Chapter 10. Climate Change

10.1 Overview

This chapter describes the historical climate observed at NASA ARC and compares it to future projections in climate as defined by the current state of knowledge of possible outcomes from continuing current trends in GHG emissions. In addition, it describes the regulatory mandate under which federal agencies, including NASA, are required to evaluate their climate change risks and vulnerabilities and to manage the local effects of climate change on their mission and operations. Possible risks to NASA Ames infrastructure, human capital, and natural ecosystems from projected changes in climate are also discussed.

This chapter was prepared by ARC's Climate Adaptation Science Investigators (CASI) team for the purposes of this ERD and to inform ARC's planners. Sources include many CASI-funded publications. Many thanks to Cristina Milesi for leading the development of this chapter, and the CASI members that contributed directly to its writing or whose work was drawn upon as sources: Cristina Milesi, Mariza Costa-Cabral, William Mills, Sujoy Roy, John Rath, Robert Coats, Norman Miller, Peter Bromirski, Max Loewenstein, Felicia Chiang, Nick Murphy, and James Podolske.

10.2 Regulatory Background

10.2.1 Federal Regulations

10.2.1.1 Executive Order 13514

In 2009, President Obama issued EO 13514, titled "Federal Leadership in Environmental, Energy, and Economic Performance," that mandates that all federal agencies, including NASA centers, "evaluate agency climate-change risks and vulnerabilities to manage the effects of climate change on the agency's operations and mission in both the short and long-term." In response to this mandate, NASA is integrating climate factors into its existing management plans. NASA has assembled a team of CASI scientists that work together with the operational stewards at each NASA Center to investigate and manage local climate risks. The emphasis of the CASI effort is on adaptation to climate change through science-informed planning at each of the NASA centers.

10.2.1.2 Executive Order 13653

EO 13653, "Preparing the United States for the Impacts of Climate Change," was issued by President Obama on November 1, 2013 to supplement EO 13514 (discussed above). Whereas EO 13514 is primarily concerned with water conservation and climate change mitigation through energy conservations and reductions in GHG emissions, EO 13653 contains specific language, goals, and objectives to prepare the Nation for the impacts of climate change by undertaking actions to enhance climate preparedness and resilience.

EO 13653 requires federal agencies, including NASA, to engage in partnering with other agencies to develop and share timely data, information, and decision-support tools to assist with climate preparedness and resilience. Agencies are also required to modernize federal programs to support climate resilient investment and manage lands and waters for climate preparedness and resilience. Specific requirements for agency Adaptation Plans are described, as are requirements for establishment of a new Council on Climate Preparedness and Resilience and State, Local, and Tribal Leaders Task Force.

10.2.1.3 *Draft National Environmental Policy Act Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions*

In February 2010, the CEQ issued a draft guidance memorandum on the ways in which Federal agencies can improve their consideration of the effects of GHG emissions and climate change in their evaluation of proposals for federal actions under NEPA. The draft guidance was intended to help explain how agencies of the federal government should analyze the environmental effects of GHG emissions and climate change when they describe the environmental effects of a proposed agency action in accordance with Section 102 of NEPA and the CEQ Regulations for Implementing the Procedural Provisions of NEPA (40 CFR parts 1500-1508).

On December 18, 2014, the CEQ issued a second draft guidance intended to provide further direction on how federal agencies should address the effects of GHG emissions and climate change under NEPA. The proposed guidance supersedes the earlier draft guidance issued by the CEQ in 2010.

10.3 Global and Regional Setting

10.3.1 Climate

Climate is the average and the statistical variability of the weather recorded at a location over a long period of time. *Climate change* refers to the long-term change in these statistical characteristics. With a progression that started with the industrial revolution, the climate over much of the Earth surface has been warming in response to the greenhouse effect of increased rates in fossil fuel burning, deforestation, and other anthropogenic changes. Air temperatures have increased across the San Francisco Bay Area, including Moffett Field (Cayan et al. 2012).

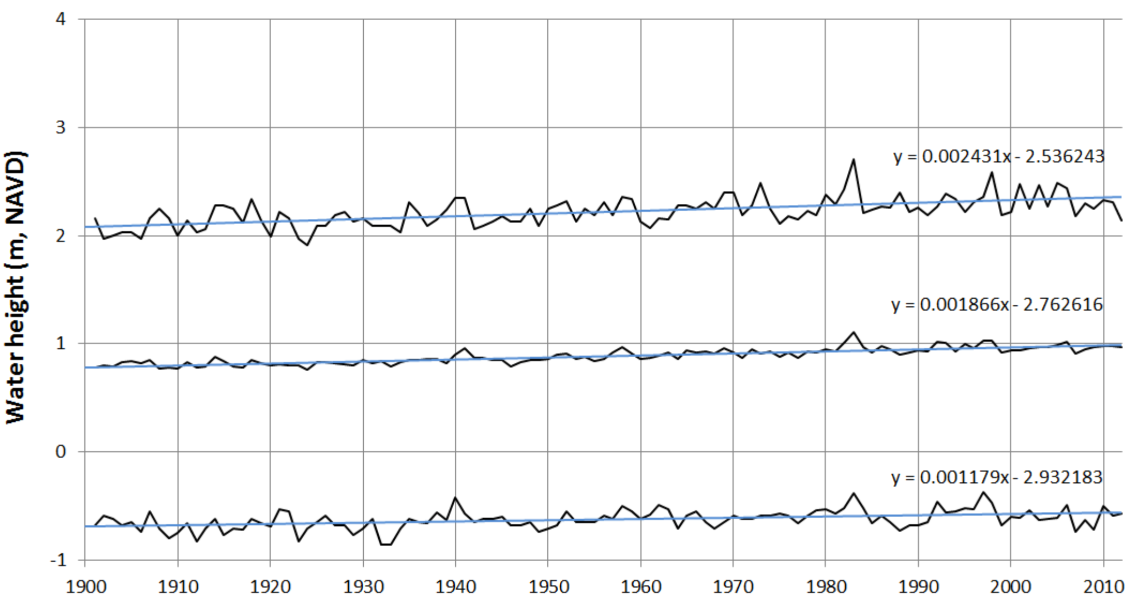
10.3.2 Sea Level Rise

Sea levels are rising globally as a consequence of global warming, though with large geographic variations. Global warming acts on sea levels through two main mechanisms. First by warming the oceans, which expand as the temperatures increase, and secondly by melting land ice (glaciers and ice sheets) and adding water to the oceans. Over the past decade the rate of ice loss has accelerated and now ice melting contributes to 80% of the total increase in sea level, up from about 50% in the previous decade, when melting was as important as thermal expansion (Benoit and Cazenave 2012).

The tidal gauge at the Golden Gate is the nation's oldest continually operating tidal observation station, with a record starting in 1854. It has been observed that mean sea level at the Golden Gate tidal station has increased about 2.2 millimeters/year (or 2.2 centimeters/decade) from 1930 to present. Satellite measurements since 1993 from

TOPEX/POSEIDON and Jason satellites and tidal gauges indicate that global sea level is now rising at a rate of about 3 millimeters/year (or 3 centimeters/decade; Hay et al. 2015). As shown in Figure 10-1, hourly observations of water height at Golden Gate indicate that here the annual maximum has been rising faster than the minimum. The lower curve represents the observed lowest of all hourly records in each year, the upper curve represents the highest, and the middle curve represents the annual average of hourly records. Each of the three time series has a different long-time trend, approximated here by linear regression coefficients. The series of maxima has the fastest increasing trend, at an average of 2.43 millimeters per year over this period, or 0.243 meters per century.

Figure 10-1. Summary of Hourly Observations of Water Height at San Francisco by Golden Gate (Gauge # 9414290)



(Note: Analysis courtesy of Mariza Costa-Cabral)

10.4 Current and Future Site Conditions

10.4.1 Current Climate

NASA ARC enjoys a coastal Mediterranean climate with a dry season in the summer and a mild, generally wet, winter. The local climate is strongly influenced by its proximity to the Pacific Ocean and the San Francisco Bay (SF Bay).

The summer climate is regulated by the North Pacific High, a semi-permanent high pressure condition centered over the northeastern Pacific Ocean, between Hawaii and California. The North Pacific High is strongest during the summer and shifts south during the winter, when it is replaced by the Aleutian Low. The North Pacific High keeps storms away from the California coast during summer and fall. At the same time, the presence of a thermal low pressure area on the Sonoran-Mojave Desert associated with the North American Monsoon, contributes to creating a gradient that induces a northwesterly flow of air onshore over the Bay and an upwelling of cold water along the coast. This band of colder waters along the coast, about 80 miles wide, is responsible for the high frequency of fog and stratus clouds met in the SF Bay area during the evening and morning hours of the summer. Fog and stratus clouds are the result of condensation of the westerly moist cool air as this flows over the band of cool waters along the coast. They form offshore and move into the Bay Area during the late afternoon hours. Generally the clouds dissipate the following late morning, as the land warms, except in areas immediately adjacent to the coast, creating sunny and clear conditions. Natural climate variability can produce changes in ocean circulation and sea surface temperatures that can cause large variations in coastal climate. For example, during El Niño years upwelling diminishes and sea surface temperatures increase along the coast.

The winter climate is influenced more often by the Aleutian Low, while the Pacific High weakens and shifts south. The Aleutian Low is a semi-permanent low pressure centered near the Aleutian Islands that induces the formation of strong cyclones steered by the Polar Jet winds. When the Jetstream moves south, low-pressure conditions over the California coast cause cloudiness and stormy conditions, often with heavy precipitation. Extreme precipitation events can alternatively be caused by atmospheric rivers, long narrow bands of warm moist air from the subtropics. Atmospheric rivers are responsible for 20-50% of the local annual precipitation. High-pressure systems in winter can produce cool stagnant conditions that lead to the formation of radiation fog and haze.

The San Francisco Bay, which borders the northern edge of the research facility, also exerts a strong microclimatic influence on NASA ARC. This influence establishes a steep gradient in temperatures, from the cooler and windier Northern portion of the facility, close to the Bay shores, to the warmer southern edge of the campus.

A record of daily temperature and precipitation for NASA ARC exists since 1945 from the Moffett Federal Airfield meteorological station (KNUQ, station identifier GHCND: USW00023244) showing that during the recent decades the climate at NASA ARC has become slightly warmer during the day. However, quantifying how much temperatures have increased at NASA ARC is difficult because of the limited length of the station record, discontinuities in the location of the weather station, and changes in microclimate induced by infrastructure development at the Center of the past decades. In spite of the warming, the climatic conditions at NASA ARC are still considered mild because of the ventilation provided by the proximity to the Bay.

10.4.2 **Current Temperature Conditions**

The average annual temperature recorded at NASA ARC for the 1981-2010 reference period (years 1994-1998 excluded because of incomplete data) is 15.7°C (60.3°F). Annual maximum temperature averages 20.7°C (69.3°F), while average annual minimum temperatures is 10.7°C (51.2°F). Yearly maximum annual temperatures are recorded in the summer, and the maximum recorded over the reference period was 36.8°C (98.2°F). On average, there are 6 days a year when maximum temperatures surpass 32°C (90°F). Yearly minimum annual temperatures are recorded in the winter and the record low during the reference period was -0.2°C (31.6°F). Over the 1981-2010 reference period temperatures have rarely been below freezing, less than one day a year on average.

Temperatures from the Moffett Airfield meteorological record show a slight warming compared to the 1961-1990 reference period. In the 1961-1990 period the average annual temperature was 15.2°C (59.4°F). Annual maximum temperature averaged 20.0°C (68.1°F), while average annual minimum temperatures was 10.5°C (50.8°F). The maximum daily temperature recorded over the 1961-1990 period was 36°C (96.8°F). On average, there were 4 to 5 days a year when maximum temperatures surpassed 32°C (90°F). The minimum annual temperature for 1961-1990 was also -0.2°C (31.6°F), with 1.4 days of subfreezing temperatures a year.

The comparison of temperatures between the two reference periods shows a modest asymmetric warming over the past decades, with maximum temperatures rising faster than minimum temperatures. Most studies worldwide had the opposite finding, of minimum temperatures rising faster than maximum temperatures (IPCC 2007). Whether global warming was solely responsible for driving this slight warming at Moffett Field cannot be determined at this time. It should be noted that the meteorological station was moved to a new location on the airfield in 1996. Additionally, expansion of built-up area in the region may also have affected the record through an urban-induced climate change (the urban heat island effect). On the other hand, the amount of heat island effect from the extensive urbanization the South Bay has undergone during the past 50 years is expected to be higher than the small amount observed. This buffering of the temperature trend would be consistent with a coastal cooling effect observed at other stations of the SF Bay Area. This cooling effect has been attributed to an increase in sea breeze caused by a steepening of the temperature gradient between the air over the ocean and a warming inland region (Lebassi et al. 2009).

10.4.3 **Current Precipitation**

Most of the annual rainfall at ARC falls between the months of November and March, with peaks in December, January and February. During the 1981-2010 reference period average annual rainfall was 376 millimeters, but with large historical interannual variability, ranging from 157 millimeters (in 1953) to 798 millimeters (in 1998). The two rainiest years were those of the strongest El Niño conditions: 1983 (798 millimeters) and 1998 (778 millimeters). On average there are 68 wet days per year. No distinct changes in precipitation are observed with respect to the previous reference period (1961-1990), when total annual rainfall averaged 352 millimeters and interannual variability was similar. A greater difference in average annual precipitation can be observed when comparing the 1978-2014 period versus the 1948-1977. The break point of 1978 marks the shift in dominant sign of the Pacific Decadal Oscillation (PDO), a long-lived El Niño-like pattern of Pacific climate variability (Zhang et al. 1997). During 1948-1977, a period of predominantly negative sign of the PDO index (PDOI), mean annual precipitation recorded at Moffett Field was 339 millimeters. In the subsequent period 1978-2010, when the PDOI was predominantly positive, the recorded mean annual precipitation was higher, 376 millimeters. However, this difference is still small in light of the wide range of recorded annual values.

10.4.4 Projected Climate Change

Climate projections represent a set of possible climate outcomes given a set of influential conditions. Since the Anthropocene (late 1800s to present), the main influence on changes in climate is the increasing rate in GHG emissions from fossil fuel burning. On a more regional scale, changes in climate can also be caused by natural processes in the climate system, such as changes in ocean circulation patterns. Examples of natural changes in the climate system that influence ARC are changes in ocean circulations that cause El Niño/La Niña conditions, acting on interannual variability, and the PDO, which acts on the time scale of two to three decades. Additional drivers for regional changes in climate are large-scale modifications in land cover that impact energy exchanges between the earth surface and the atmosphere, such as the expansion of irrigated agriculture over the Central Valley of California.

Likewise, the intensity and rate of future climate change will depend on rate of increase in GHG concentration in the atmosphere and how these increases will interact with natural influences on climate and other anthropogenic landscape transformations. To understand how the climate system reacts to perturbations in any of its components and project how it will evolve into the future, simulations from Global Circulation Models (GCM) under different scenarios of population growth and economic development are compared and compiled into ensemble means. The GCMs have a very coarse spatial resolution, with a grid-cell size on the order of 2.5° × 2.5° (approximately 275 × 275 square kilometers). To make the information from the GCM relevant at the local scale, statistical techniques are employed to downscale the results to a spatial resolution sufficient to incorporate the orographic complexity.

Here we analyze downscaled results from Coupled Model Intercomparison Project Phase 5 (CMIP5) GCM modeling results from the Intergovernmental Panel on Climate Change (5th Assessment Report (IPCC 2013) for the Representative Concentration Pathway (RCP) 8.5. RCP 8.5 assumes a business as usual of increasing GHG emissions throughout the 21st century. Daily CMIP5 GCM model results used here are downscaled to 1km spatial resolution by means of the Bias Correction Statistical Downscaling (BCSD) technique (Thrasher et al. 2013). Projected changes in temperature and precipitation are provided for three future 30-year periods centered on 2020, 2050 and 2080, respectively from a group of GCMs that best matched the observed record at Moffett Field Air Station (CCSM4, CESM1-BGC and MIROC5).

10.4.5 Projected Changes in Temperature

The temperatures at NASA ARC are overall expected to continue to rise over the coming decades. While on average the climate is expected to remain mild, heat stress is likely to increase as the asymmetric daytime warming trend will persist and the number of days above 32°C (90°F) will more than double by mid-century. Changes in minimum temperatures are expected to be more modest and will continue to have about one night of freezing temperatures per year. A summary of the baseline precipitation variables from the Moffett Airfield meteorological station (1980-2010 reference period) and projected changes in temperature from selected CMIP5 models under RCP 8.5 (high GHG emission scenario) are presented in Table 10-1.

Table 10-1. Baseline Temperature Variables from the Moffett Airfield Meteorological Station and Projected Temperatures from downscaled CMIP5 models

Variable	Baseline	2020s	2050s	2080s
Average Temperature (°F)	60.3	+1 to 2 °F	+2 to 3 °F	+5 °F
Max Temperature (°F)	69.3	+2 to 3 °F	+4 to 5 °F	+6 to 7.2 °F
Min Temperature (°F)	51.2	No change	+1 °F	+3 to 4 °F
Max Temperature above 90°F (days)	6	10 to 12	7 to 14	20 to 25
Min Temperature below 32°F (days)	1	1 to 5	0 to 6	1
Note: Analysis by Cristina Milesi.				

10.4.6 Projected Changes in Precipitation

A summary of the baseline precipitation variables from the Moffett Airfield meteorological station (1980-2010 reference period) and projected changes in precipitation from selected CMIP5 models under RCP 8.5 (high GHG emission scenario) are presented in Table 10-2. Projected changes in precipitation remain uncertain. Overall little change in total annual precipitation is expected. The projections from the BCSD-downscaled models suggests modest increases in precipitation throughout the century, more likely in the 2020s and 2080s, while the 2050s may see a small decline in total annual rainfall. The seasonality of the rainfall is projected to remain unchanged, with about 80% of the annual rainfall continuing to fall between November and March throughout the century.

While little changes are predicted in terms of total annual precipitation, it is projected that the winter rainfall at NASA ARC will come from bigger storms in fewer days and the 100-year return period for extreme storm events will increase (Chiang et al. 2014), increasing the risk of floods at the center.

Since warmer daytime temperatures and thus enhanced evapotranspiration rates will accompany these modest changes in precipitation, drought stress in the region is also likely to increase.

Table 10-2. Baseline Precipitation Variables from the Moffett Airfield Meteorological Station and Projected Precipitation Variables from downscaled CMIP5 models

Variable	Baseline	2020s	2050s	2080s
Annual Precipitation (mm)	376	+5 to 11%	-14 to +8%	-7 to +36%
Nov-March precipitation (%)	82	76 to 82	82 to 84	84%
Wet Days	68	61-63	51-58	55-69
Note: Analysis by Cristina Milesi				

10.4.7 Projected Sea Level Rise

At NASA ARC rates of change in local mean sea level and extreme tides need to be closely monitored even though major uncertainties exist with global and regional sea level rise projections. Knowles (2009), in a study that is widely used for planning purposes by the BCDC, estimated a rise of 0.4 meters (16 inches) by 2050 and 1.4 meters (55 inches) by 2100. More recently, the National Research Council (NRC 2012) published projections for California, Oregon and Washington, taking into account regional subsidence and uplift, as well as the contributions from thermal expansions of the oceans and melting of grounded glaciers and ice sheets. According to this study, sea level along much of the California coast south of Cape Mendocino will rise 5 to 30 centimeters (2 to 12 inches) by 2030, 13 to 61 centimeters (5 to 24 inches) by 2050, and 43 centimeters to 1.68 meters (17 to 66 inches) by 2100. Figure 10-2 shows the low, medium, and high projections from the NRC report (NRC 2012) and an estimate from Knowles (2009).

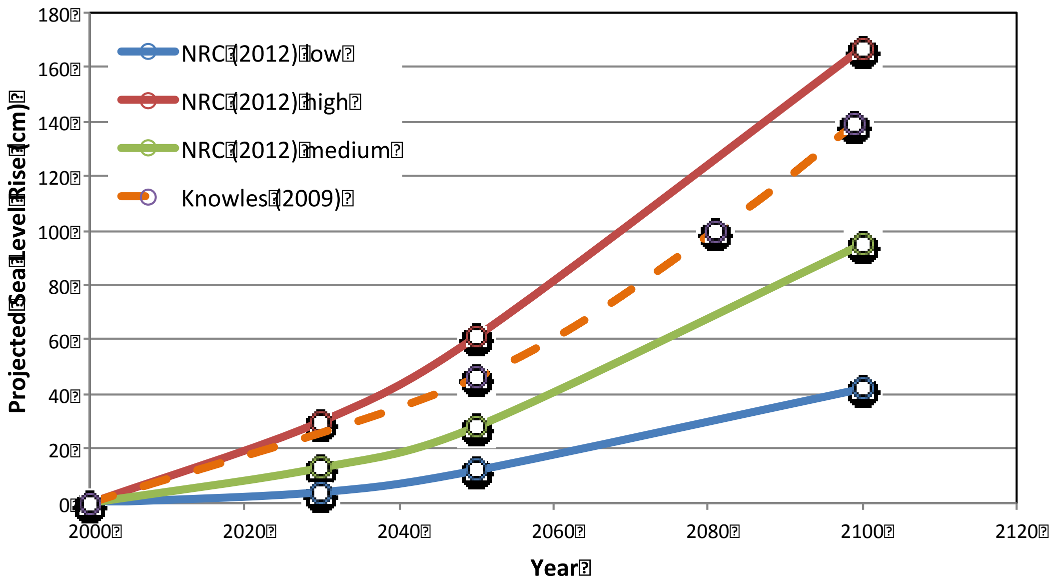


Figure 10-2. Low, Medium, and High Sea Level Rise Projections

(Sources: Knowles 2009; NRC 2012)

As shown in Figure 10-3, vulnerability of the SF Bay to inundation from rising sea levels has been mapped with the Knowles (2009) projections of 16 inches (light blue) and 55 inches (light blue) mean water heights. Such maps assume that no levees exist. The existing salt pond levees are embankments that were built to create salt evaporation pools when salt extraction was active in the South Bay. These levees are not FEMA certified but are currently providing protection from inundation given that portions of the South Bay have already subsided below mean sea level when water pumping for irrigation was common in the region.

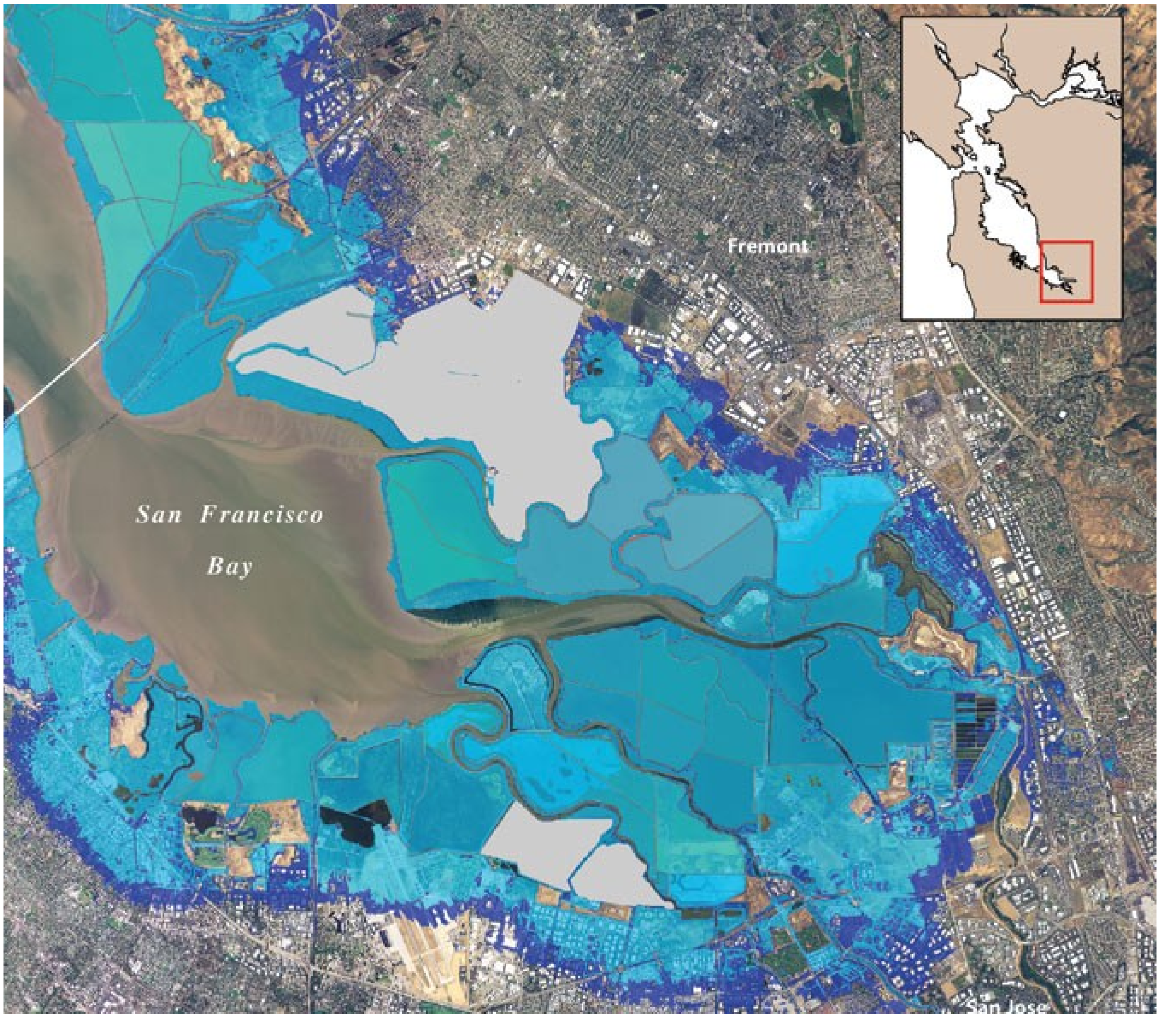


Figure 10-3. Bay Area Vulnerability to Sea Level Rise

(Source: BCDC 2011)

With rising sea levels in the SF Bay, a more immediate threat to NASA ARC infrastructure comes from winter storm surge in coincidence with a high tide (possibly a king tide). Figure 10-4 shows an overview of the South Bay centered on the NASA ARC property. The perimeter of the SWRP is indicated with the black and purple lines. The salt pond levees are highlighted with the green line. On the right side of the figure are photographs of Stevens Creek along the SWRP during yearly maximum (king tide) and average conditions in December 2012.

Surge can account for a large contribution to the local sea level during a major winter storm since the local sea level increases with lowered surface pressure in a large cyclonic disturbance. As shown in Figure 10-5, predictions of the sea level assume 95 centimeters (3.12 feet) of sea level rise from year 2000 to 2100. The annual values plotted were derived from hourly data from the National Oceanic and Atmospheric Administration for the San Francisco tidal gauge (# 9414290, record period 1901-2013). The value used for "high surge" varies for each of the 12 months and corresponds to the 99.9th percentile for that month (i.e. it has a return period of 1,000 hours, slightly less frequently than once per year for the given month) and takes account of astronomical tide, storm surge and particular historical surge peaks often associated with El Niño events (such as in 1982/83 and 1997/98). The red line (annual maximum water height) represents total water height if this high surge were to occur in the same hour as the annual maximum water height of the astronomical tide (Mills et al. 2013).

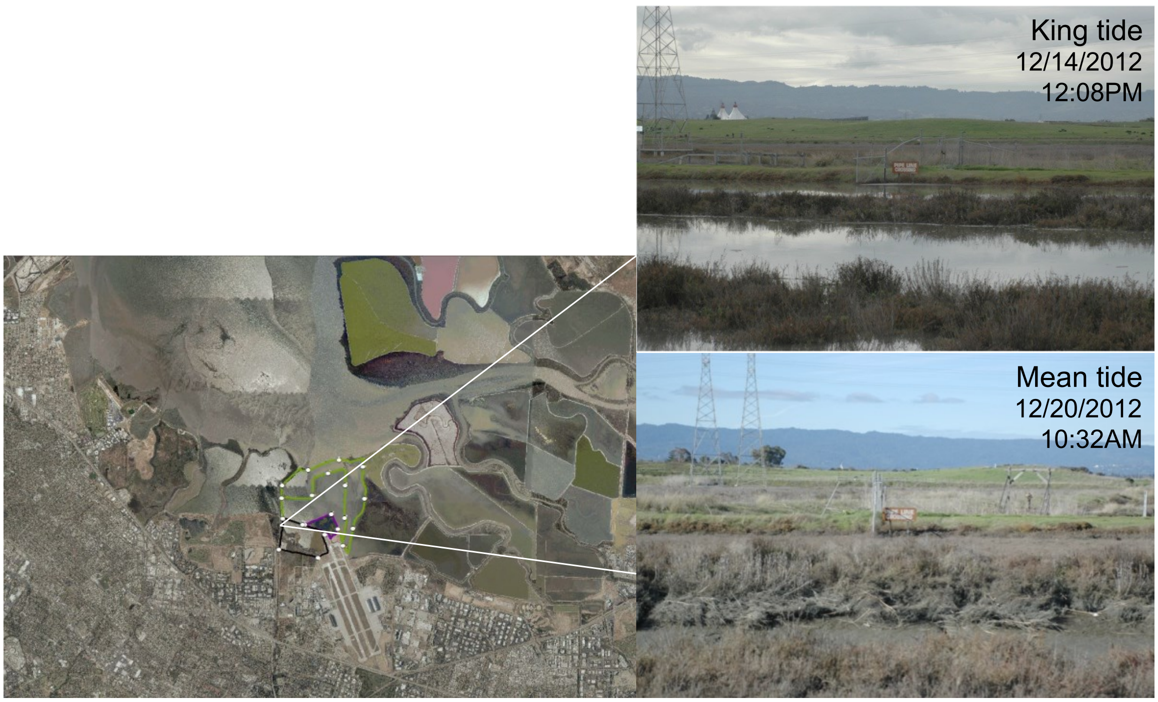


Figure 10-4. Stevens Creek during 2012 Yearly Maximum (King Tide) and Average Tidal Conditions

(Sources: Google Earth [aerial]; Cristina Milesi [photos])

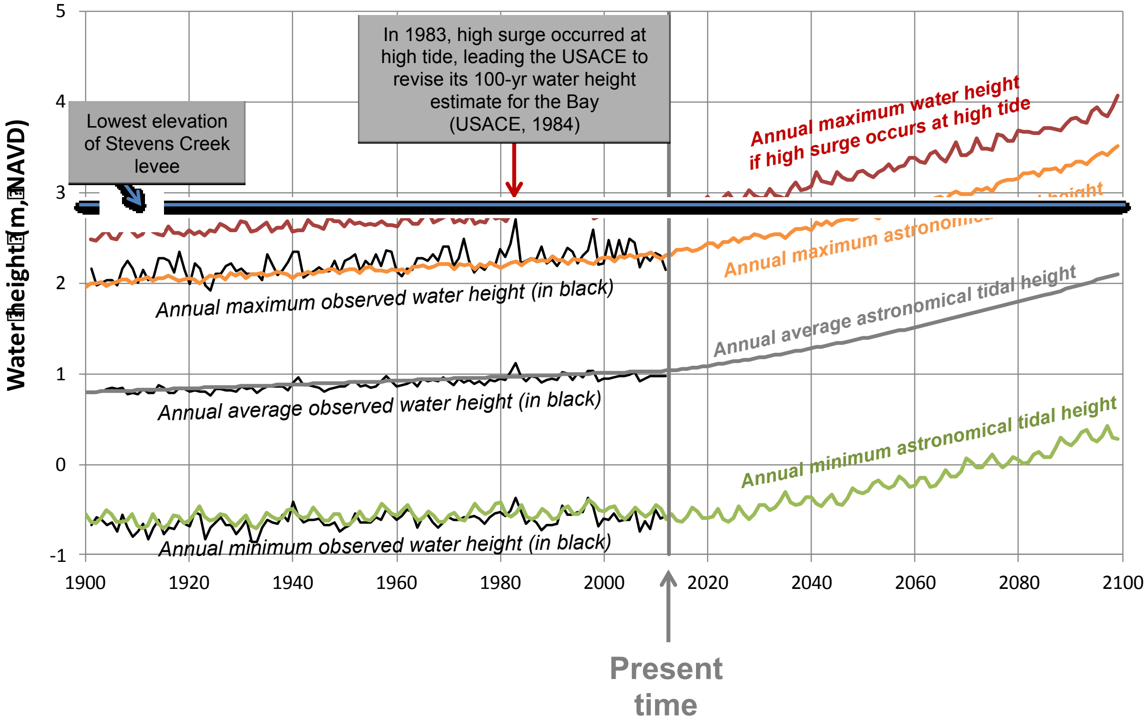


Figure 10-5. Historical and Projected Water Height at San Francisco, Golden Gate Bridge

(Source: Mills et al. 2013)

Water height estimates at San Francisco, Golden Gate Bridge, can be used to predict sea level rise at the NASA ARC location after a southward tidal amplification is taken into account. Figure 10-6 shows 100-year water height estimates in the Bay and at NASA ARC for the present time and by 2100 under the medium projection of a 95- centimeter rise in sea level (NRC 2012). The white line represents the present time, and the yellow line represents the end of this century (year 2100) assuming a sea level rise of 95 centimeters (3.12 feet), corresponding to the medium estimate by NRC (2012).

If no changes in hydrodynamics occur, sea level protection at NASA ARC by the end of the century will need to withstand a 100-year water height of 14.8 feet, plus a 3- foot freeboard, for a total of 17.8 feet NAVD88 (5.4 meters NAVD88) (Mills et al. 2013). Results are preliminary and assume no future changes in extra-tidal height (from El Niño–Southern Oscillation effects, storm surge, or wind) or hydrodynamics.

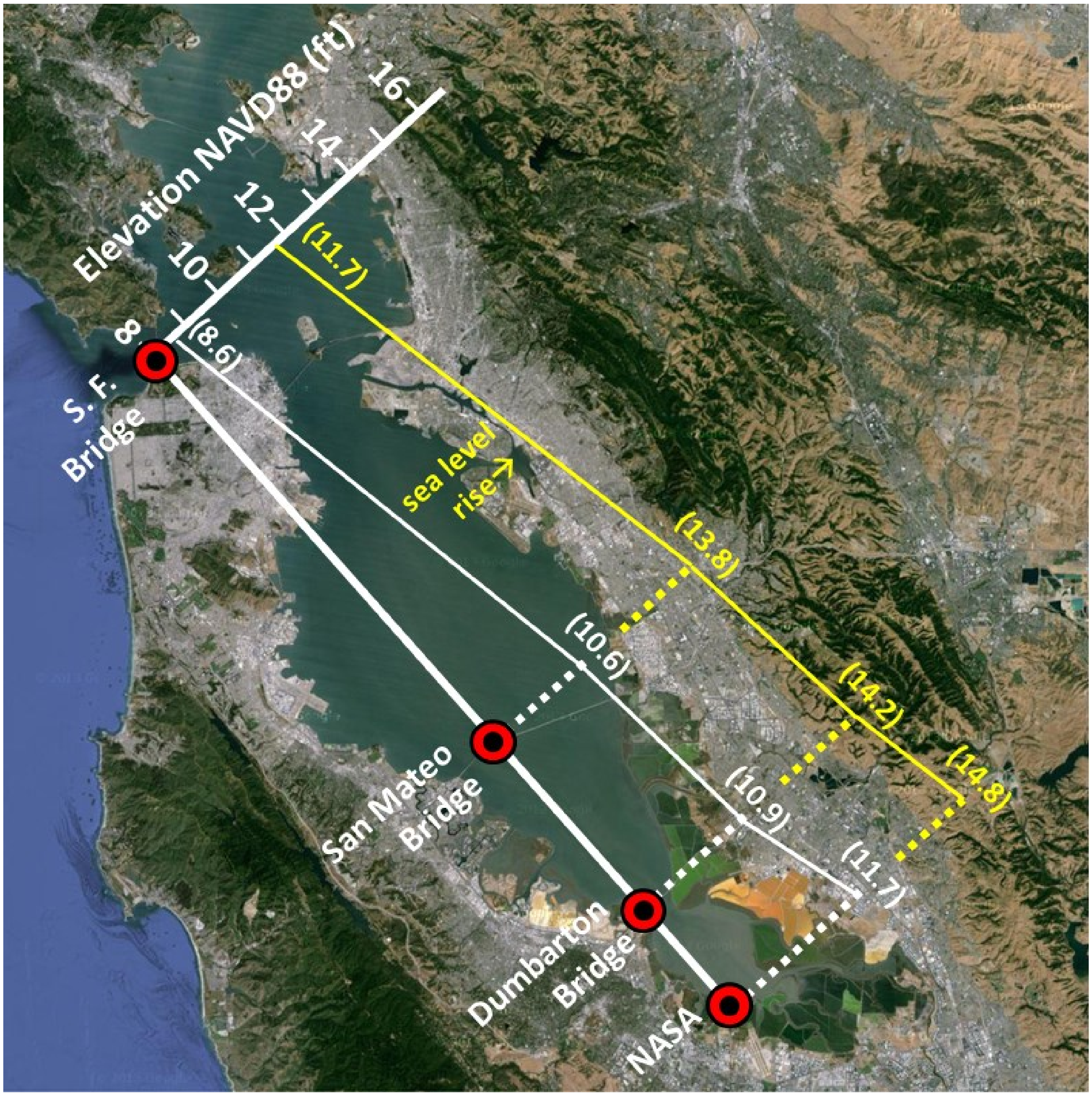


Figure 10-6. Estimated Water Height at the San Francisco Bridge, and Three South Bay Locations, Including NASA ARC

(Source: NRC 2012)

10.4.8 Risks to NASA Ames

Changes in climate have the potential to impact NASA ARC by challenging operations and exposing infrastructure and employees to an increased frequency of hazards. Challenges from a changing climate may be the consequence of local climatic changes or to changes in the broader region with which NASA ARC has strong interdependencies (i.e., changes in precipitation in the Sierra Mountains may affect water availability locally).

10.4.9 Risk of Inundation from Sea Level Rise

NASA ARC will have to accommodate continuing sea level rise and the related vulnerability of its infrastructure and of the protected ecosystems located within the boundaries of the Center. Scientists at NASA ARC have partnered with local experts to accurately measure the elevation of the Ames property that is most vulnerable to inundation and of the existing salt pond levees that are currently providing protection from the waters of the Bay. This will help to plan for the necessary improvements to the levees that will ensure protection to as much as 1.5 meters (4.9 feet) sea level rise but coordination with the local adjacent communities is essential. If the existing levees were to fail during an extreme storm causing 1.5 meters of sea level rise, a large fraction of the low-lying portions of NASA ARC would be flooded and several buildings would be impacted, as simulated by Kirkendall et al. (2013) and shown in Figures 7 and 8. Figure 10-7 shows flooding vulnerability for an extreme storm causing a 1.5-meter (4.9-foot) sea level rise compared with the 100-year and 500-year recurrence intervals at NASA ARC. Figure 10-8 depicts flood depth over NASA ARC for an extreme storm causing a 1.5-meter (4.9-foot) sea level rise in the absence of levee protection.

Evaluation of habitat protection of the endemic and endangered species that live in the local wetlands is also required to adapt to rising sea levels as some of these habitats would be impacted. If sea levels were to rise above the existing levees, wetlands would be limited in their inland expansion, as they would encroach with other land uses. If the levees were to be raised significantly from their current levels, wetland area would be lost to the footprint of the levees. Alternatives for new levee installations were considered as part of a study on the feasibility of tidal restoration in the NASA ARC SWRP (Brown and Caldwell, 2005). Calculations presented in Mills et al. (2013) show that to accommodate these alternative levees could require mitigating for the loss of 20-22 acres of wetland.

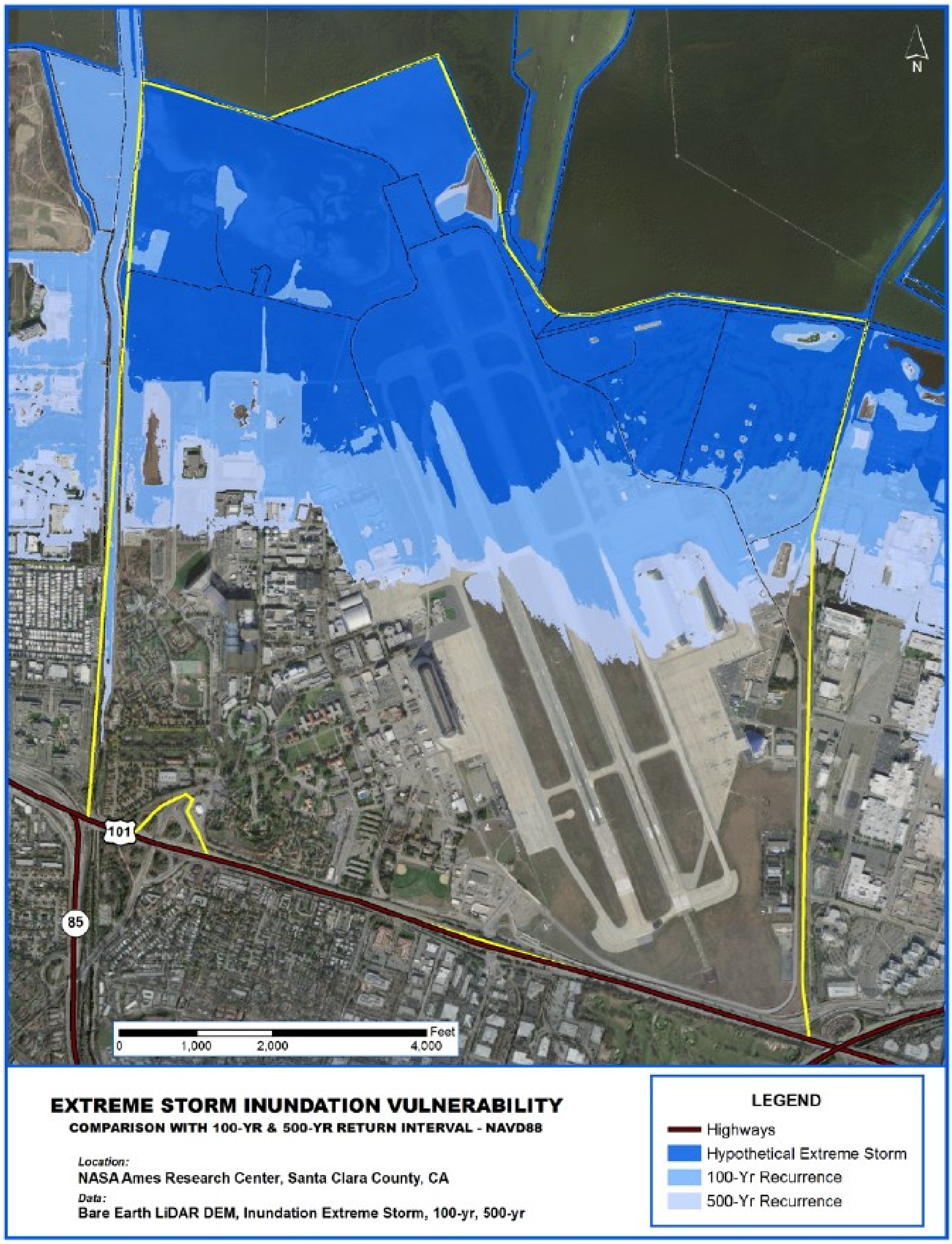


Figure 10-7. Extreme Storm Inundation Vulnerability at NASA ARC

(Source: Kirkendall et al. 2013)

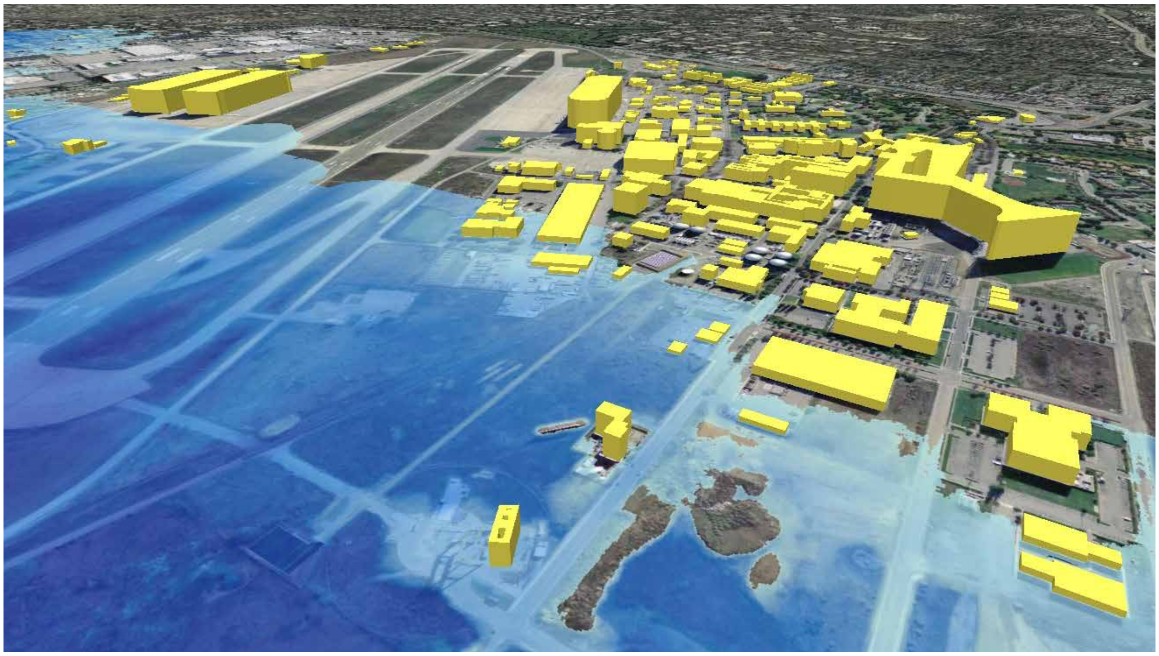


Figure 10-8. Flood Depth at NASA ARC from an Extreme Storm

(Source: Kirkendall et al. 2013)

10.4.10 **Risk of Inundation from Extreme Storm Runoff**

Other vulnerabilities of Center operations arise from the potential of increased storm intensity and of its impact on storm water drainage. All the runoff developed on the western portion of the NASA ARC campus collects in a SWRP serving as a closed sink that evaporates during the summer (shown in black and purple lines in Figure 10-4). The pond, whose capacity is around 900 acre-feet, has been contaminated from use over many years as a containment volume for toxic materials. Flooding at NASA ARC can occur when excessive yearly rainfall surpasses the capacity of the pond and the pumping rate of the existing pump. The pump is available to empty the runoff into the adjacent Stevens Creek but it is activated only when the retention pond is full. Thus, the capacity of the retention pond should be monitored during the rainy season. Simulations of the runoff generated during extreme rainfall events from the daily BCSD-downscaled models are shown in Figure 10-9. Figure 10-9 shows the results of pond filling for historical and predicted winter storms. Several predicted extreme storm events were chosen from the CMIP5 model runs as indicated by notations in the figure. Results to date show that the storms will be more likely surpass in intensity historical extreme storms, with increased risk of filling or overtopping the SWRP (Milesi et al. 2014). The simulation results are in agreement with the predictions of increased 100-year return period of extreme precipitation calculated from the downscaled CMIP5 models (Chiang et al. 2015).

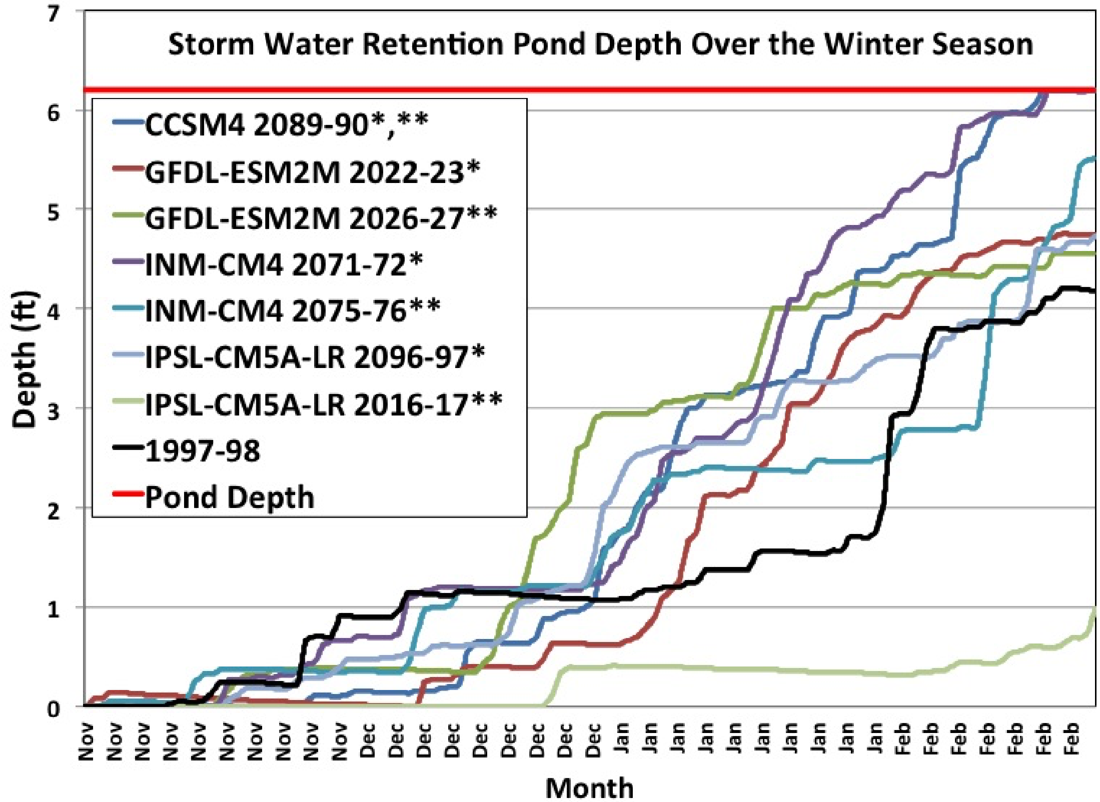


Figure 10-9. Projections of Extreme Runoff from the SWRP

(Notes: * Indicates simulation with time series [Nov-Feb] with extreme winter rainfall;
** indicates time series [Nov-Feb] with extreme individual rainfall event)

(Source: Milesi et al. 2014)

10.4.11 **Impacts on Center Costs from Water and Power**

Increases in average and extreme temperatures are likely to increase NASA ARC consumption and cost of water and power. NASA ARC depends entirely on purchased hydroelectric power for buildings, large computer cooling, and wind tunnel operations. The future availability of this power source will depend on winter snowmelt and runoff from the Sierra Nevada Mountains. With snowmelt predicted to occur earlier, the seasonality of runoff is projected to change, potentially affecting both the power generation and the quantity of water available for various summertime needs. In dry years in particular, with lower hydroelectric generation and reduced water availability, costs for both electricity and water might increase for both the NASA ARC and the region, and regardless of costs, impose greater conservation requirements. Recent extreme droughts have already led to steep increases in water use rates in parts of the Bay Area.

An indirect effect on NASA ARC electricity costs may occur as a result of California's adoption of AB 32, the California Global Warming Solutions Act of 2006, which requires a sharp reduction of GHG emissions statewide (80% reduction from 1990 levels). The effect of this regulation on the prices of electricity from non-GHG-emitting sources is not known, but it is possible that there will be greater demand for sources such as those currently providing power to NASA ARC.

A watershed of high interest is the Upper Tuolumne Watershed, where the municipal water for the San Francisco Bay Area originates. Ecohydrological variables such as vegetation biomass, evapotranspiration, and runoff are simulated with TOPS, the Terrestrial Observation and Prediction System, an ecosystem modeling tool developed at NASA ARC (Nemani et al. 2009). TOPS is a modeling framework that aggregates weather observations, historical climate statistics and climate projections, satellite data of surface conditions, and information about soils and land use and land cover together in compatible formats to be input into ecosystem models for the purpose of producing ecological forecasts. End-of-century climate forecasts are analyzed under scenarios of moderate (A1B) and highest CO_2 emissions (A2). In the Upper Tuolumne Watershed, warming can cause a decrease in biomass (indicated here as Gross Primary Productivity, or GPP, left) and an earlier growing season. With snowmelt occurring earlier, at the end of the century runoff is projected to peak in the month of February rather than the late spring, as it is currently (right). This would increase the risk for summer drought. Figure 10-10 illustrates TOPS predictions of future declines in GPP, an indicator of biomass, and earlier, more intense melt water runoff in the Upper Tuolumne watershed (Rosenzweig et al. 2014).

a)

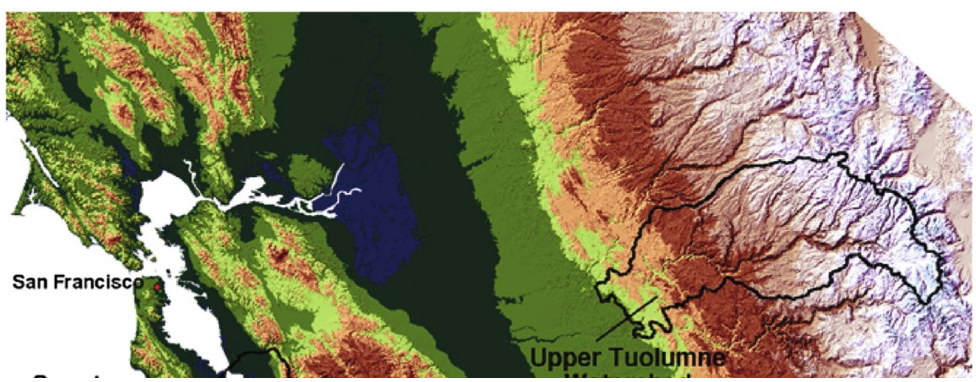


Figure 10-10. TOPS Simulations of Upper Tuolumne Watershed under Present and End-of-Century Conditions

(Rosenzweig et al. 2014)

10.4.12 Impacts on Human Capital

Climate change may impact the personnel at NASA ARC in multiple ways over the next several decades. While the climate at NASA ARC is expected to remain mild overall, the number of days above 90°F is expected to more than double by mid- century, and quadruple by the end of the century (Table 10-1). This increase in extreme temperatures may cause restrictions on outdoor working hours during the summer months. Additionally, the higher temperatures are expected to worsen air pollution, and negatively impact people with respiratory illness. Additionally, because much of the personnel reside away from the coast, and a steep gradient causes the temperatures to be much higher in the surrounding communities, the discomfort and health consequences of rising temperatures felt when the workforce is at home can impact work productivity.

Other impacts on human capital can be caused by interruptions in transportation caused by flooding during extreme storm events, from extremes of runoff, and/or storm surge. Just like extreme precipitation and sea level rise can cause flooding of portions of the Center, such events can also flood the highways and other roads in the South Bay and prevent personnel from reaching or leaving the Center.

Additional ways in which climate can impact the human capital should be considered and analyzed.

10.5 Environmental Requirements

NASA has identified the following environmental plans, policies, and strategies that address climate change risks to operations and future development at ARC.

10.5.1 NASA Procedural Directive 8500.1, NASA Environmental Management

Per NPD 8500.1, it is NASA policy to: maintain compliance with all applicable federal, state, and local environmental requirements; to incorporate environmental risk reduction and sustainable practices to the extent practicable throughout NASA's programs, projects, and activities; and to consider environmental factors throughout the life cycle of programs, projects, and activities (as defined in NPD 7120.4, *NASA Engineering and Program/Project Management Policy*, and related documents), including planning, development, execution, and disposition activities. Examples of environmental factors include consideration of environmental impacts as required by the NEPA and NHPA; the proposed use of hazardous materials; the potential for waste generation; the need to acquire necessary permits, waivers, and authorizations; and the use of environmentally-preferable materials and processes wherever practicable.

NPR 8500.1, Section 1(b), includes the following applicable policies regarding climate change resilience.

> *(5) Apply NASA's scientific expertise and products so that we can incorporate climate information into our decision making and planning; create innovative, sustainable, and flexible solutions; and share best practices; in order to create climate-resilient NASA Centers.*

10.5.2 NASA 2014 Strategic Sustainability Performance Plan

In addition to outlining new requirements for GHG management and sustainable buildings and communities, to mention only a few of the requirements, EO 13514 (discussed above) requires NASA and all federal agencies to develop, implement, and annually update a SSPP.

Goal 9 of NASA's SSPP is devoted to strategies to ensure climate change resilience. As of September 30, 2013, ARC and other NASA centers are integrating climate factors into their existing management plans through the adaptation process. Additionally, NASA's Master Planning Community of Practice and Senior/Center Sustainability Officers are discussing climate design and other climate adaptation policies at regularly scheduled meetings.

Per the SSPP, planned future actions in support of Goal 9 include the continuation of NASA's adaptation workshops to reinforce early progress and extend momentum towards a more climate-resilient Agency; continued contributions by NASA to national and international climate research efforts; and updates to CASI's climate projections for NASA centers through incorporation of advanced climate models.

10.5.3 NASA 2014 Climate Risk Management Plan

In response to EO 13514 and 13653 (discussed above), which require federal agencies to develop Climate Adaptation Plans to evaluate their climate change risks and vulnerabilities and to manage the effects of climate change on each agency's operations and mission, NASA has developed a "Climate Risk Management Plan." The Plan, which is appended to the 2014 SSPP, describes NASA's overall goal and strategy "to create climate-resilient NASA centers able to execute NASA's mission." The plan also identifies long- and short-term risks from climate change on NASA's strategic objectives, roles, and responsibilities; opportunities and approaches for managing climate-related risks; trends and factors that may affect NASA's climate risk identification and adaptation strategies; and governance processes and organizational resources within NASA that provide oversight of climate change-related issues.

As highlighted in the Plan, the following strategies are being implemented at ARC and other NASA centers to address local climate risks and preserve mission capabilities.

- Ongoing investigations by CASI into local climate risks at ARC and other centers assists NASA with its goal of creating climate-resilient NASA centers and reducing risk to mission.
- NASA has well-established communities of practice in the areas of master planning and climate change adaptation that are coordinated by NASA Headquarters and staffed by one or more individuals from each center or facility, including ARC.
- The NEPA process at ARC and other centers enables NASA to incorporate climate risks into decision-making and planning, which further reduces NASA's exposure to future climate-related risks.
- The Center Sustainability Officer at ARC, as at other centers, is tasked with the role of assessing the Center's vulnerabilities, identifying risks, and developing and implementing climate change adaptation strategies endorsed by Center or Headquarters leadership.

10.5.4 Ames Procedural Requirements 8500.1, Ames Environmental Procedural Requirements

APR 8500.1 sets forth general procedural requirements to ensure compliance with applicable federal, state, and local environmental laws; regulations and EOs; and NASA policies and procedures. Organizational directors, division chiefs, branch chiefs, section heads, supervisors, managers, and CORs are responsible for planning, designing, constructing, managing, operating, and maintaining facilities in conformance with applicable regulatory directives, and should obtain environmental review from the

Environmental Management Division early in project planning consistent with NASA's NEPA implementing procedures (NPR 8580.1 and EO 12114), NASA policies and procedures for programs and projects (NPR 7120), and NASA regulations related to environmental quality (14 CFR 1216). Program and project managers should coordinate with the Environmental Management Division in a timely manner to ensure that any new or modified programs, projects, and activities comply with regulatory requirements.

10.5.5 **Ames Environmental Work Instructions**

Ames's EWIs, which replace the previous Ames Environmental Handbook (APR 8800.3), set forth requirements to ensure that programs, projects, and activities at ARC comply with applicable federal, state, and local laws; regulations and EOs; and NASA policies and procedures. Each EWI lists relevant regulatory authorities and documents, assigns individual and organizational responsibilities within ARC, and identifies specific requirements applicable to the work being performed.

The following EWIs are relevant with respect to climate change risks to operations and future development at ARC.

- EWI 12, Public Involvement
- EWI 14, NEPA and Environmental Justice
- EWI 18, Environmental Requirements for Construction Projects (Under review)