Oakland Harbor Turning Basins Widening

Coastal Engineering

May 2024

PORT OF OAKLAND

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1. Introduction

This coastal engineering appendix was developed as part of the Oakland Harbor Turning Basins Widening Navigation feasibility study. This appendix summarizes exiting physical conditions as well as presents the findings of the engineering analysis conducted to support the development of recommend improvements to the Oakland Harbor Inner and Outer turning basins.

1.1. Project Area Description

The Port of Oakland and the Oakland Inner and Outer Harbors are located on the eastern side of the San Francisco Bay in Alameda County, California approximately 4 miles east of downtown San Francisco. The outer harbor is located directly south of the San Francisco-Oakland Bay Bridge and the inner harbor is located between the cities of Alameda and Oakland. The inner harbor was originally developed in the natural estuary of San Antonio Creek. A map of the San Francisco Bay area and the area of interest for this study are shown in Figure 1. Further detail for each navigational component of this study in provided in the following text. The Port of Oakland is one of the busiest container ports in the United States and has a total of six terminals. The four active terminals include Ben E. Nutter, TraPac, Matson, and the Oakland International Container Terminal. The inactive terminals include Charles P. Howard and Outer Harbor. Overall, the maritime component of the Port of Oakland spans approximately 1,500 acres.

1.1.1. Outer Harbor Turning Basin

The Oakland Outer Harbor turning basin is located in the outer harbor channel near berths 25 through 30. The turning basin is located in a bend of the outer harbor channel and has a diameter of 1,650 feet and is maintained to a depth of -50 feet (MLLW).

1.1.2. Inner Harbor Turning Basin

The Oakland Inner Harbor turning basin is located approximately 18,000 feet to the east of the Oakland Harbor entrance. The turning basin had a diameter of 1,500 feet and is maintained to a depth of -50 feet (MLLW).

2. Project History

The first federal improvement of the Oakland harbor was authorized by the Rivers and Harbors Act adopted June 23, 1874. These improvements consisted of constructing two jetties to act as training walls to confine the flow of the San Antonio Estuary to scour a channel, the jetties were completed in 1894. The jetties no longer serve a navigational purpose and segments have been removed during subsequent improvements to the harbor. Significant change in the federally authorized channel have taken place in 1931, 1942, 1974-1975, and 2001-2010. In 1931, the Outer Harbor entrance was widened. The Outer harbor was deepened to 35 feet and the turning basin was expanded in 1942. The deepening of the Inner Harbor to 35 feet was authorized in the Act of 1962 and completed in 1974. The authorized project for deepening the Entrance Channel, Outer Harbor and Inner Harbor channels to 42 feet was completed in 1998 and authorized by Section 202 of the Water Resources Development Act of 1986. Finally, between 2001 and 2010 the federally maintained channels in the Inner and Outer Harbor were deepened to 50 feet.

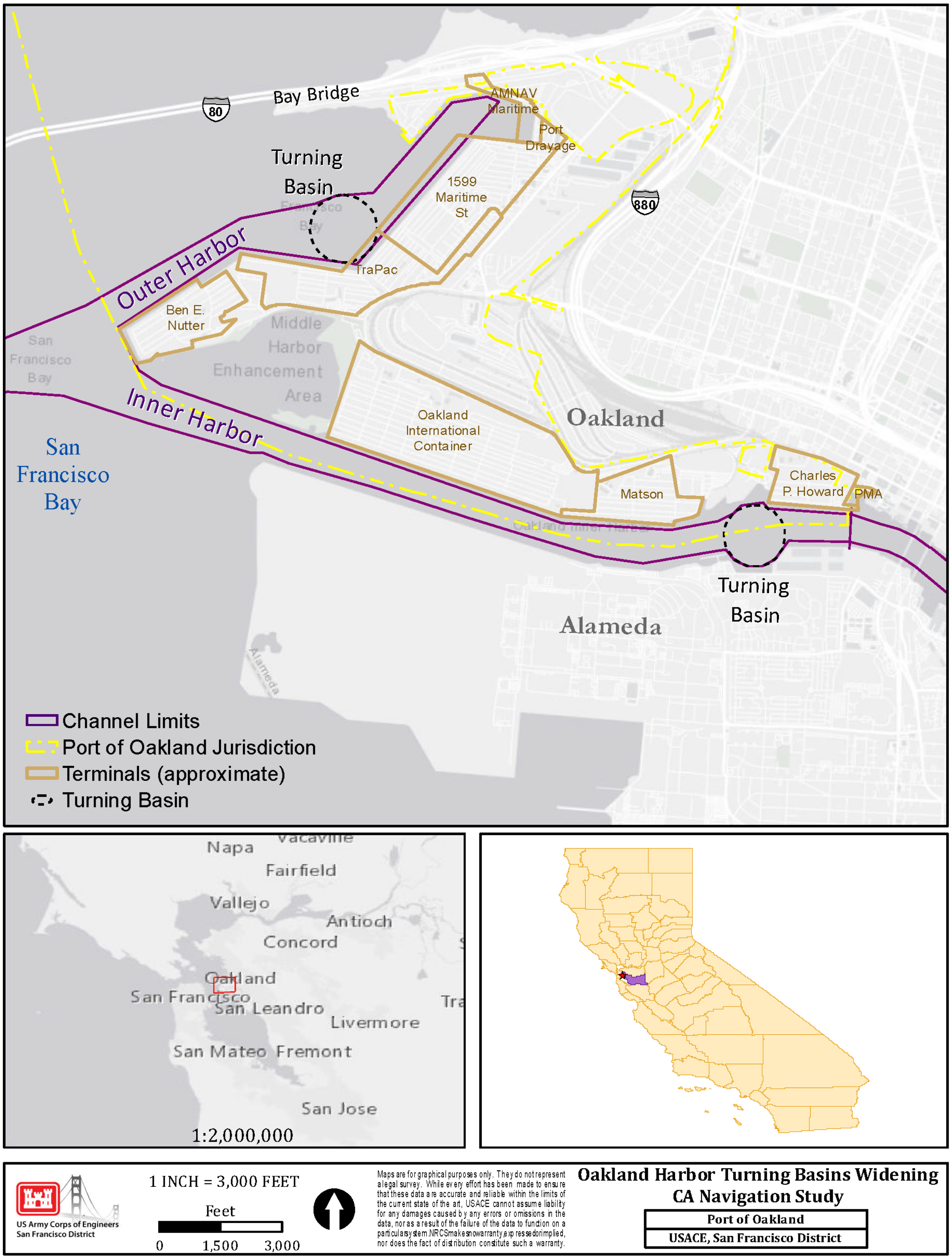


Figure 1: Study Area Location Map

3. Physical Environment

3.1. Climate

The San Francisco Bay climate is described as Mediterranean, the area is subject to cool, dry summers and mild, wet winters. The major influence of the regional climate is the Eastern Pacific High, a strong persistent anticyclone. Season variations in the position and strengths of this system are a key factor in producing weather changes in the area.

The Eastern Pacific High attains its greatest strength and most northerly position during summer, when it is centered west of Northern California. In this location, the High effectively shelters California from the effects of polar storm systems from the North Pacific. Due to the large-scale atmospheric subsidence associated with the High, an elevated temperature inversion often occurs along the West Coast. The base of this inversion is usually located 1,000 to 3,000 feet above mean sea level, depending on the intensity of subsidence and the prevailing weather condition. Vertical mixing is often limited to the base of the inversion, trapping air pollutants in the lower atmosphere. Marine air trapped below the base of the inversion is often condensed in fog and stratus clouds by the cool Pacific Ocean. This condition is typical of the warmer months of the year from roughly May through October. Typically, the stratus forms offshore and moves into coastal areas during the evening hours. As the land heats up the following morning, the clouds will burn off to the immediate coastline, then move back onshore the following evening.

As winter approaches, the High begins to weaken and shift to the south, allowing polar storms to pass through the region; these storms produce periods of cloudiness, strong shifting winds, and precipitation. The number of days with precipitation can vary greatly from year to year, resulting in a wide range of annual precipitation totals. Storm conditions are usually followed by periods of clear skies, cool temperatures, and gusty northwest winds as the storm systems move eastward. Precipitation is generally lowest along the coastline and increases inland toward higher, mountainous terrain. Annual precipitation totals for the Metropolitan Oakland International Airport ranged from 4.89 to 29.37 inches during a 72-year period of record (1948 through 2020), with an annual average of 17.69 inches. About 90 percent of the rainfall occurs during the months of November through April.

The average high and low temperatures at the Metropolitan Oakland International Airport in July are 71.2°F and 56.2°F, respectively. January average high and low temperatures are 56.4°F and 42.0°F. Extreme high and low temperatures recorded from 1948 through 2020 were 104.0°F and 25.0°F, respectively. Temperatures within the Bay are generally less extreme, due to the moderating effect of the Pacific Ocean. A climograph based on NOAA 30-year norms for 1981-2010 is shown in Figure 2.

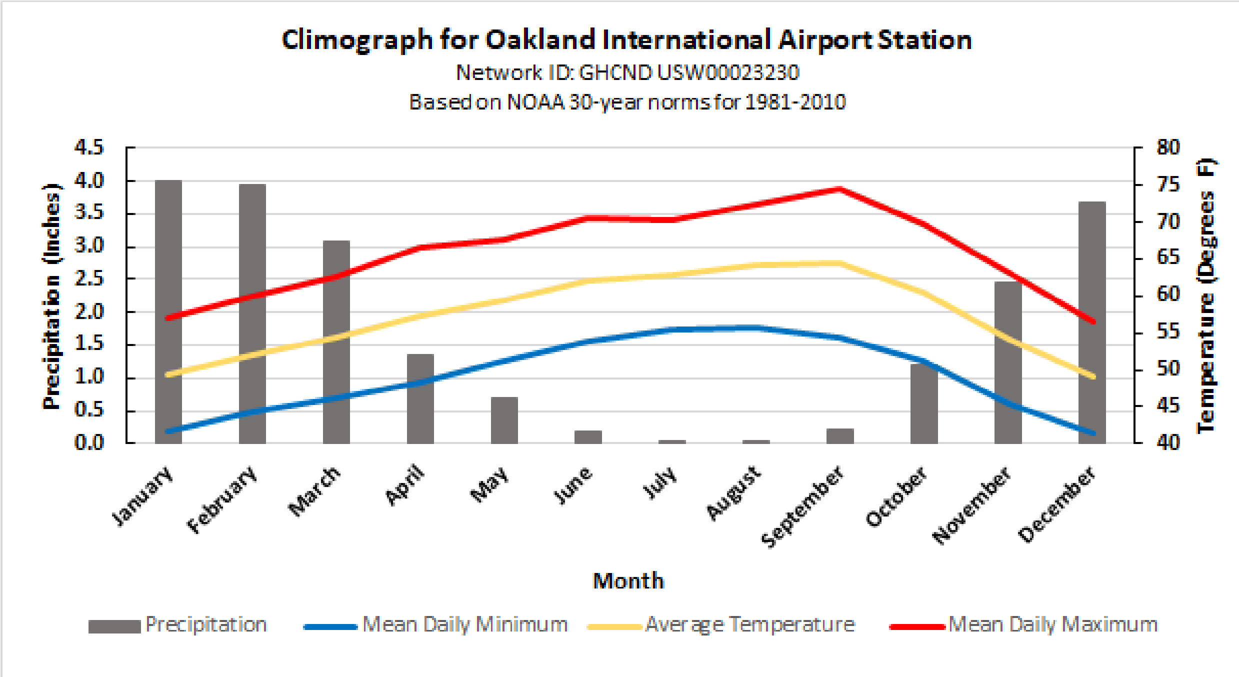


Figure 2: Climograph for Oakland International Airport Station for 1981-2010. Source: https://www.ncdc.noaa.gov/cdo-web/datatools/normals

3.2. Hydrology

The San Francisco Bay receives freshwater inflow and sediment loads from three watersheds (Table 1). Hydrologic Unit Code (HUC) Region 1805 includes the upland watersheds and marshes surrounding San Francisco Bay, San Pablo Bay, and Suisun Bay. Although they account for just 7% of annual average fluvial flow, the tributaries adjacent to the Bay supply most (61%) of the suspended sediment to the Bay (McKee et al 2013). All three HUC regions are impacted by wildfires.

Table 1: Major sources of freshwater inflow and sediment supply to San Francisco Bay

HUC Region	Watershed	Area (mi^2)	Area (km^2)
1802	Sacramento River	27,804	72,013
1804	San Joaquin River	15,825	40,986
1805	San Francisco Bay	5,371	13,910

The Sacramento and San Joaquin River watershed flows are influenced by snowmelt runoff from the Sierra Nevada Mountain Range, and nearly all major rivers in these watersheds are highly regulated (the Cosumnes River is a notable exception). The smaller watersheds surrounding the Bay have shorter lag times than the Sacramento-San Joaquin watersheds, can be steep, and have negligible runoff from snowmelt. Most Bay Area watersheds are highly urbanized, including the watersheds adjacent to Oakland Harbor.

Precipitation in California is strongly influenced by atmospheric rivers and the orographic enhancement of precipitation. Atmospheric rivers are long streams of concentrated, near-surface water vapor above the Pacific Ocean which deliver masses of warm, moist air to the California Region (USACE 2015). Runoff to the San Francisco Bay is highly variable from year to year (McKee et al 2013).

3.3. Winds

The proximity of the Eastern Pacific High and a thermal low-pressure system in the Central Valley region to the east produces a general west to northwest airflow along the central and Northern California coast for most of the year. The persistence of these breezes is a major factor in minimizing air quality impacts on the people that live in the regions. As this flow is channeled through the Golden Gate bridge, once inside the Bay, it branches off to the northeast and southeast. As a result, winds often blow from the southwest in the Berkeley area and from the northwest in the South Bay. Easterly winds that blow toward the offshore water can also occur but are mainly nocturnal and during the wintertime. These land breezes may extend many miles offshore during colder months of the year until daytime heating reverses the flow onshore.

As shown in Figure 3, winds in the Oakland Harbor are predominantly from the west-southwest through the west-northwest.

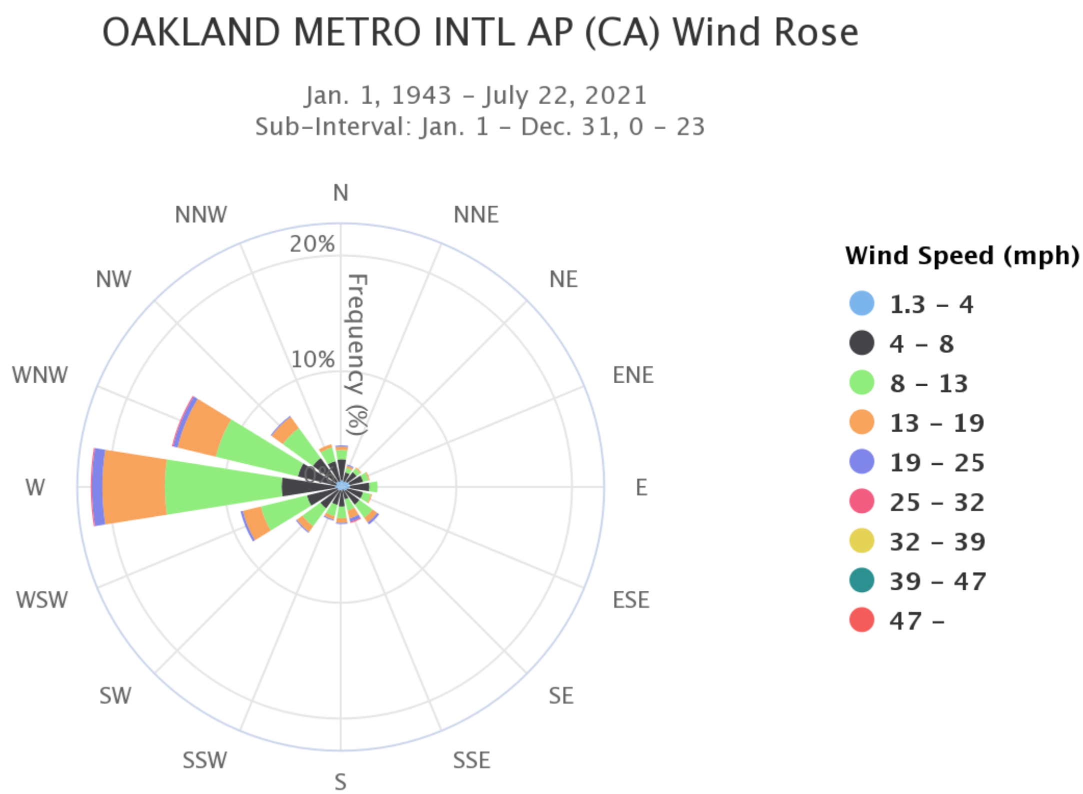


Figure 3: Wind Conditions, Oakland Metropolitan International Airport (1943-2021)

3.4. Waves

The area outside of the Golden Gate inlet is subjected to high energetic waves that are generated from swell traversing the Pacific Ocean. Portions of the central bay experience open ocean waves that pass through the Golden Gate inlet. Outside of the central bay wind generated waves are the dominant wave source. The sub regions of the San Francisco Bay are fetch limited with the predominant winds out of the west and northwest. Wave conditions at the entrance to the Oakland Harbor are not typically an issue, however the combination of waves, current, and winds can make egress and ingress of vessels to the harbor a challenge.

3.5. Tides

The tides in the San Francisco Bay are classified as mixed semidiurnal, the tidal range and elevations vary throughout the Bay. Mixed semidiurnal tides have two high and low tides per day with each tide having a unique elevation. Tidal ranges at Alameda, CA (NOAA Station 9414750) are shown in Table 2. The ranges are shown with respect to Mean Lower Low Water (MLLW) datum, as determined from the tidal epoch spanning 1983 to 2001. The mean range of the tide is 4.84 feet, while the great diurnal range is 6.60 feet. Annual tidal peak most often occurs during the summer and winter season following a solstice. Increases in tidal elevation beyond the astronomical tide levels can be due to storm surge, El Nino-Southern Oscillation (ENSO), local wind setup, and freshwater inflows into the bay.

Table 2: Tidal Datum at Alameda, CA NOAA Station 9414750

Datum Plane	Elevation, Feet, MLLW
Highest Observed Water Level	9.65
Mean Higher High Water (MHHW)	6.60
Mean High Water (MHW)	5.98
Mean Tide Level (MTL)	3.56
Mean Sea Level (MSL)	3.45
Mean Low Water (MLW)	1.14
North American Vertical Datum 1988 (NAVD88)	0.23
Mean Lower Low Water (MLLW)	0.00
Lowest Observed Water Level	-2.57

3.6. Currents

Predominant currents in San Francisco Bay outside of the Oakland Harbor entrance are in the north-south direction, perpendicular to the current directions inside the inner and outer harbors. Shear or cross currents at the entrance to Oakland Harbor provide navigational challenges, often forcing ships to enter the channel in the up-current side to avoid being grounded on the down-current side of the channel. Ebb currents exiting the inner harbor channel have a northwest direction. Flood currents have a southeasterly direction. Tidal current velocities exiting the inner harbor near Berth 38 can regularly exceed 2 knots.

Current velocity data in the Oakland Inner Harbor is available from two National Oceanic and Atmospheric Administration (NOAA) stations (SFB1213 & SFB 1214) deployed during a current survey which measured currents velocities between May 21, 2012 and July 13, 2012. The acoustic doppler current profilers (ADCP) deployed by NOAA were located at 37.79500° N, -122.31830° W (SFB1213) and 37.79290° N, -122.28552° W (SFB1214). SFB1213 was located in the Inner Harbor Channel Near Berth 56. SFB1214 was located to the east of the existing turning basin, see Figure 4. Due to the instrumentation at station SFB1213 flipping on its side during deployment there is limited valid data available. The instrument did right itself eventually and continued to collect data. The total collection period for station SFB1213 was May 21, 2012 22:12:00 UTC through May 29, 2012 16:00:00 UTC and July 4, 2012 16:36:00 UTC through July 12, 2012 21:54:00 UTC. The total collection period for Station SFB1214 was from May 22, 2012 00:30:00 UTC to July 13, 2012 00:24:00 UTC.

Figure 4: NOAA 2012-2013 Current Survey Locations in Oakland Inner Harbor

The tidal current velocity data from the NOAA deployed ADCPs was averaged over the depth of the water column. The data shows that the tidal currents in the Oakland Inner Harbor channel are predominantly below 0.5 knots. There are sporadic spikes in the tidal currents as seen in Figures 5 & 6, the spikes are inconsistent and are likely generated by instrumentation noise. These spikes are believed to not be true representations of the tidal currents in the channel.

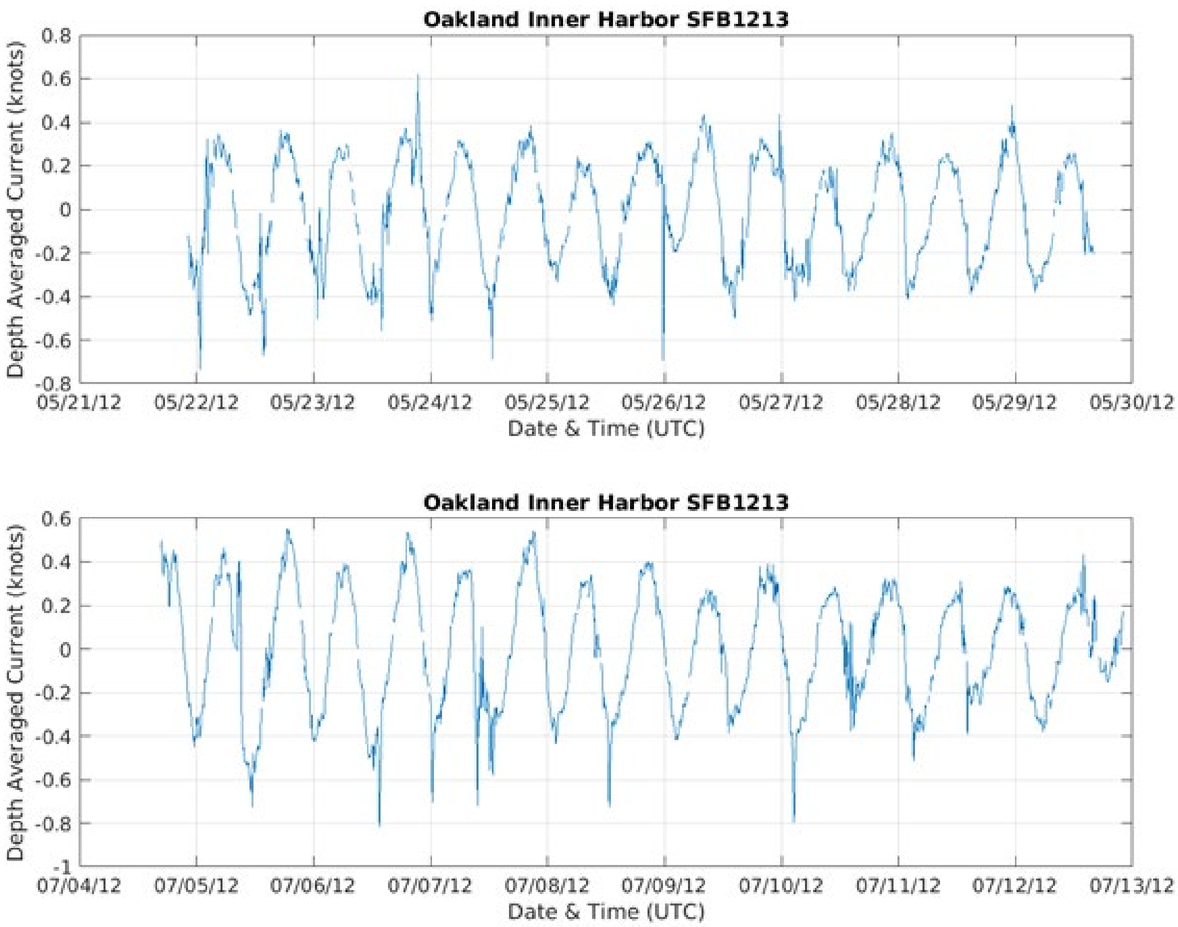


Figure 5: Depth Averaged Current Data for NOAA Station SFB1213

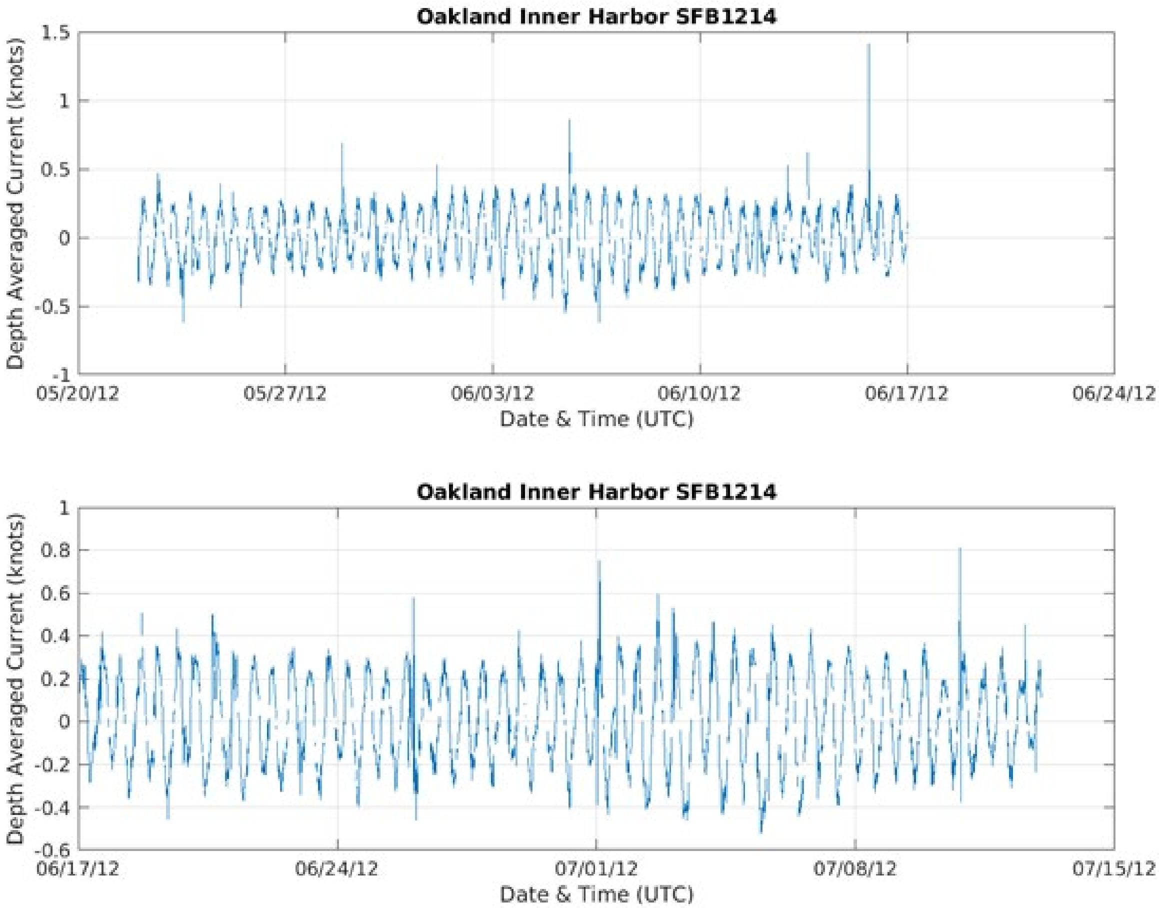


Figure 6: Depth Averaged Current Data for NOAA Station SFB1214

3.7. Geology

The geologic formations present in the Oakland Harbor vicinity include Fill, Young Bay Mud, the San Antonio Formation, Old Bay Mud, and the Alameda Formation. These geologic units were identified during substantial subsurface explorations during the 50-foot deepening project. The formations likely encountered in the navigational channels are Young Bay Mud, San Antonio Formation (Merritt Sand), and Old Bay Mud. Young Bay Mud is a soft to medium stiff fat clay and was identified as being between 10 to 50 feet thick. The San Antonio Formation which primarily consist of Merritt Sands was found to be between 0 to 55 feet thick. Old Bay mud is a stiff to hard fat clay that occasionally contains thin lenses of fine-grained sand, it is typically found with a thickness of 50 to 110 feet. For more information on sediment characteristic see the Geotechnical Appendix (Appendix B2).

3.8. Sedimentation

The proposed project is located within the San Francisco Bay/ Delta estuarine system. The San Francisco Bay / Delta estuarine system drains over 40 percent of the land area in the state of California. Shoaling of navigation channels results from a combination of new sediments entering the system and re-suspension of existing sediment resulting from fluvial, tidal, and wind-driven waves, currents, and propeller wash. One of the main sources of sediment transport in the Oakland Harbor turning basins and channels is from propeller wash from the large propellers of the commercial vessels transiting the channel (USACE, 2021). Due to environmental conditions, vessels utilizing the Inner Harbor turning basin almost always turn in the clockwise direction, therefore the northern region of the Inner harbor turning basin shoals significantly less that than southern portion of the basin. This disparity in shoaling can be seen in 10-year average shoaling rates shown Figure 8, note the impact of propellor wash along the center of the channels as well.

The net sediment supply to the San Francisco Bay between 1995 and 2016 was 1.9 +/- 0.8 million metric tons per year, with sixty-three percent of that sediment being generated by the smaller watershed surrounding the Bay (Schoellhamer, 2018). The period of record for historical maintenance dredging volumes is from 1932 to 2020 and can be separated into five distinct periods that are separated by time periods when the expansion projects were completed. The five periods can be defined as follows: Period A (1932 to 1941), Period B (1943 to 1973), Period C (1976 to 1991), Period D (1992 to 2001), and Period E (2010 to 2020). A summary of the dredge volumes for each period can be seen in Table 3. In the most recent period, Period E, maintenance dredge volumes have ranged from approximately 400,000 cubic yards to 1,700,000 cubic yards with an average annual volume of approximately 840,000 cubic yards.

Table 3: Oakland Inner and Outer Harbor Summary of Maintenance Dredging for Period of Record (1932-2020)

Period of Record	**Period A 1932 to 1941**	**Period B 1943 to 1973**	**Period C 1976 to 1991**	**Period D 1992 to 2001**	**Period E 2010 to 2020**
Number of Years in Period	10	31	16	10	11
Total Federal Dredging in Authorized Project (cy)	3,047,882	21,703,600	5,967,361	3,563,481	9,208,854
Mean Volume (cy)	304,788	700,116	372,960	356,348	837,169
Standard Deviation	395,945	477,176	191,598	321,452	341,869

4. Design Considerations

For discussion of the design considerations regarding the widening of the Oakland Inner and Outer Harbor Turning Basins please see Appendix B1 (Channel Design). The Channel Design appendix discusses design assumptions, construction sequencing, quantities, and placement of materials dredged during the widening of the basins.

5. Operations and Maintenance

5.1. Operations and Maintenance Dredging

Historically, channel deepening and widening projects result in a net increase in operations and maintenance dredging requirements. This has been well documented over multiple historic deepening and widening projects (Rosati 2005). The Oakland Harbor channels have been widened and deepened on multiple occasions and each event has had a subsequent increase on the annual maintenance dredging volumes. Design documentation for the 50-foot deepening estimated an annual increase of approximately 112,000 cubic yards per year. As the focus of this study is limited to the Inner and Outer turning Basins, this analysis will estimate the shoaling rates of the outer boundaries of the turning basins using historical hydrographic survey data, collected annually between 2010 through 2020. This analysis utilized hydrographic survey data derived from single-beam (prior to 2012) and multibeam surveys of the Inner and Outer Harbor channels conducted by the U.S. Army Corps of Engineers, San Francisco District's Hydro Survey section. It should be noted that the multibeam surveys provide a much more detailed depiction of bathymetry than the single-beam surveys. As a result, it is likely that the bathymetric changes computed with single-beam derived data will not be as accurate as those computed with multibeam data. However, the single beam datasets are sufficiently accurate to facilitate identification of trends in bathymetric changes, such as erosion or shoaling.

As part of the Oakland Inner and Outer Harbor maintenance dredging activities, the federal channels are surveyed approximately three times a year. A condition survey (CS) is completed in the spring or summer to provide insight into the channel condition and help estimate expected dredge volumes. A before dredge survey (BD) is completed immediately prior to the commencement of the annual maintenance dredging to determine the volumes to be dredged. Finally, an after-dredge survey (AD) is completed post-dredging to determine that all dredging has been complete and to the specified depths. This data can provide insight into the morphological changes of the channel and how the bathymetry changes throughout the year.

5.1.1. Shoaling Rate

The hydrographic survey data is generated at 10 foot by 10-foot resolution, these points are then used to develop a mesh grid that produces a uniform grid that is utilized for the additional surveys in the sequence. The sequence of analysis is as follows: AD data, CS data, & BD data. This sequence is analyzed for each annual dredge cycle. The CS and BD data is interpolated on the uniform grid allowing for the vertical accretion at each individual point to be estimated. Using the dates of when the hydro surveys were conducted a shoaling rate can be estimated. The estimated shoaling rates for the regions of interest can be seen in Table 4. Additionally, the 10-year (2010 – 2020) average shoaling rate for the Oakland harbor channels can be seen in Figure 8.

This analysis focused on the boundaries of the existing turning basins as it is assumed that shoaling in these regions will be similar to the new expanded regions. The three regions analyzed are the north portion of the inner harbor turning basin, the southern portion of the inner harbor turning basin, and the eastern portion of the outer harbor turning basin. The analysis regions are shown in Figure 7. The analysis only included the areas within the existing federal navigation channels and did not include the side slopes outside of the channel limits. The tentatively selected plan proposes expanding the Oakland Inner and Outer Harbor turning basins by approximately 636,600 square feet and 665,400 square feet, respectively. Maximum allowable dredging depth for Oakland Inner and Outer Harbors includes 2 feet of over dredge tolerance beyond the project design depth to account for inaccuracies during dredging operations and to ensure design depth is maintained in the channels. The annual increase to O&M dredge material volumes presented here include the overdepth material. The estimated volume increase includes 90 percent of the first foot of overdepth and 15 percent of the second foot of overdepth. These percentages of included overdepth are based on assumptions from historical dredge volumes and discussions with District personnel. It is estimated that widening the Oakland Harbor Turning basins will increase the annual O&M paid dredge material volume by approximately 86,000 cubic yards per year and the Annual O&M total dredge material volume by approximately 93,000 cubic yards per year. It must be clarified that these volumes are only estimates, and that actual shoaling rates are expected to vary significantly from year to year, depending on rainfall and other climate drivers. The data analysis period includes both wet and dry water years.

Table 4: Oakland Turning Basin Shoaling Rates and Proposed O&M Annual Dredge Volume Increase

Analysis Region	**Shoaling Rate (ft/yr)**	**Proposed Turning Basin Expansion (ft^2)**	**Annual Increase to Paid O&M Dredging Volume (cy)**	**Annual Increase in O&M Dredging Volume (cy)**
Northern Limits of the Oakland Inner Harbor Turning Basin	0.30	330,412	14,663	16,499
Southern Limits of the Oakland Inner Harbor Turning Basin	0.58	306,198	16,751	18,452
Northern Limits of the Oakland Outer Harbor Turning Basin	1.31	665,359	54,476	58,172
Total			**85,890**	**93,123**

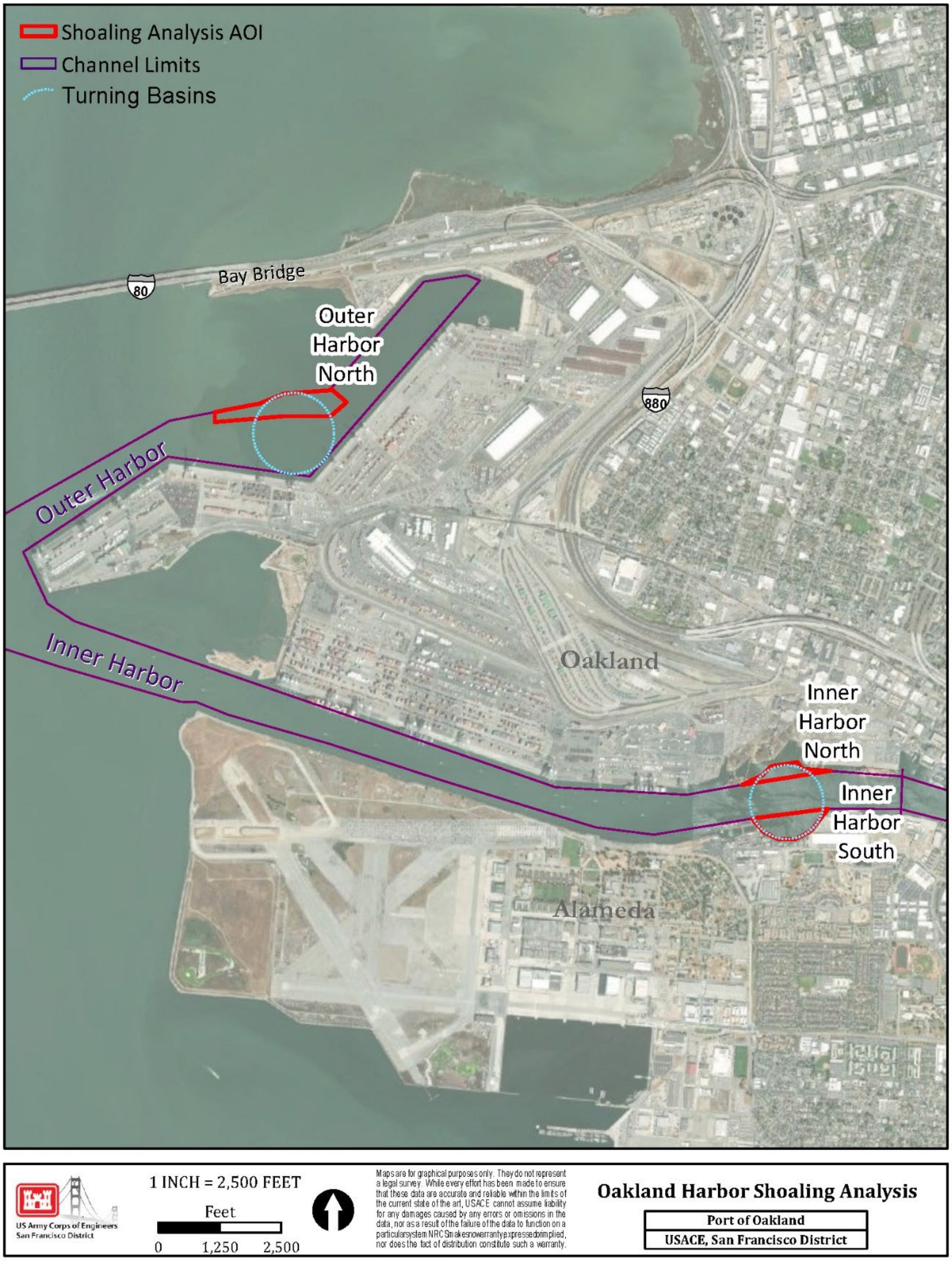


Figure 7: Areas of Shoaling Analysis for the Oakland Inner and Outer Harbor Turning Basins

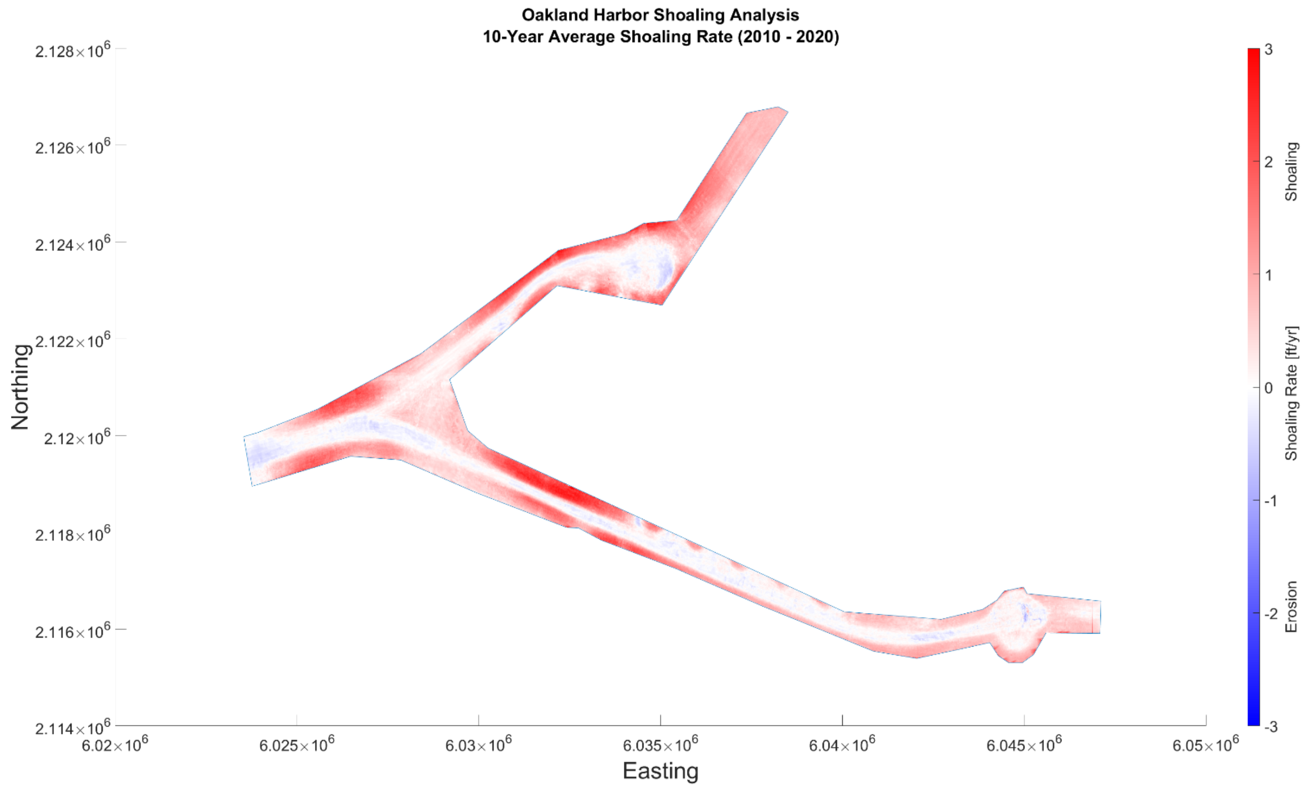


Figure 8: 10-Year average shoaling rate for Oakland Harbor

5.1.2. Shoaling Depths and Patterns

To examine the annual variability in sedimentation depths and patterns at the Oakland Harbor project site, as built hydrosurvey data from 2013 was compared to annual before dredge hydrosurvey data for years from 2014 through 2020 (Figure 9-Figure 15). Spatial patterns of erosion and deposition are similar for all years. Erosion in the center of the dredged channels generally increases (i.e., gets deeper) year after year. Deposition along the channel sides can either increase or decrease from year to year (i.e., depth of deposits is variable). The maps have not been normalized. The analysis period includes both wet and dry water years.

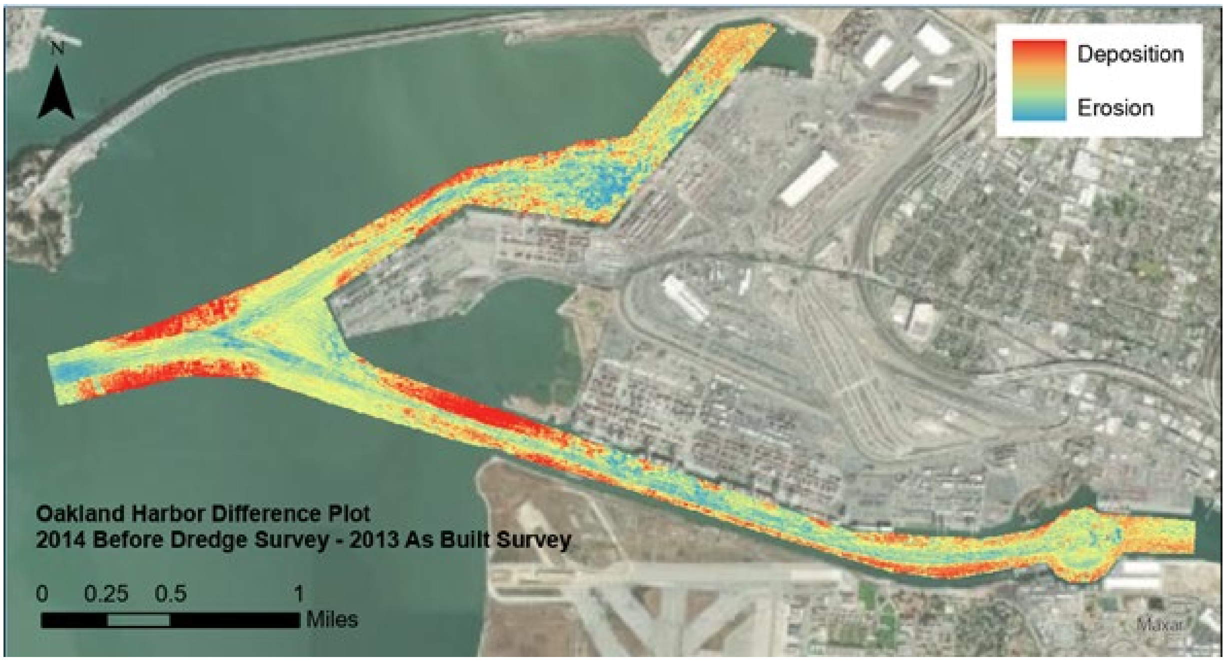


Figure 9: 2014 Difference Plot

Figure 10: 2015 Difference Plot

Figure 11: 2016 Difference Plot

Figure 12: 2017 Difference Plot

Figure 13: 2018 Difference Plot

Figure 14: 2019 Difference Plot

Figure 15: 2020 Difference Plot

5.1.3. Dredge Material Management

The USACE is currently in the process of developing a Regional Dredge Material Management Plan (RDMMP) for the San Francisco Bay area, which will outline strategies for future management of dredged sediment from the federal channels. Since 2011, dredge material from annual O&M dredging in Oakland Harbor has been placed at various locations including the Montezuma Wetland Restoration Project (MWRP), Hamilton Wetland Restoration, Winter Island upland beneficial reuse sites, the Alcatraz disposal site (SF-11), and at the San Francisco Deep Ocean Disposal Site (SF-DODS). The volume of dredge material removed from the Oakland Harbor channel and deposited at the placement sites between 2010 and 2020 can be seen in Table 5.

Table 5: Oakland Harbor O&M Dredge Material Placement Volumes at Individual Placement Sites (source: DMMO annual reports)

	Placement Volume (cy)					
Year	**SF-11**	**MWRP**	**Hamilton**	**Winter Island**	**SF-DODS**	**Total**
2010	0	0	290,378	4,000	0	294,378
2011	233,506	50,021	594,120	0	0	877,647
2012	0	727,722	0	0	302,500	1,030,222
2013	124,200	358,597	0	0	1,473,200	1,955,997
2014	0	341,808	0	0	0	341,808

2015	0	197,491	0	0	107,393	304,884
2016	0	503,823	0	0	596,590	1,100,413
2017	0	0	0	62,159	554,900	617,059
2018	0	460,931	0	0	481,306	942,237
2019	0	708,499	0	0	99,448	807,947
2020	0	0	0	0	873,553	873,553

SF-DODS is the deepest (~9,000 ft) ocean dredged material disposal site in the United States and is located approximately 55 nautical miles offshore of San Francisco. The annual capacity limit for SF-DOS is 4.8 million cubic yards per year, as set by the Environmental Protection Agency (EPA). The annual volume of material placed at SF-DODS can be found in Table 6. Placement quantities have rarely approached the EPA capacity during the last 30 years; therefore, it can be determined that SF-DODS will have sufficient capacity to handle the estimated increase to the annual O&M maintenance dredging due to widening the Oakland Harbor turning basins.

Table 6: Annual Placement of Dredge Material at the San Francisco Deep Ocean Disposal Site

Disposal Year	Estimated Volume (cy)	Source
1993	1,200,000	EPA SMMP, 2010
1995	243,980	EPA SMMP, 2010
1996	1,022,254	EPA SMMP, 2010
1997	4,642,864	EPA SMMP, 2010
1998	2,561,584	EPA SMMP, 2010
1999	350,200	EPA SMMP, 2010
2000	775,000	2020 DMMO Annual Report
2001	566,679	2020 DMMO Annual Report
2002	866,400	2020 DMMO Annual Report
2003	1,113,814	2020 DMMO Annual Report
2004	341,000	2020 DMMO Annual Report
2005	137,717	2020 DMMO Annual Report
2006	954,456	2020 DMMO Annual Report
2007	1,554,362	2020 DMMO Annual Report
2008	175,855	2020 DMMO Annual Report

2009	72,289	2020 DMMO Annual Report
2010	285,460	2020 DMMO Annual Report
2011	652,970	2020 DMMO Annual Report
2012	772,760	2020 DMMO Annual Report
2013	1,632,515	2020 DMMO Annual Report
2014	130,006	2020 DMMO Annual Report
2015	717,555	2020 DMMO Annual Report
2016	758,887	2020 DMMO Annual Report
2017	922,594	2020 DMMO Annual Report
2018	643,308	2020 DMMO Annual Report
2019	246,188	2020 DMMO Annual Report
2020	1,010,317	2020 DMMO Annual Report

Note: Estimated volumes do not include dredging outside the LTMS/DMMO area

5.1.4. SLC and Shoaling Impact on Projects

As sea levels rise around the world, the depth within navigational channel is increased negating the effects of shoaling. As rates of sea level rise increase, design depths in channel will require less maintenance dredging.

6. Further Analysis and Design Development Needs

6.1. Hydrodynamic and Sediment Modeling and Analysis

Hydrodynamic modeling was initially planned for the preliminary portion of this feasibility study. It was, however, determined that, given the array of alternatives being considered, the results of this modeling would not impact the selection of the tentatively selected plan. It was decided that this modeling could be prudently postponed and is now recommended for the PED phase of this study.

The San Francisco Bay Regional Dredged Material Management Plan (RDMMP) is a long-term (20-year) plan that estimates future maintenance dredging volumes, evaluates management alternatives, and selects a recommended plan (the "Federal Standard"). Oakland Harbor is included in the RDMMP. As part of the RDMMP, SPN is conducting data gaps analyses to identify Beneficial Use of Dredged Material (BUDM) opportunities, including areas affected by sea level rise.

SF Bay has a long history of studying sediment loading and supply to the Bay. In 2021, San Francisco Estuary Institute released “Sediment for Survival” (https://www.sfei.org/projects/sediment-survival) which summarized the state of science of sediment supply to the Bay, as well as sediment “demand” for baylands adaptation to sea level rise. This quantified the need for beneficial use of dredged material from navigation channels as well as other options such as watershed reconnection to the backs of marshes, and other pilot efforts to increase delivery of sediment to marshes through Beneficial Use. This information is being built upon as SPN is working with the San Francisco Estuary Institute (SFEI), USACE Engineer Research and Development Center (ERDC), and the Institute for Water Resources (IWR) to conduct modeling and analysis efforts to identify priority locations for beneficial use in the near- and long-term, and to quantify comprehensive benefits (i.e., environmental, social, economic) of new placement sites and methods. These efforts are a response to data gaps identified by regional stakeholders including local, state, and federal resource management agencies, ports, and the dredging industry (collectively referred to as the Interagency Working Group). Specifically, four efforts were contracted based on the data gaps identified: Sediment Transport Modeling; Regional Analysis Report; Ecological Model; and a Sediment Monitoring Framework. Additionally, Benefits Analysis and a Decision Support Tool are under development in coordination with ERDC and IWR. Through the sediment transport task, ERDC, SPN and partners are developing a 2-D hydrodynamic model of SF Bay to test locations that would be suitable for BU methods such as strategic placement and water column seeding as sea levels rise. The RDMMP PDT is targeting a recommended plan by 1st quarter FY 2024 alongside a contracted NEPA Environmental Assessment. The intent is to have an approved regional base plan for the 11 federal navigation projects within SPN for the FY 2025 – 2034 O&M dredging program in time for the FY 2025 dredging season. Subsequent RDMMP updates may be implemented (per WRDA 2020 Section 125c guidance) as new placement sites and methods come online.

6.2. Ship Simulation Modeling

Ship navigation modeling was initially planned for the preliminary portion of this feasibility study. Navigation modeling was to be conducted at the ERDC Ship/Tow simulator in Vicksburg, MS with assistance from the San Francisco Bar Pilots. Pilots were planned to pilot a simulated ship at the ERDC facility to determine whether the proposed turning basin widenings are sufficient for a range of weather, current, tide and traffic scenarios. It was decided that this modeling could be prudently postponed and is now recommended for the PED phase of this study.

7. Climate Assessment

A summary of climate risk is presented in Table 7.

Table 7. Climate Risks Table

Residual Risks					
Project Feature or Measure	**Trigger**	**Impact or Hazard**	**Harm**	**Qualitative Likelihood**	**Justification for Rating**

Dredging Requirements (O&M costs)	Increased temperature. Increased precipitation from more frequent high intensity storms. Sedimentation (supply).	Sediment supply to San Francisco Bay increases	Sediment in channel	Low	Temperature and precipitation increase associated with climate change projections trigger processes which increase wildfire frequency and magnitude in the watersheds supplying sediment to San Francisco Bay. The SF Bay watershed is highly urbanized and could be less impacted by the future wildfires that could increase existing sediment supply.
Dredging Requirements (O&M costs)	Relative Sea Level Change	Sea level change may change local hydrodynamics	Sediment in channel	Low	Observed shoaling magnitudes are variable in the project area. O&M dredging requirements may change due to ship traffic and local hydrodynamics due to sea level rise which could increase the existing deposition potential. The increase in depth to the navigation channel may offset any increase in deposition
Navigation depth requirement	Relative Sea Level Change	Sea level rise may offset the navigation depth requirement.		Low	Sea levels are trending along the low curve, project design maintains depth requirement, high sea level rates will not

					impact depth requirement
Port Infrastructure	Relative Sea Level Change	High frequency coastal water levels/tidal flooding	Inundation of critical infrastructure to support navigation	Low	Sea levels at the Alameda tide gage are trending along the low curve. Crane platform elevations do not become impacted until after 2095 under the high sea level curve scenario.

7.1. Guidance

The content of this climate assessment was prepared in accordance with USACE guidance relevant to inland hydrology and sea level change assessments. Relevant guidance at the time of this assessment is shown in Table 8.

Table 8. USACE guidance relevant to climate assessments

Guidance Document	Description	Date
ECB 2018-14	*Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies*	10 Sep 2020 (Rev 1)
ER 1100-2-8162	*Incorporating Sea Level Change in Civil Works Programs*	31 December 2019
EP 1100-2-1	*Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation*	30 June 2019

7.2. Observed and Projected Precipitation and Temperature Trends

7.2.1. Temperature

The average annual temperature of the contiguous United States has risen by approximately 1.2°F to 1.8°F over the twentieth century (Vose et al 2017). The Southwest National Climate Assessment (NCA) region experienced an increase in annual average, annual average minimum, and annual average maximum temperatures of 1.61°F between the present-day measurement period (1986-2016) and the first half of the last century measurement period (1901-1960) (Vose et al 2017). Higher air temperatures are associated with an increase in the intensity of extreme precipitation events (Easterling et al 2017). Figure 16 shows the spatial variation of temperature increases across the Southwest region.

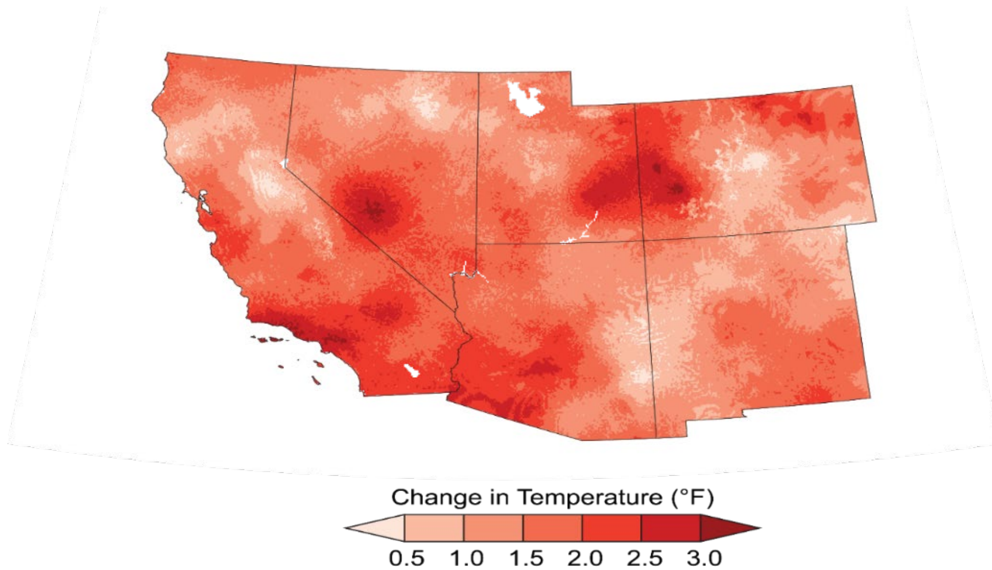


Figure 16. Difference between 1986–2016 average temperature and 1901–1960 average temperature for the Southwest Region (Gonzalez et al 2018)

Temperatures are expected to increase throughout the United States under both the low and high emissions scenarios (Figure 17). In general, northern latitudes and inland areas will experience greater increases in temperatures than coastal areas. Daily extreme temperatures (e.g., coldest and warmest daily temperatures) are also expected to increase in most areas by mid-century (Vose et al 2017).

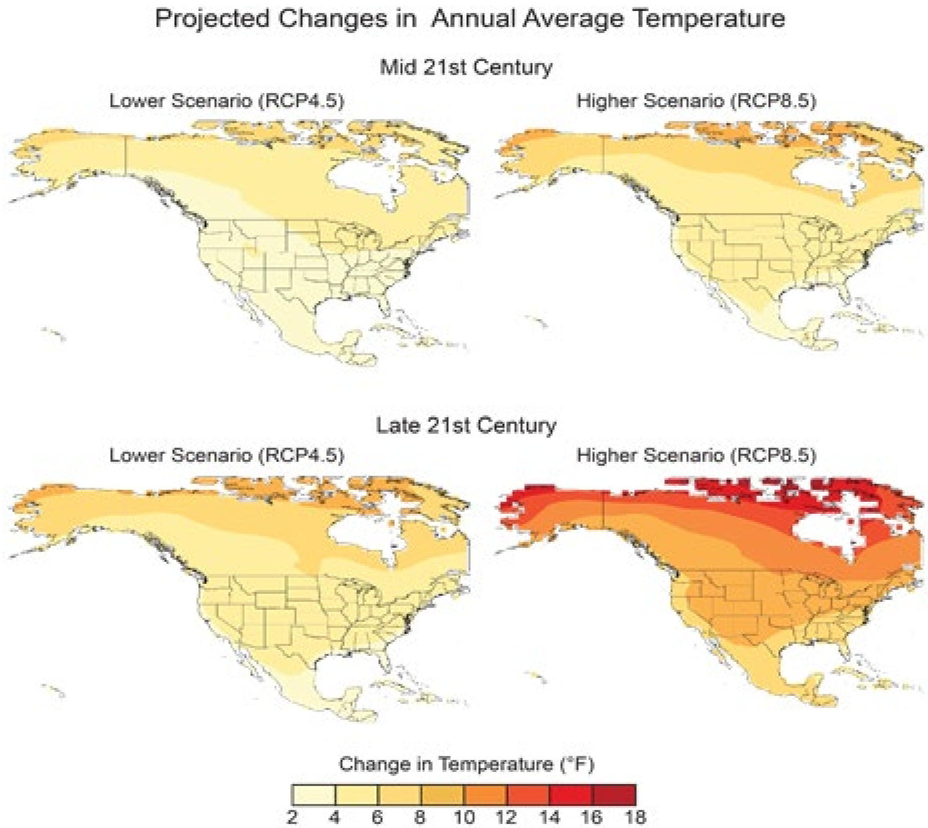


Figure 17. Projected changes in annual average temperatures (°F) for mid and late 21st century under low and high Representative Concentration Pathways (RCP) (i.e., emission) scenarios. Changes are the difference between the average for mid-century (2036–2065; top) or late-century (2070-2099, bottom) and the average for near-present (1976–2005) (Vose et al 2017)

7.2.2. Precipitation

Annual and seasonal precipitation have changed throughout the United States from the first half of the last century (1901-1960) to the present (1986-2015). Average annual precipitation for the entire country has increased by approximately 4%, but the observed change in magnitude vary by season and by region ((Easterling et al 2017; Figure 18).

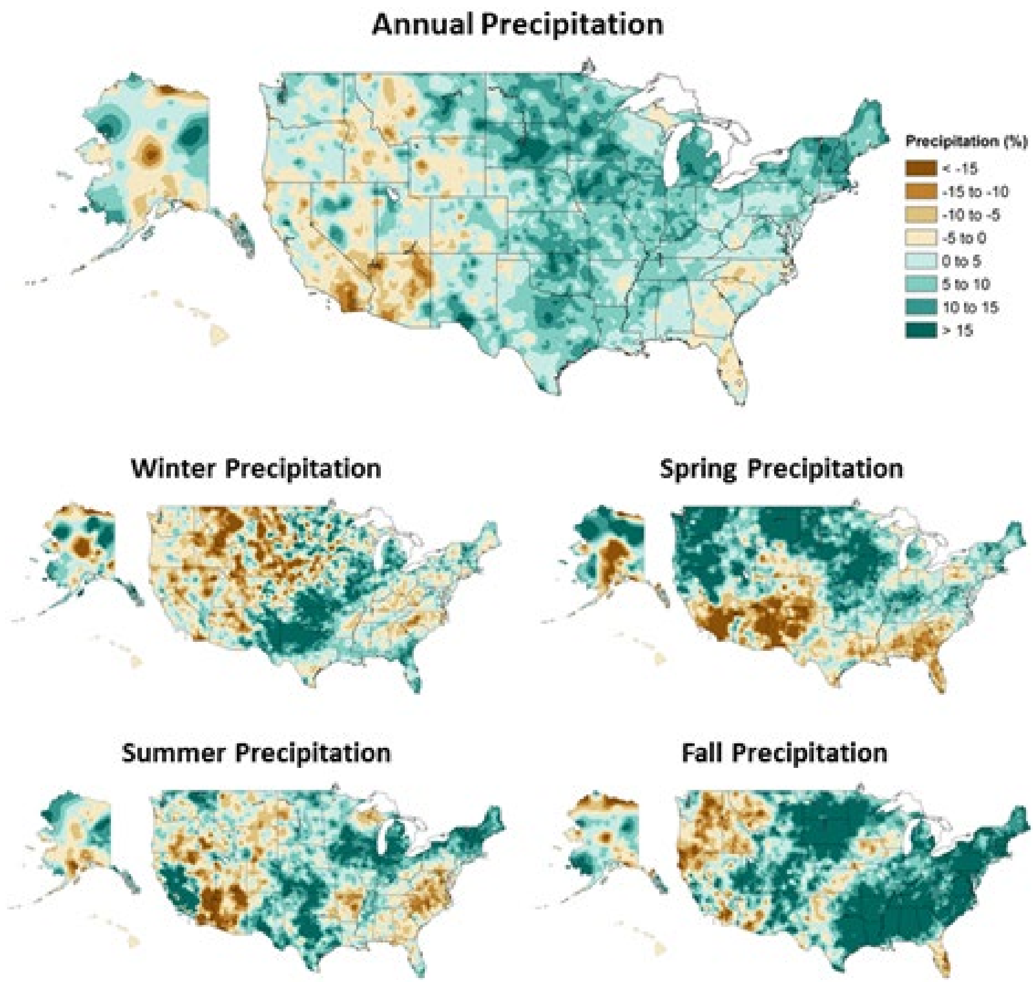


Figure 18. Annual and seasonal changes in average precipitation in the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Easterling et al 2017)

Extreme precipitation indices have also shown increases (Easterling et al 2017). Figure 19 shows a general increasing trend for most of the country in daily 20-year return level precipitation by season.

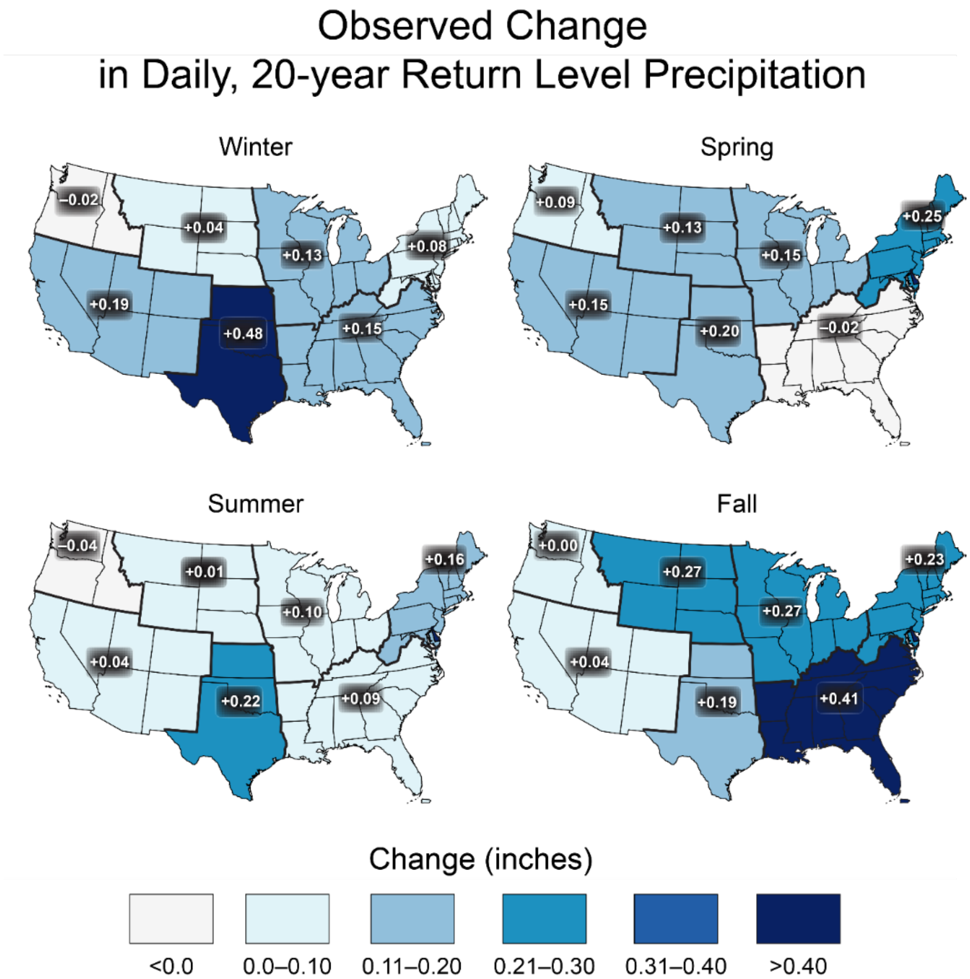


Figure 19. Observed change in the 20-year return value of the seasonal daily precipitation totals ever the period 1948 to 2015 (Easterling et al 2017)

Changes in seasonal mean precipitation is projected to vary by region across the country (Easterling 2017). Extreme precipitation is expected to increase throughout all NCA regions (Easterling 2017; Figure 20). The increases in extreme precipitation tend to increase with return level, such that increases for the 100-year return level are about 30% by the end of the century under a higher scenario (RCP8.5) (Easterling 2017). Along the West Coast, atmospheric rivers are responsible for a significant portion of annual precipitation and have historically been connected to flood events (Kossin et al 2017). Climate projections indicate greater frequency of atmospheric rivers in the future (Wehner et al 2017) and an increase in atmospheric river water vapor transport by the end of the 21st century (Easterling 2017).

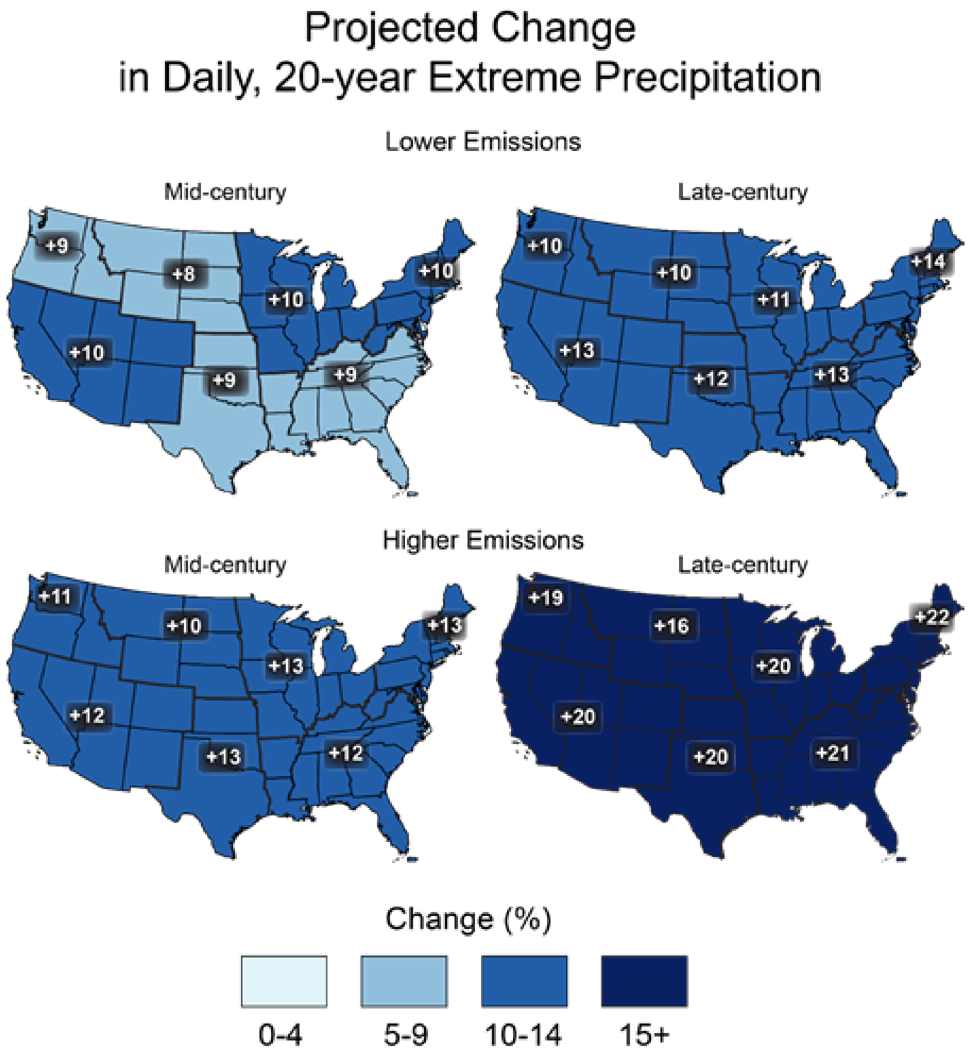


Figure 20. Projected change in the 20-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower scenario (top maps; RCP4.5) and for a higher scenario (bottom maps, RCP8.5) (Easterling et al 2017).

7.3. Sea Level Change

Sea level change is an uncertainty, potentially increasing the frequency of extreme water levels. Planning guidance in the form of an USACE Engineering Regulation (ER), USACE ER 1100-2-8162 (USACE 2019), incorporates new information, including projections by the Intergovernmental Panel on Climate Change and National Research Council (IPCC 2007, NRC 2012). Planning studies and engineering designs are to evaluate the entire range of possible future rates of sea-level change (SLC), represented by three scenarios of "low", "intermediate", and "high" sea-level change.

7.3.1. Datums

ER 1100-2-8162 also recommends that a National Oceanic and Atmospheric Administration (NOAA) water level station should be used with a period of record of at least 40 years. The water level station used for this analysis is NOAA Station 9414750 Alameda, CA, which has an 81-year period of record. NOAA currently uses the National Tidal Datum Epoch of 1983-2001 for this station. The midpoint for this tidal epoch is 1992. Datums referenced to NAVD 88 for this station are shown in Figure 21.

The use of sea level change scenarios as opposed to individual scenario probabilities underscores the uncertainty in how local relative sea levels will actually be reflected in the future. At any location, changes in local relative sea level (LRSL) reflect the integrated effects of global mean sea level (GMSL) change plus local or regional changes of geologic, oceanographic, or atmospheric origin.

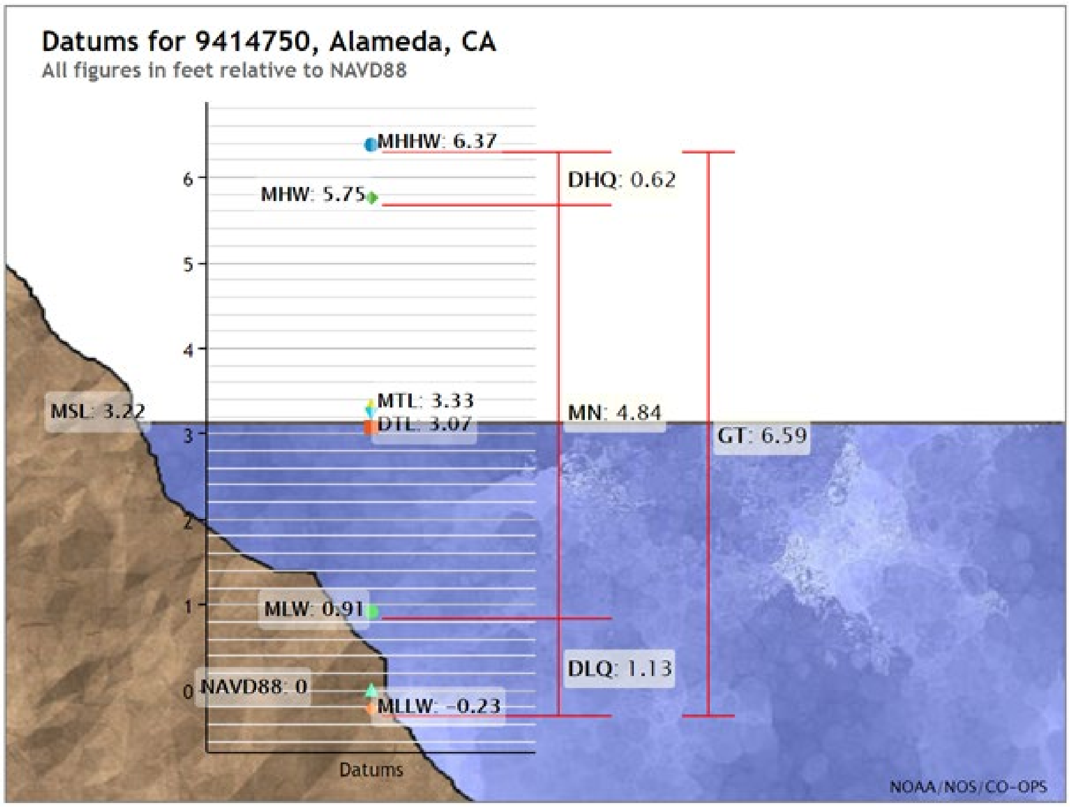


Figure 21: Datums for NOAA Station 9414750 (Alameda, CA) relative to ft NAVD88

7.3.2. Estimated Relative Sea Level Change

Utilizing the USACE Sea-Level Change Curve Calculator (Version 2021.12) and the relative sea level trend of 0.87 mm/yr (.00285 ft/yr) from NOAA station 9414750 Alameda, California (Figure 22), a projection can be made for each of the three SLC scenarios from the base year of 1992. The low USACE scenario represents historical trend, uses 1992 as a base year, and estimates relative sea level change using .00285 ft/yr. Projected rates for all three scenarios (low, medium, and high) from 1992 to 2130 are shown in Table 9 and Figure 23. With respect to deep draft navigation channel depth, any sea level rise could be seen as a net positive if channel depth increases and channel maintenance needs are reduced.

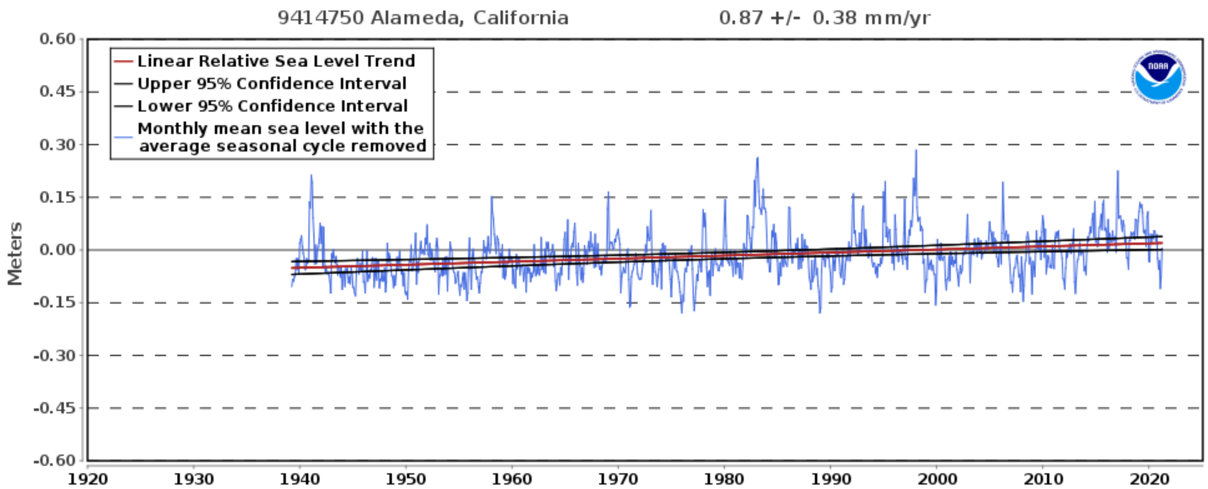


Figure 22: Relative Sea Level Trend for NOAA Station 9414750 Alameda, CA

Table 9. Estimated Relative Sea Level Change - Alameda, CA (NOAA gage 9414750)

Estimated Relative Sea Level Change from 1992 to 2030
Gauge Status: Active and compliant tide gauge
Epoch: 1983 to 2001
9414750, Alameda, CA
User Defined Rate: 0.00285 feet/yr
All values are expressed in feet relative to LMSL

Year	USACE Low	USACE Int	USACE High
1992	0.00	0.00	0.00
1995	0.01	0.01	0.01
2000	0.02	0.03	0.05
2005	0.04	0.05	0.10
2010	0.05	0.08	0.17
2015	0.07	0.11	0.26
2020	0.08	0.15	0.37
2025	0.09	0.19	0.50
2030	0.11	0.24	0.64
2035	0.12	0.29	0.81
2040	0.14	0.34	0.99
2045	0.15	0.40	1.19
2050	0.17	0.46	1.41
2055	0.18	0.53	1.65
2060	0.19	0.61	1.91
2065	0.21	0.68	2.18
2070	0.22	0.76	2.48
2075	0.24	0.85	2.79
2080	0.25	0.94	3.12
2085	0.27	1.03	3.47
2090	0.28	1.13	3.84
2095	0.29	1.24	4.23
2100	0.31	1.35	4.63
2105	0.32	1.46	5.06
2110	0.34	1.57	5.50
2115	0.35	1.70	5.96
2120	0.37	1.82	6.44
2125	0.38	1.95	6.94
2130	0.39	2.09	7.45

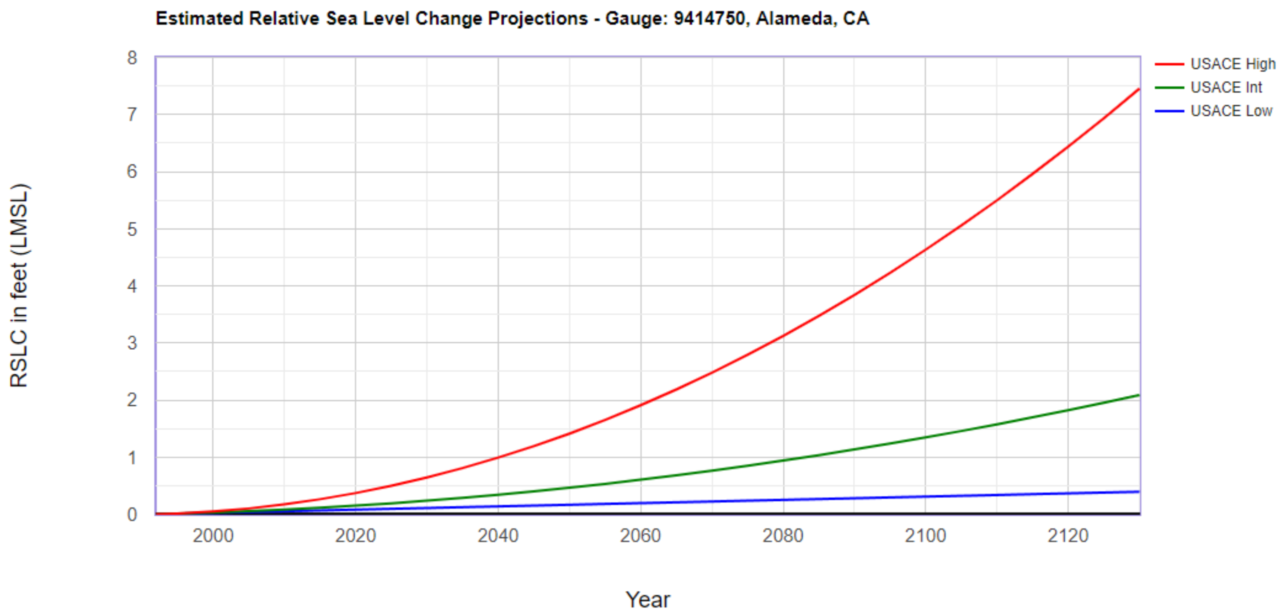


Figure 23: Relative Sea Level Rise Projections for NOAA gage 9414750 (Alameda, CA). Projections begin in 1992, the midpoint of the last tidal epoch (1983-2001). The project base year is 2030, the 50-year economic period of analysis is 2030-2080 and the 100-year adaptation horizon is 2030-2130.

7.3.3. Future Impacts of Sea Level change – Critical Thresholds

The biggest potential risk associated with SLC is inundation to the local service facilities, including the piers, sea cranes, and utilities serving the berthing areas. Impacts to facilities are assessed using the king tide elevation combined with predicted SLC scenarios plus estimates for wave setup and interannual variation in sea level (Table 10). If this combined water surface elevation exceeds the deck height of the terminals on the waterways, it is assumed to be in a condition that would require significant structural modifications. Typical container crane elevation deck heights for the Port of Oakland Terminals (Figure 24) range between 12.5 ft and 15 ft NAVD 88 (Table 11). Based on projections, this is enough to avoid inundation under the low and medium scenarios for all years, and until approximately year 2095 under the high SLC scenario (Figure 25). This indicates there is a low overall sea level rise risk to the inner and outer harbor crane decks over the 100-year project life cycle.

Figure 24: Port of Oakland Terminals. Source: https://www.portofoakland.com/wp-content/uploads/2016/03/terminal-map.jpg

Table 10. Estimated Total Water Surface Elevation for Sea Level Change Assessment

	2080 Low SLC	2080 Int SLC	2080 High SLC	2130 Low SLC	2130 Int SLC	2130 High SLC
1. Predicted king tide at Alameda gage (ft NAVD 88)	7.6					
2. Estimated Interannual Variability (ft)	0.7					
3. Estimated Wave Setup (ft)	0.3					
4. Projected RSLC (ft)	0.3	0.9	3.1	0.4	2.1	7.5
5. Total Estimated Water Surface Elevation (1+2+3+4) (ft NAVD 88)	**8.9**	**9.5**	**11.7**	**9.0**	**10.7**	**16.1**

Predicted king tide is average of NOAA annual maximum predicted tides for the Alameda station (9414750) from 1983-2001.

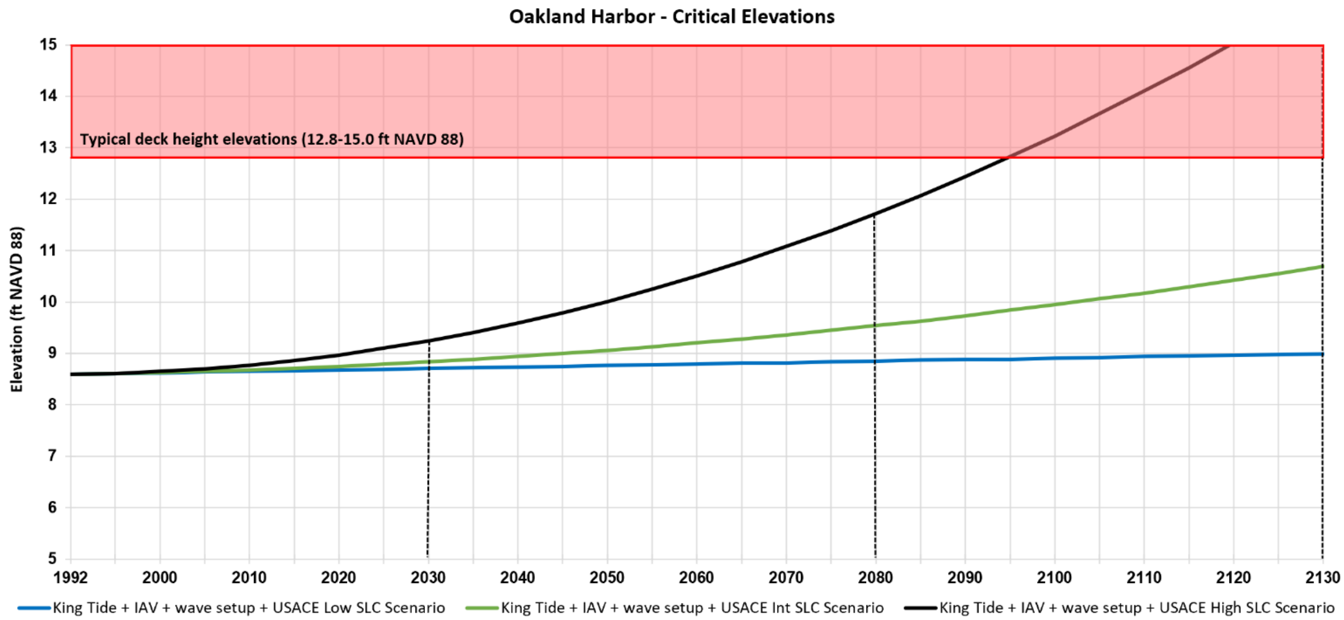


Figure 25: Critical elevations for container crane deck heights compared to estimated total water surface elevations for the project base year (2030), economic analysis period (2080), and adaptation horizon (2130).

Table 11. Container crane deck heights compared to estimated future combined water level scenarios

Terminal Name	Typical Deck Heights (ft NAVD 88)	King Tide + 2080 SLC (Low/Med/High) + estimated IAV and wave setup (ft NAVD 88)	King Tide + 2130 SLC (Low/Med/High) + estimated IAV and wave setup (ft NAVD 88)
B20-33 - TraPac and adjacent Terminal	13.4-14.5	8.9/9.5/11.7 (All scenarios are below deck heights)	9.0/10.7/16.1 (Low and medium scenarios are below deck heights)
B35-38 - Ben E Nutter Terminal	13.1-14.0		
B55-59 - Oakland International Container Terminal	13.8-15.0		
B60-63 - Matson Terminal	13.2-14.2		
B67-68 - Charles P Howard Terminal	12.5-13.2		

King Tide is estimated as 7.6 ft NAVD 88, interannual variation in sea levels is estimated as 0.7 ft, and wave setup is estimated as 0.3 ft (from Table 10).

7.3.4. Observed Changes in Mean Sea Level for Alameda, CA

The USACE Sea Level Tracker was used to compare the historical (observed) changed in mean sea level (MSL) at the Alameda NOAA CO-OPS gage against the USACE sea level change projections. The 19-year midpoint moving average tracks just below the USACE low sea level change scenario. (Figure 26)

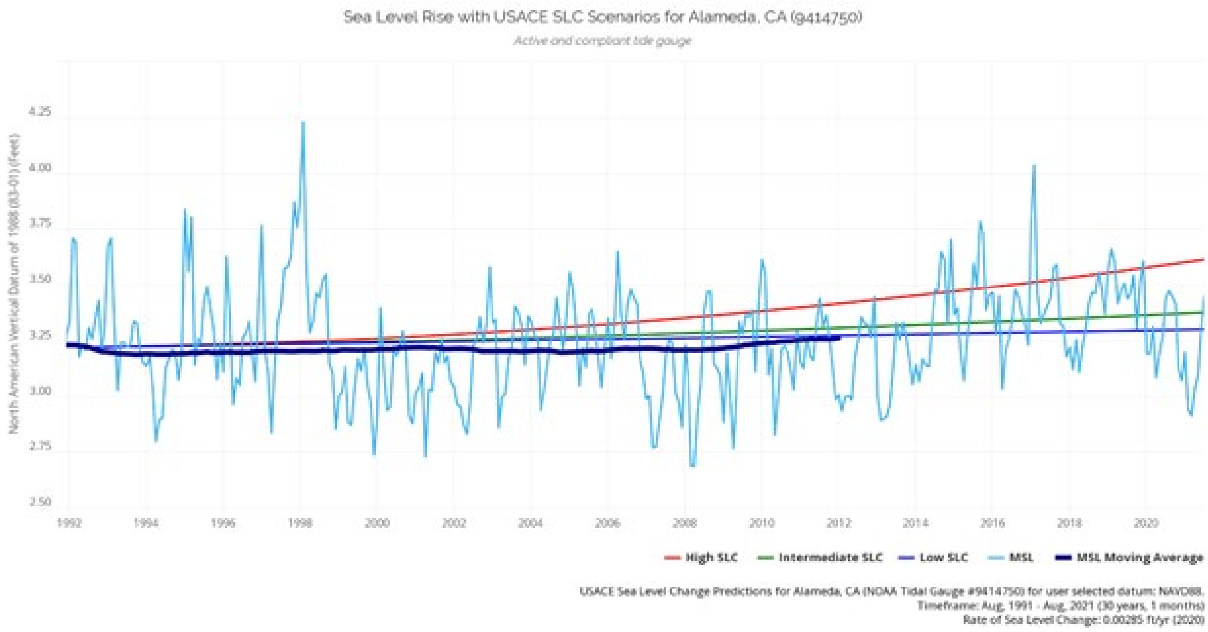
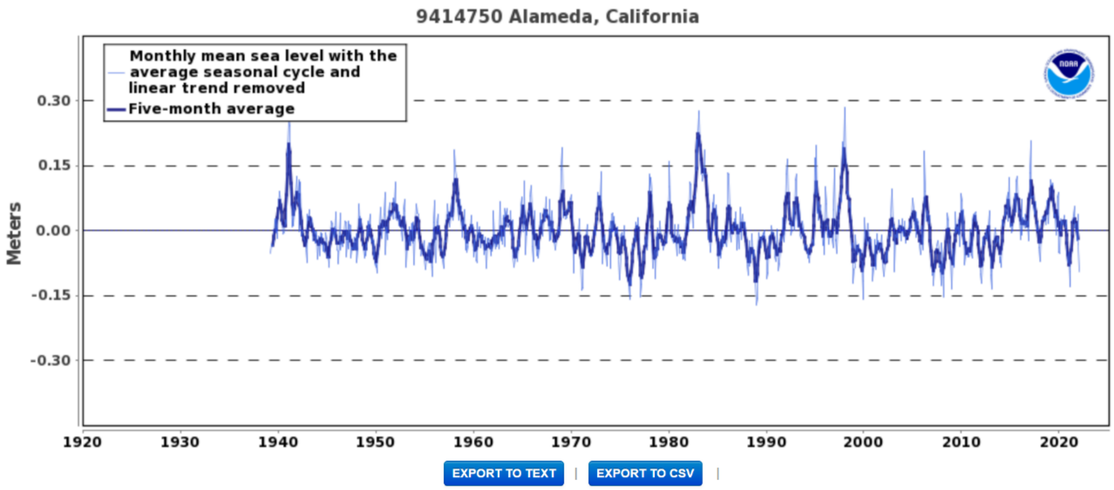


Figure 26: Historical Sea Level Rise for Alameda, CA (NOAA gage 9414750). Source: USACE Sea Level Tracker

7.3.5. Interannual Variation for Alameda, CA

An adjustment to the predicted king tide for interannual variation can be made based on the interannual variation in the historical tide record. The historical record reflects the impact that irregular fluctuations have had on actual (recorded) water surface elevations. At the Alameda gage, the highest observed magnitudes of interannual variation were observed during 1941, 1982-1983, and 1998 (Figure 27). Some of the highest averages (e.g., in 1982-1983 and 1998) have coincided with some of the highest ENSO Index values on record (i.e., during strong El Niño phases) and/or some of the highest fluvial flows on record for streams draining to the San Francisco Bay.

Interannual Variation
9414750 Alameda, California



The plot shows the interannual variation of monthly mean sea level and the 5-month running average. The average seasonal cycle and linear sea level trend have been removed. Interannual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The interannual variation for many Pacific stations is closely related to the El Niño Southern Oscillation (ENSO). If present, solid vertical lines indicate times of any major earthquakes in the vicinity of the station and dashed vertical lines bracket any periods of questionable data or datum shifts.

Figure 27: Interannual variation for NOAA Alameda tide gage. Source: https://tidesandcurrents.noaa.gov

7.4. Wildfire Hydrology

A preliminary trend analysis was conducted on historical wildfire time series data (1935-2020) for the three HUC regions. The three regions for analysis include:

- HUC4 Watershed #1802 (Sacramento)
- HUC4 Watershed #1804 (San Joaquin)
- HUC4 Watershed #1805 (San Francisco Bay)

Results of the trend analysis are shown in Table 12. All regions exhibited increasing, positive trends in acres burned over the historical period. The trends for HUC 1802 and HUC 1804 are significant (< .05 significance level) under both the Mann-Kendall and Speakman Rank-Order significance tests.

Table 12. Results of trend analysis for acres burned

	HUC 1802 - Sacramento	HUC 1804 - San Joaquin	HUC 1805 - San Francisco Bay
Trend Line Slope (Traditional)	+3398	+1263	+858
Trend Line Slope (Sen's)	+415.29	+293.83	+15.856
p-value (Mann-Kendall)	0.017683	0.000043511	0.090865
p-value (Spearman Rank-Order)	0.014286	0.000042859	0.07873

Temperature increases and precipitation changes associated with climate change projections trigger processes which increase wildfire frequency and magnitude in the watersheds supplying sediment to San Francisco Bay. Wildfires can impact watershed hydrology, sediment yield, and erosion mechanisms, typically increasing sediment yield for approximately 2-10 years post-fire (East et al 2021). There is some indication that changing climate will impact hydrology in the future, and there are clear increasing trends in wildfire acres burned in the Sacramento and San Joaquin watersheds. There is also some evidence that projected changes in streamflow will lead to increases in suspended sediment concentrations in the Sacramento River watershed (e.g., Stern et al 2020). However, not enough is known at this point about the hydrodynamics at the Oakland project site to link these trends directly to projected O&M dredging costs. Additionally, McKee et al (2013) show that much of the suspended sediment in the San Francisco Bay is supplied by tributaries surrounding the bay, which may not be highly impacted by wildfires due to urbanization (though they would potentially be impacted by any future changes in flows).

7.5. Vulnerability Assessment

The USACE Watershed Climate Vulnerability Assessment (VA) Tool facilitates a screening-level, comparative assessment of the vulnerability of a given business line and HUC-4 watershed to the impacts of climate change, relative to the other HUC-4 watersheds within the continental United States (CONUS). It uses the Coupled Model Intercomparison Project (CMIP5) to define projected hydrometeorological inputs, combined with other data types, to define a series of indicator variables to define a vulnerability score.

Vulnerabilities are represented by a weighted-order, weighted-average (WOWA) score generated for two subsets of simulations (wet—top 50% of cumulative runoff projections; and dry—bottom 50% cumulative runoff projections). Data are available for three epochs. The epochs include the current time period ("Base") and two 30-year, future epochs (centered on 2050 and 2085). The Base epoch is not based on projections and so it is not split into different scenarios. For this application, the tool was applied using its default National Standards Settings. In the context of the VA Tool, there is some uncertainty in all of the inputs to the vulnerability assessments. Some of this uncertainty is already accounted for in that the tool presents separate results for each of the scenario-epoch combinations rather than presenting a single aggregate result. Under the National Standard settings, the vulnerability threshold for each business line is typically 20% (i.e., 20% of HUC4 watersheds throughout the country are classified as the most vulnerable).

The Oakland Harbor project is in HUC 1805 (San Francisco Bay) and classified under the Navigation business line. Table 13 and Figure 27 show that HUC 1805 is among the 20% most vulnerable watersheds for the Navigation business line for all scenario/epoch combinations.

Table 13. Results of Climate Vulnerability Assessment for HUC 1805

Business Line	Epoch	Dry Subset of Scenarios	Wet Subset of Scenarios
Navigation	2050	Most Vulnerable	Most Vulnerable
	2085	Most Vulnerable	Most Vulnerable

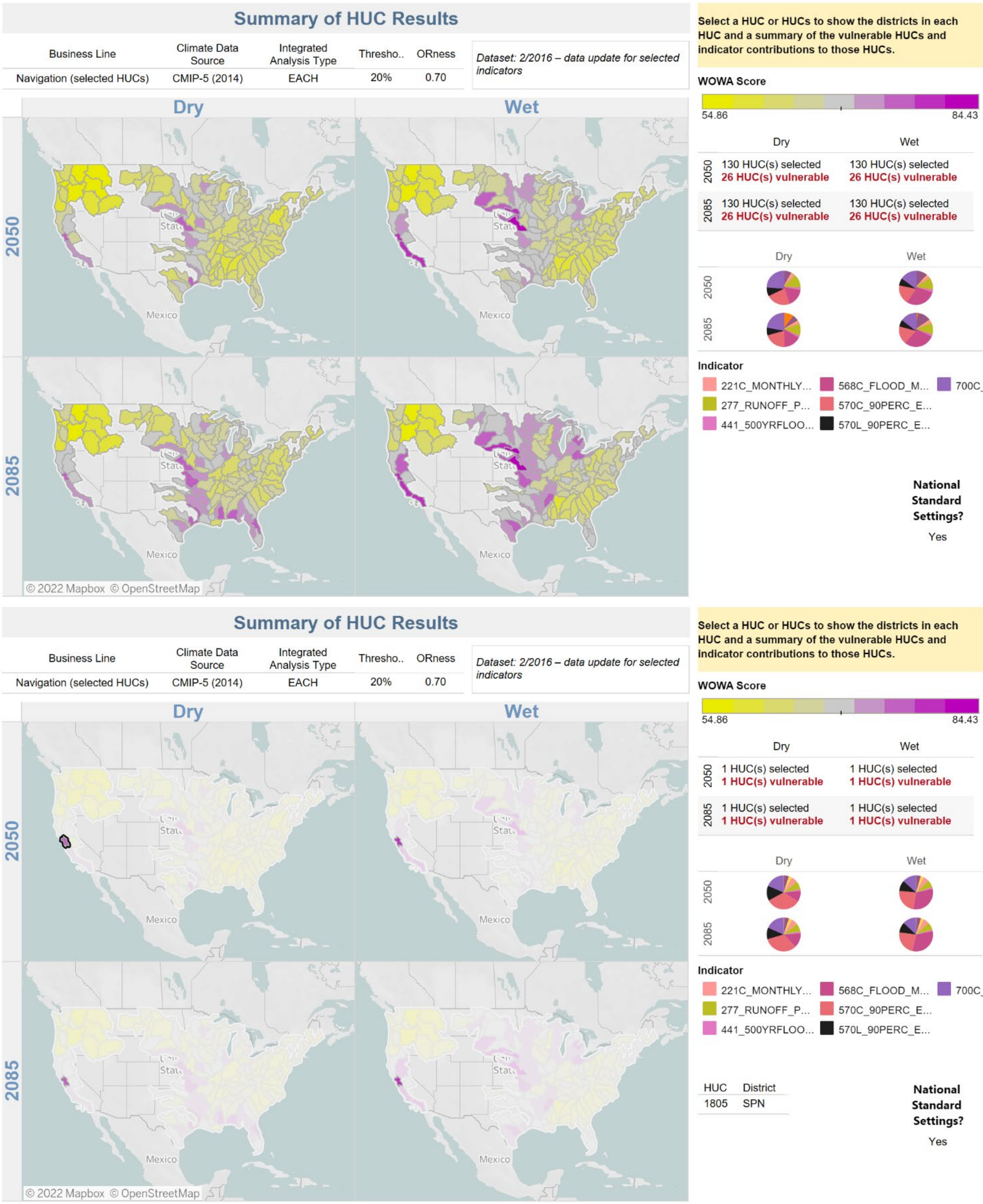


Figure 27. Top: For the Navigation Line of Business, approximately 20% of included HUC4

watersheds (26 out of 130) are considered to be among the most vulnerable watersheds nationwide. Bottom: HUC 1805 (San Francisco Bay watershed) is considered to be one of the most vulnerable watersheds under all epoch/scenario combinations.

Table 14 shows the three indicators exhibiting the highest contribution to climate change vulnerability for each scenario/epoch combination. Changes in fluvial flows are likely related to the interannual variability observed in San Francisco Bay water levels. Impacts of fluvial flows on harbor water levels may need to be investigated at later stages of the study, particularly if extreme low water levels have negatively impacted port operations in the past.

Table 14. Key Indicators for HUC 1805

Business Line	Epoch	Dry Subset of Scenarios	Wet Subset of Scenarios
Navigation	2050	1. Low Flow: Monthly Flow Exceeded 90 Percent of Time – Cumulative Runoff (570C) 2. Change in Low Flow Runoff: Ratio of Indicator 570C to Indicator 570C in the base period (700C) 3. Low Flow: Monthly Flow Exceeded 90 Percent of Time – Local Runoff (570L)	1. Flood Magnification – Cumulative Runoff (568C) 2. Low Flow: Monthly Flow Exceeded 90 Percent of Time – Cumulative Runoff (570C) 3. Change in Low Flow Runoff: Ratio of Indicator 570C to Indicator 570C in the base period (700C)
	2085	1. Low Flow: Monthly Flow Exceeded 90 Percent of Time – Cumulative Runoff (570C) 2. Change in Low Flow Runoff: Ratio of Indicator 570C to Indicator 570C in the base period (700C) 3. Flood Magnification - Cumulative Runoff (568C)	

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