ASSESSING VULNERABILITY AND IMPROVING RESILIENCE OF CRITICAL EMERGENCY MANAGEMENT INFRASTRUCTURE IN CALIFORNIA IN A CHANGING CLIMATE

A Report for:

California's Fourth Climate Change Assessment

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CALIFORNIA natural resources AGENCY

Edmund G. Brown, Jr., *Governor*

August 2018
CCCA4-CNRA-2018-015

ACKNOWLEDGEMENTS

We gratefully acknowledge the guidance and support of the California Fourth Climate Change Assessment management team, especially Jamie Anderson, JR DeLaRosa, Guido Franco, and Joey Wall.

We also received essential data, guidance, and feedback from Victoria LaMarr-Haas, Tom Ducker, and Jose Lara from the CA Office of Emergency Services, Sandra Khan from the CA Department of General Services, and Michael McCormick from the CA Office of Planning and Research.

At RAND, we thank James Syme and David Groves for the levee vulnerability analyses, and Ben Preston and Sarah Hunter for helpful comments.

PREFACE

California's Climate Change Assessments provide a scientific foundation for understanding climate-related vulnerability at the local scale and informing resilience actions. These Assessments contribute to the advancement of science-based policies, plans, and programs to promote effective climate leadership in California. In 2006, California released its First Climate Change Assessment, which shed light on the impacts of climate change on specific sectors in California and was instrumental in supporting the passage of the landmark legislation Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), California's Global Warming Solutions Act. The Second Assessment concluded that adaptation is a crucial complement to reducing greenhouse gas emissions (2009), given that some changes to the climate are ongoing and inevitable, motivating and informing California's first Climate Adaptation Strategy released the same year. In 2012, California's Third Climate Change Assessment made substantial progress in projecting local impacts of climate change, investigating consequences to human and natural systems, and exploring barriers to adaptation.

Under the leadership of Governor Edmund G. Brown, Jr., a trio of state agencies jointly managed and supported California's Fourth Climate Change Assessment: California's Natural Resources Agency (CNRA), the Governor's Office of Planning and Research (OPR), and the California Energy Commission (Energy Commission). The Climate Action Team Research Working Group, through which more than 20 state agencies coordinate climate-related research, served as the steering committee, providing input for a multisector call for proposals, participating in selection of research teams, and offering technical guidance throughout the process.

California's Fourth Climate Change Assessment (Fourth Assessment) advances actionable science that serves the growing needs of state and local-level decision-makers from a variety of sectors. It includes research to develop rigorous, comprehensive climate change scenarios at a scale suitable for illuminating regional vulnerabilities and localized adaptation strategies in California; datasets and tools that improve integration of observed and projected knowledge about climate change into decision-making; and recommendations and information to directly inform vulnerability assessments and adaptation strategies for California's energy sector, water resources and management, oceans and coasts, forests, wildfires, agriculture, biodiversity and habitat, and public health.

The Fourth Assessment includes 44 technical reports to advance the scientific foundation for understanding climate-related risks and resilience options, nine regional reports plus an oceans and coast report to outline climate risks and adaptation options, reports on tribal and indigenous issues as well as climate justice, and a comprehensive statewide summary report. All research contributing to the Fourth Assessment was peer-reviewed to ensure scientific rigor and relevance to practitioners and stakeholders.

For the full suite of Fourth Assessment research products, please visit www.climateassessment.ca.gov. This report advances the understanding of the effect of climate change on flooding and wildfire risk to state-owned and -operated emergency response infrastructure.

ABSTRACT

Maintaining operability of state-owned and -operated emergency management and response infrastructure in California is critical for ensuring the state's ability to effectively respond to disasters. This analysis examines the risk to this infrastructure from two important climate-related hazards, coastal flooding and wildfire.

We describe an interactive tool that combines a database of California critical emergency response infrastructure (state-owned or -operated, having a direct role in facilitating emergency response operations, and sufficiently unique that it is not ubiquitous, easily replaceable, or interchangeable) with projected flood and wildfire hazard footprints to examine the exposure and associated impacts to infrastructure statewide from these hazards. The database contains over 600 assets, such as emergency services and health care facilities. Outputs include maps and tables describing facility exposures, flood and fire risks, property damage estimates from flooding, and estimates of operational disruption. Analyses examine a range of conditions spanning different emissions scenarios, climate models, hazard severity, and other factors in 20-year time intervals through the year 2100. The tool also provides the ability to examine results for particular facility types, specific counties, and for facilities located in disadvantaged communities.

We find that, under current conditions, 25 facilities are at risk of flooding from a flood event with a 1 percent annual chance of occurring (100-year flood event). Current estimated 100-year flood depths exceed 10 feet at 5 facilities. If all 25 of these facilities flooded to the modeled depth, the total estimated property damage would be $90 million. In the case of wildfire, 28 facilities are located in a grid cell in which 50% or more of the land has a 1 percent annual chance of burning (100-year wildfire). By the end of the century risks are projected to have increased such that 30 facilities are at risk of flooding in a 100-year flood event, with expected losses of over $1.7 billion. 112 facilities are in grid cells projected to be at risk from a 100-year wildfire, with several in areas projected to burn over 90%. These findings are for a particular set of assumptions, and the tool allows the user to examine the effect of varying these assumptions.

State decisionmakers can combine the findings of this analysis with other information, such as the role and relative importance of individual facilities in the state's response capabilities, to help target and allocate scarce resources in ways that maximize the benefit to the state in terms of maintaining a robust ability to respond to emergencies throughout the state.

Keywords: climate change, infrastructure, emergency response, vulnerability, flood, wildfire, decision support tool

Please use the following citation for this paper:

LaTourrette, Tom, Andrew Lauland, Jordan Fischbach, Neil Berg, Chuck Stelzner. (RAND Corporation). 2018. ***Assessing Vulnerability and Improving Resilience of Critical Emergency Management Infrastructure in California in a Changing Climate***. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-015.

HIGHLIGHTS

- California owns or operates over 600 facilities that are critical to the state's ability to respond to disasters
- We have developed a decision-support tool, CERI-Climate, to help evaluate the risk to these facilities from flood and wildfire and how climate change may affect these risks; risks depend on a number of assumptions that can be explored with the tool
- Under current conditions, 54 of these facilities are at risk of damage or disruption from a 100-year flood and 66 are in grid cells at risk of damage or disruption from a 100-year wildfire
- The estimated property damage at risk among all the facilities exposed to 100-year flooding under current conditions is $90 million
- By the end of the century, 68 facilities are projected to be at risk of damage or disruption from a 100-year flood and 271 in grid cells projected to be at risk of damage or disruption from a 100-year wildfire
- The estimated property damage at risk among all the facilities exposed to 100-year flooding by the end of the century is $1.7 billion
- The tool distinguishes facilities that are located in disadvantaged communities, allowing decision makers to account for this in allocating mitigation resources
- These results will help state decision-makers target and allocate scarce resources in ways that mitigate risk and maximize the benefit to the state in terms of maintaining a robust ability to respond to emergencies throughout the state

WEB LINKS

CERI-Climate tool is available at:

https://public.tableau.com/profile/rand4185#!/vizhome/CJ302-1000_CERI-Climate_20180625/Title

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1: Introduction

1.1 Background and Objectives

The safety and resilience of citizens and communities in California is inextricably linked with the state's ability to effectively respond to and recover from natural and manmade emergencies. The state government of California, which oversees statewide response operations, is dependent on a variety of state-owned and -operated critical infrastructure which is subject to exposure to natural hazards that can cause damage and short- and long-term operational disruption. Impeding the state emergency response capability increases the risk of loss of lives and property. As a result, it is important to assess the risk to such infrastructure from natural hazards. However, the risk to individual state-owned critical infrastructure assets is not likely to be constant over time; rather, the level of risk from and whether an asset is exposed to a specific natural hazard may change over time as a result of climate change.

The need to understand such risks to emergency response infrastructure is called out in the Emergency Management Sector Plan of the *Safeguarding California Plan,* which describes California's climate adaptation strategy.[1]

As part of California's Fourth Climate Change Assessment, RAND worked with the California Office of Emergency Services (Cal OES) and other state stakeholder agencies to identify the exposure of state-owned and -operated emergency response infrastructure to coastal flooding and wildfire, how this exposure might change over time due to climate change, and how vulnerable different types of state infrastructure are to disruption and damage from different types of hazards. The objective of the analysis was to help Cal OES and other state agencies to distinguish facilities according to risks from coastal flooding and wildfire hazards and to help them to target and prioritize efforts to mitigate these risks.

This work follows earlier work assessing the risks from earthquakes to state-owned critical emergency response infrastructure.[2] That work developed a screening method to identify seismically vulnerable buildings and an approach for developing mitigation plans for those buildings. That effort took a detailed engineering approach and was implemented on small scale at selected buildings.

This project similarly identifies state-owned critical emergency response infrastructure at risk from coastal flooding and wildfire, but differs in that it takes a state-wide assessment approach rather than a facility-specific engineering approach. Consequently, our analysis takes a more comprehensive approach in attempting to encompass all state-owned and -operated critical emergency response infrastructure in California, but takes a necessarily more general approach to exposure and damage assessment. In taking this approach, our analysis is focused less on obtaining accurate damage assessments for individual facilities than on identifying buildings at

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[1] http://resources.ca.gov/climate/safeguarding/

[2] Guthrie JB and Nelson JK (2014) CAL VIVA: Assessing the seismic vulnerability of California's state-owned buildings through planning & engineering, Tenth U.S. National Conference on Earthquake Engineering, July 21-25, 2014, Anchorage, Alaska, https://content-calpoly-edu.s3.amazonaws.com/arce/1/news-events/documents-14-15/10NCEE-000449_Nelson_Guthrie.pdf

relatively higher risk from coastal flooding and wildfire and that might be prioritized for mitigation efforts.

Given the number of parameters involved in assessing these risks, we present our analysis and results in the form of a decision-support tool. The tool is intended to be used by Cal OES and its partner agencies in their ongoing use in response planning and operations. This report serves as an introduction and companion to the California Emergency Response Infrastructure Climate Vulnerability Tool (abbreviated as CERI-Climate), an interactive natural hazard and critical infrastructure visualization tool which was developed in the course of this project. While this report provides an overview of the current and future exposure of state-owned critical infrastructure, it would be impossible to identify and include every potential analysis of interest to future Cal OES stakeholders; similarly, the state's underlying infrastructure, as well as the state's understanding of that infrastructure, may change over time, making a "living tool" more desirable. The tool is accessible at: https://public.tableau.com/profile/rand4185#!/vizhome/CJ302-1000_CERI-Climate_20180625/Title

1.2 Approach

Our analysis proceeded through a series of steps that led to the production of the CERI-Climate tool and the analysis in this report. First, we worked with subject matter experts in the California state government to define and identify state-owned and -operated critical emergency response infrastructure of interest. Next, we identified the natural hazards most likely to disrupt this infrastructure for which models were available to project the potential impact on infrastructure and the effect of climate change on this impact. We then created data layers for these natural hazards and infrastructure assets and conducted overlay analyses to evaluate hazard exposures and impacts. We developed the CERI-Climate tool to provide an accessible means of visualizing the exposure of state critical infrastructure assets to these hazards, and developed a methodology for estimating the potential physical damage to and likelihood of operational disruption from exposure. Lastly, we used the CERI-Climate tool to evaluate risks from coastal flooding and wildfire and identify those facilities at particularly high risk, under current conditions and in the coming decades. Detailed methods for each step are described in the subsequent sections of this report.

To ensure that the Fourth Assessment research results are internally consistent and amendable to cross-sectoral integration, this project and all other research projects supported under the Fourth Assessment employ a common set of primary climate scenarios identified by the State of California.

2: Identification of State-Owned and -Operated Infrastructure Supporting Emergency Response

2.1 Data Sources

A key aspect of this effort is defining and identifying the infrastructure to be included in our analysis. While a wide range of facilities can provide important capabilities in the event of a disaster, given the objectives of the project, Cal OES and RAND agreed to focus on assets which are state-owned or -operated and, among those assets, the subset which are critical for response to disasters.

Working in coordination with Cal OES, we considered a number of sources and approaches for compiling our facility database. These include the Cal OES Critical Infrastructure Database, facilities identified or inferred from State response plans, U.S. Department of Homeland Security (DHS) Infrastructure Program critical infrastructure databases, and the California State Property Inventory. These sources are described briefly below.

- ***Cal OES** Critical Infrastructure Database.* Cal OES's Critical Infrastructure Protection (CIP) Unit is responsible for the identification, categorization, and prioritization of critical infrastructure. In 2010, Cal OES CIP undertook an effort to develop criteria for defining "state significant" critical infrastructure, to identify assets meeting those criteria, and to perform baseline risk analysis and prioritization. These efforts resulted in a set of California Critical Infrastructure Criteria for Infrastructure Prioritization, which adapted the U.S. Department of Homeland Security's (DHS) taxonomy of critical infrastructure sectors and subsectors to reflect California's needs, and which identify and provide definitions for the sectors and subsectors of California critical infrastructure. These criteria were subsequently used by Cal OES to collect information on federal, state, local and privately owned assets in California and were compiled into a searchable database containing approximately 1,800 assets and systems deemed to either meet California's criteria themselves, or to be nodes of systems which meet the criteria.
- ***DHS HSIP Gold and Freedom.*** RAND also considered leveraging the databases of critical infrastructure maintained by DHS's Homeland Security Infrastructure Program (HSIP). HSIP maintains two related databases of government and private sector owned critical infrastructure nationwide which are available for use by state partners. HSIP Gold is an unclassified but for-official-use-only geospatial database assembled by the National Geospatial-Intelligence Agency in partnership with DHS. It compiles over 560 geospatial datasets composed of critical infrastructure assets assembled from Federal agencies, commercial vendors, and State partners. HSIP Freedom is a subset of HSIP Gold and is made up of 356 HSIP Gold layers and is less restricted in its use.[3]
- ***Statewide Property Inventory (SPI).*** California's Department of General Services (DGS) is the custodian of a statewide inventory of all property owned or leased by state government agencies in California. The SPI is "a detailed inventory of the State's real property assets including land, structures/improvements, leased space and State-owned space leased to others."[4] The SPI contains reference information for geo-locating assets, including street address and latitude and longitude. In addition, the SPI contains data fields for year built, number of floors, square footage, a condition code, and cost of the structure.

[3]For additional information please see https://gii.dhs.gov/HIFLD/hsip-guest

[4] See https://www.dgsapps.dgs.ca.gov/RESD/SPI-Web/wscripts/spi.asp?action=Main

- ***State Emergency Response Plans.*** We also considered reviewing state response plans as an additional check and validation of which state assets would be critical to response. These plans lay out how the state government responds to emergencies and disasters, including coordination with local government and non-government organizations. They include potential hazards, organization, and agency roles and responsibilities for responding to and recovering from disasters.[5]

Each source has strengths and weaknesses. The Cal OES critical infrastructure database is relatively current and the output of a deliberate process designed to identify critical state facilities. The general criteria for inclusion in the Cal OES critical infrastructure database center around the importance of a facility in terms of the provision of key services for sustaining the government and economy or for responding to disasters. The majority of facilities are government-owned, though there are some private facilities included, particularly large arenas and stadiums that could provide shelters to people displaced from their homes. Cal OES cautioned that while every attempt had been made to account for every asset in the state which met the criteria, in many cases the information in the database is self-reported, and some state agencies may either not have identified all assets under their control at the time of data collection, or may have failed to update the information as assets were added or disposed of over time.

RAND considered whether additional information might be available in either HSIP dataset which were not available in the Cal OES database, but discussions with Cal OES confirmed that, because the HSIP database is built primarily from input from states, more complete and accurate data reside in the Cal OES database.

In principle, the SPI represents the most comprehensive source for state-owned and -leased properties. However, the SPI is assembled by means of voluntary contributions from state agencies. Discussions with the database manager indicated that participation rates are low and their ability to proactively solicit participation is very limited. As a result, the SPI is very incomplete. Specifically, the SPI contains entries for less than 15% of the entries in the Cal OES critical infrastructure database. Further, many of the SPI records are incomplete or inaccurate. Consequently, the SPI provides very little information not already included in the Cal OES database.

Finally, we contacted the State Hazard Mitigation Officer (SHMO) within Cal OES to discuss the possibility of deriving key emergency response facilities from state emergency response plans. During our analysis, the SHMO and Cal OES staff indicated that the State Emergency Plan was currently being updated.[6] In addition, while the plan lays out agency roles and responsibilities, it does not describe or identify specific resources such as facilities or equipment. It was therefore concluded that a review of plans was unlikely to add value.

Based on the strengths and weaknesses of each source, we opted to use the Cal OES critical infrastructure database as the basis for our database of state-owned and -operated critical

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[5] See http://www.caloes.ca.gov/cal-oes-divisions/planning-preparedness/state-of-california-emergency-plan-emergency-support-functions.

[6] The plan was approved after our analysis was completed.

emergency response infrastructure. Among other information, the database identifies assets by name, street address, latitude and longitude, agency ownership, sector, and subsector. In addition to basic descriptive information, the database included rankings by subject matter experts (SMEs) obtained by Cal OES on mission value (asset importance) and economic value.

2.2 Development of Final Project Dataset

The State of California owns and operates a large and diverse array of facilities and assets which meet the CIP Unit's criteria for inclusion in the State critical infrastructure database. However, Cal OES and RAND agreed that some assets which met the criteria for inclusion in the database may not be critical for response to natural disasters. Examples include educational facilities, courthouses, water management infrastructure; these assets meet the criteria for state significant critical infrastructure because their ongoing operation is essential to maintaining the effective operation of critical government services, but they are not themselves critical to conducting response operations.

Accordingly, we adopted a general set of decision rules regarding whether or not categories of assets (e.g. sectors, subsectors, or specific asset types within subsectors) would be candidates for inclusion. We developed four general decision rules:

1. **The asset must be State-owned or operated.** While non-state-owned assets may clearly play an important role in response to natural disasters, Cal OES cautioned RAND that given the already broad scope of the project, the most useful results would focus on assets directly under the State's control and to which the State might reasonably be expected to direct State mitigation funding toward. This criterion includes some non-state-owned facilities that could play a role during an emergency response under the Standardized Emergency Management System (SEMS). These include county emergency operations centers, public health agencies, and coroners.[7] These also include several large auditoriums and stadiums, most of which are a privately owned, that may be called upon to act as emergency temporary shelters during an incident in which large numbers of people are displaced from their homes.

2. **The asset must have a direct role in facilitating emergency response operations.** The Cal OES critical infrastructure database targets facilities critical to the functioning of a broad range of government services. Many of these facilities are of vital importance, but have no direct relevance to supporting emergency response operations following natural disasters. Assets which would require assistance or which could significantly add to the burden on State response operations if damaged or destroyed would not meet this criterion. Similarly, assets that indirectly provide services used in emergency response, such as power and water, are not included.

[7] Because SEMS uses the Incident Command System, in which command is established at the lowest level that can perform that role effectively, these facilities may not technically be state-operated during a response. However, their direct role in a state-wide response effort merits their inclusion.

3. **The asset must be sufficiently unique such that it is not ubiquitous, easily replaceable, or interchangeable.** Assets must not be sufficiently common that they are essentially interchangeable with or easily replaced by other readily available assets. Assets which are either irreplaceable or for which there is not a ready substitute would be included in the analysis. These would include key transportation corridors, as well as very large (i.e., stadium-sized) shelter resources. In addition, while state-level fire and law enforcement (Highway Patrol) stations are included, local level stations, which could fall under state-level management during disaster operations, are not.

The decision rules were employed as general guidelines, rather than hard and fast rules, and in all cases we attempted to err on the side of good judgement. Table 2.1 provides an example of how these criteria were applied to asset types in California's critical infrastructure database and other example asset types.

Table 2.1–Examples of Included and Excluded Infrastructure

	State-Owned/Operated	Direct Response/Recovery Role	Rare	Include?
Local EOC	X	X	X	Y
Large Stadium	X	X	X	Y
Major Tunnel	X	X	X	Y
Water Treatment Plant	X		X	N
Local Fire Station	X	X		N
Heavy Equipment Supplier		X	X	N

Using these decision rules as a starting point, RAND employed a multi-step process to identify a comprehensive set of state-owned and -operated infrastructure sectors and subsectors which are truly critical to response for inclusion in the study:

- **Preliminary identification of sectors and subsectors for inclusion in the study.** Using the decision rules, we performed an initial screen of Cal OES's critical infrastructure sector and subsector taxonomy and identified sectors and subsectors for inclusion.

- **Review by Cal OES.** Representatives of Cal OES CIP and Hazard Mitigation divisions reviewed RAND's preliminary selections with RAND and provided feedback. Based on these discussions, RAND prepared a modified set of sectors and subsectors for inclusion in the study.

- **Review by state agency experts/stakeholders.** Cal OES identified a set of 58 subject matter experts (SMEs) representing more than 40 State departments, agencies, and offices to review and assess the proposed sectors/subsectors (see Appendix A). Cal OES shared our initial sector selection with this stakeholder group, and asked them to review the proposed list and indicate any sectors/subsectors for which they believed the initial designation should be changed. Unfortunately, very few responses were received and as a result, few changes were made to the asset database.

- **Final selection of sectors/subsectors for inclusion.** We further refined the database by performing a record-by-record review of facilities and removed any individual facilities that did not meet the decision rules for inclusion. In addition, we included Cal Fire and California Highway Patrol stations to the database. While they were not part of the Cal OES critical infrastructure database, they meet our decision criteria for inclusion.

As a result of this process we ultimately identified five sectors for inclusion in the study, screening out individual subsectors and assets based on the previously described processes. The sectors identified for inclusion are:

- Commercial Facilities (including assets in the Public Assembly subsector, primarily very large stadiums and convention centers)
- Emergency Services
- Government Facilities (including large facilities or those housing essential services)
- Health Care and Public Health (including laboratories, state hospitals, and state and local public health facilities)
- Transportation (including assets in the Aviation, Highways, and Mass Transit subsectors)

Within these sectors, our selection process led to the inclusion of 604 state-owned or -operated critical emergency response facilities statewide. Numbers of facilities by sector and subsector are listed in Table 2.2. Sectors are further described in Appendix B. The distribution of these facilities throughout the state are shown in Figure 2.1.

Table 2.2–Numbers of facilities by sector and subsector

Sector and Subsector	Number of Facilities
Commercial Facilities	
Public Assembly	22

Emergency Services	
Emergency Management	100
Fire Service	252
Law Enforcement	109
Government Facilities	
Personnel-Oriented Government Facility	9
Healthcare and Public Health	
Direct Patient Healthcare	5
Fatality/Mortuary Facility	12
Health Supporting Facility	6
Public Health Agency	57
Transportation[a]	
Aviation	11
Maritime	1
Mass Transit	6
Road	14
Total	604

[a]Transportation infrastructure includes only point facilities such as ports, bridges, and interchanges

At the request of Cal OES, we also identified which of the facilities are located in disadvantaged communities. California Senate Bill 535, passed on 2012, requires that 25% of the income from California's cap and trade program, part of the California Global Warming Solutions Act of 2006, go to fund projects that provide benefits to disadvantaged communities.[8] Assembly Bill 1550 in 2016 further specifies that 25% of proceeds from the fund be spent on projects located in disadvantaged communities.[9] In 2017, the California Office of Environmental Health Hazard Assessment, on behalf of the California Environmental Protection Agency, developed the California Communities Environmental Health Screening Tool, called CalEnviroScreen 3.0,[10] to designate disadvantaged communities for the purposes of allocating these funds.

[8]https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201120120SB535

[9]https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB1550

[10]https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

CalEnviroScreen 3.0 uses pollution burden, population health characteristics, and socioeconomic factors to define disadvantaged communities at the census tract level.

We used disadvantaged community designations from CalEnviroScreen 3.0 to identify each facility that is located in a disadvantaged community. A total of 101 of the 604 facilities in our database are in designated disadvantaged communities. The distribution of these facilities is shown in Figure 2.2.

Figure 2.1–Distribution of State-Owned and -Operated Critical Emergency Response Facilities

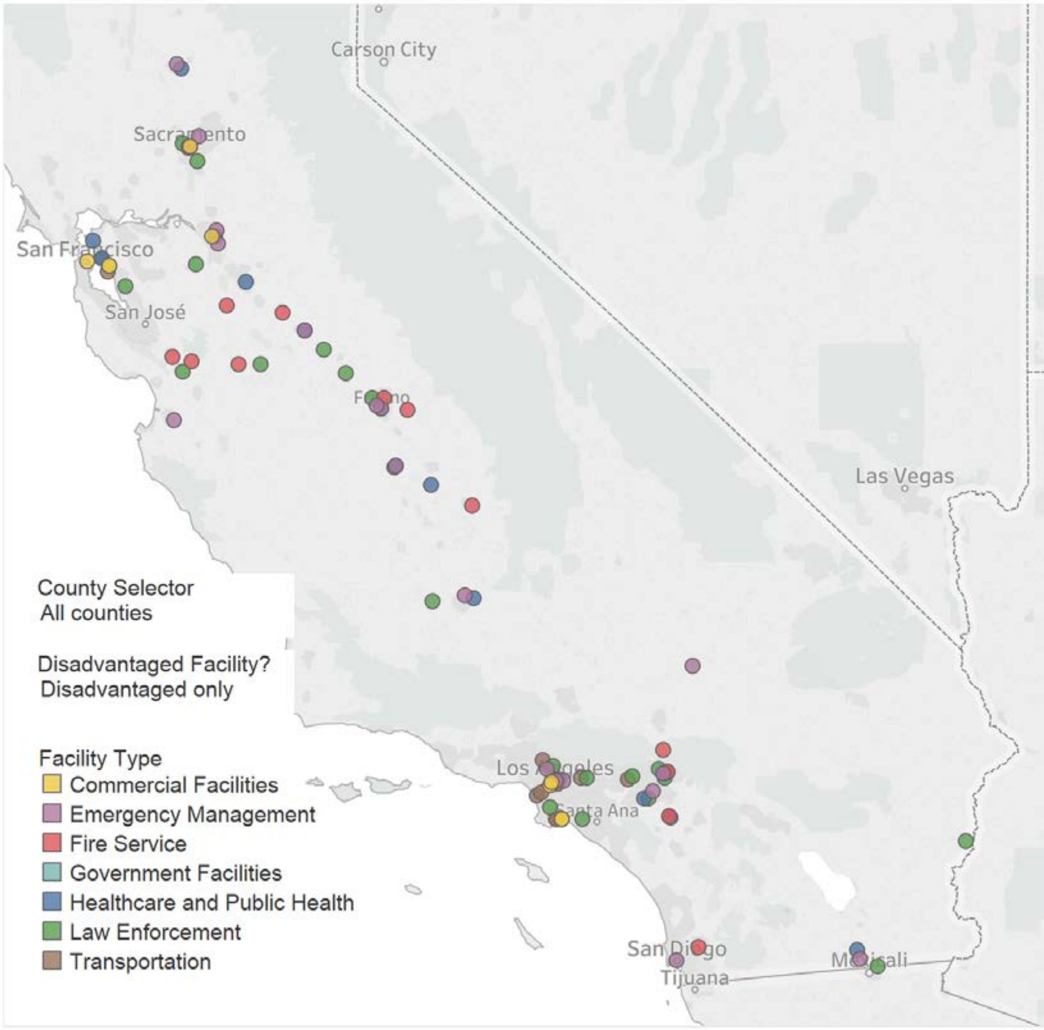

Figure 2.2–Distribution of State-Owned and -Operated Critical Emergency Response Facilities in Disadvantaged Communities

3: Natural Hazard Selection and Climate Adjustment

3.1 Natural Hazard Selection

California is exposed to a large number of natural hazards that could create emergencies and potentially disrupt response operations using state-owned infrastructure. This analysis focuses on impacts to emergency response building infrastructure from hazards whose risk is anticipated to increase with climate change. Accordingly, our decision about which hazards to include in our analysis was guided by three factors:

- The extent to which the hazard is related to the climate and therefore susceptible to evolve with climate change
- The extent to which the hazard is known or anticipated to have a direct physical impact on built infrastructure
- The availability of data and methods that would allow us to characterize the magnitude of the hazard on a state-wide scale at a spatial resolution useful to the analysis.

Of the many known climate-related hazards, we arrived at evaluating risks from wildfires and coastal flooding. The flooding hazard integrates different types of flooding that span a range of recurrence timescales. Tidal flooding affects coastal land areas that are flooded on a short-term basis from tidal fluctuations. Tidal flooding is simulated at recurrence intervals ranging from 1 month to 10 years. Storm surge affects coastal land areas that are flooded on a short-term basis from passing storms. Storm surge flooding is simulated at a 100-year recurrence interval.

These hazards are highly relevant to California. The state's coastline is vulnerable to rising seas and associated hazards of tidal flooding and storm surge. More inland regions, particularly the Coastal Ranges and Sierra Nevada, are highly susceptible to wildfire. In addition, the spatial extent, frequency, and/or intensity of these hazards may change with future climate, and can be projected in future time spans using the Fourth Assessment-provided sea level rise (SLR) projections and wildfire simulations.

Other climate-related hazards were excluded because suitable models of risks to infrastructure are not available. Extreme temperature and drought can increase the risk of power outages if power lines are affected by wildfires,[11] and can increase the risk of land subsidence.[12] Modeling the effect of fires on powerlines requires a wildfire model with very high spatial resolution and a power grid model that links each facility to associated power lines, neither of which is available. Subsidence modeling is still in early stages of development and has not been applied in California.[13] Landslides could be a serious risk to infrastructure. However, we are unaware

[11] U.S. Department of Homeland Security Operational Analysis Division (2015) *Drought Impacts to Critical Infrastructure*, https://hazdoc.colorado.edu/bitstream/handle/10590/3367/C023661.pdf?sequence=1

[12] Corti T, Wüest M, Bresch D, and Seneviratne SI (2011) *Drought-induced building damages from simulations at regional scale*, Nat. Hazards Earth Syst. Sci., 11, 3335-3342.

[13] U.S. Department of Homeland Security Operational Analysis Division (2015) *Drought Impacts to Critical Infrastructure*, https://hazdoc.colorado.edu/bitstream/handle/10590/3367/C023661.pdf?sequence=1

of a methodology for projecting landslide risk under future climate conditions, particularly at high-resolution on a state-wide scale as needed for this analysis. Inland flooding hazards were similarly excluded due to a lack of available high-resolution projections across the State.

3.2 Hazard Mapping and Climate Adjustment

Here we provide details on the data sets and methodologies used for mapping and climate-adjusting each of the natural hazards, along with the final set of mapping dimensions for each hazard. We examined future, climate-adjusted, hazards in five 20-year time periods between 2000 and 2100.

3.2.1 Tidal Flooding

3.2.1.1 Data sets

- Fourth Assessment-provided hourly probabilistic SLR projections
- NOAA Digital Coast Digital Elevation Model

3.2.1.2 Methodology

Land areas projected to flood under high tides in future conditions were determined by first calculating the maximum hourly tide within each month between 2000-2099 at each of the 9 stations provided by the Fourth Assessment. We then computed return values (i.e., a monthly max tide) associated with the one-month as well as 1-, 2-, 5-, and 10-year return periods based on the time series of daily or monthly maximum hourly tides within five 20-year time periods: 2000-2019, 2020-2039, 2040-2059, 2060-2079, 2080-2099. This exercise was performed using SLR projections corresponding to each recommended likelihood percentile (50th, 95th, 99.9th), emissions scenario (RCP) and general circulation model atmospheric/oceanic forcing (GCM). For each time period, likelihood, RCP, GCM, and return period combination, we then created a California-wide tidal map by spatially interpolating between values at each of the 9 stations. Subtracting tidal levels for a given combination from land elevations revealed regions that are inundated by tidal flooding events.

The Bay-Delta region, which includes a series of islands protected by earthen levees, was treated as a special case. Here, we used a more detailed approach that incorporated the levee protection system. This approach nevertheless accounted for levee protection, and also incorporated the possibility of levee failure and island flooding due either to earthquake hazards or overtopping into statistical estimates of tidal flood recurrence. The methodology for estimating levee failure and the simulation model applied to estimate flood probabilities for each island are documented in a forthcoming RAND report (Groves et al., forthcoming[14]). We then updated the tidal flood return periods taking into account these additional failure probabilities.

Note that, though the Bay-Delta approach better represents both the additional benefits and risks from the levee system, it is still simplified with respect to hydrologic or hydraulic connectivity and other systems detail. Tidal flooding results, along with the more simplified

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[14] Groves DG, Kalra N, Syme S, Ellis H, Gardiner CL, Roth, LH (forthcoming) Decision Support Tool for the San Francisco Bay-Delta Levees Investment Strategy: Documentation and Use, RAND RR-2139-DSC.

approach applied elsewhere in this analysis, are most appropriate for statewide, screening-level analysis, and should not be overinterpreted for specific geographic locations.

3.2.1.3 Hazard mapping dimensions

A total of 480 tidal flooding maps at a grid resolution of approximately 300 meters are created according to the following dimensional combinations:

- Hazard metric: flooding depth (feet)
- 3 likelihood percentiles: 50th, 95th, 99.9th
- 5 time periods: 2000–2019, 2020–2039, 2040–2059, 2060–2079, and 2080–2099
- 2 RCPs: RCP 4.5, RCP 8.5
- 4 GCMs: CNRM-CM5, CanESM2, HadGEM2-ES, MIROC5[15]
- 5 return periods: 1-month, 1-, 2-, 5-, and 10-year

3.2.2 Storm Surge

3.2.2.1 Data sets

- Fourth Assessment-provided probabilistic SLR curves
- CA tidal gauge year 2000 mean sea level (MSL)
- NOAA Digital Coast DEM
- FEMA 100-year Special Flood Hazard Layer (SFHL)

3.2.2.2 Methodology

We began by transforming the single, California-wide set of probabilistic SLR projections provided by the Fourth Assessment to a more spatially detailed product through factoring in regional datum differences along the California coast. Specifically, we created a set of probabilistic SLR projections at 13 California tidal gauges maintained by NOAA (https://opendap.co-ops.nos.noaa.gov/axis/, Table 3.1). Since the California-wide probabilistic SLR projections are relative to the year 2000 MSL, station-specific projections were computed by simply adding each station's year 2000 MSL (Table 3.1) to the original single set of projections. We then created a new set of California-wide probabilistic SLR curves by spatially interpolating the station-specific projections along the entire coastline. Subtracting land elevations from probabilistic sea levels by 2020, 2040, 2060, 2080, and 2100 revealed maps of permanent inundation (i.e. land elevations below sea levels) at these five future time periods under each recommended 50th, 95th, and 99.9th likelihood percentiles and each recommended emissions scenarios of Representative Concentration Pathway (RCP). We then added those flood levels to the flood elevations of the Base Flood Elevation (BFE) 100-year flood polygons found in FEMA's

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[15] Initial results suggest that variability across the GCM atmospheric/oceanic forcing component to the full tidal projection is relatively minor compared to the other dimensions. Therefore, we have also included a GCM-average dimension that when used, reduces the number of layers from 480 to 120.

Special Flood Hazard Layer[16] (SFHL) database. The summed flood depths at the outer edges of the SFHL polygons were then extrapolated outward, and surrounding ground topography was subtracted in the areas outside of the SFHL polygons, resulting in relative flood depths. All areas outside of and directly adjacent to the SFHL polygons that contained positive relative flood depths were then retained and added to the SFHL polygons to create an extended SFHL area. Finally, we added any outlying areas with positive relative flooding that were within one raster cell of the extended SFHL area, building the extended SFHL area out until all relevant additional areas had been added, yielding the final, climate-adjusted maps of the 100-year storm surge flood plain.

Table 3.1–Year 2000 MSL (ft. NAVD 88) for CA stations

Station Name and ID	Year 2000 MSL
Alameda (9414750)	3.10
Arena Cove (9416841)	2.95
Crescent City (9419750)	3.19
La Jolla (9410230)	2.46
Los Angeles (9410660)	2.53
Monterey (9413450)	2.86
North Spit (9418767)	3.41
Point Reyes (9415020)	3.00
Port Chicago (9415144)	3.58
Port San Luis (9412110)	2.61
San Diego (9410170)	2.38
San Francisco (9414290)	3.09
Santa Monica (9410840)	2.54

3.2.2.3 Hazard mapping dimensions

A total of 30 storm surge maps were created according to the following dimensional combinations at a grid resolution of approximately 300 meters:

- Hazard metric: flooding depth (feet)
- 3 likelihood percentiles: 50th, 95th, 99.9th
- 5 time periods: 2000–2019, 2020–2039, 2040–2059, 2060–2079, 2080–2099

[16] https://www.fema.gov/national-flood-hazard-layer-nfhl, accessed April 10th, 2017

- 2 RCPs: RCP 4.5, RCP 8.5
- 4 GCMs: CNRM-CM5, CanESM2, HadGEM2-ES, MIROC5[17]

3.2.3 Wildfire

3.2.3.1 Data sets

- Fourth Assessment-provided wildfire projections[18]

3.2.3.2 Methodology

We use the Fourth Assessment-provided wildfire simulation model to calculate the average burned area (unit hectares) for each grid cell at four different exceedance probability levels (return periods) during each 20-year time period in the 21st century. We use climate information from 4 available GCMs under the RCP 4.5 and RCP 8.5 emissions scenarios, along with 3 land use/land cover (i.e., population) scenarios. We also averaged results across the 4 GCMs to create another set of results representing the ensemble average. Exceedance probabilities include the 2 percent annual chance (50-year), 1 percent annual chance (100-year), 0.2 percent annual chance (500-year), and 0.1 percent annual chance (1,000-year).

3.2.3.3 Hazard mapping dimensions

A total of 150 wildfire maps were created according to the following dimensional combinations:

- Hazard metric: percent of grid cell burned
- 5 time periods: 2000–2019, 2020–2039, 2040–2059, 2060–2079, 2080–2099
- 2 RCPs: RCP 4.5 RCP 8.5
- 4 GCMs: CNRM-CM5, CanESM2, HadGEM2-ES, MIROC5, GCM average
- 3 land use/land cover (i.e., population) scenarios: low, business-as-usual, high
- 4 return periods (50-year, 100-year, 500-year, 1,000-year)

3.3 Summary

Figures 3.1 through 3.3 show hazard maps for annual tidal flooding, 100-year storm surge flooding, and 100-year wildfire, respectively.[19] In each case, specific user-selectable thresholds were chosen (e.g., time period, hazard return interval, emission/sea level rise scenario) to provide meaningful examples; however, as noted above, in each case a substantially larger

[17] Initial results suggest that variability across the GCM atmospheric/oceanic forcing component to the full tidal projection is relatively minor compared to the other dimensions. Therefore, we have also included a GCM-average dimension that when used, reduces the number of layers from 480 to 120.

[18] Westerling AL (in press) *Wildfire Simulations for the Fourth California Climate Assessment: Projecting Changes in Extreme Wildfire Events With a Warming Climate*, Draft report for the California's Fourth Climate Change Assessment.

[19] Note that the 100-year floods and wildfires refer to probabilities at a given location and do not refer to a single event that affects the entire state at once.

number of scenarios are available through our analysis. Flood hazard footprints show the depth of flooding, while wildfire hazard footprints show the percent of the grid cell projected to burn. As expected, flooded areas cluster along the coast, particularly in the San Francisco Bay area and the delta region. Wildfire footprints are spread throughout the state, with greater burning in the mountainous areas such as the coastal and Sierra Nevada ranges.

The CERI-Climate visualization tool, which will be described in greater detail in Chapter 5, was used to create these analyses and allows the user to vary a number of parameters that influence the hazard footprints. As noted above, Figures 3.1 through 3.3 are examples for a single set of conditions; altering parameters will result in different hazard maps.

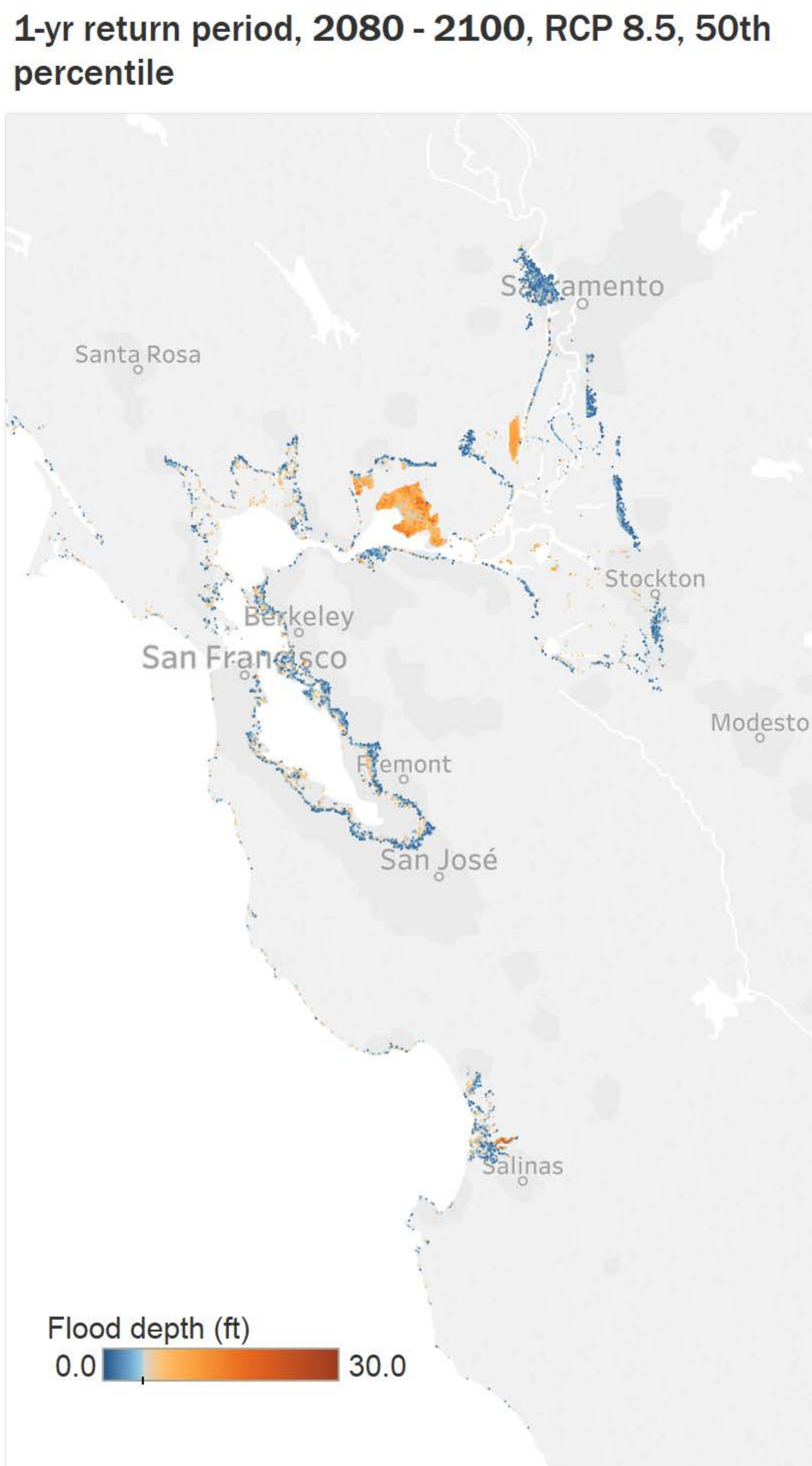


Figure 3.1–Tidal Flooding in the Bay-Delta Region in 2080–2100

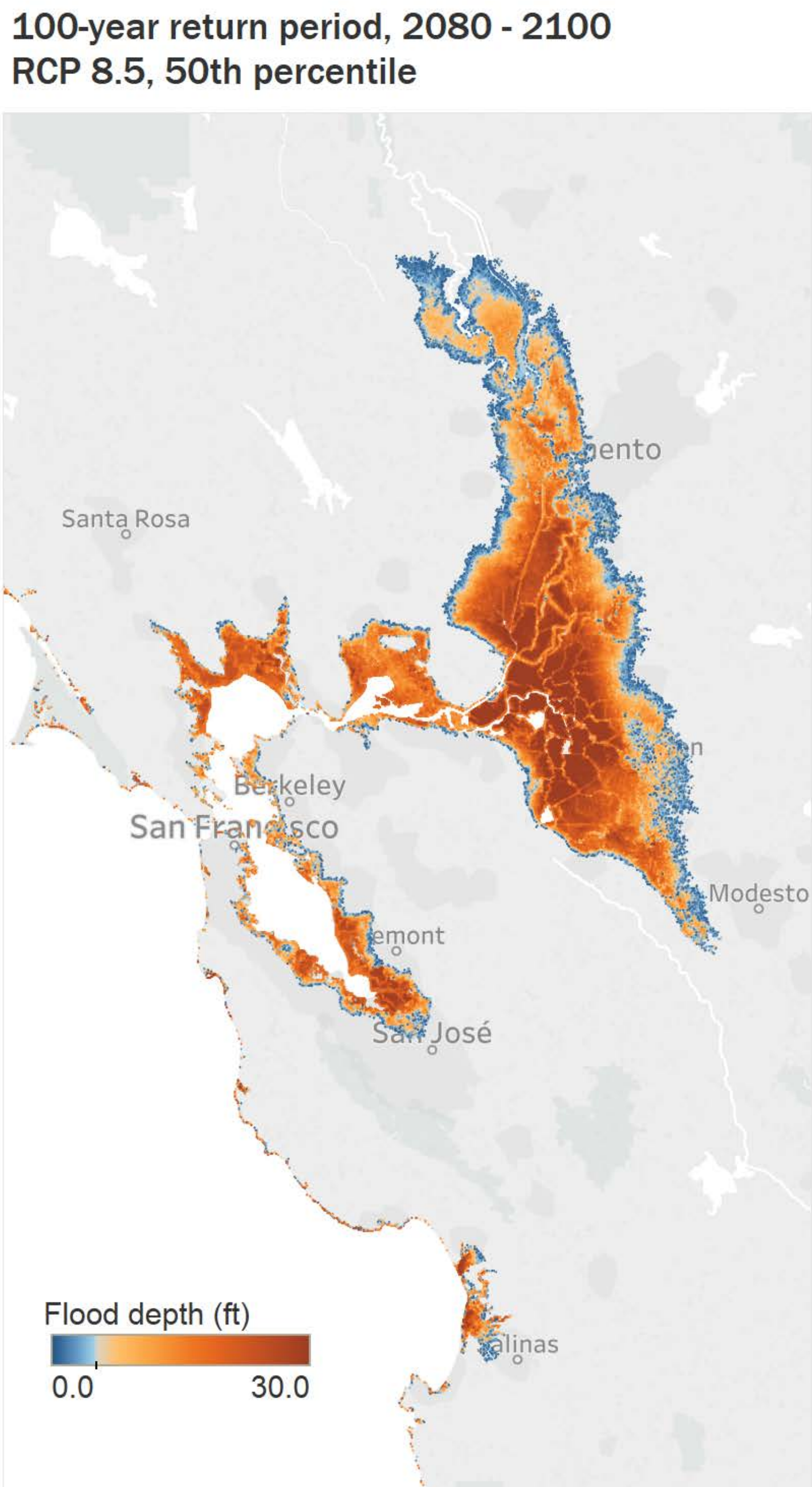


Figure 3.2–Storm Surge Flooding in the Bay-Delta Region in 2080–2100

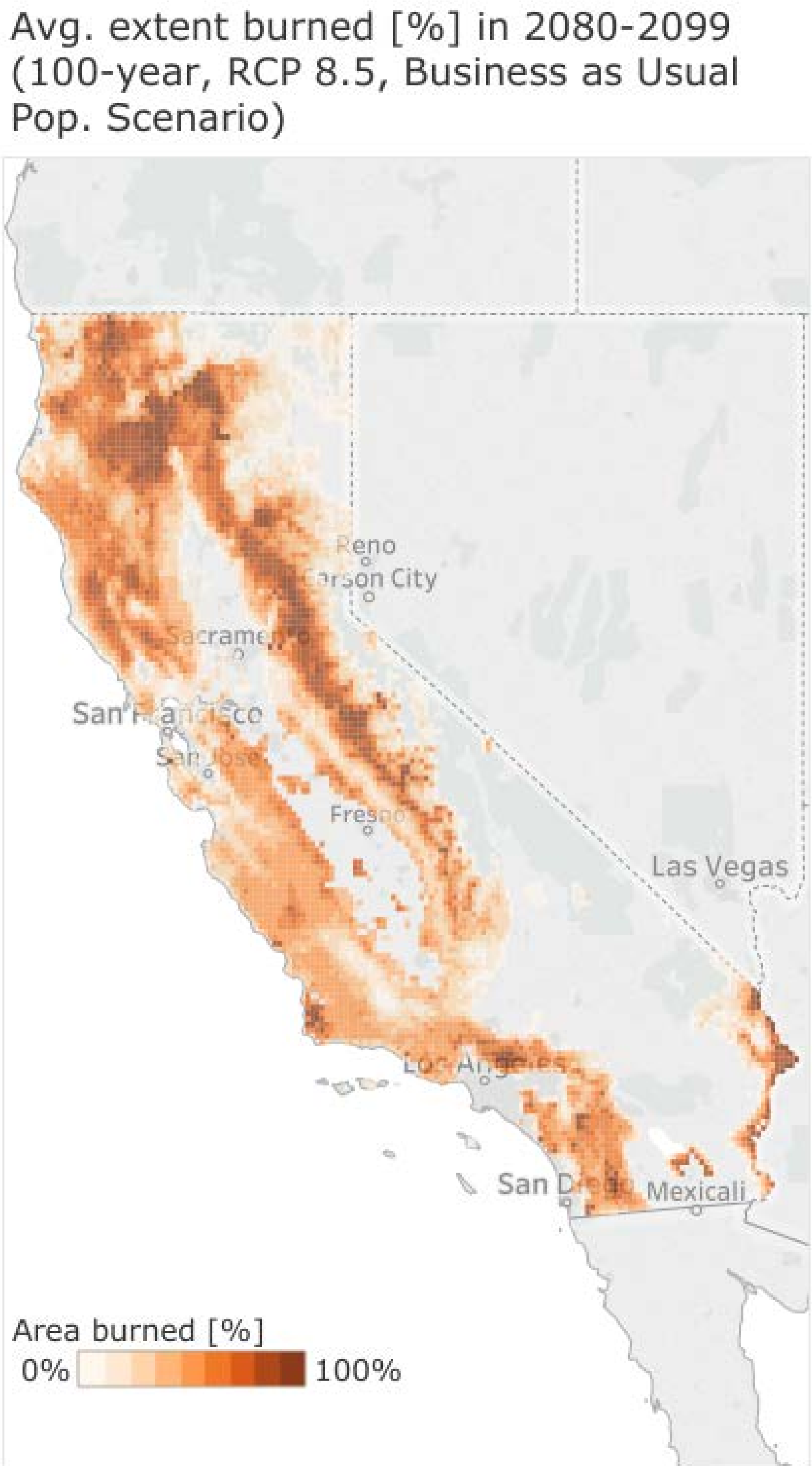


Figure 3.3–Wildfire Hazard in 2080–2100

4: California Critical Infrastructure Exposure to Climate Change Impacted Natural Hazards

The geocoded infrastructure locations and hazard maps described above and the CERI-Climate tool allow us to examine spatial relationships between California's emergency response infrastructure and the footprints of natural hazards that may impact the state at various points in the future. For our analysis we consider two degrees of interaction between infrastructure and hazard footprints: direct and indirect exposure.

Direct exposure occurs when a facility falls within the footprint of a hazard as determined from a geographic information system overlay analysis. The footprint of a hazard is defined as the area experiencing a hazard exposure exceeding a minimum threshold value (specifically, flood depth or percent of cell burned). The minimum threshold for direct exposure can be varied from zero (any flooding or fire exposure at all) to some non-zero threshold below which exposure is neglected (e.g., a flood depth of 0.5 feet) depending on the user's preference. For example, choosing a threshold of zero (any flooding or fire exposure) would reflect a low tolerance for risk, whereas a non-zero threshold might reflect a belief that a facility could be exposed to some low level of flooding or fire hazard. Direct exposure is expected to result in both damage to the exposed property and disruption to the operation of the facility.

Indirect exposure occurs when a facility falls outside the hazard footprint but within a specified distance from the edge of the hazard footprint. Indirect exposure is not expected to result in property damage from the hazards we considered, but is important to consider, particularly in regard to emergency response, as it could result in operational disruption. For example, indirect exposure could prevent access to or use of a facility by making it physically inaccessible, as might occur with flooding, or as a result of mandatory or voluntary evacuation due to unsafe conditions in the area surrounding a hazard, as could occur with either flooding or wildfires.

Our attempts to derive an estimate for the size of the indirect exposure zone empirically from past incidents failed to identify useful and reliable data or guidelines for estimating evacuation zones. In practice, evacuation zones are expected to be incident-specific and influenced by the rate at which the hazard is evolving, natural barriers, road networks, and other factors including human decision-making. Accordingly, as a proxy we defined the indirect exposure zone to comprise any grid cells adjacent to a grid cell within the hazard footprint. This amounts to a 1-grid cell buffer zone around the hazard zones. For flooding hazards, the width of a grid cell, and hence buffer zone size, is approximately 300 meters, while for wildfires the distance is about 6 km.[20]

Examples of direct and indirect exposures of critical emergency response infrastructure to coastal flooding and wildfire hazards are shown in Figures 4.1–4.6. These figures show the facilities directly exposed to flooding or wildfire as well as those that may suffer operational disruption as a result of needing to evacuate the facility due to proximity to flooding or wildfires. The example results shown are for the 2080–2099 time period, which is the farthest time period into the future that our analysis covered. We show this period because as sea level

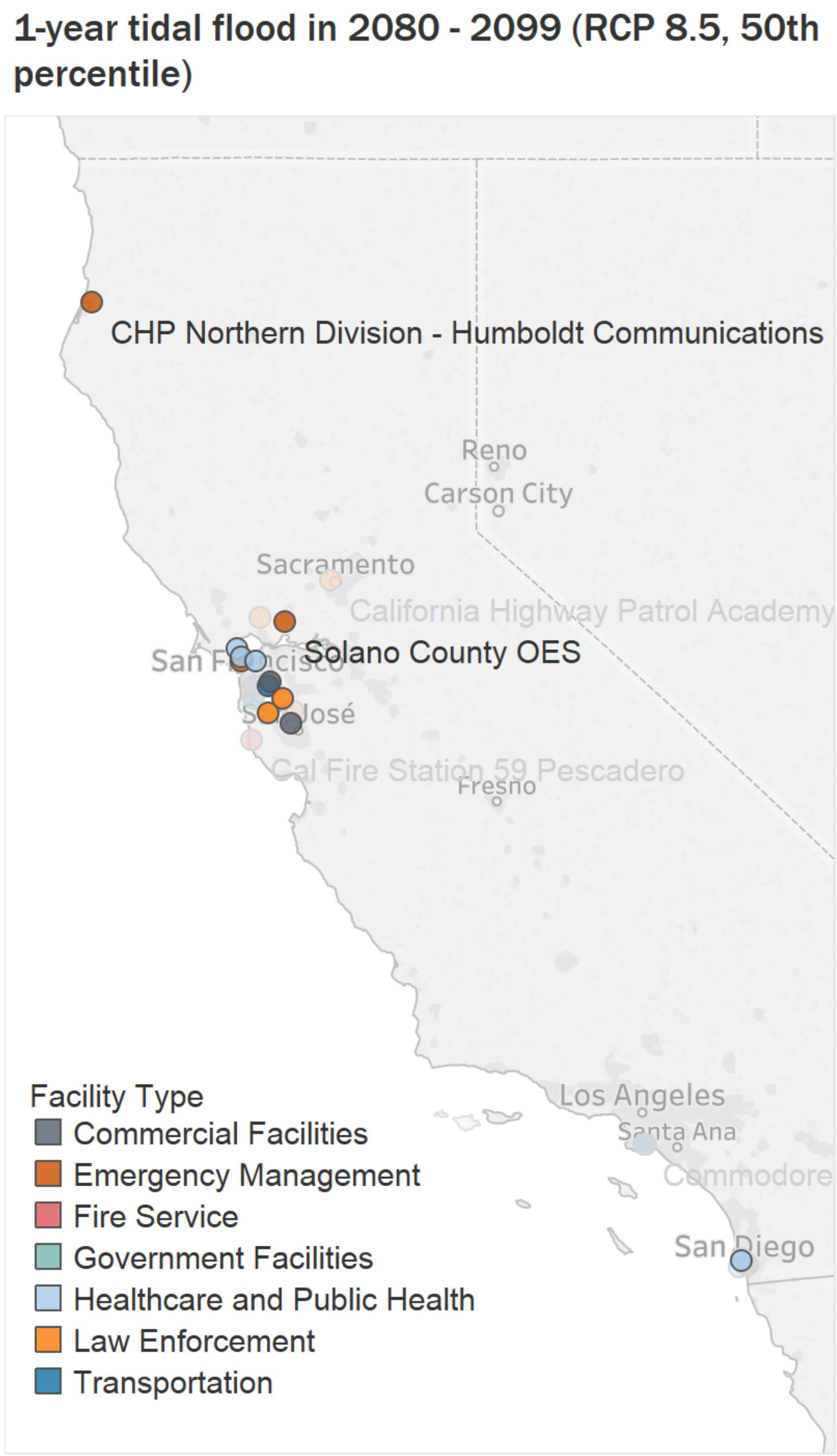
[20] Because grid cells are defined in terms of degrees of latitude and longitude, the shapes of the grid cells vary slightly with latitude.

rise and warming increase with time in all GCMs, and coastal flooding and wildfire risks increase with sea level rise and warming, the 2080–2099 time period shows the greatest extent and/or most severe intensity of hazard exposure identified in our analysis (e.g., representing a potential upper bound for exposure, which may be useful for planning purposes). For simplicity and continuity, we fix several other modeling parameters in our exposure illustrations and risk profiles presented below. These include:

- RCP = 8.5
- 50th percentile (flooding) or average (wildfire) among the GCMs
- Flood exposure threshold = 0.5 feet
- Wildfire exposure threshold = 50% burned
- Wildfire population scenario = Business-as-usual
- Include all (disadvantaged and non-disadvantaged) communities

All of these parameters are user-selectable in CERI-Climate and changing any of them will change the exposures and risk profiles. For example, as explained above, the selection of a flood exposure threshold of 0.5 feet for the examples which follow means that the facilities identified in the analysis below are exposed to at least half a foot of flooding.

Paralleling the hazard maps presented above, Figures 4.1–4.4 show that flooding exposure is concentrated in the San Francisco Bay area and other areas along the coast. Despite substantial flooding risk in the delta area, there is little exposure there because there is little state emergency response infrastructure in this area. Under the conditions illustrated, 13 facilities are directly exposed to annual flooding and 20 more may be exposed to operational disruption from annual flooding (Figures 4.1 and 4.2). Put in other words, under these assumptions and holding other conditions constant, these facilities would be expected to flood and/or be disrupted, respectively, on average at least once a year by the 2080-2099 time period. For a 100-year storm, 30 facilities are exposed to direct flooding and 38 more may be exposed to operational disruption. A 100-year storm has a much greater flooding potential than annual tidal flooding, so both the number of facilities affected and the extent of impact on those facilities will be greater.



Operational disruption threshold: 0.5 ft
Flood exposure threshold: 0.5 ft

Figure 4.1–Direct Exposure to Annual Flooding in 2080–2099

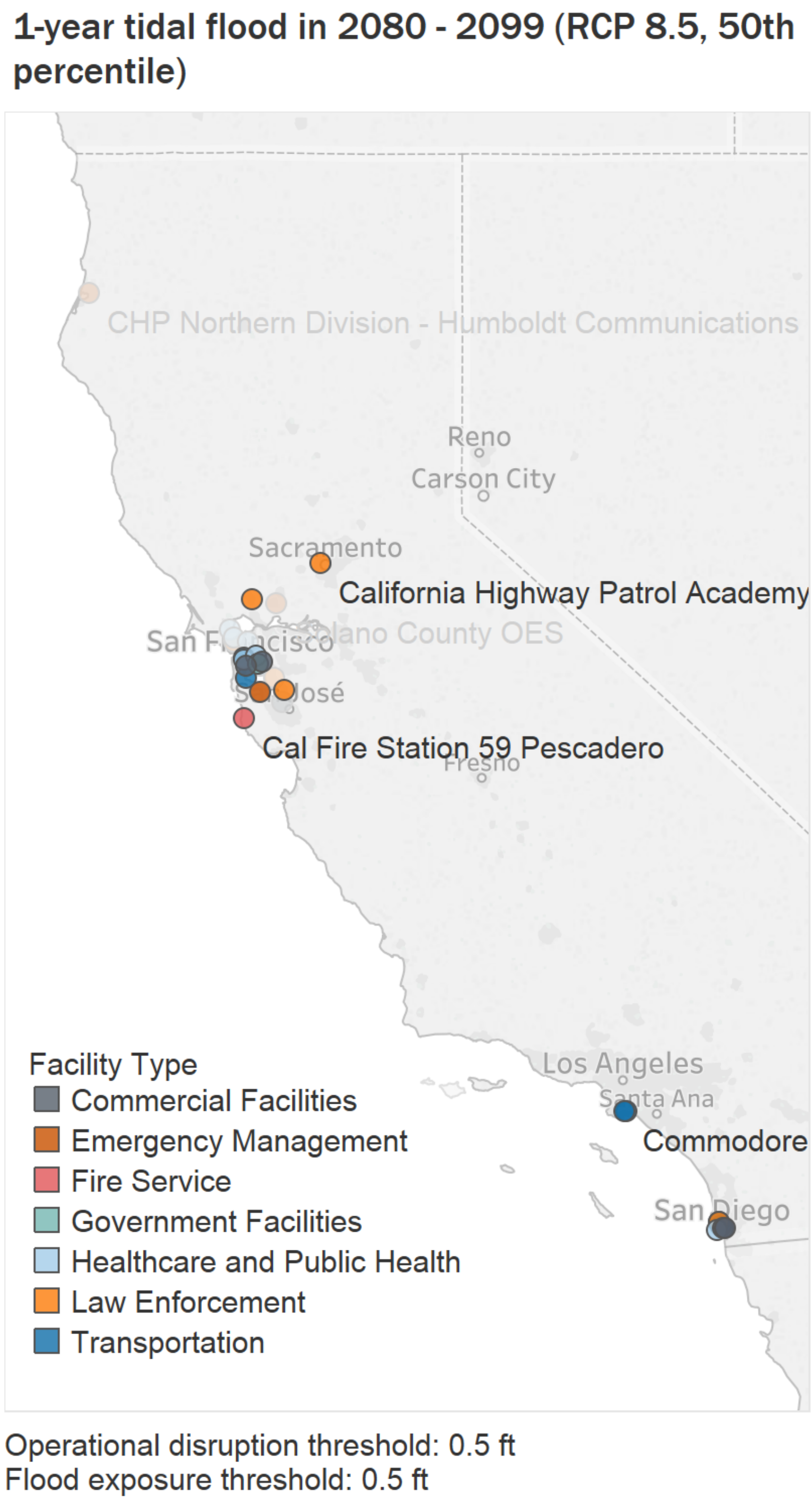


Figure 4.2–Operational Disruption from Annual Flooding in 2080–2099

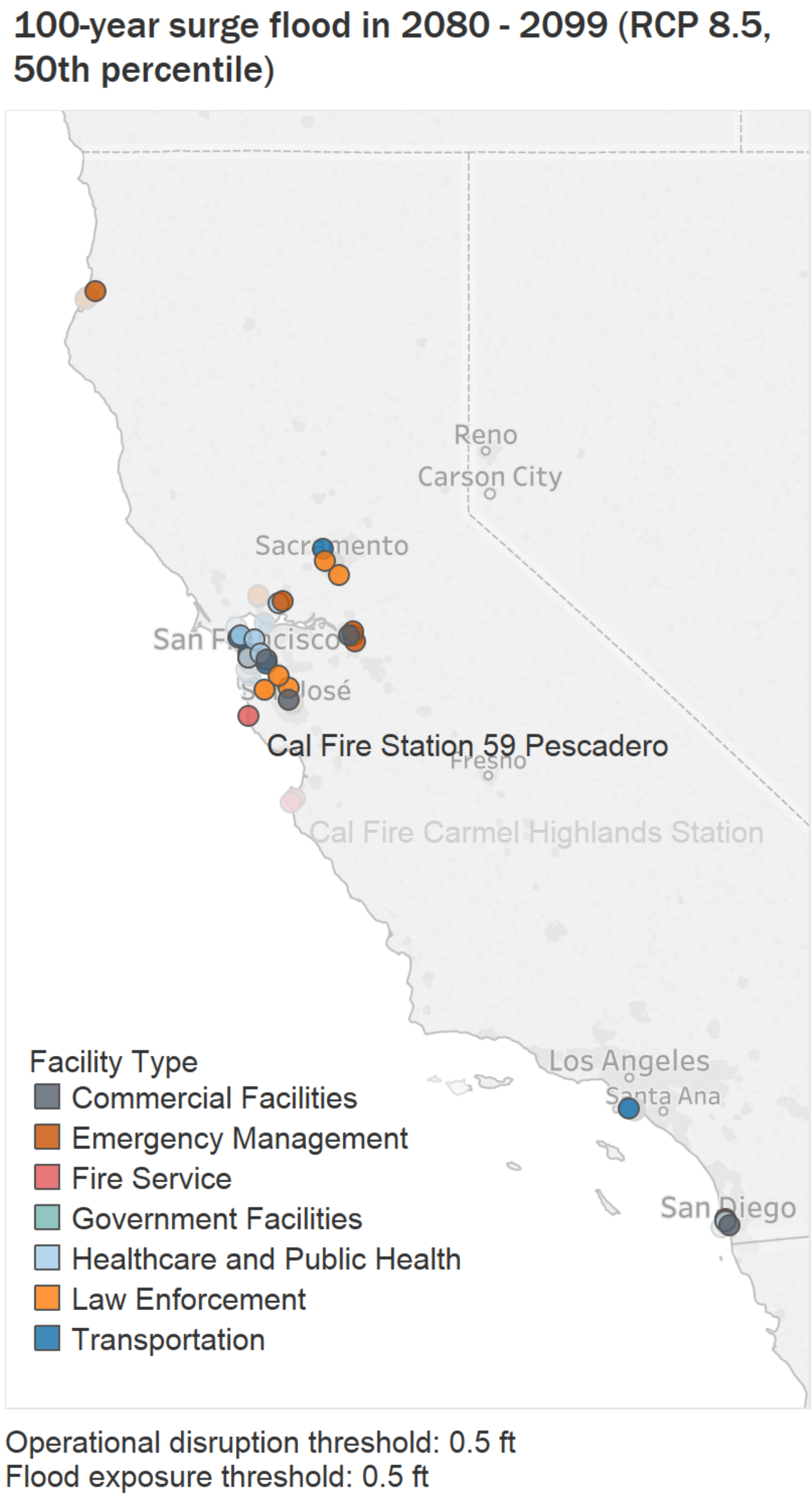


Figure 4.3–Direct Exposure to 100-year Flooding in 2080–2099

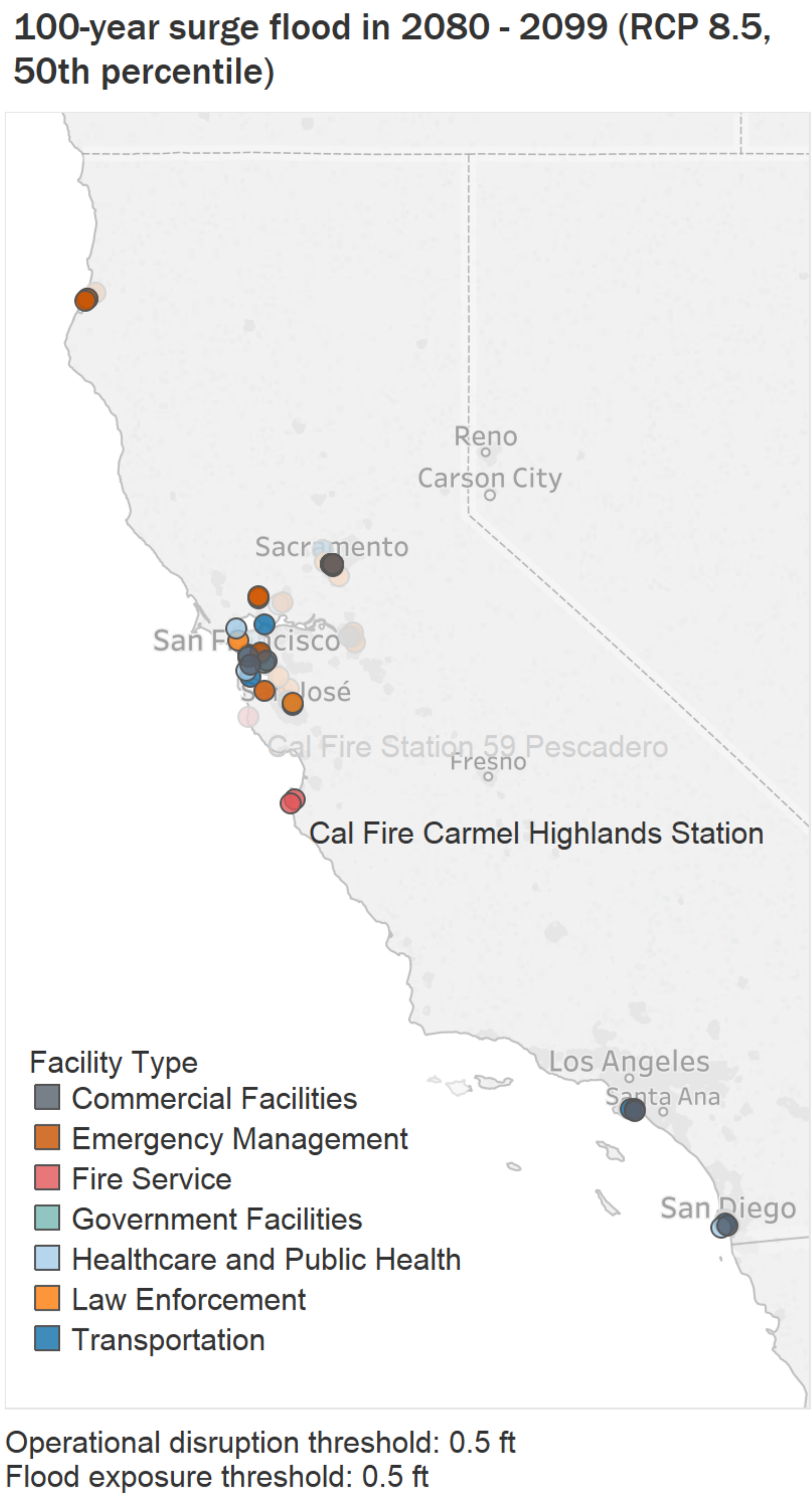


Figure 4.4–Operational Disruption from 100-year Flooding in 2080–2099

Figures 4.5 and 4.6 show facilities in grid cells exposed to a 1 percent annual chance (100-year) wildfire in the 2080–2099 time period. These figures show results for an exposure threshold of 50%, meaning that they show facilities associated with grid cells in which at least 50% of the area is projected to burn under the specified conditions. As in the case of the flooding examples provided above, this is arguably a relatively high threshold for exposure. Using these parameters, 112 facilities are directly exposed, with another 159 exposed to operational disruption.

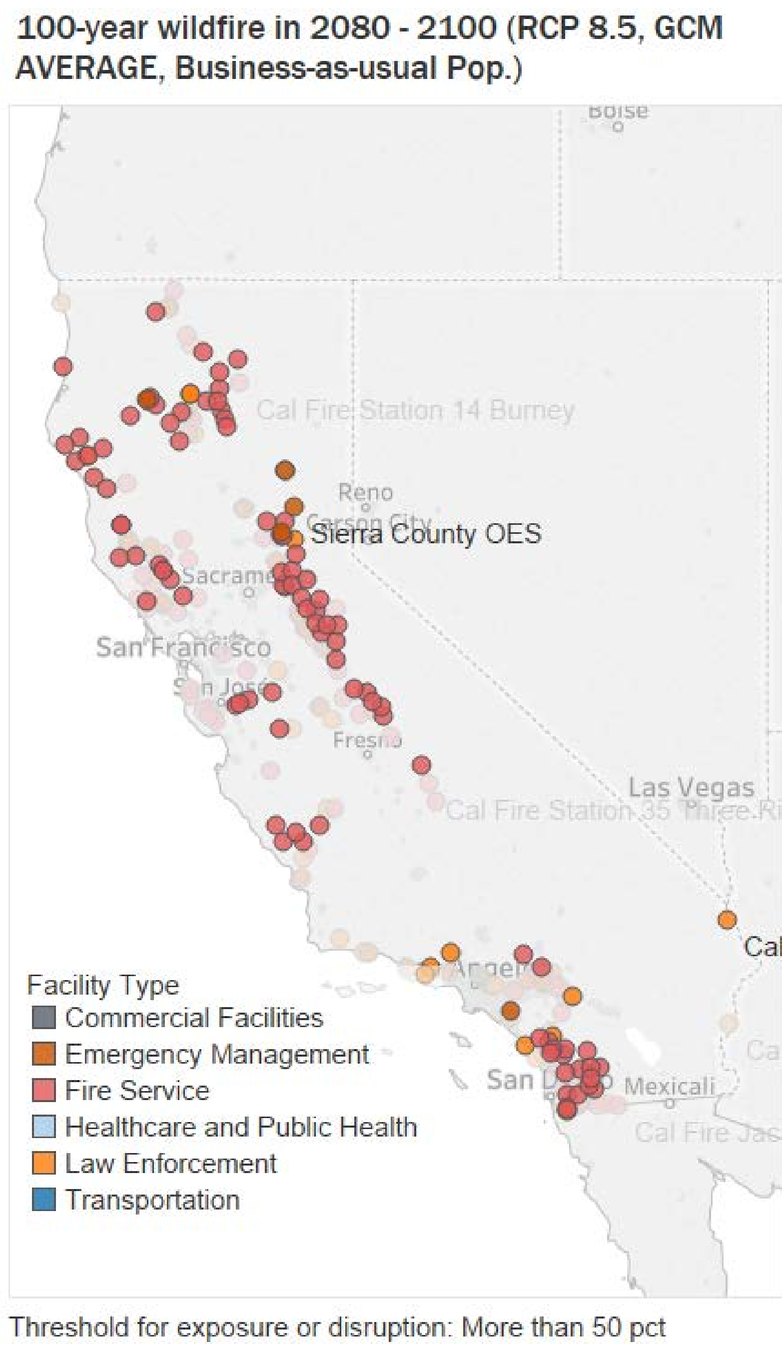


Figure 4.5–Direct Exposure to 100-year Wildfire in 2080–2099

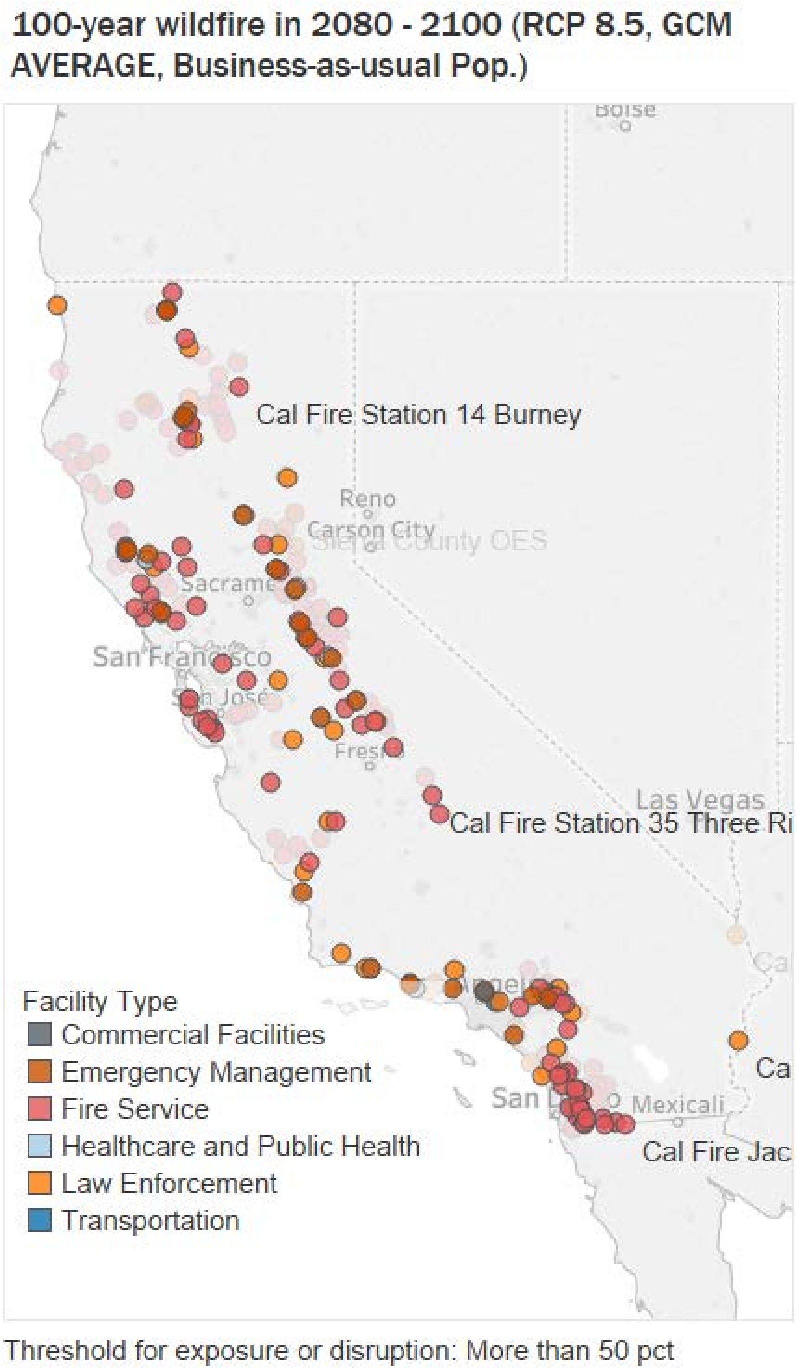


Figure 4.6–Operational Disruption from 100-year Wildfire in 2080–2099

As noted above, the CERI-Climate tool allows users to view hazard exposure in various time periods and under varying assumptions about future climate conditions and exposure thresholds. As a result, an important reminder to the reader is that the maps above are merely examples showing exposure at one point in time and under a single set of parameters. Although not included here due to space constraints, analyses showing current exposure, exposure in the nearer future, and exposure to any non-zero level of hazard, as well as many other variations, are likely to be of great interest to emergency managers.

5: Estimates of the Impact of Exposure to Coastal Flooding and Wildfire

As discussed above, there are a variety of ways that coastal flooding and wildfire may impact state-owned and -operated emergency response infrastructure. Impacts can include physical damage to structures, loss of operational capability, and broader degradation of the emergency management and response system. For this analysis we consider the first two of these impacts—property damage and operational disruption. While system-wide impacts from the loss of individual infrastructure facilities are potentially important, we have been unable to develop performance metrics for emergency response that we could use to assess such impacts.[21] The sections which follow provide more detailed discussions of the process we used for estimating property damage and operational disruption as a result of exposure to the natural hazards included in our analysis.

5.1 Property Damage

5.1.1 Flood Damage

To estimate property damage and operational degradation from flooding, we draw upon depth-damage relationships used in the HAZUS model[22]. HAZUS provides relationships between flood depth and degree of damage (which are commonly known as damage functions) for a number of structure types and occupancy classes compiled from a variety of sources. Degree of damage is characterized in terms of a percentage of the property value. The HAZUS damage functions also indicate the depth threshold beyond which a facility is considered non-operational. It is important to note that the damage functions in HAZUS were developed for large-scale loss modeling and application anywhere within the United States. As a result, they are necessarily generalized to characterize typical facilities. Specific facilities differ in important details which could significantly change the degree of damage any given facility would experience. For example, a facility may have specific mitigation measures which most facilities of its type do not. As a result, in some cases a site visit would be required to reasonably estimate vulnerability and damage. Nevertheless, the HAZUS damage functions are extremely useful for conducting analysis of a large number of facilities simultaneously.

We reviewed the HAZUS database and identified a set of damage functions appropriate for the California emergency response infrastructure included in our analysis. We have used these functions to generate damage estimates from flood depths for most of the facility types included

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[21] An example of what a systems-level analysis might entail includes the potential impact on the emergency response system from operational disruption to or destruction of several assets at once, for example, losing multiple police barracks at the same time.

[22] HAZUS is a methodology developed by the Federal Emergency Management Agency (FEMA) to estimate potential losses from a variety of natural hazards. For additional information please see https://www.fema.gov/hazus

in our analysis, including emergency operations centers, office buildings, public health departments, medical care facilities, analytical labs, and fire and police stations. These damage functions are shown in Figure 5.1.

The flood depth for each facility is converted to property damage (in terms of percentage of property value) using the appropriate depth-damage relationship. This property damage estimate is then converted to a monetary value by multiplying by the property value estimate included in the Cal OES Critical Infrastructure Database. Cal OES property value estimates were developed by expert judgement and each facility was assigned one of five values: less than $1 million, $1 million–$10 million, $10 million–$100 million, $100 million–$1 billion, and greater than $1 billion. These property value estimates are clearly imprecise and intended only to provide order of magnitude values, but were the best information available. We also reviewed the facility cost information in the Statewide Property Inventory (SPI), discussed in Chapter 2, but the SPI did not contain cost data for most of the facilities included in our analysis. Where cost data were available, the wide variation in cost estimates across similar facilities suggested that the same methodology had not been used even where estimates were available; in contrast, the Cal OES database contained a cost estimate (albeit a range) for each facility in our analysis that was developed using an internally consistent methodology. Despite their uncertainty, the estimates in the Cal OES database allow us to place a first-order monetary value on the impacts of coastal flooding and wildfire. For our analysis, we assigned each facility a property value in the middle of the range provided in the Cal OES database. Facilities in the less than $1 million bin were valued at $500,000, and facilities in the greater than $1 billion bin were valued at $5 billion.

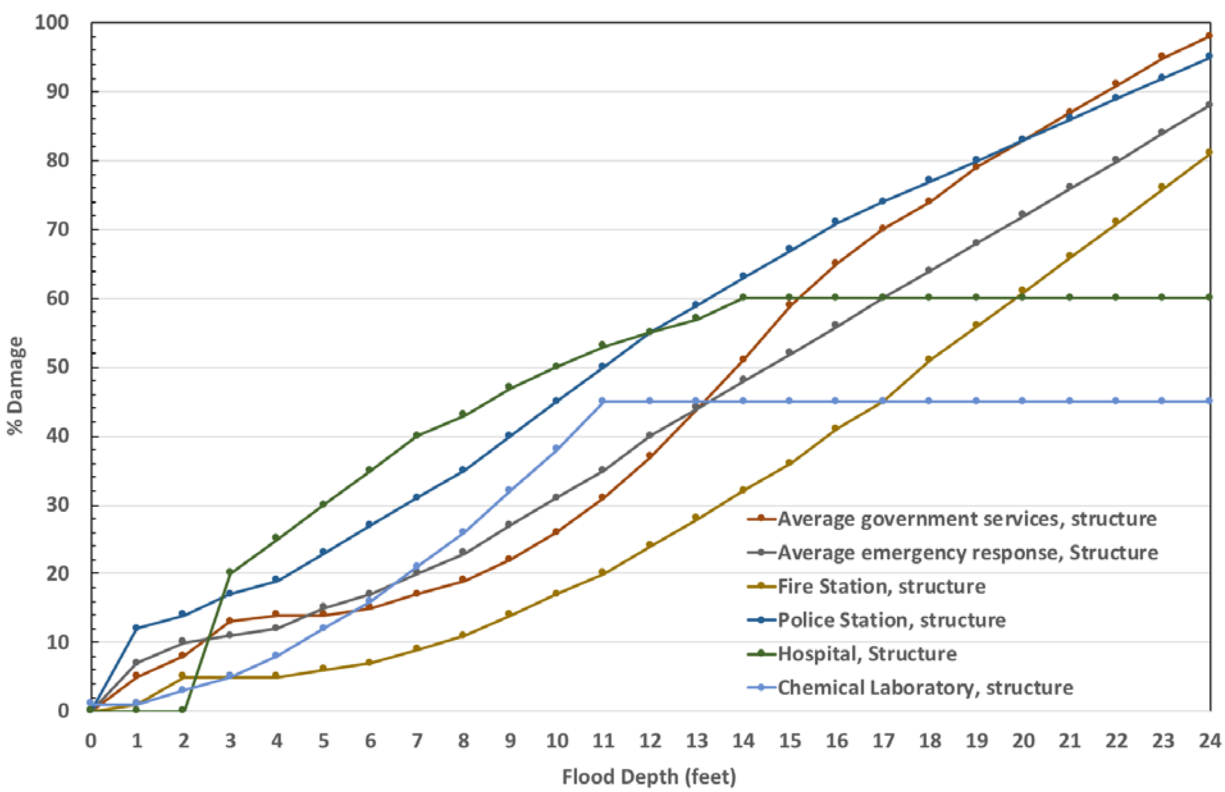

Figure 5.1–Damage Functions For Different Classes of Emergency Response Facilities

For bridges and highway interchanges, HAZUS estimates no flooding damage except for scouring by high velocity water. Such scouring would typically only occur under particular conditions of very fast moving water such as a river, which is not relevant to most of the exposed facilities in this analysis. Finally, HAZUS does not estimate damage functions for stadiums, arenas, airports, or railway stations and tunnels. Lacking damage relationships, we present only flood depths for such facilities, which fall in the transportation and commercial facilities sectors.

5.1.2 Wildfire Damage

In contrast to the case for flooding, loss from wildfires is anticipated to be more akin to a binary case rather than following a continuous depth-damage function; that is, a facility is more likely to either burn and suffer a total loss, or not burn and suffer no loss. There is also a potential for a facility to suffer smoke damage that can range from minor to major loss. For wildfire, our exposure analysis provides the fraction of a grid cell expected to burn with a given return interval. Hence, the damage estimate hinges on estimating the probability that a facility will fall within the footprint of a fire and, if so, whether it will burn. However, two important uncertainties prevent us from estimating loss probabilities. First, because of the much larger grid cell size for wildfire (~40 km^2) compared to flooding (~0.1 km^2), the hazard level averages over an area much larger than an individual structure. Consequently, we cannot confidently translate the extent of burning predicted in a grid cell to the probability that an individual facility within that grid cell will fall within a wildfire footprint. Sub-grid-scale variations in topography, temperature, soil moisture, vegetation cover, or land use may lead to a probability of burning at any specific point within a grid cell that differs from the cell-wide average. Second, because of the idiosyncrasies of individual property layouts (e.g., brush clearances, construction types) and firefighting efforts targeted to prioritize structure protection, we cannot assess the probability of burning of any specific facility that may fall within a wildfire footprint.

5.2 Operational Capacity Impacts

Any damaged facility would be expected to become inoperable. As noted above, the HAZUS model includes a flood depth threshold beyond which a facility is considered non-operational. For emergency services facilities, this depth ranges from 0.5 to 2 feet. This level is low compared to the projected flood depths in our analysis, indicating that most facilities would become inoperable soon after the onset of flooding. We therefore assume all flooded facilities would be inoperable.

In addition to operational disruption associated with physical damage, in some cases operability may be impacted prior to or in the absence of any physical damage. This is most likely to occur as a result of evacuation of a zone adjacent to the area being directly affected due to unsafe conditions. Consequently, our model includes an operational disruption impact in a one-grid cell wide zone around the hazard footprint.

The frequency and duration of operational disruption will vary for the different hazards. In the case of permanent inundation, flooding would be permanent and the facility would cease to be able to operate in its current location. Tidal and storm surge flooding would be intermittent, with the inoperability lasting hours to days, but would recur periodically. The exposures and damages presented above are for a 1-year tide, meaning they can be expected to occur annually, and for a 100-year storm, so reflect extreme conditions that would occur rarely. Operational disruption from wildfire would be expected to last days to perhaps weeks. As with storm surge flooding, the fire exposures are for a 100-year wildfire, reflecting rare conditions.

6: Using the Hazard and Exposure Visualization Tool to Support Decisionmaking

6.1 Objectives of the Tool

The analysis described above has been implemented through a visualization tool that allows the user to explore risks to state-owned and -operated critical emergency response infrastructure from coastal flooding and wildfire under a variety of conditions. The tool, the California Emergency Response Infrastructure Climate Vulnerability Tool, or CERI-Climate, is intended to support decisions about targeting and allocating resources for planning and mitigation.[23] The tool focuses on risks of damage and access to facilities resulting from coastal flooding and wildfires. In addition, the tool distinguishes facilities located in disadvantaged communities. State decisionmakers can combine this information with other information, such as the role and relative importance of individual facilities in the state's response capabilities, to help allocate scarce resources in ways that maximize the benefit to the state in terms of maintaining a robust ability to respond to emergencies throughout the state.

6.2 Description of the Tool

CERI-Climate is implemented in Tableau®, a web-based data visualization and analysis platform.[24] The tool provides visualizations, through maps, figures, and tables, of exposures and impacts to California emergency response facilities from coastal flooding and wildfire under a range of different conditions. The tool is laid out as a set of independent panes, with each presenting a different component of the analysis. Panes include selection tools that allow the user to set viewing preferences (e.g., geographic focus, facility type) and the conditions for the analysis (e.g., time period, hazard severity).

Following the title pane, CERI-Climate contains 12 analysis panes, each of which is described below.

EM Critical Infrastructure

Displays the map locations of the 604 state-owned and operated critical emergency response infrastructure included in the analysis. Facilities can be distinguished by county, facility type, and whether they are located in a disadvantaged community.

Tidal Flood Depths

Presents a map of the tidal flooding hazard footprint. Footprints can be selected for different flooding return periods (1 month and 1, 2, 5, and 10 years), the five different 20-year time periods examined in our analysis, the two different RCPs examined in our analysis (4.5 and 8.5), and the 50th, 95th, and 99.9th percentile results from among the different GCMs included in the analysis. This pane also presents a second map displaying the change in depth between the selected time period and the 2000–2019 time period.

[23] The tool is accessible at: https://public.tableau.com/profile/rand4185#!/vizhome/CJ302-1000_CERI-Climate_20180625/Title

[24]https://www.tableau.com

Storm Surge Flood Depths

Presents a map of the 100-year storm surge flooding hazard footprint. Footprints can be selected for the five different 20-year time periods examined in our analysis, the two different RCPs examined in our analysis (4.5 and 8.5), and the 50th, 95th, and 99.9th percentile results from among the different GCMs included in the analysis. This pane also presents a second map displaying the change in depth between the selected time period and the 2000–2019 time period.

Coastal Flood Impacts: State

Displays the map location and flood depth and damage estimate (in dollar losses) for all facilities experiencing property damage or operational disruption. Facilities can be distinguished by type, county, and whether they are located in a disadvantaged community. Note that no damage estimates are provided for Commercial and Transportation Facilities because, as noted above, we do not have depth-damage relationships for these facility types. Impacts can be presented for different exposure thresholds, time periods, RCPs, percentiles, and flood return periods.

Coastal Flood Impacts: Facility

Presents figures showing detailed flood impact results for individual facilities. The upper, middle, and lower figures show flood depth, exposure type, and property damage, respectively, as a function of time period for each flood return period. Impacts can be presented for each individual facility under different exposure thresholds, RCPs, and percentiles.

Flood Impact Facility Table

Presents flood impacts for individual facilities in table form. Each row shows impact as a function of 20-year time period for a specific facility. Impacts can be presented for different counties, disadvantaged communities, exposure thresholds, RCPs, percentiles, and flood return periods.

Flood Impact Summary

Presents summary tables for flooding impacts by facility type. Upper table shows numbers of facilities experiencing operational disruption and property damage by facility type and time period. Lower table shows cumulative property loss by facility type and time period. Impacts can be presented for different counties, disadvantaged communities, exposure thresholds, RCPs, percentiles, and flood return periods.

Wildfire Extent Burned

Displays a map of the wildfire hazard footprint. Presents the average extent burned in each grid cell for different time periods, wildfire return periods, and RCPs. In addition, the wildfire hazard can be examined under any one of 4 different GCMs or the average of all 4, as well as three different projected population scenarios. This pane also presents a second map displaying the change in average extent burned between the selected time period and the 2000–2019 time period.

Wildfire Impacts: State

Displays the map location and associated grid cell burn extent for all facilities experiencing property damage or operational disruption. Facilities can be distinguished by type, county, and disadvantaged community. Impacts can be presented for different exposure thresholds, time periods, RCPs, GCMs, population scenarios, and wildfire return periods.

Wildfire Impacts: Facility

Presents detailed wildfire impact results for individual facilities. The upper and lower figures show grid cell burn extent and exposure type, respectively, as a function of time period for each wildfire return period. Impacts can be presented for each individual facility under different exposure thresholds, RCPs, GCMs, and population scenarios.

Wildfire Impact Facility Table

Presents wildfire impacts for individual facilities in table form. Each row shows impact as a function of 20-year time period for a specific facility. Impacts can be presented for different counties, disadvantaged communities, exposure thresholds, wildfire return periods, RCPs, GCMs, and population scenarios.

Wildfire Impact Summary

Presents a summary table for wildfire impacts by facility type. The table shows the number of facilities experiencing operational disruption and property damage by facility type and time period. Impacts can be presented for different counties, disadvantaged communities, exposure thresholds, wildfire return periods, RCPs, GCMs, and population scenarios.

6.3 Identification of High-Risk Facilities Based on Climate Vulnerability

The primary purpose of CERI-Climate is to assist decisionmakers in prioritizing facilities for mitigation efforts based on their risk to coastal flooding and wildfire. In extreme cases, relocation may be desirable. In the case of flooding, we have flood depth-damage relationships for several building types which allow us to compute property damage estimates from flood depths and property values. For building types for which we have depth-damage relationships, the flooding risk is expressed in terms of property damage (in dollars). For building types for which we do not have depth-damage relationships, we cannot compute property damage and can only carry the risk estimate as far as flood depth. We also identify facilities adjacent to flooded areas that may suffer operational disruption. Hence a second component of flooding risk is whether or not a facility suffers operational disruption.

In the case of wildfire, our analysis provides the percentage of area burned for the grid cell in which a facility is located. Because we are unable to convert this percentage to a property loss estimate, wildfire damages must be left in the form of grid cell burn percentages. However, despite not being able to estimate absolute loss estimates for property damage from wildfires, the extent of burning in a grid cell may provide a reasonable proxy for the *relative risk* of property damage from wildfire. That is, we can use differences in the projected percent of burning in different grid cells to estimate the relative risk of loss among facilities in those cells. This approximation depends on the assumption that the uncertainties related to the probability of a facility burning are general enough to apply to all facilities roughly equally. As with flooding, we also identify facilities adjacent to burned areas that may suffer operational disruption.

We use these measures of risk to evaluate the vulnerability of state-owned and -operated emergency response infrastructure to coastal flooding and wildfire hazards and to identify those facilities at higher risk and which may therefore warrant priority for mitigation efforts. For the purposes of presentation, modeling parameters are maintained at the same values as described in section 4. As noted earlier, different parameter settings will affect the results.

Different settings can be explored by users in CERI-Climate, allowing the tool to be used to perform analysis under different assumptions, risk tolerance levels, and for different climate scenarios.

6.3.1 Facilities at Risk Today

Based on our analysis, a number of state critical infrastructure facilities in California face substantial flood and wildfire risks in the present (2000–2019) time period. Table 6.1 shows that 1 facility (Solano County OES) is at risk for annual flooding and an additional 24 facilities are at risk for operational disruption. For a 100-year flooding event, 25 facilities are at risk of flooding and 29 more are at risk for operational disruption. Of these 54 facilities, 17 are in disadvantaged communities. Estimated flood depths for the 100-year flood under current conditions exceed 10 feet at 5 facilities (Table 6.2). If all 25 of these facilities flooded to the modeled depth, the total estimated property damage would be $90 million.[25]

For wildfire, 28 facilities are in grid cells with at least a 1 percent annual chance of burning (100-year wildfire) and an additional 38 facilities are at risk for operational disruption (Table 6.1). Of these, 9 are in disadvantaged communities. 2 facilities are located in grid cells in which over 70% of the area is projected to burn at the 100-year return period (Table 6.2).

It is important to note that our exposure estimates do not take into account local mitigation measures that may have already been put in place. Sea walls, jetties, brush clearance, and other hazard mitigation measures would reduce exposure risks for facilities that we estimate to be currently exposed.

Table 6.1–Numbers of facilities at risk today

Facility Type	Annual flooding		100-year flood		100-year wildfire	
	Op. Disrupt.	Flooding	Op. Disrupt.	Flooding	Op. Disrupt.	Wildfire
Commercial Facilities	5		5	3		
Emergency Management	2	1	3	4	1	1
Fire Service	1		2	1	25	23
Government Facilities	1		3			
Healthcare and Public Health	4		3	6	2	
Law Enforcement	5		3	7	10	4
Transportation	6		10	4		
Total	24	1	29	25	38	28

[25] This total excludes damage to commercial facilities (stadiums and arenas) and transportation assets because we have no depth-damage relationships for these structures.

Table 6.2–Highest risk facilities today

Facility Name	100-year flood depth (feet)[a]	100-year wildfire % burned[b]
Cal Fire Station 59 Pescadero	11	
CHP Hayward Area Office	11	
Levi's Stadium	11	
CHP Northern Division Humboldt Communications Center	12	
Stockton Arena	16	
Cal Fire Flinn Springs Station		71
Cal Fire Harbison Canyon Station 24		71

[a]Facilities with flood depths over 10 feet
[b]Facilities in cells with burn percentages over 70%

6.3.2 Facilities at Greatest Risk from Future Climate Change

As a result of climate change, flood and wildfire hazard footprints, and therefore infrastructure exposure and impacts, are projected to increase with time. By the 2080–2099 time period, we find that 13 facilities are at risk for annual flooding and 20 more could suffer operational disruption. 30 facilities are at risk of flooding and 38 more are at risk of operational disruption in a 100-year flood event (Table 6.3). Of these 68 facilities, 24 are located in disadvantaged communities. Flood depths are projected to exceed 10 feet at 10 facilities (Table 6.4). If all 30 of the facilities projected to flood were flooded to the modeled depth, the total property damage is estimated to be $1.7 billion.[26]

In the case of a 100-year wildfire, 112 facilities are at risk from burning and an additional 159 facilities are at risk for operational disruption (Table 6.3). Of these, 18 are in disadvantaged communities. 7 facilities are located in grid cells in which over 90% of the area is projected to burn (Table 6.4).

Table 6.3–Numbers of facilities at risk in 2080–2099

Facility Type	Annual flooding		100-year flood		100-year wildfire	
	Op. Disrupt.	Flooding	Op. Disrupt.	Flooding	Op. Disrupt.	Wildfire
Commercial Facilities	4	2	7	4	1	
Emergency Management	1	2	6	4	25	5

[26] This total excludes damage to commercial facilities (stadiums and arenas) and transportation assets because we have no depth-damage relationships for these structures.

Fire Service	1		2	1	82	91
Government Facilities	1		7			
Healthcare and Public Health	3	4	5	7	18	3
Law Enforcement	4	3	4	7	32	13
Transportation	6	2	7	7	1	
Total	20	13	38	30	159	112

Table 6.4–Highest risk facilities in 2080–2099

Facility Name	100-year flood depth (feet)[a]	100-year wildfire % burned[b]
Bay Area Rapid Transit (BART) Transbay Tube / Ventilation System – SF	10	
Department of Public Health - San Diego County	10	
CalTrain San Francisco Station - 4th St./King St.	11	
Department of Public Health - San Joaquin County	13	
Solano County OES	13	
Levi's Stadium	15	
California Highway Patrol Hayward Area Office	15	
CHP Northern Division Humboldt Communications Center	16	
Cal Fire Station 59 Pescadero	16	
Stockton Arena	21	
Cal Fire Amador El Dorado Unit Headquarters Station 20		91
Cal Fire Pine Valley Station 44		91
Cal Fire Station 57 Ogo		94
Cal Fire Air Attack/Helitack Base Grass Valley		98
Cal Fire Nevada City Station		98
Department of Public Health - Nevada County		98
Cal Fire Station Cameron Park Station 89		100

[a]Facilities with flood depths over 10 feet
[b]Facilities in cells with burn percentages over 90%

Because flooding is limited to coastal areas and the wildfire risk tends to be concentrated in the mountainous areas, flood and wildfire risks tend not to be correlated. While a small number of coastal grid cells are projected to burn over 90% in a 100-year wildfire event, there are no critical emergency response facilities in these cells. As a result, we have not identified any facilities at high risk for both coastal flooding and wildfire.

7: Summary Observations

The primary purpose of this effort was to develop a tool to help decisionmakers in California identify state-owned and -operated emergency response infrastructure at relatively higher risk for impact from coastal flooding and wildfire. These risk estimates are intended to serve as key inputs into decisions about how to target and prioritize resources for reducing these risks through mitigation efforts.

We close with some general observations relevant to decisionmakers concerned with protecting state-owned and -operated emergency response infrastructure.

- **Relatively few facilities are at risk for flooding or wildfire damage.** Our database of state-owned and -operated emergency response infrastructure includes over 600 facilities. Under the most severe flooding conditions examined (a 100-year flood event in the 2080–2099 time period) and when weighing all GCMs equally, 30 facilities are at risk from flooding. For a 100-year wildfire in the 2080–2099 interval, 112 facilities are in grid cells projected to burn more than 50%. This subset of facilities can then be ranked in order of flood depth, property loss, or burn percentage to prioritize risk. The tool can also be used to distinguish facilities in disadvantaged communities. These results can help decisionmakers target mitigation efforts to the most at-risk facilities.
- **Several facilities are at risk now.** In the 2000–2019 period, 25 facilities are at risk from flooding in a 100-year storm. While projected flood depths increase substantially in future time periods, the number of facilities at risk increases only modestly to 30 by the 2080–2099 time period. In the case of a 100-year wildfire, 28 facilities are at risk (located in grid cells projected to burn more than 50%) now. While these estimates do not account for currently existing mitigation steps that protect these facilities in the short-term, they indicate that substantial climate-related risks exist today.
- **Relative risk rankings are more robust than specific projections.** While projected exposures and hazard levels are subject to a number of uncertainties, the relative rankings of facilities are less sensitive to these uncertainties and can be used to focus mitigation efforts. Uncertainty stems from a number of factors, including future greenhouse gas emissions, climate modeling, and limitations in the spatial resolution of climate and hazard simulation. While we have not quantified the magnitude of uncertainty, the uncertainty for wildfire risk is expected to be greater than that for flooding, primarily because the grid cell size is much greater (~40 km^2 vs. 0.1 km^2 for flooding). However, the relative ranking of facilities in terms of the degree of hazard exposure and damage are expected to be far less uncertain than the absolute values. This ranking can thus be reliably used as a guide to prioritize mitigation investments.
- **More detailed data could be developed on exposed facilities.** The CERI-Climate analysis could be used as a "pointer" to identify locations where it might be valuable to conduct site surveys and develop more detailed information. For example, while it is likely to be prohibitively difficult to obtain more accurate cost information on all 604 facilities included in the analysis, it would be far more feasible to do so only for the relatively small subset of facilities facing the greatest risk. Similarly, site surveys and other related information could be collected on these facilities (e.g. topographic details,

existing mitigation measures) to further refine the state's understanding of their relative risk and priority for mitigation funding.

- **Hazard exposure data can be used when planning future infrastructure placement, evacuation routes, and in other aspects of emergency management planning.** In addition to assessing current infrastructure exposure, the natural hazard footprints available in the CERI-Climate tool can be used by planners when assessing where to place future critical infrastructure or making other decisions with geographic considerations.

APPENDIX A:
State Stakeholder Group

- California Fire Safe Council
- California Health and Human Services Agency - Office of Statewide Health Planning and Development
- California Natural Resources Agency (CNRA) - California Ocean Protection Council/Coastal & Ocean CAT
- California Seismic Safety Commission
- California Wildlife Conservation Board
- California Board of Forestry and Fire Protection
- California Department of Conservation/CA Geological Survey
- California Department of Corrections and Rehabilitation (CDCR)
- California Department of Fish and Wildlife
- California Department of Food and Agriculture
- California Department of General Services (DGS) - Office of Risk and Insurance Management (ORIM)
- California Department of General Services (DGS) - Structural Engineering Unit (SEU)
- California Department of General Services (DGS) - Division of the State Architect (DSA)
- California Department of General Services (DGS) - Emergency Management
- California Department of Housing and Community Development (HCD)
- California Department of Public Health (CDPH)
- California Department of Social Services - Volunteer Emergency Services Team (VEST)
- California Department of Transportation
- California Department of Water Resources
- California Department of Water Resources (DWR) - FloodSAFE
- California Department of Water Resources, Public Affairs Office
- California Earthquake Authority

- California Energy Commission - Climate Change Research
- California Environmental Protection Agency (CalEPA)
- California Ocean Science Trust
- California Resiliency Alliance (CRA)
- California Seismic Safety Commission
- California State Lands Commission
- California Utilities Emergency Association (CUEA)
- California Department of Public Health (CDPH) - Office of Health Equity
- Delta Protection Commission
- Delta Stewardship Council
- Emergency Medical Services Authority (EMSA)
- Governor's Office of Planning and Research
- Office of Statewide Health Planning and Development (OSHPD)
- California Geologic Survey
- Department of Water Resources
- Association of Bay Area Governments
- California Department of Social Services (CDSS) - Disaster Services Bureau
- California Department of Forestry and Fire Protection (Cal Fire) - Fire and Resource Assessment Program
- CA Health and Human Services (HHS) - Office of Statewide Health Planning and Development (OSHPD)
- Cal OES - Southern Region
- Cal OES - Southern Region VI Fire Coordinator - Mono, Inyo, San Bernardino, Riverside, San Diego, & Imperial Counties

APPENDIX B: California Critical Infrastructure Sectors and Subsectors Identified for Inclusion

3. Commercial Facilities[27]

3.3 Public Assembly

3.3.1 Stadiums and racetracks with a capacity greater than 20,000 individuals.

3.3.2 Arenas and amphitheaters with a capacity greater than 2,000 individuals and an annual attendance greater than 500,000 individuals.

3.3.3 Convention centers with a trade show, exhibit, or performance space that exceeds 100,000 square feet and capacity greater than 1,000 individuals.

6. Emergency Services

Multiagency coordination systems, mutual-aid systems, command-control-cyber intelligence-information technology (CCIIT) systems, and specialized emergency response systems, including key Emergency Operations Centers or dispatch centers whose exploitation or destruction would impact the following regions: Cities and/or incorporated areas with over 300,000 residents; Regions with numerous California critical infrastructure facilities of the other sectors; Regions proximate to high-risk earthquake, wildfire or flooding zones.

9. Government Facilities (hand-screened to include only those relevant to emergency management and response)

9.1 Government-owned or -leased buildings, whether federal, state or local, that either: Have occupancy of greater than 1,000 individuals, or have a height greater than 300 feet.

9.2 Government owned or leased facilities with three or more federal or state service-providing agencies sharing a single building, regardless of building occupancy or size.

9.3 Government facilities that conduct unique or nationally significant work. Such assets may include: Research facilities, Data centers, Archives.

14. Public Health

14.1 Strategic National Stockpile (SNS) facilities.

14.2 Biological Safety Level (BSL) 3 or higher laboratories or other facilities dealing with select agents or other highly infectious pathogen(s).

[27] California identifies a total of 18 critical infrastructure sectors. Each sector is assigned a number from 1 to 18, with subsectors assigned corresponding numbers identifying the sector followed by a decimal and a number designating the subsector (e.g., 1.1, 1.2, 1.3 and so on). Numbers indicating the sector and subsector in California's critical infrastructure system are included here. Not all sectors have subsectors.

14.4 General acute care hospital or acute psychiatric hospital facilities with a capacity of at least 500 beds. ("Extremely Large" category as defined by CA Department of Health Services).

14.5 Medical and diagnostic laboratories or medical research facilities receiving more than $5 million in federal research grant funding.

14.6 State and county Public Health Department offices and County Coroner or Medical Examiner headquarters for counties in the top five Metropolitan Statistical Areas (by population).

16. Transportation

16.1 Aviation

16.1.1 Large hub commercial service primary airports (per 2011-2015 National Plan of Integrated Airport Systems (NPIAS) report released October 2010).

16.1.2 Medium hub commercial service primary airports (per 2011-2015 National Plan of Integrated Airport Systems (NPIAS) report released October 2010).

16.2 Highways

16.2.1 Highway tunnels and bridges that have annual average daily traffic (AADT) greater than 200,000 vehicles and a detour length greater than 1 mile.

16.2.2 Significant highway tunnels and bridges collocated with important infrastructure (e.g., major pipelines, railways, and telecommunications) that cannot be readily re-routed and would create regional or national impacts if destroyed.

16.3 Mass Transit: Transit facilities that serve large metropolitan areas and that have daily ridership of over 10,000 passengers.

16.5 Maritime

16.5.3 Ferry Terminals not located in ports covered under criteria 16.5.1 or 16.5.2.