trends

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

5.2.1 National and Regional Observations

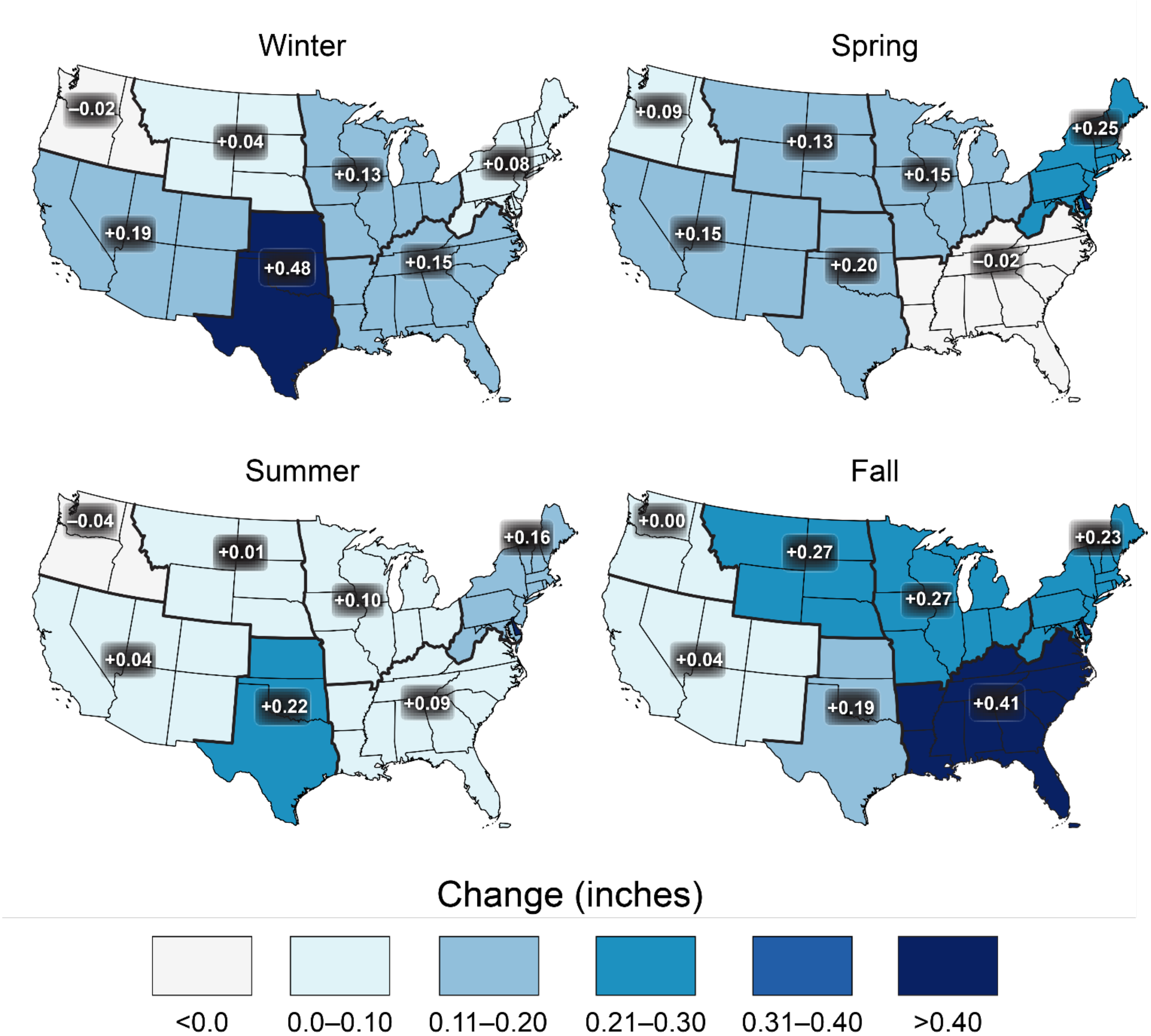
Annual and seasonal precipitation have changed throughout the U.S. over the past century. The period from 1986-2015 is about 4% wetter on average across the country compared to the first half of the last century (1901-1960) (Easterling et al. 2017). However, the degree of change varies greatly by geography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

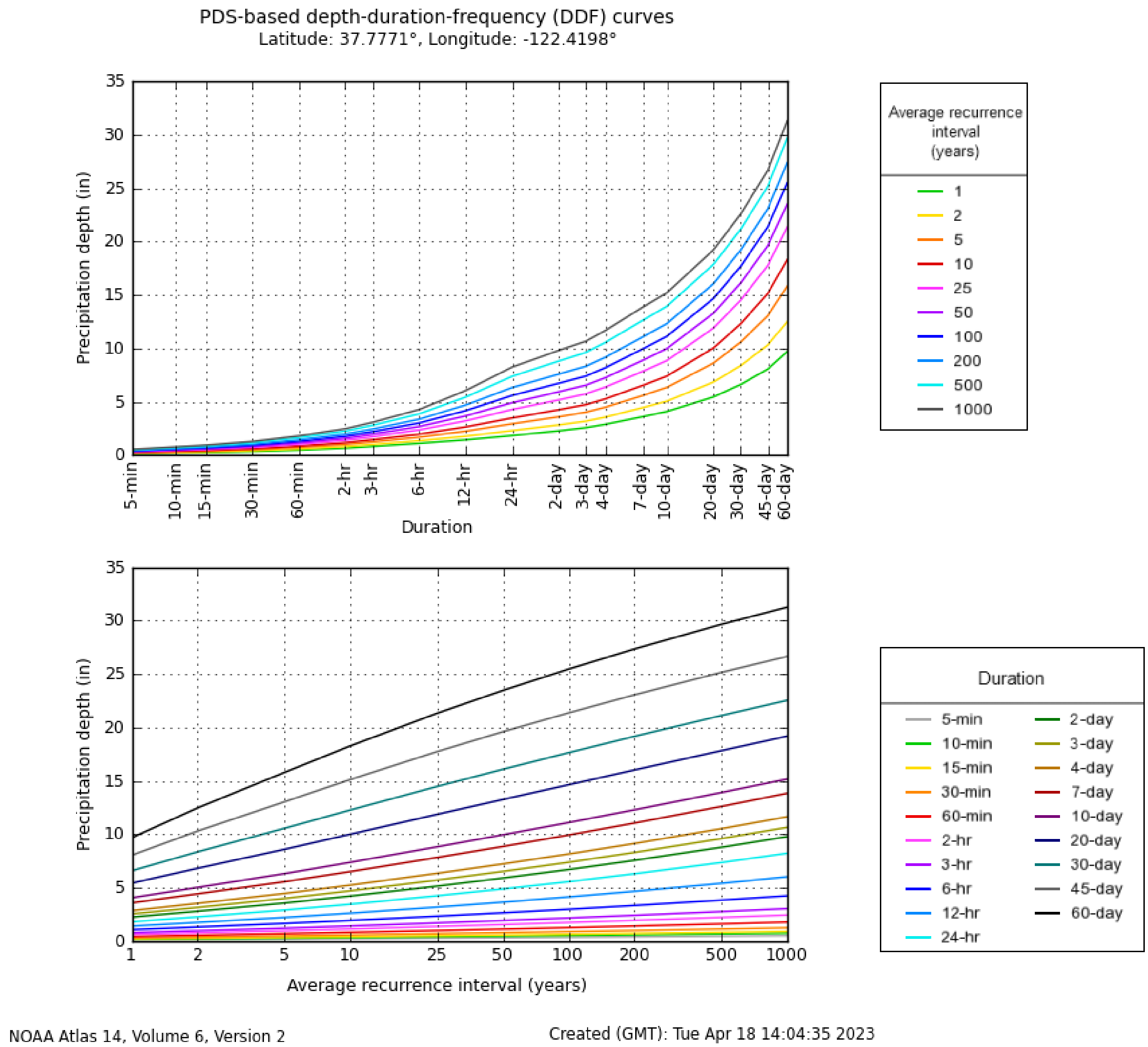
Figure J-15: Observed Change in Daily, 20-year Return Level Precipitation

5.2.2 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 and the assumption of stationarity. 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 changing hydrologic and meteorological conditions 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 IDF curves for San Francisco.



Source: (NOAA 2014)

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

5.2.3 Recent Storms and Compound Events

A recent study by Mak et al. (2023a) identified 15 extreme storms that impacted San Francisco and the Bay Area, 6 of which were selected to model to assess how extreme precipitation could change under a warmer climate. Details on the 15 extreme storms and their selection is available from 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 Niña 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.

Although high coastal water levels and heavy precipitation can co-occur, a joint probability analysis between coastal water levels and precipitation was not completed for this feasibility study. In addition, the impacts of compound flooding and consecutive events were not assessed. However, as the scientific basis for understanding future extreme events improves, analyses may be required during the design phase.

The following sub-sections describe two extreme storm events documented in Mak et al. 2023a.

5.2.3.1 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 Integrated Water Vapor Transport (IVT) values (greater than 1,000 kilograms of water vapor per meter per second [kg/m/s]) and AR duration (more than 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

5.2.3.2 Winter 2022-2023 Consecutive and Compounding Atmospheric River and Extratropical Cyclones

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, that 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.

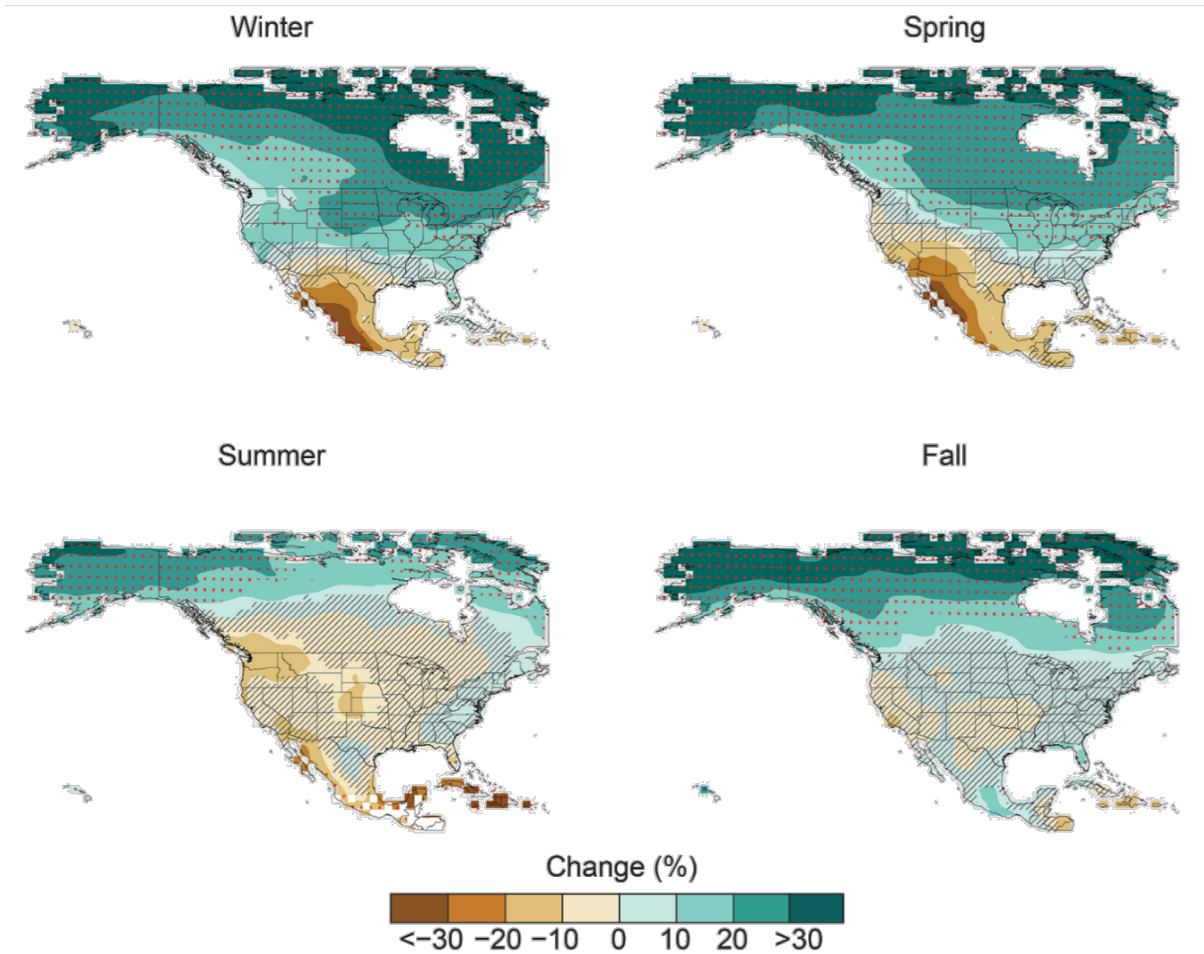
Although the October 2021 storms led to widespread flooding, damage, and disruption, the shorter duration of the events did little to provide relief for California's extreme drought conditions. However, the back-to-back series of storms in winter 2022-2023, and the continued rainfall and snowfall that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

5.3 Projected Precipitation Trends

This section discusses the projected precipitation trends.

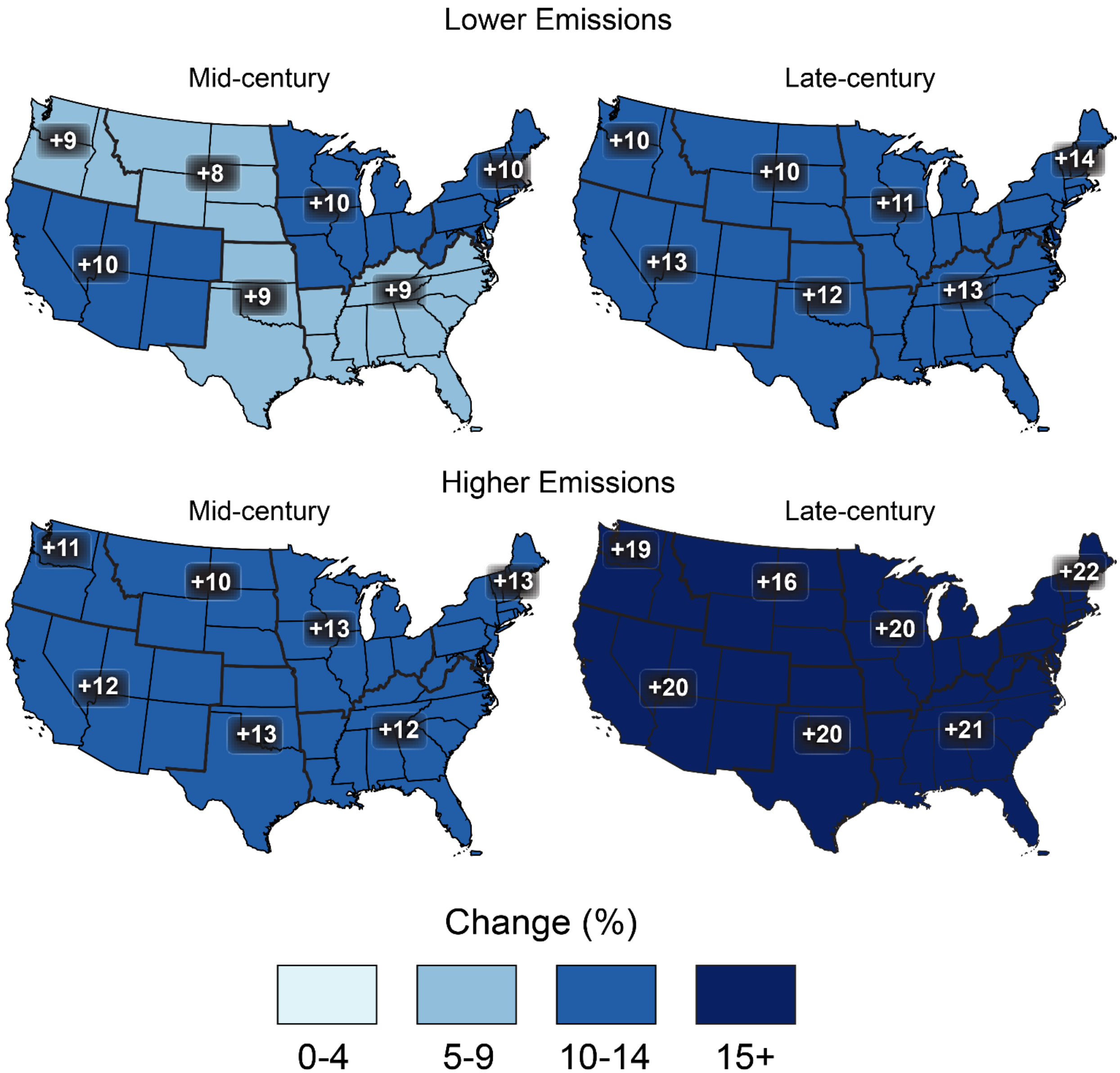
5.3.1 National Climate Projections

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 ARs 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

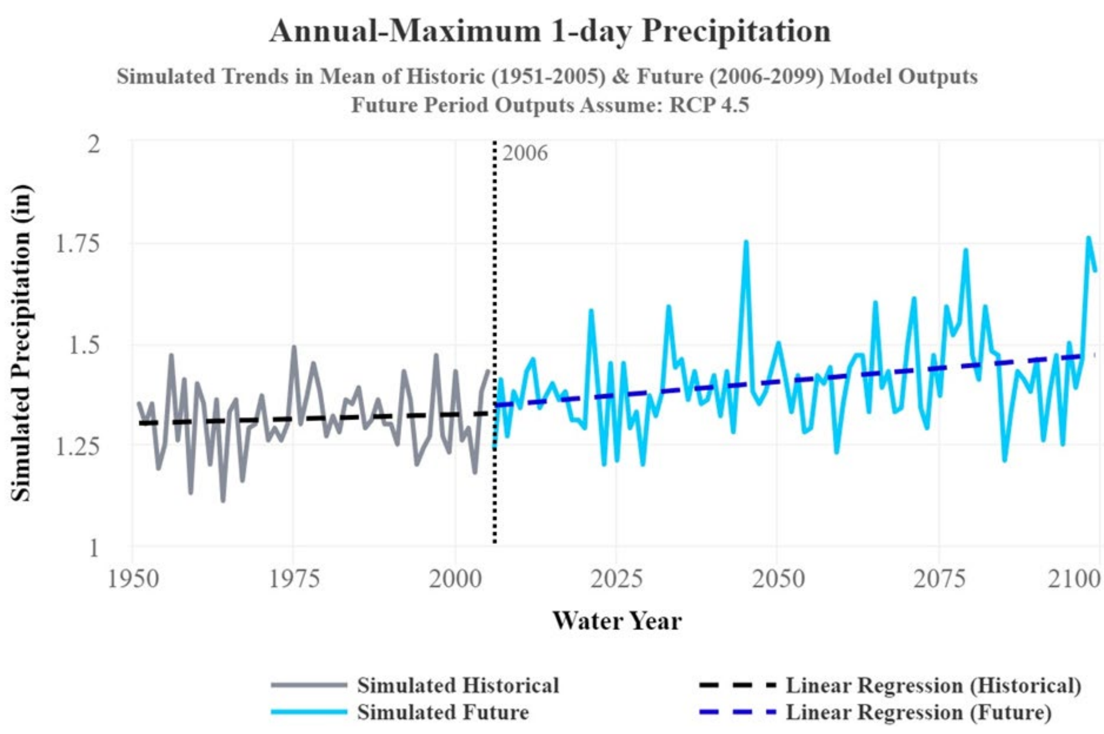
5.3.2 Local Climate Projections

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

Figure J-19 shows the observed and projected trends for the annual maximum 1-day precipitation, based on 93 different hydrologic simulations of changing meteorological conditions for the period of 1950-2099 and assuming the Representative Concentration Pathway (RCP) 4.5 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 regional climate modeling to better understand how Bay Area storms could change under changing meteorological and hydrological conditions. In the Bay Area, where the highly variable and complex topography (that is, combinations of low-lying areas surrounded by steep hills) influences both temporal and spatial differences in local precipitation, global climate models are inadequate.

The grid resolution of global climate models (for example, 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 Pacific coast ARs. 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: (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 IDF curves that incorporate projections through the end of the century, are anticipated to inform infrastructure planning and design throughout the Bay Area.

Study findings include:

- Storm duration could increase between 9 and 24% by 2050 and from 18 to 55% by the end of century, both relative to historical 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 (for example, 3 hours or less, **Table J-4** and **Figure J-20**) is increasing faster than longer durations (for example, 24 hours 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

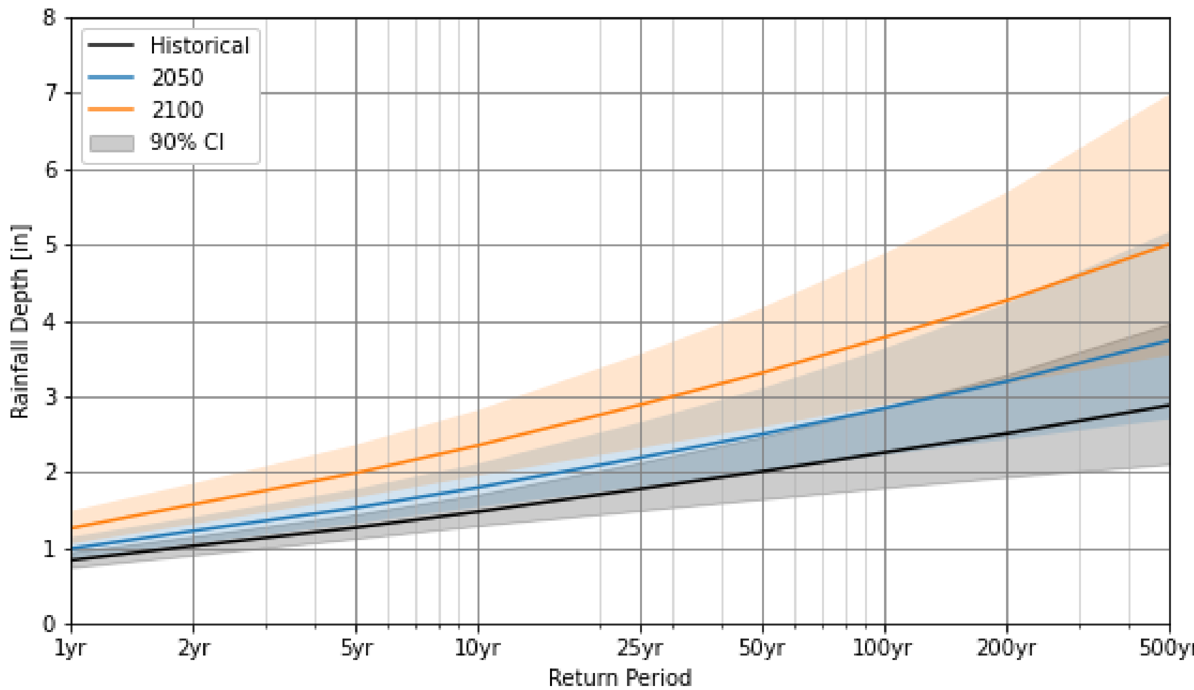
Time Period	CI (%)	5-year; 3-hour (%)	100-year; 3-hour (%)
Historical (NOAA Atlas 14)	–	+0	+0
	90	-11 to +14	-20 to +27
2050 (Mak et al. 2023a)	–	+20	+26
	90	+12 to 30	+16 to 35
2100 (Mak et al. 2023a)	–	+56	+67
	90	+38 to +75	+47 to +87

Source: (Mak et al. 2023a)

Note: Future precipitation intensity is shown relative to historical (NOAA Atlas 14) for the San Francisco downtown rain gage. NOAA Atlas 14 is based on historical observations and the assumption of stationarity. Regional climate modeling of extreme San Francisco Bay Area storms (Mak et al. 2023a, 2023b) highlights the increase in precipitation intensity that could occur in the future under the high emission scenario (SSP5-8.5/RCP8.5) due to the nonstationarity of the climate system. The 90% CI for each estimate is shown to highlight the variability underlying both historical and future estimates of precipitation intensity.

CI = confidence interval

SSP = Shared Socioeconomic Pathway



Source: (Mak et al. 2023b)

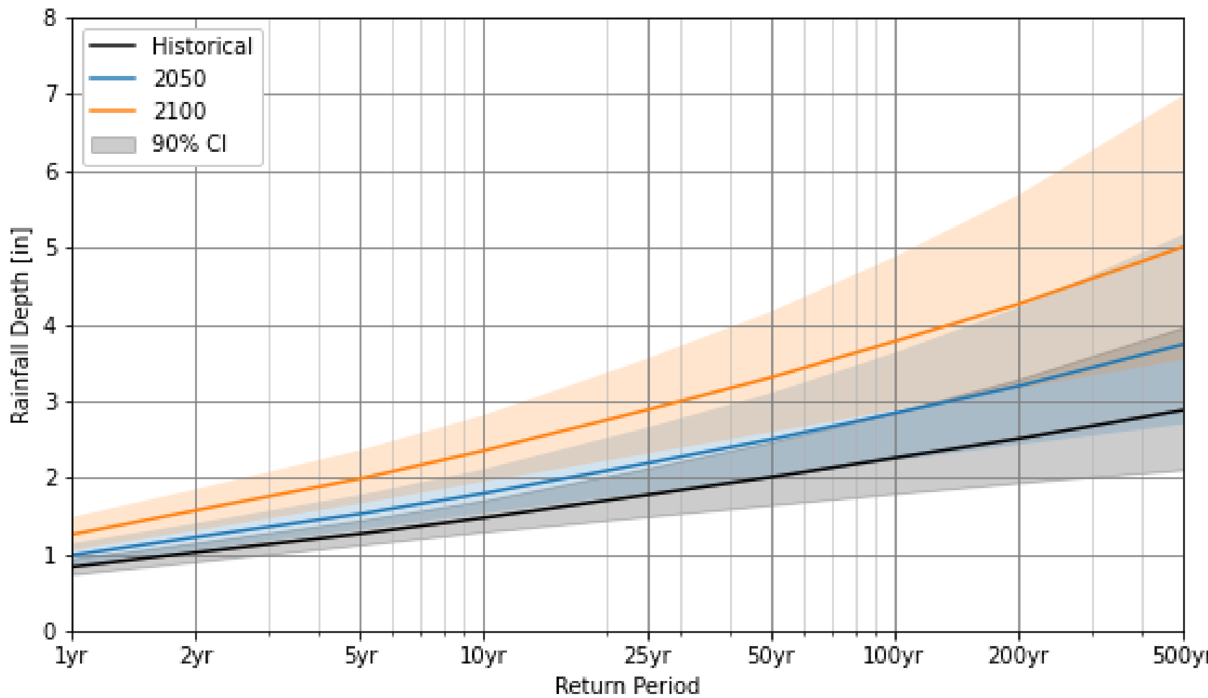
Figure J-20: Historical and Future Return Period Compared to Rainfall Depth for 3-hour Durations

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

Time Period	CI (%)	5-year; 3-hour (%)	100-year; 3-hour (%)
Historical (NOAA Atlas 14)	–	+0	+0
	90	-10 to +13	-17 to +23
2050 (Mak et al. 2023a)	–	+17	+22
	90	+7 to 27	+12 to 32
2100 (Mak et al. 2023a)	–	+41	+51
	90	+26 to 57	+35 to +67

Source: (Mak et al. 2023a)

Note: Future precipitation intensity is shown relative to historical (NOAA Atlas 14) for the San Francisco downtown rain gage. NOAA Atlas 14 is based on historical observations and the assumption of stationarity. Regional climate modeling of extreme San Francisco Bay Area storms (Mak et al. 2023a, 2023b) highlights the increase in precipitation intensity that could occur in the future under the high emission scenario (SSP5-8.5/RCP8.5) due to the nonstationarity of the climate system. The 90% CI for each estimate is shown to highlight the variability underlying both historical and future estimates of precipitation intensity.



Source: (Mak et al. 2023b)

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

6.0 Relative Sea Level Change

This section discusses RSLC and Bay water levels as relevant to the study area.

6.1 Overview of San Francisco Bay Water Levels

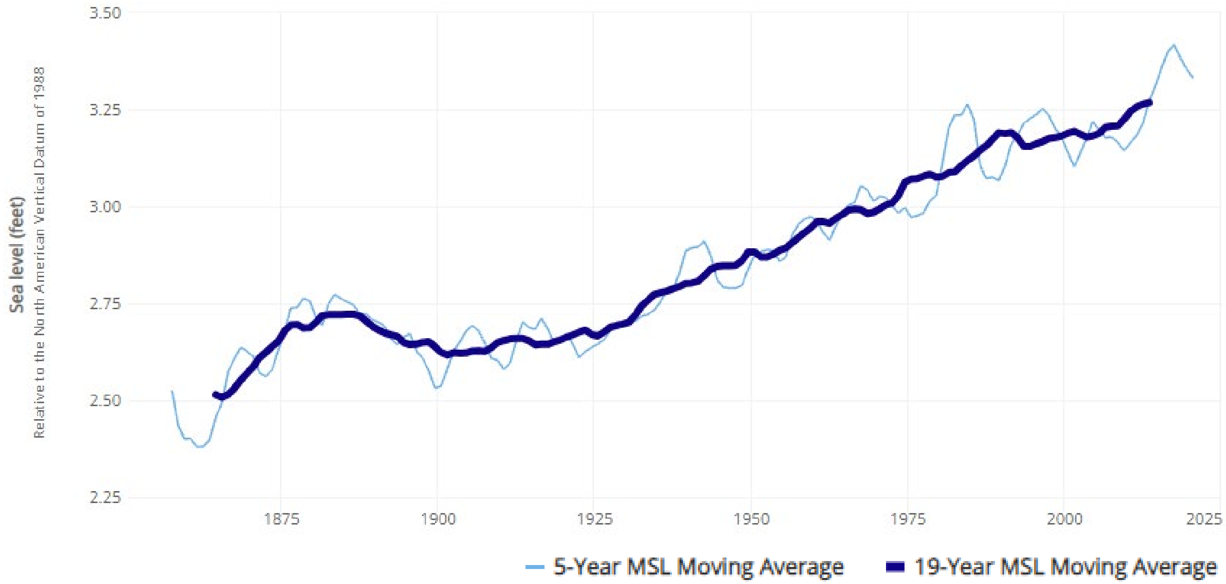
Annex B.1.1 Coastal Extreme Water Levels and High Tide Flooding provides a robust description of the cycles and processes (for example, tidal, oceanic, and atmospheric) that drive regular variations in Bay water levels. In summary, the tidal, oceanic, and atmospheric processes that drive natural climate variability in Bay water levels are as follows:

- **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 and La Niña cycle (ENSO), when every 2 to 7 years, the equatorial trade winds relax, or even reverse, and warm surface water moves back along the equator toward South America (Park et al. 2012; USGS 1999). The El Niño and La Niña cycles can influence water levels for several months at time.
  - The Pacific Decadal Oscillation (PDO) is a long-term (for example, 20- to 30-year) ocean fluctuation of sea surface temperatures in the Pacific Ocean. When the PDO drives warmer waters along the Pacific coast of North America (and colder waters in Alaska), water levels along the Pacific 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 RSLC 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 RSLC has increased along the Pacific coast (Fasullo and Nerem 2018). Assessing ocean cycles and their influence on global SLC trends remains an area of active research (Nerem et al. 2020).
- **Atmospheric processes** (for example, the weather), including extreme storm events, that influence the combination of tidal and oceanic cycles, including:
  - 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 the 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 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.

6.2 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 historical MSL 5-year and 19-year moving averages (**Figure J-22**). 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 5.1.



Source: (USACE 2020)

Figure J-22: Sea Level Data and Projections for Presidio Tide Gage (9414290)

6.3 Projected Sea Level Trends

This section discusses the projected sea level trends.

6.3.1 National and Regional Relative Sea Level Change Projections

As described in Section 3.1, Intergovernmental Panel on Climate Change (IPCC) produces regular updates to the state of scientific, technical, and socioeconomic knowledge on changing meteorological conditions, its impacts, and future risks at a global scale. The most recent updates for RSLC science were released in 2021 from Working Group 1 on the Physical Science Basis (IPCC 2021).

The Federal Sea Level Rise Task Force, comprising 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 RSLC projections (Sweet et al. 2022).

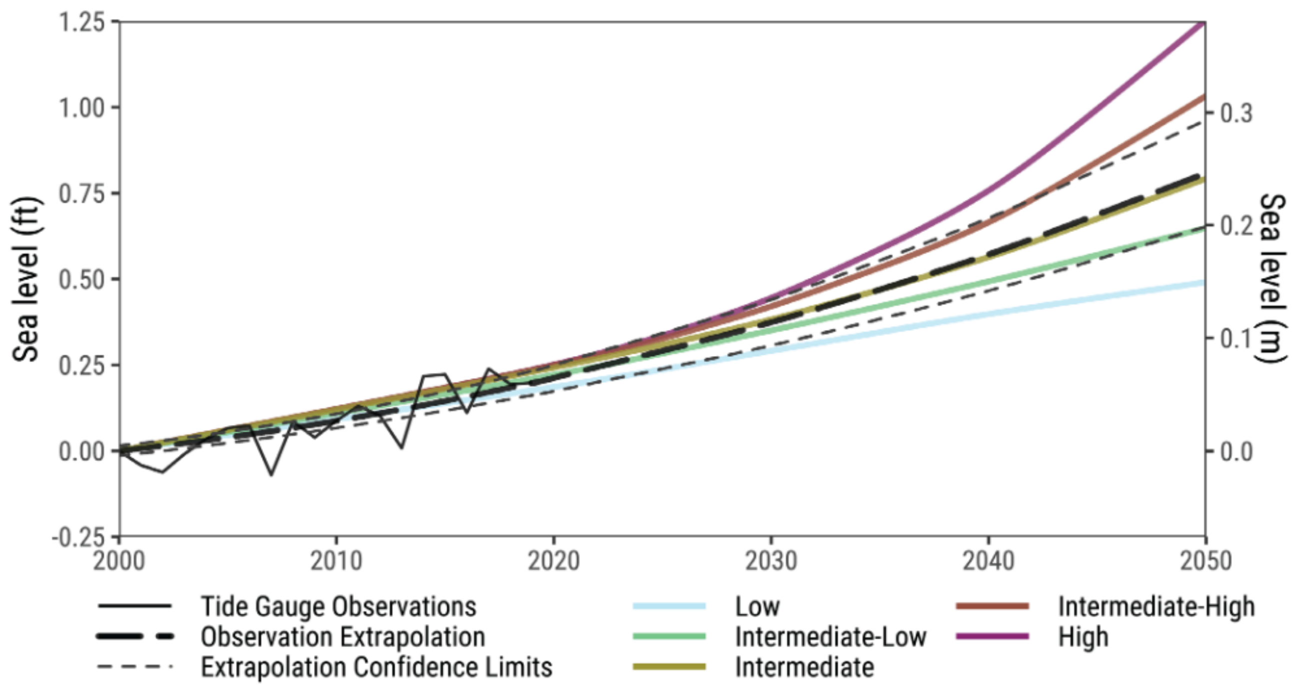
A significant scientific contribution of Sweet et al. (2022) is detailed analysis of tide gage and satellite observations, and the observation-based extrapolation of this information from 2020 to 2050 (**Figure J-23**). This analysis and extrapolation are made possible due to the increased number and 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 to 2020 could become dominant (Sweet et al. 2022).

Figure J-23 presents the observation extrapolation of MSL for California and southern Oregon (the Southwest Region in Sweet et al. [2022], which is not exactly aligned with the NCA regions), and highlights that the observation extrapolation of sea levels along the California coast is aligned with the 2022 Southwest Intermediate scenario.

Figure J-24 presents the monthly MSL observations from the Presidio tide gauge, along with the USACE Low, Intermediate, and High RSLC scenarios for the same time period as **Figure J-23** (that is, 2020 to 2050) for comparison purposes. The USACE Low RSLC scenario represents the extrapolation of the Presidio tide gauge observations. In 2050, the USACE extrapolation corresponds to 4.5 inches of RSLC, and the Sweet et al. (2022) extrapolation corresponds to roughly 9 inches of RSLC. Although the extrapolations use different methods, they are in reasonable agreement given the uncertainty in future RSLC projections. Both extrapolations are provided for illustrative purposes only. The extrapolations were not used to inform plan formulation.

Figure J-25 presents the USACE Low, Intermediate, and High RSLC scenarios used within the SFWCFS relative to the 2022 RSLC scenarios from Sweet et al. (2022). The 2022 scenarios reflect slower acceleration before 2050, and greater acceleration thereafter, producing similar estimates of RSLC by 2100. Future updates to the observation extrapolations by the Federal Sea Level Rise Task Force will be instrumental in assessing the climate trajectory after 2050.

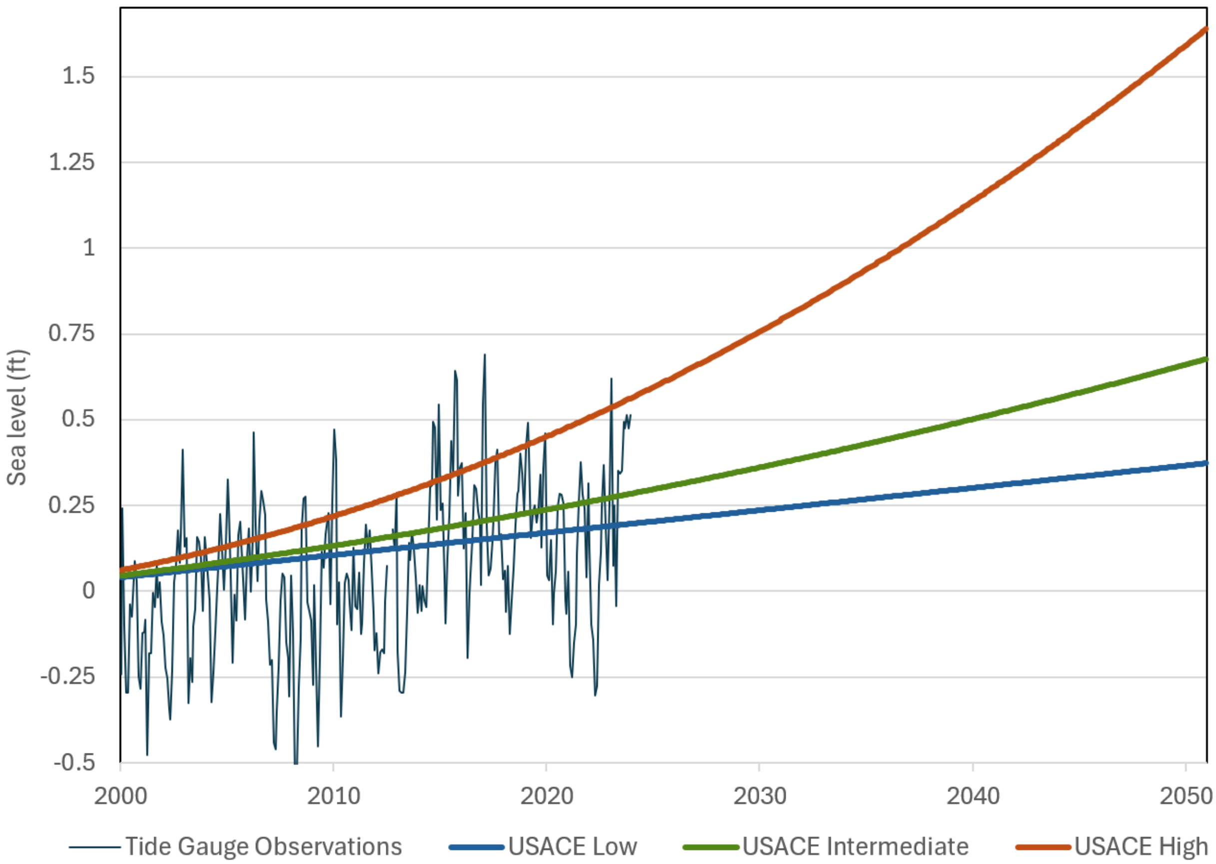
The USACE Low, Intermediate, and High RSLC scenarios used to support this feasibility assessment are based on IPCC (2007a, 2007b) and NRC (2012), as recommended in EP 1100-2-1 and ER 1100-2-8162 (USACE 2019a, 2019b).



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

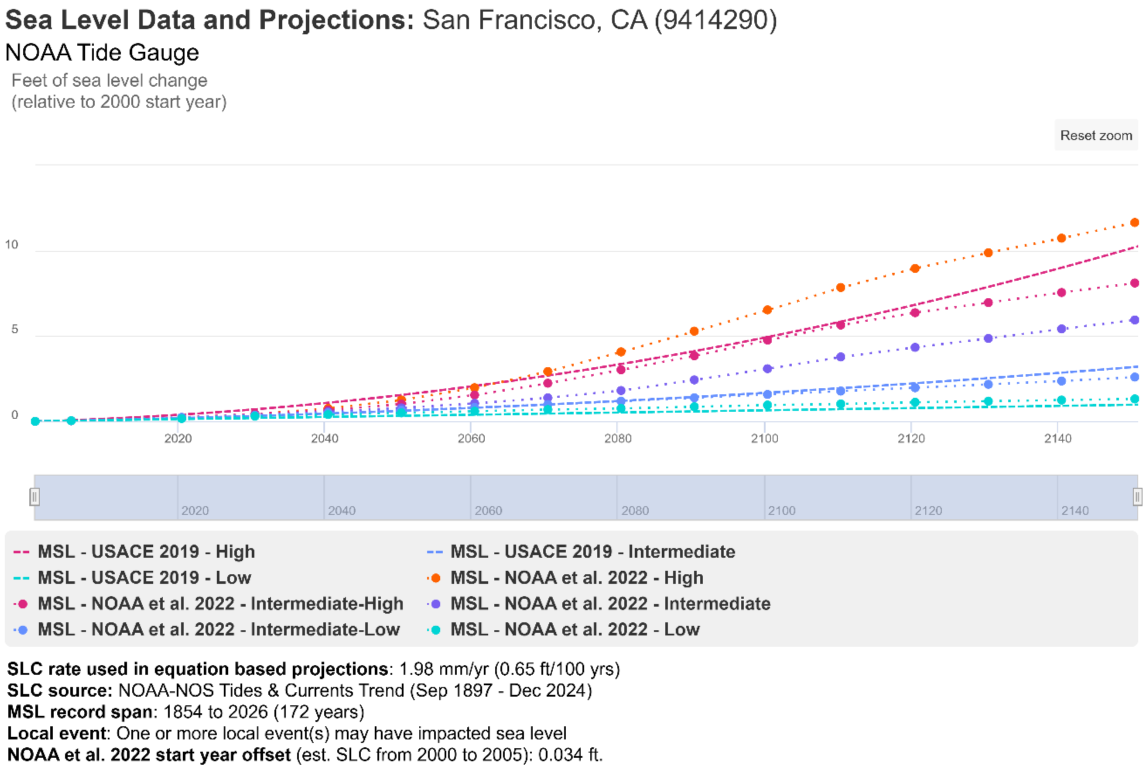
Average annual water levels from tide gages are overlaid for context. The extrapolation confidence limits represent the 17th and 83rd percentile CI for the observation-based extrapolations.

Figure J-23: Southwest Region (California and Southern Oregon) Relative Sea Level Change Scenarios and Observation-based Extrapolations



Source: (USACE 2020)

Figure J-24: San Francisco (Presidio) Tide Gauge Observations and USACE Relative Sea Level Change Scenarios



Source: (USACE, 2026; Sweet et al., 2022)

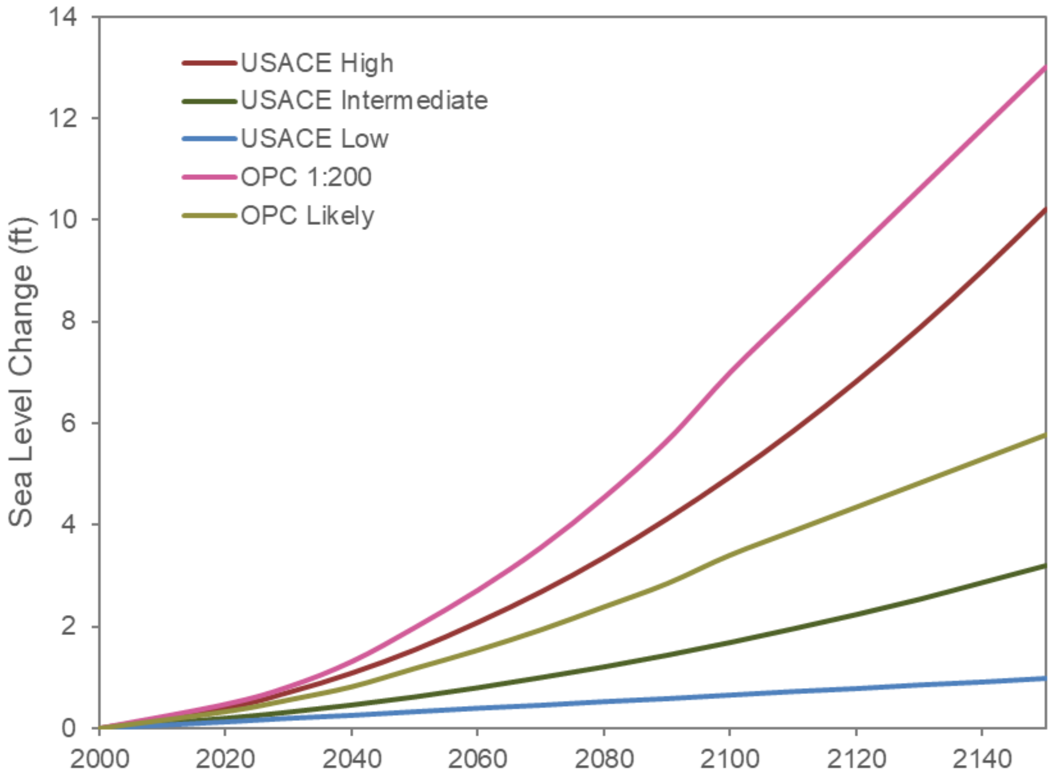
All projections are baselined to the year 2000 for the purposes of illustration. Inputs for analysis were developed in accordance with USACE requirements, detailed in Annex B.1.1 Coastal Extreme Water Levels and High Tide Flooding.

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

6.3.2 State and Local Relative Sea Level Change Scenarios

The State of California adopted RSLC scenarios in 2018 based on IPCC (2014) and the Federal companion U.S.-based RSLC scenarios from Sweet et al. (2017). The State updated its guidance to reflect the recommendations from Sweet et al. (2022) in 2024.

CCSF adopted the 2018 state scenarios and recommended the use of the higher-end values associated with RCP8.5 for projects directly along the shoreline (CCSF 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 RSLC scenarios with the three USACE RSLC scenarios used within the SFWCFS.



Source: (OPC and 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 Sub-Appendix B.1.1 Coastal Extreme Water Levels and High Tide Flooding.

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

6.4 Shallow Groundwater Response to Relative Sea Level Change

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 (*Annex B.1.5 Qualitative Shallow Groundwater Assessment*).

6.4.1 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 RSLC 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 not 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 4.4.3.2; therefore, the results from this study may underestimate the height of the existing highest annual shallow groundwater table.

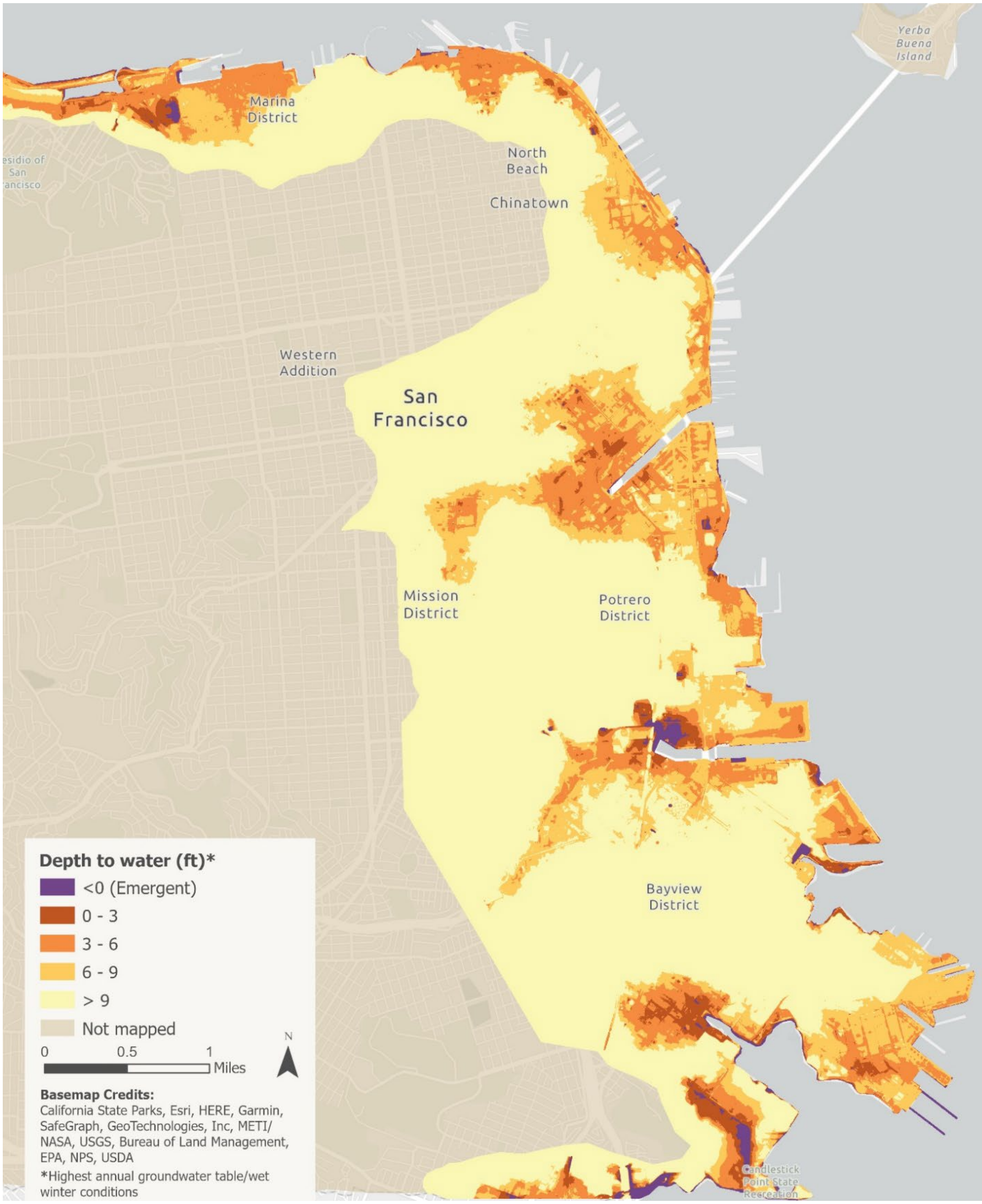
Figure J-27 shows the existing highest annual shallow groundwater table for San Francisco. The areas with groundwater within 0 to 9 feet of the existing groundwater surface are generally areas that were filled for development between the 1800s and mid-1900s. This includes areas along the northern waterfront that were filled behind the Embarcadero seawall, and the floodplains, marshplains, and mudflats of the historic Islais and Mission Creeks.

6.4.2 Future Projections

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

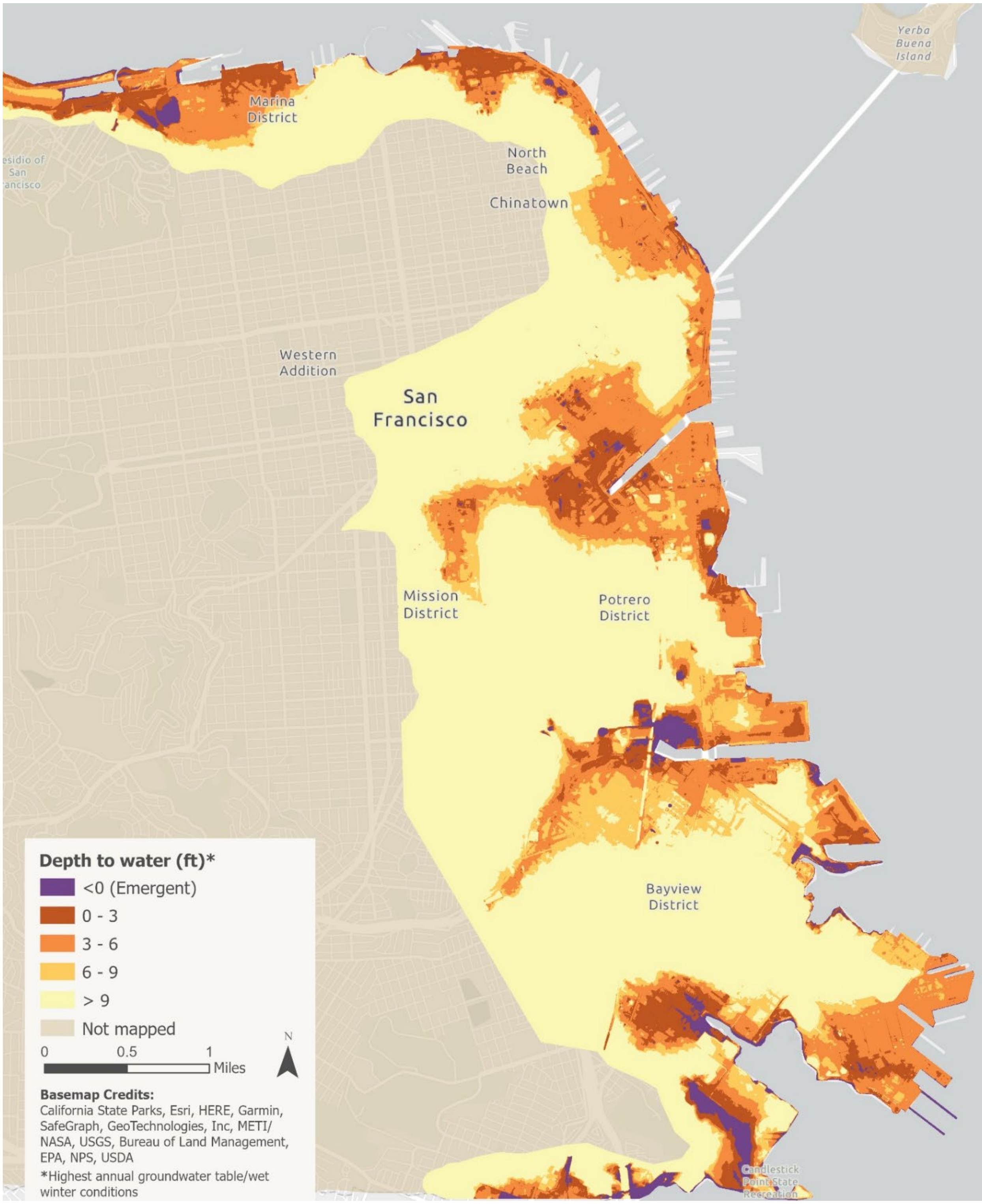
Figure J-30 presents the worst-case scenario, showing both areas that could be inundated with 108 inches of RSLC by Bay floodwaters overtopping the shoreline, and inland areas that are likely to have emergent groundwater with 108 inches of RSLC. With this scenario, all areas filled for development are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

Figure J-26 through **Figure J-30** show the depth below ground of the shallow groundwater table, and areas with potential emergent groundwater, for existing and future scenarios. The information qualitatively informed the formulation and evaluation of alternatives *Annex B.1.5 Qualitative Shallow Groundwater Assessment*.



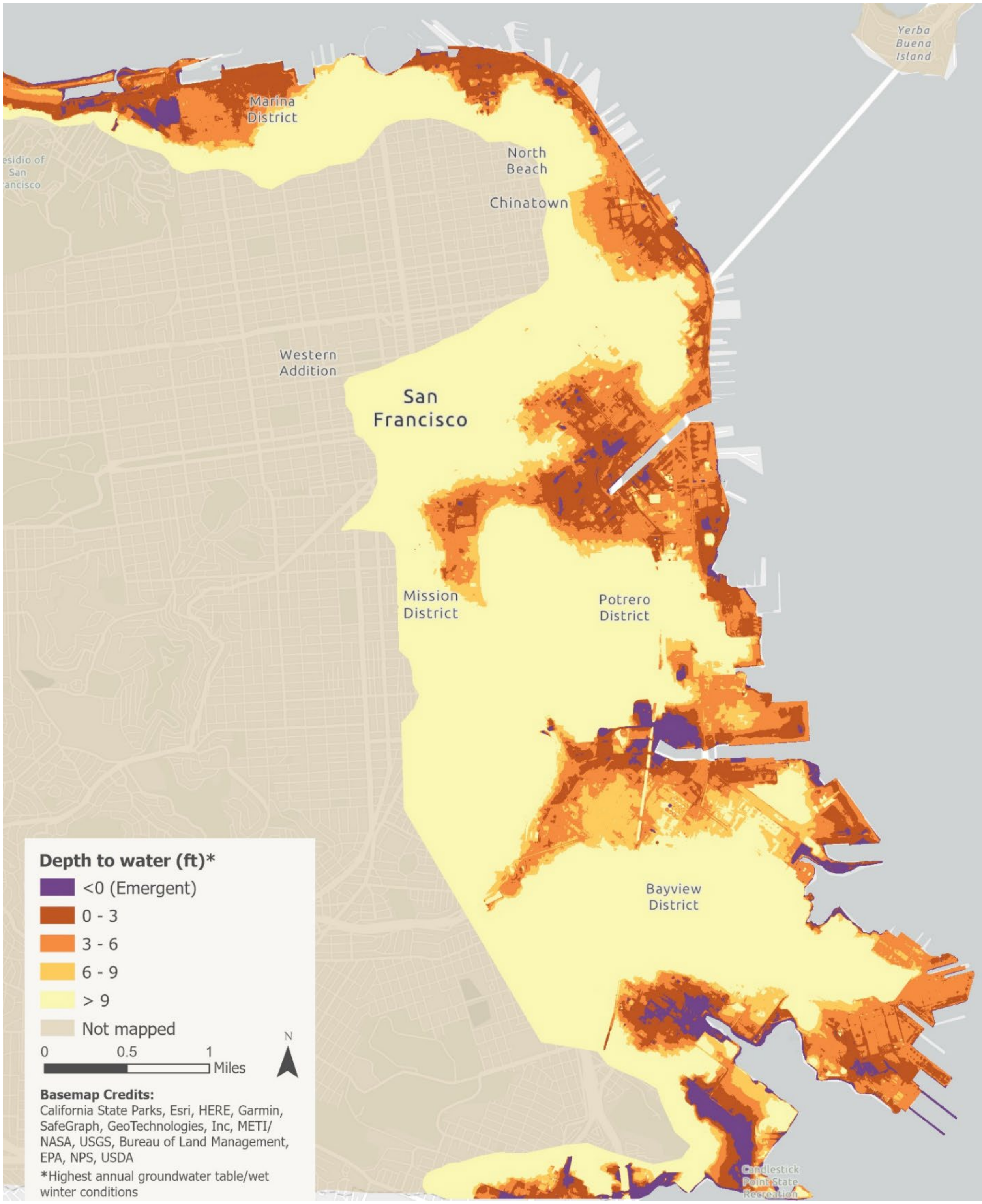
Source: (May et al. 2022)

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



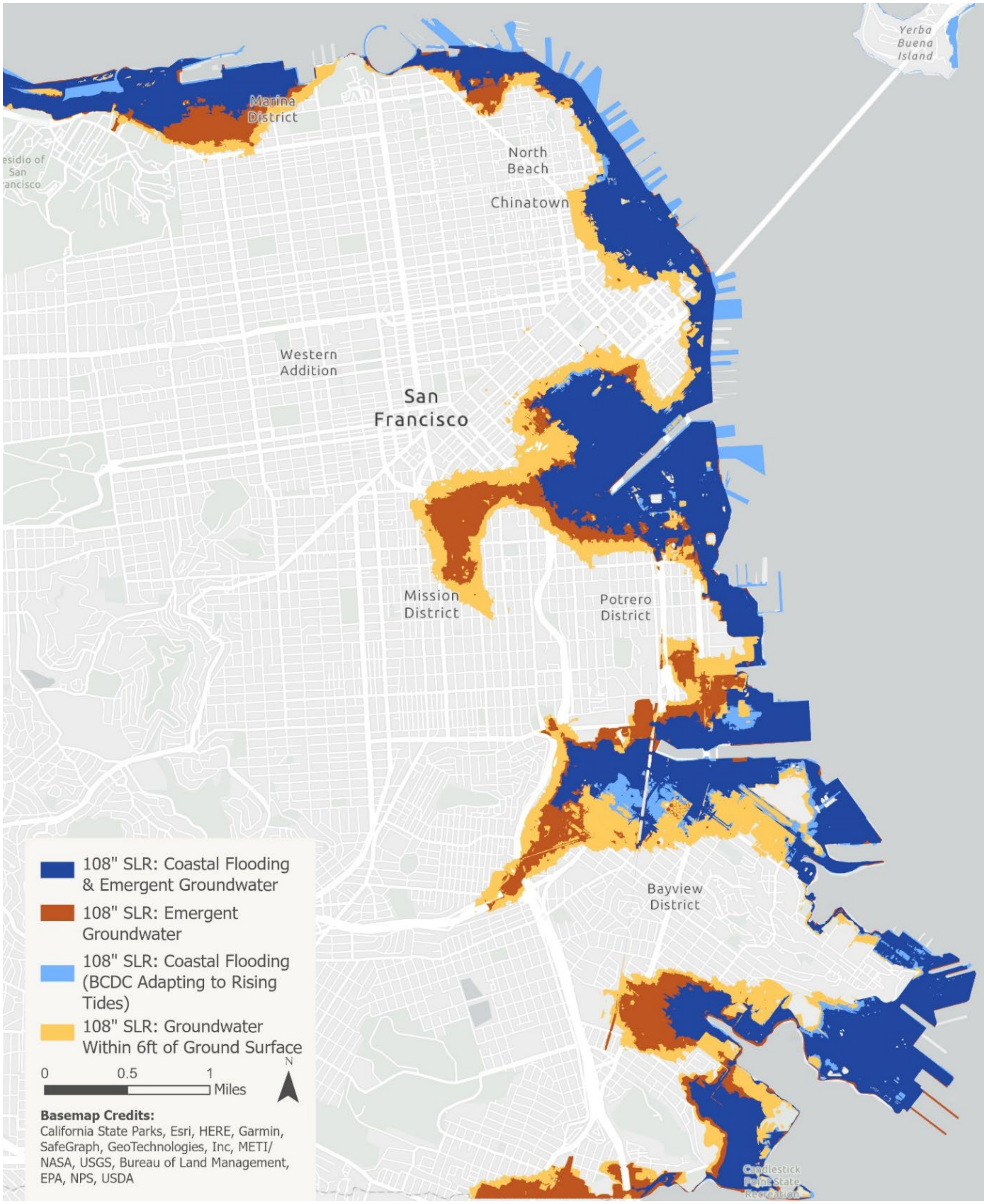
Source: (May et al. 2022)

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



Source: (May et al. 2022)

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



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

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

7.0 Inland Hydrology

This section provides information about inland hydrology within the study area.

7.1 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.

7.2 Watersheds

USACE maintains a Vulnerability Assessment Tool (VAT) that provides a comparison of the vulnerability from changing meteorological conditions 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 changing conditions and assigns a climate vulnerability score to a range of USACE sectors (for example, 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 to 2064) and 2085 (2070 to 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 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 compared to 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 U.S. watersheds for the Base, Dry 2050, and Dry 2085 scenarios. However, the vulnerability increases by 27% for the Wet 2050 and by 33% for the Wet 2085 scenarios. This result is notable, as the indicators for the Flood Risk Reduction business sector are linked to inland flooding compared to 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** presents information on the constituent indicators used to represent watershed vulnerability related to USACE Flood Risk Reduction business sector, and **Table J-8** shows the changes in these indicators between selected scenarios. 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 in Various USACE Sectors

USACE Business Sector	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
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 the Base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM 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 the Base period.	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM output	Sep-14
590 URBAN 500YR FLOODPLAIN 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 - 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 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 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 freshwater inputs (cumulative).	Data calculated from interagency CMIP5 GCM - BCSD - VIC dataset (2014)	Using GCM output	Sep-14

Indicator Short Name	Indicator Name	Indicator Description	Data Sources	Projection	Last Updated
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 output	Sep-14

Source: (USACE 2016)

BCSD = Bias Correction and Statistical Disaggregation

CMIP5 = Coupled Model Intercomparison Project Phase 5

EPA = U.S. Environmental Protection Agency

FEMA = Federal Emergency Management Agency

ICLUS = Integrated Climate and Land Use Scenario

VIC = Variable Infiltration Capacity

WRR = Water Resources Research

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 Precipitation	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 500-year Floodplain 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)

7.3 Urban Stormwater

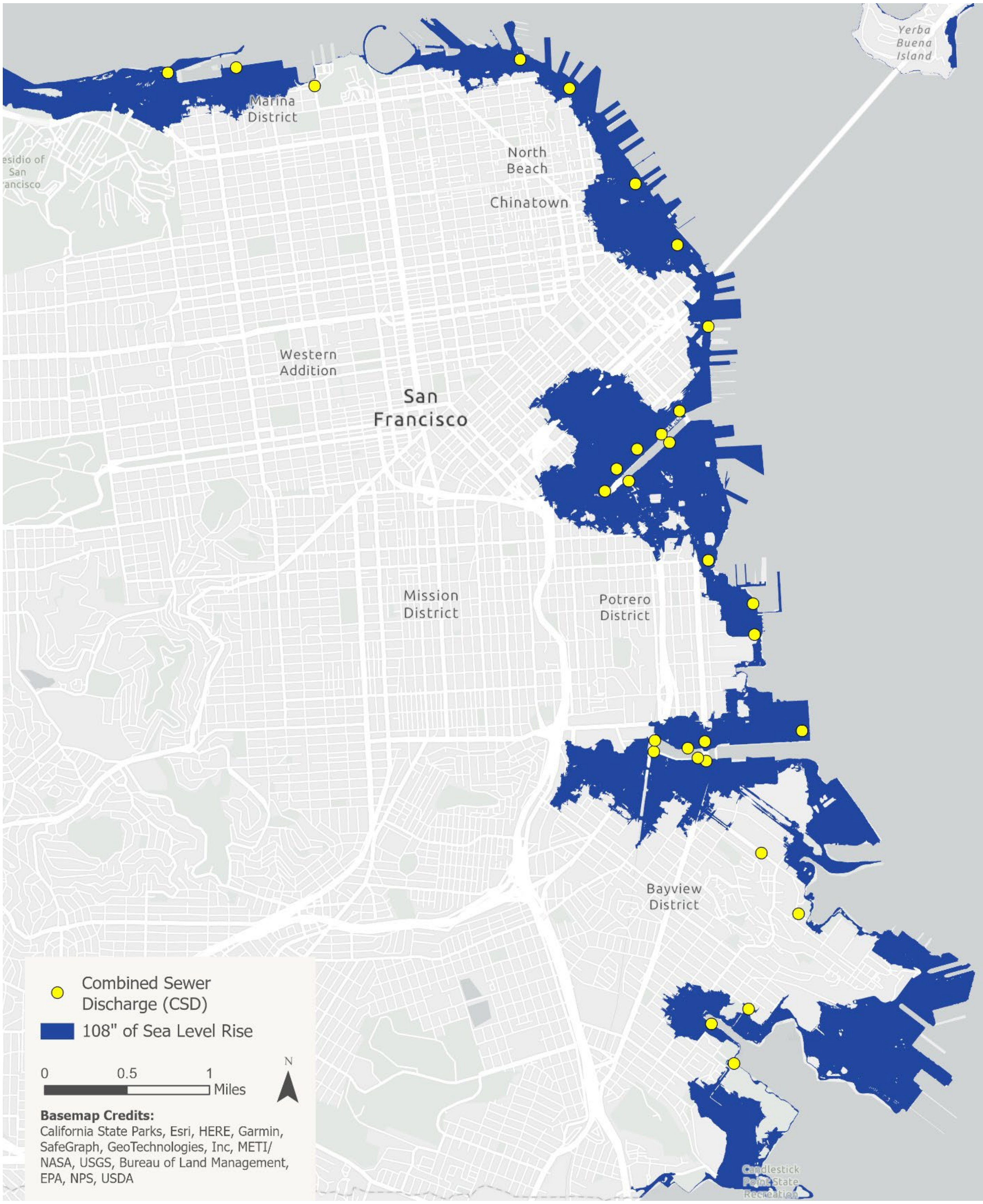
The San Francisco Public Utilities Commission (SFPUC) operates and maintains a combined sewer system to manage wastewater and stormwater flows throughout most of San Francisco. Major infrastructure in the network includes three treatment plants, 26 pump stations, 1,900 miles of pipe, and 36 combined sewer discharge outfalls (CCSF 2020). The major system components and the current watersheds as delineated by SFPUC are shown on **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 plant (the Northpoint Wet Weather Facility near Pier 39) is operated to provide additional treatment capacity for the combined wastewater and stormwater flows (CCSF 2020).

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).

Source: (SFPUC 2020)

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



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

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

8.0 References

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