Draft Environmental Impact Statement (EIS)/Environmental Impact Report (EIR)

APPENDIX G
Inland Hydrology

US Army Corps of Engineers
Corte Madera Creek Flood Risk Management Project
October 2018

Appendix G

Corte Madera Climate Change Impacts to Inland Hydrology Qualitative Analysis

1.1 Guidance

Analysis of climate change impacts to all USACE undertakings is conducted in accordance with the following policy and guidance:

- USACE Climate Preparedness and Resilience Policy Statement (June 2014).
- Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.
- Engineering Technical Letter (ETL) 1100-2-3, Guidance for Detection of Nonstationarities in Annual Maximum Discharges.

A portion of the project area is affected by sea level rise. Analysis of the impact of future sea level change on project hydrology was completed in accordance with Engineer Regulation (ER) 1100-2-8162, Incorporating Sea Level Change in Civil Works Programs (31 December 2013). This information is included in the hydrologic analyses (see Appendix A).

1.2 Current Climate and Observed Climate Trends

The project area is located immediately east of San Francisco in Marin County, along the north shore of San Francisco Bay (Figure 1). This part of California has a Mediterranean climate with hot dry summers (May through September) and cool wet winters (October through April). The dominant control on the seasonality of precipitation is the location of the semi-permanent Pacific high, which deflects the storm track to the north of the region during the summer months. Winter precipitation extremes typically result from atmospheric river events, which can bring very heavy rain and flooding to the region (Dettinger et al. 2011; WRCC 2018). Historically, in the Bay Area, the greatest precipitation events have occurred in the coastal mountains of northern Sonoma County (Ackerly et al., 2018). Flooding is not uncommon in the region: the highest peak daily discharge at the Corte Madera Creek gage in Ross, California (Figure 2) occurred in January 1982, caused extensive flooding the Bay area (https://pubs.usgs.gov/wri/1988/4236/report.pdf) and approximately $280 million in damages (https://en.wikipedia.org/wiki/Floods_in_California#January_1982:_Northern_California_flood).

The study area is in Marin County, and benefits from the ameliorating influence of the bay and marine air masses on the local climate. Data from the Kentfield National Weather Service Cooperative Observer (COOP) station (044500) adjacent to the study area (https://wrcc.dri.edu/summary/climsmsfo.html) show cool, moist winters (January average daily high temperatures of 55.6°F, average minimmum daily temperatures of 39.5°F, and mean monthly precipitation of 10.47 inches) and warm, dry summers (July average daily high temperature of 84.0°F, average daily minimum temperature of 51.4°F, with a monthly average 0.07 inches of precipitation).

Temperatures have risen significantly in the San Francisco Bay area (Figure 2). Between 1950 and 2005, average annual temperatures have increased by 1.7°F (Ackerly et al., 2018). Statewide, extremely hot days and nights have become more frequent since 1950 (OEHHA 2018). Summertime fog hours over the Bay area have decreased by 33% over the last century, driven in part by changes in land-sea temperature contrast (Johnstone and Dawson 2010). Although there has been little change in average annual precipitation in the Bay Area (Ackerly et al., 2018), precipitation has become more variable from year to year, with larger swings between extreme drought and extreme precipitation years (OEHHA 2018). In drought years, in part due to warmer temperatures and drier conditions as well as to greater construction in the wildland urban interfaces, wildfires burn areas and intensities have increased (OEHHA 2018), with five of the largest fire years occuring since 2006. This increase in wildfire is concerning because of the profound changes in hydrology that may occur in a watershed following a large, high-severity wildfire.

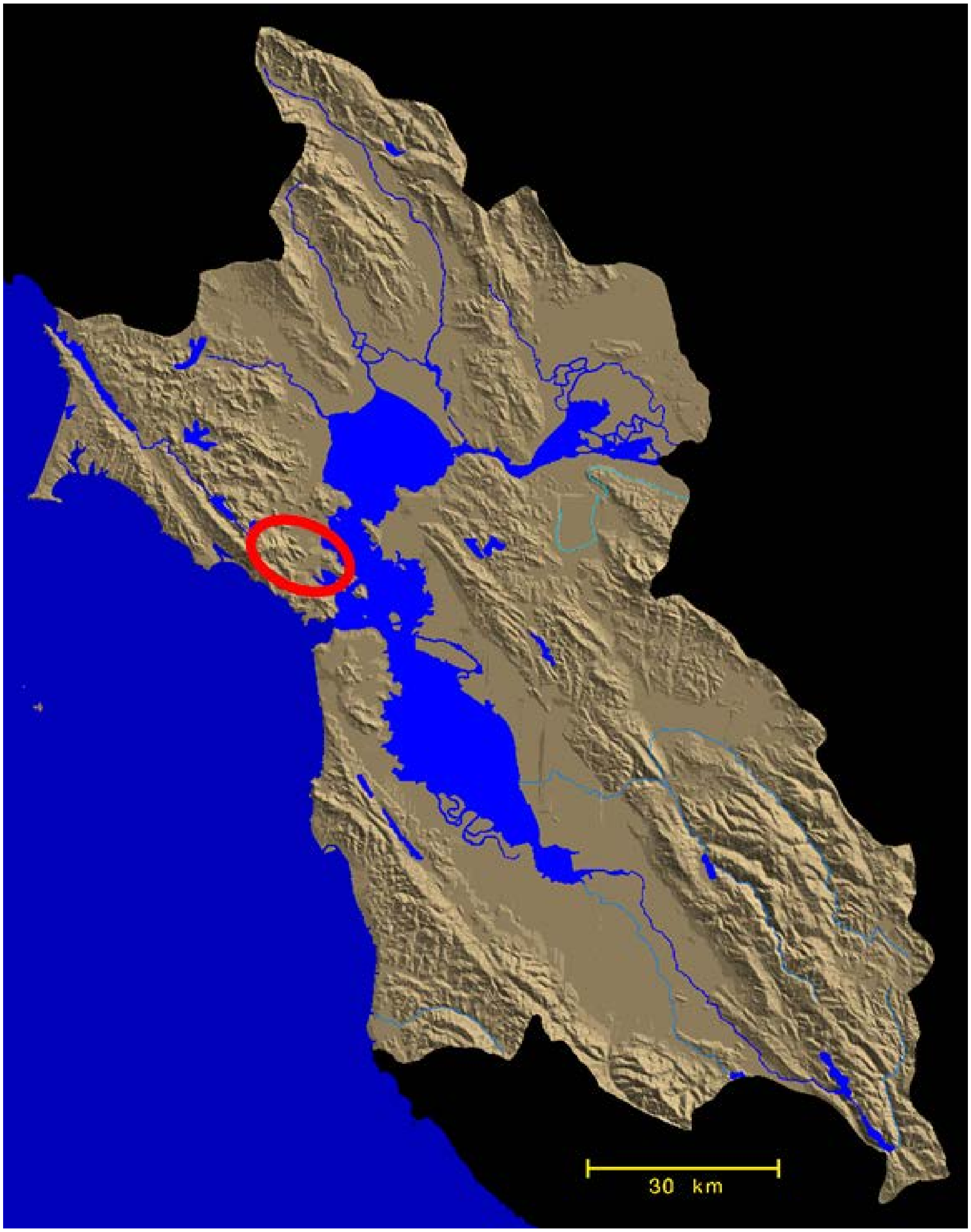


Figure 1. Image showing topography and major drainages of San Francisco Bay hydrologic unit. Approximate Corte Madera Creek watershed area is located in red oval. Source: Montana State University Environmental Statistics Group. http://www.esg.montana.edu/gl/huc/1.

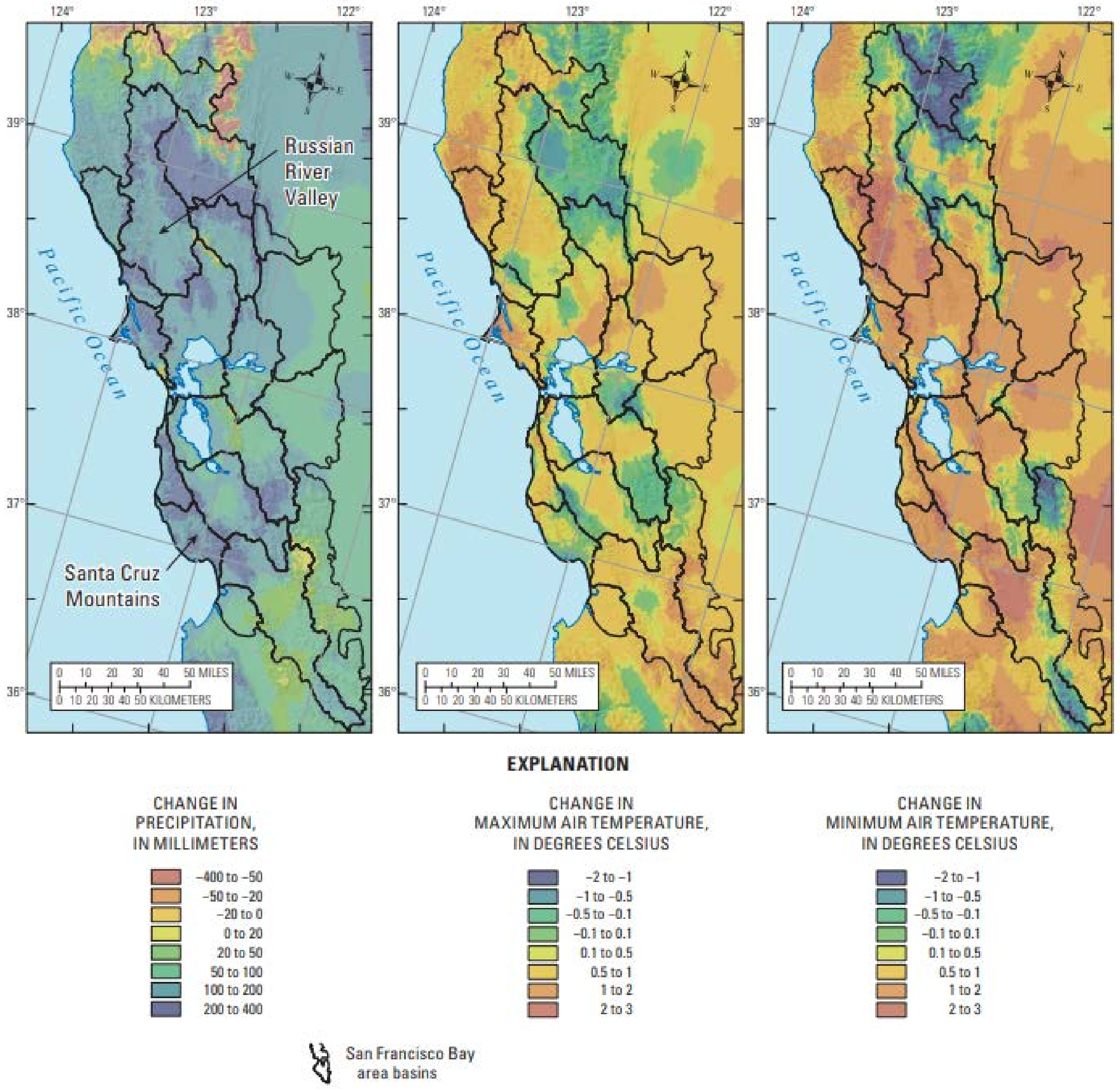


Figure 2. Observed changes in precipitation and temperature, San Francisco Bay area watersheds (Flint and Flint 2012: Figure 2).

At the Corte Madera Creek in Ross CA gage, the continuous period of records extends from 1952 to 1993. The USACE Climate Hydrology Assessment Tool (CHAT, https://maps.crrel.usace.army.mil/projects/rcc/portal.html) was used to assess historical trends in peak instantaneous stream flow at the gage (Figure 3). Consistent with the lack of trend in observed precipitation, there is also no statistically-significant trend in peak instantaneous stream flows at the gage. The lack of continuous record into the 21st Century prevents assessment of the effect of changes in precipitation variability on annual peak stream flows. For the same period of record, there are no significant nonstationarities in the stream flow dataset (Figure 4), although the USACE Nonstationarity Tool (https://maps.crrel.usace.army.mil/projects/rcc/portal.html) results do highlight the unusual magnitude of the peak flows responsible for the 1982 flood.

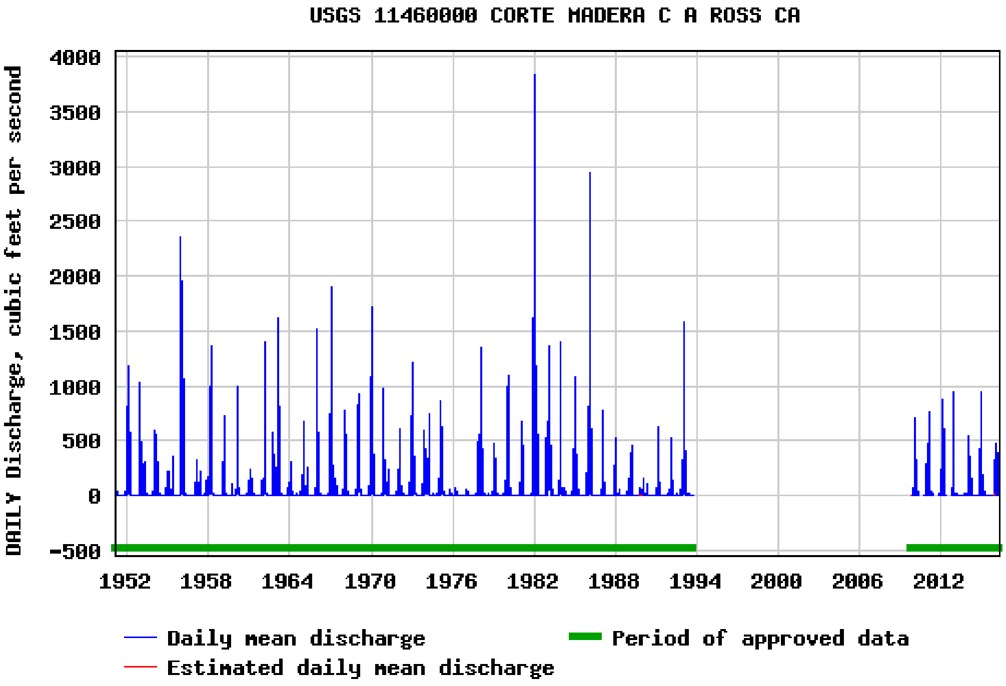
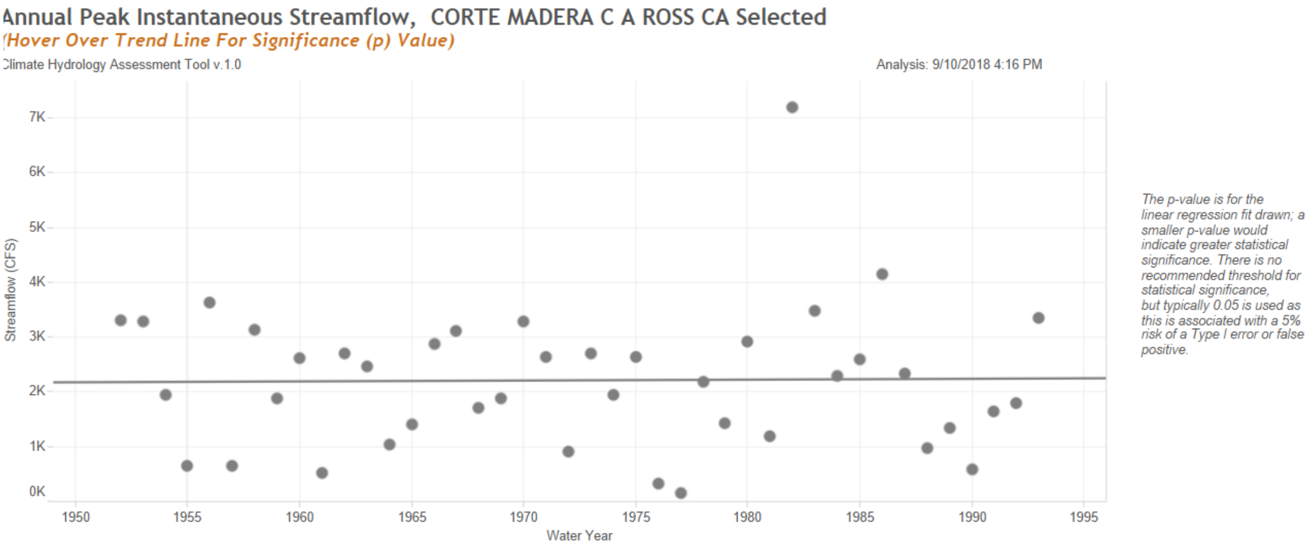
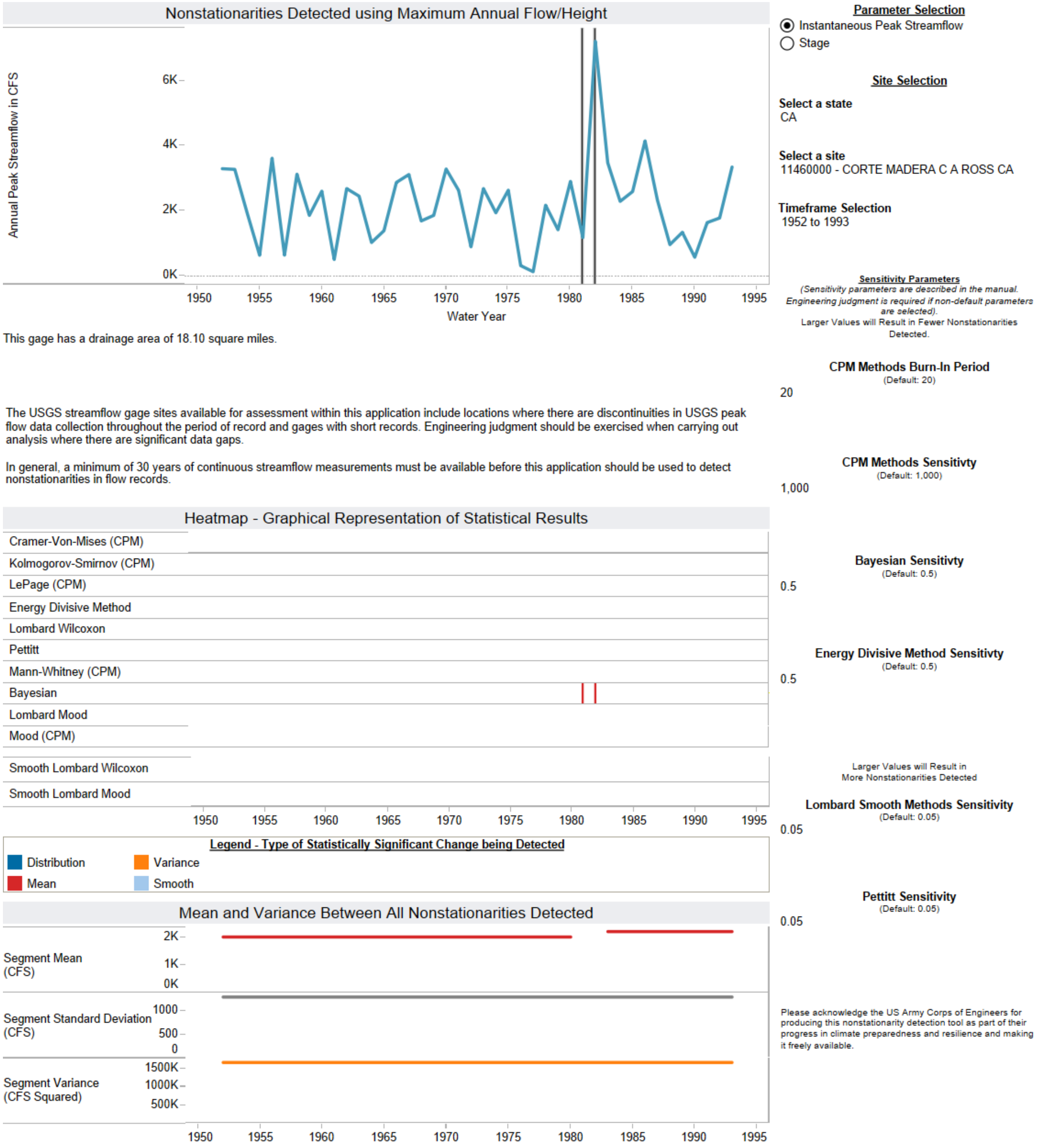


Figure 3. Daily mean discharge at the Corte Madera Creek gauge in Ross, CA. Significant data gap from 1994 to 2009. Source: USGS. http://waterdata.usgs.gov/nwis/dv/?site_no=11460000&PARAmeter_cd=00060 .



The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

Figure 4. Annual peak instantaneous stream flow, Corte Madera Creek at Ross, CA USGS gage. Trend line: 1.59015*Water Year-927.183, $R^2 = 0.0002301$, p-value= 0.924048



This gage has a drainage area of 18.10 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow

○ Stage

Site Selection

Select a state
CA

Select a site
11460000 - CORTE MADERA C A ROSS CA

Timeframe Selection
1952 to 1993

Sensitivity Parameters

(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).

Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period
(Default: 20)
20

CPM Methods Sensitivty
(Default: 1,000)
1,000

Bayesian Sensitivty
(Default: 0.5)
0.5

Energy Divisive Method Sensitivty
(Default: 0.5)
0.5

Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity
(Default: 0.05)
0.05

Pettitt Sensitivity
(Default: 0.05)
0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 5. Results of the Nonstationary Tool for the Corte Madera Creek at Ross, California gage.

1.2.1 Summary

The project area has a Mediterranean climate characterized by warm, dry summers and cool, moist winters. Flood risk in the project area results from winter storms, primarily but not exclusively the result of atmospheric river events. Over the last 50 years, average annual temperatures in the region have increased by 1.7°F and there has been an increase in extremely hot days and nights. The number of fog hours in the Bay area has decreased by 33%. Annual precipitation totals are unchanged, but year-to-year precipitation variability has increased, resulting in larger swings between drought and wet years. In drought years, wildfires have increased in frequency and intensity, reflecting both an increase in weather conditions favorable to wildfire ignition and spread, and the increasing encroachment of housing and human activity in wildland areas. The Climate Hydrology Assessmetn and Nonstationarity Tools show no changes to the frequency and mangitude of peak floods along Corte Madera Creek in the historic period.

1.3 Future Without Project Climate Conditions in the Study Area

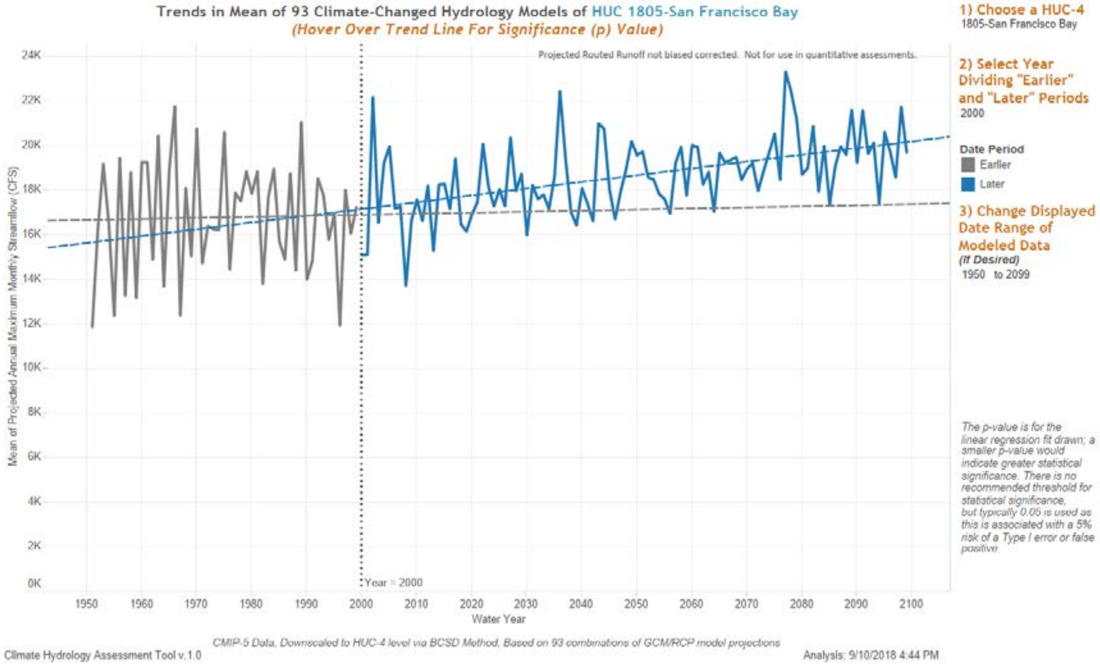
Climate in the project area is projected to change significantly over this century. Average annual temperatures are projected to rise 3.3 to 4.4°F by mid-Century (average for 2040-2069) and 4.2 to 7.2°F by the end of the Century (2070-2099) (Ackerly et al. 2018). Extreme temperatures are anticipated to increase at a faster rate, with maximum temperatures reaching 3.9 to 6.3°F higher the present in cooler coastal areas and 6.4 to 10.0°F higher in inland areas by Century's end (Ackerly et al. 2018).

Although mean annual precipitation is not anticipated to change significantly (USGCRP 2017), precipitation variability is anticipated to increase, with larger swings between wet and dry years (Swain et al. 2018), and an increase in the intensity and damage caused by the largest winter storms. Uncertainty exists in the precipitation estimates because there is considerable model uncertainty over the future position of the winter storm track (Ackerly et al. 2018), which is responsible for steering much of the precipitation into the project area. Precipitation extremes are likely to be enhanced, with increases in both wet extremes and dry extremes (Swain et al. 2018). The magnitude of the largest precipitation events are projected to increase from 6 to 37% by the end of the Century and large events may increase in frequency (Ackerly et al. 2018). Finally, higher annual temperatures will drive up evaporation rates, contributing to more frequent and more intense drought (Wehner et al. 2017). Consequently, "whiplash events", in which extremely dry periods are followed by extremely wet periods, may increase in frequency (Swain et al. 2018). Increased drought severity is also expected to increase wildfire burn area and intensity, particularly in the wildland-urban interface (Ackerly et al. 2018).

Hydrologically, increased precipitation extremes are likely to contribute to greater variability in stream flow extremes. There is a particular concern that an increase in winter flood hazard risk in rivers will result from increases in flows of atmospheric moisture into California's coastal ranges (Garfin et al. 2014), and by implication increase flood risk in the project area. A recent study projects an increase of 2.5 times in the occurrence of extreme wet years by 2100 compared to 1895-2017, and five-fold increase in the risk of severe storm sequence with 40-day precipitation totals similar to those during California's Great Flood of 1862 which turned the Central Valley into an inland waterway (Swain et al. 2018).

However, there is considerable model uncertainty in the magnitude and timing of these changes, even within emissions scenarios (e.g., Flint and Flint 2012). Some projections that show increases in precipitation consistently show precipitation concentrated in midwinter months (December and January) (Flint and Flint 2012), which may result in an increase flood risk. Hydrologic models project reductions in early and late wet season runoff, leading to a longer dry season and increased climatic water deficit (Flint and Flint 2012). The resulting longer, drier dry season is likely to be more favorable to wildfire ignition and spread. In a separate study using a 7 climate model ensemble, Dettinger (2011) found that years with multiple atmospheric river events are likely to increase in frequency, and the intensity of the largest of these storms may increase. Thus, several lines of evidence suggest that at the extreme tail of the distribution future flood magnitudes may be greater than at present.

The CHAT was used to investigate future changes in mean monthly stream flows in hydrologic unit code 1805, which encompasses the small watersheds that drain into the San Francisco Bay. The average of the 93 CMIP5 climate-changed hydrology model runs indicates a statistically significant increasing trend in annual monthly maximum flows (Figure 6); however the trend line has low explanatory power (low R^2 value), consistent with the very wide range of model projections (Figure 7).



The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

CMIP-5 Data, Downscaled to HUC-4 level via BCSD Method, Based on 93 combinations of GCM/RCP model projections

Climate Hydrology Assessment Tool v.1.0

Analysis: 9/10/2018 4:44 PM

Figure 6. Modeled climate-changed hydrology for HUC 1805, San Francisco Bay (Future: 30.3205*WaterYear-43500.6, R^2= 0.261043, p <0.0001; Historic: 4.7568*Water Year+7370.51, R^2= 0.0006967, p=0.857128).

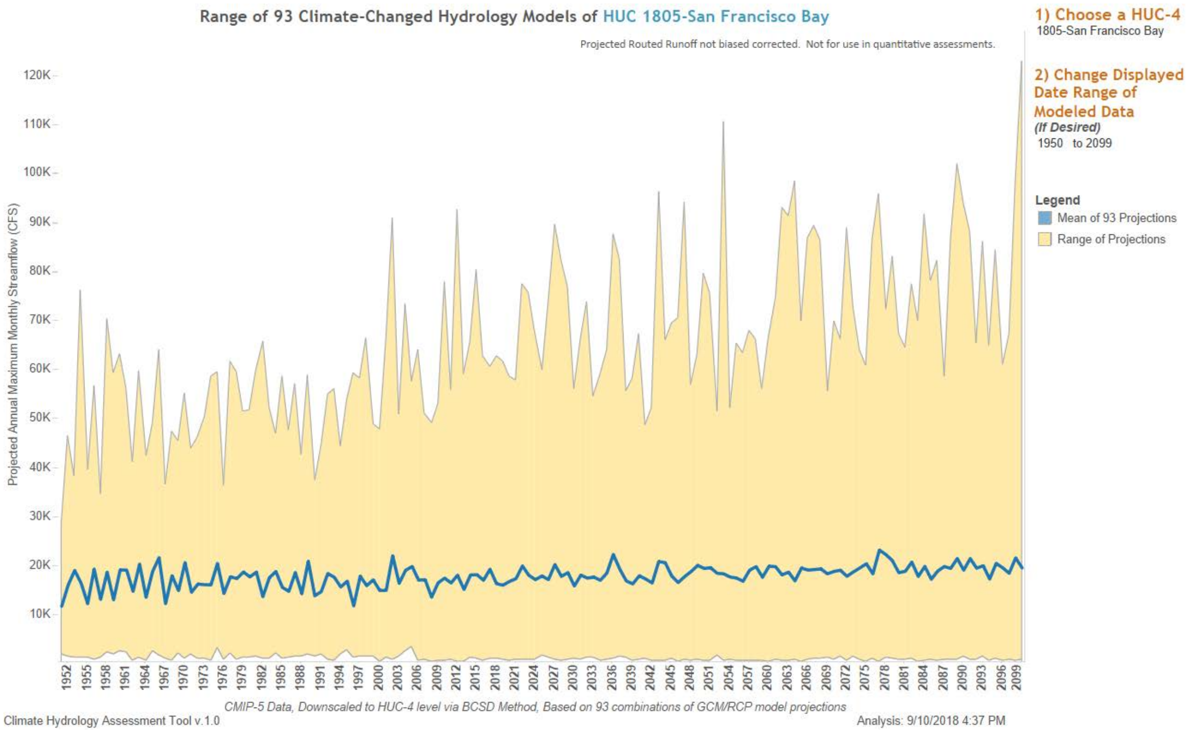


Figure 7. Range of 93 climate-changed hydrology models of HUC 1805, San Francisco Bay.

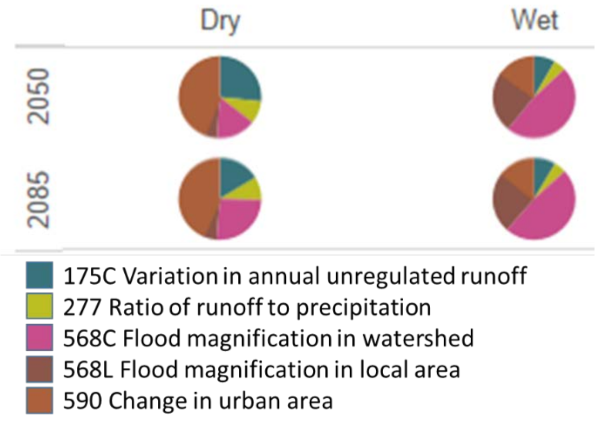


Figure 8 Results of the Vulnerability Assessment Tool with respect to the flood risk management business line for HUC 1805, San Francisco Bay.

The USACE Civil Works Vulnerability Assessment Tool was used to further explore flood risk vulnerability in the project area (Figure 8). It shows that in a drier future, flood risk is driven by interannual variation in runoff (wet-dry "whiplash" discsused above), and runoff from an increasingly urban landscape. In a wetter future, flood risk is more sensitive to flood magnification, which is the change in flood runoff in the future as compared to the present. Watershed vulnerability is driven by increases in discharge that are projected for the 10% annual chance exceedance event.

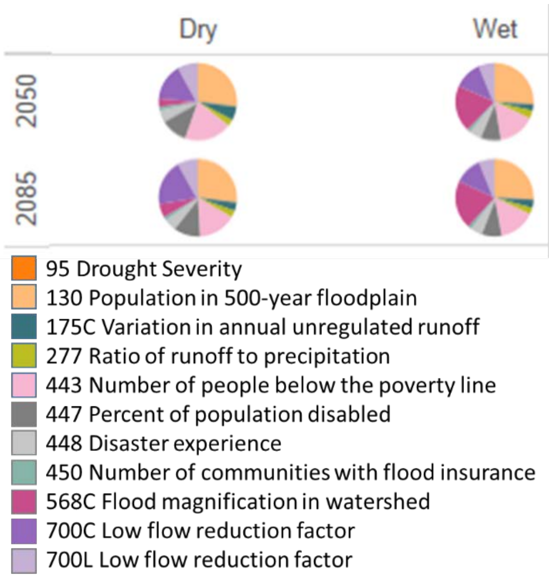


Figure 9 Results of the Vulnerability Assessment Tool with respect to the emergency management business line for HUC 1805, San Francisco Bay.

The Vulnerability Assessment Tool was also used to investigate future emergency management risk the project area. The dominant additional risks rise from increases in drought (again, related to the "wet-dry whiplash", above), the presence of a larger and vulnerable urban population within the 500-year floodplain, and the potential for increases in flood discharge during the winter rainy season.

1.3.1 Summary

The analysis of climate change was conducted in accordance with Engineering and Construction Bulletin (ECB) 2018-14, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects.

Climate in the project area is projected to change significantly over this century. Average annual temperatures are projected to rise 3.3 to 4.4°F by mid-Century (average for 2040-2069) and 4.2 to 7.2°F by the end of the Century (2070-2099) (Ackerly et al. 2018). In response to climate warming, winter storm magnitudes are likely to increase in frequency and intensity, and the inter-annual variation in precipitation is likely to increase (increased frequency of drought and flood years). However, there is considerable uncertainty in the timing and magnitude of changes in precipitation in the project area because of climate model differences in the future position of the winter storm track. Studies indicate that the magnitude of the largest precipitation may increase from 6 to 37% by the end of the Century and large events may increase in frequency 2.5-fold compared to the historic period. At the same time, higher temperatures will exacerbate drought conditions, both in terms of drought frequency and duration. The result is likely to be an increase in “whiplash events”, in which extremely dry periods are followed by extremely wet periods. Consequently, hydrologic regimes are also likely to become more variable with increases in both the frequency and magnitude of extreme events.

The Climate Hydrology Assessment Tool shows a statistically significant increase in annual maximum monthly flows, but this trend is dwarfed by the magnitude of the range of future projections. The Vulnerability Assessment Tool results support the finding that future flood risk is driven by interannual variability (“whiplash”) and increase in the magnitude of the largest floods, and also indicates that increasing development resulting in less pervious surfaces may also contribute to rising flood risk in the watershed.

1.4 Future With Project Condition

The construction and maintenance of this project will result in negligible effects to the clinate.

1.5 Climate Risk and the Tentatively Selected Plan

The TSP provides protection for floods up to and including the 4%AEP flood. In the future, climate models indicate changes in the magnitude and frequency of precipitation resulting from winter storms, which is likely alter the flow magnitudes for different annual chance exceedance events. Climate models differ, however, in the rate and magnitude of hydrologic change, and therefore there is considerable model uncertainty: qualitatively, flood risk is likely to increase in the study area, but lack of certainty with respect to the magnitude, frequency, and timing of these changes prevents quantitative analysis at this time.

Feature	Trigger	Hazard	Harm	Qualitative Likelihood
Unit 4 Bypass	Increases in the frequency and magnitude of precipitation (winter storms become larger, more intense)	Increase in flood magnitude and frequency	Increase in frequency of inundation in areas that would be inundated under flows >4% AEP with the TSP	Likely
Fish Ladder Removal / Downstream channel modifications / Allen Park Riparian Corridor	Increases in the frequency and magnitude of precipitation (winter storms become larger, more intense)	Increase in flood magnitude and frequency	Increase in frequency of inundation of Allen Park Riparian Corridor at flows greater than current 4% AEP	Likely
Floodwals	Increases in the frequency and magnitude of precipitation (winter storms become larger, more intense)	Increase in flood magnitude and frequency	Increase in frequency of inundation in areas that would be inundated under flows >4% AEP with the TSP Chaning flood characteristics may result in a changes to the level of performance in the future if the flows associated with the 4% AEP change	Likely Likely

1.6 References Cited

Ackerly, D., A. Jones, M. Stacey, and B. Riordan. 2018. *San Francisco Bay Area Summary Report*. California's Fourth Climate Change Assessment. Publication number: CCCA4-SUM-2018-005.

Dettinger, M. 2011. Climate change, atmospheric rivers, and floods in California – a multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association* 47(3):514-523.

Dettinger, M.D., F. M. Ralph, T. Das, P.J. Neiman and D.R. Cayan. 2011. Atmospheric rivers, floods and water resources of California. *Water* 2011(3):445-478. doi:10.3390/w3020445.

Flint, L.E., and Flint, A.L., 2012, Simulation of climate change in San Francisco Bay Basins, California: Case studies in the Russian River Valley and Santa Cruz Mountains: U.S. Geological Survey Scientific Investigations, Report 2012–5132, 55 p., online at https://pubs.usgs.gov/sir/2012/5132/pdf/sir20125132.pdf.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom, 2014: Ch. 20: Southwest. In *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 462-486. doi:10.7930/J08G8HMN, online at http://nca2014.globalchange.gov/report/regions/southwest .

Johnstone, J. A., and T. E. Dawson. 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. *Proceedings of the National Academy of Sciences* 107(10): 4533-4538.

OEHHA (Office of Environmental Health Hazard Assessment, California Environmental Protection Agency). 2018. Indicators of Climate Change in California (May 2018), online at https://oehha.ca.gov/media/downloads/climate-change/report/2018caindicatorsreportmay2018.pdf.

Swain, D.L., B. Langenbrunner, J.D. Neelin and A. Hall. 2018. Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change* 8:427-433.

USGCRP (U.S. Global Change Research Program). 2017. *Climate Science Special Report: Fourth National Climate Assessment, Volume 1*. Washington, D.C.

Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande. 2017. Droughts, floods, and wildfires, in *Climate Science Special Report: Fourth National Climate Assessment, Volume 1*. Washington, D.C.

WRCC (Western Region Climate Center). 2018. Climate of California, online at https://wrcc.dri.edu/Climate/narrative_ca.php.