United Heckathorn Superfund Site
Climate Vulnerability Assessment

Technical Memorandum

July 12, 2023

Executive Summary

The United States Environmental Protection Agency (EPA) defines vulnerability in the context of climate assessments as:

> "*The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes; it is a function of the character, magnitude, and rate of climate variation to which a system is* ***exposed****; its* ***sensitivity****; and its* ***adaptive capacity***" (EPA, 2021a)

Key Definitions

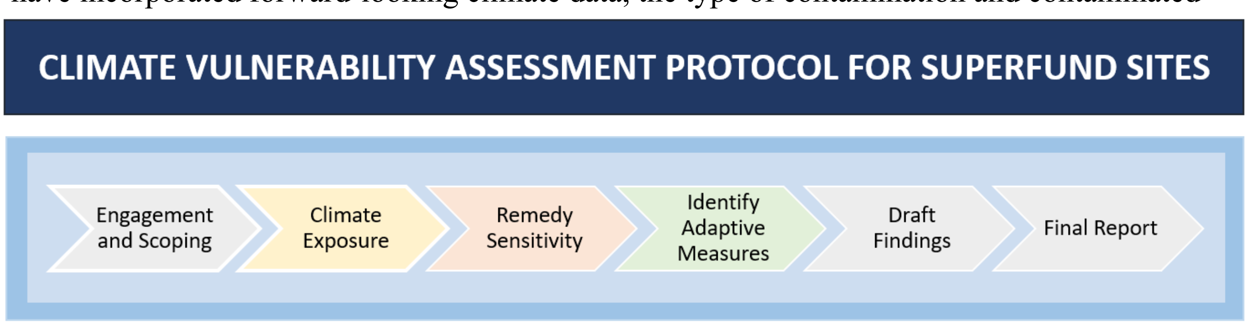
- **Exposure:** Whether a site could experience a climate hazard
- **Sensitivity:** Whether a site would experience impacts as a result of climate hazard exposure
- **Adaptive Capacity:** A site's ability to cope with the impacts

In June 2021 the EPA Office of Superfund Remediation and Technology Innovation (OSRTI) issued a Memo on *Consideration of Climate Resilience in the Superfund Cleanup Process for non-Federal NPL Sites*. Consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Oil and Hazardous Substance Contingency Plan (NCP) and associated EPA Superfund guidance, the Memo recommends the following approach for EPA regions to consider when evaluating climate resilience during the remedy selection and implementation process: (1) assess the vulnerability of a remedial action's components and evaluate the impact of climate change on the long-term integrity of a selected remedy; (2) identify and evaluate adaptation measures that increase the system's resilience; and (3) implement adaptation measures necessary to ensure the long-term integrity of CERCLA remedial actions.

As part of EPA's commitment to develop technical guidance, OSRTI released a series of Climate Resilience Technical Fact Sheets focusing on adaptation measures to increase a remedy's resilience to climate change impacts for contaminated sediment sites (EPA, 2019a), contaminated waste containment systems (EPA, 2019b) and groundwater remediation systems (EPA, 2019c).

In response to requests from RPMs for assistance in determining site vulnerabilities to climate change, OSRTI offers climate vulnerability assessments as part of the Optimization Program under the Technology Integration and Information Branch (TIIB).

The diagram below summarizes the climate vulnerability assessment protocol for Superfund sites. This process includes a review of future climate exposure and remedy sensitivity to identify key climate vulnerabilities at an individual site. The focus of each individual assessment is guided by current or planned site infrastructure, the extent to which site and remedy analyses have incorporated forward-looking climate data, the type of contamination and contaminated



media at the site, and the phase of the Superfund cleanup. Adaptive measures already in place are also accounted for when evaluating remedy sensitivity and vulnerability.

Climate projections are inherently uncertain and depend on factors like the adoption of major policies to reduce global greenhouse gas emissions. Each assessment uses projections for the 90th percentile of the high emissions scenario (Representative Concentration Pathway [RCP] 8.5) to better understand the "worst case" scenario and conservatively screen for all potential climate risks to the site. RCP 8.5 assumes greenhouse gas concentrations continue to rise throughout late-century. Also evaluated is RCP 4.5 to understand a middle-of-the-road scenario.

Climate Vulnerability Assessment Findings

This report provides an independent, third-party review of critical intersections between climate exposure and potential site-specific remedy sensitivities and vulnerabilities at the United Heckathorn Superfund site. The objective of this report is to provide site regulators and stakeholders with the best possible information to design and maintain protectiveness of the remedies. The assessment summarizes projected climate changes at the site for mid- and late-century using the best available climate data and models and provides a set of considerations to improve remedy resilience. The considerations in this report are based on an independent review and represent the opinions of the climate vulnerability assessment review team. These considerations are not requirements; they are provided to assist the EPA Region and other site stakeholders with advancing climate resilience. Also, note that while the considerations may provide details pertaining to remedy sensitivity to climate hazards, they do not replace other, more comprehensive, planning documents such as work plans, sampling plans, and Quality Assurance Project Plans (QAPPs). An analysis of climate resilience considerations, beyond those provided in this report, may be needed prior to implementation of adaptive measures.

The table below summarizes the key climate vulnerability assessment findings.

Summary of key findings for United Heckathorn

Hazard	Climate Projections	Remedy Sensitivities
Precipitation	• Monthly precipitation totals are projected to increase for September through April. • Extreme precipitation is projected to increase in frequency and intensity, increasing runoff.	• Capacity of the on-site stormwater treatment system is designed for the current rainy season and is sensitive to increases in total and extreme precipitation events. • Potential impact to upland gravel cap.
Coastal Hazards and Flooding	• Sea level rise and storm surge projections are projected to increase coastal flood risk. • Groundwater is projected to rise by late-century under future sea level rise.	• Proposed cap of contaminated sediment could be destabilized by an increase in currents associated with sea level rise. • Increases in groundwater levels may increase migration of contaminants between soil and surface water
Drought	• Heavy rainfall events are projected to be punctuated	• Low risk to current and proposed site remedies.

Hazard	Climate Projections	Remedy Sensitivities
	by longer extended dry periods, increasing the risk of drought.	
Temperature	• Both average and extreme temperatures are projected to increase at the site.	• Low risk to current and proposed site remedies.
Wildfire	• Wildfire risk is projected to increase slightly.	• Low risk to current and proposed site remedies.
Landslides	• The site is in an area with very low to low landslide susceptibility.	• Low risk to current and proposed site remedies.

The United Heckathorn Superfund site is located in Richmond Harbor, on the east side of San Francisco Bay in Contra Costa County, California. The location of the former United Heckathorn facility is currently being used as a marine shipping terminal operated by the Levin Richmond Terminal Corporation. The site has been divided into two Operable Units (OUs): OU1 consists of the approximately 5-acre upland area; and OU2 is comprised of all the contaminated channels (Lauritzen, Santa Fe, Parr, and Inner Harbor) and their associated waters and marine sediments. The remedies for OU1 and OU2 were selected in a 1994 ROD and modified by a 1996 Explanation of Significant Differences (ESD).

The selected remedy for OU1 included capping the 5-acre upland area with reinforced concrete in areas used for material stockpiling, and a geotextile fabric and gravel cap in low traffic areas. The reinforced concrete cap is likely resilient to the projected increases in storm events. Areas covered by only the gravel cap may be vulnerable to increases in extreme precipitation events. The site operations and maintenance plan should include post-storm event inspection of the site to identify impacts to the gravel cap as they occur. Increases in sea level and storm surge are projected to cause the site groundwater table to rise and may increase contact between groundwater and contaminated soils. An elevated groundwater table in conjunction with tidal pumping has the potential to increase contaminant migration from the contaminated soils to the surface water. Increases in storm events may increase the rate of degradation to the gravel and concrete caps.

On-site stormwater is collected through a series of drop inlets and piping. In response to third-party litigation, the current property owner installed an on-site treatment system in 2014 to treat stormwater before it is discharged directly to the Lauritzen Channel. The system has been designed to address a precipitation volume as modeled by the current rainy season. The site team should evaluate the capacity of the stormwater treatment system considering the projected precipitation increases, and increase capacity as needed to maintain protectiveness.

The remedy for OU2 was implemented in 1997 and consisted of dredging of contaminated sediment in the Lauritzen and Parr channels and placement of clean sand. However, annual monitoring results of marine sediments and surface water in the Lauritzen Channel have exceeded the remediation goals. In response, EPA drafted a Focused Feasibility Study (FFS) in February 2015 to update the conceptual site model (CSM) and evaluate new remedy technologies including full or partial dredging and application of a carbon-amended sand layer.

Future climate exposure should be considered when evaluating remedial alternatives for the contaminated channel sediment. As the selected remedy will need to allow the Lauritzen Channel to remain navigable, significant challenges exist in implementing and maintaining a resilient sediment cap.

The 2015 FFS also developed and evaluated shoreline source control measures for OU2. As an elevated groundwater table has the potential to increase contaminant migration from the contaminated soils to the surface water, the design of shoreline source control measures should consider future rises in sea level and groundwater and the resulting increased flux of contaminants from the groundwater to the surface water. The selection and design of all remedy components with a lifespan of at least 30 years should incorporate future climate projections, ensuring adaptive measures are designed to withstand the projected increases in sea level rise and extreme precipitation events.

Notice and Disclaimer

Work described herein, including preparation of this report, was performed by ICF for the EPA under Task Order 08 of EPA contract EP-W-14-001 with ICF.

This climate vulnerability assessment is an independent study funded by EPA performed by a team of independent technical experts and climate scientists that evaluate existing data, identifies and models future climate change scenarios expected to affect the site, analyzes remedy sensitivities, and provides considerations for improving remedy resilience. Detailed consideration of EPA policy was not part of the scope of work for this review. This report does not impose legally binding requirements, confer legal rights, impose legal obligations, implement any statutory or regulatory provisions, or change or substitute for any statutory or regulatory provisions. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by EPA.

The considerations are based on an independent evaluation of existing Site information, represent the technical views of the climate vulnerability assessment review team. These considerations do not constitute requirements for future action; rather, they are provided to assist the EPA Region and other site stakeholders in ensuring climate resilience.

Considerations provided in this report are not meant to supersede other, more comprehensive planning documents such as work plans, sampling plans, and quality assurance project plans, nor are they intended to override applicable or relevant and appropriate requirements established in the Record of Decision. Further analysis of considerations, including review of EPA policy, may be needed before implementation.

The site boundary geospatial information used in this report is provided by EPA as a public service. EPA does not vouch for the accuracy, completeness, or currency of data; geospatial data provided by external parties is not independently verified by EPA. This geospatial data is used strictly for informational purposes. The geospatial data does not represent EPA's official position, viewpoint, or opinion, express or implied. It is not intended for use in establishing liability or calculating Cost Recovery Statutes of Limitations and cannot be relied upon to create any rights, substantive or procedural, enforceable by any party in litigation with the United States or third parties.

Section 1 – Introduction

The EPA Office of Superfund Remediation and Technology Innovation (OSRTI) provides technical support to EPA regional offices by performing climate vulnerability assessments at Superfund sites. This technical memorandum summarizes the climate vulnerability assessment conducted at the United Heckathorn Superfund site (EPA ID: CAD981436363). The assessment provides an independent, third-party review of the best available climate data and potential, site-specific, remedy sensitivities and vulnerabilities. The purpose of this assessment is to identify potential climate risks to the Superfund site and provide site regulators and stakeholders with the best possible information to design and maintain protectiveness of the remedies. This memorandum is organized as follows:

- Section 2 – Site Background provides background information on the United Heckathorn Superfund Site.
- Section 3 – Climate Exposure describes site exposure to climate hazards that have the potential to impact remediation efforts.
- Section 4 – Remedy Vulnerabilities and Resilience describes the sensitivities, vulnerabilities, and adaptive measures for the remedy alternatives proposed for the site.

This climate vulnerability assessment uses climate screening tools and modeled climate variables to identify potential risks to site remedies under future climate conditions at a local, site-specific scale. Where possible, this assessment uses climate projections for the 90th percentile of the high emissions or "business as usual" scenario (Representative Concentration Pathway [RCP] 8.5) to conservatively screen for all potential climate risks to the site.[1] Site documents are used to assess existing or planned remedy infrastructure that may be at risk to the identified climate impacts and identify climate resilience features that may mitigate or alleviate the identified risk.

The results of the assessment can then help inform remedy design and maintenance decisions to ensure protectiveness against potential vulnerabilities. Assessing potential climate change impacts on receptor or ecosystem communities or on contaminant toxicity mediated by changing physical/chemical speciation is outside the scope of this report. However, climate projections may be used by the site team to consider potential impacts to these areas.

[1] Additional information on Representation Concentration Pathways can be found on EPA's EnviroAtlas website: https://www.epa.gov/enviroatlas/changes-over-time

Section 2 – Site Background

Location and History

The United Heckathorn Superfund site is located in Richmond Harbor, on the east side of San Francisco Bay in Contra Costa County, California (Figure 1). The location of the former United Heckathorn facility is currently being used as a marine shipping terminal operated by the Levin Richmond Terminal Corporation. The areas of contamination that comprise the site include an approximately 5-acre upland area of the terminal and marine sediments and the waters of several harbor channels: Lauritzen, Santa Fe, Parr, and Inner Harbor.

Figure 1. The United Heckathorn Superfund Site boundary (left) and regional view (EPA, 2012).

The Site was placed on the National Priorities List by EPA in 1990. The site includes the former United Heckathorn facility where organochlorine pesticides were processed, packaged, and shipped, and the adjacent waterways that have been contaminated by releases from the former facility. Dichlorodiphenyltrichloroethane (DDT) was the most commonly processed pesticide. Aldrin, dieldrin, and endrin were also processed onsite in smaller quantities. The former facility was located on the approximately 5-acre, upland area of the terminal. The contaminated waterways are the four harbor channels: Lauritzen, Santa Fe, Parr, and Inner Harbor. The most contaminated of which is the Lauritzen Channel. The site has been divided into two OUs: OU1 is comprised of the approximately 5-acre upland area; and OU2 is comprised of all the contaminated channels (Lauritzen, Santa Fe, Parr, and Inner Harbor) and their associated waters and marine sediments.

Removal Actions

Removal actions are conducted to quickly address immediate threats from hazardous substances to eliminate dangers to the public. Multiple excavations and removal actions have been conducted at the site (EPA, 1994). Prior to its listing on the NPL multiple excavations were performed at the site by previous landowners, including the removal of contaminated upland soils and placement of gravel on the site and ballast rock over the Lauritzen Channel embankment. Following the site's listing on the NPL, EPA issued an EPA Removal Order to excavate highly contaminated soil and pesticide residue from the Lauritzen Channel embankment and upland areas for off-site disposal. The 1994 ROD estimated that the removal actions, both PRP and EPA led, had removed over 99% of the mass of pesticides from the upland portion of the site.

Remedial Actions

The remedy for the site (OU1 and OU2) was selected in a 1994 ROD (EPA, 1994) and modified by a 1996 Explanation of Significant Differences (ESD). The RAOs include:

- RAO for OU1: prevent contact with DDT and dieldrin in upland soils and to prevent the erosion of upland soil into the adjacent marine area.
- RAO for OU2: reduce DDT and dieldrin concentrations in marine sediments and water to levels protective of human health and the environment.

Table 1 lists the remedies by OU that have been selected and implemented as of the Fifth Five-Year Review (FYR) Report (EPA, 2021b).

Table 1. Selected Remedy Summary.

Operable Unit	Selected Remedy
OU1	• Capping of an approximately 5-acre upland area, including the northern half of the Levin-Richmond terminal (former United Heckathorn facility), to prevent erosion of contaminated soil. • Maintenance and monitoring of the cap to ensure it remains protective and prevent erosion of upland soil into the adjacent marine area. • Deed notice placement to prevent construction and incompatible use of the approximately 5-acre upland area without further study and likely remediation.
OU2	• Dredging of all upper, soft and more recently deposited sediments (i.e., Younger Bay Mud) from the Lauritzen and Parr channels, with offsite disposal of dredged material, followed by placement of clean sediment after dredging. • Annual monitoring of marine sediments, surface water, and animal tissues to determine if surface water and marine sediment remediation goals have been achieved and would continue to be achieved in the future.

The cap for OU1 was completed in July 1999 and consisted of reinforced concrete in areas used for material stockpiling, and a geotextile fabric and gravel cap in low traffic areas. The cap and drainage system included design elements to control surface water runoff using "Best Management Practices" under the National Pollution Discharge Elimination System (NPDES) program. On-site stormwater was collected through a series of drop inlets and piping and discharged to the local Publicly Owned Treatment Works (POTW). In response to third-party litigation regarding violations for exceeding the POTW's water quality intake limits, the current property owner (Levin Richmond Terminal) installed an on-site treatment system in 2014. Stormwater is now treated by this system before it is discharged directly to the Lauritzen Channel.

The system consists of multiple treatment steps, including flocculation/settling and sand filtration, prior to discharge. The system is regularly tested under the substantive requirements of the NPDES program. The stormwater system has been designed to have sufficient capacity to hold all stormwater runoff generated during the current rainy season (October through May), though infrequent direct discharges to the Lauritzen Channel have been recorded (EPA, 2021b).

The remedy for OU2 was implemented in 1997 and consisted of dredging of contaminated sediment in the Lauritzen and Parr channels. Approximately 107,000 cubic yards (yd^3) of contaminated sediment were transported by rail from the site and disposed of at designated disposal facilities. Post dredging samples confirmed that pesticide concentrations in channel sediments and surface water had been reduced. The reduction was most pronounced in the Lauritzen Channel, with a reduction of apparently at least two orders of magnitude of total DDT in the sediments of that channel. An average of 18 inches of clean sand was placed over the dredged areas as part of the OU2 remedy to reduce resuspension of contaminated sediments.

The Fifth Five-Year Review identified the following issues and recommendations (EPA, 2021b):

- Concentrations of contaminants in sediment and surface water in the Lauritzen Channel continue to exceed remediation goals more than twenty years after remedy implementation.
- The most recent Parr Channel surface water samples were collected in 2013 and exceeded remediation goals, and there is no monitoring program to track recent progress.
- Monitoring of seeps discharging from the upland area into the Lauritzen Channel is not required under the current remedy. The 2021 FYR discusses the identification and sampling of several seeps originating from the sheet pile wall and included a recommendation to consider seep monitoring and sampling as part of a future remedy modification.
- Conduct a climate-change exposure assessment and climate-change sensitivity assessment to estimate the likelihood for potential climate change hazards to reduce the protectiveness of the remedy.

In response to the surface water and tissue samples of the downgradient water bodies exceeding the cleanup goals identified in the 1994 ROD for OU2, EPA drafted a Focused Feasibility Study (FFS) in February 2015 to update the conceptual site model (CSM) and evaluate new remedy technologies to restore the marine environment of OU2 (EPA, 2015). Technologies retained for the development of remedial alternatives included: additional dredging of the upper sediment layer (i.e., Younger Bay Mud) of the Lauritzen Channel of OU2; source control measures including sheet piling, active capping, and/or shoreline pipe removal/mitigation; and storm drain sediment removal in OU1.

Section 3 – Climate Exposure

Climate change is increasing the frequency of extreme events such as drought, wildfire, and floods (USGCRP, 2018a). While current climate models may not capture the full range of future changes, the directionality of change—and the likelihood of increased intensity and frequency of extreme events—is clear. This section considers extreme events under their respective climate hazards, such as temperature and precipitation. Future projections of different climate hazards at the site are provided for mid-century (2036-2065) and late-century (2070-2099) and are compared to a historical baseline (1976-2005), unless noted otherwise.

The following sections provide both a high-level summary of climate trends for the Southwest region of the U.S. from the Fourth National Climate Assessment (USGCRP, 2018a), and site-specific climate data for the variables presented in Table 2. The site-specific projections again focus on the high end of climate projections (RCP 8.5) to conservatively screen for all potential climate risks to the site. The appendix provides a range of climate projection data—RCP 4.5 50th percentile to RCP 8.5 90th percentile—for select climate variables to better inform next steps and capture a range of potential futures.

Table 2 summarizes the climate hazards, variables, and data sources used to assess historical and future site exposure.

Table 2. Climate variables and sources included in the climate assessment. Variables marked with an asterisk (*) are included in the appendix.

Hazard	Variables	Data Sources	Scenario
Precipitation	• Total monthly precipitation*	LOCA downscaled precipitation projection data (Pierce, 2014)[2]	RCP 8.5, 90th percentile model values
	• Largest annual five-day precipitation event*	LOCA downscaled precipitation projection data (Pierce, 2014)	RCP 8.5, 90th percentile model values
Flooding	• Historical 100-year and 500-year floodplain	FEMA flood rate insurance maps (FEMA, 2015)	N/A
	• Return period storms*	LOCA downscaled precipitation projection data (Pierce, 2014), NOAA Atlas 14 Point Frequency Estimates (Perica, et al., 2014)	RCP 8.5, 90th percentile model values

[2] The temperature and precipitation projections were created using localized constructed analogs (LOCA) downscaled data, with a high greenhouse gas (GHG) emissions scenario known as Representative Concentration Pathway (RCP) 8.5. The LOCA downscaled data are calculated from raw, location-specific data generated by 32 Global Climate Models (GCMs), which were developed as part of the state-of-the art Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor, Stouffer, & Meehl, 2012) . Raw model outputs from GCMs have coarse resolutions and contain biases (e.g., some models trend hotter or wetter than others), so using LOCA downscaled data provides this assessment with finer resolution (approximately 6x6 km grid cells) and more meteorologically realistic data. Additionally, model change values were applied to observed baseline values to account for model biases. Ninetieth percentile model values were calculated to understand potential climate change trends of higher extremity, which have a potential for greater impacts to remediation efforts at the site. In the Appendix, climate projection data for RCP 4.5 in addition to RCP 8.5 are provided for select climate variables to better inform future decision-making.

Hazard	Variables	Data Sources	Scenario
Coastal Hazards	• Amount of site area inundated*	Coastal Storm Modeling System (CoSMoS)[3], U.S. Geological Survey (Barnard, et al., 2018)	Intermediate low and high sea level rise scenarios
	• Groundwater depth	U.S. Geological Survey (Befus, Hoover, Barnard, & Erikson, 2020)[4]	Intermediate and high sea level rise scenarios
Drought	• Consecutive dry days*	LOCA downscaled precipitation projection data (Pierce, 2014)	RCP 8.5, 90th percentile model values
Temperature	• Number of days above 95°F*	LOCA downscaled temperature projection data (Pierce, 2014)	RCP 8.5, 90th percentile model values
	• 1-in-10 year temperature*	LOCA downscaled temperature projection data (Pierce, 2014)	RCP 8.5, 90th percentile model values
Wildfire	• Wildfire danger days*	MACAv2 METDATA downscaled projections for 100-hour fuel moisture (Hegewisch, 2022)[5]	Days with 100-hour fuel moisture above the 80th (High), 90th (Very high) and 97th (Extreme) RCP 8.5 percentile model values
Landslides	• Landslide susceptibility	Landslide Hazard Assessment for Situational Awareness model (NASA, 2022)	N/A

[3] The CoSMoS model estimates total water level due to sea level rise. Total water level is a combination of relative sea level rise, tides, seasonal effects, river discharge, and wave runup.

[4] Groundwater depths were obtained from Befus et al. (2020), which developed a model for projecting sea level rise-driven groundwater shoaling and emergence. The data includes low-elevation areas less than ten meters above mean sea level along the California coast. Groundwater heads for current and future sea level rise scenarios using a range of hydraulic conductivity (Kh) scenarios are available. This report uses the lowest hydraulic conductivity of 0.1 m/day and mean higher-high water.

[5] Fire danger day projections were derived from the Multivariate Adaptive Constructive Analogs (MACA) downscaled data using moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios for summer and fall months (June through November). The MACA method is a statistical downscaling method that utilizes a training dataset (e.g., METDATA from 1979-2012) to remove bias and match spatial patterns to create projections for 2006-2099. Fire danger day projections are provided for near-future (2010-2039) and mid-century (2040-2069) and are compared to a historical baseline (1971-2000). The metric used to calculate fire danger days is calculated from 100-hour fuel moisture, which is an estimate of the average moisture content of the soil ¾ to 4 inches below the surface. Fuel moisture is measurement of the amount of water in vegetation available to a wildfire and is widely used to understand fire potential. Less fuel moisture means wildfires are more likely to start and spread. Fuel moisture is dependent on vegetation characteristics and environmental conditions, such as topography and humidity.

Section 3.1 – Precipitation

The west coast of the US is expected to see increased variability in precipitation. This means long, dry periods will be punctuated by short, intense bursts of precipitation. As a result, both drought and intense rainfall events, such as rainfall associated with atmospheric rivers[6], are projected to become more common by late-century.

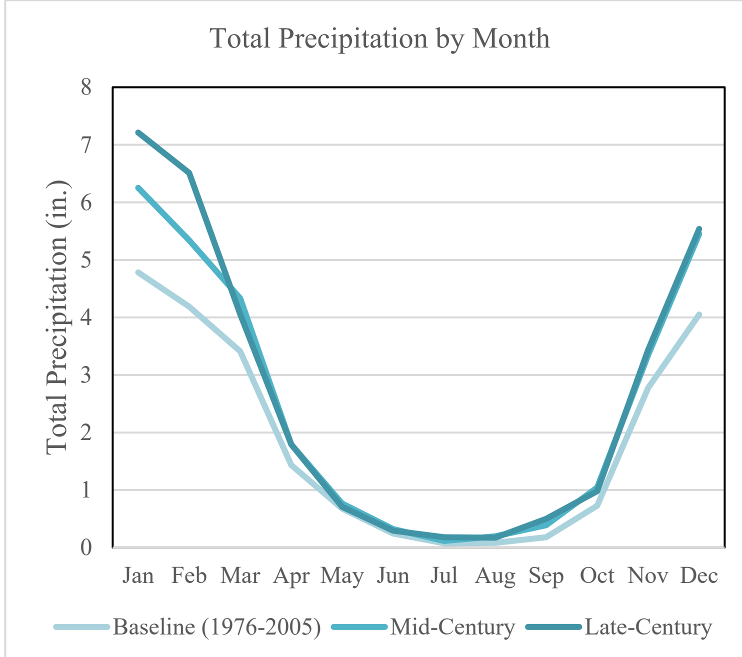


Figure 2. Total monthly precipitation at United Heckathorn based on RCP 8.5 90th percentile projections.

The site typically sees a dry period in late spring through fall and a wet period in late fall through early spring. Figure 2 shows that precipitation totals during summer will remain relatively unchanged from historical baseline estimates, **while the months of September through April are projected to experience increased precipitation.** By mid-century, approximately 1 to1.5 inches per month of additional precipitation may fall in the wettest months (December through March). For example, the amount of precipitation falling in January could increase from 4.8 inches historically to 6.3 inches by mid-century (a 31% increase) and 7.2 inches by late-century (a 51% increase).

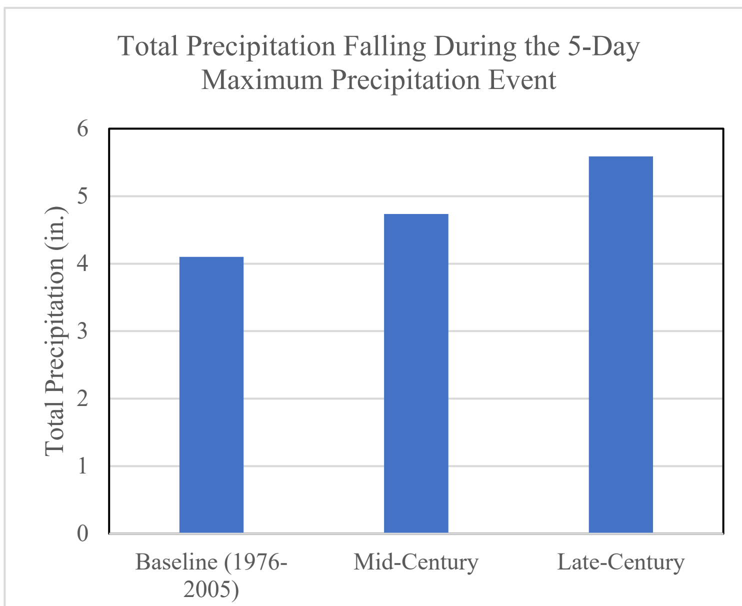


Figure 3. Total precipitation projected to fall during the largest 5-day precipitation event at United Heckathorn based on RCP 8.5 90th percentile projections.

Extreme precipitation events are also likely to increase in severity and frequency at the site. For example, the amount of precipitation falling in the year's largest 5-day precipitation event is expected to increase approximately 16% by mid-century (an increase from 4.1 inches historically to 4.7 inches) and 36.3% by late-century (to 5.6 inches) (see Figure 3). The 5-day precipitation event refers to the total amount of

[6] Atmospheric rivers are columns of condensed water vapor in the atmosphere that release large amounts of precipitation and snow when they make landfall. Atmospheric rivers form in the tropics, where high temperatures cause evaporation. This water vapor is pulled into narrow bands by atmospheric currents that carry it towards the poles. When atmospheric rivers reach mountains, they are pushed up and much of the vapor condenses, falling to the ground as rain or snow.

rain received over five consecutive days and is used to anticipate changes in heavy precipitation events that have the potential to create flood conditions.

Section 3.2 – Flooding

Increased intensity and frequency of extreme precipitation events in California are likely to contribute to flooding and debris flows that can damage roadways and infrastructure (USGCRP, 2018b). Warmer air holds more moisture, increasing the size of atmospheric rivers and heightening the risk of flooding.

Most of the site is located in the historical 100-year FEMA floodplain. The FEMA 100- and 500-year floodplain maps were used to assess flood exposure at the site; however, these maps are based on historical data and do not consider future climate change. As shown in Figure 4, approximately 67% of the site lies within the FEMA 100-year floodplain. The 100-year floodplain indicates a historical 1% annual chance of flooding. The 500-year floodplain has a 0.2% annual chance of flooding and includes areas in the 100-year floodplain.

As noted in *Section 3.1*, **precipitation patterns are changing which will increase the frequency and severity of flooding.** Return period storm events are high-volume precipitation events with a low annual percent chance of occurrence each year. For

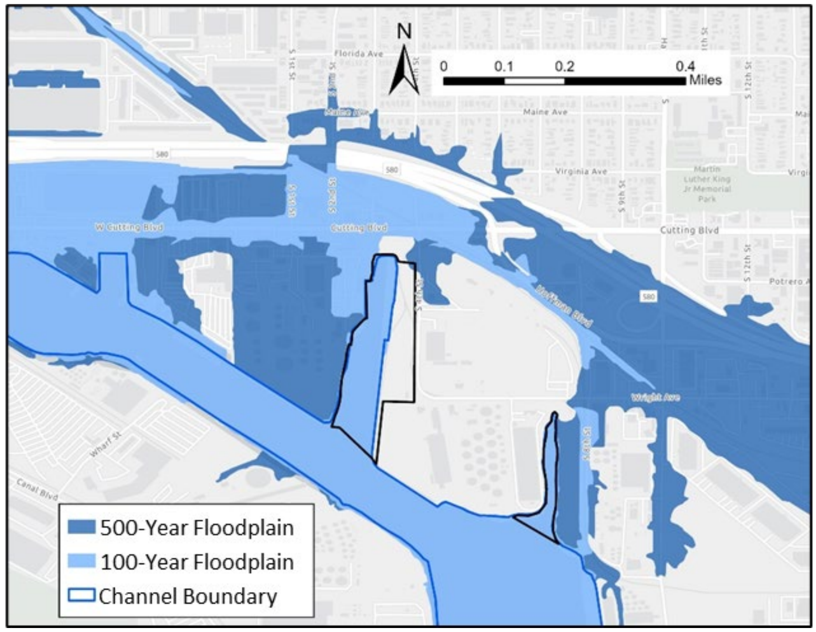


Figure 4. FEMA 100 and 500-year floodplains at United Heckathorn, and boundary of existing water bodies (FEMA, 2015).

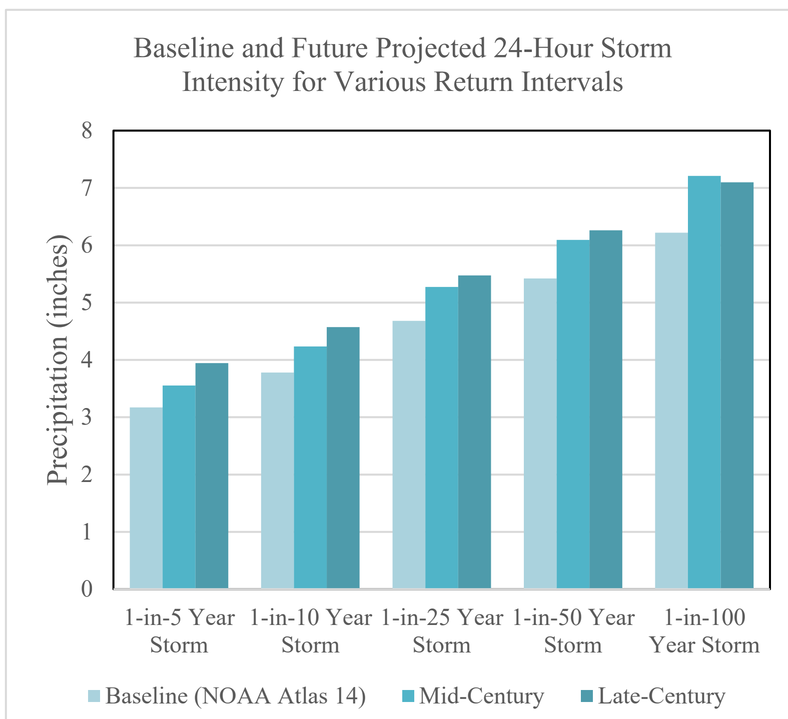


Figure 5. Historical and projected amount of precipitation falling during the 24-hour precipitation event for the 1-in-5 year storm, 1-in-10 year storm, 1-in-25 year storm, 1-in-50 year storm, and 1-in-100 year storm at United Heckathorn based on NOAA Atlas 14 and RCP 8.5 90th percentile model projections.

example, the 1-in-5 year event has a 20% chance of occurring each year, the 1-in-50 year event has a 2% chance of occurring each year, and the 1-in-100 year rainfall event has a 1% chance of occurring each year. Analyzing how these events may change in mid- and late-century projections provides insights into future flood risk. **The frequency and intensity of these return period storm events are projected to increase over time.**

Figure 5 illustrates how the precipitation amount associated with each of these return period storm events is increasing. For example, historically the 24-hour, 1-in-50 year storm is defined by 5.4 inches of precipitation. This is projected to increase to 6.1 inches by mid-century and 6.3 inches by late-century.[7] This data can also illustrate how the frequency of large precipitation events are changing. For example, 5.4 inches of precipitation has historically represented a 1-in-50 year storm (2% annual chance of occurrence). By late-century, 5.5 inches is expected to represent a 1-in-25 year event (4% annual chance of occurrence).

Section 3.3 – Coastal Hazards

Sea level rise is already a threat to much of coastal California. Sea level rise projections indicate that three feet of sea level rise would inundate low-lying land where over 200,000 people in California currently live (USGCRP, 2018b).

By mid-century, sea levels could rise to 1.9 feet in the Bay Area under a high emissions scenario, increasing the water level in the Lauritzen Channel. By late-century, sea levels could rise almost 7 feet, inundating l most of the surrounding area west of the Lauritzen Channel (see Figure 6). Sheet piling along the eastern shoreline of the Lauritzen Channel may help mitigate some projected inundation of the OU1 area suggested in Figure 6. Sea level rise projections account for global sea level rise, regional ocean circulation patterns, tide effects, seasonal effects, river discharge, and wave runup.

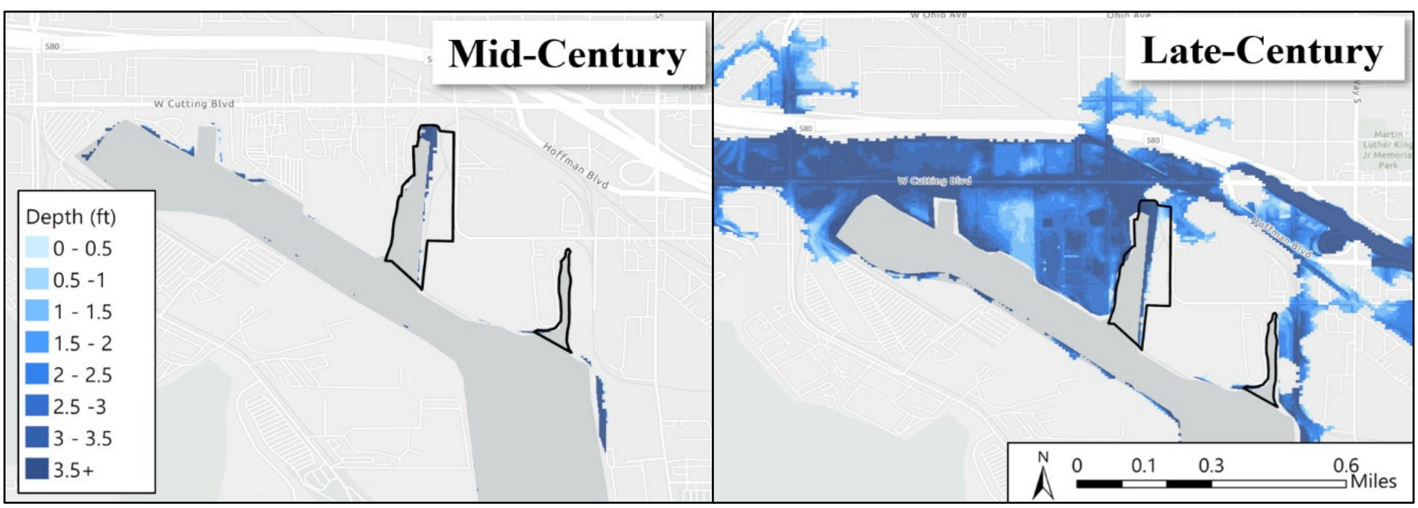


Figure 6. Projected sea level rise extent and depth in in the San Francisco Bay Area under a high emissions scenario (Barnard, et al., 2018).

[7] Larger return period intervals (e.g., 1-in-100 year event) have greater uncertainty (historically a 90% confidence interval of approximately ±1 inches) due to the rarity of these high-intensity events relative to the timeframe available in climate model projections, making precise long-term projections more challenging. In addition, projected increases in local extreme precipitation may not be linear throughout the 21st century. Therefore, the most important takeaway is the general direction and magnitude of the potential future increase relative to the baseline, rather than comparing the mid-century and late-century projections.

Sea level rise will exacerbate the damage inflicted by storm surge along the coast. Communities along the California coast are already experiencing more extensive flooding during storms and periodic tidal flooding and experiencing increased coastal erosion (California Ocean Protection Council, 2018). Figure 7 shows projected storm surge extent and depths for the 1-in-100 year storm under future sea level rise. **Flooding from storm surge will inundate nearly all of OU1 by late-century under a high emissions sea level rise scenario.** Storm surge projections account for sea level rise, regional ocean circulation patterns, tide effects, seasonal effects, river discharge, and wave runup.

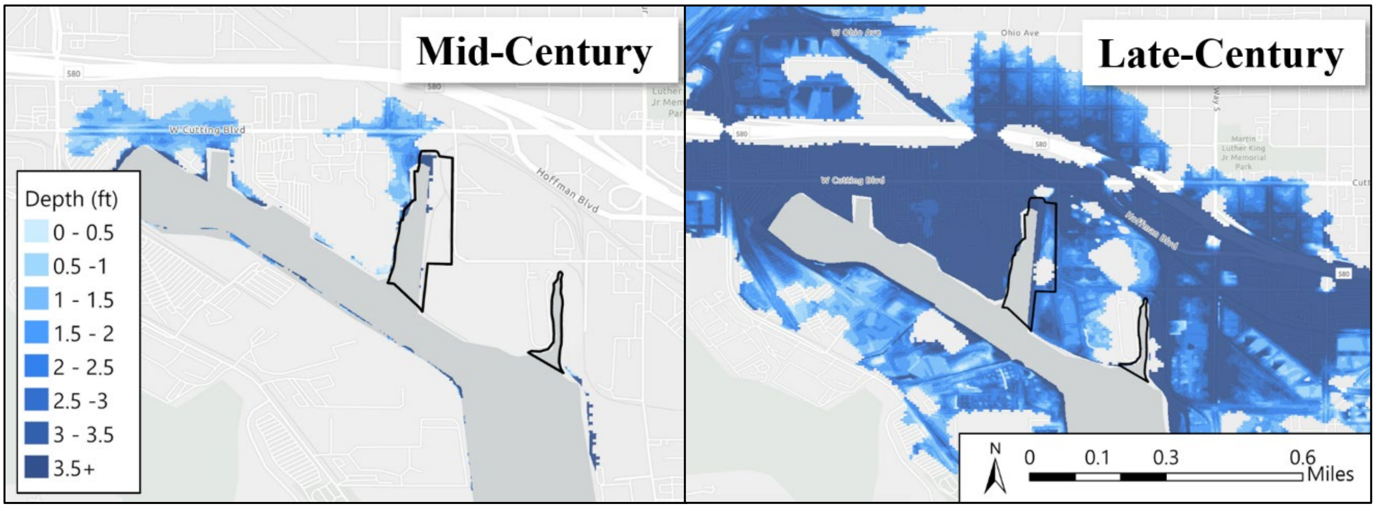


Figure 7. Projected storm surge extent and depth under projected sea level rise (Barnard, et al., 2018).

Sea level rise is also expected to intrude into coastal aquifers and raise groundwater tables. This will lead to shoaling, or pushing groundwater closer to the surface, and in some cases groundwater emergence. (Befus, Hoover, Barnard, & Erikson, 2020). Rising groundwater could also free pollutants, amplify flooding during storm events, and damage underground infrastructure. Befus et al. (2020) developed the CoSMoS-GW tool to predict coastal groundwater conditions in response to sea level rise projected using the Coastal Storm Modeling System (CoSMoS). By mid-century, groundwater levels are projected to rise by 3 to 6 feet in areas surrounding the site but will not change significantly within site boundaries (Figure 8). By late-century, the projections indicate the area west of the Lauritzen Channel will be inundated by sea level rise, and the upland portion of the site east of the Lauritzen Channel will have very shallow to emergent groundwater.

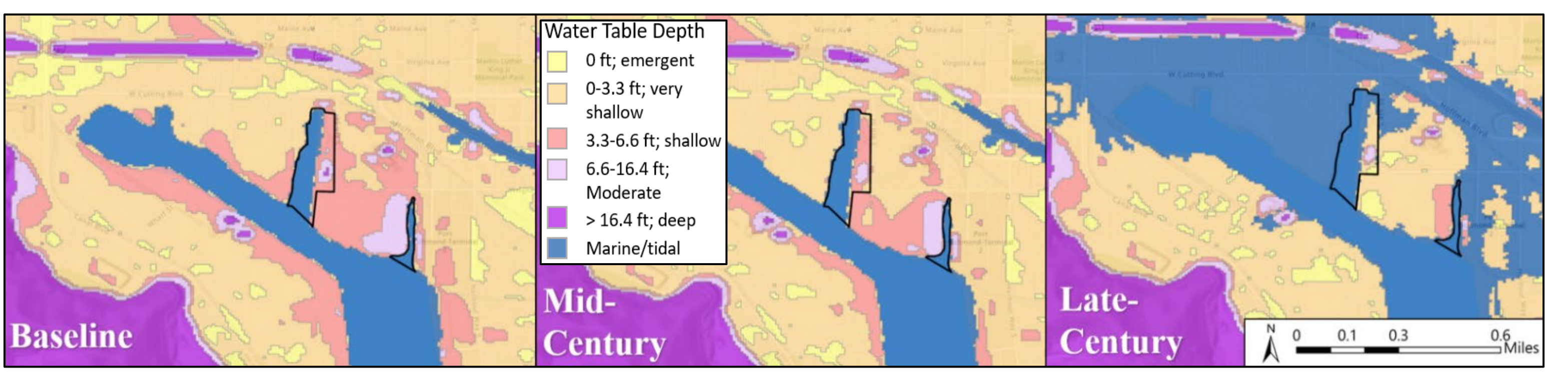


Figure 8. Projected water table depth in mid-century and late-century under projected sea level rise (Befus, Hoover, Barnard, & Erikson, 2020).

Section 3.4 – Drought

Rising temperature coupled with less snowfall have exacerbated droughts in California, which are projected to become more frequent, more severe, and last longer under future warming (USGCRP, 2018b). By late-century, California is projected to experience an increase in decadal megadroughts (dry periods lasting longer than a decade) under a high emissions scenario (USGCRP, 2018b).

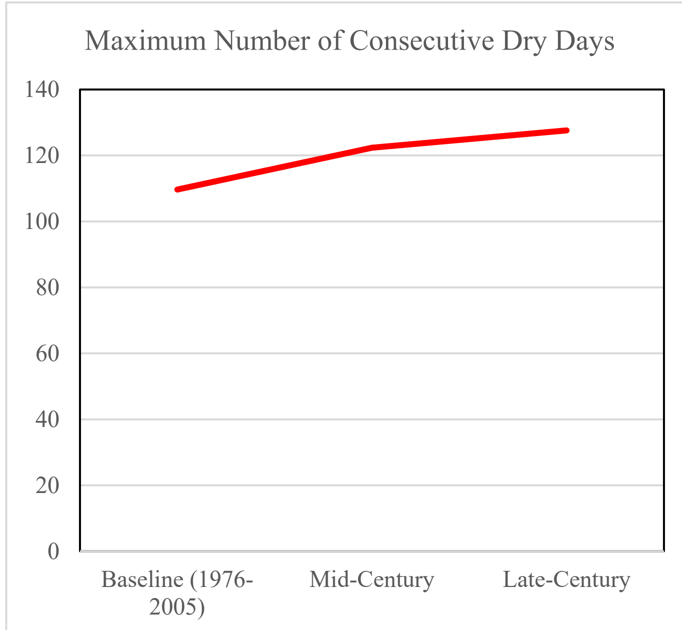


Figure 9. Consecutive dry days at United Heckathorn based on RCP 8.5 90th percentile projections.

Heavy rainfall events are expected to be punctuated by **longer extended dry periods, increasing the risk of drought.** Consecutive dry days are the number of days in a row with less than 0.01 inches of precipitation and are used frequently as a proxy for potential changes in drought risk. Historically, the site has experienced an average annual maximum of 110 consecutive dry days each year. At the site, consecutive dry days are expected to increase to 122 days by mid-century and 128 days by late-century (see Figure 9).

Section 3.5 – Temperature

Average temperatures in the western US have risen nearly 2°F since 1900. Average annual temperatures in this region are projected to increase by an additional 2.5°F by mid-century, and by 7°F to 8°F by late-century under a high emissions scenario. Extreme temperatures, such as those experienced during heatwaves, are also expected to increase (USGCRP, 2018b).

Both average and extreme temperatures are projected to increase at the site through late-century. Historically, the site has experienced 1 day per year where maximum temperatures reach at least 95°F (see Figure 10). The number of days above 95°F can be a useful proxy for understanding potential heat-related health stressors for on-site outdoor workers as well as remedy heat sensitivities. The number of days per year above 95°F could increase to as many as 4 days by mid-century (Figure 10) and 8 days by late-century.

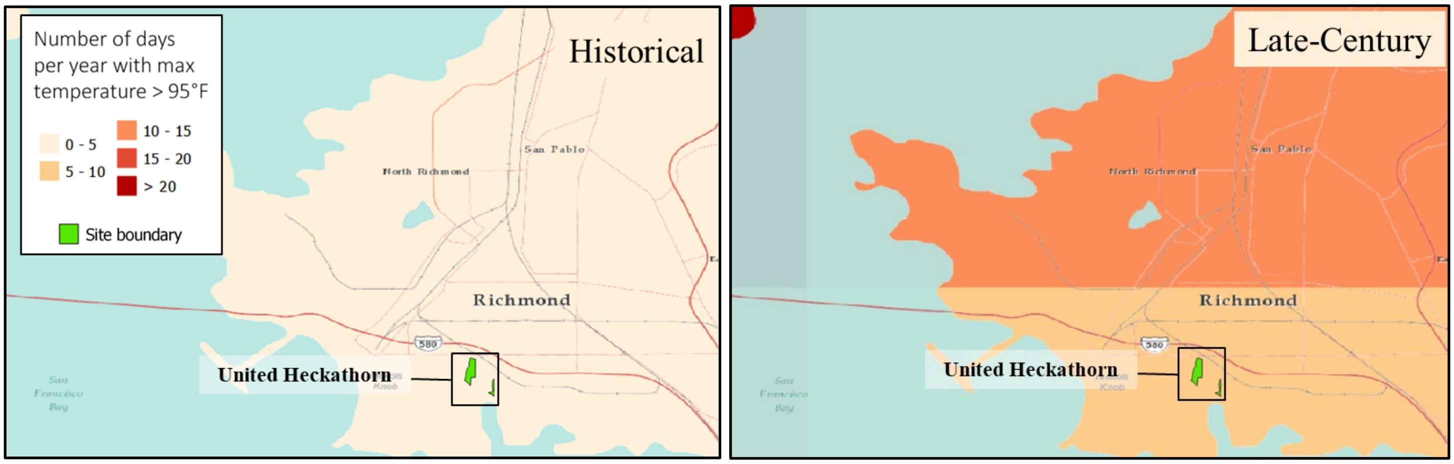


Figure 10. Number of days per year above 95°F at United Heckathorn based on RCP 8.5 90th percentile model projections. The top left and right figures show historical (1976-2005) and late-century future projected number of days per year above 95°F, respectively.

To better understand temperature extremes, the 1-in-10 year temperature — or the daily maximum temperature with a 10% annual chance of occurrence — provides another way to estimate changes in extreme heat and implications for site remedies. Historically, the 1-in-10 year maximum temperature has been just over 101°F at the site. This is expected to increase to 108°F by mid-century (Figure 11) and 112°F by late-century.

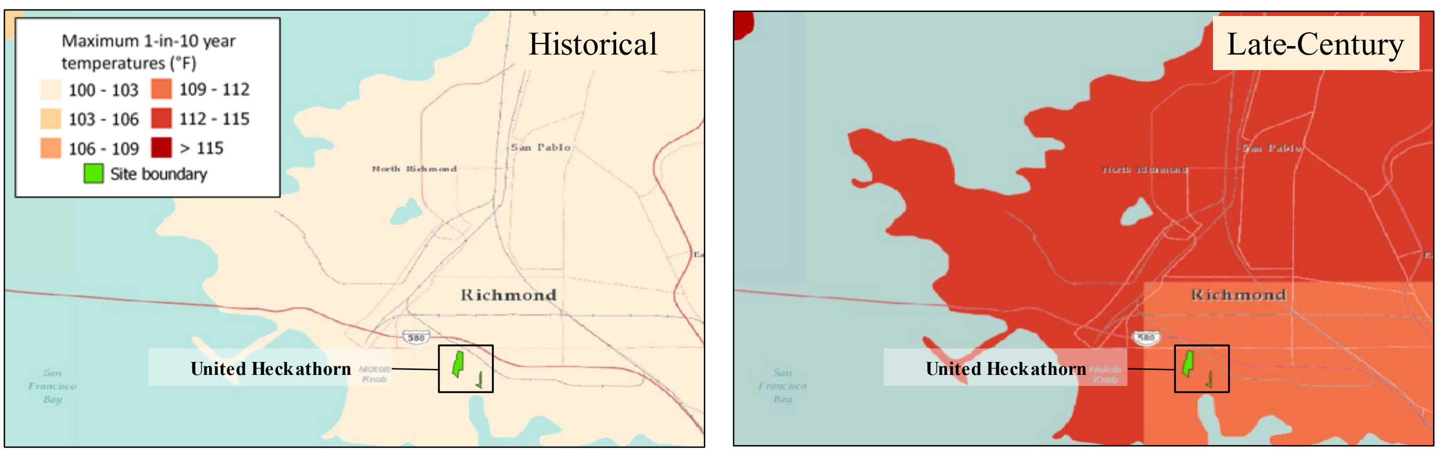


Figure 11. Maximum 1-in-10 year temperatures at United Heckathorn based on RCP 8.5 90th percentile model projections. The left and right figures show historical (1976-2005) and late-century future projected maximum 1-in-10 year temperatures, respectively.

Section 3.6 – Wildfire

Increases in temperature, intensified drought, and warmer fall months are driving longer and more intense wildfire seasons in this region (USGCRP, 2018b). High temperatures increase evaporative demand, drying out soil and vegetation that serve as fuel for fires. Warmer temperatures and later winter precipitation can extend the wildfire season into the fall months, when strong offshore winds that dry out vegetation and amplify wildfires sweep across California.

Wildfires are most likely to occur on hot days with low humidity in areas with dry fuel, such as dead wood and dried vegetation. Figure 12 shows the number of days projected to have high, very high, and extreme fire danger by near-future and mid-century. The bars are stacked, so days with extreme and very high fire danger are included in projections for days with high fire danger, and days with extreme fire danger are included in projections for days with very high fire danger. High fire danger days are calculated as days with 100-hour fuel moisture below the 20th percentile from historical years, very high fire danger days correspond to the 10th percentile, and extreme fire danger days correspond to the 3rd percentile from historical years.

The number of days with high fire danger is projected to increase slightly at the site and nearby area through mid-century. Currently the site experiences 40 total days during summer and fall months under high, very high, or extreme wildfire danger conditions. Under a high emissions scenario, the number of days during summer and fall months (June to November) with at least high fire danger is projected to increase from 40 days to 43 days by near-future and 44 days by mid-century (see Figure 12).

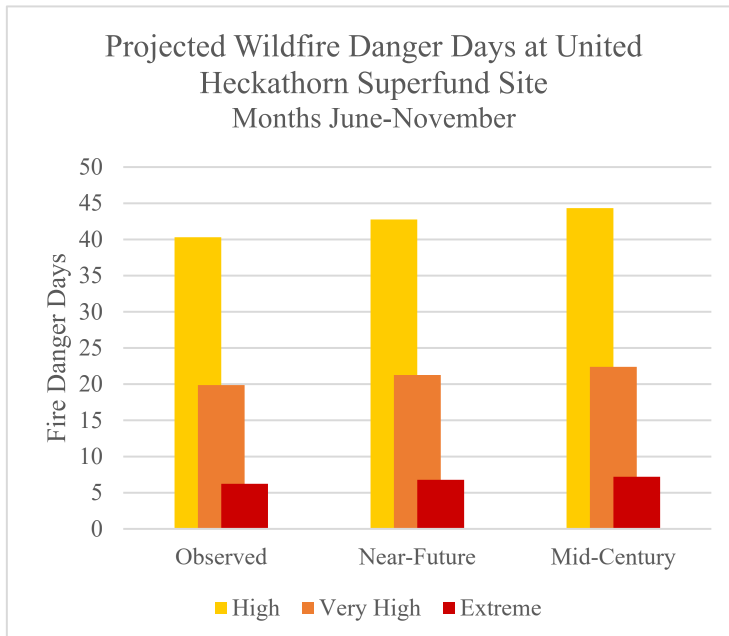


Figure 12. Wildfire danger days from June to November at United Heckathorn based on RCP 8.5 100-hour fuel moisture projections (Hegewisch, 2022).

Section 3.7 – Landslides

Landslides are a potential concern at the site. The site is in an area of **very low to low landslide susceptibility** (see Figure 13). Susceptibility is the likelihood of a landslide occurring based on historic rainfall, history of past landslides, slope gradient, rock and soil type, vegetation, seismic conditions, and human activities.

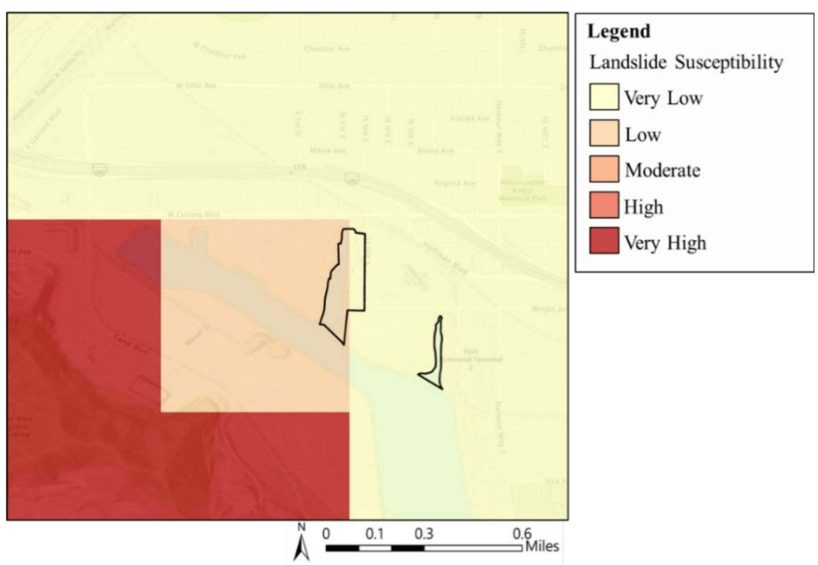


Figure 13. Landslide susceptibility at United Heckathorn and surrounding area (NASA, 2022).

Section 4 – Remedy Vulnerabilities and Resilience

The evaluation of a remedy's sensitivity to climate hazards involves assessing the likelihood of a specific hazard to reduce the remedy's effectiveness. The remedy sensitivity is then further analyzed in conjunction with the projected climate exposure for the site to determine actual remedy vulnerabilities.

Discussion of the assessment of remedy vulnerability at the United Heckathorn Site is based on the details of the implemented remedies and the alternatives currently being considered for implementation based on the 2004 ROD, 2006 ESD, Draft 2015 FFS, and 2021 FYR.

Section 4.1 – Operable Unit 1

The protectiveness of the OU1 remedy relies on the capacity of the stormwater management system to handle the volume of precipitation that will fall at the site. The system is currently designed to address a precipitation volume as modeled by the current rainy season (EPA, 2021b). However, rainy season precipitation is projected to increase 30% by mid-century and 50% by late-century. Additionally, heavy precipitation including annual 5-day maximum storms and various return interval precipitation events are projected to increase. The projected increases in total and extreme precipitation events could increase the frequency of direct stormwater discharges to the Lauritzen Channel. Adaptive measures include evaluating **the capacity of the stormwater treatment system considering the projected precipitation increases, and increasing system capacity as needed to maintain protectiveness**. The location of the treatment system should be compared to projected sea level rise maps provided for the site, and plans developed for potential relocation if in a susceptible area. Finally, the O&M plan already includes sampling of stormwater treatment effluent during major storm events; the site team should consider including a concurrent inspection of stormwater interceptors, if not already required.

The protectiveness of the OU1 remedy also relies on the integrity of the multifaceted cap, which is composed of reinforced concrete, geotextile fabric, and gravel. Portions of the cap consisting of reinforced concrete are likely resilient to the projected increases in storm events. **Areas covered by only the gravel cap may be vulnerable to increases in extreme precipitation events**. The Fifth FYR (EPA, 2021b) suggests monitoring of the cap is performed annually and gravel is replaced as needed. Furthermore, periodic topographic surveys are performed to identify and address areas of differential settlement to ensure cap integrity.

Increases in sea level and storm surge are projected to cause the site groundwater table to rise and may increase contact between groundwater and contaminated soils. **An elevated groundwater table in conjunction with tidally influenced fluctuations of the groundwater table, or tidal pumping, has the potential to increase contaminant migration from the contaminated soils to the surface water.** Furthermore, increases in storm events may increase the rate of degradation to the gravel and concrete caps.

Adaptive measures for the cap include **ensuring the O&M plan includes post-storm event inspection of the gravel cap** to confirm the protectiveness of the remedy during such events. Additional adaptive measures that address the migration of contaminants from the soil to the surface water are discussed in *Section 4.2*.

Section 4.2 – Operable Unit 2

The original remedy for OU2 that included dredging and capping was completed in 1997. However, annual monitoring results of surface and subsurface sediments and surface water in the Lauritzen Channel have exceeded the remediation goals. The Focused Feasibility Study (EPA, 2015) included a screening of several remedial technologies to address the remaining contaminated sediment in the channel. Technologies retained for the development of remedial alternatives included full or partial dredging and the application of a carbon-amended sand layer. The climate hazards most likely to affect the proposed remedial technologies for OU2 are increases in flooding and storm severity, resulting in wave action and underwater turbulence that could disturb any placed capped material. **Future climate exposure, including how increases in wave action and turbulence would impact a carbon-amended sand layer placed over undredged sediment, should be considered when evaluating remedy alternatives for the contaminated channel sediment.** As the selected remedy will need to allow the Lauritzen Channel to remain navigable, significant challenges exist in implementing and maintaining a resilient sediment cap. The successful dredging of all contaminated sediments in the shipping channels would remove concerns about the resiliency of an amended cap.

The FFS also developed and evaluated shoreline source control measures (EPA, 2015). As discussed in *Section 4.1*, increases in sea level and storm surge are projected to cause the site groundwater table to rise and increase contact between groundwater and contaminated soils. An elevated groundwater table in conjunction with tidal pumping has the potential to increase contaminant migration from the contaminated soils to the surface water. To the extent possible, **the selection and design of shoreline source control measures, such as sheet piling and an active cap, should consider future rises in sea level and groundwater and the resulting increased flux of contaminants from the groundwater to the surface water.** Advantages and limitations of specific amendments used in sediment caps, including considerations for areas with significant groundwater flow, are discussed in the OSRTI document *Use of Amendments for In Situ Remediation at Superfund Sediment Sites* (EPA, 2013). If it is impractical or not feasible to design such remedy components to remain protective under future flood stages at this time, the criteria and method for improving the remedy as sea level rise progresses and storm surges intensify should be identified.

The selection and design of all remedy components with a lifespan of at least 30 years should incorporate future climate projections, ensuring adaptive measures are designed to withstand the projected increases in sea level rise and extreme precipitation events. Additional information on the design of a resilient sediment remedy is available in the OSRTI document *Climate Resilience Technical Fact Sheet: Contaminated Sediment Sites* (EPA, 2019a).

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Appendix - Climate Projections

The vulnerability assessment used the high emissions or "business as usual" scenario (RCP 8.5) to conservatively screen for all potential climate risks to the site. This appendix provides a range of climate projections (50th percentile RCP 4.5 to 90th percentile RCP 8.5) for select climate variables, including monthly precipitation, largest annual 5-day precipitation event, consecutive dry days, number of days above 95°F, 1-in-10 year temperature, and wildfire danger days. It is recommended to consider a range of potential futures when determining next steps (e.g., designing strategies to mitigate risks). This appendix also includes a table of the 90th percentile RCP 8.5 projections for return period storms.

Monthly Precipitation:

Table 3. Total monthly precipitation projections for United Heckathorn. All percent change values are relative to the historical baseline.

Month	Historical (1976-2005)	Mid-Century (2036-2065)				Late-Century (2070-2099)			
		RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	Baseline (inches)	Value (inches)	Percent Change	Value (inches)	Percent Change	Value (inches)	Percent Change	Value (inches)	Percent Change
January	4.8	5.1	6.5%	6.3	30.7%	5.1	7.0%	7.2	50.8%
February	4.2	4.2	1.0%	5.3	27.5%	4.3	3.8%	6.5	55.5%
March	3.4	3.3	-3.5%	4.3	26.9%	3.5	3.9%	4.1	18.9%
April	1.4	1.3	-7.3%	1.8	24.9%	1.3	-10.2%	1.8	25.1%
May	0.7	0.6	-17.4%	0.8	13.3%	0.7	-2.4%	0.7	4.7%
June	0.2	0.2	-19.4%	0.3	32.2%	0.2	-27.3%	0.3	20.5%
July	0.1	0.1	-1.3%	0.1	52.5%	0.1	5.9%	0.2	140.8%
August	0.1	0.1	-11.3%	0.2	138.1%	0.1	0.9%	0.2	108.3%
September	0.2	0.2	17.6%	0.4	115.3%	0.2	6.9%	0.5	176.8%
October	0.7	0.7	-2.8%	1.0	43.6%	0.6	-11.8%	1.0	34.7%
November	2.8	2.5	-9.5%	3.3	20.6%	2.5	-11.5%	3.4	23.9%
December	4.0	4.1	1.5%	5.4	34.6%	4.1	0.6%	5.5	36.8%
ANNUAL	**22.6**	**22.4**	**-1.1%**	**29.4**	**29.7%**	**22.7**	**0.2%**	**31.4**	**38.7%**

Largest Annual Five-Day Precipitation Event:

Table 4. Largest annual five-day precipitation event for United Heckathorn. All percent change values are relative to the historical baseline.

Historical (1976-2005)	Mid-Century (2036-2065)				Late-Century (2070-2099)			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
Baseline (Inches)	Value (Inches)	Percent Change	Value (Inches)	Percent Change	Value (Inches)	Percent Change	Value (Inches)	Percent Change
4.1	4.3	4.3%	4.7	15.5%	4.4	7.1%	5.6	36.3%

Return Period Storms:

Table 5. Change in precipitation amount for return period storm events at United Heckathorn. All percent change values are relative to the historical baseline.[8]

Storm	Annual Percent Chance	Historical	Mid-Century (2036-2065)		Late-Century (2070-2099)	
			RCP 8.5		RCP 8.5	
		Baseline (Inches)	Value (Inches)	Percent Change	Value (Inches)	Percent Change
1-in-5 Year	20%	3.2	3.6	12.1%	3.9	24.4%
1-in-10 Year	10%	3.8	4.2	12.0%	4.6	20.9%
1-in-25 Year	4%	4.7	5.3	12.7%	5.5	17.0%
1-in-50 Year	2%	5.4	6.1	12.5%	6.3	15.5%
1-in-100 Year	1%	6.2	7.2	15.9%	7.1	14.1%
1-in-500 Year[9]	0.2%	8.4				

[8] Larger return period intervals (e.g., 1-in-100 year event) have greater uncertainty (historically a 90% confidence interval of approximately ±1 inches) due to the rarity of these high-intensity events relative to the timeframe available in climate model projections, making precise long-term projections more challenging. In addition, projected increases in local extreme precipitation may not be linear throughout the 21st century. Therefore, the most important takeaway is the general direction and magnitude of the potential future increase relative to the baseline, rather than comparing the mid-century and late-century projections.

[9] Due to the inherent uncertainty of the 1-in-500 year return period as described in the footnote above, only the historical estimate is provided as a reference point. The estimate for the historical 1-in-500 year storm has a 90% confidence interval of approximately ±2 inches.

Consecutive Dry Days:

Table 6. Number of consecutive dry days at United Heckathorn. All change values are relative to the historical baseline.

Historical (1976-2005)	Mid-Century (2036-2065)				Late-Century (2070-2099)			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
Baseline (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)
109.7	107.3	-2.1	122.4	+11.6	109.3	-0.4	127.6	+16.4

Number of Days Above 95°F:

Table 7. Number of days above 95°F at United Heckathorn. All change values are relative to the historical baseline.

Historical (1976-2005)	Mid-Century (2036-2065)				Late-Century (2070-2099)			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
Baseline (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)
1.3	2.0	+0.7	3.9	+2.6	2.4	+1.1	7.8	+6.5

1-in-10 Year Temperature:

Table 8. The 1-in-10 year temperature or the highest temperature occurring about once every ten years at United Heckathorn. All change values are relative to the historical baseline.

Historical (1976-2005)	Mid-Century (2036-2065)				Late-Century (2070-2099)			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
Baseline (°F)	Value (°F)	Change (°F)	Value (°F)	Change (°F)	Value (°F)	Change (°F)	Value (°F)	Change (°F)
101.4	105.2	+3.8	108.1	+6.7	105.7	+4.3	111.6	+10.2

Summer and Fall Wildfire Danger Days:

Table 9. Wildfire danger days at United Heckathorn for summer months (June through November). All change values are relative to the historical baseline.

Fire Danger Level[10]	Historical (1971-2000)	Near-Future (2010-2039)				Mid-Century (2040-2069)			
		RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	Baseline (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)	Value (Days)	Change (Days)
High	40.3	40.9	+0.6	42.8	+2.5	44.1	+3.8	44.3	+4.0
Very High	19.9	19.7	-0.1	21.3	+1.4	22.0	+2.2	22.4	+2.5
Extreme	6.2	6.2	0.0	6.8	+0.6	7.5	+1.2	7.2	+1.0

[10] Values for high, very high, and extreme fire danger days are nested so extreme fire danger days are counted within very high and high fire danger days, and very high fire danger days are counted within high fire danger days.