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# **OAKLAND HARBOR TURNING BASINS WIDENING, CA**

## **NAVIGATION STUDY**

### **DRAFT INTEGRATED FEASIBILITY REPORT & ENVIRONMENTAL ASSESSMENT**

## **APPENDIX B4: Coastal Engineering**



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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 existing physical conditions as well as presents the findings of the engineering analysis conducted to support the development of recommended 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 west 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 is provided in the following text. The Port of Oakland is one of the busiest container Port 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

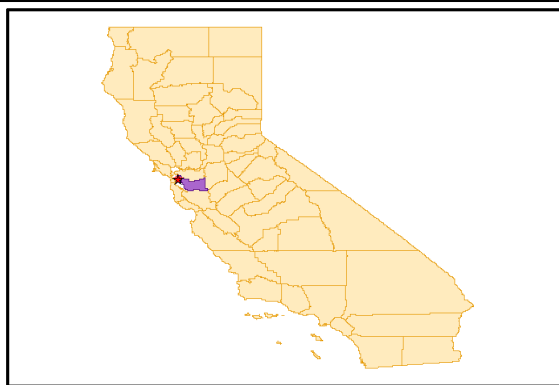
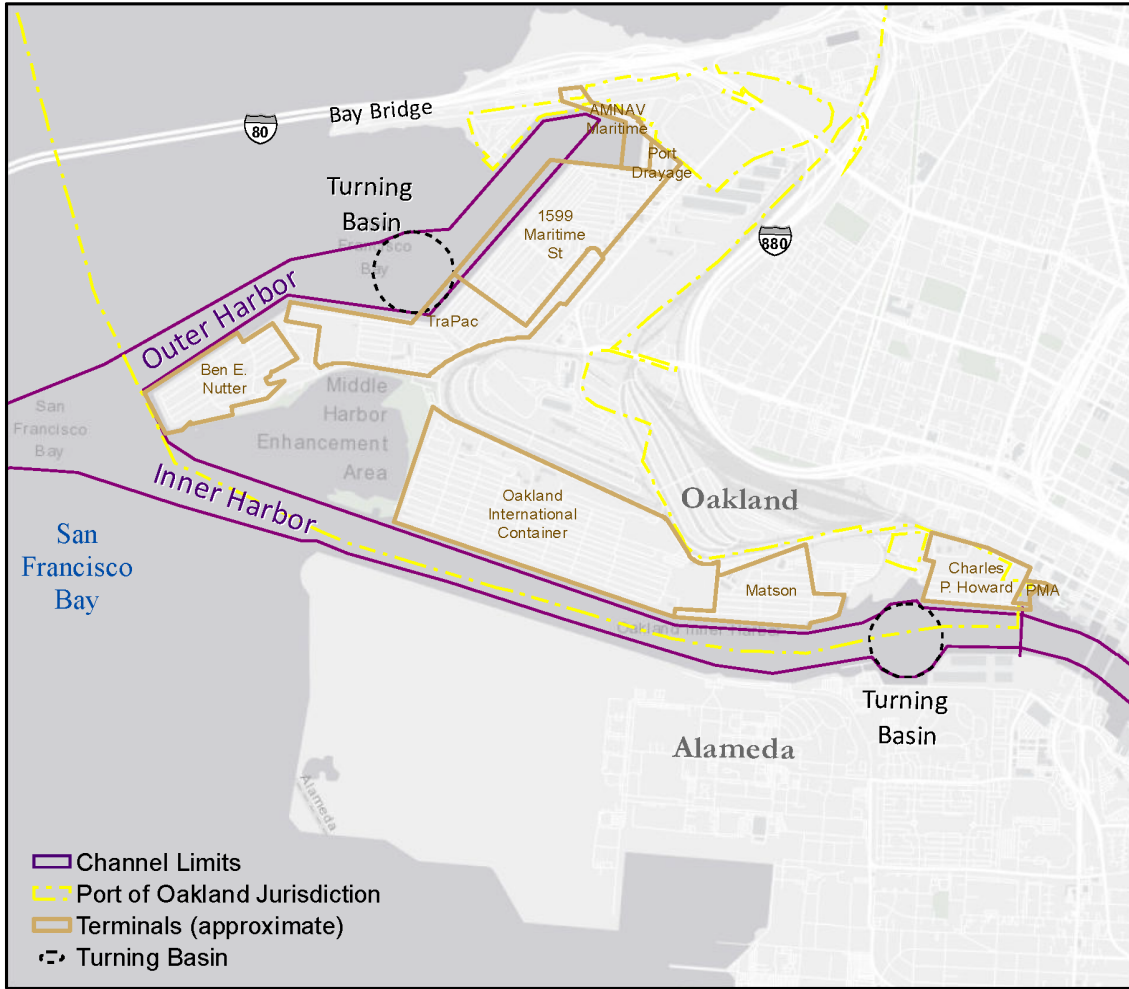
The Oakland Outer Harbor turning basin is located in the outer harbor channel near berths 25 through 30. The turning basin is located in a bend of the outer harbor channel and has a diameter of 1,650 feet and is maintained to a depth of -50 feet.


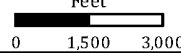

### 1.1.2. Inner Harbor Turning Basin

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.

## 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.




**1 INCH = 3,000 FEET**  



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**CA Navigation Study**  
**Port of Oakland**  
**USACE, San Francisco District**

## 3. Physical Environment

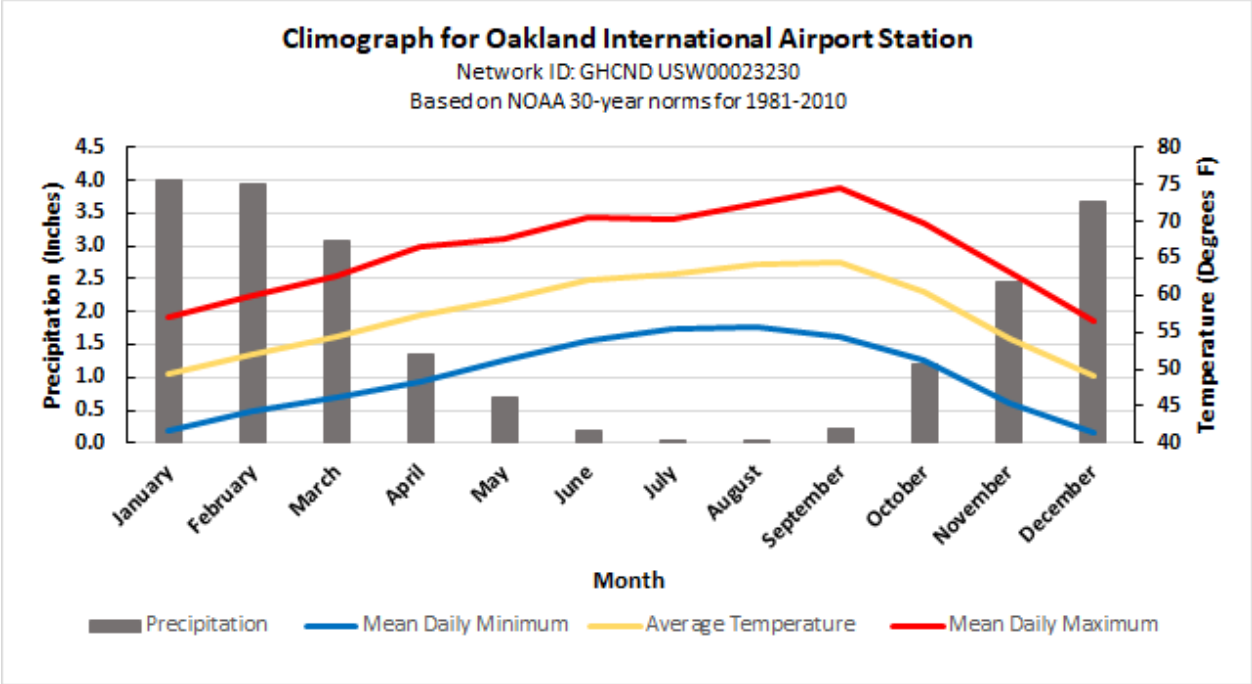
### 3.1. Climate

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 the 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.



### 3.2. Hydrology

The San Francisco Bay receives freshwater inflow and sediment loads from three watersheds (Table 1). 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 <sup>2</sup> )	Area (km <sup>2</sup> )
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 also occur but are mainly nocturnal and wintertime land breezes. 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.

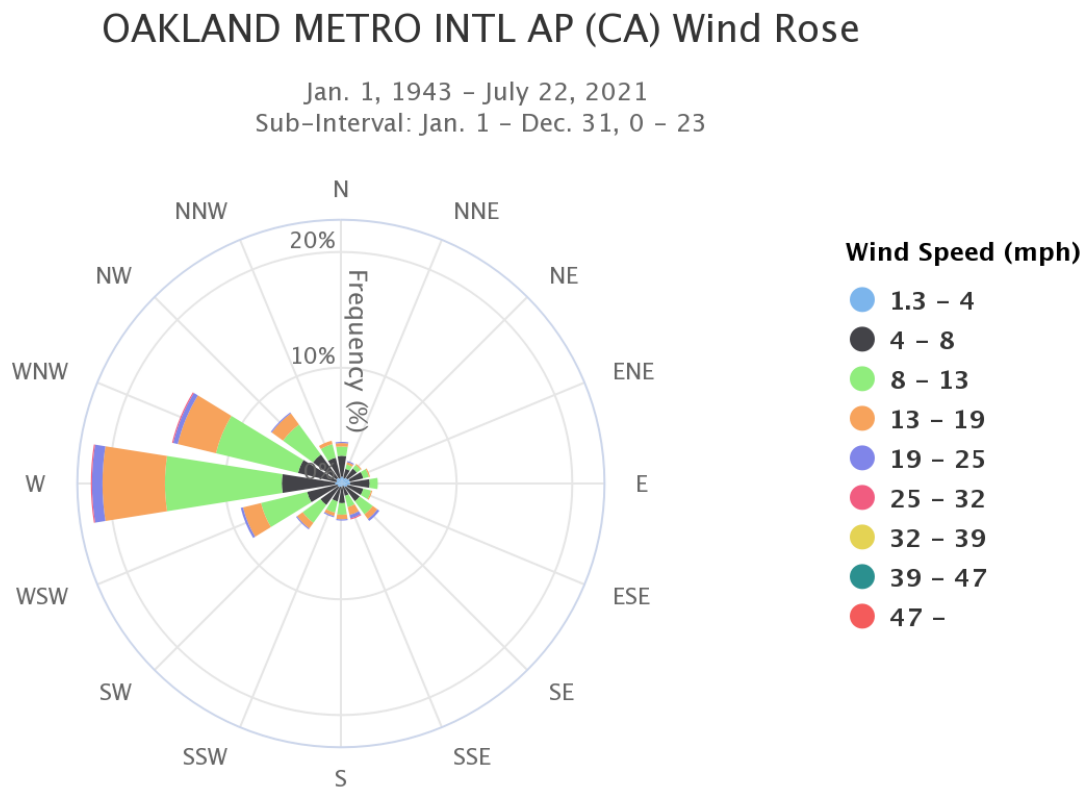


Figure 3: Wind Conditions, Oakland Metropolitan International Airport (1943-2021)

### 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 experiences open ocean waves that pass through the golden gate inlet. Outside of the central bay wind generated waves are the dominate wave source. The sub regions of the San Francisco 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 from the inner harbor channel have a northwest direction and have velocities that exceed 2 knots. Flood currents have a southeasterly direction.

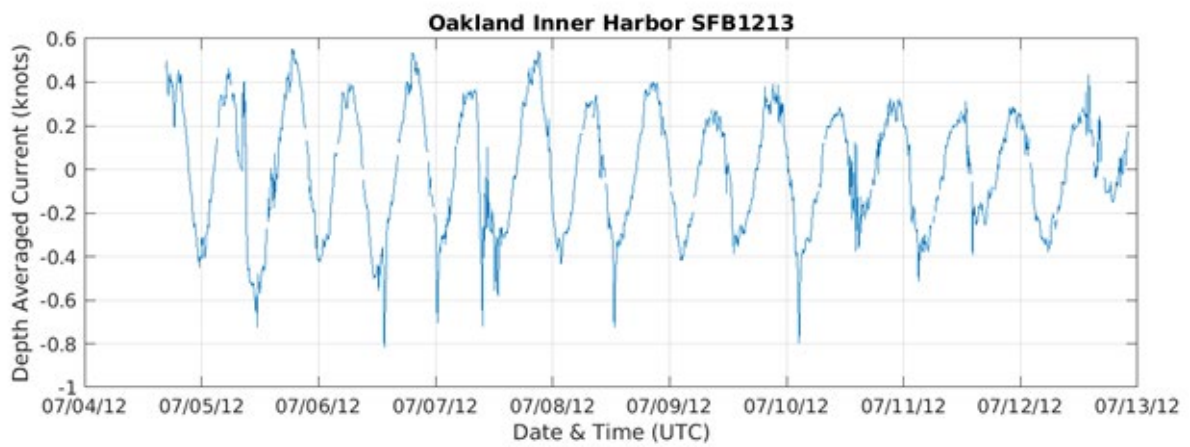
Current velocity data in the Oakland Inner Harbor is available from two National Oceanic and Atmospheric Administration (NOAA) stations (SFB1213 & SFB 1214) deployed during a current survey which measured currents velocities between May 21, 2012 and July 13, 2012. The acoustic doppler current profilers (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*

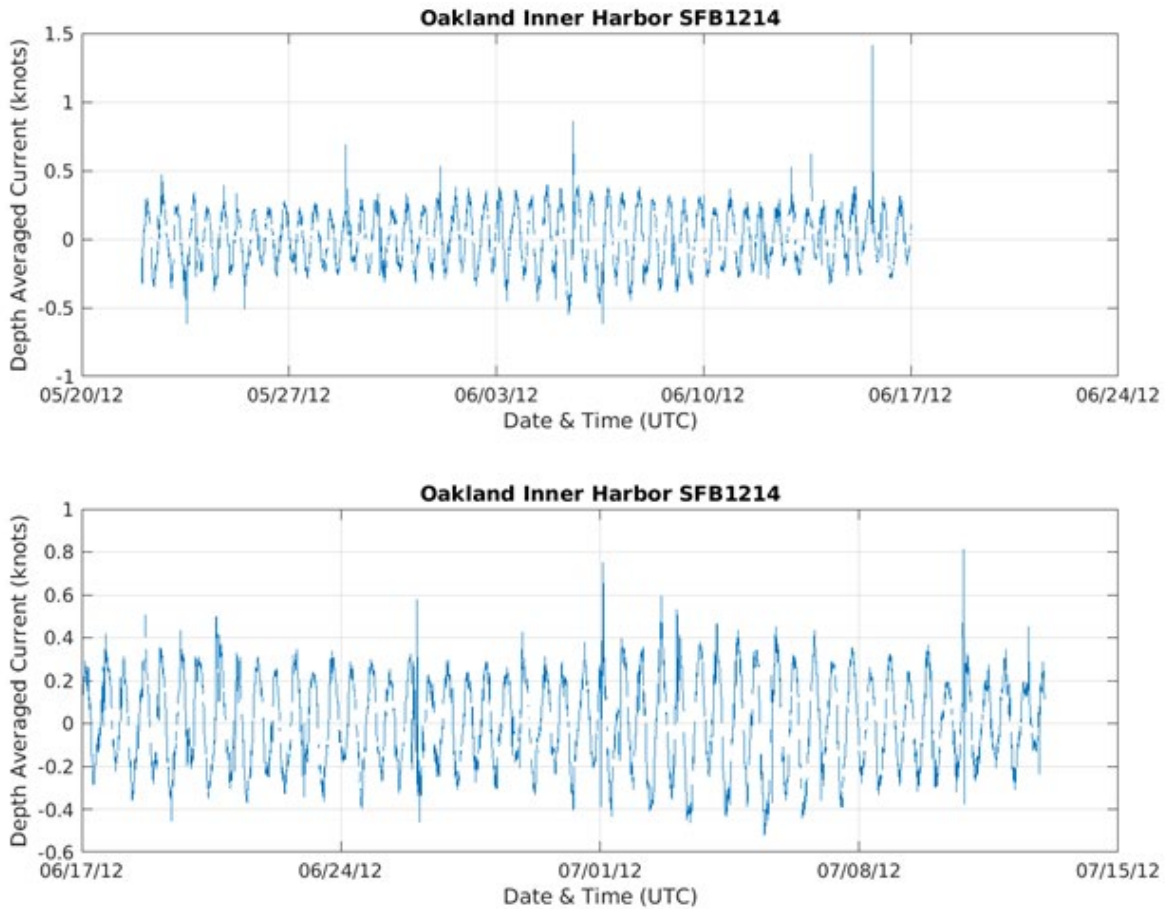


Figure 6: Depth Averaged Current Data for NOAA Station SFB1214

### 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 and 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 than southern portion of the basin. This disparity in shoaling can be seen in 10-year average shoaling rates shown Figure 9, 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: Summary of Maintenance Dredging for Period of Record (1932-2020)*

<b>Period of Record</b>	<b>Period A 1932 to 1941</b>	<b>Period B 1943 to 1973</b>	<b>Period C 1976 to 1991</b>	<b>Period D 1992 to 2001</b>	<b>Period E 2010 to 2020</b>
<b>Number of Years in Period</b>	10	31	16	10	11
<b>Total Federal Dredging in Authorized Project (cy)</b>	3,047,882	21,703,600	5,967,361	3,563,481	9,208,854
<b>Mean Volume (cy)</b>	304,788	700,116	372,960	356,348	837,169
<b>Standard Deviation</b>	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 as 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 usually 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 expected 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 tentatively selected plan proposes expanding the Oakland Inner and Outer Harbor turning basins by approximately 551,000 square feet and 458,000 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 65,000 cubic yards per year and the Annual O&M total dredge material volume by approximately 70,000 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*

<b>Analysis Region</b>	<b>Shoaling Rate (ft/yr)</b>	<b>Proposed Turning Basin Expansion (ft<sup>2</sup>)</b>	<b>Annual Increase to Paid O&amp;M Dredging Volume (cy)</b>	<b>Annual Increase in O&amp;M Dredging Volume (cy)</b>
<b>Northern Limits of the Oakland Inner Harbor Turning Basin</b>	0.30	280,170	12,433	13,990
<b>Southern Limits of the Oakland Inner Harbor Turning Basin</b>	0.58	270,897	14,820	16,325
<b>Eastern Limits of the Oakland Outer Harbor Turning Basin</b>	1.31	457,850	37,486	40,030
<b>Total</b>			<b>64,739</b>	<b>70,345</b>





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

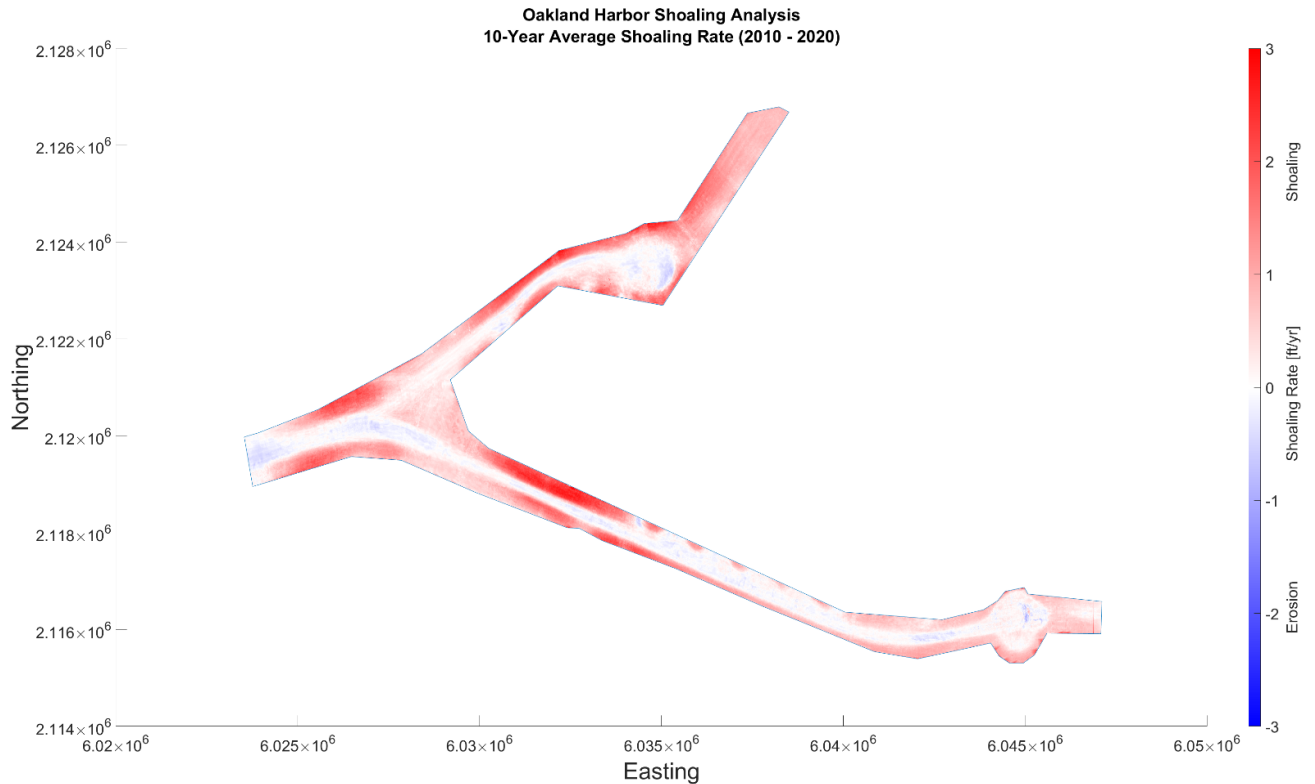


Figure 8: 10-Year average shoaling rate for Oakland Harbor

### 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)

Year	Placement Volume (cy)				
	SF-11	MWRP	Hamilton	Winter Island	SF-DODS
2010	0	0	290,378	4,000	0
2011	233,506	50,021	594,120	0	0
2012	0	727,722	0	0	302,500
2013	124,200	358,597	0	0	1,473,200
2014	0	341,808	0	0	0
2015	0	197,491	0	0	107,393

<b>2016</b>	0	503,823	0	0	596,590
<b>2017</b>	0	0	0	62,159	554,900
<b>2018</b>	0	460,931	0	0	481,306
<b>2019</b>	0	708,499	0	0	99,448
<b>2020</b>	0	0	0	0	873,553

SF-DODS is the deepest 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*

<b>Disposal Year</b>	<b>Estimated Volume (cy)</b>	<b>Source</b>
<b>1993</b>	1,200,000	EPA SMMP, 2010
<b>1995</b>	243,980	EPA SMMP, 2010
<b>1996</b>	1,022,254	EPA SMMP, 2010
<b>1997</b>	4,642,864	EPA SMMP, 2010
<b>1998</b>	2,561,584	EPA SMMP, 2010
<b>1999</b>	350,200	EPA SMMP, 2010
<b>2000</b>	775,000	2020 DMMO Annual Report
<b>2001</b>	566,679	2020 DMMO Annual Report
<b>2002</b>	866,400	2020 DMMO Annual Report
<b>2003</b>	1,113,814	2020 DMMO Annual Report
<b>2004</b>	341,000	2020 DMMO Annual Report
<b>2005</b>	137,717	2020 DMMO Annual Report
<b>2006</b>	954,456	2020 DMMO Annual Report
<b>2007</b>	1,554,362	2020 DMMO Annual Report
<b>2008</b>	175,855	2020 DMMO Annual Report
<b>2009</b>	72,289	2020 DMMO Annual Report
<b>2010</b>	285,460	2020 DMMO Annual Report

<b>2011</b>	652,970	2020 DMMO Annual Report
<b>2012</b>	772,760	2020 DMMO Annual Report
<b>2013</b>	1,632,515	2020 DMMO Annual Report
<b>2014</b>	130,006	2020 DMMO Annual Report
<b>2015</b>	717,555	2020 DMMO Annual Report
<b>2016</b>	758,887	2020 DMMO Annual Report
<b>2017</b>	922,594	2020 DMMO Annual Report
<b>2018</b>	643,308	2020 DMMO Annual Report
<b>2019</b>	246,188	2020 DMMO Annual Report
<b>2020</b>	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.

### **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
<b>Dredging Requirements (O&amp;M costs)</b>	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.
<b>Dredging Requirements (O&amp;M costs)</b>	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 will likely offset any increase in deposition

<b>Navigation depth requirement</b>	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
<b>Port Infrastructure</b>	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 2100 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.

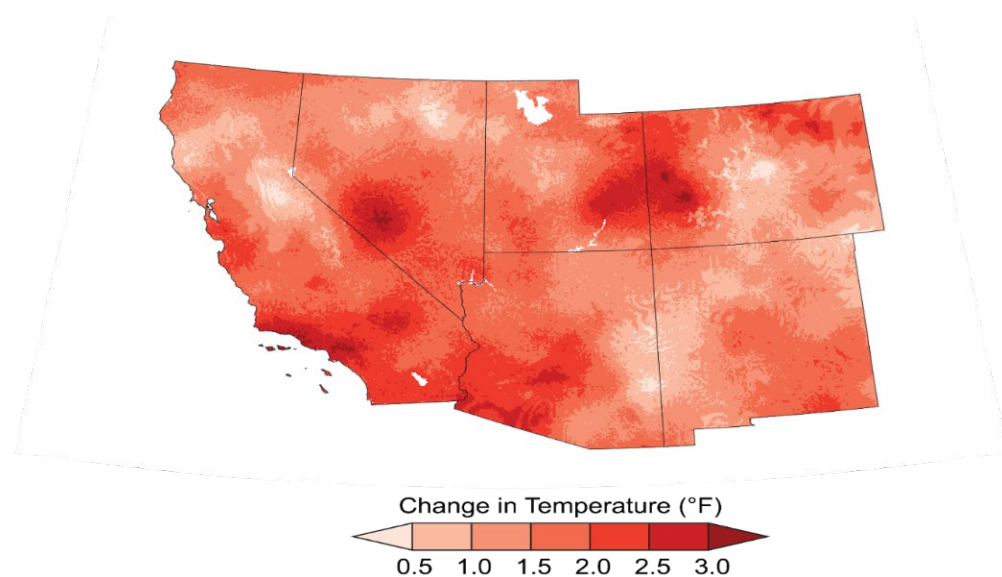
*Table 8. USACE guidance relevant to climate assessments*

<b>Guidance Document</b>	<b>Description</b>	<b>Date</b>
ECB 2018-14	<i>Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies</i>	10 Sep 2020 (Rev 1)
ER 1100-2-8162	<i>Incorporating Sea Level Change in Civil Works Programs</i>	31 December 2013
EP 1100-2-1	<i>Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation</i>	30 June 2019

## 7.2. Observed and Projected Precipitation and Temperature Trends

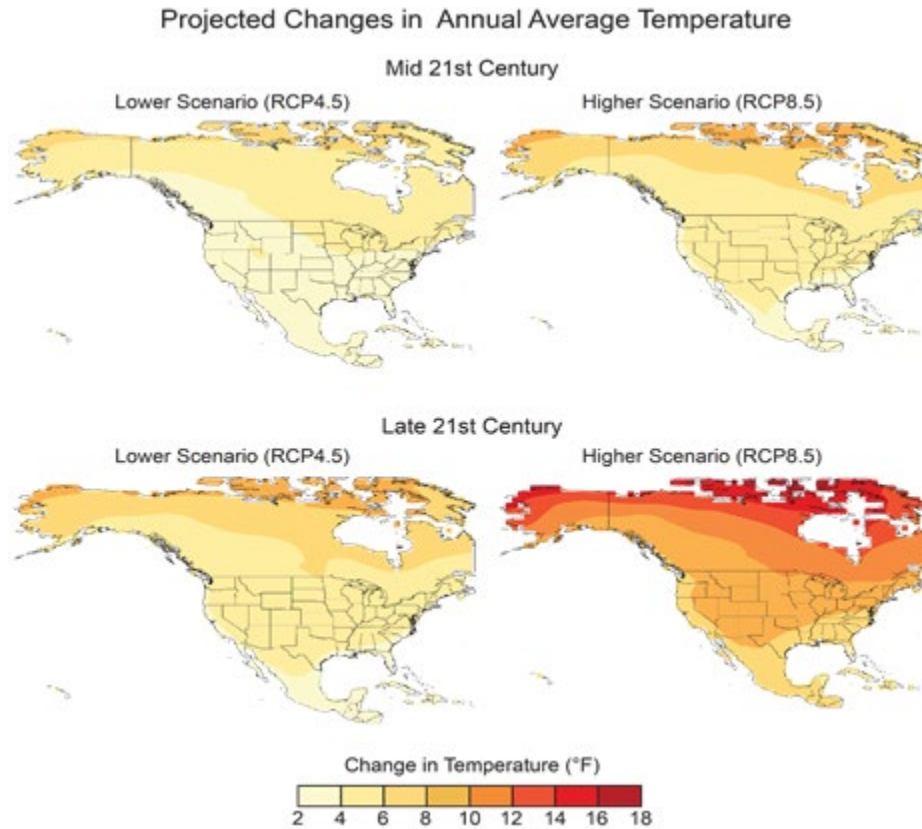
### 7.2.1. Temperature

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)*

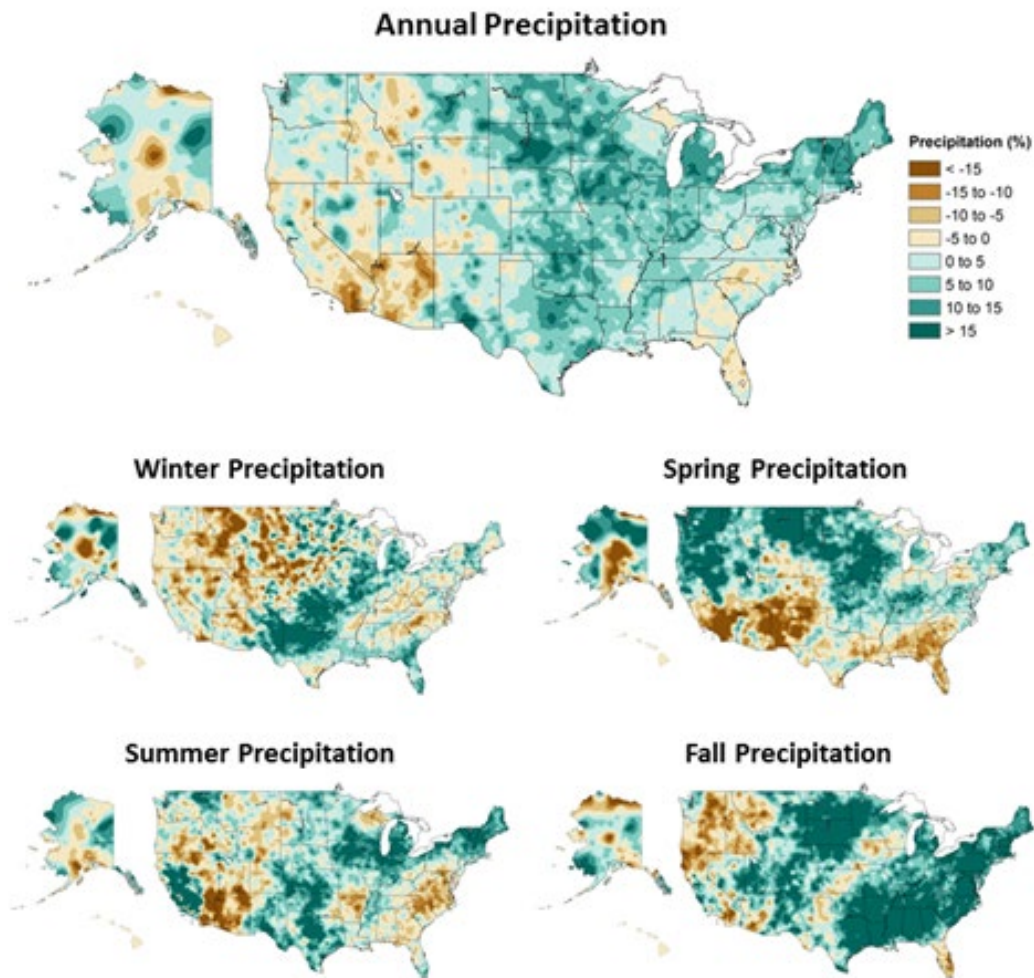
Temperatures are expected to increase throughout the United States under both the low and high emissions scenarios (Figure 17). In general, northern latitudes and inland areas will experience greater increases in temperatures than coastal areas. Daily extreme temperatures (e.g., coldest and warmest daily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

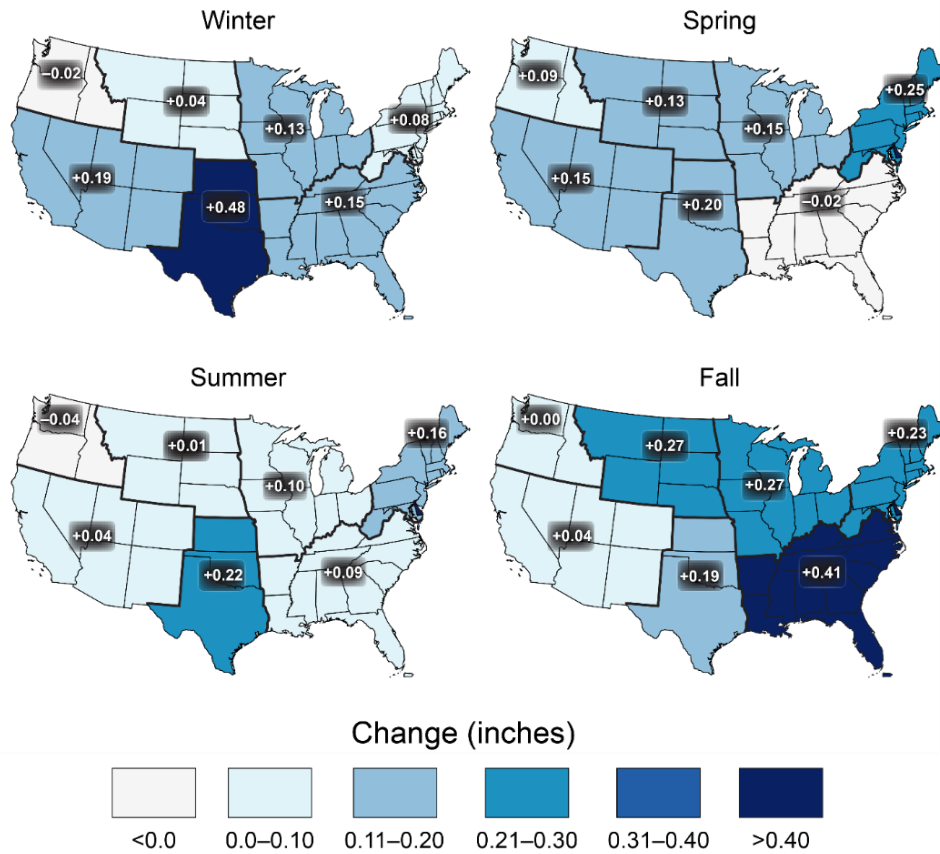
Annual and seasonal precipitation have changed throughout the United States from the first half of the last century (1901-1960) to the present (1986-2015). Average annual precipitation for the entire country has increased by approximately 4%, but the observed change in magnitude vary by season and by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

## Observed Change in Daily, 20-year Return Level Precipitation



*Figure 19. Observed change in the 20-year return value of the seasonal daily precipitation totals over 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 21<sup>st</sup> century (Easterling 2017).

## Projected Change in Daily, 20-year Extreme Precipitation

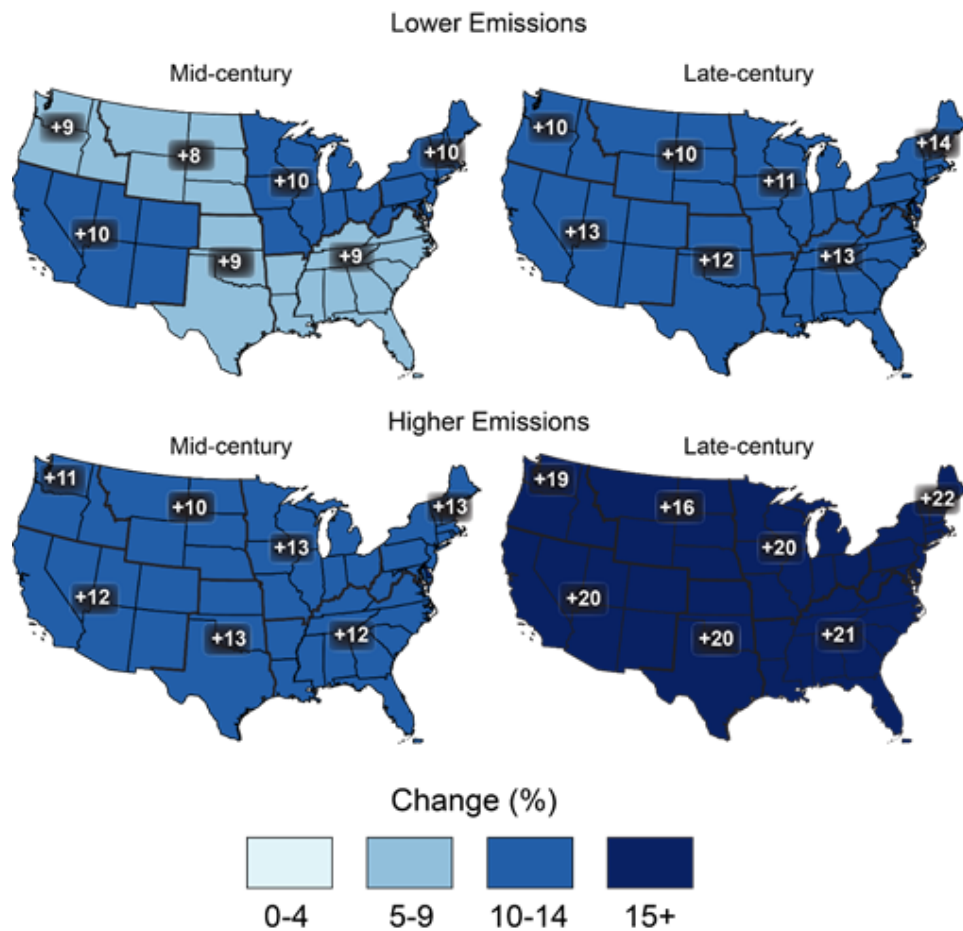


Figure 20. Projected change in the 20-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps). Results are shown for a lower scenario (top maps; RCP4.5) and for a higher scenario (bottom maps, RCP8.5) (Easterling et al 2017).

### 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.

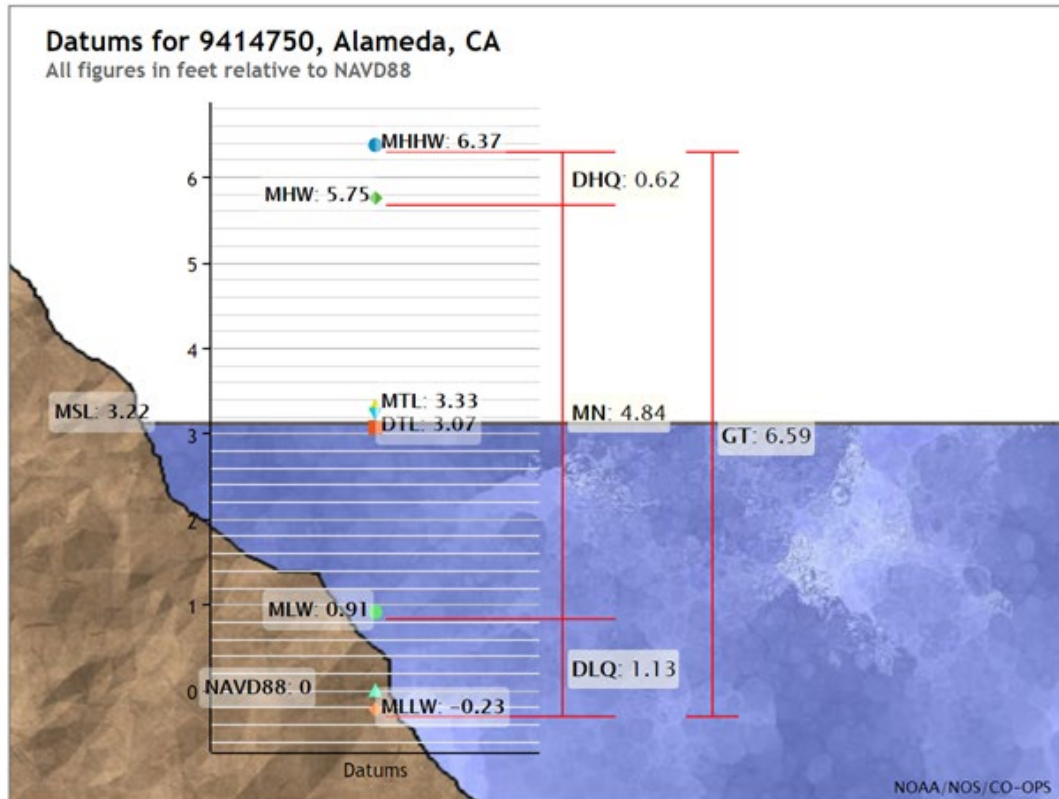
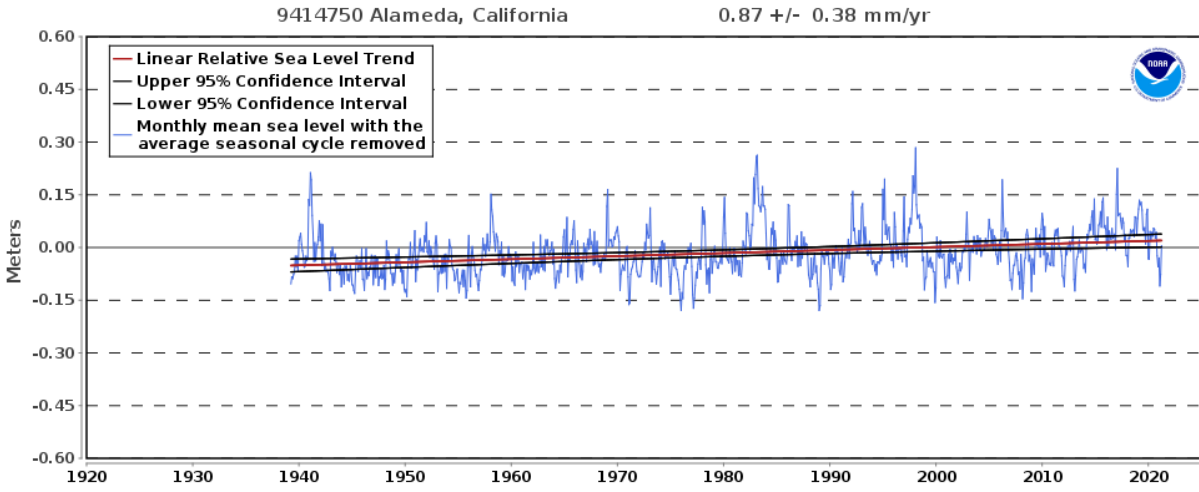


Figure 21: Datums for NOAA Station 9414750 (Alameda, CA) relative to ft NAVD88

### 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 is seen as a net positive due to the increased channel depth and reduced channel maintenance needs.





*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

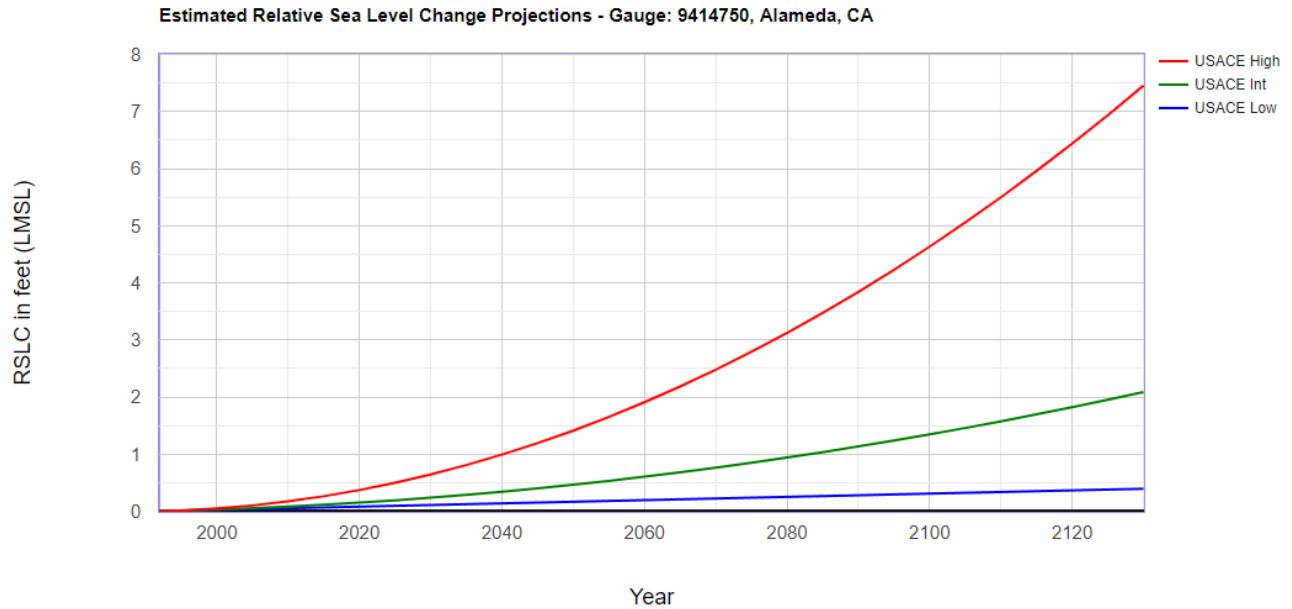


Figure 23: Relative Sea Level Rise Projections from 1992-2130, Alameda, CA, NOAA gage 9414750

### 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 (the king tide is added to each SLC scenario). If SLC coupled with the king tide 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 10). Based on projections, this is enough to avoid inundation under the low and medium scenarios for all years, and until at least the year 2100 under the high SLC scenario (Figure 25). This indicates there is a low overall 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>

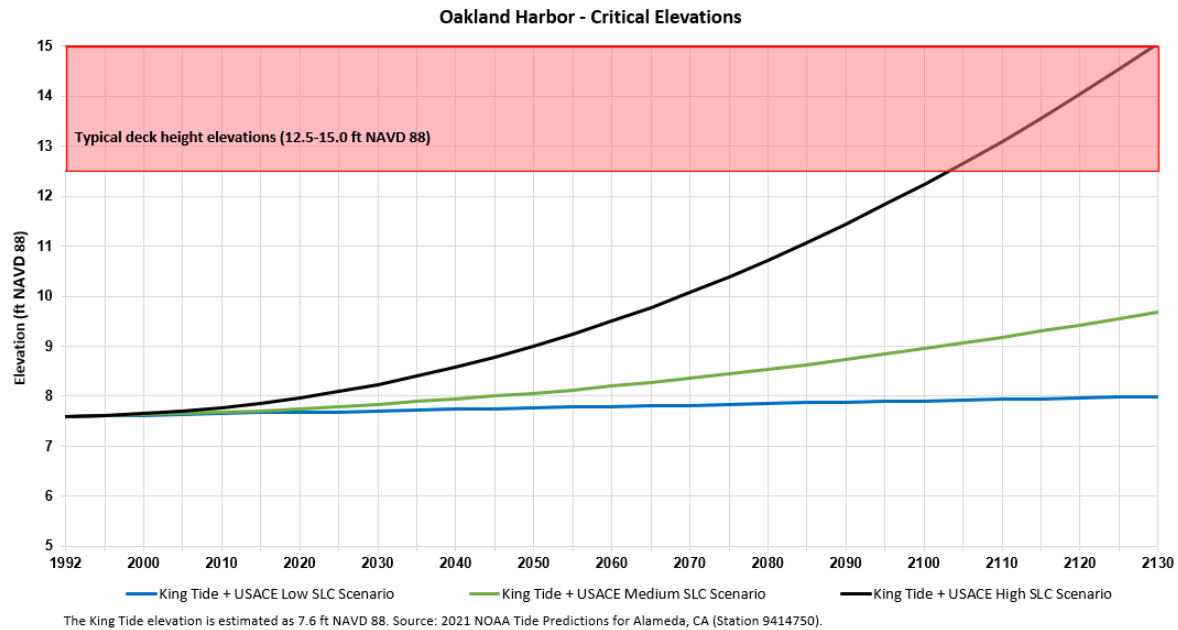


Figure 25: Critical elevations for container crane deck heights

Table 10. Container crane deck heights compared to estimated future King Tide

Terminal Name	Typical Deck Heights (ft NAVD 88)	King Tide <sup>1</sup> + 2080 SLC (Low/Med/High) (ft NAVD 88)	King Tide <sup>1</sup> + 2130 SLC (Low/Med/High) (ft NAVD 88)
B20-33 - TraPac and adjacent Terminal	13.4-14.5	7.85/8.54/10.72 (All scenarios are below deck heights.)	7.99/9.69/15.05 (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		

<sup>1</sup>The King Tide is estimated as 7.6 ft NAVD 88. Source: 2021 NOAA predicted tide tables for the Alameda station (9414750).

### 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) 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)

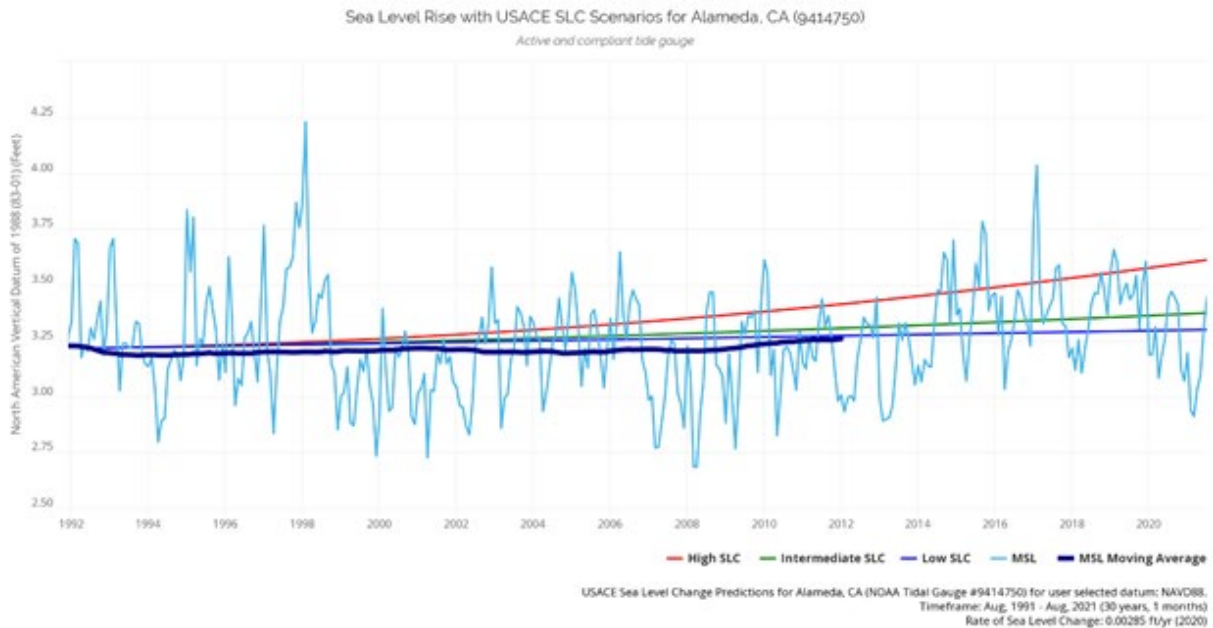


Figure 26: Historical Sea Level Rise for Alameda, CA (NOAA gage 9414750). Source: USACE Sea Level Tracker

## 7.4. 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 11. 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 Spearman Rank-Order significance tests.

*Table 11. Results of trend analysis for acres burned*

	<b>HUC 1802 - Sacramento</b>	<b>HUC 1804 - San Joaquin</b>	<b>HUC 1805 - San Francisco Bay</b>
<b>Trend Line Slope (Traditional)</b>	+3398	+1263	+858
<b>Trend Line Slope (Sen's)</b>	+415.29	+293.83	+15.856
<b>p-value (Mann-Kendall)</b>	0.017683	0.000043511	0.090865
<b>p-value (Spearman Rank-Order)</b>	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) GCM-BCSD-VIC dataset (2014) 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.

As shown in Figure 27, the San Francisco Bay watershed (HUC 1805) is considered relatively vulnerable to climate change impacts for the navigation business line, being among the 20% most vulnerable watersheds for this business line in the CONUS (202 HUC04s). This is true for both the wet and dry scenarios and both the 2050 and 2085 epochs.

For the wet scenarios, the dominant indicator contributing 31-32% to the vulnerability score for HUC 1805 is Flood Magnification. For the dry scenarios, the dominant indicator is Low Flow (monthly flow exceeded 90% of the time) contributing 32-33% of the score.

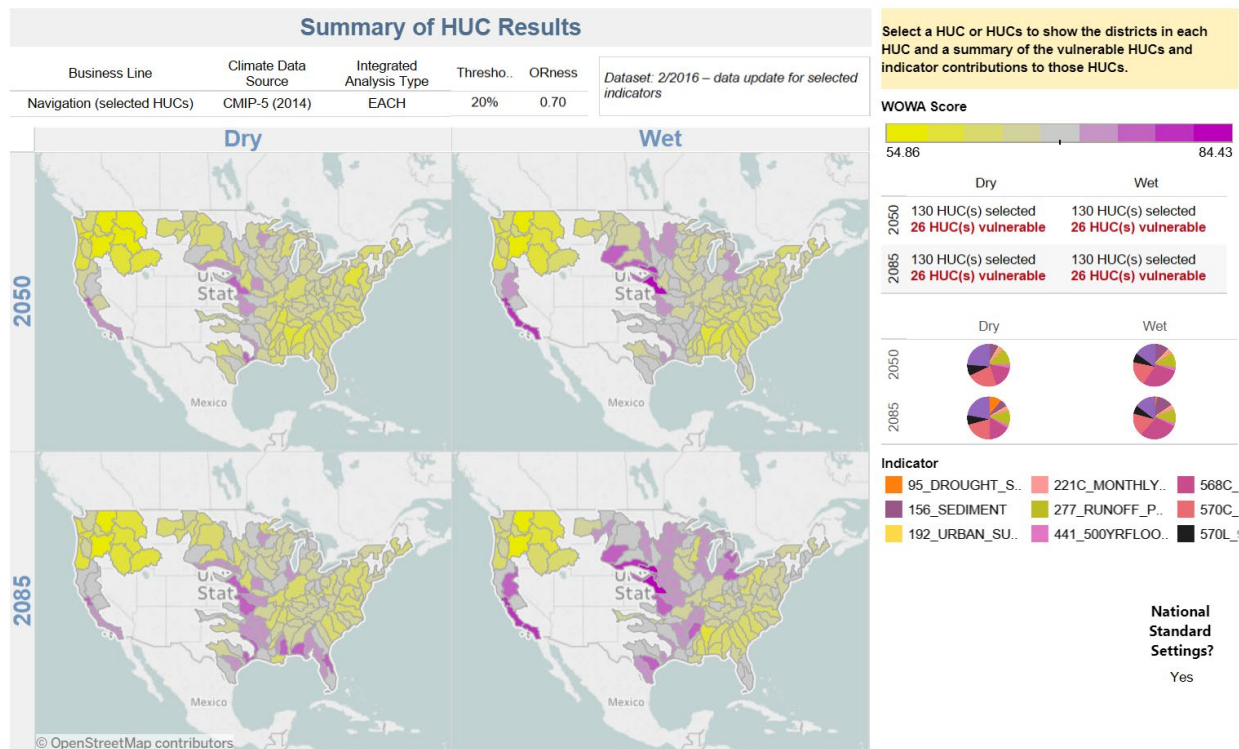


Figure 27. Output of the VA tool indicates that the San Francisco Bay watershed is among the 20% most vulnerable CONUS watersheds for the Navigation business line

## 8. References

Conomos, T.J., Smith, R.E. & Gartner, J.W. Environmental setting of San Francisco Bay.

- Hydrobiologia 129, 1–12 (1985). <https://doi.org/10.1007/BF00048684>.
- DMMO, (2021). “Dredged Material Management Office (DMMO) Dredging and Placement of Dredged Material in San Francisco Bay January-December 2020 Report.” June 2021.
- East, A. E., Logan, J. B., Dartnell, P., Lieber-Kotz, O., Cavagnaro, D. B., McCoy, S. W., & Lindsay, D. N. (2021). Watershed sediment yield following the 2018 Carr Fire, Whiskeytown National Recreation Area, northern California. *Earth and Space Science*, 8, e2021EA001828. <https://doi.org/10.1029/2021EA001828>
- Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/J0H993CC.
- Gonzalez, P., G.M. Garfin, D.D. Breshears, K.M. Brooks, H.E. Brown, E.H. Elias, A. Gunasekara, N. Huntly, J.K. Maldonado, N.J. Mantua, H.G. Margolis, S. McAfee, B.R. Middleton, and B.H. Udall, 2018: Southwest. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1101–1184. doi: 10.7930/NCA4.2018.CH25
- Environmental Impact Agency, (2011). “Review/Synthesis of Historical Environmental Monitoring Data Collected at the San Francisco Deep Ocean Disposal Site (SF-DODS) in Support of EPA Regulatory Decision to Revise the Site's Management and Monitoring Plan.” US EPA Region 9. June 2011.
- Kossin, J.P., T. Hall, T. Knutson, K.E. Kunkel, R.J. Trapp, D.E. Waliser, and M.F. Wehner, 2017: Extreme storms. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 257-276, doi: 10.7930/J07S7KXX.
- McKee, L.J., Lewicki, M., Schoellhamer, D.H., Ganju, N.K., (2013). “Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California.” *Marine Geology*, Volume 345, Pages 47-62.
- National Research Council, (2012). “Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.” Committee on Sea Level Rise on California, Oregon, and Washington, Board on Earth Sciences and Resources and Ocean Studies Board. Washington, DC: National Academy Press.
- Olson, Sarah, Nguyen, Marie, Sant-Miller, Aaron & White, Kate (2021) *US Army Corps of Engineers Time Series Toolbox User Guide*. US Army Corps of Engineers: Washington, DC.
- Port of Oakland, (2019). “Sea Level Rise Assessment.” July 2019.
- Rosati, JD, (2005). “Coastal Inlet Navigation Channel Shoaling with Deepening and Widening.”



- U.S. Army Corps of Engineers, Coastal Hydraulics Laboratory. ERDC/CHL CHETN-IV-64.
- Schoellhamer, D., L. McKee, S. Pearce, P. Kauhanen, M. Salomon, S. Dusterhoff, L. Grenier, M. Marineau, and P. Trowbridge. 2018. Sediment Supply to San Francisco Bay, Water Years 1995 through 2016: Data, trends, and monitoring recommendations to support decisions about water quality, tidal wetlands, and resilience to sea level rise. Published by San Francisco Estuary Institute, Richmond, CA. SFEI Contribution Number 84
- Stern, Michelle A., Lorraine E. Flint, Alan L. Flint, Noah Knowles, and Scott A. Wright. "The Future of Sediment Transport and Streamflow Under a Changing Climate and the Implications for Long-Term Resilience of the San Francisco Bay-Delta." *Water Resources Research* 56, no. 9 (2020): e2019WR026245.
- U.S. Army Corps of Engineers, San Francisco District, (1975). "USACE Final composite environmental statement, Maintenance Dredging, Existing navigation projects, San Francisco Bay Region, California, Volume I." December 1975.
- U.S. Army Corps of Engineers, (2019). "Incorporating sea level change in Civil Works Programs –Engineering Regulation." Engineering Regulation No. 1100-2-8162.
- U.S. Army Corps of Engineers, San Francisco District, (1998). "Oakland Harbor Navigation Improvement (-50 Foot) Project Volume III Appendices A through E." May 1998.
- U.S. Army Corps of Engineers, San Francisco District, (1998). "Oakland Harbor Navigation Improvement (-50 Foot) Project, Volume I Final Feasibility Study." May 1998.
- U.S. Army Corps of Engineers, San Francisco District, (2001). "Oakland Harbor Navigation Improvement (-50 Foot) Project, Final Initial Design Documentation Report." March 2001.
- USACE (2015). Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Water Resources Region 18, California. Civil Works Technical Report, CWTS 2015-18, USACE, Washington, DC.
- U.S. Army Corps of Engineers, San Francisco District, (2021). "Oakland Harbor 2021 Maintenance Dredging Tier I Evaluation." March 2021.
- U.S. Army Corps of Engineers, (2006). "Engineering and Design – Hydraulic design of deep draft navigation projects." Engineering Manual No. 1110-2-1613. 31 May 2006.
- U.S. Army Corps of Engineers, (2019). "Incorporating sea level change in Civil Works Programs –Engineering Regulation." Engineering Regulation No. 1100-2-8162.
- U.S. Army Corps of Engineers, Seattle District, (2021). "Tacoma Harbor, WA Feasibility Study Pierce County, Washington Final Integrated Feasibility Report and Environmental Assessment." July 2021.
- U.S. Army Corps of Engineers, Seattle District, (2021). "Tacoma Harbor, WA Feasibility Study Pierce County, Washington Final Integrated Feasibility Report and Environmental Assessment, Appendix B - Engineering." July 2021.
- USGCRP. 2017. Climate Science Special Report: Fourth National Climate Assessment. Edited by D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K.

Maycock. Vol. 1. 2 vols. Washington, DC,: U.S. Global Change Research Program.  
<https://science2017.globalchange.gov/>.

Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, 2017: Temperature changes in the United States. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 185-206, doi: 10.7930/J0N29V45.

Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande. “Droughts, Floods, and Wildfires.” In *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, edited by D.J. Wuebbles, D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, 231–56. Washington, DC, USA: U.S. Global Change Research Program