CLIMATE CHANGE VULNERABILITY ASSESSMENT

Public Review Draft

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OAKLAND 2045
GENERAL PLAN

Climate Change Vulnerability Assessment for the City of Oakland

March 2023

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Acronyms and Abbreviations

°F	degrees Fahrenheit
°C	degrees Celsius
$\mu g/m^3$	Micrograms per Cubic Meter
AAMLO	African American Museum and Library at Oakland
AB	Assembly Bill
ACS	American Community Survey
AC Transit	Alameda-Contra Costa Transit
ADA	Americans with Disabilities Act
ART	Adapting to Rising Tides
AFFF	Aqueous Film Forming Foams
BART	Bay Area Rapid Transit
BAAQMD	Bay Area Air Quality Management District
BCDC	Bay Conservation and Development Commission
BIPOC	Black, Indigenous, People of Color
CAL FIRE	California Department of Forestry and Fire
CHAS	Comprehensive Housing Affordability Strategy
COPD	Chronic Obstructive Pulmonary Disease
DR	Major Disaster Declaration
EBCE	East Bay Community Energy
EBMUD	East Bay Municipal Utility District
ECAP	Equitable Climate Action Plan

EM	Emergency Declaration
EOP	Emergency Operations Plan
ESM	Emergency Services Management
FEMA	Federal Emergency Management Agency
FHSZ	Fire Hazard Severity Zones
FIS	Flood Insurance Study
GI	Green Infrastructure
GSI	Green Stormwater Infrastructure
HUD	U.S. Department of Housing and Urban Development
LHMP	Local Hazard Mitigation Plan
MRP	Municipal Regional Stormwater Permit
NCDC	National Climatic Data Center
OPRYD	Oakland Parks, Recreation, and Youth Development
PG&E	Pacific Gas and Electric
PSPS	Public Safety Power Shutoffs
RCP	Representative Concentration Pathway
SB	Senate Bill
SLR	Sea Level Rise
UFMP	Urban Forestry Master Plan
UWI	Urban-Wildland Interface
VHFHSZ	Very High Fire Hazard Severity Zones
SF WETA	San Francisco Water Emergency Transportation Authority

1 Introduction

Climate change is a real and present danger that threatens the Bay Area's ability to thrive in the near and long term. With more than 20 miles of shoreline, significant bay-fronting infrastructure, and wildfire and drought vulnerability, Oakland is no exception. Oakland's frontline communities, including Black, Indigenous, People of Color (BIPOC) and low-income communities, are likely to be disproportionately affected by climate change impacts and thus should be centered in the City of Oakland's decision making. The City of Oakland's 2030 Equitable Climate Action Plan (ECAP) identified an equitable path toward meeting Oakland's local climate emission reductions goals and presents a variety of strategies and actions the City must implement to prepare for, and where possible brunt, the worst impacts of climate change. This document responds to the ECAP's call under Action A-3 as well as mitigation action O-21 identified in the Local Hazard Mitigation Plan (LHMP) for the City to prepare a citywide vulnerability assessment and provides a starting place for additional, sustained community engagement to identify feasible, impactful, and culturally-responsive climate adaptation actions and measures that build resilience and advance racial equity.

The purpose of this Climate Change Vulnerability Assessment is to assist the City and community in identifying and evaluating climate change hazards and risks that are likely to impact Oakland. The Climate Change Vulnerability Assessment highlights specific locations and communities most likely to be severely impacted by wildfires, sea-level rise and flooding, and temperature increases. California Senate Bill (SB) 379 (2015) requires all cities and counties in California to address climate adaptation and resiliency in their general plans. This document has been prepared as part of the City's 2045 General Plan Update to inform policies for the Safety, Environmental Justice, Land Use and Transportation, and other pertinent general plan elements.

This vulnerability assessment synthesizes climate change projections, historical data pertaining to natural events and hazards, and socio-demographic trends to determine which climate impacts are most likely to affect Oakland, where these impacts may manifest, who will be affected, and how severely. Projection documentation is provided through Cal-Adapt, an online climate data visualization tool that allows users to explore climate data and simulation modeling to anticipate the impact of climate change throughout California. The vulnerability assessment considers existing and planned development in identified at-risk areas, including structures, roads, utilities, and essential public facilities. The assessment identifies the federal, state, regional, and local agencies responsible for the provision of public health, safety, transportation, and environmental services, including special districts and local offices of emergency services. Findings from this document will help to inform key issues and strategies to address climate vulnerability in Oakland's General Plan update.

Chapter 1 of this document introduces the climate change vulnerability assessment and defines the concept of climate vulnerability.

Chapter 2 outlines key climate change impacts that are likely to affect the Oakland region such as temperature increase, precipitation changes, wildfire, sea level rise, and groundwater intrusion. This chapter discusses the origin of these impacts, their projected severity, permanence, and rate of increase, as well as key secondary disruptions to the climate, weather, the environment, infrastructure, and health and safety that may result.

Chapter 3 identifies and assesses socially vulnerable populations in Oakland that are at greater risk to climate change effects, also known as "frontline" communities. This chapter identifies socially vulnerable populations exposed to high hazard areas to guide future targeted climate adaptation interventions.

Chapter 4 discusses physical vulnerability and identifies critical facilities and infrastructures in Oakland that are most vulnerable to climate change. This chapter identifies critical infrastructure exposed to high hazard areas to guide future targeted climate adaptation interventions.

Chapter 5 focuses on the City's ability to build adaptive capacity to climate change by suggesting adaptation prioritization strategies and identifying federal, state, regional, and local agencies responsible for the protection of public health and safety and the environment.

1.1 What is Climate Vulnerability?

Climate change vulnerability refers to the extent to which individuals, communities, and infrastructure systems are exposed to, susceptible to, and/or unable to cope with or adapt to the effects of climate change, including climate variability and extremes.[1] The level of climate change vulnerability for a particular area emerges over time based on the interaction of several related components of both the climate system and surrounding social, physical, and political environment. These components include exposure, sensitivity, and adaptive capacity.[2]

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1 Cal-Adapt, Frequently Asked Questions. Oct 29, 2019: https://cal-adapt.org/help/faq/.

2 . Thomas, K., Hardy RD., Lazrus H., Mendez M., Orlove B., Rivera-Collazo, I., Roberts JT., Rockman M., Warner BP., Winthrop R., Explaining differential vulnerability to climate change: A social science review (December 2018). Oct 29 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

Exposure describes whether and to what degree a community or individual will experience a stress or hazard due to climate change.[3] For example, a low-lying coastal community, such as Oakland's flatlands, has a higher degree of exposure to sea level rise than the Oakland Hills community located farther above sea level.

Sensitivity is the degree to which climate change impact affects a community or system. If sea level rise does occur in a community, the community may be affected depending on such factors as the location of housing developments and roads. Sea level rise will more severely affect a community that locates major housing developments or critical healthcare or utility services within a coastal, low-lying area than a community that locates or restores wetlands in this location.

Adaptive capacity refers to the ability to respond to climate change impacts. If a community has the resources to construct natural landscaping buffers and flood-proof homes, and educate residents and home developers about the potential risk associated with living and building in an area likely to be exposed to sea level rise, then this community has greater adaptive capacity to address sea level rise than a community that lacks these resources. Factors influencing adaptive capacity include levels of economic resources, technological capacity, education and knowledge, and equity in access to and distribution of resources. All else being equal, those individuals, communities, and cities with a greater degree of adaptive capacity will suffer less harm from exposure to climate impacts and will recover more quickly from the impact.[4]

The concept of **resilience** is closely related to that of adaptive capacity. **Resilience** is the ability of a system, community, structure, or individual to withstand and recover from shocks and stresses while maintaining its core functions or meeting the core needs of community members. Resilience involves the ability to be responsive to change while simultaneously preserving core structure and function.[5] Building resilience also involves restorative justice, which includes focused city investment and support to communities where capacity for resilience has been depleted because of past institutional discrimination or harm. Resilience-building features can take many forms, including strong and supportive social ties within a community, redundancies in key infrastructural systems that prevent service interruptions, and responsive governance. Climate resilience is a subtype that deals specifically with resilience to the impacts of climate change.

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3. Nutters, H., Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning (2012). Oct 29 2019: http://www.adaptingtorisingtides.org/wp-content/uploads/2015/04/ART_Equity_WhitePaper.pdf.

4. Ibid.

5. Ibid.

Exposure is often an inherent feature of the climate system—the underlying probability that a given climate change impact will occur in a particular location. Knowing a community's exposure level is a critical piece of understanding vulnerability and thus of making well-informed growth and development decisions that minimize long-term risk. Exposure, however, is not something that a community will likely be able to significantly change on its own. In contrast, making well-informed development and investment decisions can help a community improve its sensitivity and adaptive capacity.

Measures of a community's sensitivity and adaptive capacity can also be highly subjective. Different members of the community will see different community features as being worthy of protection, will be affected by climate change impacts in different ways or to different degrees, and will see relatively more or fewer benefits from a given adaptive capacity-building strategy. For that reason, it is important to take stock of a variety of voices and experiences throughout the vulnerability assessment process, highlighting Oakland's rich diversity both in terms of how different groups of people may experience climate change differently and in terms of the wide range of response and resilience strategies that different communities are able to employ.

Likewise, vulnerability is not an inherent and unchangeable characteristic of an individual, community, or city. The level of vulnerability emerges from a dynamic and interacting web of physical, environmental, and social factors such as environmental exposure, infrastructural integrity, and historical and present-day decisions regarding development patterns, allocation of key resources, and distribution of political power.[6] For example, as described in the Oakland 2045 Environmental Justice and Racial Equity Baseline, low-income neighborhoods with a greater percentage of communities of color are the most likely to lack access to supermarkets and healthful food, have less access to parks, and are more likely to be located near acute sources of air pollution. It is the cumulative, unequal distribution of exposure, sensitivity, and adaptive capacity that creates an unequal distribution of climate change vulnerability, and this distribution is often emblematic of patterns of structural inequality present in society. Without a comprehensive adaptation plan, Oakland's preexisting disparities in health and wealth would likely be exacerbated by climate change impacts. This makes the work of analyzing and responding to vulnerability even more urgent. Effective equity-based strategies have the potential to lessen or eliminate these inequalities related to climate change and are a core part of the City's overall hazard reduction strategy.

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[6] Thomas, K., Hardy RD., Lazrus H., Mendez M., Orlove B., Rivera-Collazo, I., Roberts JT., Rockman M., Warner BP., Winthrop R., Explaining differential vulnerability to climate change: A social science review (December 2018). Oct 29, 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

The 2045 General Plan Update is an opportunity to enhance resilience for all Oakland communities with policies in support of ECAP innovations. For example, the ECAP identifies Action A-1, Fund the Creation and Operation of Resilience Hubs, as key to successful climate adaptation. Resilience hubs are defined as "community-serving facilities that support residents year-round and support resource distribution and onsite services before, during, or after a natural hazard event." General Plan policies could further support resilience hubs to protect frontline communities during climate crises and could also support other resilience approaches, such as the expansion of green infrastructure to mitigate sea-level inundation along with temperature and health impacts, protection of key facilities to ensure community energy resilience, and adaptive reuse of structures to create indoor spaces resilient to climate change.

1.2 Racial Equity and Climate Change

Frontline communities are those who have been and will continue to be hit first and worst by the impacts of environmental injustice and the climate crisis. Frontline communities face intersecting vulnerabilities, including racial discrimination, poverty, disability, housing insecurity, linguistic isolation, poor air quality, and more, which magnify climate threats. As a result, they are often the least able to adapt, resist, or recover from climate impacts.

Many studies have discussed climate change impacts on frontline communities, but few have quantified disproportionate risks to vulnerable groups across multiple impacts and levels of climate change.[7,8] However, a recent EPA study shows that racial and ethnic minority communities continue to remain disproportionately vulnerable to the greatest impacts of climate change, with racial disparities only increasing in the future.[9] Results reveal that Black and African American individuals are projected to face higher impacts of climate change that include poor air quality, extreme temperature, coastal flooding, and inland flooding. Black and African American individuals are 34 percent more likely to currently live in areas with the highest projected increases in childhood asthma

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[7] Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, and Sinh BT. 2012. Determinants of risk: exposure and vulnerability. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, and Midgley PM (eds.)] A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108.

[8] Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, and Winthrop R. 2018. Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change, 10(2). doi: 10.1002/wcc.565.

[9] EPA. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. U.S. Environmental Protection Agency, EPA 430-R-21-003. www.epa.gov/cira/social-vulnerability-report.

diagnoses. In addition, they are 40 percent more likely to currently live in areas with the highest projected increases in extreme temperature related deaths.

In addition, Hispanic and Latinx individuals have high participation in weather-exposed industries, such as construction and agriculture, which are especially vulnerable to the effects of extreme temperatures. Hispanic and Latinx individuals are 43 percent more likely to currently live in areas with the highest projected reductions in labor hours due to extreme temperatures. With regards to transportation, Hispanic and Latinx individuals are about 50 percent more likely and Asian individuals are about 23 percent more likely to currently live in areas with the highest estimated increases in traffic delays due to increases in coastal flooding.

Given the pervasive disparities associated between racial equity and climate change, this Vulnerability Assessment identifies and evaluates areas in Oakland that should be prioritized for climate adaptation actions and measures that build resilience and advance racial equity. The Vulnerability Assessment's focus on socially vulnerable and frontline communities builds on the City's ongoing efforts to achieve racial equity in Oakland. It is informed by the frameworks established by the City's 2018 Oakland Equity Indicators Report, the 2020 Racial Equity Impact Assessment and Implementation Guide for the Oakland's 2030 Equitable Climate Action Plan (ECAP), and other previous studies that have laid the foundation to ensure that the City integrates equity and social justice into its policies, practices, and actions.

1.3 The Climate Change Readiness Landscape in California

The State of California has adopted several legislative actions to mitigate the onset of climate change and prepare for its impacts. Passed in 2015, SB 379 requires that, beginning January 1, 2017, all cities and counties in California include climate adaptation and resiliency strategies in the safety element of their general plan as part of the general plan revision process. The climate adaptation update must include community goals, policies, and objectives informed by a climate change vulnerability assessment, as well as measures for addressing climate vulnerabilities.

SB 99 was passed in 2019 and requires the city or county, upon the next revision of the housing element on or after January 1, 2020, to review and update the safety element to include information identifying residential developments in hazard areas that do not have at least two emergency evacuation routes.

The State of California has also issued several plans and pieces of legislation pertaining to climate change and adaptation. These include the California Adaptation Planning Guide, SB 246, and AB 1482. Collectively, these plans and policies identify the key climate impacts most likely to affect California, provide guidance on how to analyze climate change vulnerabilities and adaptation opportunities as part of the community planning process, and help local and regional governments and agencies collaborate to identify and implementation equity-promoting adaptation strategies.

Additionally, in 2018, the State of California published the Fourth Climate Change Assessment, including the San Francisco Bay Area Regional Report. Primary climate impacts discussed in the report include warming air and water temperatures, more extreme heat waves, drier landscapes, less snow, variable precipitation and seasonal shifts, more intense droughts and floods, less frequent fog, increased risk of wildfire, sea level rise, and loss of ecosystem habitat. The report concludes that public health challenges will arise in the form of more extreme heat events, increased air pollution from ozone formation and wildfires, longer and more frequent droughts, and flooding from sea level rise and high-intensity rain events. Risks are compounded due to elevated levels of socioeconomic inequity in the Bay Area. The statewide report includes recommendations for reducing climate change risks, including developing climate-smart buildings and more accessible public cooling centers, fire reduction practices, enhanced emergency preparedness with a focus on disadvantaged communities, and land use planning practices that focus on extreme floods and drought.

OAKLAND'S CLIMATE READINESS LANDSCAPE

The City of Oakland, along with many regional agencies, have already taken concrete steps towards addressing climate change vulnerability and implementing mitigation and adaptation strategies and programs. Table 1-1 summarizes key local and regional climate change plans below.

The East Bay region is also home to several organizations that are actively involved in addressing climate issues in Oakland. While not exhaustive, key organizations and activities are summarized in Chapter 5, Adaptive Capacity.

Table 1-1: Key Climate Change Plans and Assessments Relevant to the City of Oakland

Name	*Date Published*	*Description*
Resilient Oakland Playbook	October 2016	The Resilient Oakland Playbook is a coordinated effort to align resources, plans, and actions in support of a thriving and resilient community. Oakland was competitively selected in December 2013 to join 100 Resilient Cities, an initiative Pioneered by the Rockefeller Foundation that aims to help cities around the world build resilience to the social, economic, and physical challenges of the 21st century.
Oakland Preliminary Sea Level Rise Road Map	2017	The Preliminary Sea Level Rise Road Map was developed as part of Resilient Oakland, a coordinated effort to align resources, plans, and actions in support of a thriving and resilient community. The Road Map helps identify SLR adaptation actions to best address the conditions, needs, and issues in Oakland.
Oakland Walks! 2017 Pedestrian Plan Update	2017	The Oakland Walks! Plan sets goals, outlines related policies and programs, and establishes a prioritization strategy to implement recommendations that will improve our pedestrian environment over the next five years and beyond.
East Bay Municipal Utility District's (EBMUD) Local Hazard Mitigation Plan (LHMP)	2018	Currently being updated, the LHMP reflects EBMUD's most current system upgrades, improvements, and mitigation measures to reduce the community's exposure to hazards and to improve the reliability of its services to the public.
Let's Bike Oakland 2019 Oakland Bike Plan	July 2019	The Oakland Bike Plan identifies new projects and programs that will work to enhance existing communities and their mobility needs; and sets a goal that Oakland will be a bicycle-friendly City where bicycling provides affordable, safe, and healthy mobility for all Oaklanders.
City of Oakland Green Stormwater Infrastructure Plan	September 2019	The City of Oakland (City) Green Stormwater Infrastructure Plan (GSI Plan) describes how the City identifies, prioritizes, implements, tracks and reports green stormwater infrastructure (GSI) projects in Oakland. This plan will be updated based on a new iteration of the Municipal Regional Permit (MRP) which is in effect as of July 1, 2022, which includes new green stormwater infrastructure requirements and planning.
Oakland Department of Transportation Transit Action Strategy	2020	The Transit Action Strategy is a to-do list for OakDOT and AC Transit. The strategy outlines the different types of actions that will quickly help improve transit.

Name	*Date Published*	*Description*
East Bay Municipal Utility District's (EBMUD) Urban Water Management Plan	2020	The EBMUD Urban Water Management Plan assesses water supplies against expected water demands for a 30-year planning horizon and outlines actions to deal with future uncertainties which includes a diversified and resilient portfolio as well as recycled water and conservation programs.
Sanitary Sewer Master Plan	2020	The plan provides technical guidance to both the sanitary sewer rehabilitation capital improvement program and the sanitary sewer operation and maintenance program in compliance with the 2014 Consent Decree for the next decades. The master plan will help the City mitigate inflow/infiltration sewer infrastructures more effectively, efficiently, and equitably. The plan also provides guidance to the City for future funding needs, development requirements, and asset management.
Bay Area Conservation and Development Commission (BCDC) Adapting to Rising Tides (ART) Bay Area	March 2020	The ART Bay Area report is a regional comparison of the impacts of sea level rise on people, the environment, and the regional systems the Bay Area relies on. This report provides a better understanding of where the Bay Area is vulnerable and lays out a pathway to plan for the future.
Oakland 2030 Equitable Climate Action Plan (ECAP)	July 2020	The ECAP is rooted in equity and a deep community engagement process: it identifies ambitious and realistic actions the City can take to combat climate change and adapt to the impacts of the climate crisis, while ensuring that frontline communities will benefit first and foremost from climate action.
East Bay Municipal Utility District's (EBMUD) Climate Action Plan	2021	To prepare for the future uncertainties associated with climate change, the EBMUD Climate Action Plan has undertaken a rigorous evaluation of potential impacts to ensure that EBMUD continues to provide reliable, high-quality water and wastewater services to their customers.
Emergency Operations Plan	2021	The Emergency Services Management Division updated the Emergency Operations Plan, a document providing guidance and information for emergency response personnel in performance of their duties before, during, and through initial emergency recovery. This document contains hazard specific annexes related to emergency response procedures for climate-related hazards such as wildfires and severe weather.
Storm Drainage Master Plan	2021	The updated Storm Drainage Master Plan provides recommendations for the rehabilitation of the existing storm drainage system, construction of new improvements, and the maintenance and care of the City's existing drainage assets. The City intends to use this study to establish and prioritize storm drainage capital improvement projects, identify permitting requirements, and develop improved maintenance and management practices

Name	*Date Published*	*Description*
		and standards that address water quality issues consistent with the MRP and other associated stormwater management guidelines and regulations.
City of Oakland 2021 – 2026 Local Hazard Mitigation Plan (LHMP)	July 2021	The LHMP identifies potential hazards that the City of Oakland is most vulnerable to, assess risks to the City's residents, buildings and critical facilities, and develop a mitigation strategy to reduce the risk of exposure and allow a swift and organized recovery should a disaster occur.
Plan Bay Area 2050	October 2021	Plan Bay Area 2050 is the Bay Area's regional long-range plan adopted by MTC and the Association of Bay Area Governments (ABAG). The plan was developed in collaboration with Bay Area residents, partner agencies, and nonprofit organizations. It lays out a $1.4 trillion vision for a more equitable and resilient future for Bay Area residents. Thirty-five strategies make up the heart of the plan to improve housing, the economy, transportation and the environment across the Bay Area's nine counties.
Zero Emission Vehicle Action Plan	2023	The City of Oakland Zero Emission Vehicle Action Plan provides a roadmap for transitioning to a zero-emission transportation system. The plan includes strategies to increase access to zero emission vehicles (ZEV), electric vehicle supply equipment (EVSE), and hydrogen fueling stations for all Oakland residents and visitors.
City of Oakland Urban Forestry Master Plan (UFMP)	In-progress; anticipated launch in 2023	A 50-year management plan for planning and sustaining a healthy urban forest will be developed. The UFMP will make recommendations on what resources are needed to maintain Oakland's urban forest and achieve tree canopy equity goals.
Building Electrification Roadmap	Forthcoming	In December 2020, the City began requiring all new construction to be all-electric. The forthcoming Building Electrification Roadmap will provide strategies to pursue cost-effective, equitable pathways to eliminate natural gas use in buildings. Electrifying all buildings as rapidly as possible will help reduce greenhouse gras emissions and is an important component of the City's ambitious climate goals.

2 Climate Change Effects

This chapter provides an overview of how climate change impacts are likely to manifest in the City of Oakland. It begins with a brief discussion of the nature of climate modeling, then discusses the nature of the effects that temperature increase, changes in precipitation patterns, wildfire, and sea level rise are predicted to have on the city.

2.1 Climate Change in Oakland

BROAD CHANGES IN THE REGIONAL CLIMATE SYSTEM

Climate change represents more than short-term extreme weather events, but a long-term, large-scale shift in the entire climate system. Everything in the climate system is connected: climate change manifests not only in discrete, observable weather events, but a host of other climatic and geophysical states and processes such as air quality, erosion rates, water quality, soil composition, and growing seasons. Each of these secondary climate change impacts occur at different rates, in different ways, and may have more severe impacts on some communities and community members than others.

The primary climate change impacts that are expected to be experienced in California include:

- Increases in average temperature and number of extreme heat days
- Shifts in the water cycle
- Increased wildfire frequency and intensity
- Sea level rise, flooding, and elevated groundwater levels from saltwater intrusion

Increases in average temperature and number of extreme heat days

Average summer temperatures in California have risen by approximately 3 degrees Fahrenheit (°F) or 1.8 degrees Celsius (°C) since 1896, with more than half of that increase occurring since the early 1970s. If global greenhouse gas emissions continue at current rates, California is likely to experience further warming by more than 2°F by 2040, more than 4°F by 2070, and by more than 6°F by 2100. More frequent and intense heat waves, fewer cool nights, and worsening air quality will accompany these temperature increases.[10]

For Oakland, the Cal-Adapt model projects an increase in average annual maximum temperature of 3 to 4 degrees by mid-century and 4.4 to 7 degrees by the end of the century compared to baseline historical levels between 1961 and 1990. Extreme heat events are projected to increase from the currently experienced four extreme heat days per year to 11-14 by mid-century and as many as 13-28 by the end of the century. Oaklanders can also anticipate experiencing heat waves more often, for a longer duration, and at higher temperatures.

These changes pose a health risk—especially for those unable to seek shelter from heat and those whose physiology makes it difficult to regulate body temperature. In addition, heat contributes to the buildup of air pollutants leading to increased respiratory illness and risk for heat stroke.[11] Changes in temperature regimes will also impact regional snowmelt and wildfire patterns and increase warm season electrical load.

Shifts in the water cycle

As global temperatures rise, precipitation patterns in California are expected to change. Less precipitation will fall as snow, and instead, more will fall as rain. Reduced winter snowpack will negatively impact local water availability, particularly during drought periods. Drought frequency will also increase as rainstorms become less likely during the summer months. Intermittent, intense episodes of rain may become the norm, which will strain local stormwater management systems, increase flood risk, and exacerbate erosion which can trigger landslides. Water cycle shifts are also likely to increase food insecurity, as California's agriculture will be dramatically impacted, likely leading to increased prices and potentially scarcity of certain items.

For Oakland, the Cal-Adapt model projects an increase in annual precipitation for the region. The number of inches of rain received per year is projected to increase by about three inches by mid-century and up to six inches by end-of-century. However, this increase will not occur at a uniform rate. Precipitation in the region will continue to exhibit high year-to-year variability with very wet and very dry years. Historically, the City of Oakland

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[10] Bedsworth, L., Cayan D., Franco G., Fisher L., Ziaja S. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-013.

[11] Centers for Disease Control and Prevention. "Heat Exposure and Cardiovascular Health: A Summary for Health Departments." Climate and Health Technical Report Series (2020). Jan 4 2023: https://www.cdc.gov/climateandhealth/docs/HeatCardiovasculoarHealth-508.pdf.

has experienced about two extreme rain events per year. This number could increase to an average of about four extreme rain events per year by the end-of-century.

Increased wildfire frequency and intensity

Climate change is expected to increase the annual frequency and intensity of wildfires. Statewide, total annual acres burned by wildfire are projected to almost double by the end-of-century. Changes in wildfire regimes (or the general pattern in which fires naturally occur) can give rise to a host of secondary social and environmental consequences, including changes in forest composition, impacts to transmission lines, reductions in air quality due to the presence of smoke, and safety threats to those living in high-exposure areas. Further, public safety power shutoffs (PSPS) used to prevent wildfires can pose a health risk to those who need power, such as the elderly and those who rely on medical equipment.

Wildfires are common in the Bay Area; the Cal-Adapt model projects the average annual number of acres burned in wildfire per year in the region to increase by about 43 percent by mid-century and 50 percent by end-of-century. A notable increase in the annual area affected by wildfire is projected to occur in the Oakland Hills.

Sea level rise and flooding

Sea level rise can expose coastal areas to inundation and flooding, impact water quality, and increase rates of coastal erosion. Oakland will experience the impacts from sea level rise as San Francisco Bay water levels rise. As noted in the ECAP, sea level rise will likely increase flooding in West Oakland, the Jack London District, and near the airport and Coliseum—predominantly impacting BIPOC communities first.

Interpreting Climate Change Predictions

The summaries of the extent, severity, rate of onset, and duration of the climate change impacts discussed in this document draw from climate change projections provided by Cal-Adapt. Cal-Adapt is the result of a partnership between the California Energy Commission, California Natural Resources Agency, and the Public Interest Energy Research Program, which provides an online climate data visualization tool that allows users to explore a wealth of climate data pertaining to climate change impacts in California. Cal-Adapt data contributors include the Pacific Institute, Santa Clara University, Scripps Institution of Oceanography, UC Berkeley, UC Merced, and the U.S. Geological Survey.

To understand the descriptions and visualizations of projected climate change impacts that appear in this document, it is important to understand the types of data provided through Cal-Adapt, its strengths, and limitations.

Cal-Adapt provides projections of different future climate scenarios. Climate projections are not definitive statements about what types of weather patterns or climate impacts are guaranteed to occur in a particular year but provide general guidance on how climatic conditions might be expected to change over time. Climate projections are the output of global climate models—sophisticated computer modeling tools that simulate how the global climate system works.

Despite the sophistication of these computer programs, the complexity of the global climate system and the significant uncertainty regarding long-term greenhouse gas emissions means that the results of different climate projections can look quite different. Cal-Adapt helps demonstrate this variability in modeling results by allowing users to work with different emissions scenarios and different climate models. Each tool in Cal-Adapt shows possible outcomes for two Representative Concentration Pathways (RCPs), which depict two different future greenhouse gas emission scenarios: a high-emissions scenario, in which greenhouse gas emissions continue to rise over the 21st century (RCP 8.5), and a medium-emissions scenario, in which greenhouse gas emissions level off around the middle of the 21st century and are lower than 1990 levels by the end-of-century (RCP 4.5).[12] **This vulnerability assessment uses the RCP 8.5 high-emissions scenario as the basis for the maps.** Results from both high and medium emissions scenarios are discussed in the text to help decision-makers prepare for worst case climate scenarios, while also providing an indication of the scale of future climate variability. However, it is important to keep in mind that both the medium and high emissions scenarios are based on assumptions of likely—not guaranteed—future emissions patterns; future greenhouse gas emissions may not adhere to either of these scenarios.

As a default, Cal-Adapt allows users to compare the results produced by four different climate models: CanESM2 (Average), HadGEM2-ES (Warm/Drier), CNRM-CM5 (Cooler/Wetter), and MIROC5 (Complement). These results each represent the average values from a variety of models. This document uses the CanESM2 model because it represents an average primary climate model. For additional details regarding the emissions scenarios and climate models, see the Appendix at the end of this document.

For the sake of this document, there are two time periods of interest: mid-century, extending from 2035 to 2064, and end-of-century, occurring from 2070 to 2099. Since Cal-Adapt produces more accurate projections within a period of at least a few decades, both the typical mid-century (2035-2064) and end-of-century (2070-2099) windows are thirty-

[12] Cal-Adapt, How to Use Cal-Adapt. Oct 29 2019: http://v1.cal-adapt.org/resources/using-caladapt/.

year time slices. Mid-century and end-of-century projected climate conditions are averages of the projected conditions occurring in these windows unless otherwise noted.

2.2 Primary and Secondary Impacts

This work begins with an assessment of the primary and secondary climate change impacts most likely to affect the City of Oakland. Primary and secondary impacts are identified in accordance with the California Adaptation Planning Guide: Planning for Adaptive Communities, and via consultation with City of Oakland staff. A primary impact can be understood as a major disruption to the weather or environment that results from climate change. A secondary impact is a shift in the weather or environment that occurs as a result of the primary impact. Primary and secondary climate impacts are outlined in Table 2-1. Potential effects on human health and critical infrastructures are discussed under secondary impacts where appropriate. Each primary impact contains an assessment of that impact's temporal and spatial scale, as well as its level of uncertainty and estimated level of disruption to community function.

Table 2-1: Summary of Assessed Primary and Secondary Climate Change Impacts in Oakland

Primary Impact	*Secondary Impacts*	*Temporal Extent*	*Spatial Extent*	*Permanence*	*Level of Disruption*	*Level of Uncertainty*
Temperature Increase	• Heat waves • Urban heat islands • Warm nights	Moderate Effects will be most extreme in August and September, but may be felt anytime between June and October	High Effects will be felt throughout the city, but will be most extreme in and around urban heat islands	High The most extreme of effects will be seasonal, but average ambient temperatures will increase steadily over the course of the century	Moderate Possible disruptions include strains to energy infrastructure, increased risk of blackouts, and heat-related illness	Low
Precipitation Changes	• Flooding • Snowpack reduction • Drought • Increased demand for groundwater • Hillside erosion	High Precipitation is expected to increase most dramatically in winter months. Effects of declines in winter snowpack may be felt most acutely in summer	High The effects of flooding will be felt most acutely in coastal and low-lying areas, areas susceptible to hillside erosion, and areas with limited stormwater infrastructure	High The most extreme of effects will be seasonal, but changes in precipitation patterns are expected to continue over the course of the century	High A large storm could cause significant health and infrastructure impacts over potentially large portions of the city.	Moderate The exact timing of large storms and rainfall can be difficult to predict
Wildfire	• Declines in air quality • Soil and water quality impacts	Moderate Wildfire extent and severity is projected to exhibit high levels of variability, but on average will increase over the course of the century. In the future, the fire season may expand beyond the period from early spring to late fall	High The Oakland Hills are located in Very High and High Fire Hazard Severity Zones. Wildfire smoke will also affect the entire City	Moderate Average wildfire intensity is expected to gradually increase over time, with significant year-to-year variability	High Wildfires occur within the city limits and wildfires in the region have a significant impact on the city's air pollution from wildfire smoke	Moderate
Sea Level Rise	• Flooding • Ecosystem impacts • Elevated groundwater levels	Low Sea level rise is projected to occur gradually over the course of the century	Moderate The city's entire shoreline is at risk	High	Moderate Effects may be more severe when coinciding with flooding	Low

Note: Summary of impacts were identified using historical and projected annual climate change data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland.

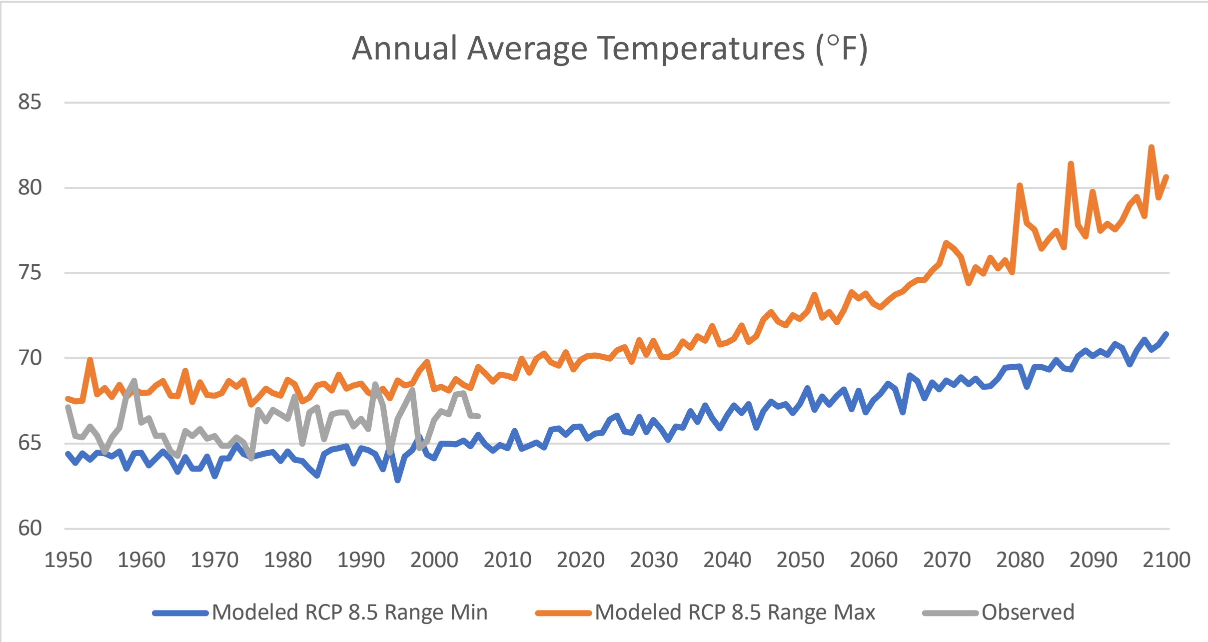
PRIMARY IMPACT: TEMPERATURE INCREASE

Oakland will experience notable increases in temperature throughout the 21st century. Historically (between 1961 and 1990), the average annual maximum temperature in the City of Oakland has been 66.0°F. This value is projected to increase to between 69.1°F and 70.0°F by mid-century, and to between 70.4°F and 73.1°F by the end-of-century (Chart 2-1). Increasing average daytime temperatures are expected to be accompanied by higher nighttime temperatures. Historically, the average annual minimum temperature has been 49.1°F. This number is projected to increase to between 52.1°F and 53.0°F by mid-century and to between 53.4°F and 56.4°F by the end-of-century (Chart 2-1). Overall temperature increase is associated with several secondary impacts, including increased incidence of extreme heat days, warm nights, and heatwaves, urban heat islands, heat-related health impacts, and heat-related damage to infrastructure (Table 2-2), as discussed below.

Table 2-2: Temperature Increase

Temporal Extent	Effects will be felt most acutely in August and September, but excessive heat may occur June through October
Spatial Extent	The entire City of Oakland is likely to be affected As shown in Figure 2-1, the location of hotspots varies throughout the city. Effects will be felt most acutely in highly built-up areas, where the urban heat island effect is most likely to occur
Permanence	Annual average temperatures are projected to continue to increase through the end-of-century, though the projected rate of increase is higher under a high emissions scenario
Level of Disruption	Increased heat strains the electrical service sector by reducing the efficiency of electrical transmission and increasing demand for air conditioning Heat-related illnesses may increase hospital visits and demand for medical services High temperatures can damage transportation infrastructure and increase discomfort associated with active and public transportation
Level of Uncertainty	Low

Chart 2-1: Average Annual Temperatures, City of Oakland



Created using historical and projected annual temperature data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. Both the average maximum and minimum temperatures are projected to increase over the course of the century.

Secondary Impact: Extreme Heat Days

Cal-Adapt defines an extreme heat day as a day falling between April and October where the maximum daily temperature exceeds the 98th percentile of daily maximum temperature, based on historical data from between 1961 and 1990.[13] For Oakland, the threshold to be considered an extreme heat day is 88.2°F. Extreme heat days are dangerous because they increase fire danger, strain the power grid, and impact public health through illnesses such as heat stroke.

Between 1961 and 1990, the City of Oakland experienced an average of four extreme heat days per year. By mid-century, the city is projected to experience between 11 and 14 extreme days per year. At the end-of-century, extreme heat days could rise to be between 13 and 28 days per year (Chart 2-2 through 2-3).

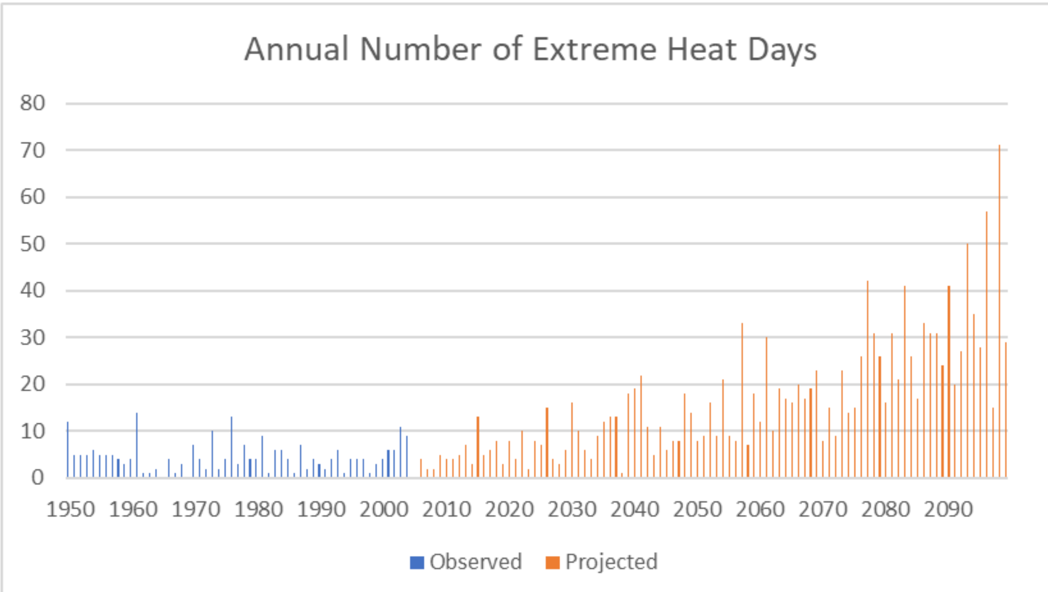
August and September are likely to be the most critical months for increased temperature effects. Historically, these months have experienced the highest temperatures. By the end-of-century, at least six days in the month of September may be an extreme heat day (Chart 2-4). However, the effects of high heat days will be felt throughout May and the spring, summer, and early fall. Historically, high heat days in May, August, and October have been rare (on average, fewer than

[13] Cal-Adapt, Extreme Heat Days & Warm Nights. Oct 28, 2019: https://cal-adapt.org/tools/extreme-heat/.

one high heat day every year). By the end-of-century, each of these months is projected to experience an average of at least one high heat day per year (Chart 2-4).

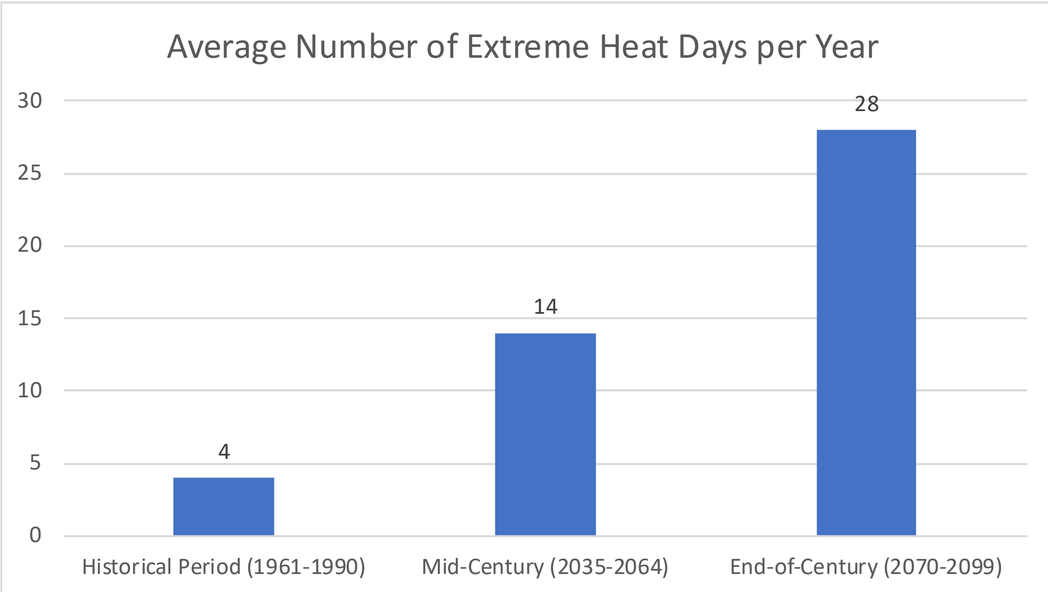
The average temperature of extreme heat days is projected to gradually increase over the course of the century. Historically, the average temperature of a high-heat day has been about 88.2°F. By the end of this century, this value may increase to 93.3°F (Chart 2-5).

Chart 2-2: Annual Number of Extreme Heat Days



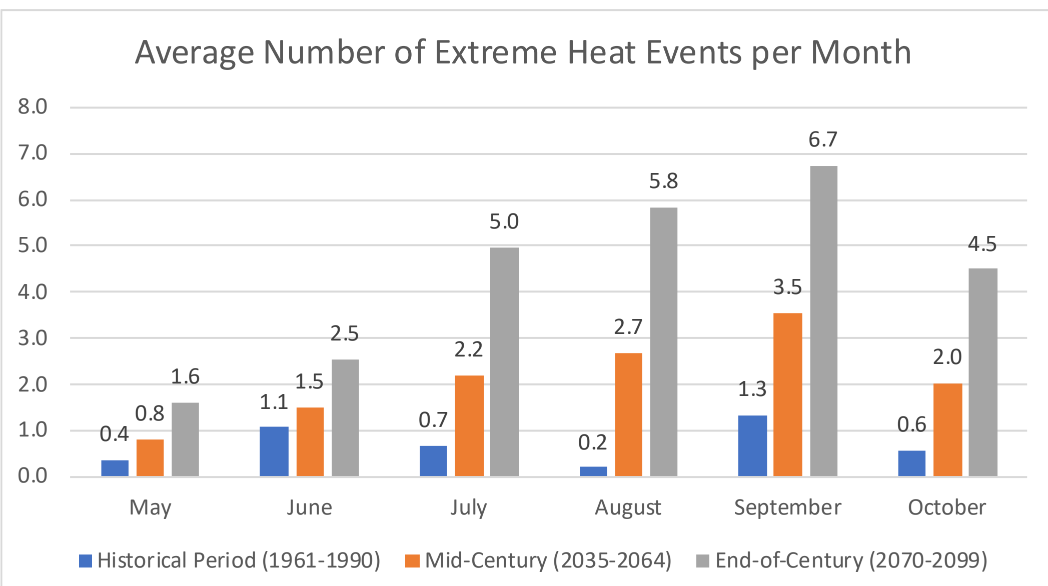
Created using historical and projected annual temperature data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While some variability in the annual number of extreme heat days is projected to occur in the future, there is a clear upwards trend in the number of extreme days that occur per year. By the end-of-century, the annual number of extreme heat days is projected to be significantly higher than anything that has been observed historically.

Chart 2-3: Average Number of Extreme Heat Days per Year



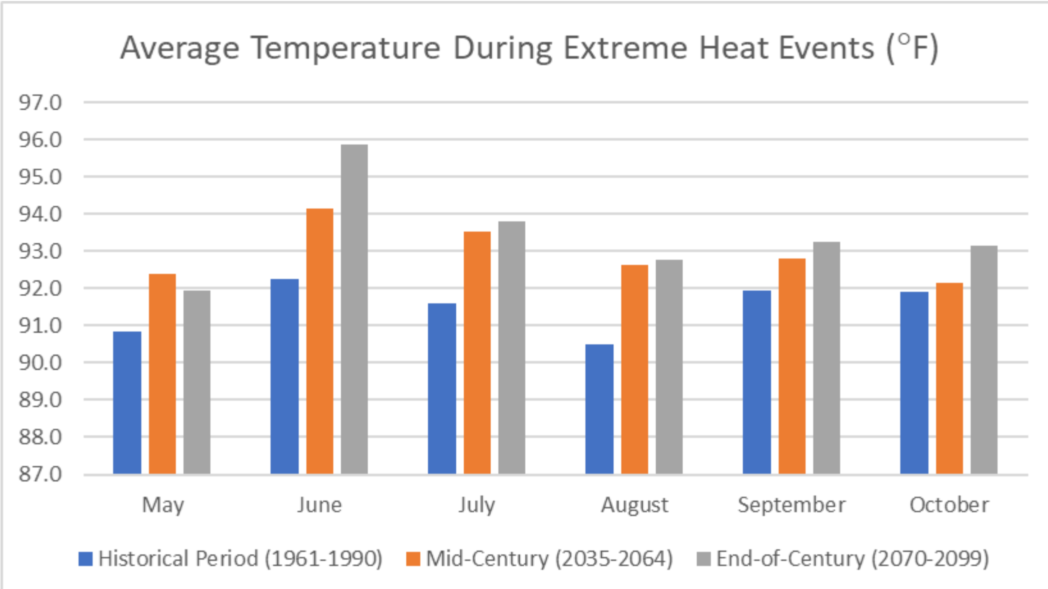
Created using historical and projected annual temperature data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. This chart shows the number of extreme heat events either observed or projected to occur, averaged over the time period indicated.

Chart 2-4: Average Number of Extreme Heat Events per Month



Created using historical and projected annual temperature data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The number of extreme heat events occurring per month are projected to increase dramatically by the end-of-century, particularly in the months of July, August, and September.

Chart 2-5: Average Temperature During Extreme Heat Events



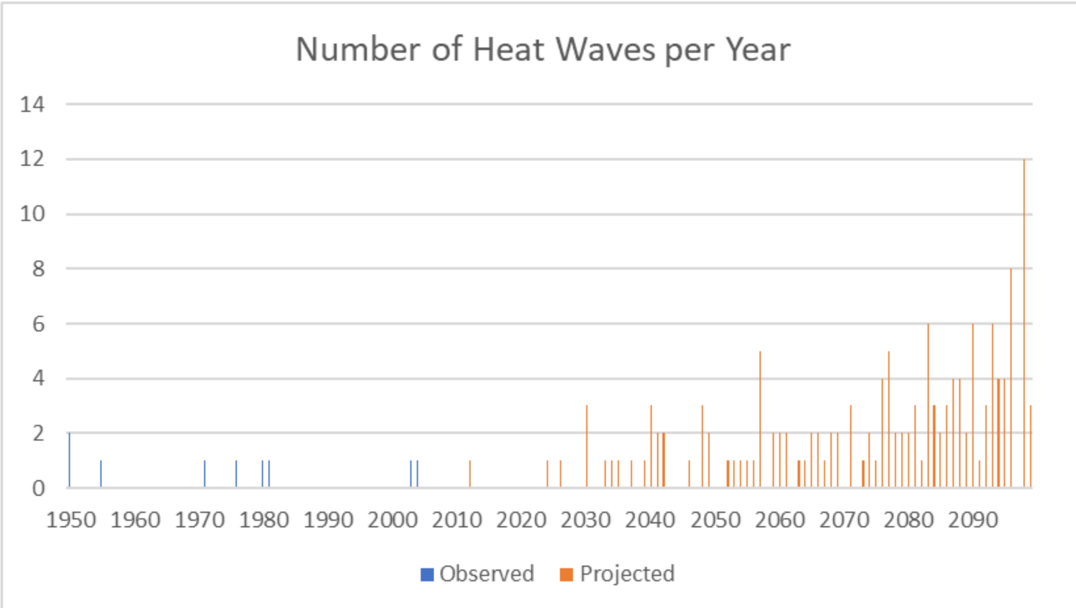
Created using historical and projected annual temperature data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. Dramatic increases in the average daily high of extreme heat days are projected to occur, particularly in June, July, and August.

Secondary Impact: Heat Waves

While there is no universal definition of a heat wave, heat waves are characterized as periods of sustained, extreme heat. Cal-Adapt defines a heatwave as a period of four consecutive extreme heat days or warm nights.[14] Between 1961–1990, the city experienced about zero to one heatwave per year. By mid-century (2035-2064), the City of Oakland may experience an average of 0.5 to 1.1 4-day heat waves per year. At the end-of-century (2070-2099), this range is predicted to rise to an average of 0.7 to 3.2 four-day heat waves per year (Chart 2-6). Between 1961–1990, the typical heat wave duration the city experienced was 2.2 days. The typical heat wave duration is predicted to grow to between 3.5 and 4.4 days by mid-century and between 4.2 and 7.1 days by the end-of-century (Chart 2-7 through 2-8).

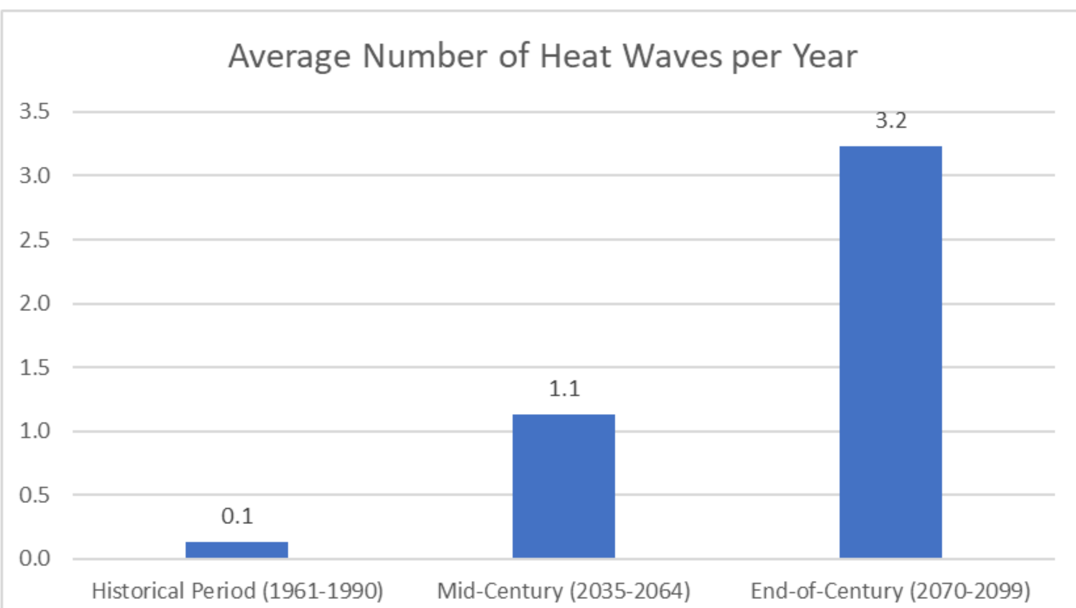
[14] Cal-Adapt, Extreme Heat Days & Warm Nights. Oct 28, 2019: https://cal-adapt.org/tools/extreme-heat/.

Chart 2-6a: Number of Heat Waves Per Year



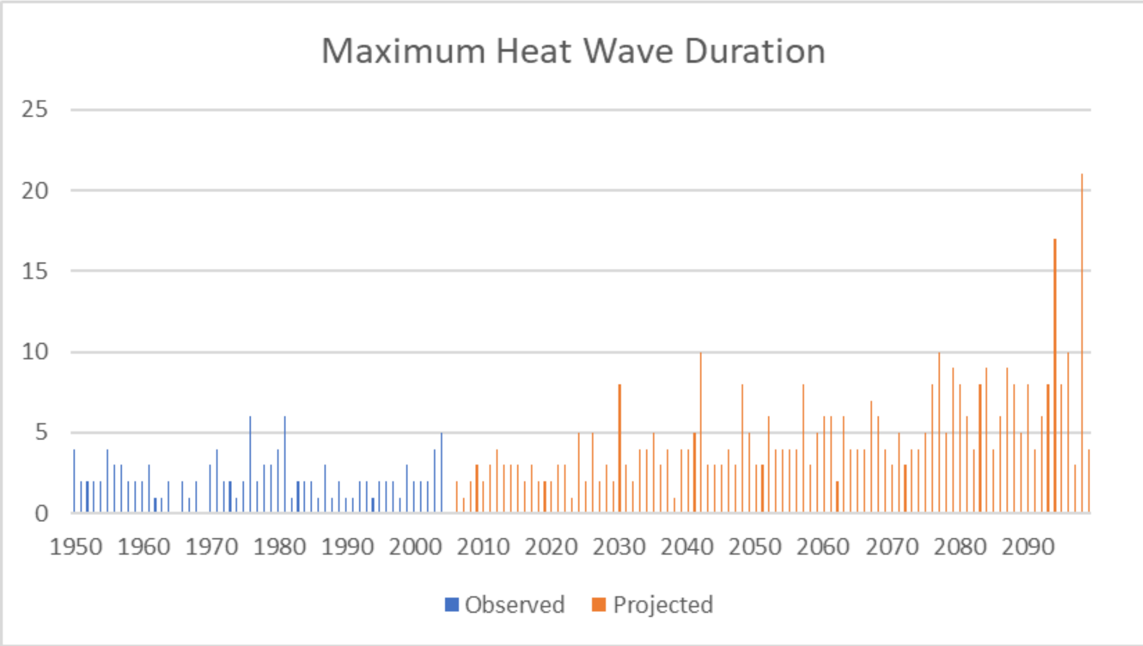
Created using historical and projected heat wave data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While considerable variability in the annual number of heat waves is projected to continue into the future, the number of heat waves projected to occur per year does increase dramatically by the end-of-century.

Chart 2-6b: Number of Heat Waves Per Year



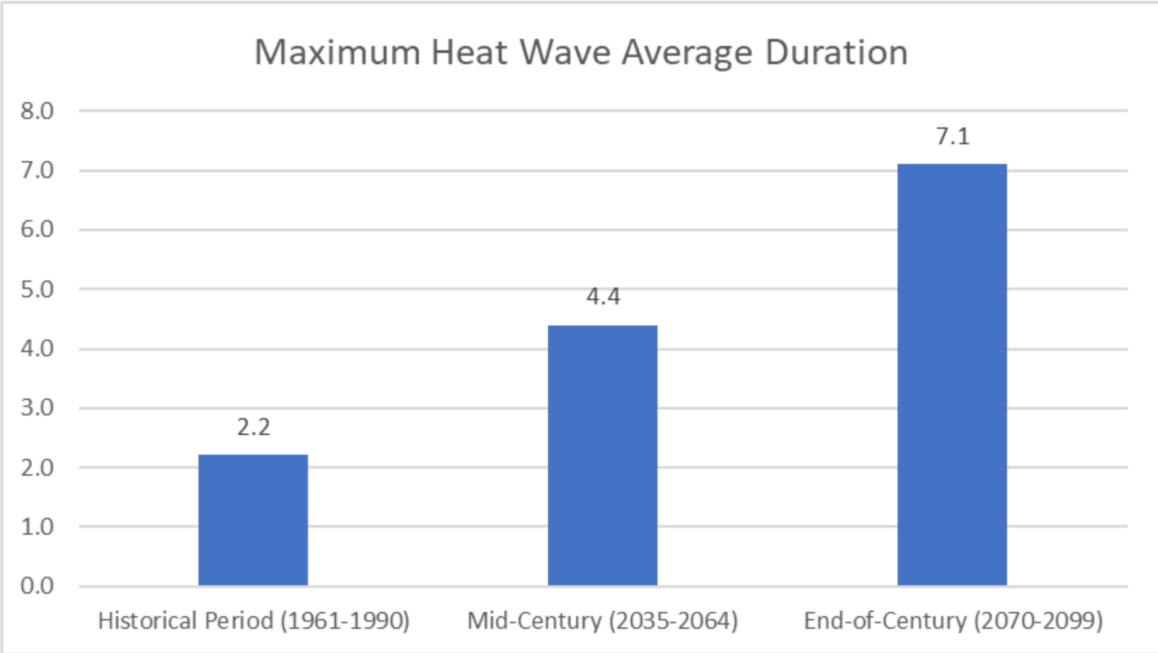
Created using historical and projected heat wave data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While considerable variability in the annual number of heat waves is projected to continue into the future, the number of heat waves projected to occur per year does increase dramatically by the end-of-century.

Chart 2-7: Maximum Heat Wave Duration



Created using historical and projected heat wave data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The length of the longest heat wave is projected to gradually increase over the course of the century.

Chart 2-8: Maximum Heat Wave Average Duration



Created using historical and projected heat wave data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland.

Secondary Impact: Urban Heat Islands

Increases in urban temperature may be felt most acutely by those living in urban heat islands – pockets of the urban environment where temperatures can dramatically exceed those in neighboring non-urban areas. Urban heat islands are associated with several negative environmental and health effects, as well as increased demands for energy.

Urban heat islands form where high levels of development intersect with limited landscape vegetation. Natural elements such as trees and green spaces provide cooling via evapotranspiration, the process by which water moves from the earth's surface into the atmosphere, and shade.[15] In contrast, many materials that constitute the built environment, such as asphalt and concrete, absorb heat. These materials re-radiate absorbed heat and can raise nearby temperatures by several degrees.[16, 17] Other activities such as running air conditioners and operating internal combustion engines can also raise urban temperatures.[18,19] The location of urban heat islands can also shift with changes in atmospheric conditions such as prevailing wind patterns.[20] Because a vast majority of homes and buildings in Oakland lack air-conditioning and adequate insulation due to the City's moderate Mediterranean climate, a risk of increasing temperatures is that more people will install air-conditioners[21], straining the electrical grid which can lead to power outages and potentially release both greenhouse gases and excess heat into areas impacted by urban heat islands.

The pockets of high temperature created by urban heat islands facilitate the formation of ozone and smog.[22, 23] Additionally, high pavement and rooftop surface temperatures can heat stormwater

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[15] Golden JS. "The Built Environment Induced Urban Heat Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity." *Environmental Sciences*, 2004. May 1, 2020: https://www.tandfonline.com/doi/abs/10.1080/15693430412331291698.

[16] Golden JS. "The Built Environment Induced Urban Heat Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity." *Environmental Sciences*, 2004. May 1, 2020: https://www.tandfonline.com/doi/abs/10.1080/15693430412331291698.

[17] US EPA. "Heat Island Effect." *US EPA*, 28 Feb. 2014, www.epa.gov/heatislands.

[18] Memon RA, Leung DY, Chunho L. "A review on the generation, determination and mitigation of urban heat island." *Journal of Environmental Sciences*, 2008. May 1, 2020: https://www.ncbi.nlm.nih.gov/pubmed/18572534.

[19] Salamanca F. Georgescu M, Mahalov A, Moustaoui M, Wang M. "Anthropogenic heating of the urban environment due to air conditioning." *Advancing Earth and Space Science*, May 9, 2014. May 1, 2020: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013JD021225.

[20] Wilby, RL. "A Review of Climate Change Impacts on the Built Environment." *Built Environment*, Mar 13 2007. May 4 2020: https://www.ingentaconnect.com/content/alex/benv/2007/00000033/00000001/art00003

[21] US EPA. "Heat Island Effect." *US EPA*, 28 Feb. 2014, www.epa.gov/heatislands.

[22] Akbari, H. "Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation." (2001). May 1, 2020: https://www.osti.gov/servlets/purl/860475.

[23] US EPA. "Heat Island Effect." *US EPA*, 28 Feb. 2014, www.epa.gov/heatislands.

runoff. This heated runoff can enter local rivers and lakes, where it may upset the metabolism and reproduction of aquatic species.[24]

Increased daytime temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can exacerbate public health effects. Potential health complaints include general discomfort, respiratory difficulties, heat cramps and exhaustion, heat stroke, and heat-related mortality.[25, 26, 27]

The impacts of urban heat islands are pronounced during the summer months, heat waves, and at early morning and night.[28, 29] Those most vulnerable to urban heat island health effects include those who reside in or around the heat island who cannot afford or lack access to heat relief services. Particularly, studies have found that increases in extreme temperature-related premature mortality are projected to occur in many U.S. cities, but the largest increases are expected in areas with larger shares of low income and minority populations.[30]

Figure 2-1: Land Surface Temperature (August 28, 2021), illustrates the land surface temperatures of a late summer day in Oakland. It is noted that although Figure 2-1 shows land surface temperature, which has a direct relationship with air temperature, how hot a person feels depends on many factors including their health, biology, and personal preferences. Figure 2-1 reveals that there are local hotspots in the city that would increase heat exposure due to urban heat islands; the areas in red and orange—including parts of Fruitvale/South Kennedy, the Coliseum Industrial Complex, Frick/Bancroft Business area, Castlemont, Oak Knolls-Golf Links/Chabot Park, Webster, and the Oakland International Airport area—are hotter than their surroundings.

As shown in Figure 2-1, areas most susceptible to urban heat island impacts in Oakland are generally among the lowest income and formerly redlined BIPOC communities with higher rates of failing infrastructure, rental properties, and substandard housing. Therefore, those who live in

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[24] Ibid.

[25] US EPA. "Heat Island Effect." *US EPA*, 28 Feb. 2014, www.epa.gov/heatislands.

[26] Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P. "The Impact of Heat Islands on Mortality in Paris during the August 2003 Heat Wave." *Environmental Health Perspectives*, Feb 1, 2012. May 1, 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1103532

[27] Memon RA, Leung DY, Chunho L. "A review on the generation, determination and mitigation of urban heat island." *Journal of Environmental Sciences*, 2008. May 1, 2020: https://www.ncbi.nlm.nih.gov/pubmed/18572534.

[28] Memon RA, Leung DY, Chunho L. "A review on the generation, determination and mitigation of urban heat island." *Journal of Environmental Sciences*, 2008. May 1, 2020: https://www.ncbi.nlm.nih.gov/pubmed/18572534.

[29] Golden JS. "The Built Environment Induced Urban Heat Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity." *Environmental Sciences*, 2004. May 1, 2020: https://www.tandfonline.com/doi/abs/10.1080/15693430412331291698.

[30] United States Environmental Protection Agency. 2021. Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts. Publication number: EPA 430-R-21-003.

the most intense urban heat islands tend to have the least access to indoor refuges from the heat and the least recourse to retrofit their homes to adequately protect them from heat.

Over the course of the next several decades, continued warming from climate change is expected to worsen urban heat islands.[31] In areas that are already urbanized, local climate change will be the primary contributor to future changes in urban heat islands. In areas that will be urbanizing between now and 2050, the impacts on air temperature will result from both changes in land use type and changes in climate.

Trees are a potential solution that can both reduce intensity of the urban heat island effect and improve air quality. As seen in Figure 2-2: Tree Canopy, Oakland's tree canopy is disproportionately distributed. Many of the more affluent/majority-white census tracts in North Oakland and the Oakland Hills contain significantly greater percentage of tree canopy cover compared to Downtown, West Oakland, and East Oakland neighborhoods. However, trees planted in urban heat islands will also need to be able to endure increased temperatures and droughts under climate change in order to provide the benefits of green infrastructure. Further, expansion of the urban tree canopy requires City resources for proactive maintenance. This has disproportionately impacted frontline communities as lower-income neighborhoods often have fewer resources to proactively fill the void in public tree maintenance to preserve the tree canopy.

In addition to trees and vegetation, other potential strategies to mitigate the urban heat island effect include cool roofs and cool pavements.[32] A high solar reflectance—or albedo—is the most important characteristic of a cool roof as it helps to reflect sunlight and heat away from a building, reducing roof temperatures. Similarly, cool pavements include a range of established and emerging technologies that communities are exploring as part of their heat island reduction efforts. The term currently refers to paving materials that reflect more solar energy, enhance water evaporation, or have been otherwise modified to remain cooler than conventional pavements. In addition to reducing urban heat islands, such interventions can also reduce energy use, air pollution, greenhouse gas emissions, and stormwater runoff.

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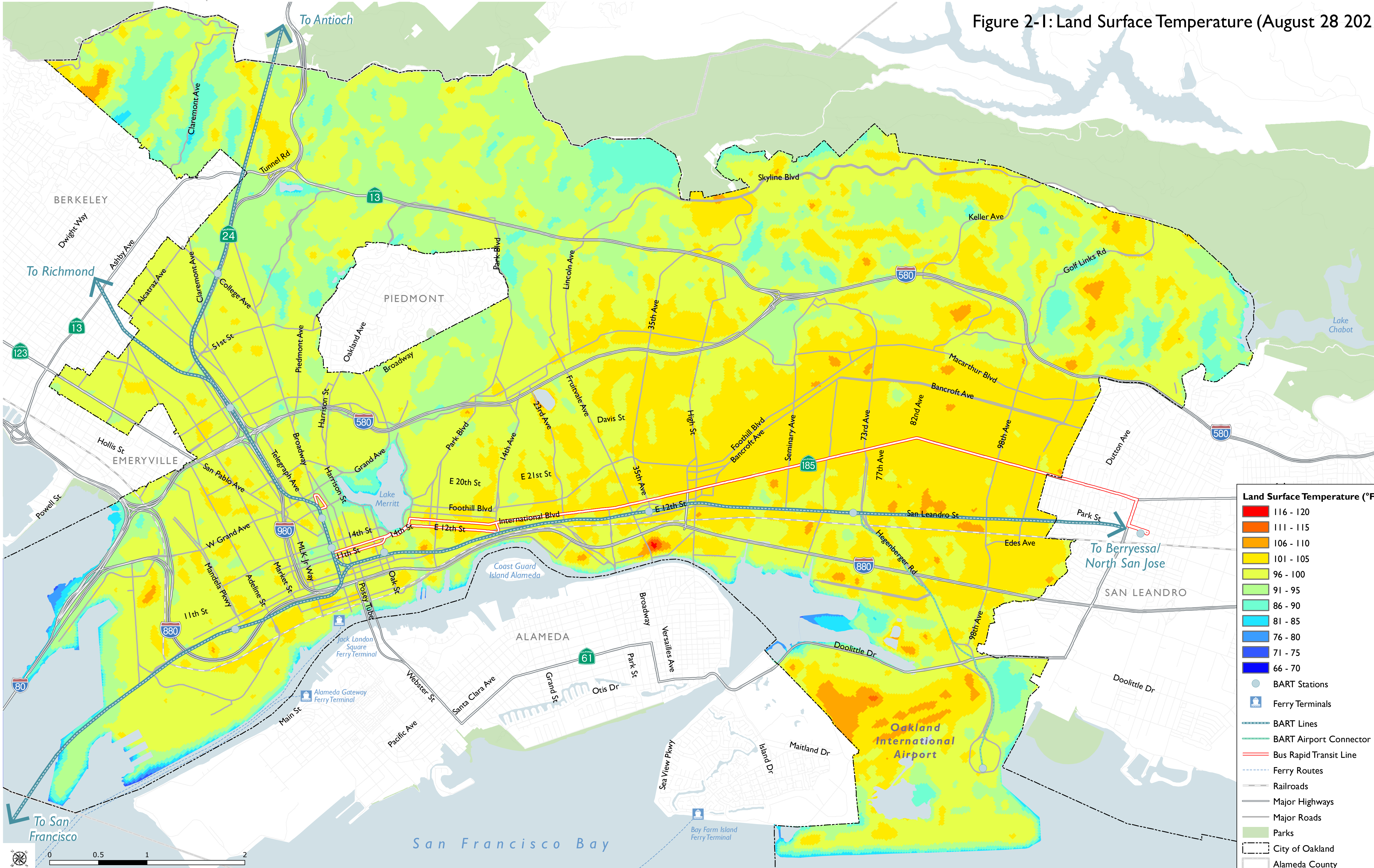
[31] US EPA. "Heat Island Effect." *US EPA*, 28 Feb. 2014, www.epa.gov/heatislands.

[32] Ibid.

Figure 2-1: Land Surface Temperature (August 28 2021)



SOURCE: CalEPA, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

DYETT & BHATIA Urban and Regional Planners

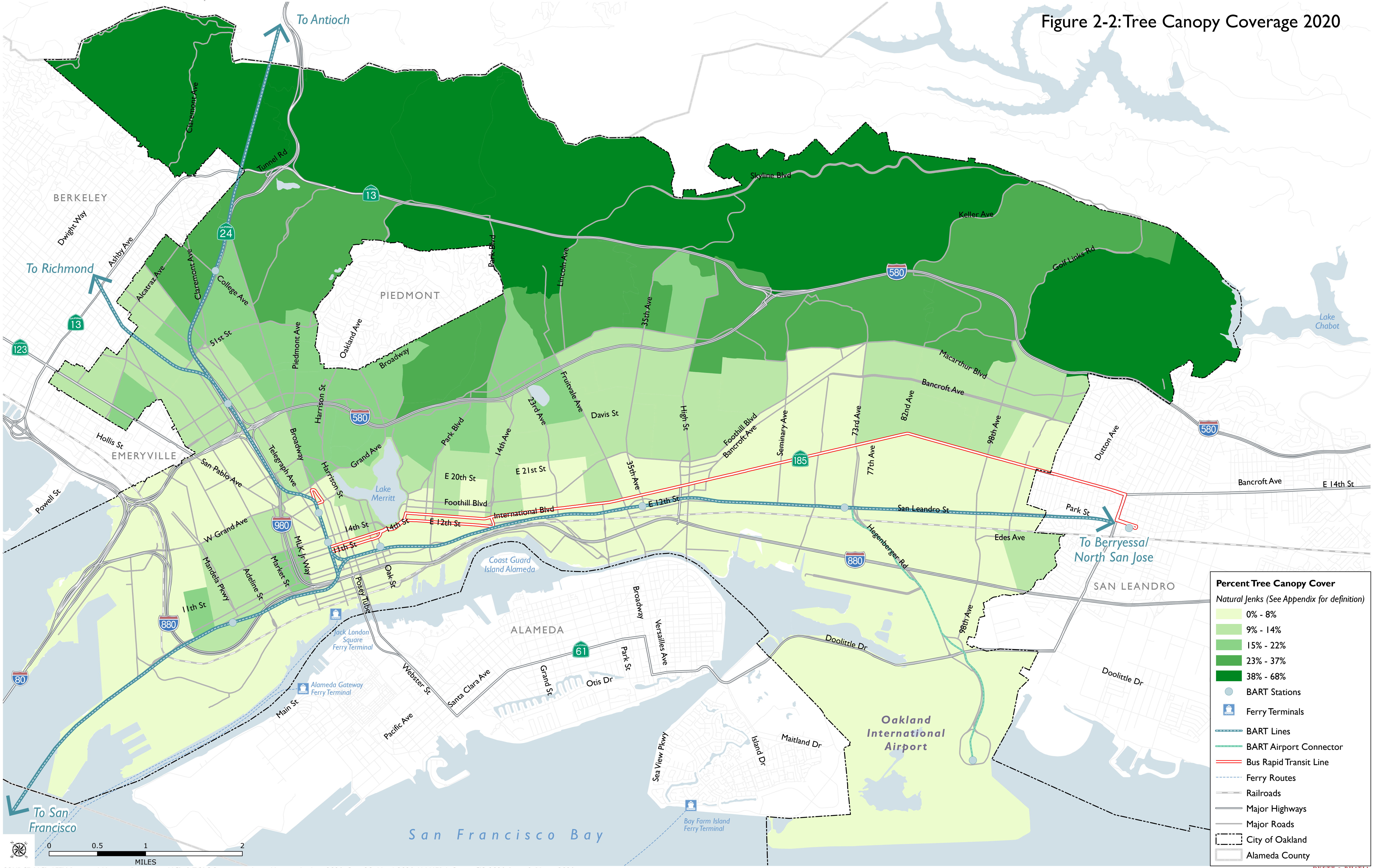


Figure 2-2: Tree Canopy Coverage 2020

SOURCE: HCD AFFH Data and Mapping Resources - HCD & TCAC Opportunity Areas Mapping Analysis, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

DYETT & BHATIA Urban and Regional Planners

Secondary Impact: Warm Nights

Cal-Adapt defines a warm night as a night falling between April and October when the daily minimum temperature exceeds the 98th historical percentile of daily minimum temperatures observed from 1961 to 1990.[33] For the City of Oakland, nights where the temperature stays above 60.1°F are considered warm nights.

Both the frequency and intensity of warm nights are projected to substantially increase in the future. Historically, the City of Oakland has experienced an average of seven warm nights per year. By mid-century, the city is predicted to experience approximately 49 to 72 warm nights per year. By the end-of-century, this chart could climb as high as 149 warm nights per year (Chart 2-9 and 2-10). The majority of these warm nights are projected to occur between July and October. By the end-of-century, almost every night in July, August, and September may be a warm night. Warm nights may also become a larger concern in May, June, and October, months in which warm nights have historically been rare (Chart 2-11).

Historically, the average warm night temperature has been about 60.1°F. By mid-century, average warm night temperature is projected to increase to 63.0°F. By the end-of-century, average warm night temperature is projected to further increase to 65.1°F. The most dramatic increases in nighttime temperature are projected to occur in August and September (Chart 2-12).

Stretches of consecutive warm nights are also expected to increase in length. Historically, it has been unusual to see significantly more than three warm nights in a row. By mid-century, consecutive stretches of warm nights may be between 10 and 21 nights long. At the end-of-century, the length of the average stretch of consecutive warm nights may climb up to 97 nights in a row (Chart 2-13 and 2-14).

Elevated nighttime temperatures limit the body's opportunity to offload excess heat acquired during the day, increase mortality risk[34, 35], and can disrupt sleep.[36] Within the city, the effects of warm nights may be felt most acutely in heavily built-up areas and those with limited vegetation. These areas can become very warm during the day and continue to radiate heat at night.[37] Nighttime air conditioner use, while providing relief to residents, may exacerbate these effects by

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[33] Cal-Adapt, Extreme Heat Days & Warm Nights. Oct 28 2019: https://cal-adapt.org/tools/extreme-heat/

[34] Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P. "The Impact of Heat Islands on Mortality in Paris during the August 2003 Heat Wave." Environmental Health Perspectives, Feb 1, 2012. May 1, 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1103532.

[35] Murage P, Hajat S, Kovats S. "Effect of night-time temperatures on cause and age-specific mortality in London." Environmental Epidemiology, Dec 13, 2017. May 1, 2020: https://journals.lww.com/environepidem/FullText/2017/12000/Effect_of_night_time_temperatures_on_cause_and.1.aspx.

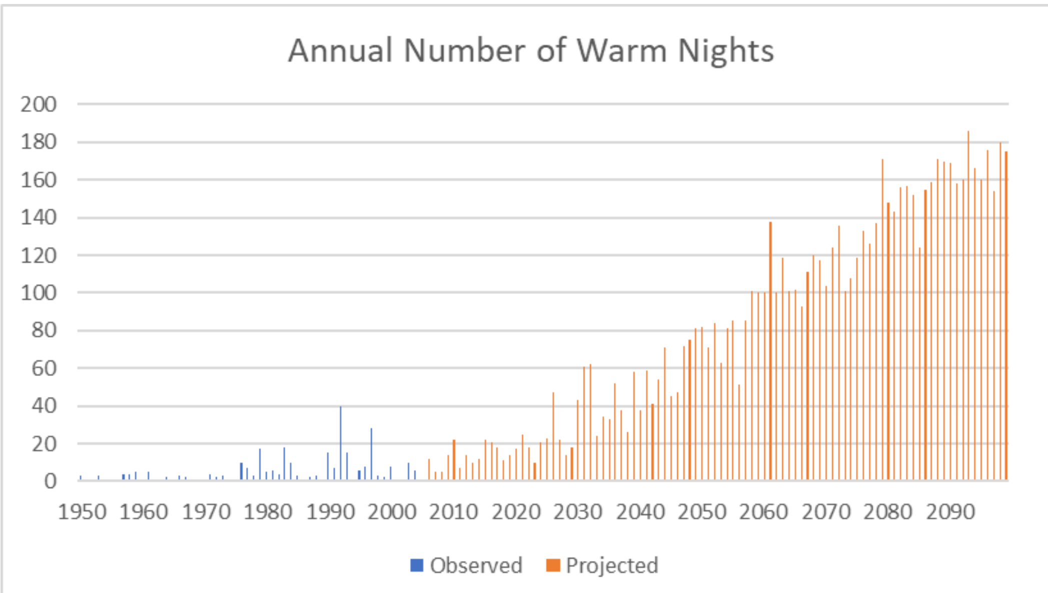
[36] Obradovich N, Migliorini R, Mednick SC, Fowler JH. "Nighttime temperature and human sleep loss in a changing climate." *Science Advances*, May 26, 2017. May 1, 2020: https://advances.sciencemag.org/content/3/5/e1601555.

[37] Lenart M, Guido Z. "Rising temperatures bump up risk of wildfires." *Southwest Climate Outlook*, March 2011. May 1, 2020: https://climas.arizona.edu/sites/default/files/pdf2011marrisingtempsfirerisk.pdf.

releasing waste heat into the environment.[38] Additionally, should air conditioner systems fail, those relying on them may have few other options for relieving heat.[39]

Just as cool nights help the body recover from high daytime temperatures, firefighters have traditionally relied on cooler evening and nighttime temperatures to slow wildfire growth. Higher nighttime temperatures enable wildfires to blaze through the night.[40, 41] Further, increasing temperatures also affect the viability of existing vegetation, which can impact the timing of and overall development of plants.[42]

Chart 2-9: Annual Number of Warm Nights



Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While some degree of variability in the annual number of warm nights that occur per year is projected to continue into the future, projections demonstrate a steadily

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[38] Salamanca F. Georgescu M, Mahalov A, Moustaoui M, Wang M. "Anthropogenic heating of the urban environment due to air conditioning." *Advancing Earth and Space Science*, May 9, 2014. May 1, 2020: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013JD021225.

[39] Gronlund CJ. "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: s Review." *Current Epidemiology Reports*, 2014. May 3 2020: https://link.springer.com/article/10.1007/s40471-014-0014-4.

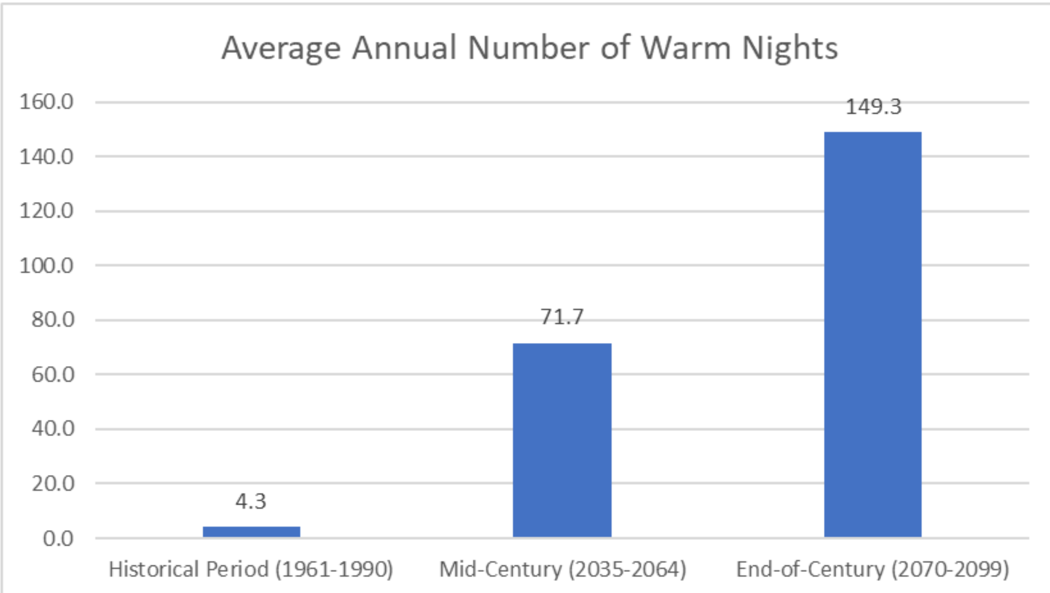
[40] McCann H, Mount J. "Managing Wildfires Requires New Strategies." *Public Policy Institute of California*, Sep 23, 2015. May 1, 2020: https://www.ppic.org/blog/managing-wildfires-requires-new-strategies/.

[41] Lenart M, Guido Z. "Rising temperatures bump up risk of wildfires." *Southwest Climate Outlook*, March 2011. May 1, 2020: https://climas.arizona.edu/sites/default/files/pdf2011marrisingtempsfirerisk.pdf.

[42] Zipper S, et al. "Urban heat island impacts on plant phenology: intra-urban variability and response to land cover." *Environmental Research Letters*, May 20, 2016. January 4, 2023: https://iopscience.iop.org/article/10.1088/1748-9326/11/5/054023#:~:text=UHI%2Dinduced%20increases%20in%20temperature,%2C%20Jochner%20and%20Menzel%202015).

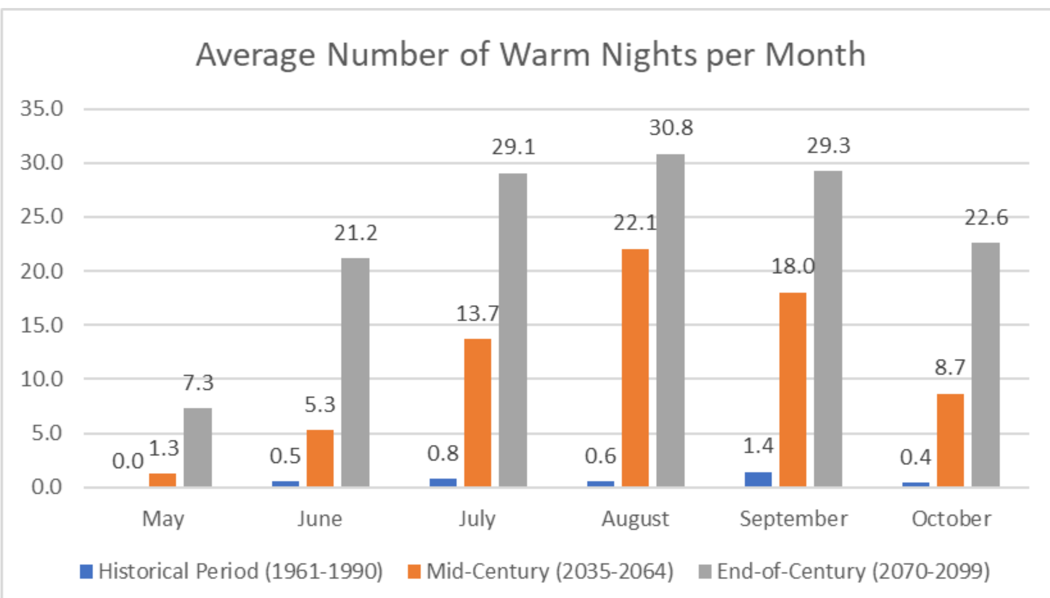
increasing trend through the end-of-century. By the end-of-century, the annual number of warm nights is projected to far exceed anything that has been observed between 1950 and 2005.

Chart 2-10: Average Annual Number of Warm Nights



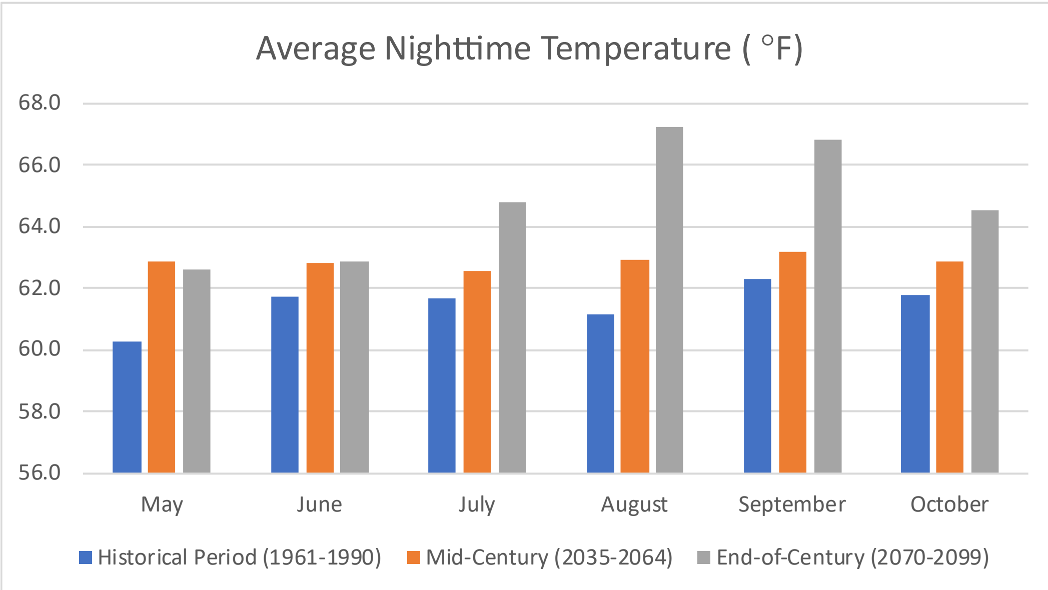
Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland.

Chart 2-11: Average Number of Warm Nights Per Month



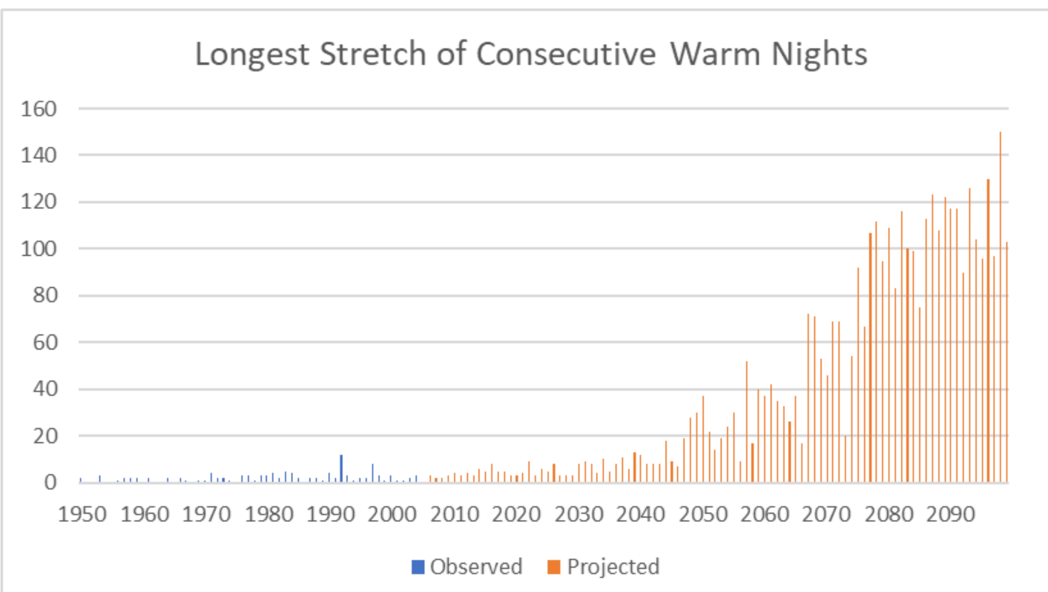
Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The average number of warm nights is projected to increase most dramatically in the summer months. However, temperature projections also illustrate increase in the number of warm nights that occur in the spring and fall.

Chart 2-12: Average Nighttime Warm Night Temperature



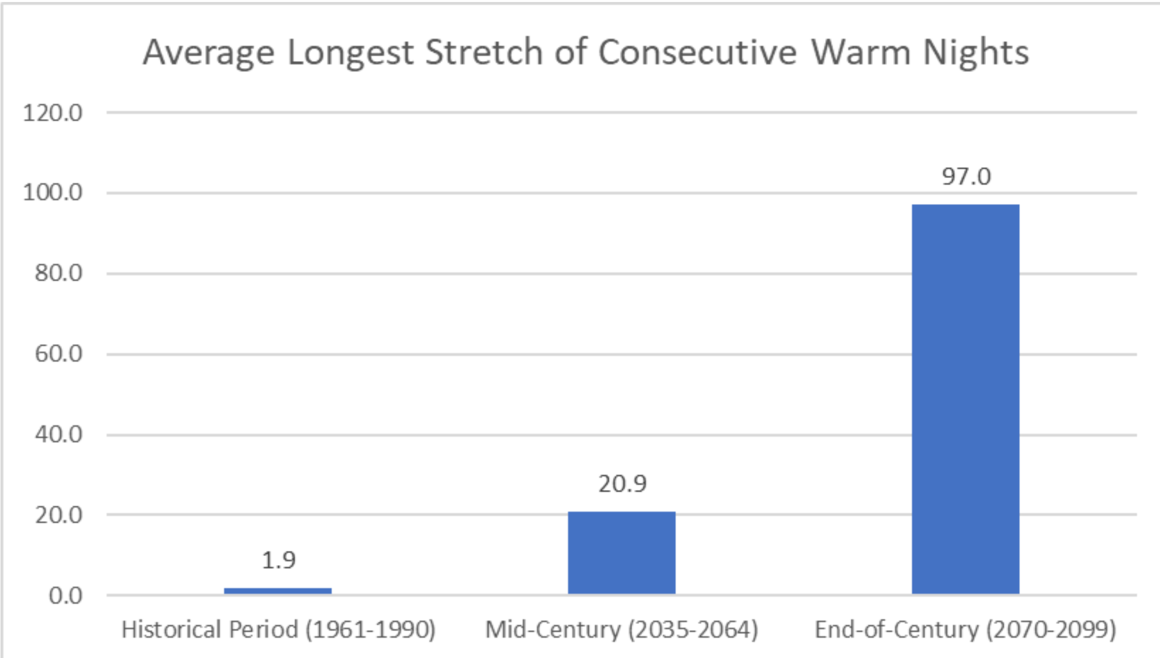
Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. Average minimum temperature is projected to increase most dramatically in August and September.

Chart 2-13: Longest Stretch of Consecutive Warm Nights



Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While considerable variability is projected to remain in the typical length of a nighttime heat wave up through the end-of-century, nighttime temperature projections do demonstrate a clear upward trend in nighttime heatwave length. This increase may occur somewhat gradually up through the middle of the century but then begin to increase rapidly thereafter.

Chart 2-14: Longest Stretch of Consecutive Warm Nights



Created using historical and projected warm night data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The chart above displays the historical and projected longest stretch of consecutive warm nights, averaged over the years indicated.

Sensitivity: Heat-Related Illness

Heat waves and sustained high heat days directly harm human health through heat-related illness such as heat cramps, heat exhaustion, and heat stroke.[43] Certain segments of the population whose natural cooling systems are inhibited are more sensitive to the health effects of heat., including older adults, those taking certain medications (anticholinergic, antihypertensive, and antipsychotic drugs), and children. [44, 45, 46, 47] Heat intensifies the photochemical reactions that produce smog, ground level ozone, and fine particulates, which exacerbate respiratory diseases in children, older adults, and people with pre-existing cardiovascular, respiratory, and

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[43] Sari Kovats R, Hajat S. "Heat Stress and Public Health: A Critical Review." *Annual Review of Public Health*, Nov 21 2007. May 3 2020: https://www.annualreviews.org/doi/full/10.1146/annurev.publhealth.29.020907.090843.

[44] Ibid.

[45] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/extreme-events

[46] Gronlund CJ. "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: s Review." *Current Epidemiology Reports*, 2014. May 3 2020: https://link.springer.com/article/10.1007/s40471-014-0014-4.

[47] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/extreme-events

cerebrovascular disease and diabetes-related conditions.[48] Conditions such as dementia and Parkinson's have also been found to be important risk factors for heat mortality. Prolonged exposure to high temperatures is associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders.[49, 50]

Increased heat can also promote the growth of pollen-producing plants, which are associated with allergies.[51] On especially hot days, cooler nights have typically provided a period of respite. Increases in nighttime temperature prevent people from being able to adequately cool down at night, further increasing their risk of suffering heat-related illness.[52, 53]

Opportunities to reduce heat exposure are not evenly distributed throughout the population. Segments of the population who face especially high levels of heat exposure include those experiencing homelessness, outdoor workers, individuals that depend on medical equipment, individuals with impaired mobility, and those without access to adequate home insulation, air conditioning, or ventilation.[54, 55]

Personal perceptions regarding heat risk and safety can also influence responses to heat. Those who fear exposure to crime may hesitate to open windows or travel to cooler locations, while some may not be aware of the dangers posed by high heat or may not think of themselves as susceptible.[56]

Social, cultural, and linguistic isolation also contribute to heat's adverse health effects.[57] While the harms of social isolation with respect to a wide range of health outcomes are still under review,

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[48] U.S. Climate Resilience Toolkit, Extreme Heat—NIHHIS. Oct 28 2019: https://toolkit.climate.gov/topics/human-health/extreme-heat.

[49] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/temperature-related-death-and-illness.

[50] Gronlund CJ. "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: s Review." *Current Epidemiology Reports*, 2014. May 3 2020: https://link.springer.com/article/10.1007/s40471-014-0014-4.

[51] Maizlish N, English D, Chan J, Devin K, English P, Climate Change and Health Profile Report: Sacramento County (Sacramento, CA, 2017). Oct 28 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHPRs/CHPR067Sacramento_County2-23-17.pdf.

[52] U.S. Climate Resilience Toolkit, Extreme Heat—NIHHIS. Oct 28 2019: https://toolkit.climate.gov/topics/human-health/extreme-heat.

[53] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/temperature-related-death-and-illness.

[54] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28, 2019: https://nca2018.globalchange.gov/chapter/11/.

[55] Gronlund CJ. "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: s Review." *Current Epidemiology Reports*, 2014. May 3, 2020: https://link.springer.com/article/10.1007/s40471-014-0014-4.

[56] Ibid.

[57] Ibid.

studies have shown that reducing social isolation could limit the impact of heat waves on the mortality of the older adult population.[58] Sometimes limited transportation options for older adults can also make it more difficult to relocate to cooler locations when local temperatures become extreme.

PRIMARY IMPACT: CHANGES IN PRECIPITATION PATTERNS

Climate change models predict changes in the seasonal distribution of precipitation, with rainfall becoming more concentrated in the winter months and falling in fewer, higher-intensity events. Meanwhile, increasing average temperatures will cause more precipitation to fall in the form of rain, as opposed to snow. These changes may result in a number of secondary impacts, such as flooding, reduction in winter snowpack, drought, groundwater depletion, increased wildfire risk, changes in streamflow, and strain to health, energy, and infrastructure systems, as described later in this section and in Table 2-3.

Table 2-3: Changes in Precipitation Patterns

Temporal Extent	Increases in annual rainfall projected to continue through the end-of-century Most dramatic increases in extreme rainfall events projected to occur in the winter months April snowpack level projected to continue to decline through the end-of-century
Spatial Extent	Flooding effects will be felt most strongly in coastal and low-lying areas, and areas with inadequate stormwater infrastructure Areas susceptible to hillside erosion will also be impacted from increased stormwater runoff
Permanence	Effects may be felt most acutely in winter months, with drought periods also becoming more likely
Level of Disruption	High
Level of Uncertainty	Low

Overall, annual precipitation is expected to increase in the Oakland region. Between the years 1961 and 1990, the City of Oakland received about 22.7 inches of rain per year. By mid-century, this number is projected to increase to between 25.0 and 25.4 inches per year. Annual precipitation may reach 28.0 inches per year by the end-of-century (Chart 2-15 through 2-16). However, this

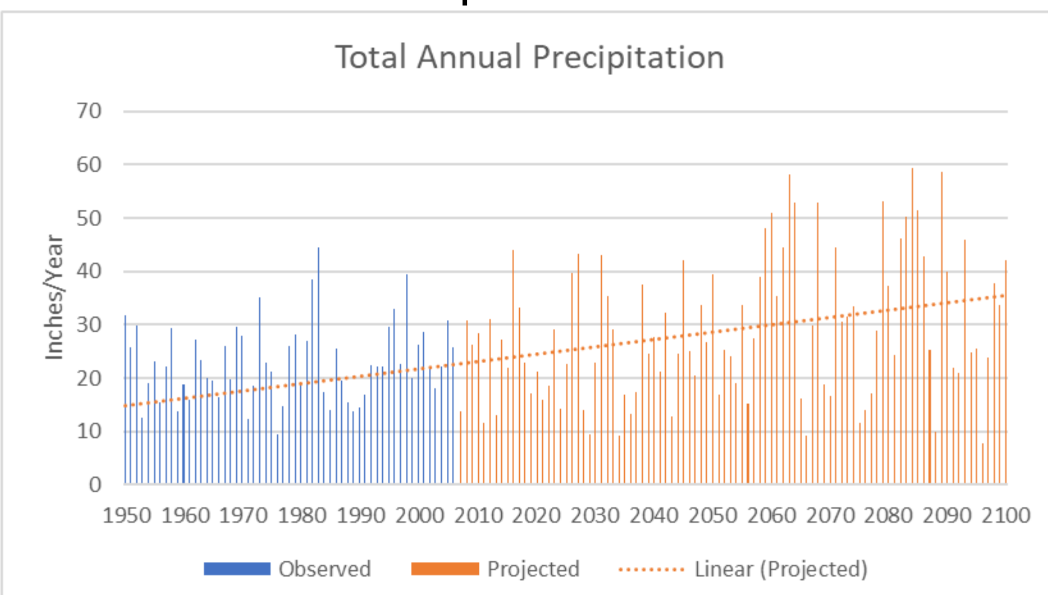
[58] Orlando, Stefano, et al. "The Effectiveness of Intervening on Social Isolation to Reduce Mortality during Heat Waves in Aged Population: A Retrospective Ecological Study." *International Journal of Environmental Research and Public Health*, vol. 18, no. 21, 4 Nov. 2021, p. 11587, https://pubmed.ncbi.nlm.nih.gov/34770101/. Accessed 25 July 2022.

increase will not occur at a uniform rate. Precipitation in the region will continue to exhibit high year-to-year variability - "booms and busts" - with very wet and very dry years.[59] Much of this increase in rainfall projected during winter months may be attributable to high intensity or extreme storms. Cal-Adapt defines an extreme rain event for the City of Oakland as successive days in which the 2-day rainfall total is above an extreme threshold of 1.26 inch. Historically, the City of Oakland has experienced about two extreme rain events per year. This number could increase to an average of about four extreme rain events per year by the end-of-century.

The most significant increases in extreme rainfall frequency are projected to occur in January and February, both of which are projected to experience more than one to three extreme rain events per year respectively by the end-of-century. By mid-century, extreme rain events may also be more common in November and December, though the frequency of these events may taper off towards the end-of-century (Chart 2-18 through 2-19).

These high intensity storms may produce higher volumes of runoff, contribute to increased flood and landslide/severe hillside erosions risk, intensify weatherization of transportation infrastructure such as roads and bridges, and contribute to creek bank, dam, and levee failure.

Chart 2-15: Total Annual Precipitation



Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. While significant variability in annual rainfall is projected to continue into the future, the dotted linear trendline illustrates a gradual increase in annual rainfall over time.

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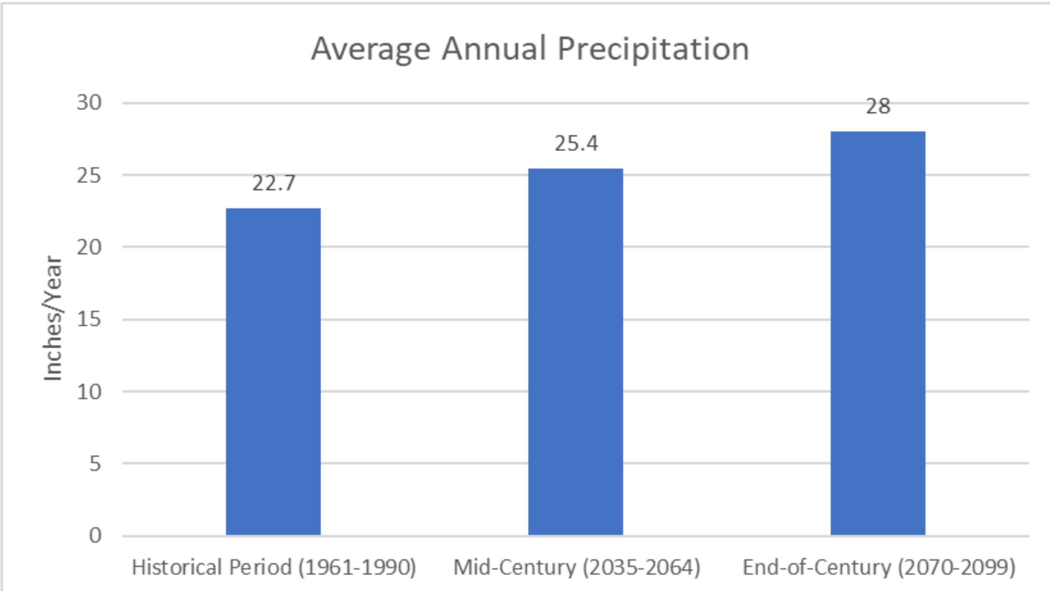
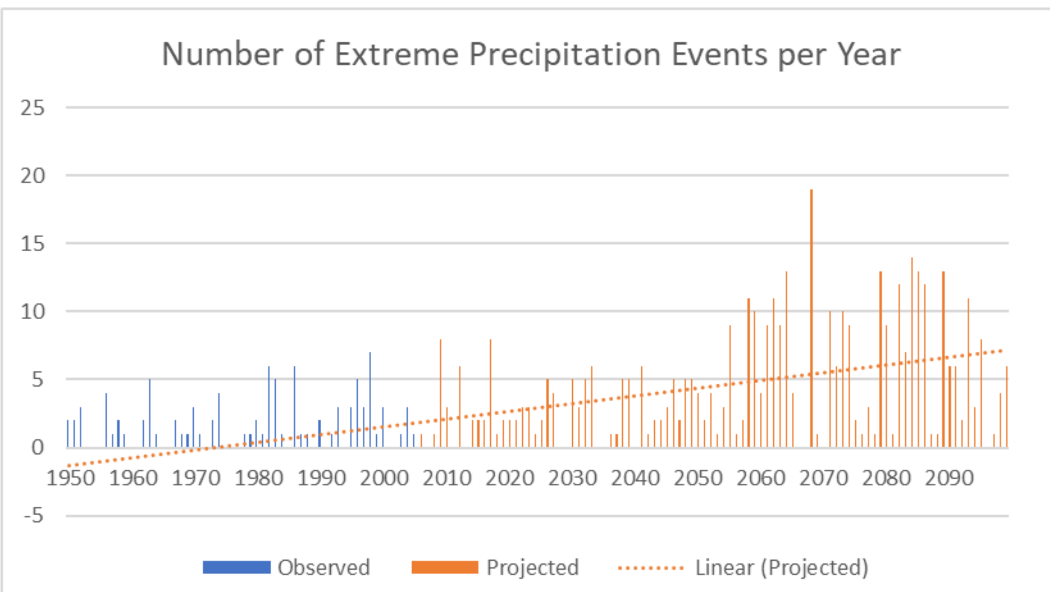
[59] California's Fourth Climate Change Assessment, San Francisco Bay Area Region Report, https://www.energy.ca.gov/sites/default/files/2019-11/Reg_Report-SUM-CCCA4-2018-005_SanFranciscoBayArea_ADA.pdf.

Chart 2-16: Average Annual Precipitation



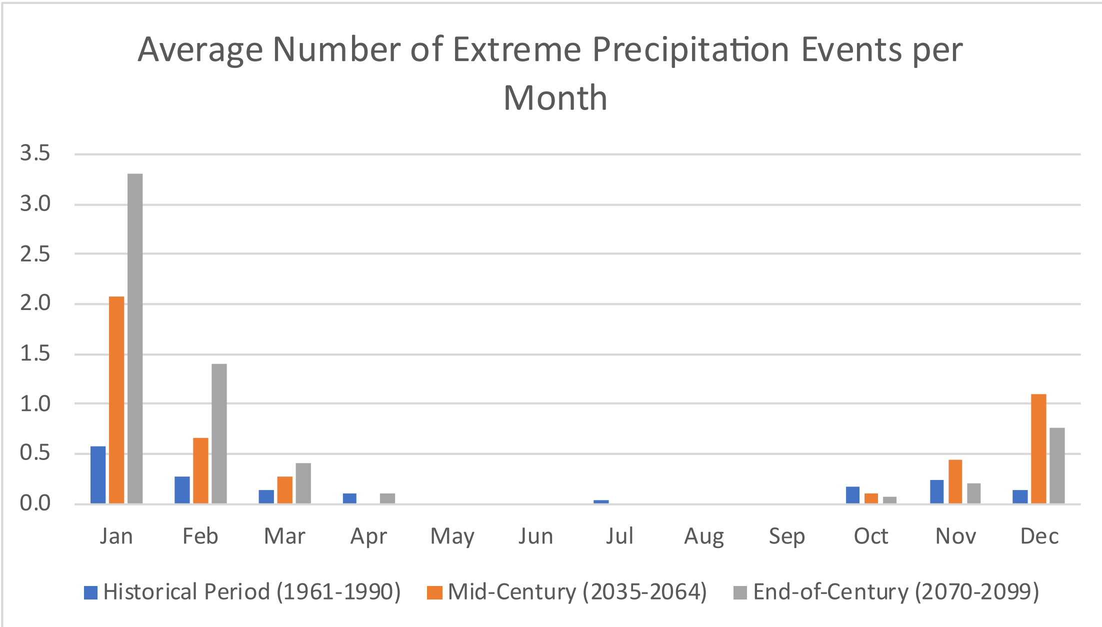
Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. There is a projected approximately equal jump in annual precipitation between the historical trends and mid-century and between Mid- and end-of-century.

Chart 2-17: Number of Extreme Precipitation Events Per Year



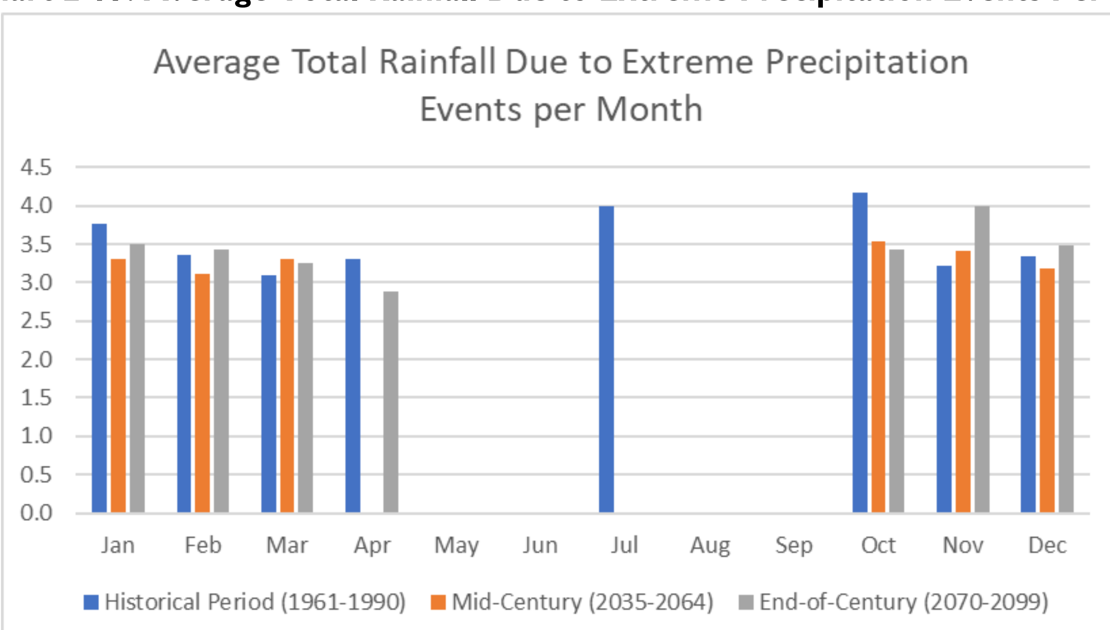
Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. A high degree of variability in the number of extreme rainfall events is projected to continue into the future. However, the dotted linear trendline illustrates, the amount of precipitation that falls during extreme events each year is projected to gradually increase.

Chart 2-18: Average Number of Extreme Precipitation Events Per Month



Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The number of extreme precipitation events occurring in January and February is projected to increase dramatically by the end-of-century; the number of extreme rain events occurring in October through December may rise at mid-century but taper off by the century's end.

Chart 2-19: Average Total Rainfall Due to Extreme Precipitation Events Per Month



Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the City of Oakland. The amount of precipitation that falls during extreme events in January and February is projected to be roughly the same by mid-century and end-of-century. In November, the amount of precipitation falling during extreme events is projected to rise by mid-century and end-of-century.

Secondary Impact: Flooding

The City of Oakland's watershed consists of 15 main creeks, over 30 tributaries, Lake Merritt, and the Oakland Estuary. The City of Oakland is subject to riverine flooding, flash flooding, tidal flooding, and stormwater flooding. According to FEMA's December 21, 2018, Flood Insurance Study (FIS), the City of Oakland drainage systems are adequate to carry low frequency storm runoff. However, with larger storms, general flooding occurs. Principal flood problems are due to inadequate capacity of the open channel or underground conduit system, or debris-plugged culverts and bridges. Generally, shallow flooding results, occurring primarily in the lower residential and industrial areas close to the shoreline.

The following are excerpts from FEMA's December 21, 2018, Flood Insurance Study (FIS) for Alameda County as the principal flood problems for the City of Oakland:

> *In the City of Oakland, many of the storm drain facilities are natural creeks meandering through residential areas. Natural vegetation growth; man-deposited debris; and encroachment of buildings, bridges, and other structures into the floodway contribute to the flood problems. In general, the drainage systems are adequate to carry low frequency storm runoff. However, with larger storms, general flooding occurs.*
>
> *There is little record of past flooding. Principal flood problems are due to inadequate capacity of the open channel or underground conduit, or debris-plugged culverts and bridges. Generally, shallow flooding results, occurring primarily in the lower residential and industrial areas close to the shoreline. Lake Merritt tidal lagoon was a source of flooding in the past. However, since the construction of the 7th Street Pump Station, the 1-percent annual chance flood is contained.*

Flood hazards are mapped by the Federal Emergency Management Agency (FEMA) as part of the National Flood Insurance Program. The 100-year Flood Zone, which has a 1 percent annual chance flood risk, and 500-year Flood Zone, which has a 0.2 percent annual chance flood risk, are depicted in Figure 2-3: Flood Hazard Zones. The primary areas of flooding in Oakland are along the shoreline of the San Francisco Bay, Oakland Estuary, and San Leandro Bay. There is also flooding associated with Lake Merritt and Glen Echo Creek, as well as Arroyo Viejo, Lion, Sausal, and Peralta Creeks. The areas near these bodies of water are at the most risk of being impacted during flood events. Most of the city's developed shoreline is not within the current 100-year Flood Zone, except the north part of the Oakland International Airport.

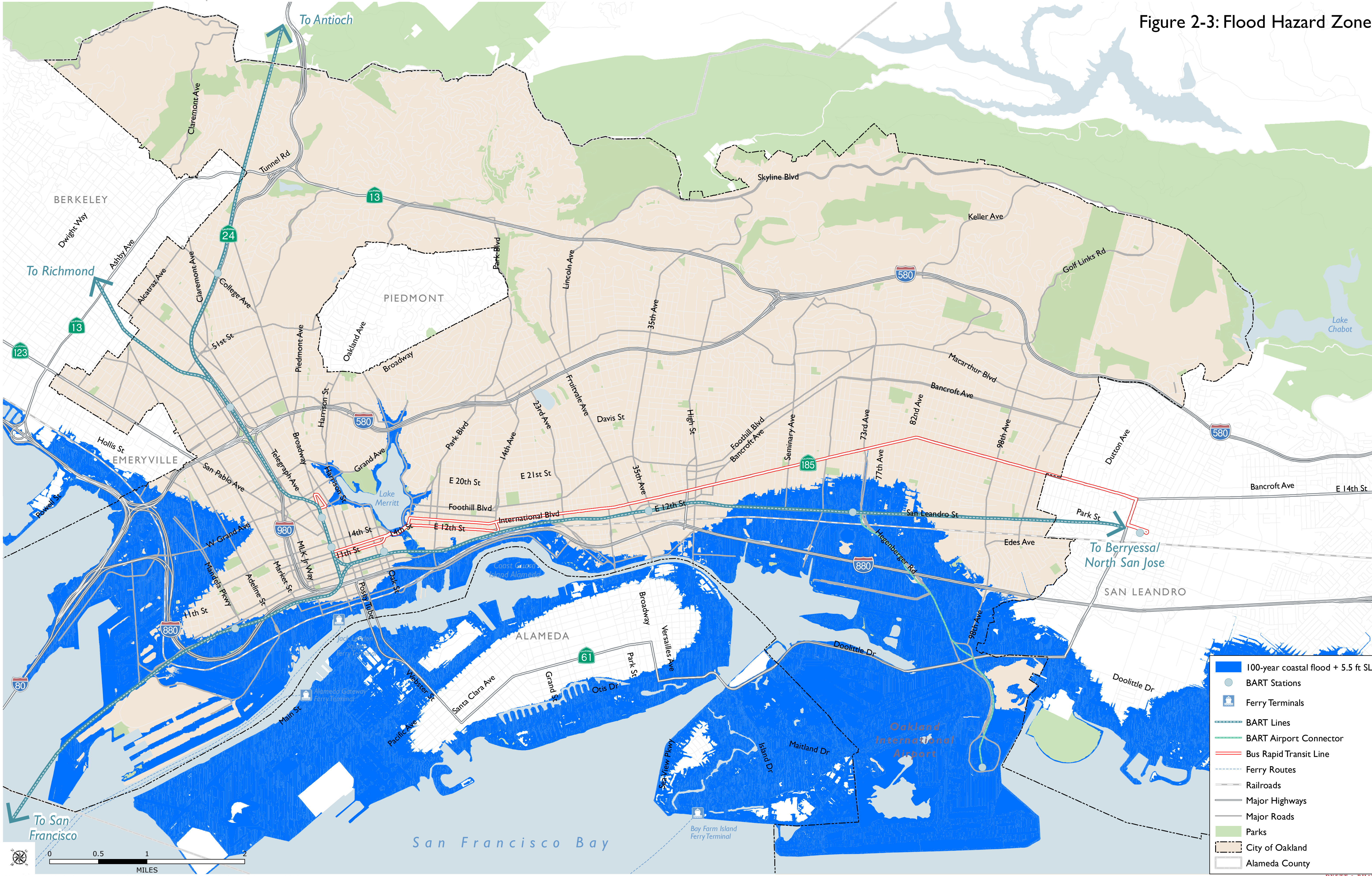
The California Department of Water Resources' Division of Safety of Dams reviews and approves inundation maps for extremely high, high, and significant hazard dams. There are four dams in Oakland that are considered extremely high hazard dams: Lake Temescal, Central, Dunsmuir Reservoir, and Chabot. Piedmont and Seneca dams are also in the vicinity, but they are considered a low hazard and do not have associated inundation maps. Figure 2-4: Dam Breach Inundation Area depicts the inundation areas for Lake Temescal, Central, Dunsmuir Reservoir, and Chabot dams.

Historically, flooding has been the most frequent natural hazard occurring in the Oakland region. Since 1950, the National Climatic Data Center (NCDC) reported flood events, 26 of which were flash floods, within Alameda County, amounting to a total of $18,349,000 in lost property damages. As described in the City of Oakland 2021 – 2026 Local Hazard Mitigation Plan (LHMP), Alameda County and the communities within it have experienced 12 flooding events since 1969 for which federal disaster declarations were issued. Many flood events do not trigger federal disaster declaration protocol but have significant impacts on their communities. Large floods can result in multiple severe and widespread impacts including damage to electric and transportation infrastructure, destruction of homes and businesses, increased rates of flood-borne disease, and loss of life.

Severe flooding in the region is often the result of a combination of topographic features; severe weather or excessive rainfall; and infrastructure characteristics such as inadequate stormwater drainage and high levels of impervious surface. Stormwater flooding is most likely to occur in areas with high levels of impervious surface and in places where stormwater infrastructure is impaired or inadequate.[60]

[60] City of Oakland 2021 – 2026 LHMP

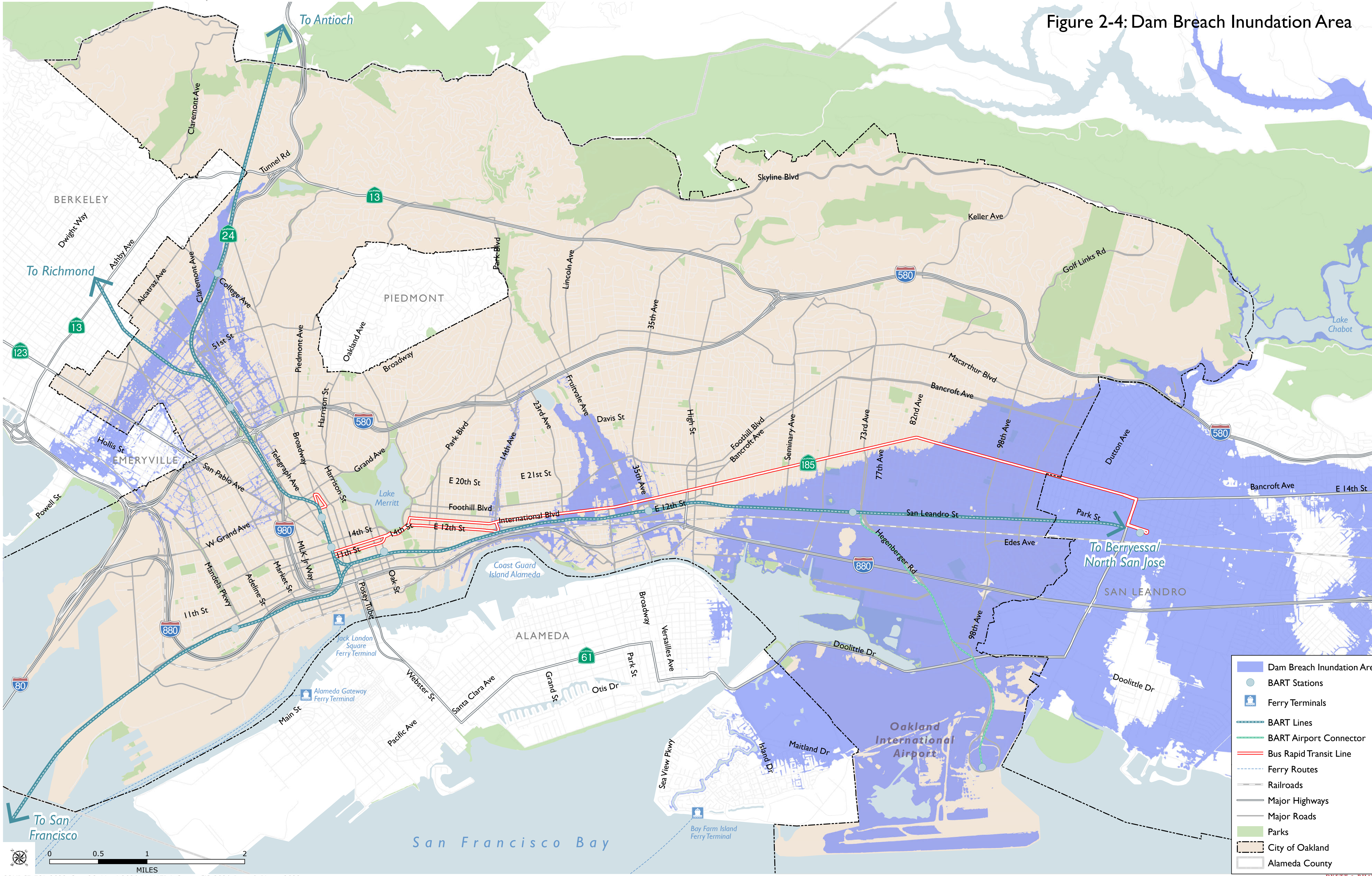
Figure 2-3: Flood Hazard Zones



SOURCE: ESA, 2022; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

DYETT & BHATIA Urban and Regional Planners

Figure 2-4: Dam Breach Inundation Area



SOURCE: ESA, 2022; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

Flooding can have negative impacts on infrastructure integrity and human health. Flooding impacts transportation infrastructure, inhibiting the movement of vehicles and increasing accident rates,[61] and can damage electricity and telecommunications infrastructure, leading to service outages.[62, 63] Floodwaters can also inundate important infrastructure such as sewer systems, water treatment facilities, and hazardous materials facilities, leading to contamination.[64, 65] These impacts can take extensive time and resources to address, meaning that a flooded area may continue to experience flooding impacts for many months after the initial flood event. Damage to transportation networks, businesses, and related infrastructure may impede workers' ability to get to work and adversely affect local employment opportunities and business revenues. Ability to reach work and other key services may be especially significant for those who rely on public transportation.[66]

Flood waters can contain myriad hazardous substances including dirt, oil, animal waste, and industrial chemicals. These waters can overwhelm sanitary sewer lines, backing up wastewater in low-lying areas and homes and providing a breeding ground for bacteria such as E. coli. Water intrusion into buildings can result in mold contamination, leading to indoor air quality problems and exacerbation of asthma, allergic reactions, and respiratory infections. Even as floodwaters begin to dissipate, remaining pools of stagnant water can provide breeding grounds for mosquitoes.[67] Exposure to floodwater can thus increase risk of exposure to viral and bacterial-borne illnesses.

Flooding can also result in forced evacuation, which may strain local and regional emergency response resources and disrupt family and community stability.[68] Indeed, extreme climate events, including major storms and flooding, have been shown to be associated with mental health

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[61] Mitsakis E, Stamos I, Diakakis M, Salanova Grau JM. "Impacts of high-intensity storms on urban transportation: applying traffic flow control methodologies for quantifying the effects." *International Journal of Environmental Science and Technology* Apr 10 2014. May 11 2020: https://link.springer.com/article/10.1007/s13762-014-0573-4.

[62] Lane K, Charles-Guzman K, Wheeler K, Abid Z, Graber N, Matte T. "Health Effects of Coastal Storms and Flooding in Urban Areas: A Review and Vulnerability Assessment." *Journal of Environmental and Public Health* May 30 2013. May 11 2020: https://www.hindawi.com/journals/jeph/2013/913064/.

[63] Porter K., et al., "Overview of the ARkStorm Scenario." United States Geological Survey (2010). July 1 2020: https://pubs.usgs.gov/of/2010/1312/.

[64] Rudolph L, Harrison C, Buckley L, North S. "Climate Change, Healthy, and Equity: A Guide for Health Departments." Public Health Institute, American Public Health Association (2018). May 11 2020: https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79.

[65] Porter K., et al., "Overview of the ARkStorm Scenario." United States Geological Survey (2010). July 1 2020: https://pubs.usgs.gov/of/2010/1312/.

[66] *2021 Local Hazard Mitigation Plan*. City of Oakland, June 2021. https://cao-94612.s3.amazonaws.com/documents/2021-07-01_OaklandHMP_AdoptedFinal-1.pdf

[67] Sacramento County, "2016 Sacramento Countywide Local Hazard Mitigation Plan Update." 2016.

[68] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/11/.

consequences, exacerbating pre-existing conditions and increase incidence of stress, post-traumatic stress disorder, anxiety, and depression.[69] By disrupting access to health services, these extreme events can continue to adversely impact health even after the event has passed.[70]

Groups especially vulnerable to the health effects of flooding include the older adults, pregnant women, people with preexisting mental illness, the poor, unhoused communities, tribal and Indigenous communities, and emergency responders.

Secondary Impact: Geological Impacts

Above average and extreme rainfall can lead to erosion, landslides, and soil liquefication. When the ground is saturated with water, a major storm can cause a landslide, liquifying the soil and spreading mud and debris over a large area.

Development of vacant land over time has increased the volume and velocity of storm water runoff during storms and the system can often be overwhelmed by heavy rains. Storm runoff, particularly during high-intensity storms, can lead to erosion and transport and redistribution of soils, sediments, and rock materials. Such activities could result in significant impacts to local species and habitats and pose a risk to human health and structures. Landslides triggered by severe storms have caused numerous casualties and hundreds of millions of dollars in damage across California.[71]

The Oakland Hills are particularly susceptible to landslides and hillside erosion that can be associated with high-intensity storms. Providing adequate stormwater runoff management in steep terrain, with some areas that lack curbs, gutters, inlets, and pipes, is a complex and challenging problem.

Unlike many other cities, Oakland does not have regulations that limit density based on slope and has established many small legal lots in the Hills, the majority dating back to the 19th century. Most of the storm drainage system was built 60 to 80 years ago, and in some areas the system is near the end of its useful life. This density of development and state of existing infrastructure in the Hills contributes to increased stormwater runoff volumes and velocities related to the increased amount of impervious surfaces (buildings, driveways, roads, etc.)

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[69] Lane K, Charles-Guzman K, Wheeler K, Abid Z, Graber N, Matte T. "Health Effects of Coastal Storms and Flooding in Urban Areas: A Review and Vulnerability Assessment." *Journal of Environmental and Public Health* May 30 2013. May 11 2020: https://www.hindawi.com/journals/jeph/2013/913064/.

[70] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/14/.

[71] Porter K., et al., "Overview of the ARkStorm Scenario." United States Geological Survey (2010). July 1 2020: https://pubs.usgs.gov/of/2010/1312/.

Secondary Impact: Severe Winds

The strong winds that can occur during heavy storms can damage structures and pose a threat to electricity infrastructure. Wooden crossbars and pole-mount transformers on distribution-voltage utility poles can be damaged by wind speeds as low as 60 miles per hour. Moderate winds can also cause lines to sway, touch, and cause cross-phase shorting.[72] Individuals living in mobile homes are especially vulnerable to the effects of high winds.[73] In addition, the Oakland Hills are at a greater likelihood of experiencing property and infrastructure damage from falling trees and utility pole. Downed trees can also exacerbate flooding by diverting creek flow and allowing water to flow over or severely erode creek banks.

Secondary Impact: Changes in Winter Snowpack

Historically, the Sierra snowpack and its spring and summer snowmelt has been a key part of the water planning process in the Oakland region and throughout the watersheds of the Sierra Nevada. California's municipalities, industries, and ecosystems rely on the gradual melting of the Sierra snowmelt to provide a reliable supply of summertime freshwater and hydroelectric power.[74] The EBMUD water supply system collects, transmits, treats, and distributes high-quality water from its primary water source, the Mokelumne River watershed in the Sierra Nevada, to its customers in the San Francisco East Bay Area.[75] As temperatures increase, more precipitation will fall as rain instead of snow and snowmelt will occur earlier in the year.[76, 77] Statewide, average April snow water equivalence, or the depth of water that would occur if all the snow were melted, has been 2.2 inches between 1961 and 1990. By the middle of this century, this number could decline to between 1.3 and 1.1 inches. By the end-of-century, April snow water equivalence is projected to be between 1.0 and 0.6 inches (Chart 2-20).

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[72] Ibid.

[73] "Severe Weather 101: Damaging Winds Basics." The National Severe Storms Laboratory. July 1 2020: https://www.nssl.noaa.gov/education/svrwx101/wind/.

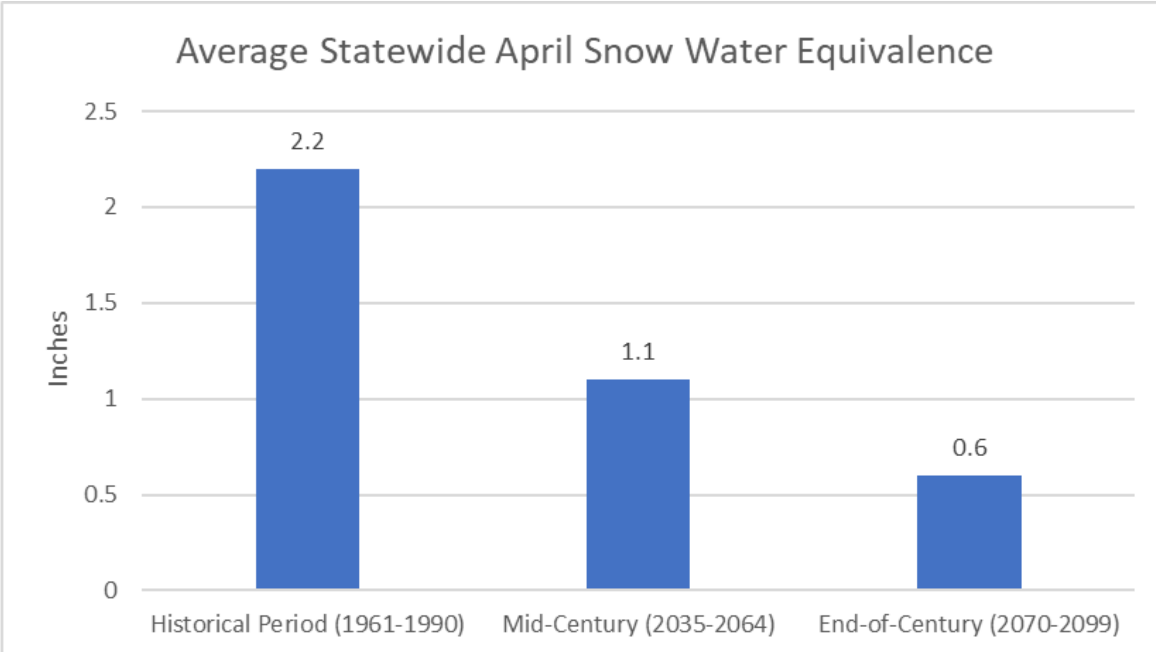
[74] Meisen P, Phares N. "Impacts of Climate Change on California's Water Supply." Global Energy Network Institute (2011). May 6 2020: https://www.geni.org/globalenergy/research/impact-of-climate-change-on-californias-water-supply/Impacts%20of%20Climate%20Change%20on%20California%92s%20Water%20Supply.pdf

[75] East Bay Municipal Utility District, Urban Water Management Plan 2020. file:///C:/Users/clare.DB/Downloads/UWMP-2020-FINAL-bookmarks.pdf.

[76] United States Department of the Interior Bureau of Reclamation, Reclamation Managing Water in the West. West-Wide Climate Risk Assessment Sacramento and San Joaquin Basins Climate Impact Assessment (2014). Nov 8 2019: https://www.usbr.gov/watersmart/baseline/docs/ssjbia/ssjbia.pdf.

[77] Reich KD, Berg N, Walton DB, Schwartz M, Sun F, Huang X, Hall A. "Climate Change in the Sierra Nevada: California's Water Future." UCLA Center for Climate Science (2018). May 6 2020: https://www.ioes.ucla.edu/wp-content/uploads/UCLA-CCS-Climate-Change-Sierra-Nevada.pdf

Chart 2-20: Average Statewide April Snow Water Equivalence (Inches)



Created using historical and projected precipitation data from Cal-Adapt. Projected data was generated for the high emissions (RCP 8.5) scenario and the averaged (CanEMS2) climate model for the State of California. Snow water equivalence is projected to decline steadily through the end-of-century.

The Sierra winter snowpack plays a pivotal role in regulating water availability throughout the State by providing a steady supply of freshwater that can be stored in dams, supplementing the scant summer rainfall, and used to produce electricity. Disruption to the processes that ensure adequate snow supply may therefore have a significant impact on energy generation, water availability, flood risk, and ecosystem health throughout California and the Oakland region.[78] Higher levels of Sierra rainfall and faster rates of snowmelt produce quantities of water that may exceed the State's reservoir capacity and therefore cannot be effectively stored for later consumption or used to generate electricity,[79, 80] while increasing risk of flooding. Earlier snowmelt will reduce the amount of water available for consumption during the summer, potentially leading to water scarcity.

[78] East Bay Municipal Utility District, 2014 Climate Change Monitoring and Response Plan file:///C:/Users/clare.DB/Downloads/2014_Climate_Change_Monitoring_and_Response_Plan%20(1).pdf.

[79] Meisen P, Phares N. "Impacts of Climate Change on California's Water Supply." Global Energy Network Institute (2011). May 6 2020: https://www.geni.org/globalenergy/research/impact-of-climate-change-on-californias-water-supply/Impacts%20of%20Climate%20Change%20on%20California%92s%20Water%20Supply.pdf

[80] Reich KD, Berg N, Walton DB, Schwartz M, Sun F, Huang X, Hall A. "Climate Change in the Sierra Nevada: California's Water Future." UCLA Center for Climate Science (2018). May 6 2020: https://www.ioes.ucla.edu/wp-content/uploads/UCLA-CCS-Climate-Change-Sierra-Nevada.pdf

Reductions in winter snowpack are associated with declines in summer soil moisture content, which increases wildfire risk [81] and reduces agricultural yields resulting in subsequent food insecurity. Additionally, reduced water flow during summer and fall months may lower water quality via reduced levels of dissolved oxygen, higher detritus and bacterial content, and increased salinity.[82] Figure 2-5 and Figure 2-6 illustrate projected April snowpack levels at the mid- and end-of-century. The stark contrast in snowpack volume demonstrates the significant degree to which Oakland may experience limited access to vital Sierra snowpack water resources as the century unfolds.

Secondary Impact: Drought

Drought is a complex phenomenon that results from the long-term interaction of temperature, precipitation, snowpack retention, and other climate factors. Drought is associated with a number of ecosystem effects, including reduced soil moisture, increased risk of wildfire, and reductions in streamflow.[83] Other environmental and health impacts of drought include dust storms, flash flooding, lower crop yields, and reduced water quality.[84, 85] Periods of surface water scarcity also increase demand for groundwater, with attendant environmental consequences as described later in this chapter. Meanwhile, drought can increase the concentrations of industrial chemicals, heavy metals, and agricultural runoff contaminants in groundwater, increasing the risk of exposure among communities that rely of groundwater resources.[86]

Drought conditions have profound impacts on water availability across California. Industries and communities especially vulnerable to the effects of drought include the agricultural sector, hydropower industry, water-related businesses (such as sales of boats and fishing equipment),

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[81] Gergel DR, Nijssen B, Abatzoglou JT, Lettenaier DP, Stumbaugh MR. "Effects of Climate Change on Snowpack and Fire Potential in the Western USA. *Climatic Change* Feb 1 2017. May 6 2020: https://link.springer.com/article/10.1007/s10584-017-1899-y.

[82] Meisen P, Phares N. "Impacts of Climate Change on California's Water Supply." Global Energy Network Institute (2011). May 6 2020: https://www.geni.org/globalenergy/research/impact-of-climate-change-on-californias-water-supply/Impacts%20of%20Climate%20Change%20on%20California%92s%20Water%20Supply.pdf

[83] Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE, Cook ER. "Contribution of Anthropogenic Warming to California's Drought 2012-2014." *Geophysical Research Letters*, Aug 20 2015. May 7 2020: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015GL064924%4010.1002/%28ISSN%291944-8007.CALDROUGHT1.

[84] CalBRACE, Climate Change and Health Profile Report Sacramento County (2017).

[85] Rudolph L, Harrison C, Buckley L, North S. "Climate Change, Healthy, and Equity: A Guide for Health Departments." Public Health Institute, American Public Health Association (2018). May 11 2020: https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79.

[86] Rudolph L, Harrison C, Buckley L, North S. "Climate Change, Healthy, and Equity: A Guide for Health Departments." Public Health Institute, American Public Health Association (2018). May 11 2020: https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79.

rural populations, and those dependent on wells.[87] The soil drying and weakening caused by long-lasting droughts can also comprise levee integrity.[88]

A combination of drier soils and increased wildfire activity, which removes vegetation and other natural soil stabilizers, increases wind erosion, and causes unhealthy dust to be released into the air. Small dust particles can travel deep into the lungs and enter the bloodstream, where they can cause or exacerbate conditions such as asthma and bronchitis. Dust can also carry pesticides and heavy metals as well as viral, bacterial, and fungal pathogens.[89]

The exact timing, location, and duration of future droughts is difficult to predict. However, studies have shown that statewide shifts in precipitation patterns towards wetter winters and drier summers make drought-like conditions more likely.[90, 91]

As of 2022, the entire state of California continues to remain in extreme drought conditions. The driest winter months in 100 years mark the third year of drought for the state. January, February, and March of 2022 had the least rain and snow on record for any of these months in California. This is the state's second extreme drought in 10 years, indicating the impacts of a changing climate.[92]

Secondary Impact: Groundwater Supply

Oakland lies over the southwestern portion of California's Niles Cone Groundwater Basin, which provides groundwater to Alameda County. Groundwater recharge occurs primarily from local runoff from the Alameda Creek Watershed, with additional recharge from water released from the South Bay Aqueduct. Local runoff from the Alameda Creek watershed accounts for about 40 percent of the Alameda County Water District's total water supply and is used to recharge the

[87] *2021 Local Hazard Mitigation Plan*. City of Oakland, June 2021. https://cao-94612.s3.amazonaws.com/documents/2021-07-01_OaklandHMP_AdoptedFinal-1.pdf

[88] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/3/.

[89] Constible J, Chang B, Morganelli C, Blandon N. "On the Front Lines: Climate Change Threatens the Health of America's Workers." Natural Resources Defense Council Jun 2020. July 31 2020: https://www.nrdc.org/sites/default/files/front-lines-climate-change-threatens-workers-report.pdf.

[90] Swain DL., Langenbrunner B., Neelin JD., Hall A., "Increasing precipitation volatility in twenty-first-century California." *Nature Climate Change* (2018).

[91] Mann ME, Gleick PH. "Climate Change and California Drought in the 21st Century." *PNAS* Mar 31 2015. May 7 2020: https://www.pnas.org/content/112/13/3858.short.

[92] California, State of. "Current Drought Conditions." *California Drought Action*, drought.ca.gov/current-drought-conditions/.

aquifers of the Niles Cone Groundwater Basin; studies have shown that regional rates of groundwater extraction increase under drought conditions.[93, 94]

Streamflow declines and changes in precipitation patterns anticipated under continued global climate change may increase demand for groundwater. There are numerous economic and ecosystem effects associated with groundwater overdraft, including higher groundwater pumping costs, decreased streamflow, land surface subsidence, and loss of wetland ecosystems.[95, 96] While the City's groundwater supplies are subject to continued extensive monitoring, protection, and enhancement activities and major overdrafts are not anticipated,[97] some of these consequences of groundwater overdraft may become more likely over the course of the 21st century.

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[93] Alameda County Water District (ACWD) Niles Cone Groundwater Basin https://www.acwd.org/380/Niles-Cone-Groundwater-Basin.

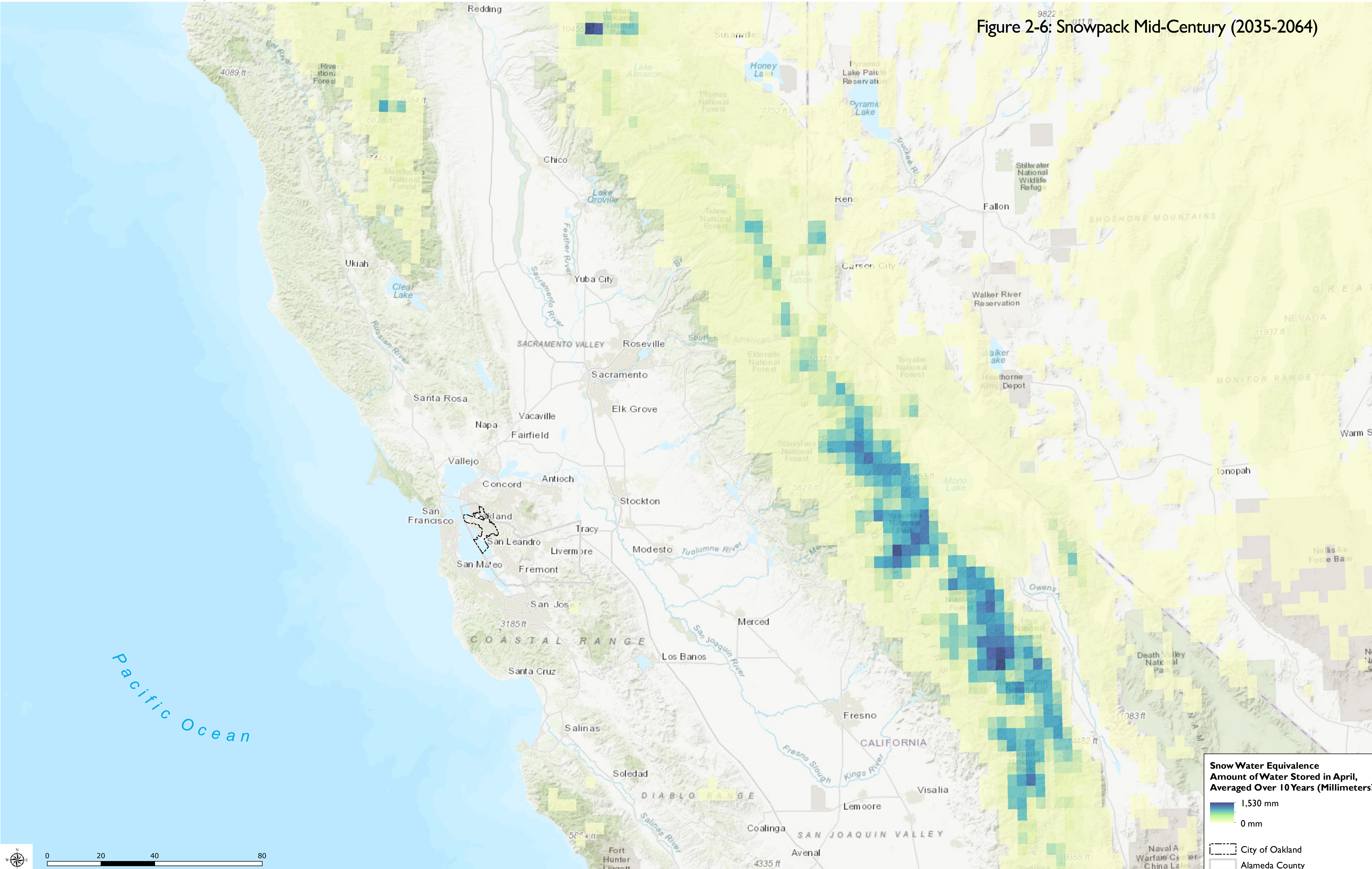
[94] Xiao M, Koppa A, Mekonnen Z, Pagan BR, Zhan S, Cao Q, Aierken A, Lee H, Lettenmaier DP. "How Much Groundwater Did California's Central Valley Lose During the 2012-2016 Drought?" *Geophysical Research Letters*, Apr 19, 2017. May 7 2020: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017GL073333.

[95] Famigletti JS. "The Global Groundwater Crisis." *Nature Climate Change* Oct 29 2014. May 7 2020: https://www.nature.com/articles/nclimate2425

[96] Lund JR, Harter T. "California's Groundwater Problems and Prospects." *California Water Blog* Jan 30 2013. May 7 2020: https://californiawaterblog.com/2013/01/30/californias-groundwater-problems-and-prospects/.

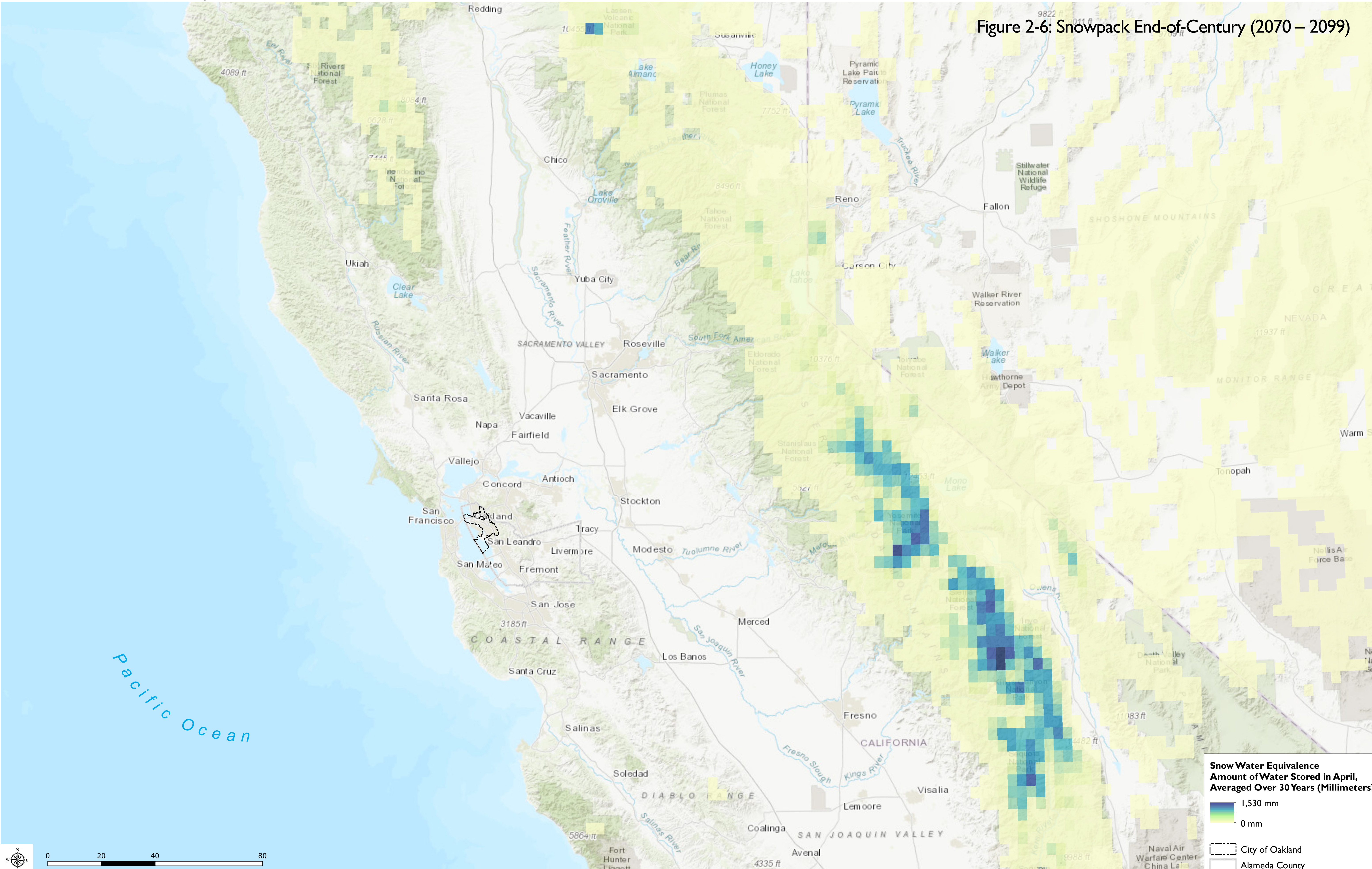
[97] Alameda County Water District (ACWD) Niles Cone Groundwater Basin https://www.acwd.org/380/Niles-Cone-Groundwater-Basin.

Figure 2-6: Snowpack Mid-Century (2035-2064)



SOURCE: CalAdapt/UC Berkeley, 2016; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

DYETT & BHATIA Urban and Regional Planners



SOURCE: CalAdapt/UC Berkeley, 2016; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

PRIMARY IMPACT: WILDFIRE

Historically, wildfire has exhibited a cyclical pattern within the State of California—some years may see intense wildfire while others may not. As wildfire emerges from a variety of climate conditions including type of vegetative cover, precipitation, and temperature, wildfire severity will continue to fluctuate over time. However, climate change will favor many of the climatic conditions that make wildfire more likely, meaning that average wildfire intensity will gradually increase. Wildfire is associated with secondary impacts such as smoke production and air quality reductions, reductions in soil and water quality, landslides and erosion, and impacts to health, energy, and transit systems, as discussed later in this chapter and Table 2-4.

Table 2-4: Wildfire

Temporal Extent	Wildfire extent and severity is projected to exhibit high levels of variability, but generally increase over time. Historically, fire season has extended from early spring through late fall. Fire season may expand in the future
Spatial Extent	The Oakland Hills are located in Very High and High Fire Hazard Severity Zones. However, the entire city may be subject to wildfire smoke originating from across the region
Permanence	The overall trend of increase wildfire intensity is fairly certain, although there will be year-to-year variability
Level of Disruption	Moderate
Level of Uncertainty	Moderate

California has an extensive history of wildfires, with large-scale, highly damaging fires becoming increasingly common. Fourteen of California's twenty largest fires have occurred since the year 2000, damaging 3,095,457 acres of land and 26,531 structures. Three of these largest fires occurred in 2018. The Camp Fire, occurring in November 2018, resulted in 18,804 structures damaged or destroyed and 85 deaths—the highest toll of any fire recorded.[98]

According to the City of Oakland 2021 – 2026 Local Hazard Mitigation Plan, wildfires are common in the Bay Area, with large historic wildfires recorded in 1961, 1962, 1964, 1965, 1970, 1981, 1985, 1988, and 1991. Between 1954 and 2020, FEMA issued major disaster (DR), emergency (EM) and fire management assistance declarations for two fire hazard-related events in Alameda County. The 1991 Oakland Hills fire killed 25 people, injured 150 others, burned 1,520 acres, destroyed thousands of homes, and caused $1.7 billion in losses. The high winds, steep terrain, and heavy fuel load made fighting this historic wildfire a major challenge.[99] Major wildfires that occur outside the city still have profound impacts on economies, health, and ecosystem function throughout the region.

[98] Cal Fire, "Top 20 Largest California Wildfires." 2019. Oct 29 2019: https://www.fire.ca.gov/media/5510/top20_acres.pdf.

[99] "Wildfire Event." *City of Oakland*, Jan. 2021, www.oaklandca.gov/resources/wildfire-event. Accessed 25 July 2022.

Wildfire risk is influenced by a number of climatic factors, including topography, fuel type and availability, temperature, soil moisture, as well as local typography, wind, and precipitation patterns. Climate change is expected to increase wildfire risk and intensity by increasing temperatures, reducing snowpack, increasing fuel (e.g., more dead vegetation due to drought), and altering precipitation patterns.[100] Large swings in rainfall from season to season can encourage vegetation growth in rainy periods, allowing more vegetation to accumulate. Meanwhile, high temperatures increase the rate of evapotranspiration in plants, making this vegetation drier and more prone to catching fire. High temperatures also reduce winter snowpack by encouraging precipitation to fall as rain instead of snow and prompting earlier snowmelt. These changes lead to longer and drier summers, during which wildfires may be more likely to occur.[101]

Across California, approximately 422,619 acres of land succumbed to wildfire per year between 1961 and 1990. The number of acres burned by wildfire per year is projected to increase to 587,886 acres per year by mid-century and may climb as high as 748,490 acres per year by the end-of-century, a 77 percent increase over historic levels. Within the Central Coast Climate Region that encompasses Oakland, an average of approximately 23,591 acres were burned in wildfire per year between 1961 and 1990. This value is projected to increase to between 32,729 and 33,804 acres by mid-century and between 34,051 and 35,365 acres per year by the end-of-century, about a 50 percent increase. Figure 2-7 and Figure 2-8 illustrate the projected increase in wildfire extent and severity that is projected to take place in Northern California as climate change progresses. A notable increase in the annual area affected by wildfire is projected to occur in the Oakland Hills. Wildfires occurring in the Sierra Nevada are also projected to increase in intensity.

Wildfires may pose a threat to the homes of those who live in the urban-wildland interface (UWI), areas where homes are built near or among lands prone to wildland fire.[102] At the UWI, structures and vegetation are sufficiently close that a wildfire could spread to a structure, or a structure fire could ignite vegetation.[103] Numerous factors can contribute to wildfire risk within the UWI, including type and distribution of vegetation, structure flammability, proximity to fire-prone vegetation, weather patterns, topography, lot size and structure density, and road construction.[104]

The Oakland Hills is one of the highest risk areas in the country for devastating UWI fires.[105] Figure 2-9 illustrates California Department of Forestry and Fire (CAL FIRE) maps areas, called Fire Hazard Severity Zones (FHSZs). Virtually the entire Oakland Hills are designated as a Very High FHSZ. Areas designated as UWI are mostly in the northern portions of the city and surrounding jurisdictions.

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[100] *2021 Local Hazard Mitigation Plan*. City of Oakland, June 2021. https://cao-94612.s3.amazonaws.com/documents/2021-07-01_OaklandHMP_AdoptedFinal-1.pdf

[101] Ibid

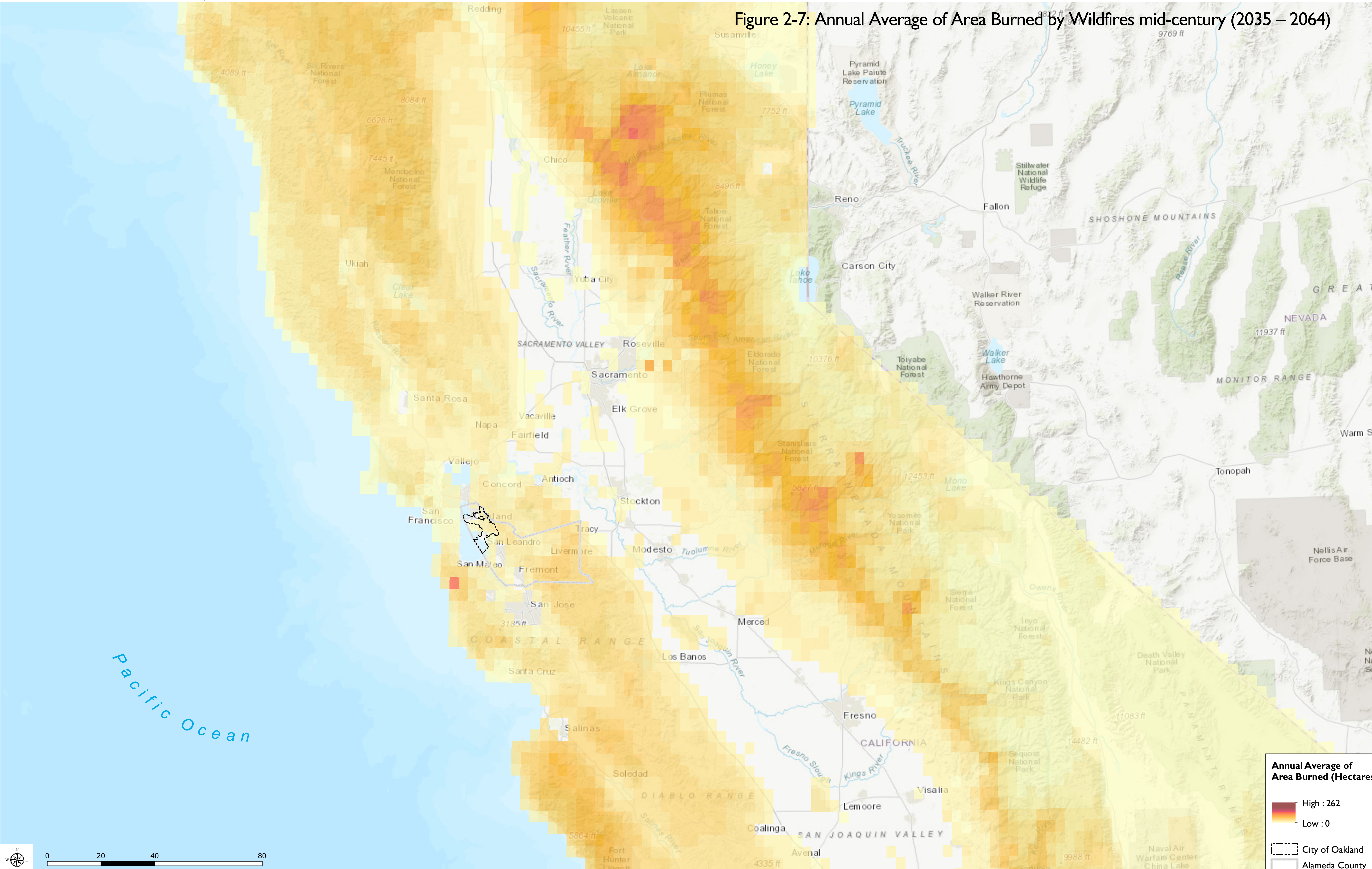
[102] International Association of Fire Chiefs, "Wildland Urban Interface." Oct 29 2019: https://www.wildlandfirersg.org/About/Wildland-Urban-Interface.

[103] *2021 Local Hazard Mitigation Plan*. City of Oakland, June 2021. https://cao-94612.s3.amazonaws.com/documents/2021-07-01_OaklandHMP_AdoptedFinal-1.pdf

[104] International Association of Fire Chiefs, "Wildland Urban Interface." Oct 29 2019: https://www.wildlandfirersg.org/About/Wildland-Urban-Interface.

[105] Dudek. 2019. Revised Draft City of Oakland, California Vegetation Management Plan. Prepared for City of Oakland Fire Department. November 2019.

Figure 2-7: Annual Average of Area Burned by Wildfires mid-century (2035 – 2064)



SOURCE: CalAdapt/UC Berkeley, 2016; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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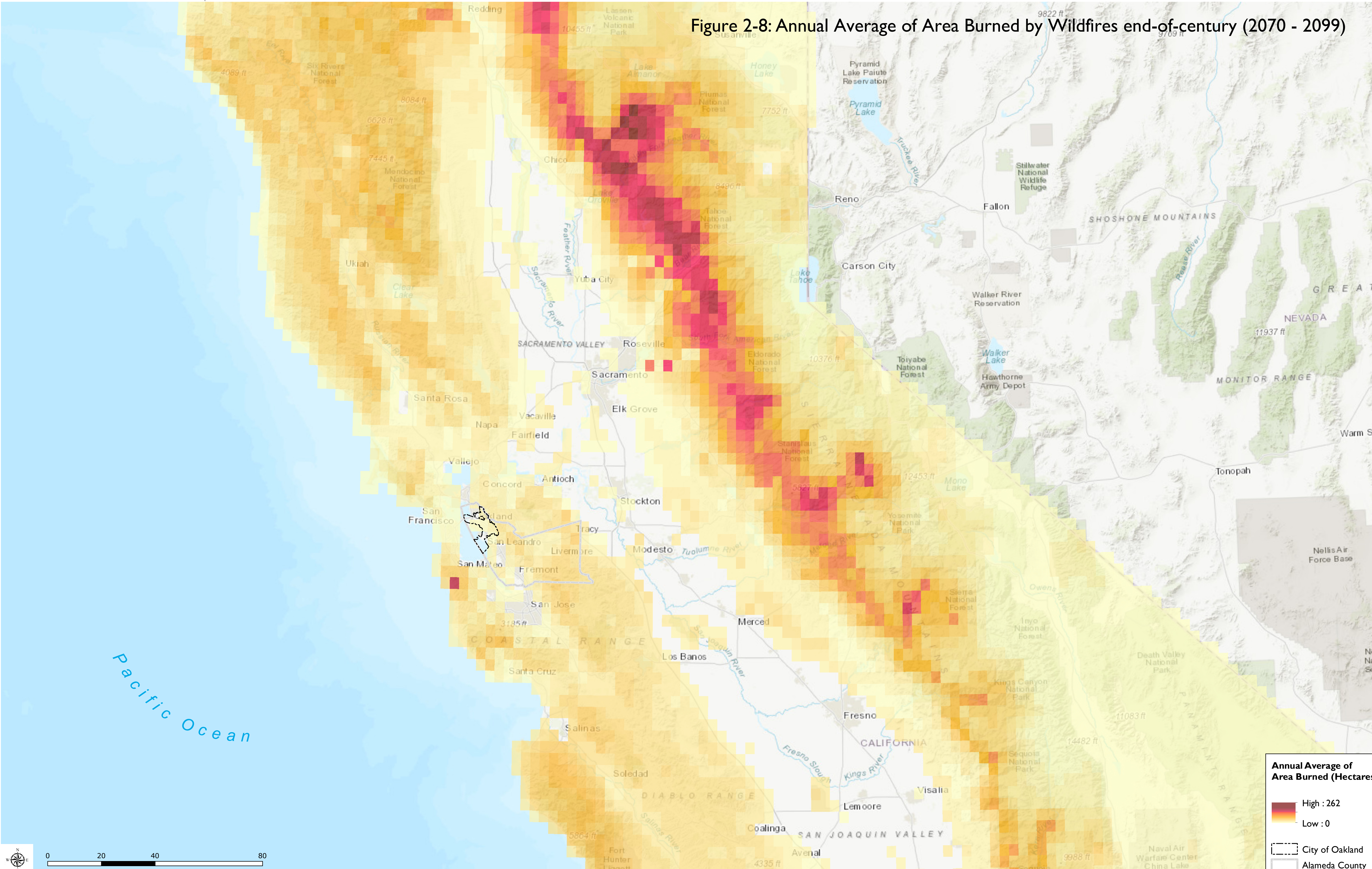
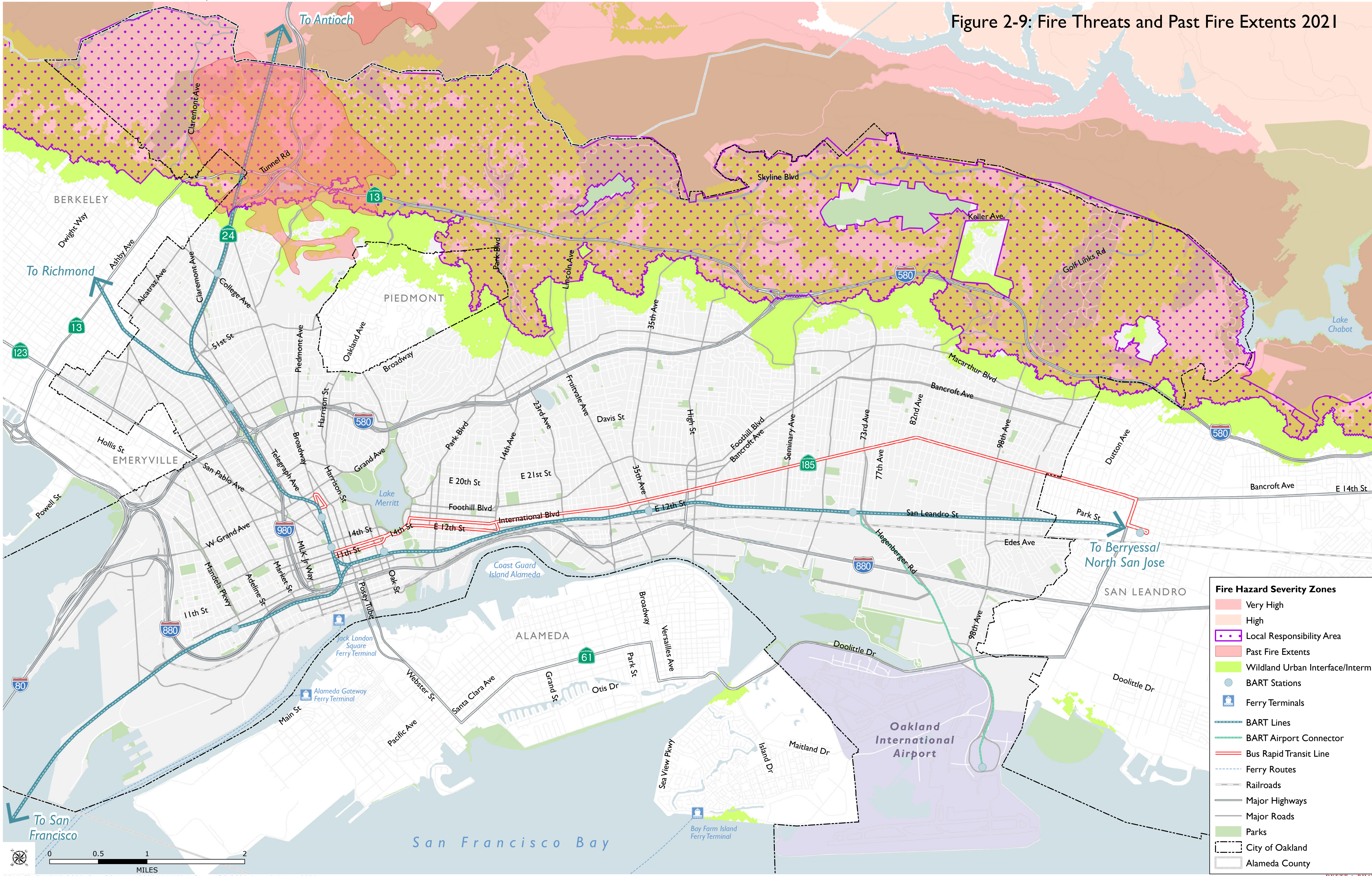


Figure 2-8: Annual Average of Area Burned by Wildfires end-of-century (2070 - 2099)

SOURCE: CalAdapt/UC Berkeley, 2016; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Figure 2-9: Fire Threats and Past Fire Extents 2021



SOURCE: CAL FIRE, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

While UWI area within the city is at significant risk to wildfires, the entire city will be impacted by wildfires occurring throughout the metropolitan region via impacts on air, water, and soil quality; damage to energy infrastructure and roads; and strain on local firefighting resources as the fire department is called to respond to fires across the region and State.

Secondary Impact: Air Quality

Residents and employees of Oakland's flatlands may not experience the direct impacts of wildfire the same way they might directly feel the immediate effects of heat waves, extreme rain events, and floods. However, wildfires are projected to increase in severity across Northern California, and their health impacts are not easily contained within City limits. In fact, particulate matter from wildfire can dissipate throughout the Oakland region and degrade air quality for extended periods of time.[106] Wildfires emit substantial quantities of particulate matter, carbon monoxide, nitrogen oxides, and volatile organic compounds.[107] The effects that wildfire smoke can have on Oakland's air quality are immense. Wildfire smoke can also cause adverse health effects including restricted breathing; eye irritation; aggravation of respiratory and cardiovascular diseases including asthma, Chronic Obstructive Pulmonary Disease (COPD), bronchitis, and pneumonia; and may increase cancer risk and impair immune function.[108, 109, 110]

Many of the chemicals released during wildfires are ozone precursors, chemicals that can interact to form ground-level ozone.[111] Populations exposed to ozone air pollution are at greater risk of dying prematurely, experiencing respiratory-related hospital admission, and contracting asthma.[112] The health impacts associated with air pollution exposure may be compounded by exposure to additional climate stressors such that, for example, the risk of dying from exposure to a given level of ozone

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106 City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

107 Centers for Disease Control and Prevention, "Wildfires." (2019). Oct 29 2019: https://www.cdc.gov/climateandhealth/effects/wildfires.htm.

108 Finlay SE., Moffat A., Gazzard R., Baker D., Murray, V. "Health Impacts of Wildfires." *PLos Currents*, Nov 2, 2012. Oct 29 2019: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3492003/.

109 U.S. Global Change Research Program, The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. (Washington, DC: 2016). Oct 29 2019: https://health2016.globalchange.gov/air-quality-impacts.

110 Cascio, WE. "Wildland Fire Smoke and Human Health." *Science of the Total Environment*, Dec 27, 2017. Apr 30, 2020:

111 United States Department of Agriculture, "Ozone Precursors." (2012). Oct 29 2019: https://www.climatesignals.org/sites/default/files/resources/ozone%20precursors.pdf.

112 U.S. Global Change Research Program, The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. (Washington, DC: 2016). Oct 29 2019: https://health2016.globalchange.gov/air-quality-impacts.

pollution may increase on warmer days.[113, 114] In addition to wildfire, conditions that favor high ozone levels include high temperatures, sunny skies, low humidity, and periods of low wind.[115, 116]

Unhoused populations; anyone living in substandard housing; young children; middle-aged and older adults; pregnant women; those with hypertension, diabetes, and COPD; and smokers are particularly sensitive to the health effects of smoke.[117, 118] African Americans have been found to experience higher rates of cardiovascular disease and asthma, which increase sensitivity to the health effects of smoke.[119] Some studies have also found associations between low socioeconomic status and health effects related to wildfire smoke exposure.[120] Low socioeconomic status is associated with a higher prevalence of preexisting diseases, limited access to medical care, and limited access to fresh food, all of which may contribute to susceptibility to the health effects of particulate matter exposure.[121] Members of the community such as outdoor workers and the homeless, who may not be able to remain indoors in order to reduce smoke exposure, are also at elevated risk for health impacts.

Many Oakland residents may be required to make behavioral or lifestyle changes to minimize exposure to poor air quality during wildfires. These changes, such as avoiding active transportation, spending less time outdoors, or avoiding public transit if facilities are not adequately ventilated, may have ripple effects on community health, energy use, and transportation-related emissions as residents may not be able to partake in daily exercise or may choose to replace alternative transportation with the use of private vehicles.

Figure 2-10 shows total annual average $PM_{2.5}$ concentrations throughout the city for the year 2018 in terms of micrograms per cubic meter (μg/m^3). The grid squares shown in the figure are 1-by-1-

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113 Ibid.

114 Orru H., Ebi KL., Forsberg. "The Interplay of Climate Change and Air Pollution on Health." *Current Environmental Health Reports*, Oct 28, 2017. Oct 29 2019: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5676805/.

115 U.S. Global Change Research Program, The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. (Washington, DC: 2016). Oct 29 2019: https://health2016.globalchange.gov/air-quality-impacts.

116 Orru H., Ebi KL., Forsberg. "The Interplay of Climate Change and Air Pollution on Health." *Current Environmental Health Reports*, Oct 28, 2017. Oct 29 2019: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5676805/.

117 Finlay SE., Moffat A., Gazzard R., Baker D., Murray, V. "Health Impacts of Wildfires." *PLos Currents*, Nov 2, 2012. Oct 29 2019: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3492003/.

118 Cascio, WE. "Wildland Fire Smoke and Human Health." *Science of the Total Environment*, Dec 27, 2017. Apr 30, 2020: https://www.sciencedirect.com/science/article/pii/S004896971733512X.

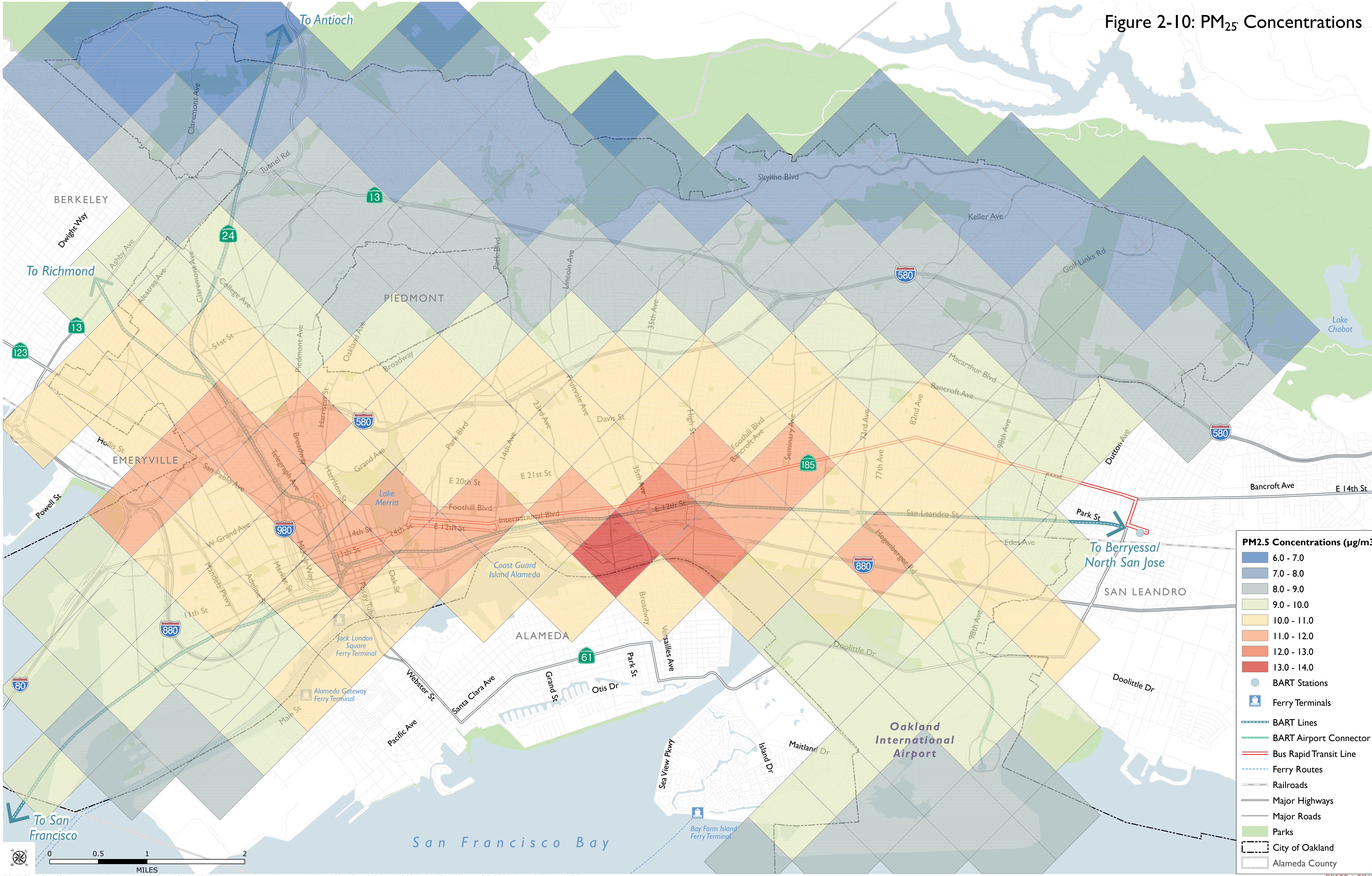
119 Rudolph L, Harrison C, Buckley L, North S. "Climate Change, Healthy, and Equity: A Guide for Health Departments." Public Health Institute, American Public Health Association (2018). May 11 2020: https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79.

120 Cascio, WE. "Wildland Fire Smoke and Human Health." *Science of the Total Environment*, Dec 27, 2017. Apr 30, 2020: https://www.sciencedirect.com/science/article/pii/S004896971733512X.

121 Sacks JD, Wichers Stanek L, Luben TJ, Johns DO, Buckley BJ, Brown JS, Ross M. "Particulate Matter-Induced Health Effects: Who is Susceptible?" *Environmental Health Perspectives,* Apr 1, 2011. Apr 30, 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1002255

kilometer squares, which is the modeling resolution of BAAQMD's regional pollutant transport model. Concentrations range from 6.2 μ/m3 in the Oakland Hills east of Interstate 13 to 13.6 μ/m3 near Interstate 880 at 29th Avenue. Concentrations of $PM_{2.5}$ are generally correlated with emissions sources since direct $PM_{2.5}$ disperses with distance from a source. However, it is important to understand that this chart shows total cumulative $PM_{2.5}$ concentrations from all emissions sources within the air basin, not just sources located within the city. For example, emissions from San Francisco and Richmond contribute to these concentrations. This figure, by identifying areas that already experience high exposure and sensitivity to air pollution, helps identify parts of the city that may experience especially high air pollution vulnerability during a wildfire.

Figure 2-10: $PM_{2.5}$ Concentrations



SOURCE: HCD AFFH Data and Mapping Resources - HCD & TCAC Opportunity Areas Mapping Analysis, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Secondary Impact: Water and Soil Quality

Even after a fire is put out, it can continue to have detrimental effects on the environment and surrounding communities. The infiltration capacity of soil is reduced following wildfire, increasing the risk of landslides and waterbody contamination.[122] Ash debris from wildfires may contain high levels of heavy metals such as arsenic, cadmium, copper, and lead, potentially causing long-term effects to soil and water quality.[123]

Further, Aqueous Film Forming Foams (AFFF) are PFAS-containing foams that are used to cool and suppress fire. Firefighters may use AFFF if there may be a liquid fuel in the structure or wildfire region, such as gas stations or oil cans. PFAS are widely used, long lasting chemicals, components of which break down very slowly over time. Scientific studies have shown that exposure to some PFAS in the environment may be linked to harmful health effects in humans and animals.[124] Thus, in the event of wildfire, PFAS may runoff or leach into surface and groundwater, presenting additional public health impacts.

Secondary Impact: Infrastructure Damage

Energy production and distribution are threatened by heat and wildfires. Physical infrastructure such as power lines or pipes in the direct path of a fire can suffer extensive damage. Transmission capacity is affected by high heat, smoke, and particulate matter, and lines may be shut down as a firefighting measure.[125] Wildfire in the Sierra Nevada may damage water and energy infrastructure upon which the Oakland region relies.[126]

Wildfire affects transportation infrastructure by causing road and airport blockages, closures, and reducing road visibility. Transportation services such as electric rail lines and traffic signals may also be affected by the disruptions to power service described above. Most roads would not be damaged except in the worse scenarios, and rail lines can also be damaged by wildfires that result in high heat.[127]

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[122] City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

[123] Finlay SE., Moffat A., Gazzard R., Baker D., Murray, V. "Health Impacts of Wildfires." *PLos Currents*, Nov 2, 2012. Oct 29 2019: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3492003/.

[124] Interstate Technology and Regulatory Council (IRTC). "Aqueous Film-Forming Foam (AFFF)." (2020). Jan 4, 2023: https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_AFFF_April2020.pdf.

[125] City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

[126] East Bay Municipal Utility District Urban Water Management Plan 2020 file:///C:/Users/clare.DB/Downloads/UWMP-2020-FINAL-bookmarks%20(1).pdf

[127] City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

Secondary Impact: Higher Demand for Fire Fighting and Support Services

The Oakland Fire Department is a full-time agency that provides fire and emergency services to the city. Twenty-five stations cover the city's 78 square miles including Oakland International Airport. Additionally, Oakland Fire is host to one of FEMA's 28 national Urban Search and Rescue teams, Task Force 4. Oakland Fire participates in mutual-aid county fire response and is part of the California Master Mutual Aid Agreement.[128] As the severity and frequency of wildfire increase across the Oakland region and beyond, municipalities throughout the state will experience increased demand for fire protection services and the City may experience increased demand for its fire protection services.

Increased levels of homelessness and higher housing costs have been reported following major California wildfires.[129, 130] Displaced residents from neighboring communities have the potential to increase demand for social support services in Oakland. Meanwhile, reductions in housing stock and increases in local demand may lead to elevated housing prices and exacerbate housing insecurity among lower income individuals and families.

PRIMARY IMPACT: SEA LEVEL RISE

Climate models anticipate that some degree of sea level rise in all areas that are connected to ocean bodies. As a bayfront City, sea level rise exacerbates flood risk and can affect the health of aquatic ecosystems and threaten the integrity of the coastal and low-lying urban areas in Oakland. The key characteristics of sea level rise's impact on the Oakland area are summarized in Table 2-5.

Table 2-5: Sea Level Rise

Temporal Extent	Projected to gradually increase over the course of the 21st century
Spatial Extent	The city's coastal and low-lying areas
Permanence	High
Level of Disruption	Moderate; effects may be more severe when coinciding with flooding and elevated groundwater levels
Level of Uncertainty	Low

Rising waters in the San Francisco Bay already affect Oakland with periodic flooding of low-lying shorelines, loss of valuable saltwater marshes, and saltwater impacts on wastewater treatment systems. When heavy rains are coupled with higher-than-normal tides, the high tides can slow the

[128] City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

[129] Raphelson S. "Wildfires Exacerbate Chronic Homelessness In Northern California." *NPR*, Dec 6, 2017. Apr 30 2020: https://www.npr.org/2017/12/06/568857057/wildfires-exacerbate-chronic-homelessness-in-northern-california.

[130] Levine AS. "After a California Wildfire, New and Old Homeless Populations Collide." *The New York Times*, Dec 3, 2018. Apr 30, 2020: https://www.nytimes.com/2018/12/03/us/california-fire-homeless.html.

drainage of runoff into the Bay, increasing the potential for urban stormwater flooding. As bay water levels continue to rise, the extent and frequency of flooding will increase. Areas once considered to be outside of the floodplain will begin to experience periodic coastal and/or urban flooding.[131]

In the last century, San Francisco Bay water levels have risen nearly eight inches.[132] Table 2-6 provides a range of estimates for Bay Area sea-level rise from the Oakland Preliminary Sea-Level Rise Road Map and Adapting to Rising Tides (ART) program considered in the City's 2021 – 2026 Local Hazard Mitigation Plan. Following from the sea-level rise (SLR) projections used in the Local Hazard Mitigation Plan, the 100-year coastal flood with 0.5 foot of SLR and 5.5 feet of SLR, respectively, provide a near-term and long-term indication of future flood hazards. For 0.5 foot of SLR (Figure 2-11), the city's exposure to 100-year coastal flooding remains similar to present day, with Oakland International Airport and the Jack London District being most at risk. A few other small sections of the city shoreline are also exposed to 100-year flood hazards. For 5.5 ft of SLR (Figure 2-12), which is estimated to have a 1-in-200 chance of occurring by 2090, the city's entire shoreline is threatened by coastal flooding during a 100-year event. These scenarios are indicative of the potential range of projected sea level rise impacts.

Table 2-6: Range of Estimates for Bay Area Sea-Level Rise

Year	Oakland Sea-Level Rise Road Map		Adapting to Rising Tides Scenarios	
	Total Rise	Annual Average	Total Rise	Annual Average
2050	11-24 inches	0.37 – 0.8 inches per year	48 inches	1.6 inches per year
2100	36-66 inches	0.45 – 0.825 inches per year	108 inches	1.35 inches per year

Sources: Resilient Oakland, 2017; ART, 2017

However, while anticipated sea-level rise and flood hazards are increasingly well-known to the City of Oakland, new research conducted by the San Francisco Estuary Institute, UC Berkeley, and the Pathways Climate Institute suggests that coastal areas also face considerable flood risk from groundwater intrusion.[133] In areas where sea water pushes the water table up

[131] City of Oakland 2021 – 2026 Local Hazard Mitigation Plan

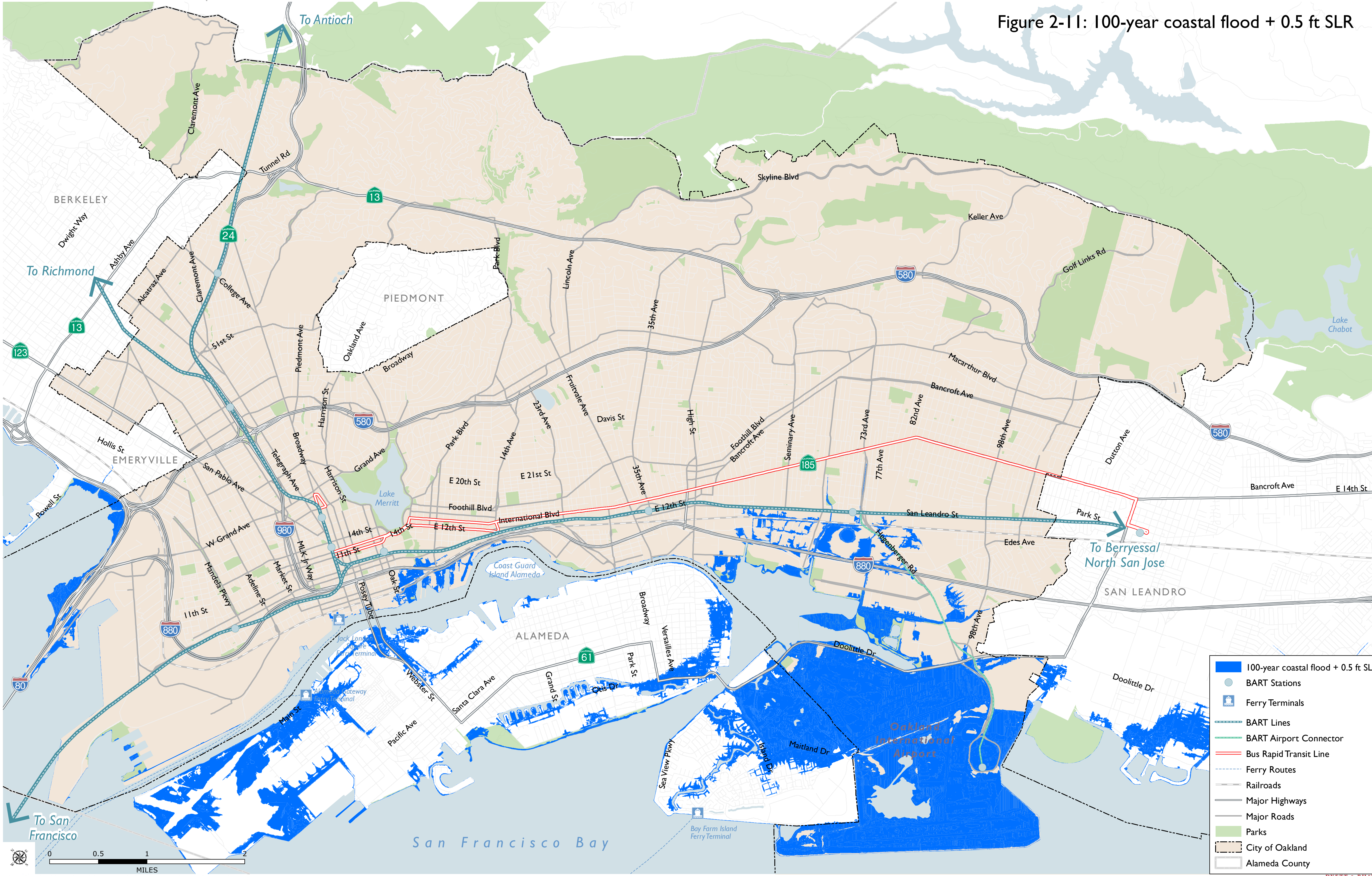
[132] National Oceanic and Atmospheric Administration (NOAA), 2018. Center for Operational Oceanographic Products and Services (CO-OPS), NOAA Sea-Level Trends 1987-2018, 2018. tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9414290.

[133] "Shallow Groundwater Response to Sea Level Rise | San Francisco Estuary Institute." *Www.sfei.org*, www.sfei.org/projects/shallow-groundwater-response-sea-level-rise. Accessed 25 July 2022.

towards—or above—the ground surface, water could intrude into and damage underground sewer pipes and systems. Over time, rising groundwater may emerge aboveground before coastal floodwaters overtop the shoreline, and groundwater infiltration and flooding can occur up to three miles from the shoreline. As soils below the groundwater surface become saturated, it reduces the ability of rainwater to infiltrate below the ground surface in permeable areas and creates more surface ponding after rain events. The rising groundwater table could also reduce the effectiveness of green infrastructure and reduce the conveyance capacity in tributaries and stormwater drainage channels in low-lying coastal areas. This suggests that inland areas of Oakland deemed safe by conventional sea level rise projections might still experience severe flooding and damage.[134] With groundwater intrusion scenarios, flooding is predicted to extend farther inland than current sea level rise and 100-year coastal flood event projections.

[134] Ibid

Figure 2-11: 100-year coastal flood + 0.5 ft SLR



SOURCE: ESA, 2022; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

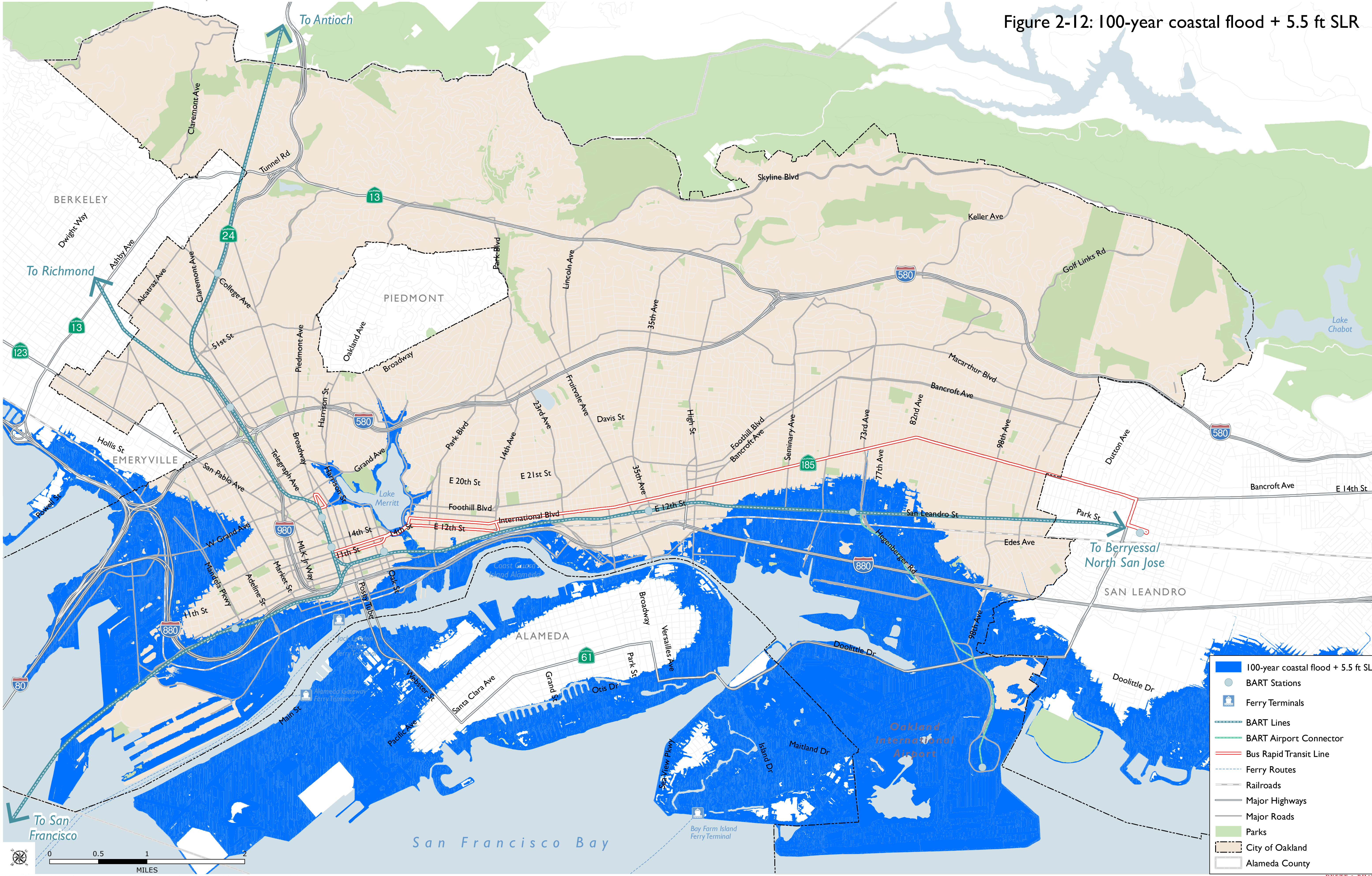


Figure 2-12: 100-year coastal flood + 5.5 ft SLR

SOURCE: ESA, 2022; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

3 Social Vulnerability

3.1 What is Social Vulnerability?

The health and economic impacts of climate change are not experienced equally, or in the same way, by all members of the population. Factors such as where people live, their access to food and reliable transportation, occupation, overall health, daily activities, and history of exposure to environmental burdens can all affect individual and community levels of exposure, degree of sensitivity, and adaptive capacity.[135] Climate change effects interact with a complex socio-cultural landscape in which various groups already experience different levels of access to economic, health, and political resources. Some of these resources include financial assets, stable housing, food, insurance, social services, transportation, communication skills, social networks, and the knowledge necessary to manage economic and climate risks. Historically, many of these resources have been out of reach to the socially marginalized.[136]

Within the United States, those groups that have been found to generally be more socially vulnerable to climate change include the poor, communities of color, older adults, young children, people with physical and mental illness, people with cognitive and physical disabilities, immigrants, those experiencing discrimination, the socially isolated, those with limited transportation options, and those with inadequate housing.[137, 138, 139] These groups of people experience elevated levels of climate vulnerability for several overlapping reasons. Some of these factors include:

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135 Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/11/.

136 Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, Winthrop R. "Explaining differential vulnerability to climate change: A social science review." *WIREs Climate Change* (2019). Nov 8 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

137 Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/14/.

138 U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

139 Benevolenza MA, DeRigne L. "The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature." *Journal of Human Behavior in the Social Environment* (2019). Nov 8 2019: https://www.tandfonline.com/doi/abs/10.1080/10911359.2018.1527739?journalCode=whum20.

Housing quality and location: Some populations have higher probabilities of living in risk-prone areas, areas with inadequate infrastructure, and areas with increased levels of air pollution.[140]

Nature of relationship with government: Members of communities of color, immigrants, and members of other groups that have historically been excluded from political decision-making processes or experienced harm as a result of institutional and environmental racism may be unwilling or unable to engage with government programs. This makes it more difficult for the government to administer successful climate programs, establish meaningful partnerships with community groups, and warn people of impeding risks.[141]

Ability to access government resources: Limited English-speaking ability may make it more difficult for certain individuals to understand information such as climate warnings and emergency preparedness plans. Additionally, lack of familiarity with American government and planning processes may present barriers to engaging in planning processes and accessing key government-provided resources.[142]

Lack of access to critical services: Public facilities and services such as hospitals and community centers are key providers of shelter and support during extreme climate events. Access to transportation that one can use to evacuate from harm's way are also important tools to addressing vulnerability. Those who lack access to reliable transportation or have limited mobility experience heightened levels of climate vulnerability.[143]

Health disparities: People experiencing higher rates of illnesses such as cardiovascular and kidney disease, diabetes, asthma, and COPD, whose effects can be exacerbated by climate change, are also more vulnerable to the potential health effects resulting from climate change.[144] Health-related climate vulnerability may be especially significant for those who lack health insurance, have limited mobility, are undocumented, are experiencing social or linguistic isolation, or have a lack of funds to pay for medical care, as these factors all pose significant barriers to obtaining medical care.[145]

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140 U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

141 Deas M, Grannis J, Hoverter S, DeWeese J. "Opportunities for Equitable Adaptation in Cities: A Workshop Summary Report." Georgetown Climate Center (2017). Nov 8 2019: www.georgetownclimate.org/files/report/GCC-Opportunities_for_Equitable_Adaptation-Feb_2017.pdf.

142 Ibid.

143 Ibid.

144 U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

145 U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

It is important to remember that individuals and communities can be affected by more than one contributing factor at once, and those who are exposed to a higher number of these factors may be especially vulnerable.[146]

The following sections identify groups that are highly vulnerable to the impacts of climate change hazards. This identification is not intended to be interpreted as an indication of failure or weakness on the part of these populations, nor as an invitation to resignation. Rather, the existence of especially vulnerable communities and individuals is emblematic of the failure of social, economic, and political systems to provide adequate support, respect, and protection to all members of society.[147]

Age (Children aged 14 and below)

Children's vulnerability to climate change arises primarily from their physiological characteristics and lifestyles, as well as their position of dependency on adults and increased sensitivity to the mental health impacts of climate change. Different contributors to vulnerability may be especially prominent at different ages and under different circumstances.

Children have proportionately higher intake of air, food, and water relative to their body weight compared to adults.[148, 149] Their relatively immature immune systems increase their sensitivity to allergy exposure and microbial contamination.[150] Children's ongoing lung development, airway size, level of physical activity, and body weight increase their susceptibility to respiratory hazards including ozone and wildfire smoke.[151]

Children's time spent outdoors increases their exposure to high temperatures. This is especially true for student athletes.[152] Newborns are also highly susceptible to temperature extremes because their capacity for body temperature regulation is limited.[153]

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[146] Deas M, Grannis J, Hoverter S, DeWeese J. "Opportunities for Equitable Adaptation in Cities: A Workshop Summary Report." Georgetown Climate Center (2017). Nov 8 2019: www.georgetownclimate.org/files/report/GCC-Opportunities_for_Equitable_Adaptation-Feb_2017.pdf.

[147] Thomas, K., Hardy RD., Lazrus H., Mendez M., Orlove B., Rivera-Collazo, I., Roberts JT., Rockman M., Warner BP., Winthrop R., Explaining differential vulnerability to climate change: A social science review (December 2018). Oct 29 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

[148] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[149] CalBrace, "Children <5 years." Nov 8 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/Children0to4_788_Narrative.pdf

[150] Gamble, J.L., J. Balbus, M. Berger, K. Bouye. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 247–286. http://dx.doi.org/10.7930/J0Q81B0T

[151] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[152] Ibid.

[153] Ibid.

Children also have fewer opportunities than the average adult to make independent choices with regard to housing conditions, transportation, money management, medical treatment, and political representation. This means that children generally have fewer opportunities to take independent actions that might reduce their vulnerability.

Climate change is likely to impact the mental health and functioning of children by increasing their exposure to traumatic events, including those that result in injury, death, or displacement. Exposure to traumatic events can impact children's ability to regulate emotions, undermine cognitive development, and contribute to PTSD, anxiety, depression, and other psychiatric disorders, to which children are highly susceptible.[154, 155] Poverty can exacerbate the effect of these traumatic exposures, as children in poverty may encounter financial barriers to receiving proper medical care and social-emotional support and may be less able to escape or recover from extreme weather events.[156]

According to 2019 American Community Survey (ACS) 5-Year Estimates, about 6.3 percent of Oakland's population is under 5 years of age, 17.0 percent are 14 years of age or younger, and 19.9 percent are younger than 18.[157] About 27.4 percent of households with children aged 18 years and younger participate in a public assistance program such as SNAP, 24.7 percent live in a household whose annual income is at or below the poverty level, and 3.7 percent have some form of disability.[158]

Within the City of Oakland, Figure 3-1 shows that higher concentrations of young children occur in neighborhoods such as West Oakland, Fruitvale, East Oakland, Elmhurst, and the Northwest Hills. These are primarily single-family neighborhoods located near schools such as Hoover Elementary, Lafayette Elementary, Martin Luther King Jr Elementary, Garfield Elementary, Allendale Elementary, Montclair Elementary, and Thornhill Elementary. Such neighborhoods in the city with higher concentrations of children are also particularly susceptible to climate hazards that include urban heat islands, flooding, poor air quality, and sea level rise.

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[154] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28, 2019: https://health2016.globalchange.gov/populations-concern.

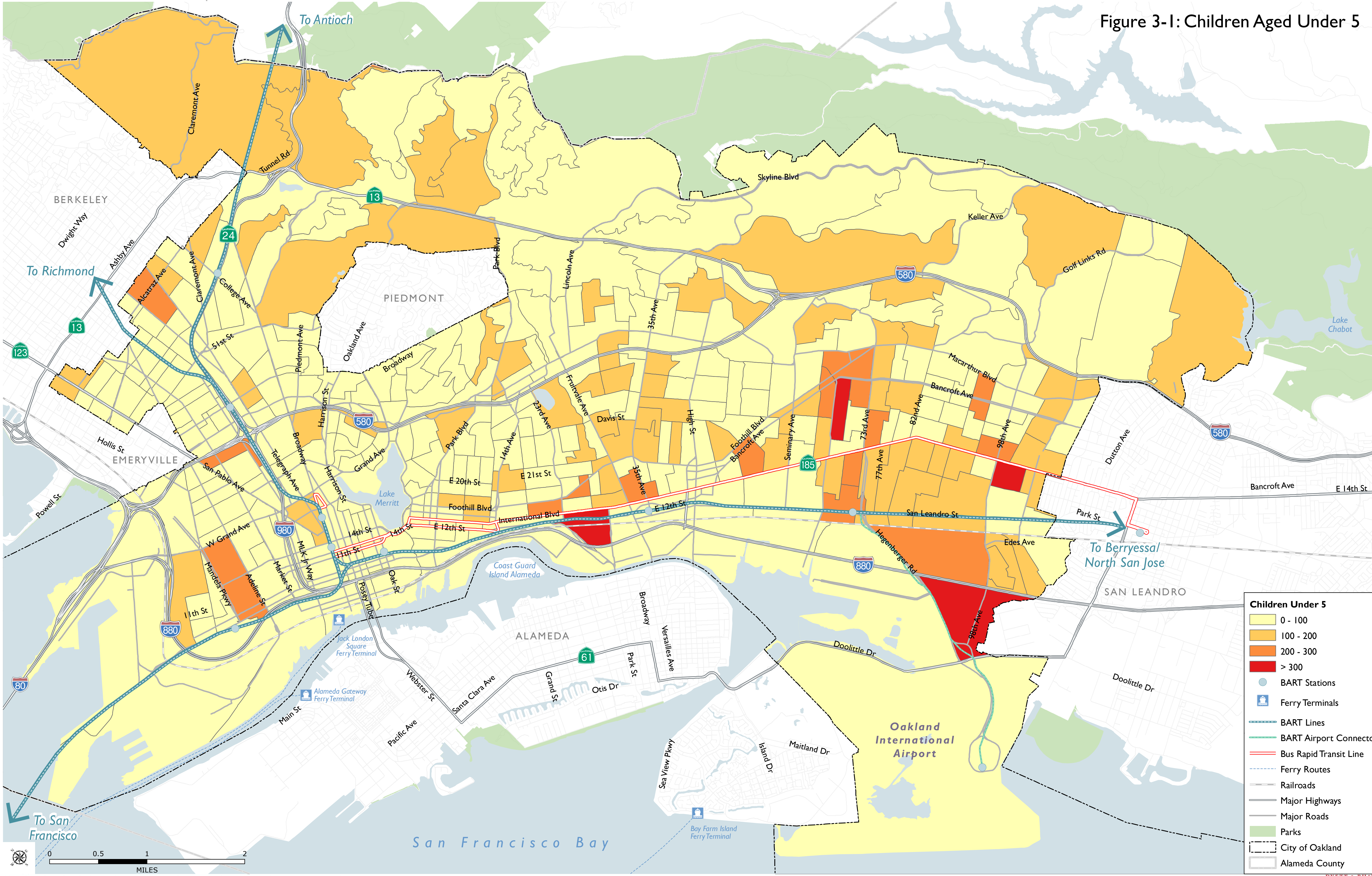
[155] CalBrace, "Children <5 years." Nov 8 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/Children0to4_788_Narrative.pdf

[156] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[157] 2015-2019 American Community Survey 5-Year Estimates

[158] 2015-2019 American Community Survey 5-Year Estimates

Figure 3-1: Children Aged Under 5



SOURCE: 2015-2019 ACS Census; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Age (Adults aged 65 or older)

Older adults are a diverse population whose vulnerability to climate change is influenced by underlying health status, economic situation, and level of social isolation.[159, 160] The body's natural aging processes and the effects of mental illness may interact to make the older adults especially vulnerable to the effects climate-driven temperature increases. Aging can impair the body's ability to regulate internal temperature.[161, 162] This is especially true for individuals taking medication that interferes with internal temperature regulation, including medications used to treat mental illnesses such as depression, anxiety, and psychosis.[163] Overall, the Bay Area average annual maximum temperature increased by 1.7°F from 1950 to 2005.[164]

Respiratory function often declines with age. Consequently, the older adults more sensitive to the effects of air pollution, airborne pathogens, and allergens than the general population.[165, 166] Older adults are also more sensitive to diseases whose range may expand as climate conditions change, such as West Nile Virus,[167] and have a higher risk of contracting gastrointestinal illnesses from contaminated drinking water.[168] Air pollution can exacerbate asthma and COPD and increase the risks of heart attack in older adults, especially those who are diabetic or obese.[169] Because many older adults live on fixed incomes, they may be especially hard-hit by increases in costs for energy and food.[170]

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[159] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[160] Benevolenza MA, DeRigne L. "The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature." *Journal of Human Behavior in the Social Environment* (2019). Nov 8 2019: https://www.tandfonline.com/doi/abs/10.1080/10911359.2018.1527739?journalCode=whum20.

[161] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[162] CalBrace, "Population aged ≥ 65." Nov 9 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/Older adults_789_Narrative.pdf.

[163] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[164] California's Fourth Climate Change Assessment, San Francisco Bay Area Region Report. https://www.energy.ca.gov/sites/default/files/2019-11/Reg_Report-SUM-CCCA4-2018-005_SanFranciscoBayArea_ADA.pdf

[165] Gamble JL, Hurley BJ, Schultz PA, Jaglom WS, Krishan N, Harris M. "Climate Change and Older Americans: State of the Science." *Environmental Health Perspectives* Jan 1 2013. May 11 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1205223.

[166] Ibid.

[167] CalBrace, "Population aged ≥ 65." Nov 9 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/Older adults_789_Narrative.pdf.

[168] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[169] Ibid.

[170] Gamble JL, Hurley BJ, Schultz PA, Jaglom WS, Krishan N, Harris M. "Climate Change and Older Americans: State of the Science." *Environmental Health Perspectives* Jan 1 2013. May 11 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1205223.

Older adults with cognitive or functional impairments may have difficulty responding to and recovering from extreme events.[171] These effects may be confounded by social isolation as older adults in isolation, especially those with cognitive impairments, may not receive emergency information or may underestimate the severity of warnings.[172] Older adults residing in assistive care facilities or with limited mobility also face additional complications during evacuations and may be adversely affected by interruptions in care for chronic medical conditions.[173, 174, 175]

In Oakland, about 13.1 percent of the population is 65 years old or older.[176] Of this population, about 51.6 percent live alone, 10.4 percent are veterans, 38.3 percent have some form of disability, 24.5 percent have limited English speaking ability, and 16.1 percent are at or below the poverty level.[177]

Figure 3-2 illustrates that Oakland's older adult population is highly concentrated in Chinatown and Downtown, the Lower Hills, and the Northwest Hills. Except for Chinatown and Downtown, these are suburban neighborhoods that neighbor parks and other scenic resources but may render seniors socially isolated from the broader community. The location of these neighborhoods could also cause additional difficulty for seniors to easily evacuate during a hazard event. Such neighborhoods with higher concentrations of older adults are also particularly susceptible to climate hazards that include urban heat islands in Chinatown and Downtown and wildfires in the Hills.

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[171] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[172] Gamble JL, Hurley BJ, Schultz PA, Jaglom WS, Krishan N, Harris M. "Climate Change and Older Americans: State of the Science." *Environmental Health Perspectives* Jan 1 2013. May 11 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1205223.

[173] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[174] CalBrace, "Population aged ≥ 65." Nov 9 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/Older adults_789_Narrative.pdf.

[175] Gamble JL, Hurley BJ, Schultz PA, Jaglom WS, Krishan N, Harris M. "Climate Change and Older Americans: State of the Science." *Environmental Health Perspectives* Jan 1 2013. May 11 2020: https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1205223.

[176] U.S. Census Bureau *2014-2019 American Community Survey 5-Year Estimates*

[177] Ibid.

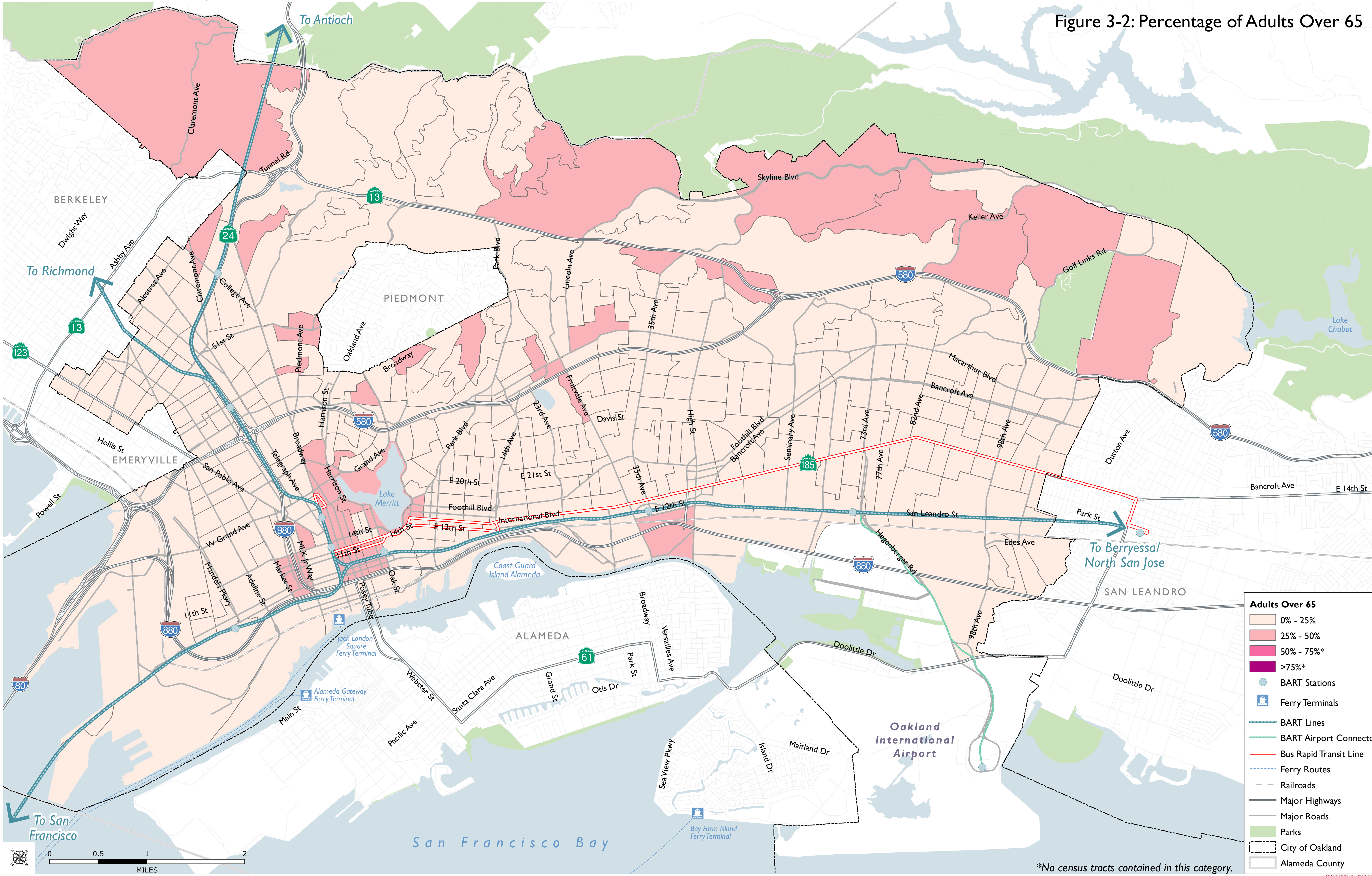

Figure 3-2: Percentage of Adults Over 65

SOURCE: 2015-2019 ACS Census; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

DYETT & BHATIA Urban and Regional Planners

Disability

Disability is a broad term that refers to any condition or impairment of the body or mind that limits a person's ability to do certain activities.[178] Those with disabilities tend to experience heightened climate change vulnerability through such societal risk factors as high poverty levels and low levels of educational attainment and employment.[179] Limited mobility and reliance on medical equipment and public transportation systems can also contribute to vulnerability, particularly during times of emergency evacuation and power interruption.[180, 181] Climate-related displacement can interrupt medical treatment, with health implications for those with chronic conditions.[182]

Risk communication materials are not always designed or delivered with accessibility in mind, potentially limiting knowledge accessibility for those who are deaf or have hearing loss, who are blind or have low vision, or those with diminished cognitive skills.

Mental health issues increase following disasters.[183] Rates of depression, anxiety disorders, post-traumatic stress disorders, substance abuse, and suicide are all projected to increase as the effects of climate change become more intense.[184] Use of certain medications, especially those used to treat mental health disorders, can increase sensitivity to high heat by interfering with the body's ability to regulate internal temperature.[185]

According to 2019 American Community Survey 5-Year estimates, about 11.7 percent of Oakland's population has some form of disability; about 5.0 percent are both disabled and older adults (adults aged 65 or older). About 28.3 percent of Oaklands's total population of people with disabilities reported yearly income at or below the poverty level; about 71.1 percent of working-age disabled individuals living in Oakland are either unemployed or do not participate in the labor force. As shown in Figure 3-4, there is a moderate concentration of people with a disability (20-30 percent) in some tracts in Downtown Oakland, including Chinatown, plus a tract in West Oakland and a tract in the Piedmont Ave neighborhood. These areas are particularly at risk to climate impacts from urban heat islands and flooding. Otherwise, there is a dispersal of persons with disabilities throughout the city.

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[178] U.S. Global Change Research Program, "Climate and Health Assessment," 2016, https://health2016.globalchange.gov/populations-concern, accessed June 2022.

[179] Ibid.

[180] Ibid.

[181] CalBrace, "Disability," November 8, 2019, https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/BRACE_Disability_Narrative_795_11-16-2016.pdf, accessed June 2022.

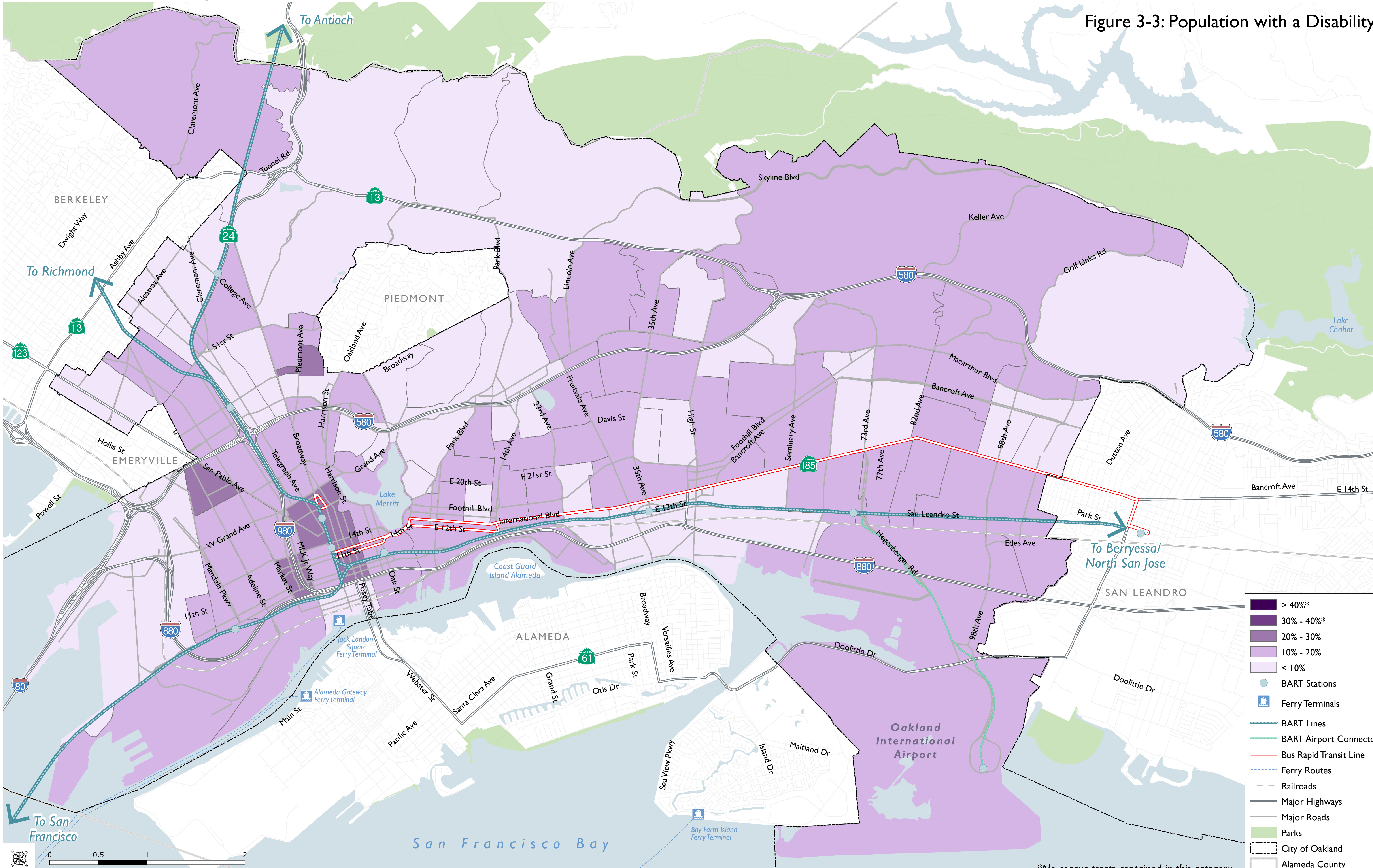
[182] Ibid.

[183] Ibid.

[184] Ibid.

[185] U.S. Global Change Research Program, "Climate and Health Assessment," 2016, https://health2016.globalchange.gov/populations-concern, accessed June 2022.

Figure 3-3: Population with a Disability



SOURCE: HCD AFFH Data and Mapping Resources - ACS, 2015-2019; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Income and Occupation

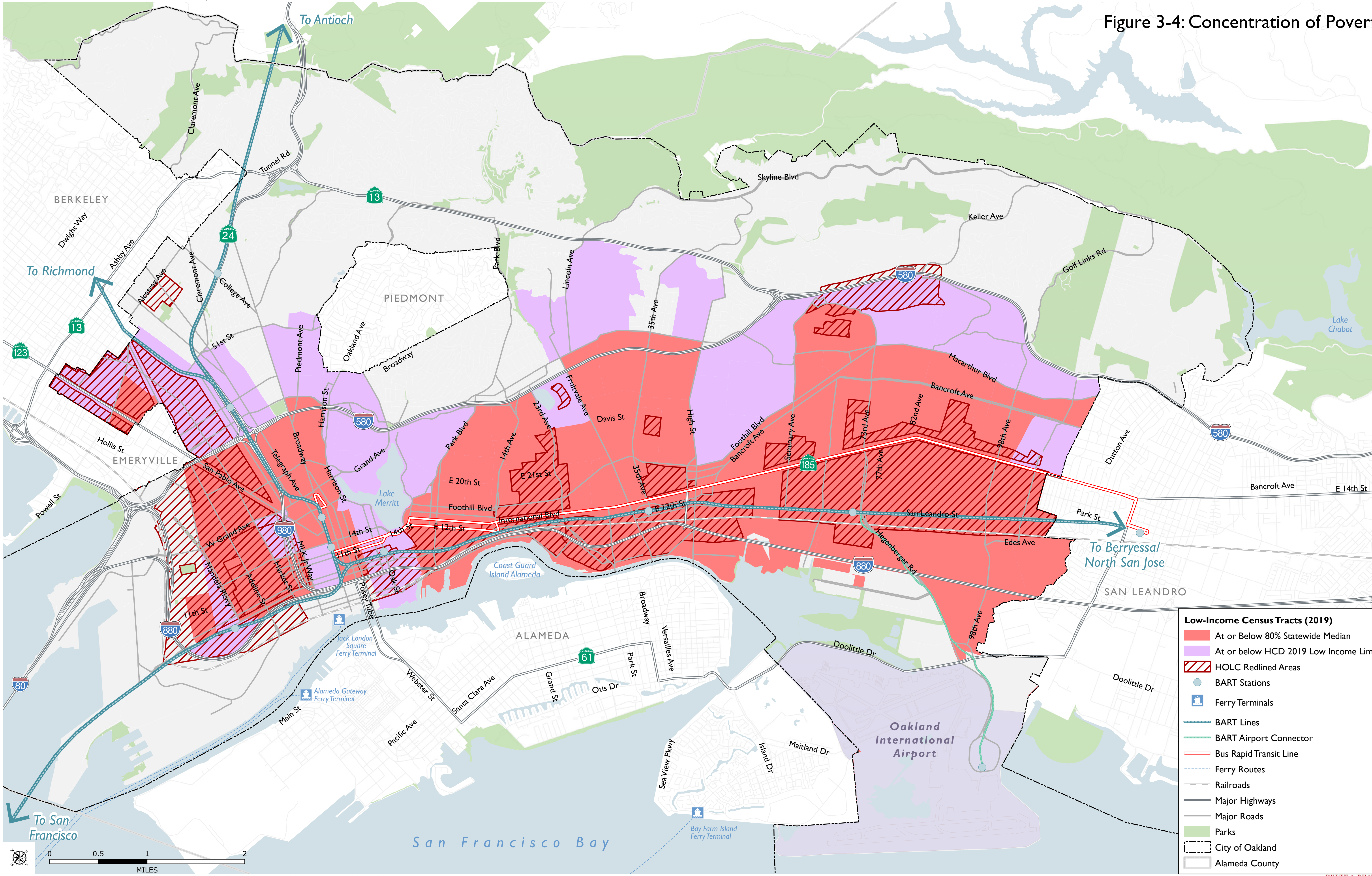
Individuals with lower incomes can be more vulnerable to climate change as a result of pre-existing health conditions, reduced mobility/transportation options, reduced access to health care, and limited ability to purchase the goods and services that could mitigate the negative effects of climate change. Poverty is also associated with societal exclusion and mental illness, and low-income individuals and families are more likely to work or live in environments that expose them to pesticides, lead, and outdoor air pollution. During high heat events, concerns about utility costs may inhibit low-income household's ability to stay cool and receive necessary medical care. Individuals with lower incomes are also more likely to suffer from chronic illnesses such as diabetes, heart disease, and stress. Anticipated increases in food, water, and utility prices under climate change may also be especially problematic for low-income households.

As discussed in heat impacts, above, lower-income Oakland residents are more likely than their higher-income counterparts to report experiencing heat-related discomfort in their home.

Low-income households face several barriers when it comes to disaster preparedness and recovery. Disaster preparedness typically involves developing disaster plans, assembling supplies, obtaining insurance, constructing defenses, investing in home upgrades and retrofits, and seeking information. Low-income individuals and households may struggle to successfully complete these tasks because of the high financial and time investments required, as well as potentially limited language abilities and lack of knowledge of useful resources and how to access them. In the aftermath of a disaster, the ability to marshal resources and leverage social support are key factors that promote recovery. These physical, capital, and social resources may be out of reach to lower-income households, thus extending their recovery time and costs and exacerbating the extent of event-related trauma.

According to 2019 American Community Survey 5-Year estimates, about 12.9 percent of Oakland families (about 16.7 percent of all people) live in poverty. Some types of families are more likely to be in poverty than others. These include families headed by a single female, those whose heads are non-white, those whose heads have not attended college, and those that include multiple children. As shown in Figure 3-4, except for the Port area, low-income areas in Oakland form almost a continuous spine through the flatlands. The North and South Hills and block groups immediately south of the City of Piedmont have the lowest concentrations of low-income areas in the city. Such low-income neighborhoods are also particularly susceptible to climate hazards that include urban heat islands, flooding, poor air quality, and sea level rise.

Figure 3-4: Concentration of Poverty



SOURCE: HCD AFFH Data and Mapping Resources - ACS, 2015-2019; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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Employment is considered a key social determinant of health because wages and benefits such as health insurance are an important factor in determining workers' ability to pay for safe housing, nutritious food, and medical care. However, individuals who engage in certain occupations may also have elevated climate change vulnerability. Outdoor workers are often among the first to be exposed to the effects of climate change such as increased ambient temperature and degraded air quality. There is emerging evidence that extreme heat can increase the risk of on-the-job injuries by making workers irritable or confused or by interfering with balance, motor control, and vision. Specific occupations that may experience heightened vulnerability include agricultural workers, groundskeepers, emergency responders, utility repair crews, and construction workers. These occupations tend to be overrepresented by Black or African Americans residents, Hispanics or Latinos, and low-wage workers, many of whom enjoy little job security and do not receive health insurance or paid sick leave.

For some groups, such as migrant laborers and day laborers, occupational-related vulnerability may be compounded by additional sources of vulnerability such as lack of access to quality housing, low income, linguistic isolation, pesticide exposure, and legal precariousness that introduces barriers to the use of emergency and legal protective services. Fear of discrimination or deportation dissuades some immigrant workers from reporting unsafe conditions or injuries and illnesses sustained on the job. Additionally, immigrant workers may be unaware of their workplace rights or ineligible for workers' compensation. Temporary and informally employed workers are more susceptible to occupational injuries and illnesses than are permanent employees because they often have less work experience, are unfamiliar with their workplaces, receive inadequate health and safety training, are assigned the most dangerous jobs, and may be fired for taking time off.

Of those Oakland residents who are employed, about 6.6 percent (14,719 individuals) work in construction or agricultural industries. Some of the largest employers in Alameda County include educational institutions such as California State University, East Bay and the University of California, Berkeley; government and utility services such as Alameda County Law Enforcement, East Bay Municipal Utility District (EBMUD), and Bay Area Rapid Transit (BART); and healthcare providers such as Kaiser Permanente and Highland Hospital.[186] The extent to which employees within these industries will be vulnerable to climate change impacts will depend on the nature of the individuals in question as well as their professional duties. However, the large scale of these sectors in the Oakland region means that any climate event that disrupts their functioning may impact the financial stability of many Oakland residents.

[186] State of California Employment Development Department, "Major Employers in Alameda County." 2022: https://www.labormarketinfo.edd.ca.gov/majorer/countymajorer.asp?CountyCode=000001.

Housing Cost and Quality

Availability of high-quality, stable, and affordable housing helps reduce exposure to extreme climate events and enables recovery. High housing costs may increase vulnerability by monopolizing financial resources, while lack of stable or high-quality housing may increase vulnerability by increasing exposure to environmental impacts.

The U.S. Department of Housing and Urban Development (HUD) defines the housing cost burdened as households who pay more than 30 percent of their income on housing. Severe cost burden is defined as paying over 50 percent of household income for shelter costs. Housing cost-burdened households may struggle to afford other necessities such as food, transportation, medical care, and—in the case of extreme climate events—emergency supplies. According to 2013-2017 HUD Comprehensive Housing Affordability Strategy (CHAS) estimates, a total of 32,479 households in Oakland experience cost burden (20.1 percent) while an additional 33,050 households experience severe cost burden (20.5 percent).

Those who are housing cost-burdened may be forced to reduce their housing costs by seeking out a more affordable housing situation. In the absence of high-quality affordable housing options, the locations in which low-income households and individuals reside are often less resilient in the face of the impacts of weather and climate change and may be more difficult to insure as well as farther from workplaces, shopping districts, and public transit—increasing the costs associated with transportation. Patterns of settlement in which lower-income households locate in especially vulnerable areas could be exacerbated in the future as the real estate market begins to take exposure to climate change effects into consideration when setting housing prices. Therefore, those who are housing insecure and/or who live in older/substandard housing, have less ability to rebuild if their home is lost/damaged in a climate disaster (flood, fire, etc.).

As described in Oakland's Environmental Justice and Racial Equity Baseline,[187] in the 1930s, Oakland adopted the federally sanctioned practice of refusing to insure mortgages in and near neighborhoods predominantly made up of communities of color. Residents of these "redlined" neighborhoods, were denied access to credit resulting in the systemic suppression of homeownership opportunities for communities of color. Accordingly, whether a resident owns or rents their housing unit may also affect climate vulnerability. Renters may have less control than homeowners when it comes to making home upgrades to reduce climate exposure or increase resiliency.

Areas with high rates of homeownership are associated with stronger local social networks, greater community involvement, and longer resident tenure. In past studies, a neighborhood's proportion of renter-occupied housing units was shown to be positively correlated with higher mortality rates among the older adults population during extreme heat events, perhaps reflecting a lack of stability,

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[187] *Oakland 2045 Environmental Justice and Racial Equity Baseline*. City of Oakland, March 2022. https://cao-94612.s3.amazonaws.com/documents/Equity-Baseline_revised4.15.22.pdf.

coping capacity, and strong community ties in these neighborhoods.[188] About 59.3 percent (96,242) of Oakland's occupied housing units are renter-occupied.[189] As shown in Figures 3-5 and 3-6, the highest rates of both homeowner and renter cost burden are located in East Oakland, plus a couple additional tracts experiencing high homeowner cost burden in the Jack London District and the Grand-Lake neighborhood.

A variety of housing types have been found to be correlated with higher sensitivity to climate change impacts. Poor quality home construction can also increase vulnerability to climate change impacts. Manufactured or mobile homes are especially vulnerable to storm damage. Rental housing, multifamily housing, manufactured housing, and subsidized housing have all been found to be correlated with higher neighborhood sensitivity to heat. In Oakland, a high percentage of homes contain no or inadequate insulation which makes residents environment more vulnerable to the impacts of extreme heat.[190]

Low-income households may struggle to afford to invest in home upgrades that reduce climate exposure. Additionally, in the aftermath of an extreme climate event, it can be especially difficult for low-income individuals to cover costs associated with home repairs or relocation, potentially perpetuating the vulnerability of the poor and housing-cost burdened.

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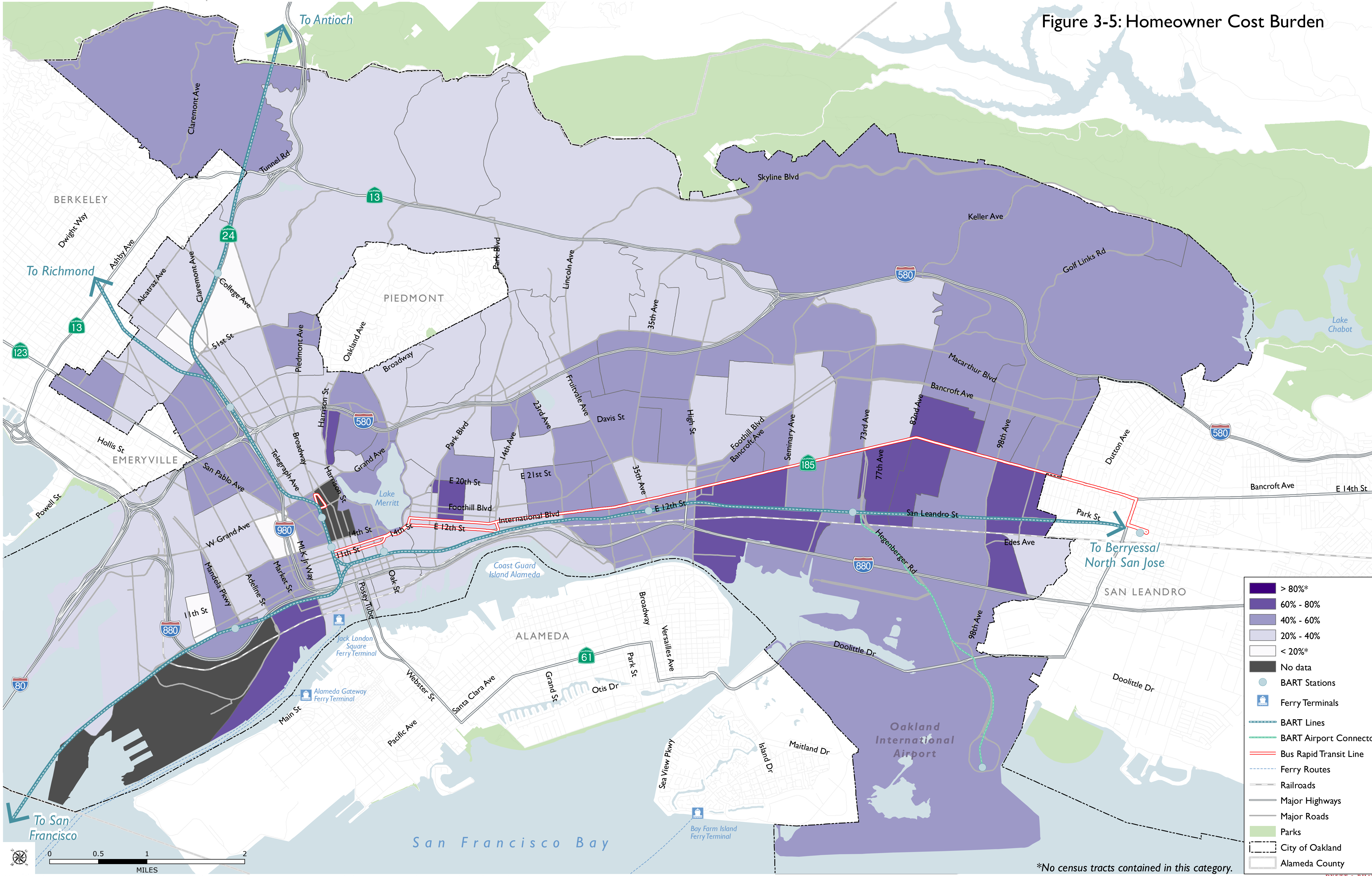
[188] Klein Rosenthal J, Kinney PL, Metzger KB. "Intra-urban vulnerability to heat-related mortality in New York Coty, 1997-2006." *Health & Place* (2014). May 11 2020: https://www.sciencedirect.com/science/article/pii/S1353829214001087.

[189] U.S. Census Bureau *2014-2019 American Community Survey 5-Year Estimates*

[190] *Pathways to Deep GHG Reductions in Oakland: Final Report*. Bloomberg Associates, March 2018. https://cao-94612.s3.amazonaws.com/documents/City-of-Oakland-CURB-Climate-Model-Final-Report.pdf.

Figure 3-5: Homeowner Cost Burden



SOURCE: HCD AFFH Data and Mapping Resources - HCD & TCAC Opportunity Areas Mapping Analysis, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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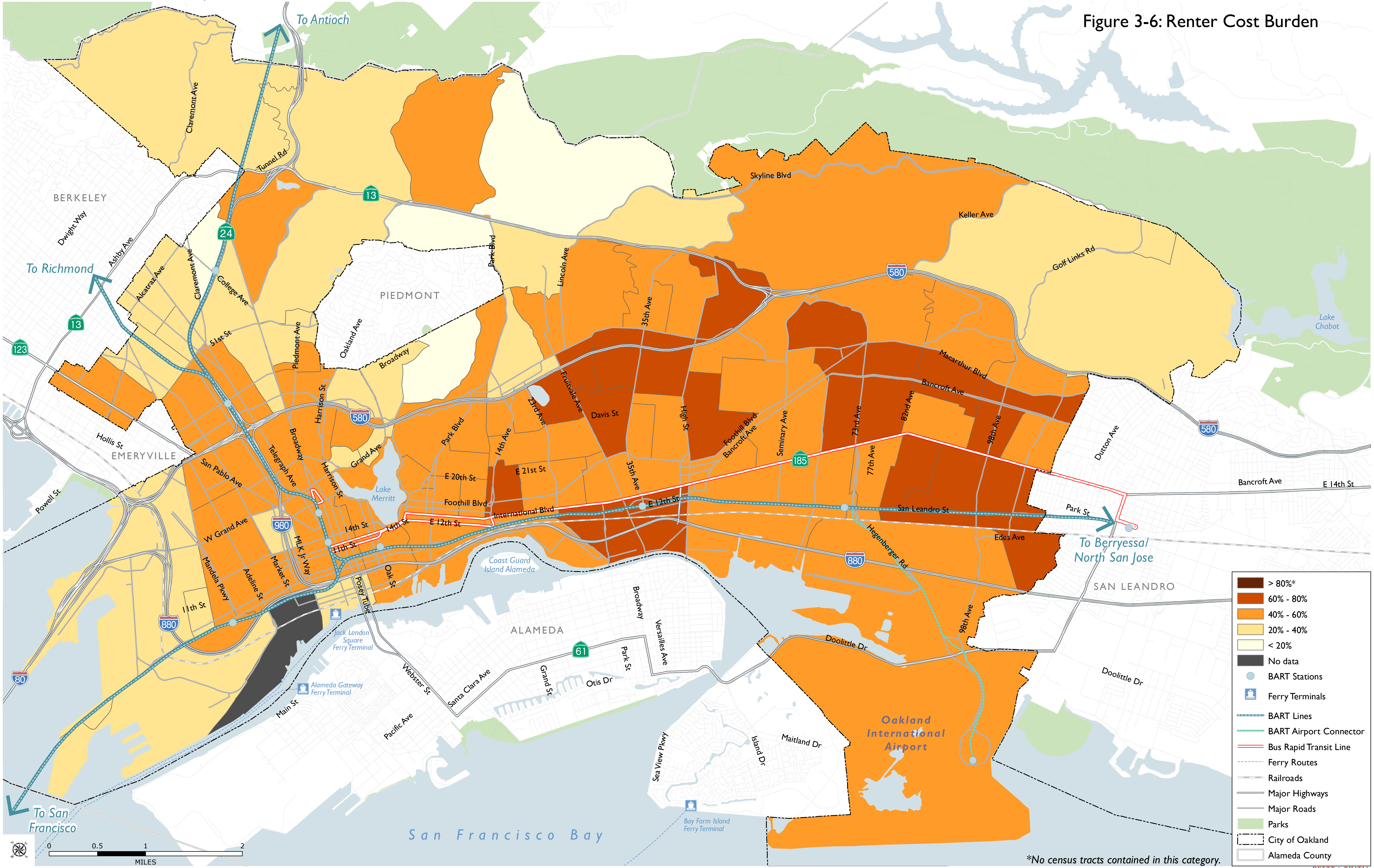
Figure 3-6: Renter Cost Burden



SOURCE: HCD AFFH Data and Mapping Resources - HCD & TCAC Opportunity Areas Mapping Analysis, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Unhoused individuals may be especially vulnerable to climate change impacts. Unhoused individuals experience elevated levels of exposure to environmental stressors such as high heat, poor air quality, and flooding. In the event of a climate emergency, they may lack a secure place to shelter and experience especially high levels of exposure to extreme weather. The needs of homeless individuals may be overlooked in disaster planning initiatives, and they are often more difficult to contact via emergency alert systems.[191] Additionally, homeless communities often lack the legal standing that may be required to access to services and resources in times of emergency.[192]

According to the Alameda County 2022 Point-in-Time (PIT) Count, there were 1,718 sheltered unhoused persons and 3,337 unsheltered persons in Oakland, for a total of 5,055 individuals. About 87 percent of these individuals were single adults over the age of 25, 10 percent were young adults between the ages of 18 and 24, and three percent were unaccompanied youth.[193] The Point-In-Time Count also found that approximately 59 percent of the homeless population in Oakland was Black or African American individuals. Further, the total number of unsheltered persons in Oakland are greatest in census tracts located in West Oakland, Downtown, Central/East Oakland, and the Coliseum/Airport neighborhoods.

Linguistic Isolation

Linguistically isolated households are those in which there is no one aged 14 years or older who speaks English fluently.[194] Linguistic isolation may hinder protective behaviors during extreme weather events or disasters by limiting access to or understanding of health and safety warnings and health information,[195] such as the City's own emergency response materials, the majority of which are only available in English. Studies have shown that people who live in linguistically isolated households are more likely to make heat-related calls to 911 during extreme heat events. In the aftermath of an extreme event, language barriers can present barriers to proper care and

[191]Thomas, K., Hardy RD., Lazrus H., Mendez M., Orlove B., Rivera-Collazo, I., Roberts JT., Rockman M., Warner BP., Winthrop R., Explaining differential vulnerability to climate change: A social science review (December 2018). Oct 29 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

[192] Ibid.

[193] Alameda County, "City of Oakland 2022 EveryOne Counts Homeless Point-in-Time County & Survey," 2022, https://everyonehome.org/main/continuum-of-care/everyone-counts/, accessed January 2023.

[194] CalBRACE, "Linguistic Isolation." Nov 8 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/BRACE_LinguisticIsolation_Narrative_11-15-2016.pdf.

[195] Ibid.

recovery services.[196] Language barriers can be a contributor to vulnerability for new immigrants, older first-generation immigrants, asylum seekers, and young children.[197]

Oakland is a place of great linguistic diversity. Approximately 40.1 percent of Oakland residents speak a language other than English at home. About 10 percent of all households in Oakland are limited English speaking. Of those who speak a language other than English at home, about 46.8 percent have limited English proficiency.[198] About 21.8 percent speak Spanish at home,[199] with other frequently spoken languages including Chinese (including Cantonese and Mandarin), Tagalog (including Filipino), and Vietnamese.

Within the City of Oakland, neighborhoods where residents experience high rates of linguistic isolation show a significant amount of overlap with those neighborhoods that are high in poverty, high cost, contain residents with disabilities, and reduced quality housing. As shown in Figure 3-7, a number of these neighborhoods are in east and west Oakland as well as downtown in the city's core. The downtown area corresponds to a high density of the city's Asian population while east and west Oakland correspond to greater densities of the city's Hispanic/Latinx populations.

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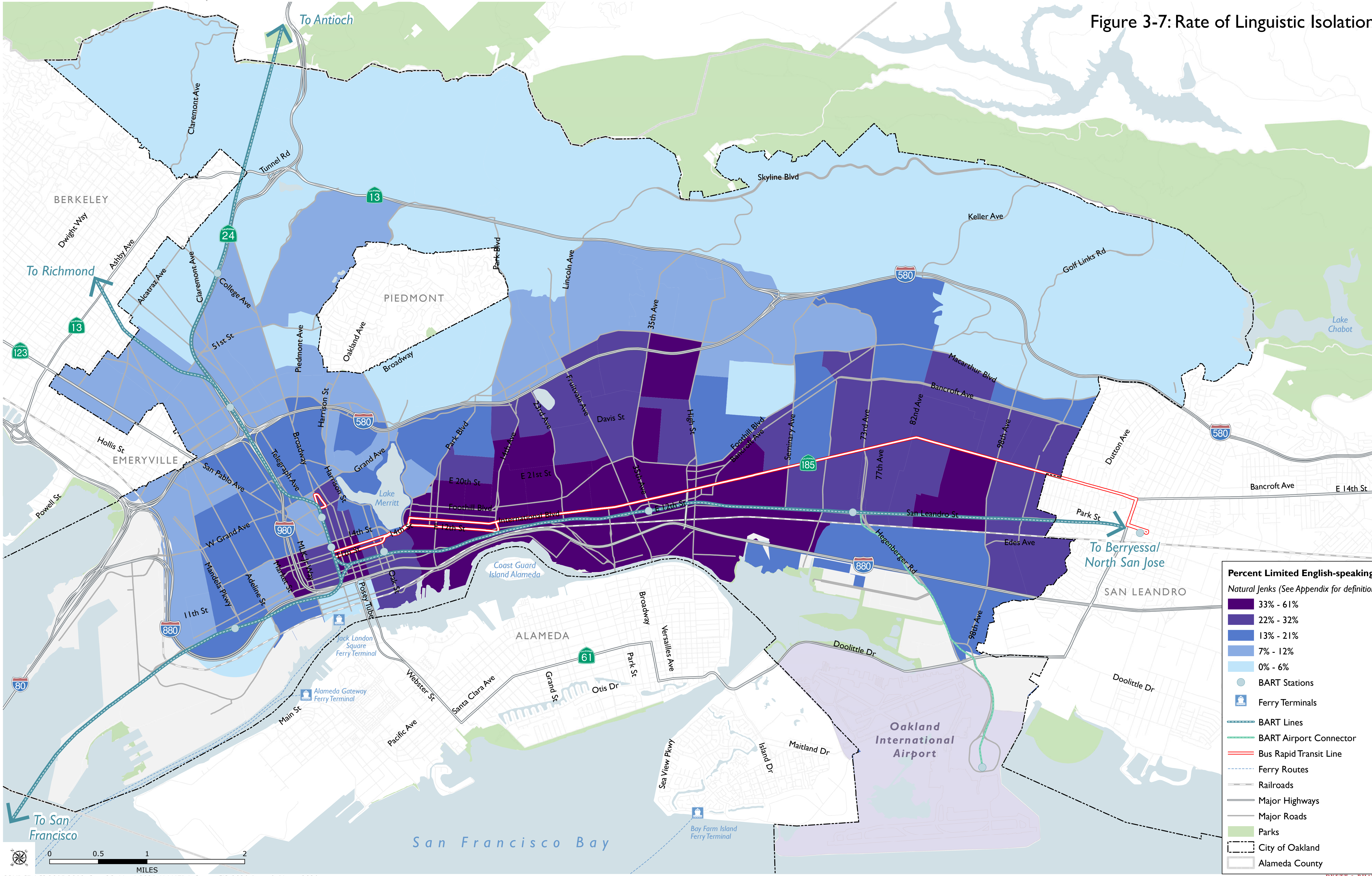
[196] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[197] CalBRACE, "Linguistic Isolation." Nov 8, 2019: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/CHVIs/BRACE_LinguisticIsolation_Narrative_11-15-2016.pdf.

[198] U.S. Census Bureau *2014-2019 American Community Survey 5-Year Estimates*

[199] Ibid.

Figure 3-7: Rate of Linguistic Isolation



SOURCE: ACS 2015-2019; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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Race

Structural racism, meaning the "totality of the social relations and practices that reinforce white privilege" contributes to the climate change vulnerability of communities of color.[200] Structural racism manifests in numerous policy-making decisions, including race-based housing segregation, lack of investment in public transit, and exclusionary zoning practices, whose legacy continues to have impacts on climate change vulnerability. Structural racism's entrenched position in American life means that this race-based source of vulnerability manifests in several interacting ways, including inequities in housing quality and location, household wealth, and educational and employment opportunities.[201, 202, 203] Historically, public policy has reinforced and compounded these inequalities as white and affluent residents have accrued disproportionate levels of wealth and influence in the political process.[204]

Further, health inequities are differences in health outcomes "that are a result of systemic, avoidable, and unjust social and economic policies and practices that create barriers to opportunities."[205] As described above, a history of structural racism has contributed to persistent inequities that are exacerbated by an increasing gap in social and economic inequalities. Impacts of institutional and environmental racism on health are also well-documented in scientific literature.[206] Many of these health inequities stem from disproportionate health burdens that are directly and indirectly tied to social, physical, and economic conditions in neighborhoods. For example, low-income neighborhoods with a greater percentage of communities of color are the most likely to lack access to supermarkets and healthful food, have fewer parks, and are more likely to be located near sources of air pollution.[207] Because many of these factors have traditionally fallen outside the responsibility of public health agencies, it is necessary for various sectors and policy areas to coordinate conscious efforts to protect community health and achieve health equity.

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[200] Thomas, K., Hardy RD., Lazrus H., Mendez M., Orlove B., Rivera-Collazo, I., Roberts JT., Rockman M., Warner BP., Winthrop R., Explaining differential vulnerability to climate change: A social science review (December 2018). Oct 29 2019: https://onlinelibrary.wiley.com/doi/full/10.1002/wcc.565.

[201] Ibid.

[202] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[203] Bolin B, Kurtz LC. "Race, Class, Ethnicity, and Disaster Vulnerability." *Handbook of Disaster Research* Nov 17 2017. May 11 2020: https://link.springer.com/chapter/10.1007/978-3-319-63254-4_10

[204] Deas M, Grannis J, Hoverter S, DeWeese J. "Opportunities for Equitable Adaptation in Cities: A Workshop Summary Report." Georgetown Climate Center (2017). Nov 8 2019: www.georgetownclimate.org/files/report/GCC-Opportunities_for_Equitable_Adaptation-Feb_2017.pdf.

[205] Rudolph, L., Caplan, J., Ben-Moshe, K., & Dillon, L. (2013). Health in All Policies: A Guide for State and Local Governments. Washington, DC and Oakland, CA: American Public Health Association and Public Health Institute.

[206] Environmental Racism Collection: Exposure and Health Inequities in Black Americans. Environmental Health Perspectives: National Institutes of Health. Accessed at https://ehp.niehs.nih.gov/curated-collections/environmentalracism.

[207] Ibid.

When analyzing the effect that race or ethnic group identity has on climate change vulnerability, this extensive history of race-based discrimination must be continuously acknowledged. Factors such as race, immigration status, income level, educational attainment, and housing and employment opportunities intersect and systematically affect access to resources, societal advantages, and environmental exposures in ways that are consistently associated with race.[208] Communities of color in the United States are statistically correlated with lower income, poorer physical health, and are often located in areas with sparse vegetation, more heat-absorbing surfaces, lower air conditioning ownership, and higher rates of participation in outdoor and farming work,[209] all factors which increase vulnerability to climate change.

Oakland is a racially diverse city. Approximately 35.5 percent of the city is white, 23.8 percent Black or African American, 15.5 percent Asian, 0.9 percent American Indian and Alaska Native, and 0.6 percent Native Hawaiian and other Pacific Islander. About 48.9 percent of Oakland residents identified having Black, Native American, Asian, or Pacific Island ancestry as their race alone or in combination with one or more other races. Approximately 23.8 percent of Oakland residents identified as belonging to two or more races or a race not identified in the U.S. Census. Approximately 27.0 percent of residents identify as Hispanic or Latinx of any race in Oakland.

Communities of color are disproportionately impacted by poor air quality from wildfire, industrial and transportation emissions, and the urban heat island effect. Because of disproportionate levels of exposure to air pollutants and elevated rate of diseases such as asthma and COPD, symptoms are exacerbated by climate change.[210] Figure 3-8 identifies a predominant Asian population in the Chinatown area with decreasing margins in surrounding tracts in Downtown and east beyond Lake Merritt; a predominant Hispanic population in Fruitvale with decreasing margins in adjacent tracts in East Oakland; a predominant African American population in both West Oakland and the Oak Knolls area in East Oakland, with decreasing margins in surrounding tracts; and a predominant white population in the North Oakland Hills, Rockridge, and immediately south of Piedmont with decreasing margins in surrounding tracts.

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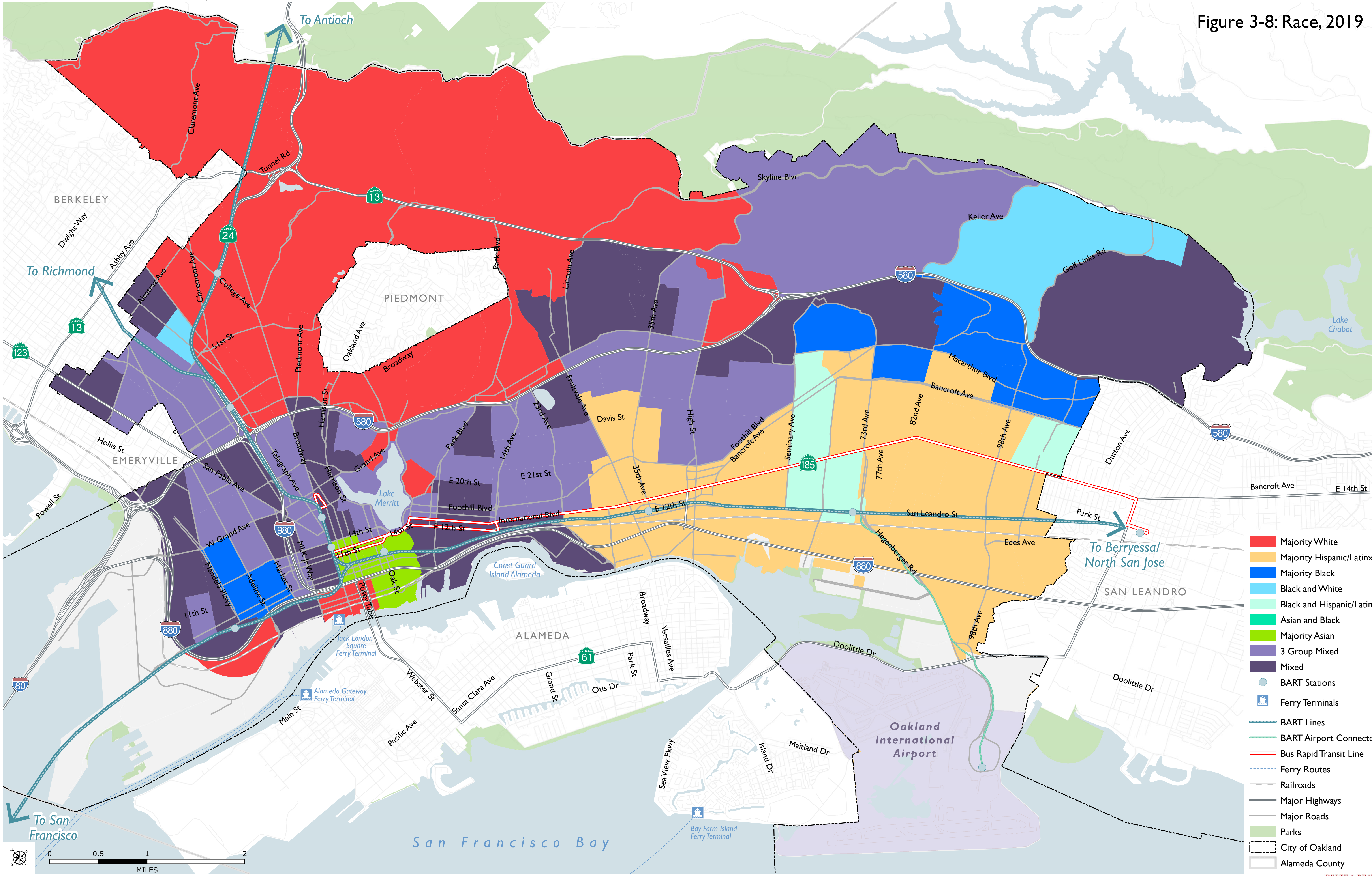
[208] Bolin B, Kurtz LC. "Race, Class, Ethnicity, and Disaster Vulnerability." *Handbook of Disaster Research* Nov 17 2017. May 11 2020: https://link.springer.com/chapter/10.1007/978-3-319-63254-4_10

[209] Gronlund CJ. "Racial and Socioeconomic Disparities in Heat Related Health Effects and Their Mechanisms: a Review." *Current Epidemiology Reports* July 1 2014. May 11 2020: https://link.springer.com/article/10.1007/s40471-014-0014-4.

[210] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

Figure 3-8: Race, 2019



SOURCE: IPUMS NHGIS, University of Minnesota, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

3.2 Summary of Social Vulnerability

A summary of assessed individuals and groups particularly vulnerable to climate impacts are outlined in Table 3-1. Socially vulnerable populations are organized by key sources of exposures, sensitivities to climate impacts, ability to adapt to such impacts, and the size of the community in Oakland.

Table 3-1: Summary of Vulnerable Populations within Oakland

Population	Key Sources of Exposure	Sensitivities	Adaptive Capacity	Size of Community in Oakland
Children Aged 14 and Under	Outdoor activities	Especially sensitive to high heat and environmental health hazards including wildfire smoke and allergens	Low. Children are often dependent on adults for financial support, housing, healthcare, and transportation.	About 17.0 percent of Oakland's population is age 14 or below.
Older adults Individuals Aged 65 and Over	Extreme climate events that require evacuation, climate changes that raise the cost of energy and food	Sensitive to water contamination, air pollution, and heat	Low. While the older adult population is diverse, older individuals are more likely than the general population to be socially isolated, on fixed incomes, and susceptible to health and mobility issues.	About 13.1 percent of Oakland's population is 65 years of age or older.
Individuals with Disabilities	May encounter barriers with regards to risk communication and evacuation, increasing exposure to extreme events	Use of certain medications, especially those used to treat mental health conditions, may increase sensitivity to heat.	Moderate. The disabled population is diverse. However, disabled individuals are more likely than the general population to be in poverty, unemployed, and experience mobility and cognitive barriers.	About 11.7 percent of Oakland's population has some form of disability.
Low-Income Individuals and Households	May be more likely than the general population to live or work in areas associated with exposure to heat and poor air quality	May be more likely to suffer from chronic illnesses that may increase sensitivity to heat and air pollution	Low. Low-income households are more likely to be unable to afford home retrofits that could increase resiliency to heat and flooding, to have reduced mobility options, and to have reduced access to medical care.	About 12.9 percent of Oakland families (about 16.7 percent of all people) live in poverty.
Outdoor and Seasonal Workers	Heat and low air quality	Physical labor and heavy protective equipment may	Low. While the makeup of the outdoor and seasonal labor force is diverse,	About 6.6 of Oakland's employed population works in construction

Population	**Key Sources of Exposure**	**Sensitivities**	**Adaptive Capacity**	**Size of Community in Oakland**
		increase sensitivity to heat.	workers often have limited opportunities to control their working environments. New immigrants and undocumented workers may be especially vulnerable.	or agricultural positions.
Housing Cost-Burdened	As households attempt to reduce housing costs, they may be confined to housing types that increase both exposure and sensitivity to heat, poor air quality conditions, and flooding.		Moderate. Due to the high proportion of income devoted to housing, the housing cost-burdened have fewer resources to invest in climate adaptation.	About 20.5 percent of Oakland's population is severely housing cost burdened.
Renters	n/a	Lack of air conditioning may make renters more sensitive to heat.	Moderate. Renters have less control than homeowners over the resiliency of their housing and may be less likely to live in a community with strong community ties.	About 59.3 percent of Oakland's housing units are renter-occupied.
Homeless	Lack of stable shelter increases exposure to heat, poor air quality, flooding, and extreme weather.	n/a	Low. The ability of the homeless community to acquire adaptive resources is hindered by such factors as lack of access to risk communication platforms, exclusion from government planning initiatives, and legal prosecution.	According to the 2022 Point-in-Time (PIT) Count, there were a total of 5,055 individuals experiencing homelessness in Oakland.
Linguistically Isolated	n/a	n/a	Moderate. The linguistically isolated may be underserved in community disaster planning and risk communication initiatives.	About 10 percent of Oakland's households are linguistically isolated.
Communities of Color	Communities of color are disproportionately impacted by exposure to environmental pollutants, such as poor air quality.	Rates of chronic diseases such as asthma and COPD are higher in communities of color, which may increase community sensitivity to poor air quality.	Moderate. Communities of color are diverse. However, within the United States, race is correlated with several factors that present barriers to acquiring adaptive capacity.	About 48.9 percent of Oakland residents have Black, Native American, Asian, or Pacific Island ancestry.

Cumulative Social Vulnerability

Individuals can belong to more than one vulnerable group and may experience especially complex forms of climate change vulnerability. To identify those communities where multiple contributors to vulnerability co-occur, a cumulative vulnerability map (See Figure 3-9) was created using the San Francisco Bay Conservation and Development Commission (BCDC) 2020 Community Vulnerability Index. This map accounts for presence of children aged 14 or under, adults aged 65 or over, low-income households, renter-occupied housing units, housing cost-burdened households, disabled individuals, linguistically-isolated individuals, communities of color, and households that do not possess a private vehicle. Census tracts with concentrations of vulnerable populations above the 70th and 90th percentile for the city were identified and classified as low, moderate, high, and very high cumulative vulnerability according to Table 3-2.

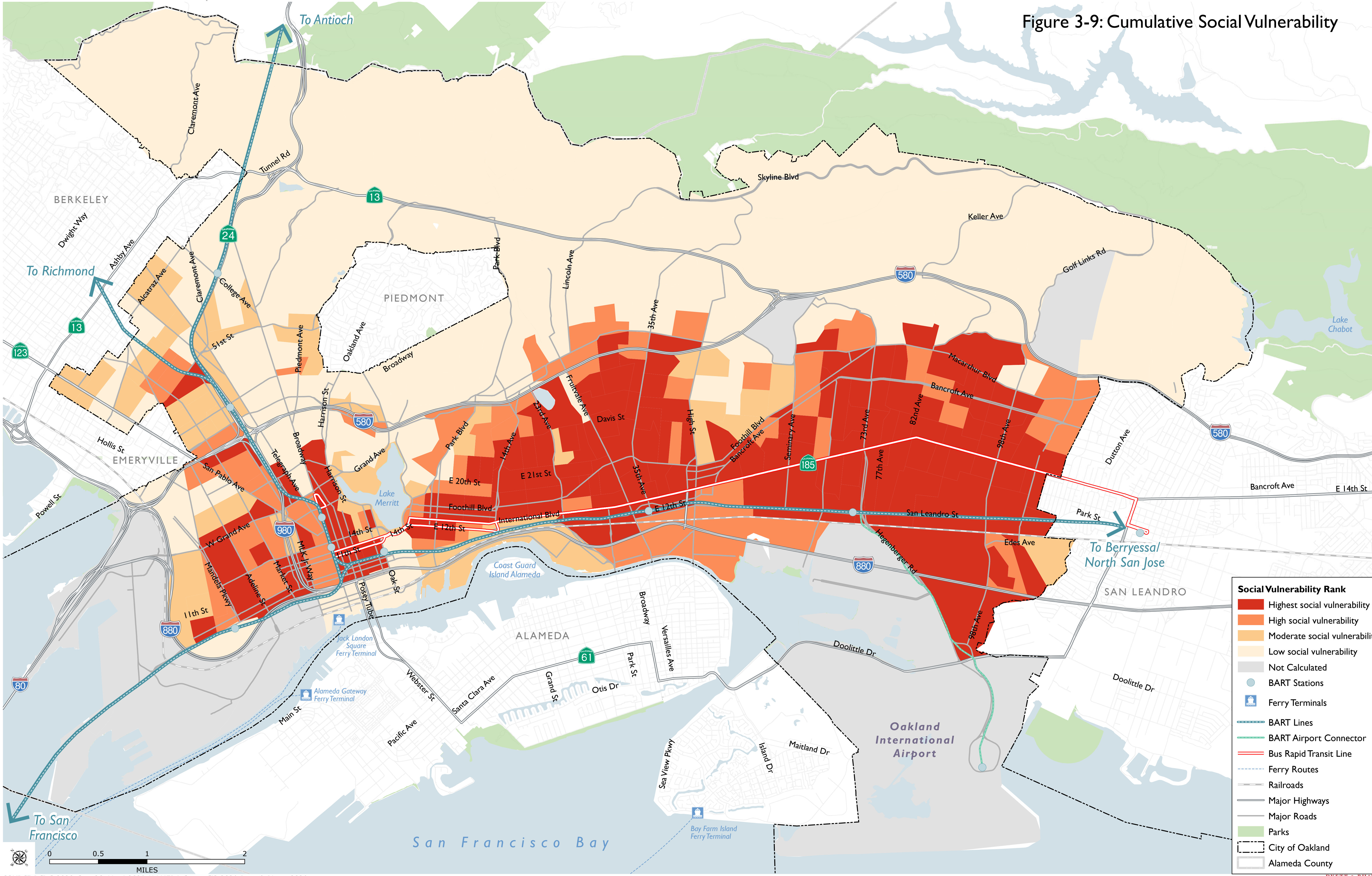
CALL OUT BOX: The purpose of the Cumulative Social Vulnerability Map is to assist the City and community in identifying areas in Oakland that are particularly susceptible to the impacts of climate change. California Senate Bill (SB) 379 (2015) requires all cities and counties in California to address climate adaptation and resiliency in their general plans. Similarly, this map has been prepared in close coordination with the Environmental Justice (EJ) Communities Map. Senate Bill (SB) 1000 requires jurisdictions to identify EJ Communities that are low-income areas and are disproportionately impacted by pollution, socioeconomic vulnerability, and adverse health impacts. Ultimately, both the Cumulative Social Vulnerability Map and EJ Communities Map help inform City investments, support community efforts, and allow other departmental plans and future General Plan elements to integrate EJ and Safety Element goals.

Table 3-2: Cumulative Vulnerability Classification Methodology

Number of Indicators Above 70th Percentile	*Number of Indicators Above 90th Percentile*	*Cumulative Vulnerability Score*
0 - 2	0 - 2	Low
3	1 - 2	Low
3	3	Moderate
4	0 - 3	Moderate
5	0 - 4	High
6	0 - 4	High
6	5	Highest
7+	0+	Highest

As Figure 3-9 demonstrates, Oakland contains several neighborhoods that are primarily ranked under the highest and high social vulnerability risk categories. These neighborhoods include West Oakland, Chinatown and Downtown, Fruitvale, Central/East Oakland, and Elmhurst. There are 61 census tracts in Oakland that contain a ranking of highest social vulnerability, 47 that contain a high ranking, 32 that contain a moderate ranking, and 75 that contain a low ranking. Combined, the city's highest social vulnerability block groups are home to an estimated 176,466 individuals, about 41 percent of Oakland's total population.

Figure 3-9: Cumulative Social Vulnerability



SOURCE: BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

3.3 Social Vulnerability and Climate Hazard Exposure

Socially marginalized groups suffer disproportionately from adverse effects of climate change, resulting in greater subsequent inequality. Disadvantaged groups tend to experience increased exposure to climate hazards, increased susceptibility of damages from these hazards, and a limited ability to cope and recover from this damage.[211] Further, disasters tend to increase prevalence of community violence, property crime, and domestic violence; those impacts are more pronounced when there is less of a safety net to recover from climate stressors. Therefore, areas with higher rates of pre-existing social vulnerabilities are at greater risk of compounding violence and crime in the wake of climate-induced disasters and stresses. Figures 3-10 through 3-14 overlay cumulative social vulnerability and climate hazard geographic data to identify areas in Oakland that are most vulnerable to climate change. Table 3-3 shows the geographic data used for the overlay analysis.

Table 3-3: Social Vulnerability and Climate Hazard Exposure Overlay Analysis Data

Layer	Threshold
Cumulative Social Vulnerability Risk	Highest social vulnerability
Land Surface Temperature (August 28, 2021)	Land Surface Temperature of 106 F and up
Flood Hazard Zones	100-year flood zone
Sea Level Rise	100-year coastal flood + 5.5 ft SLR
Fire Threats	Very high and high hazard fire severity zones
Air Quality	$PM_{2.5}$ Concentrations of 12.0 – 14.0 $\mu g/m^3$

Figure 3-10 identifies socially vulnerable populations in Oakland most exposed to increased temperatures and extreme heat. These census blocks are primarily distributed throughout Central/East Oakland and Eastlake/Fruitvale neighborhoods.

Figure 3-11 identifies where census blocks with high social vulnerability are exposed to high flood risk. These blocks are distributed primarily in Central/East Oakland, Coliseum/Airport, census blocks in Eastlake/Fruitvale located along Sausal Creek, and a few vulnerable blocks located in West Oakland. Figure 3-12 identifies where socially vulnerable census block groups in Oakland are exposed to high sea-level rise hazard. In Oakland, these populations are primarily located along the coastline in West Oakland and Central/East Oakland, as well as Downtown areas with direct proximity to Lake Merritt.

As identified in Figure 3-13, populations most vulnerable to wildfire in Oakland are in the Oakland Hills. While most of the census tracts in this region are not identified as socially vulnerable, there is one socially vulnerable census tract identified in Figure 3-13 that is exposed to high fire risk in

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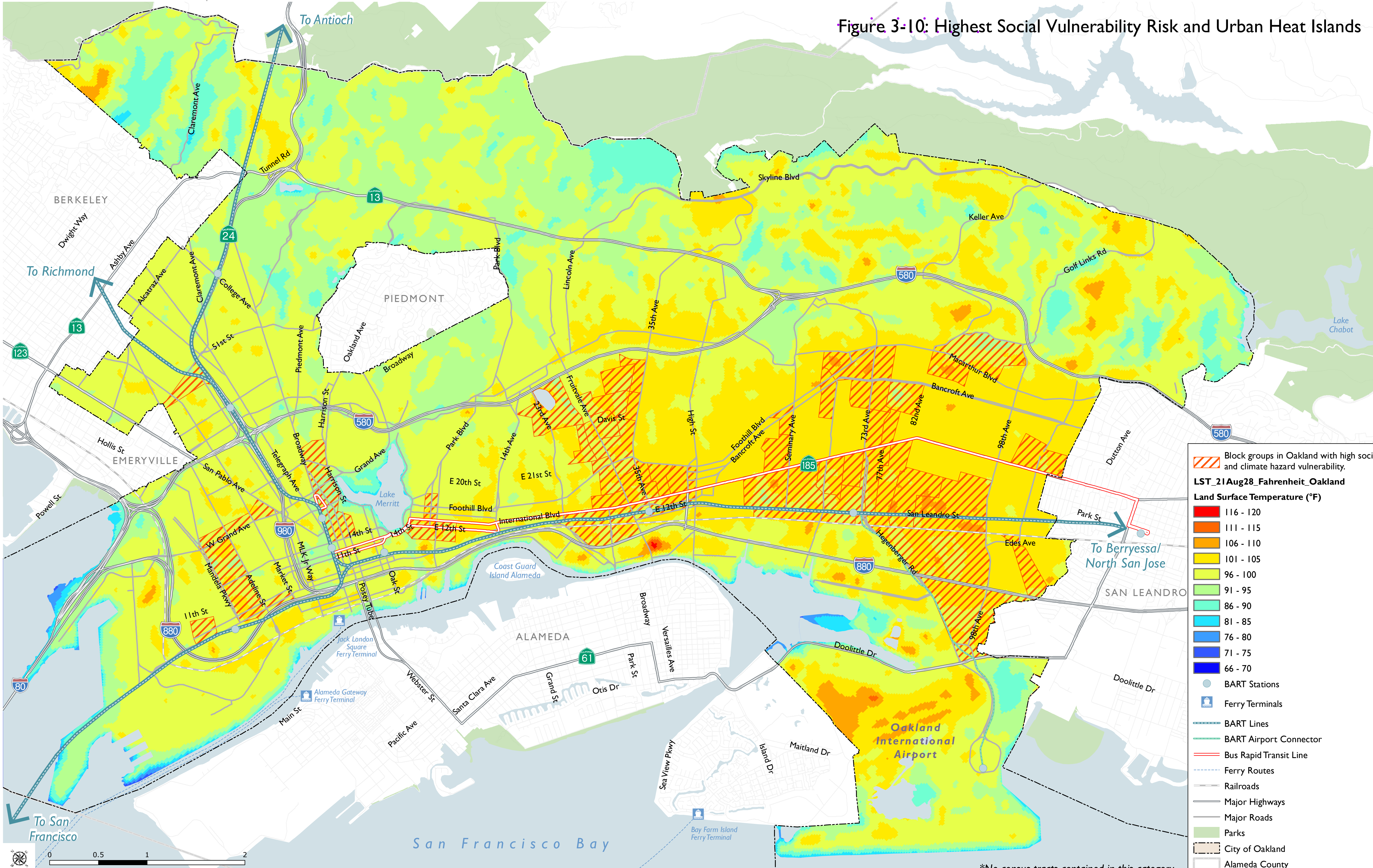
[211] Islam, S, and John Winkel. *Climate Change and Social Inequality* *. 2017.

the East Oakland Hills. Figure 3-14 demonstrates the distribution of socially vulnerable census tracts and poor air quality, which is exacerbated by wildfire smoke. The regions of Oakland most vulnerable to poor air quality are in West Oakland, Downtown, Eastlake/Fruitvale, and Central/East Oakland.

Overall, this identification of socially vulnerable communities in climate hazard zones helps identify where investments in adaptation strategies, such as increased tree cover and flood protections, will be the most equitable and effective. The next step is determining how to use the City's existing resources to implement these adaptation actions as efficiently and effectively as possible. This step involves taking an inventory of current financial and institutional assets distributed across City departments; developing strategies for overcoming institutional, financial, and political barriers to implementation; setting trackable adaptation goals; and identifying benefits and beneficiaries.

Table 2-1 summarizes the nature of the climate change impacts that are most likely to occur in Oakland, including their spatial and temporal extent, predicted level of disruption, and level of uncertainty. Figures 4-1 through 4-8 identify where critical facilities and high climate hazard areas overlap to guide investment in adaptation strategies, such as where accessible public cooling and clear air centers should be located in the city.

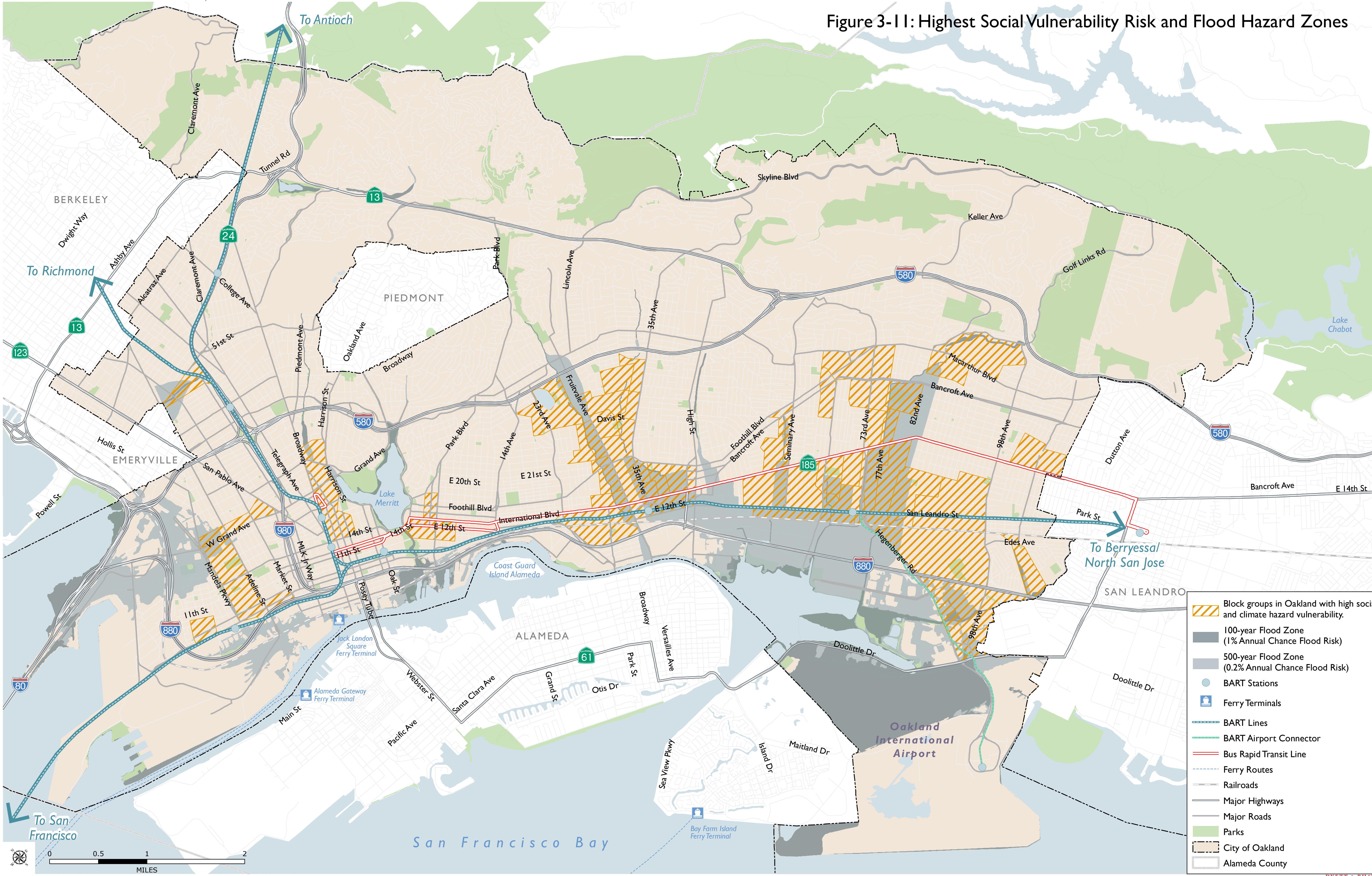
Figure 3-10: Highest Social Vulnerability Risk and Urban Heat Islands



*No census tracts contained in this category.

SOURCE: CalEPA, 2020; BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Figure 3-11: Highest Social Vulnerability Risk and Flood Hazard Zones



SOURCE: ESA, 2022; BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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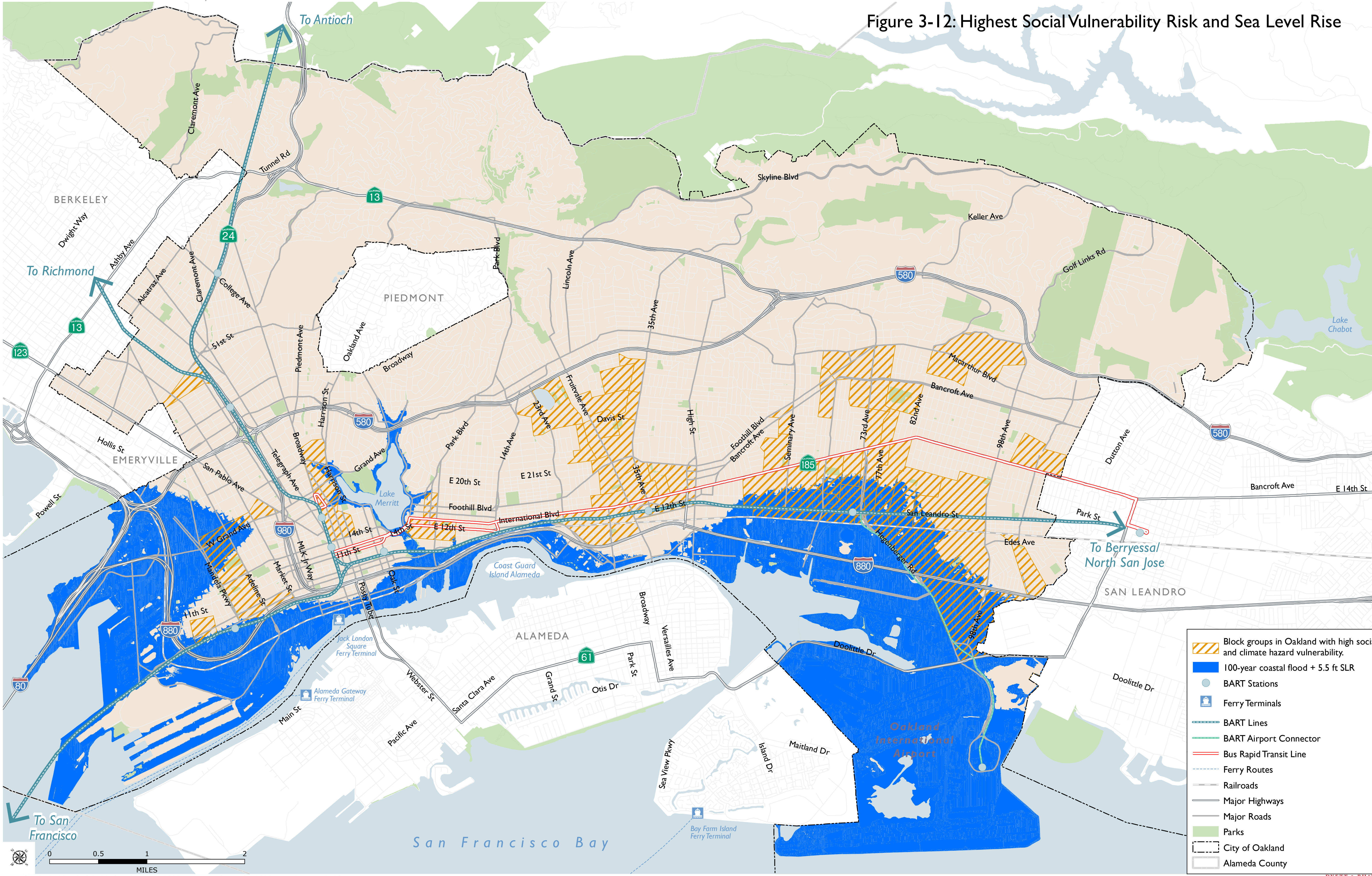
Figure 3-12: Highest Social Vulnerability Risk and Sea Level Rise



SOURCE: ESA, 2022; BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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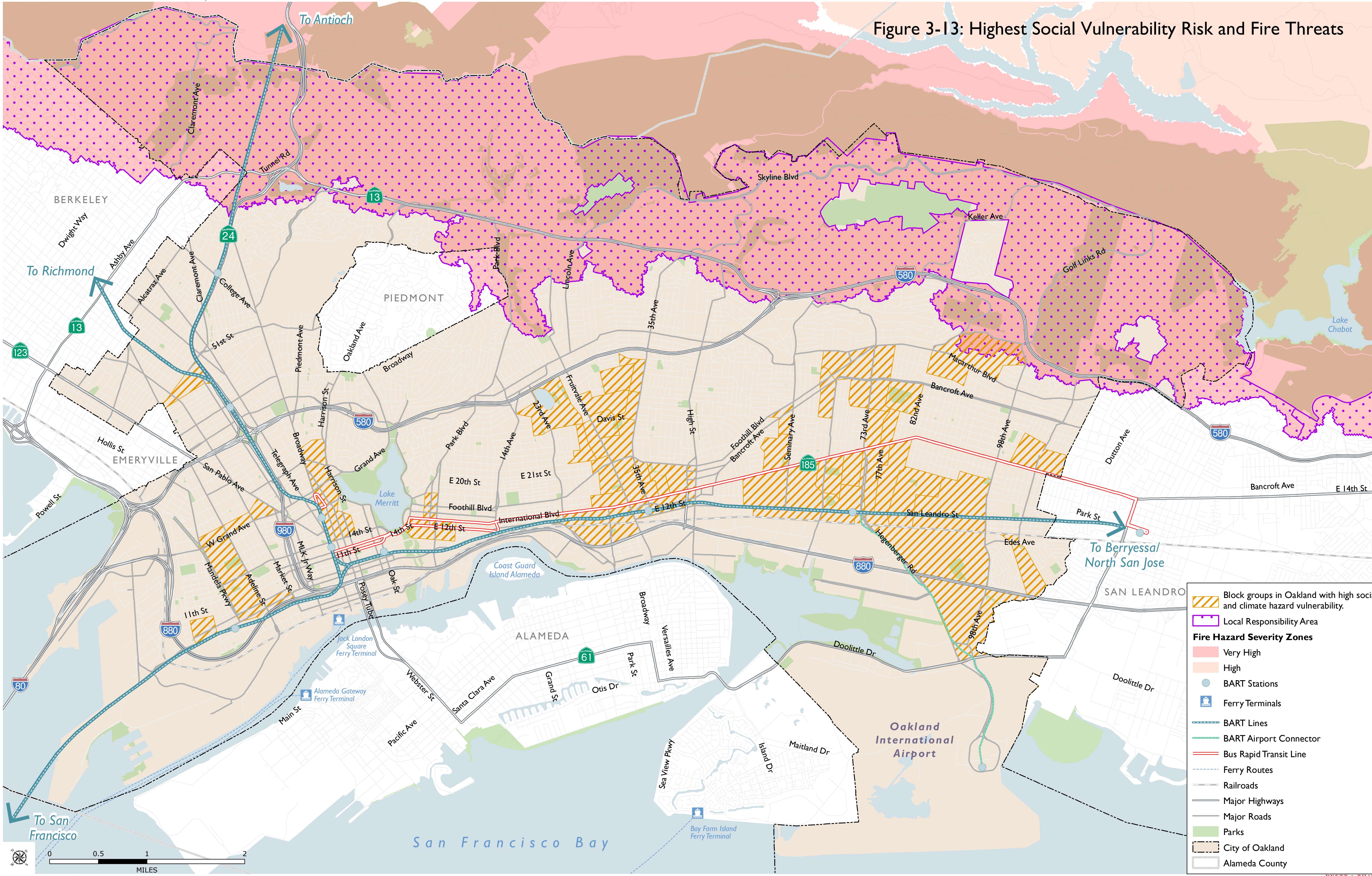
Figure 3-13: Highest Social Vulnerability Risk and Fire Threats



SOURCE: ESA, 2022; BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

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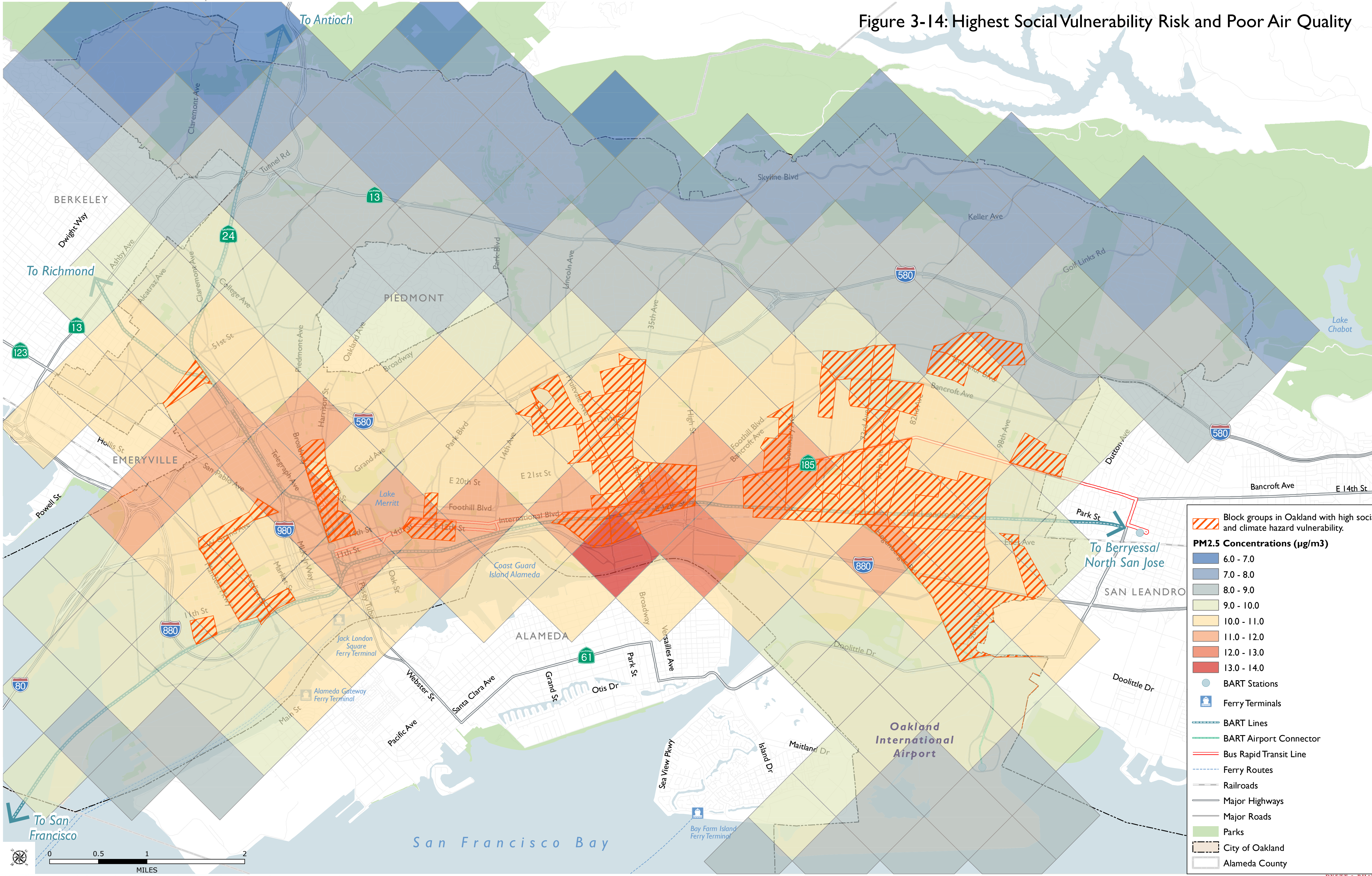
Figure 3-14: Highest Social Vulnerability Risk and Poor Air Quality



SOURCE: ESA, 2022; BCDC, 2020; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

4 Physical Vulnerability

4.1 What is Physical Vulnerability?

Based on the assessment of the primary and secondary climate change impacts most likely to affect the City of Oakland, this chapter identifies the key physical assets that are most at risk. In the following section, physical vulnerability refers to the susceptibility and limitations of physical infrastructure in the context of climate change and disaster events. This section examines the physical vulnerability of critical infrastructure and facilities whose damage or disruption would result in severe consequences to public health and safety or interrupt essential services for communities in the City of Oakland.

ASSESSING VULNERABILITY

Infrastructure and facilities are prioritized as critical if they meet some or all of the following criteria:

- The infrastructure is directly owned and operated by the City of Oakland
- Its function is essential for public health and safety
- It plays a role in emergency response
- It provides essential service for vulnerable populations

Using this criteria, critical infrastructure types are organized into seven categories: Safety and Security, Health and Medical, At-Risk Population Facilities, Communications, Energy, and Transportation. The categories applied to assess critical infrastructure in this section are drawn from section 4.7.3 of the Local Hazard Mitigation Plan, which focuses on existing critical infrastructure in the City of Oakland. The categorization of critical facilities in this assessment aligns with FEMA's "community lifelines" concept, which will position the City for future funding under FEMA grant programs and initiatives. Table 4-1 provides a list of infrastructure and facility types included within each category.

Table 4-1: Infrastructure Types Included in the Physical Vulnerability Assessment

Safety and Security	Law enforcement/security, search and rescue, fire services, responder safety, and imminent hazard mitigation
Health and Medical	Emergency medical assistance, hospitals, urgent care centers, ambulance services
Food, Water, Shelter	Shelter, community centers and resilience hubs, food/potable water, durable goods, water infrastructure and agriculture
Transportation and Evacuation	Transit networks, highway and road infrastructure, aviation, maritime
Energy and Communication	Public utilities, major hubs for telephone networks, power plants, temporary fuel, and power
Hazardous Facilities	Hazardous waste, solid waste, contaminated sites

To assess critical infrastructure's vulnerability to climate change hazards, this assessment draws upon the quantitative method outlined in Adaptation Planning Guide provided by the California State Governor's Office of Planning and Research. The Planning Guide determines that vulnerability is a function of an asset's exposure, sensitivity, and capacity to adapt to climate change stressors. Exposure is the nature or degree to which a system or population is exposed to climate hazards, and sensitivity is the degree to which critical infrastructure and supporting systems are impacted by climate change. This assessment utilizes spatial data to determine critical infrastructure's physical exposure to climate hazard impacts, and qualitative data and desk research to determine sensitivity to climate hazard impacts.

Adaptive capacity depends upon the infrastructure's ability to cope with these potential impacts, and is influenced by the programs, polices, and plans in place that are intended to help the community respond to hazardous climate events. Although a critical component of climate vulnerability, adaptive capacity alone is rarely sufficient to eliminate climate hazard threats and is not incorporated into the vulnerability scores for physical infrastructure. Further discussion of adaptive capacity is included in Chapter 5 of this assessment.

Table 4-2 provides a rubric to evaluate how vulnerable a critical infrastructure asset might be to a given climate hazard. Based on this rubric, the following scoring matrix assigns a numerical value between 1 and 5 to indicate overall vulnerability. Together, the scoring rubric and matrix can be referenced in the vulnerability summaries for each category of critical infrastructure. This scoring methodology is intended to provide a system to identify which types of infrastructure are the most vulnerable and should be prioritized in adaptation planning.

Table 4-2: Potential Impact and Adaptive Capacity Scoring Rubric

Score	*Exposure*	*Sensitivity*
Low	Critical Infrastructure is not significantly exposed climate impact	Critical Infrastructure is not significantly impacted by climate hazard, would not result in service disruptions or consequences for public health, safety
Medium	Critical Infrastructure has some exposure to climate impact	Critical Infrastructure is somewhat impacted by climate hazard, would result in some disruptions to service or some consequences for public health, safety
High	Critical Infrastructure is highly exposed to climate impact	Critical Infrastructure is highly impacted by climate hazard, would result in significant consequences to public health, safety

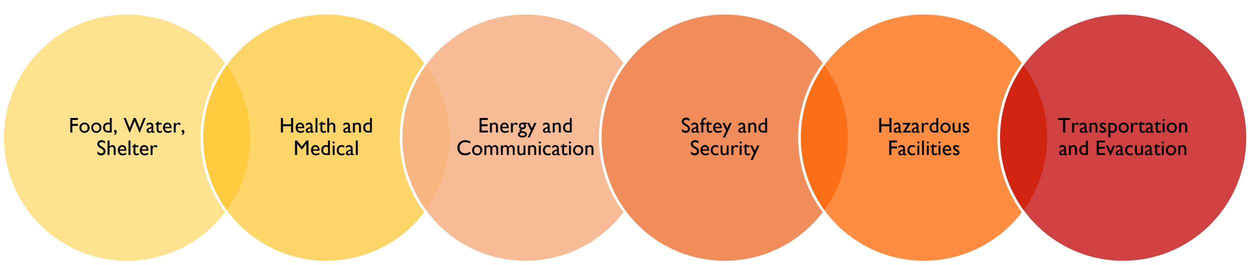
Chart 4-1: Vulnerability Score Matrix

Sensitivity				
	High	3	4	5
Sensitivity	Medium	2	3	4
	Low	1	2	3
		Low	Medium	High
			Exposure	

Each section of this chapter focuses on a different type of critical infrastructure and concludes with a vulnerability assessment table based on the scoring rubric and vulnerability score matrix. The climate hazards examined in each section are consistent with those discussed in chapters one through three, though some hazards may require more extensive discussion than others depending on the specific vulnerabilities of each category of infrastructure. To summarize these vulnerabilities, each table includes an outline of potential impacts and adaptive capacity by climate hazard.[212]

Key Takeaways

According to the following vulnerability analysis of critical infrastructure, the following diagram ranks critical infrastructure types from least to most vulnerable. This ranking can help provide a useful framework to consider how to allocate adaptive resources.



[212] Adaptive Capacity and relevant programs, agencies, and organizations are described in more depth in chapter five of this assessment.

4.2 Climate Vulnerability by Critical Facility Type

SAFETY AND SECURITY

The Oakland Fire Department is the primary emergency response service provider for the City of Oakland, and provides comprehensive strategies and training in fire prevention, fire suppression, emergency medical services, all risk mitigation, emergency preparedness, 911 services, and community-based fire services. Twenty-five fire stations are distributed throughout the City of Oakland, which are identified in figure 4-1. The Emergency Management Services Division (EMSD) team exists within the Oakland Fire Department and is the primary agency responsible for responding to, recovering from, and mitigating against any hazard that affects the City of Oakland.

In addition to the Police Administration Building located downtown, there are eight police stations, also identified in Figure 4-1. Currently, the Oakland Police Department is headquartered in downtown Oakland, though in February 2022, the Oakland City Council passed a resolution to move the police headquarters to the Coliseum area. In 2019, Oakland closed the Glenn E. Dyer Detention Facility, the last primary prison facility in Oakland. City of Oakland public records, courts, building permit and inspection services, and most other City services are also concentrated in downtown Oakland.

The City of Oakland is in the initial phases of beginning a Pilot Program known as MACRO (Mobile Assistance Community Responders of Oakland). The MACRO Program is a community response program for non-violent 911 calls intended to reduce responses by police, result in fewer arrests and negative interactions, and increase access to community-based resources for impacted individuals and families, especially Black, Indigenous, and People of Color (BIPOC).

As climate hazards intensify the scale and scope of disaster events in the City of Oakland, demand for public-safety focused disaster response teams is likely to increase, potentially straining these resources. Flooding from increased precipitation, sea level rise, and severe storm events could render roadways inaccessible and impede emergency response services. Emergency responders also face increased exposure to smoke inhalation, heat-related sickness, and infectious disease from extreme heat and wildfire hazards. As discussed in Chapter three, disasters also tend to exacerbate community violence, property crime, and domestic violence, particularly in areas with pre-existing social vulnerabilities. This suggests that in the wake of climate-related disasters, demand for emergency responders and law enforcement is also likely to increase in affected areas.

Figure 4-1 identifies seven emergency response facilities located in very high fire-hazard regions of Oakland and four stations in regions with high flood-risk. According to the Port of Oakland Sea

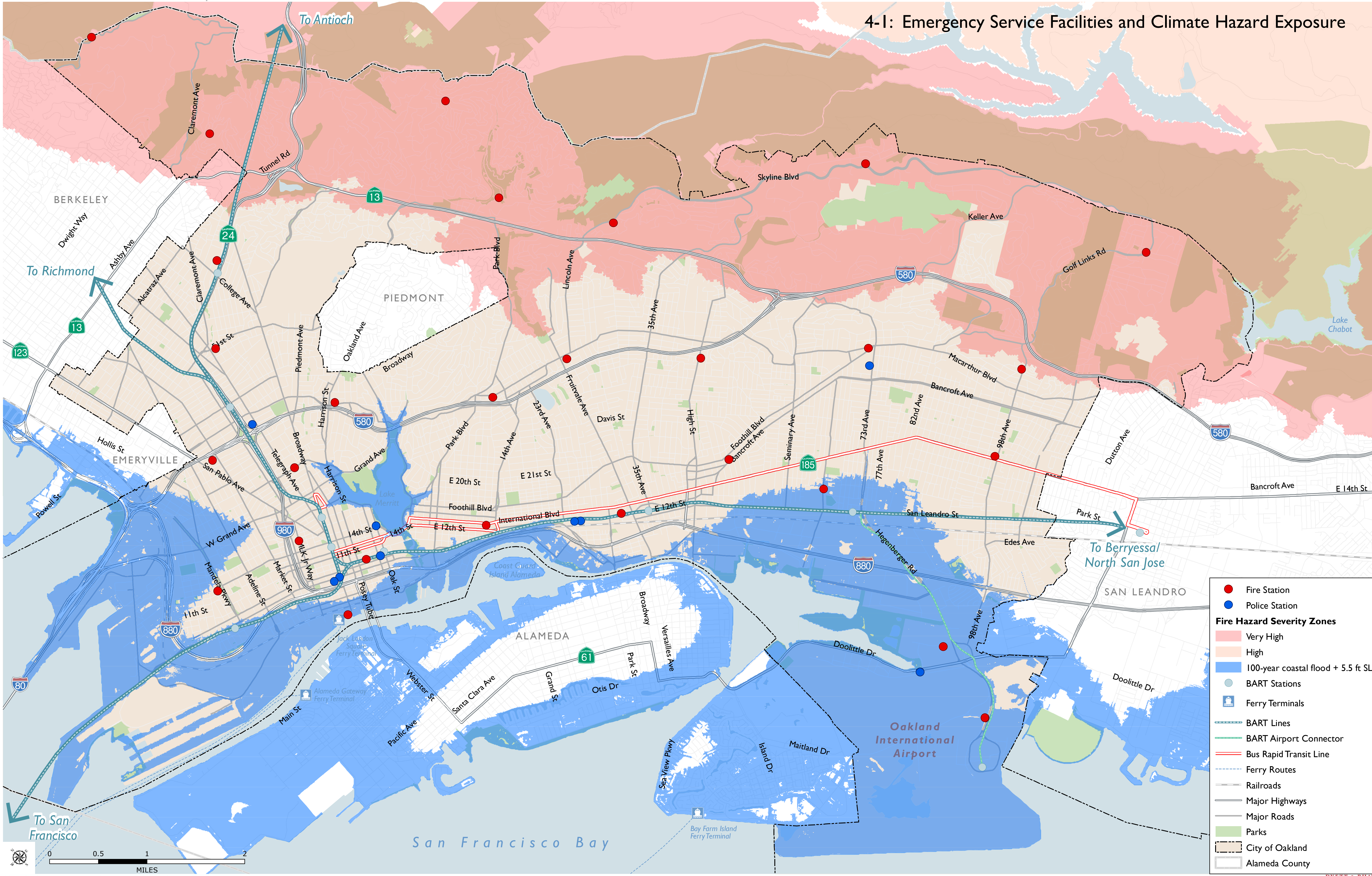
Level Rise Assessment, the Fire Department station on Clay Street is particularly exposed to extreme storm flood conditions.[213]

Table 4-3: Safety and Security Infrastructure Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	High Moderate risk of infrastructural damage; many police and fire stations located in regions with high wildfire hazard exposure	Medium Poor air quality is anticipated to increase demand for emergency response and services. Emergency response personnel also face increased rick of smoke inhalation.	4
SLR, Flooding, and Increased Precipitation	High High risk of infrastructural damage; several police and fire stations located in regions exposed to high flood risk	High Impeded emergency response services in event of severe flooding can result in significant consequences to public safety.	5
Extreme Heat and Temperature Increases	Medium Physical safety and security infrastructure have some exposure to increased temperatures and extreme heat.	Medium Extreme heat will increase demand for emergency response services and put emergency response personnel at increased risk from heat-related illnesses.	3

[213] "Port of Oakland Sea Level Rise Assessment 1." July 2019. chrome-https://www.portofoakland.com/files/PDF/Task%207_20190709%20Port%20Oak%20SLR%20Assmt_Rev2.pdf

4-1: Emergency Service Facilities and Climate Hazard Exposure



SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

HEALTH AND MEDICAL FACILITIES

Hospitals are clustered around freeways: Kaiser Permanente's flagship hospital is located close to the junction of I-580 and I-980/State Route 24, Summit Hospital in "Pill Hill" and UCSF Benioff Children's Hospital are located along State Route 24 in the north, and Highland Hospital, Alameda Health System's flagship and a renowned trauma center, is located in central Oakland adjacent to I-580. The first three hospitals are accessible from the MacArthur BART Station, and all four are located along AC Transit bus routes. Additionally, three hospitals in the adjacent City of San Leandro serve East Oakland residents; of those three, only San Leandro Hospital is accessible by public transit (AC Transit bus).

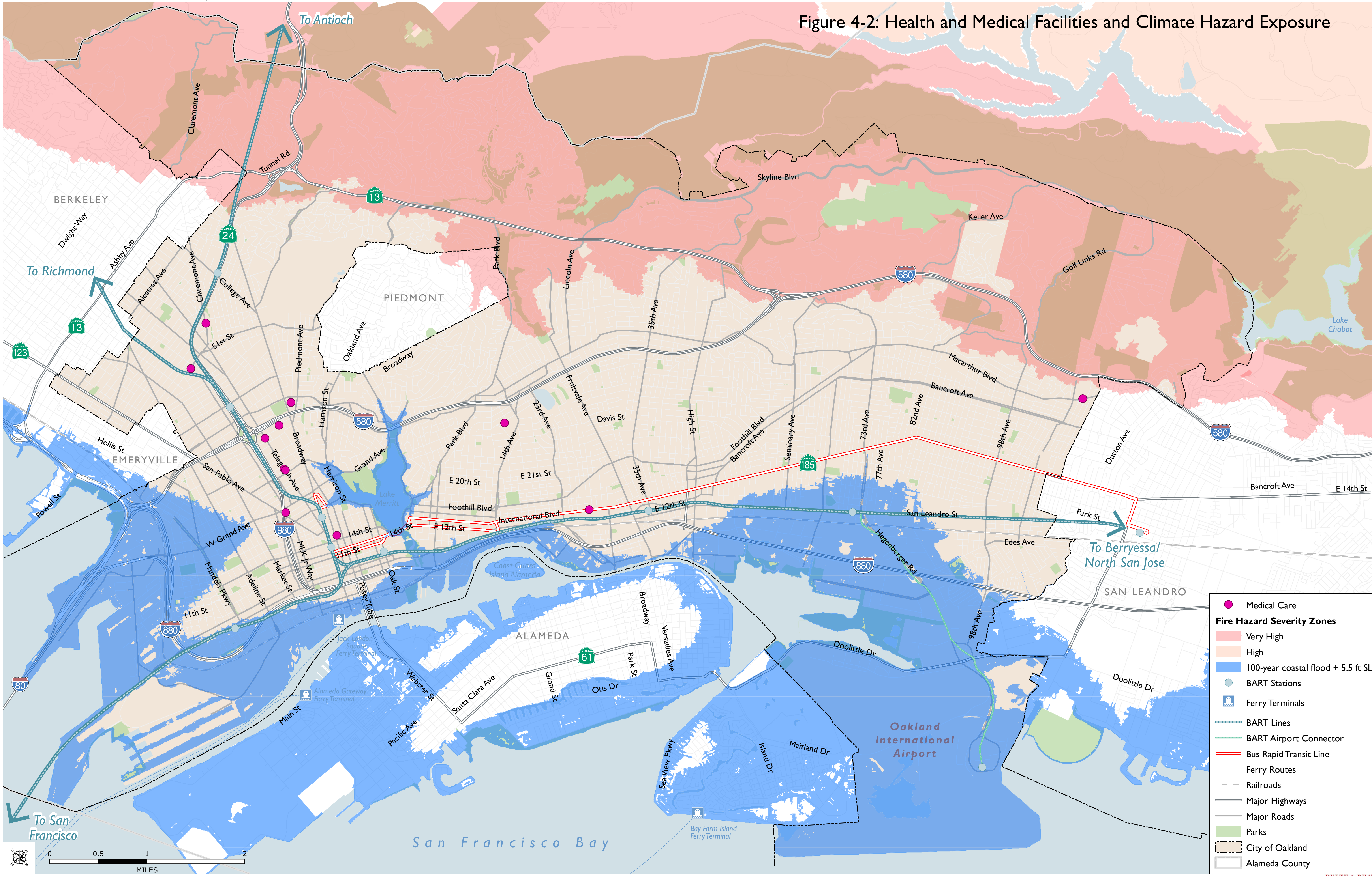
Figure 4-2 overlays the city's major health and medical facilities with flood and wildfire risk. Currently, none of Oakland's major medical facilities are directly exposed to high fire or flood hazard regions of the city. While they may not directly impact physical infrastructure, poor air quality from wildfires, flooding, and extreme heat are likely to increase demand for medical services, potentially straining hospital capacity. Similarly, climate-related disruptions to the transportation network may also disrupt transportation networks.[214] In case of Public Safety Power Shut-offs (PSPS), medical facilities are generally buffered from power loss during wildfire events because state and federal law mandate that hospitals maintain backup diesel generators in event of emergencies.

Table 4-4: Health and Medical Infrastructure Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Low Medical facilities in Oakland are not exposed to high risk of infrastructural damage from wildfire.	Medium Wildfires and reduced air quality could strain medical services capacity and impede evacuation and access to medical facilities.	2
SLR, Flooding, and Increased Precipitation	Low Medical facilities in Oakland are not exposed to high flood risk.	High Flooding could increase need for emergency medical services, strain hospital capacity, and impede medical response personnel as well as evacuation attempts, causing significant impacts to public health and safety.	3
Extreme Heat and Temperature Increases	Medium Medical infrastructure has some exposure to extreme heat.	Medium Extreme heat can create increased demand for medical services that could strain hospitals. Extreme heat also puts emergency medical responders at increased risk of heat-related illnesses and could cause impacts to public health and safety.	3

[214] *LA County Climate Vulnerability Assessment*. Oct. 2021. https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

Figure 4-2: Health and Medical Facilities and Climate Hazard Exposure



SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

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SHELTER, FOOD, AND WATER

Shelter

Due to the sensitive nature of emergency mass shelter facilities, geographic analysis of climate vulnerability is not provided in this assessment. However, this section will discuss clean air facilities, cooling facilities, planned municipal resilience hubs, and other community resource centers. Through Alameda County, the City of Oakland has established environmental impact centers offering residents refuge from wildfire smoke and extreme heat. During wildfire season, clean air centers have been established at public facilities such as the North Oakland Senior Center, the 81st Avenue Public Library, the César Chávez Branch library, and Oakland City Hall. Information on cooling centers is also available through County websites, with overlap between clean air and cooling facility locations at public facilities such as libraries, government buildings, and community centers.

In the event of wildfire-related power outages, Pacific Gas and Electric (PG&E) connects residents with drop-in Community Resource Centers during the day in counties impacted by a PSPS or longer outage. All centers provide an ADA-accessible restroom and hand-washing station, medical equipment charging, device charging, Wi-Fi, bottled water, and snacks. Indoor centers also offer air-conditioning or heating, seating, and ice. Residents may locate these centers through the PG&E website. Evacuation routes and procedures are discussed in the following section.

By nature, shelter infrastructure is adaptive to extreme conditions and emergency climate events. Because shelters are established to shield communities from physical hazards, physical vulnerability is not as much of a concern as capacity and accessibility.

Food

As described in the 2030 Equitable Climate Action Plan, "Local food systems are crucial to not only providing sustenance but also building long-term community resilience." In a 2009 community survey, 33 percent of East Oakland residents surveyed responded that there is not a full-service, affordable supermarket near their house, and most of East Oakland is considered a "food desert" by the USDA.[215] The City is working to address food insecurity through temporary relief programs that provide immediate aid to food-insecure residents, as well as structural solutions that alleviate the root socio-economic causes of food insecurity.

Oakland's Parks, Recreation, & Youth Development Department's (OPRYD) Community Gardening Program provides 16 community garden spaces for residents to grow organic food; 10 rental plot community gardens; 23 sites with youth gardening facilities; and six community gardens in partnership with schools and local nonprofit organizations such as Acta Non Verba, City Slicker Farms, Phat Beets Produce, and Oakland Based Urban Gardens. The Oakland Public Library is also committed to increasing local food security by hosting a Seed Lending Library at

[215] Communities for a Better Environment. 2009. Community-Based Research Summary 2007-2009.

four branches–Cesar Chavez, Dimond, Melrose, and the African American Museum and Library at Oakland (AAMLO).

Climate hazards have the potential to disrupt or destabilize food systems and access in Oakland. Flooding and wildfires may physically limit access to food sources by disrupting travel or through the destruction of food sources such as grocery stores and food pantries. Power outages driven by wildfires, increased precipitation, extreme storm events, and extreme heat will cut off electricity for refrigeration, leading food to spoil and reducing household food supply. With increased temperatures, it also is likely that urban agriculture will become more resource intensive.

Table 4-5: Food and Shelter Infrastructure Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Low Shelters for those displaced by wildfire will be strategically located away from fire hazards, limiting exposure. Food sources are distributed throughout an array of locations such that wildfire is unlikely to cause significant damage.	High Displacement from wildfire hazards can cause significant demand for shelter. Smoke-related air pollution from wildfire can have significant public health consequences and cause surges in demand for clean air facilities in the event of major wildfires. PSPS can cut off electricity for refrigeration, and wildfires can disrupt travel to food sources.	3
SLR, Flooding, and Increased Precipitation	Medium Shelters for those displaced by flooding will be strategically located away from flood hazards, limiting exposure.	High There are fewer shelter resources for residents displaced by flooding than other climate hazards, and flooding can significantly disrupt travel to sheltered locations. Similarly, flooding can disrupt travel to food sources, and increased precipitation may cut off electricity for refrigeration.	4
Extreme Heat and Temperature Increases	Medium Food and shelter infrastructure have some exposure to extreme heat.	Medium Extreme heat can negatively impact urban farming, and lead to power outages that cut off electricity for refrigeration.	3

Water

The East Bay Municipal Utility District (EBMUD) is the City's primary provider of water and sewage treatment services. Figure 4-3 illustrates an overlay of sanitary sewer networks in Oakland and flood exposure, and indicates that EBMUD's primary wastewater treatment center in West Oakland is exposed to flooding from potential 100-year storm events combined with 5.5 ft of sea level rise. According to the 2020 EBMUD Wastewater Climate Change Plan (WCCP), EBMUD's primary wastewater treatment plant is expected to avoid major inundation impacts due to sea level rise except during 100-year storm events, and even then, storm-related inundation is expected to only reaches facilities that are not critical to the treatment process. However, it should be noted that the Wastewater Climate Change Plan does not factor in elevated groundwater levels induced by SLR, suggesting that the potential impacts are likely more significant that the 2020 report indicates.

The WCCP also reports that "expected temperature increases will result in little to no discernible effect on the wastewater treatment process."[216] With respect to wildfire, EBMUD facilities are not significantly exposed, and many EBMUD facilities have their own power generators, including the main wastewater treatment plant in West Oakland, which provides a buffer to any potential impacts from PSPS.

The greatest climate hazard that threatens water facilities and supply in Oakland is flooding and sea level rise. If a major storm or flooding event damages sewer lines, the public will be unable to dispose of sanitary waste through home-plumbing, which will cause significant public health challenges.[217] Groundwater intrusion and contamination caused by flooding may also contaminate surface water supplies. Rising sea levels and storm events could lead to increased incidents of raw sewage seeping into fresh groundwater aquifers or backing up into streets and homes.[218] Contaminated sites along the coast at risk of both surface and groundwater flooding include active and closed landfills and "brownfields," which are undergoing or require cleanup, such as federal Superfund sites, military cleanup sites, and California Department of Toxic Substances Control sites. Additional information about hazardous sites and flooding in Oakland is provided later in this chapter.

In addition to sea level rise and flooding hazards, climate-change driven droughts are of increasing concern to Californians. During a drought, Oakland experiences higher water prices; decreased cooling options during extreme heat days; loss of shade trees, plants, and comfortable open space; and higher risk of wildfires. Extreme weather events and increased temperatures can also strain power grids, increase water system demand, and exacerbate system loss because of evaporation from aqueducts, lakes, and reservoirs.[219]

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[216] Ku, Jennifer, et al. *Wastewater Climate Change Plan*. East Bay Municipal utility District, 2020. https://www.ebmud.com/download_file/force/8348/827?EBMUD_Climate_Change_Plan_June_2020_wGuidelines.pdf

[217] PETEK, GABRIEL. "Preparing for Rising Seas: How the State Can Help Support Local Coastal Adaptation Efforts." Dec. 2019.

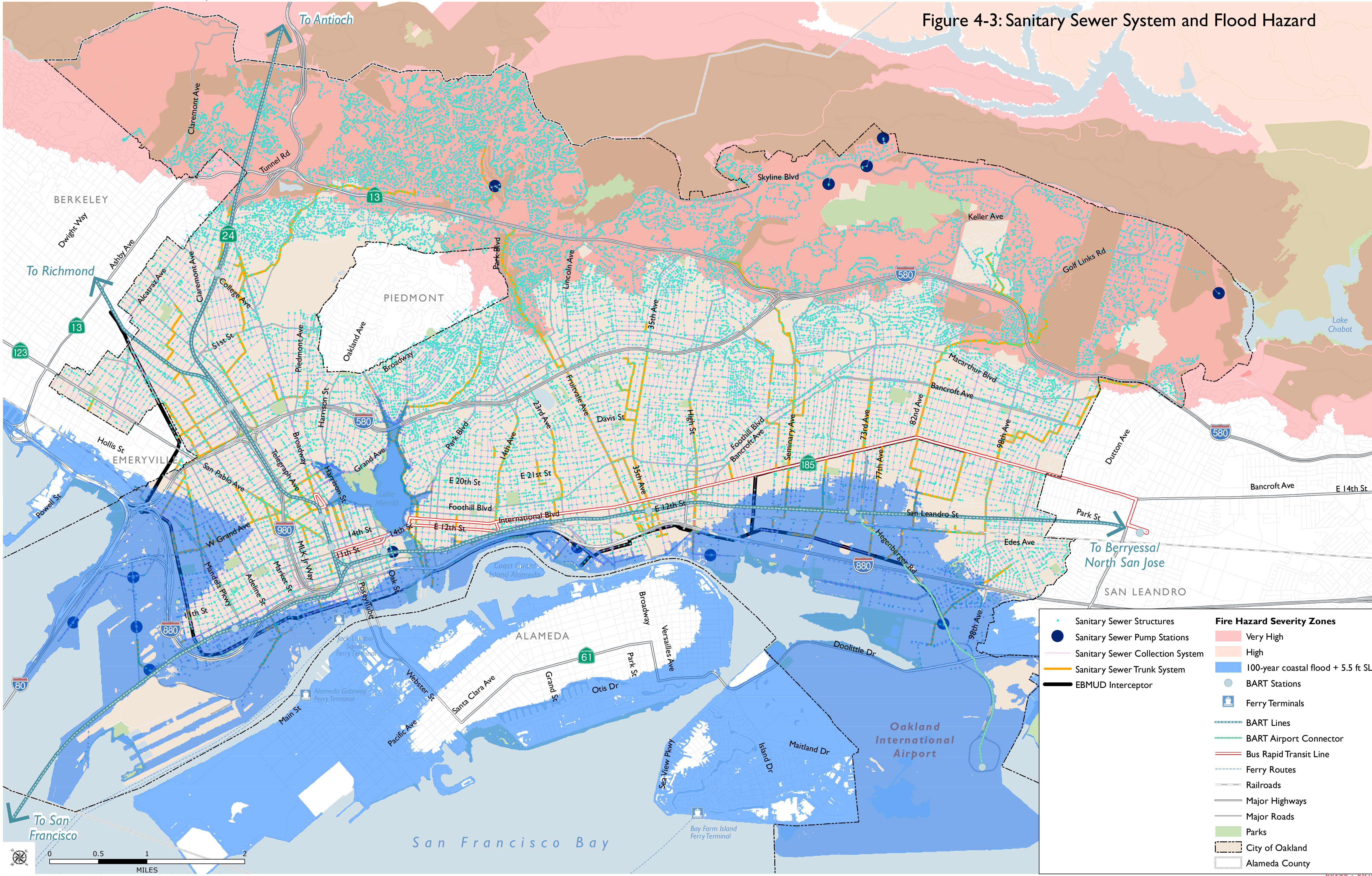
[218] *LA County Climate Vulnerability Assessment*. Oct. 2021. https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

[219] Ibid.

Table 4-6: Water Infrastructure Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Low Critical water infrastructure is not significantly exposed to wildfire hazards.	Low Critical water infrastructure is unlikely to experience significant impacts from wildfires; treatment plants and sewer systems are unlikely to be affected by power-outages.	1
SLR, Flooding, and Increased Precipitation	Medium Critical water infrastructure is somewhat exposed to hazards from SLR, flooding, and increased precipitation.	High Flooding, SLR, and increased precipitation presents significant hazards to public health and safety should it impact critical water infrastructure. Groundwater intrusion can damage sewer systems and contaminate groundwater supplies farther inland than current sea level rise and 100-year coastal flood event projections.	4
Extreme Heat and Temperature Increases	Medium Critical water infrastructure has some exposure to extreme heat and temperature increases.	Medium Drought raises water prices and damages vegetated buffers that act as cooling infrastructure. Increased temperatures and extreme heat can increase water system demand and exacerbate system loss because of evaporation from aqueducts, lakes, and reservoirs.	3

Figure 4-3: Sanitary Sewer System and Flood Hazard



SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

TRANSPORTATION & EVACUATION

Transportation

The City of Oakland is home to a robust, multi-modal transit system that functions as a major Bay Area transportation hub. Climate-resilient transportation networks are essential for supporting the movement of goods and people across the Bay Area. Maintained and operated by the City of Oakland, Oakland's public roadways are a network of 2,300 lane miles. The pavement for 39 percent of streets is in good to excellent condition; 38 percent in fair condition; and 23 percent in poor condition. There are also 1,120 miles of linear sidewalk and 150 blocks of pedestrian pathways.[220] Major routes through Oakland include Interstates 980, 880, 580, 80, and California State Routes 24 and 13. Key transit agencies operating in the City of Oakland include:

- Bay Area Rapid Transit (BART)
- Oakland Department of Transportation
- Alameda-Contra Costa Transit (AC Transit):
- Port of Oakland (Oakland Sea Port, Oakland International Airport)
- Amtrak
- San Francisco Bay Water Emergency Transportation Agency (WETA) & San Francisco Bay Ferry

Projected increases in average annual temperature and extreme heat events will have substantial effects on Oakland's paved roads and rail tracks. Extremely high temperatures can damage roadways, railways, and bridges, as well as reduce the comfort and feasibility of walking, biking, and taking public transit. Rail infrastructure is also vulnerable to extreme heat events, resulting in damage and delays to networks. Bay Area Rapid Transit (BART) operates its heavy rail transit system through the city and is subject to thermal expansion of tracks in hot weather which can cause rail buckling, train derailment, and reduce the life expectancy of the infrastructure.[221]

Flooding erodes roadway infrastructure, exacerbates existing damage, and can wash away soil supporting roadways, particularly in areas with narrow streets such as the Oakland Hills. Sea level rise modeling coupled with a 100-year storm event in 2100 in the San Francisco Bay area shows minimal temporary roadway inundation, but significant effects on critical nodes (connectors) in the regional road network, increasing the potential for major disruptions in regional commute patterns.[222] One cascading impact of climate change on roadways is that as heavy-duty vehicles transition to electric batteries, wear and tear on roadways is likely to increase which will compound wear and tear from worsened storms and flooding.

The Posey and Webster Street Tubes, a critical transportation corridor between Oakland and the City of Alameda, are highly exposed to potential impacts from sea level rise and flooding. According to the City of Alameda's 2019 Climate Action and Resiliency Plan, a small section of shoreline above the

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[220] "Streets and Sidewalks." *City of Oakland*, www.oaklandca.gov/topics/streets-and-sidewalks. Accessed 25 July 2022.

[221] Greenham, Sarah, et al. "The Impact of High Temperatures and Extreme Heat to Delays on the London Underground Rail Network: An Empirical Study." *Meteorological Applications*, vol. 27, no. 3, May 2020, 10.1002/met.1910.

[222] Bedsworth, Louise, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCCA4-2018-013.

Posey and Webster Tubes is likely to overtop due to sea level rise at and beyond three feet with projected inundation into the tubes and along nearby roads. However, the City of Alameda has planned modifications to the tubes and surrounding shoreline to protect them from flood-related disruptions, including road grading, floodwalls, and other flood-proofed infrastructural improvements.[223]

According to California's Fourth Climate Change Assessment, "Railway operations are disrupted if only 10 cm (about 4 inches) of flooding occurs. However, these disruptions are typically short lived, as rails can be quickly repaired or replaced."[224] According to the November 2022 San Francisco Bay Area Rapid Transit Local Hazard Mitigation Plan, flooding can impact BART by damaging facility property, blocking pathways, and causing service delays. However, BART has not yet experienced severe enough flooding (100- or 500- year flood events), to result in extensive damage to facilities or the right of way, though rain events have caused service disruptions in winter months.[225] Oakland International Airport and Oakland Seaport are particularly vulnerable to sea level rise and flooding. In 2019, the Port of Oakland conducted a Sea Level Rise Assessment, concluding that the Port of Oakland faces significant exposure and risk in the event of 5.5' sea level rise and 100-year storm events, which could lead to significant disruption in service and financial losses.[226]

In addition to flood risk, Oakland International Airport faces additional climate related hazards such as rising temperatures and severe weather patterns, which could threaten flight take-off and in-air flight safety. High temperatures may cause concrete pavement to buckle and non-concrete pavement to deteriorate. Extreme heat and moisture can also decrease air density, reducing aircraft lift, and necessitating longer runways or weight restrictions on planes.[227]

As demonstrated by Figure 4-4, roadway networks in the Oakland Hills are particularly vulnerable and subject to vehicular access disruptions in the event of a wildfire. Climate-related transportation impacts may increase the risk to human safety by damaging or blocking evacuation routes and limiting access for emergency responders.[228] If substantial, this roadway damage may also disrupt access to regular medical care for individuals with chronic illnesses, such as those who require dialysis treatment. These disruptions also affect those who commute into or out of the city for work, who may suffer economic losses.[229] According to the November 2022 San Francisco Bay Area Rapid Transit Local Hazard Mitigation Plan, wildfires could cause service delays from facility damage or electricity loss.[230]

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223 *City of Alameda Climate Action and Resiliency Plan*. City of Alameda, 2019, www.alamedaca.gov/files/sharedassets/public/public-works/climate-action-page/new-folder/final-carp-9-2019/alameda_carp_final_091119noappendices.pdf.

224 Bedsworth, Louise, Dan Cayan, Guido Franco, Leah Fisher, Sonya Ziaja. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCCA4-2018-013.

225 Local Hazard Mitigation Plan *San Francisco Bay Area Rapid Transit District*. Nov. 2022.

226 "Port of Oakland Sea Level Rise Assessment 1." July 2019 https://www.portofoakland.com/files/PDF/Task%207_20190709%20Port%20Oak%20SLR%20Assmt_Rev2.pdf

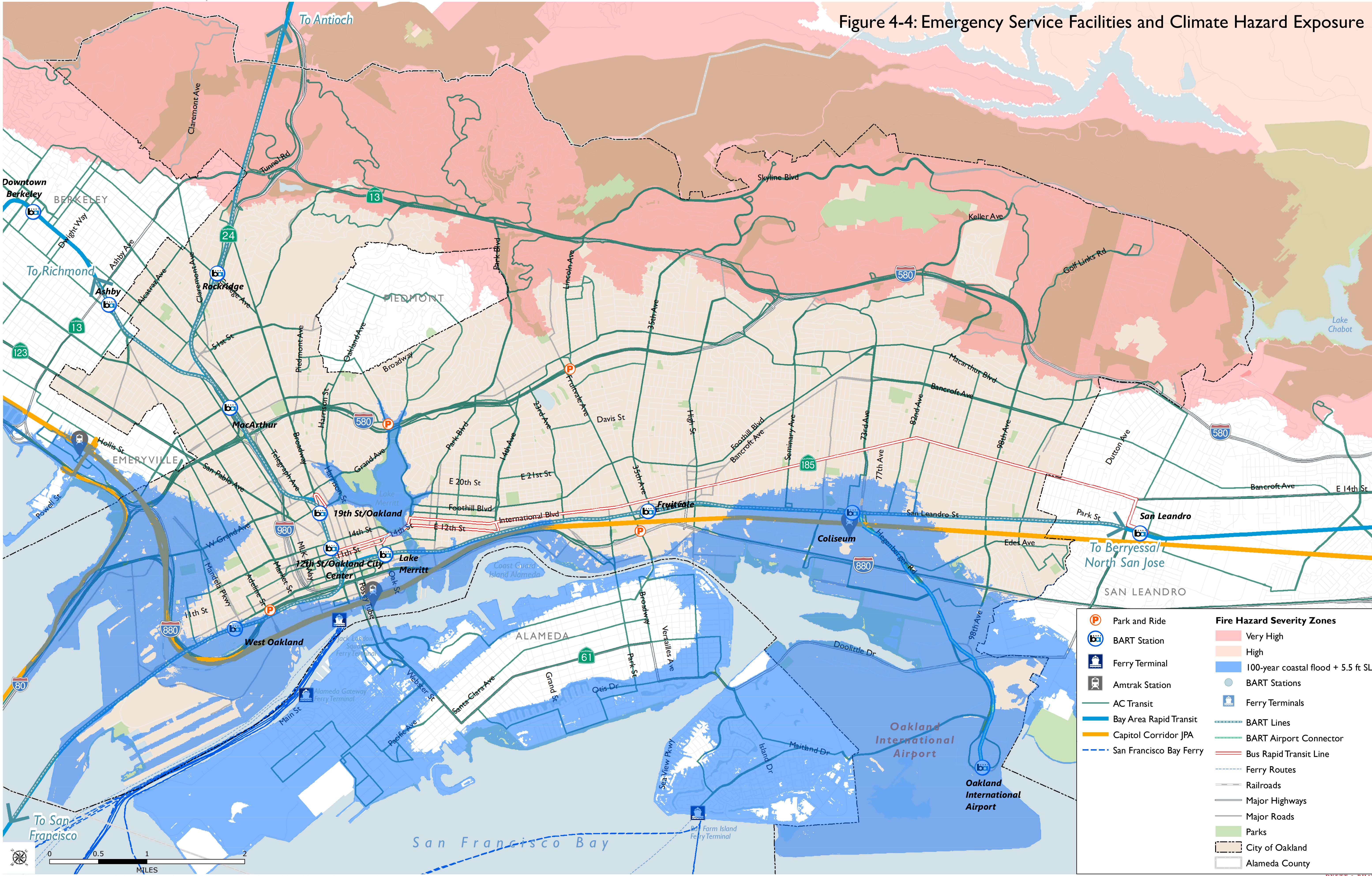
227 *LA County Climate Vulnerability Assessment*. Oct. 2021. https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

228 Bedsworth, L., Cayan D., Franco G., Fisher L., Ziaja S. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-013.

229 Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/12/.

230 Local Hazard Mitigation Plan *San Francisco Bay Area Rapid Transit District*. Nov. 2022.

Figure 4-4: Emergency Service Facilities and Climate Hazard Exposure



Park and Ride	
BART Station	
Ferry Terminal	
Amtrak Station	
AC Transit	
Bay Area Rapid Transit	
Capitol Corridor JPA	
San Francisco Bay Ferry	

Fire Hazard Severity Zones

- Very High
- High
- 100-year coastal flood + 5.5 ft SLR
- BART Stations
- Ferry Terminals
- BART Lines
- BART Airport Connector
- Bus Rapid Transit Line
- Ferry Routes
- Railroads
- Major Highways
- Major Roads
- Parks
- City of Oakland
- Alameda County

SOURCE: Caltrans, 2022; Alameda CTC, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

Evacuation Routes

Evacuation routes and key transportation corridors provide critical services during times of environmental crisis. An effective evacuation route must be able to transport substantial volumes of people safely and efficiently, often on relatively short notice. Activities between transportation agencies and first responders must therefore be discussed and coordinated well in advance of an emergency event. Therefore, maintaining a robust and resilient network of emergency evacuation corridors is an ongoing, resource-intensive process that requires collaboration between numerous government agencies and adequate funding to support roadway improvements. A detailed assessment of evacuation routes in Oakland is provided in the 2045 General Plan Update Safety Element.

Flood or fire related disruptions to evacuation routes may limit emergency response capacity in exposed neighborhoods, with serious implications for public safety. The most vulnerable residential areas in Oakland are those in the Oakland Hills, where wildfire risk is highest, and those closest to the shoreline, where flood risk is highest. Additionally, the relatively narrow residential streets in areas of the Oakland Hills may impact emergency response in the event of a fire emergency.

Evacuation procedures are most effective when residents are aware of the emergencies that are most likely to affect them and have ample time and support to prepare their own emergency plans. The City of Oakland, in conjunction with Alameda County, has a variety of systems and procedures in place to protect residents and visitors to plan for, avoid, and respond to a hazard event. The following section details emergency communications systems the City of Oakland currently has in place to communicate emergency messaging and notify residents of emergency events and operations. Parallel efforts to evaluate evacuation scenarios are underway as part of the General Plan Safety Element Update. Even if all evacuation routes are well-maintained and the City is effectively able to coordinate emergency alert and evacuation efforts, several barriers may prevent residents from evacuating. Research has shown that residents of high-density areas may require additional assistance while evacuating.[231] Some populations, such as older adults, the hospitalized,[232] individuals with low incomes,[233] individuals with mobility issues, those who lack access to reliable transportation,[234] those whose do not receive language-appropriate warning and evacuation information, and those with pets[235] may not be able to evacuate in a timely manner even if they desire to do so. When a large-scale evacuation is taking place, older adults may be left behind

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[231] Porter K., et al., "Overview of the ARkStorm Scenario." United States Geological Survey (2010). July 1 2020: https://pubs.usgs.gov/of/2010/1312/.

[232] Benevolenza MA, DeRigne L. "The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature." *Journal of Human Behavior in the Social Environment* (2019). Nov 8 2019: https://www.tandfonline.com/doi/abs/10.1080/10911359.2018.1527739?journalCode=whum20.

[233] U.S. Global Change Research Program, Climate and Health Assessment (Washington D.C., 2016). Oct 28 2019: https://health2016.globalchange.gov/populations-concern.

[234] Nutters, H. "Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning." Adapting to Rising Tides (2012). Nov 8 2019: http://www.adaptingtorisingtides.org/wp-content/uploads/2015/04/ART_Equity_WhitePaper.pdf.

[235] Porter K., et al., "Overview of the ARkStorm Scenario." United States Geological Survey (2010). July 1 2020: https://pubs.usgs.gov/of/2010/1312/.

by caretakers and families, and their specific conditions and medical needs may be overlooked by planning authorities.

Individuals who cannot afford access to private transportation and services such as hotels may also be disadvantaged during climate-related disaster events. Car ownership is an important marker of social vulnerability to storms and floods, and households without a personal vehicle may be at greater risk of harm because they lack the capacity to evacuate.[236] Approximately 15 percent of Oakland's households lack access to a household vehicle,[237] and Figure 4-5 illustrates an overlay of populations without access to a household vehicle and high-flood risk zones. However, it should be noted that this statistic does not distinguish between income levels, which is an important factor in a household's ability to respond to emergency events. Higher-income households in transit-rich neighborhoods may be able to afford personal vehicles but elect not to. Lower-income households that are farther from transit amenities are not afforded the same options for mobility and are more vulnerable to evacuation-related challenges during disaster events.

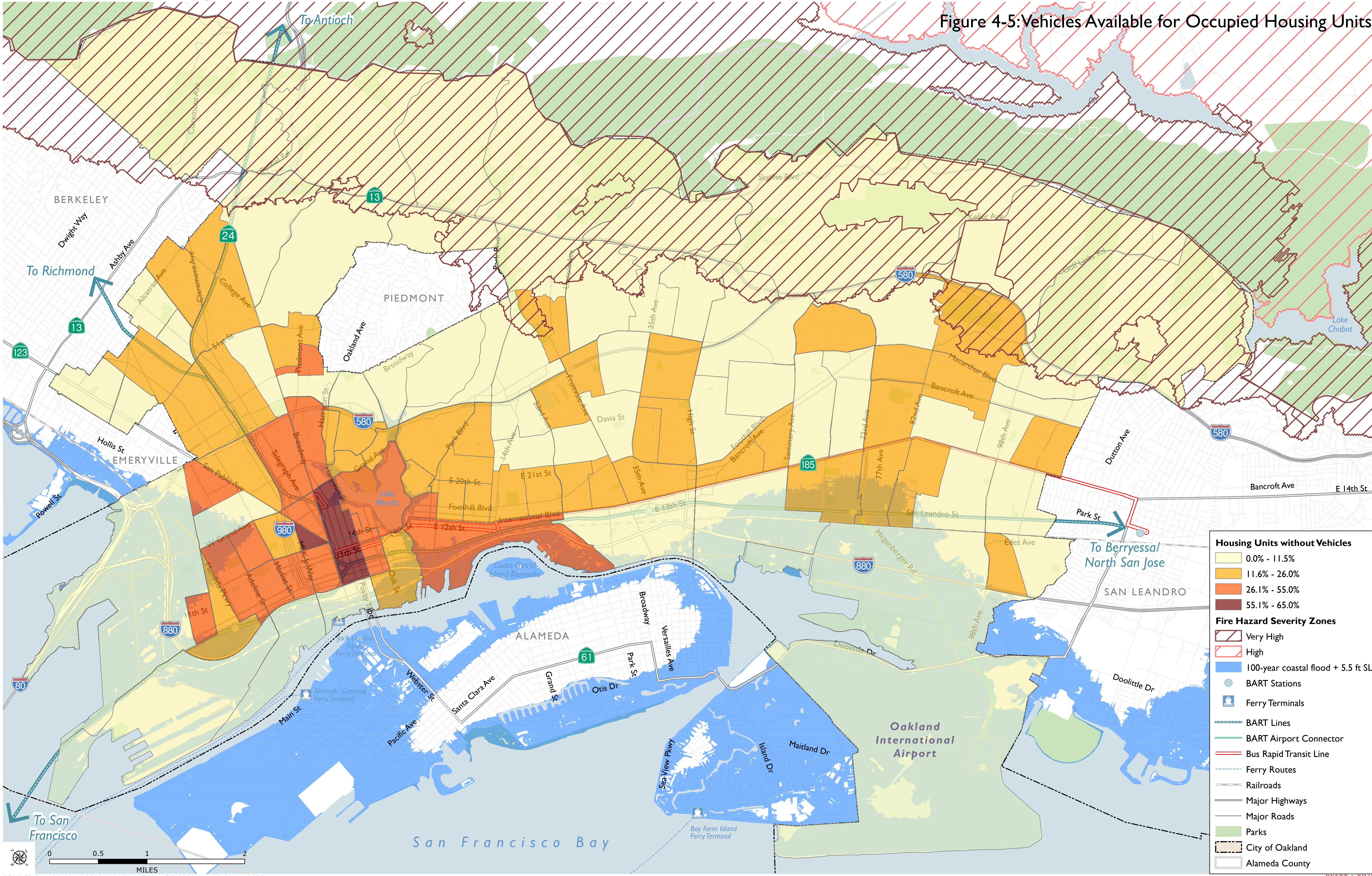
Table 4-7: Transportation and Evacuation Infrastructure Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Medium Transportation infrastructure has some exposure to wildfire hazards primarily in the Oakland Hills.	High Wildfire in the Oakland Hills could damage or block roadways, leading to significant impacts on public health and safety.	4
SLR, Flooding, and Increased Precipitation	High Transportation infrastructure is highly exposed to flood hazard, particularly the Port of Oakland and roadway infrastructure near the shoreline.	High Flooding may result in significant consequences to transportation service and public health and safety. The Port of Oakland and other transportation infrastructure near the shoreline is particularly vulnerable to flooding and SLR.	5
Extreme Heat and Temperature Increases	High Transportation infrastructure is highly exposed to extreme heat.	Medium Extreme heat may damage paved roadways and rail tracks, impact flight schedules, limit active mobility options, and may cause some disruptions to public health and safety.	4

[236] Nutters, H. "Addressing Social Vulnerability and Equity in Climate Change Adaptation Planning." Adapting to Rising Tides (2012). Nov 8 2019: http://www.adaptingtorisingtides.org/wp-content/uploads/2015/04/ART_Equity_WhitePaper.pdf.

[237] US Census Bureau ACS 5-year 2016-2020

Figure 4-5: Vehicles Available for Occupied Housing Units



SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

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ENERGY & COMMUNICATIONS

Energy systems in the City of Oakland include electricity transmission lines, natural gas lines, and energy generation facilities (e.g., solar photovoltaic systems). PG&E is the public utility providing electricity transmission and distribution as well as gas to residents and businesses in Oakland. In 2016, the County of Alameda and 11 of its cities launched East Bay Community Energy (EBCE) an independent public agency. EBCE secures electrical energy supply for residents and businesses and leads energy-related climate programs, including transportation electrification. As the nonprofit public power provider, EBCE delivers electricity with high renewable energy content, at a reduced cost to customers, through PG&E's transmission and distribution system.

As discussed in Chapter 2, typical heat wave duration and number of extreme heat days is projected to increase in the City of Oakland. In addition to the public health impacts, during periods of high temperatures, electricity demand increases because of increased air conditioning use to meet preferred indoor temperatures. As the unincorporated county experiences higher temperatures and more frequent extreme heat events due to climate change, the electricity demand will increase, placing greater stress on the electrical grid. This results in a higher risk of energy blackouts [238] and increases in energy bills.[239] These impacts can strain household budgets, increase exposure to heat, and negatively impact the provision of medical and social services.[240]

According to PG&E's 2022 Climate Strategy Report, electric grid assets are highly sensitive to high extreme heat,[241] which can cause transmission lines to sag and lose carrying capacity. Power substations also lose operating capacity due to extreme temperatures and may be overloaded and tripped by increased demand. Additionally, extreme temperatures can reduce the efficiency and output capacity of both natural gas-fired power plants and solar power plants and can impact chiller performance and lead to capacity losses for both dry cooled natural gas plants and combined cycle natural gas plants. [242]

Climate change is projected to increase wildfire risk in high-hazard areas of Oakland. Consequently, PG&E has instituted Public Safety Power Shutoffs and Enhanced Power Safety Shut Offs when forecasts indicate the potential for extreme weather. Although PG&E endeavors to provide multiple days' notice and warning to those who may be affected, these events are still

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[238] U.S. Climate Resilience Toolkit, Extreme Heat—NIHHIS. Oct 28 2019: https://toolkit.climate.gov/topics/human-health/extreme-heat.

[239] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/11/.

[240] Maxwell, K., Julius S., Grambsch A., Kosmal A., Larson L., Sonti, N., Built Environment, Urban Systems, and Cities. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (Washington D.C., 2018). Oct 28 2019: https://nca2018.globalchange.gov/chapter/11/.

[241] *PG&E Climate Strategy Report*. PG&E Corporation, June 2022.

[242] *LA County Climate Vulnerability Assessment*. Oct. 2021. https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

disruptive to many residents, especially in rural areas of the unincorporated county. In addition to the impacts of lack of electricity, health hazards can result if residents are unable to use prescribed medications and treatments that rely on electricity and refrigeration, and food insecurity can worsen due to lack of refrigeration.

Currently, no PG&E substations in Oakland are at major risk of inundation from sea level rise or 100-year storm events.[243]

Emergency Communications

As stakeholders in Safety Element focus groups have highlighted, emergency messaging and public information is essential for effective emergency response. Oakland's emergency alert and assistance systems include city-wide emergency sirens, fire and law enforcement vehicle loudspeakers, emergency response phone numbers such as 9-1-1, agency websites, and digital tools. Alameda County's AC Alert tool provides Oakland residents with rapid updates and critical information in a variety of situations, such as earthquakes, fires, severe weather, unexpected road closures, missing persons, and evacuations of buildings or neighborhoods. Residents can choose to receive notifications on mobile or business phones, email addresses, text messages, and more. In 2021, the City of Oakland launched an evacuation software system called Zonehaven, to provide residents with real-time maps and information to guide evacuation in the event of emergency events.

Notification of emergencies and evacuation instructions rely upon functioning communication facilities such as AM/FM antennas, broadband radio transmitters, and television transmitters. As identified in Figure 4-6, many energy and communications facilities are distributed throughout the Oakland Hills. Climate-change related increases in wildfire risk may threaten Oakland's energy and communications, particularly in high wildfire-hazard areas. Because many communications systems rely on electricity, impacts to energy infrastructure may also have cascading impacts on communications systems. For example, during power outages, residents may have reduced access to emergency communications that require internet connection or electricity to access.

Table 4-8: Energy and Communications Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Medium Four electric facilities are located in a VHFHSZ, as well as a number of communications facilities.	High Energy infrastructure is highly sensitive to wildfire-related impacts, which can cause major disruptions to service.	4
SLR, Flooding, and Increased Precipitation	Medium Several facilities are located in high flood hazard areas.	Low In spite of high exposure, few facilities are at risk of significant impacts from flooding or SLR.	2
Extreme Heat and Temperature Increases	High Energy and communications infrastructure is highly exposed to increases in temperature and extreme heat.	High Electric grid infrastructure is highly sensitive to extreme heat.	5

[243] *PG&E Climate Strategy Report*. PG&E Corporation, June 2022.

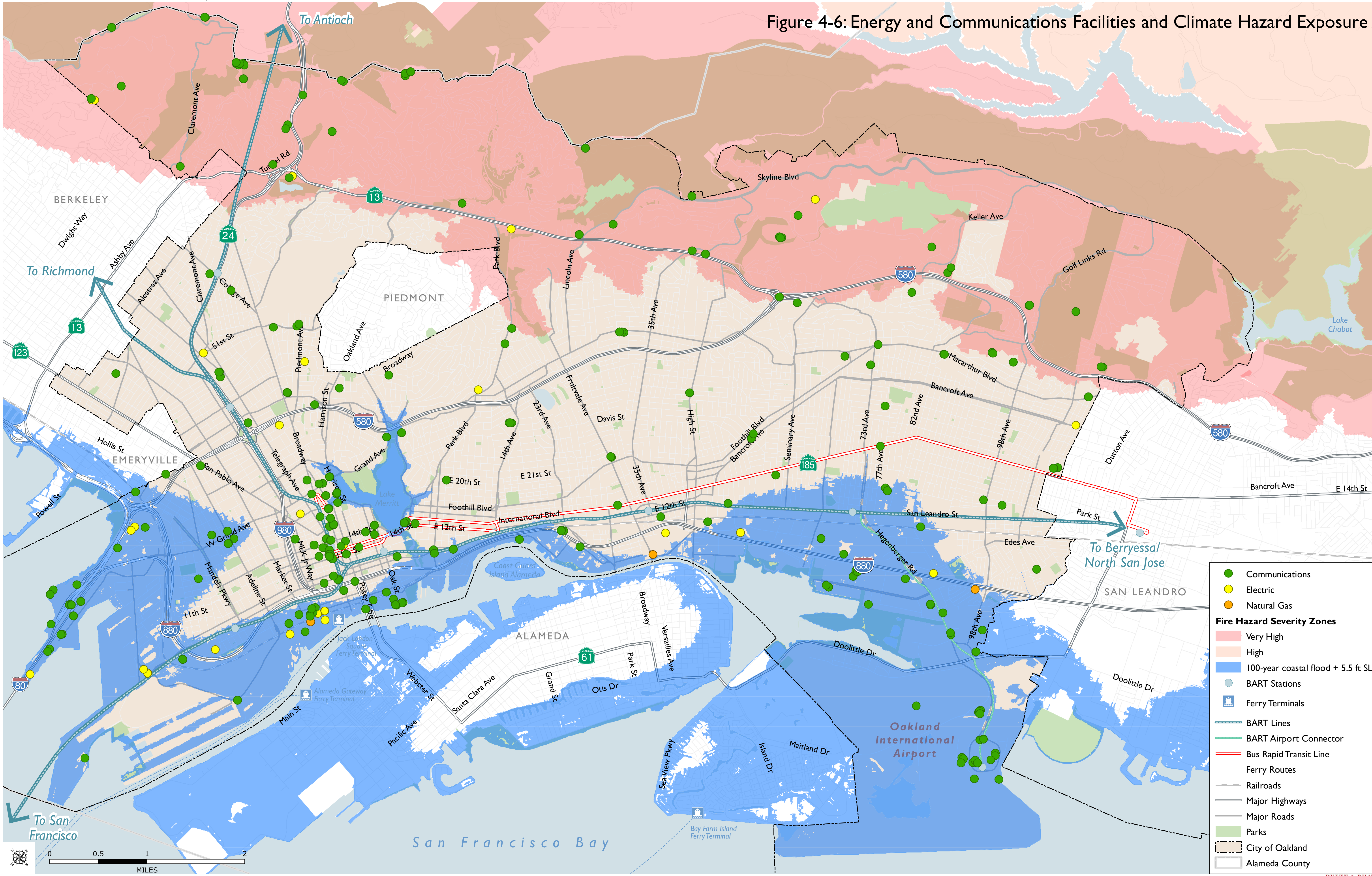

Figure 4-6: Energy and Communications Facilities and Climate Hazard Exposure

SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

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HAZARDOUS MATERIALS

Exposure to hazardous materials can result in lung damage, cancer, cardiovascular disease, low infant birth weight, and other negative outcomes that affect quality of life and reduce life expectancy.[244] Local organizations and environmental advocacy groups such as Communities for a Better Environment (CBE) have documented ongoing environmental injustices that low-income and BIPOC communities in Oakland face, and how these communities often suffer from the largest concentrations of polluters and pollution. Online regulatory databases document approximately 1,686 hazardous materials sites currently identified in the City of Oakland.[245] Hazardous materials sites were identified if they met one of the following criteria, drawn for the 2045 General Plan Update Map Atlas:

- Sites with known unauthorized releases of hazardous chemicals or petroleum under regulatory oversight.
- Sites with subsurface impacts and residual chemicals in the city.
- Sites outside of the city but where contamination had the potential to migrate and impact soil and/or groundwater in the city.
- Status on California Department of Toxic Substances Control and/or California State Water Resources Control Board lists

Based on the evaluation of the above criteria, the sites were qualitatively ranked from 5 (very high hazard) to 1 (very low hazard). A brief description of these rankings is provided in Table 4-9, also outlined in the Oakland General Plan Map Atlas. Of the 1,686 identified sites, 361 are assigned a 5 ranking, 60 are assigned a 4 ranking; 14 are assigned a 3 ranking, 152 are assigned a 2 ranking, and 1,099 are assigned a 1 ranking. Figure 4-7 identifies sites ranked 3, 4, and 5, and overlays these sites with flood risk in Oakland.

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[244] 2045 general Plan Update: Oakland Map Atlas, 2022 https://cao-94612.s3.amazonaws.com/documents/Map-Atlas_Revised.pdf

[245] Ibid.

Table 4-9: Hazard Analysis Ranking

Rank	*Hazard*	*Description*	*Consequences*
5	Very High	Potentially acute threat to human health or environment.	Immediate action needed to mitigate existing threat.
4	High	Potentially significant risk to human health or environment	Investigation or remediation needed for existing risk. Or new development will be subject to remedial measures.
3	Moderate	Potential threat/risk to human health or environment	Possible investigation needed for existing development. Residual contamination in soil and/ or groundwater may necessitate re-opening of case based on human health (vapor intrusion pathway) or groundwater impacts and revised closure standards.
2	Low	Less than significant threat/risk to human health or environment.	Special management/notification in case of subsurface work. New development may necessitate verification of closure standards and possible vapor intrusion study.
1	Very Low	De minimis condition	No action or special management needed other than possible notification.

Source: 2045 general Plan Update: Oakland Map Atlas, 2022 https://cao-94612.s3.amazonaws.com/documents/Map-Atlas_Revised.pdf

In regions where hazardous materials facilities are exposed to high flood risk, communities may be exposed to polluted runoff and other dangerous conditions during flooding events.[246] Facilities that generate and store hazardous materials, such as laboratories, manufacturing facilities, and gas stations may contaminate floodwaters from SLR or heavy precipitation. According to research by UC Berkeley, "Legacy contamination in the soil will be remobilized when the water table comes up and intersects with these areas of contaminated soil." [247] In addition to contaminated soils, floodwaters and rising water-tables may penetrate surface -level and underground tanks, mobilizing toxic liquids and waste from contaminated pits or piles. To compound these hazards, chemicals contaminating groundwater can also vaporize, putting affected communities at additional risk of health hazards from chemical inhalation.[248]

166 hazardous materials facilities ranked 3 through 5 are exposed to high flood risk in the city, though with groundwater intrusion scenarios, flooding is predicted to extend farther inland than current sea level rise and 100-year coastal flood event projections. According to researchers at UC Berkeley, the "lack of groundwater data coupled with imprecise estimates of facility boundaries may lead to potential underestimates of the number of at-risk facilities."[249]

[246] *LA County Climate Vulnerability Assessment*. Oct. 2021. https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

[247] "Toxic Tides." *Sites.google.com*, UC Berkeley, Apr. 2022, sites.google.com/berkeley.edu/toxictides/home. Accessed 25 July 2022.

[248]"Shallow Groundwater Response to Sea Level Rise | San Francisco Estuary Institute." *Www.sfei.org*, www.sfei.org/projects/shallow-groundwater-response-sea-level-rise. Accessed 25 July 2022.

[249] "Toxic Tides." *Sites.google.com*, UC Berkeley, Apr. 2022, sites.google.com/berkeley.edu/toxictides/home. Accessed 4 Jan 2023.

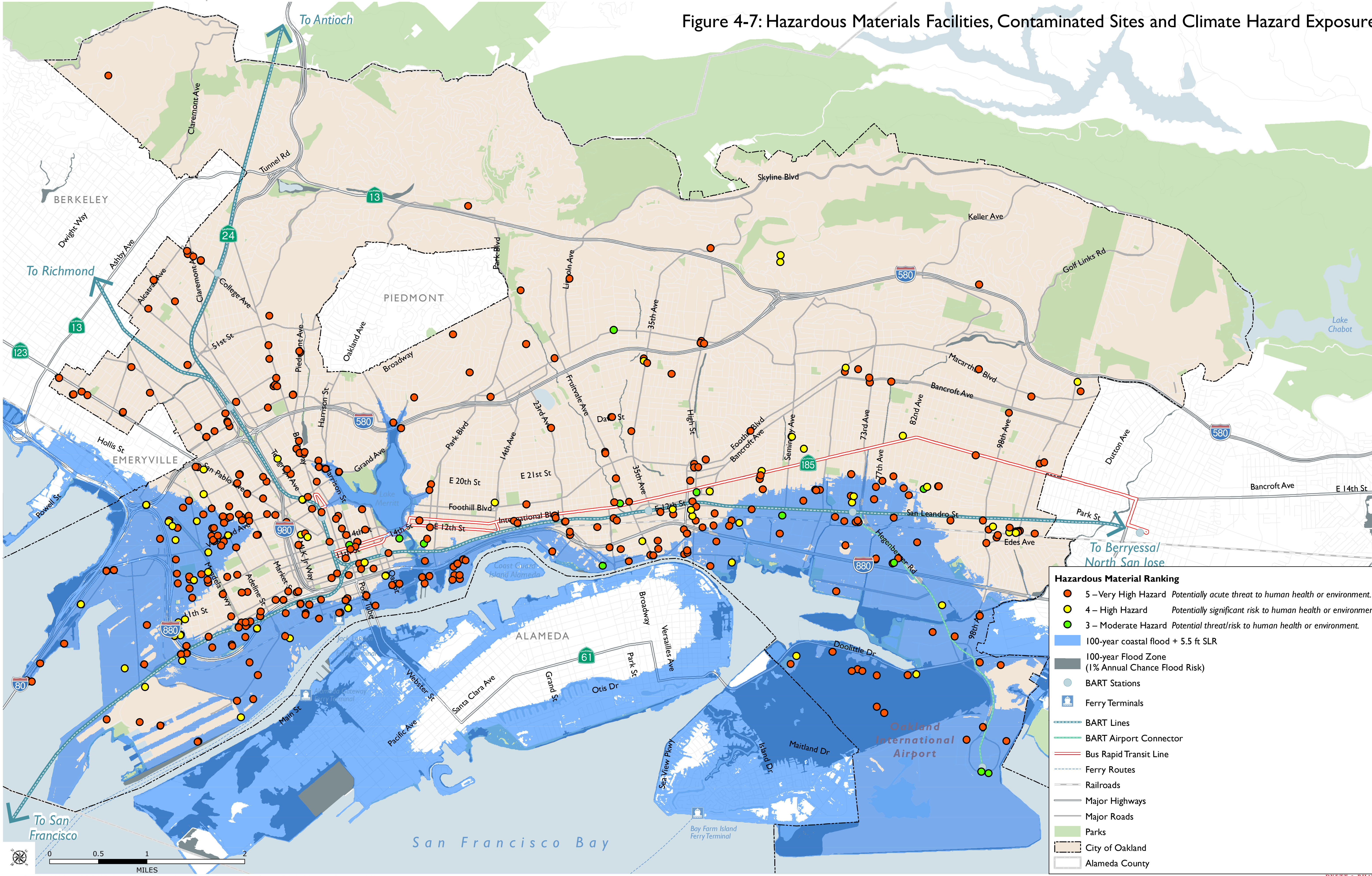
There are nine hazardous materials facilities located in a VHFHSZ. If these facilities were impacted during a wildfire, it is possible that they could release hazardous vapors, smoke, and residue from the burning and create additional human and environmental health hazards.[250] Similarly, extreme heat and increased temperatures may react with hazardous substances, and materials with greater volatility may produce higher levels of dangerous vapors at elevated temperatures if not properly contained. However, is should be noted that the risk associated with each hazardous facility and impact from wildfire or extreme heat varies depending on the type of hazardous material and is not uniform across the facilities located in the VHFHSZ.

Table 4-10: Hazardous Materials Facilities and Climate Vulnerability Summary

Climate Hazard	*Exposure*	*Sensitivity*	*Vulnerability*
Wildfire	Medium Hazardous materials facilities have some exposure to wildfire.	Medium Impacts of wildfire on hazardous materials facilities are potentially significant, but they are also uncertain and vary according to the type of hazardous material impacted by wildfire at each facility.	3
SLR, Flooding, and Increased Precipitation	High Hazardous materials facilities are highly exposed to flooding and SLR.	High Impacts of SLR, flooding, and precipitation on hazardous materials are predicted to have major consequences on public health and safety; communities may be exposed to polluted runoff, contaminated groundwater intrusion, and other dangerous conditions during flooding events.	5
Extreme Heat and Temperature Increases	High Hazardous materials facilities are highly exposed to extreme heat.	Medium Impacts of extreme heat on hazardous materials facilities could have some consequences on public health and safety, but they are also uncertain and vary according to the type of hazardous material impacted by extreme heat at each facility.	4

[250] US EPA. "Dealing with Debris and Damaged Buildings." *US EPA*, 4 June 2013, www.epa.gov/natural-disasters/dealing-debris-and-damaged-buildings.

Figure 4-7: Hazardous Materials Facilities, Contaminated Sites and Climate Hazard Exposure



SOURCE: ESA, 2022; DTSC, 2021; SWB, 2021; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

5 Adaptive Capacity

Climate change adaptation can be defined as the ongoing process of adjusting natural and human systems in anticipation of or in response to the effects of climate change, with the goal of reducing the harm of and/or increasing the benefits associated with these efforts.

There are many elements to successful climate adaptation. One of these is adaptive capacity, or the ability of an individual, community, or society to deploy the tools that enable climate adaptation. Natural and human systems are complex, as are the effects that climate change will have on them. While developing, implementing, and evaluating climate adaptation programs, it is important to be on the lookout for signs that maladaptation is occurring. Maladaptation occurs when a well-intentioned climate change adaptation program results in direct or indirect increases to climate change vulnerability. Any proposed climate adaptation strategy should be accompanied by an exercise in identifying possible detrimental effects, keeping in mind that these effects may emerge on different geographic and temporal time scales and may affect different members of the community.

5.1 Identifying Adaptation Priorities

Prioritizing adaptation actions is a multi-step process that involves identifying which climate impacts are most likely to impact Oakland, when these impacts will be felt, how severe these impacts will be, and which City services and communities are most likely to be affected. Climate change impacts given priority will include those which are:

- Most likely to occur
- Most likely to cause severe disruption
- Most likely to manifest in the near-term

Figures 3-10 through 3-14 identify regions of Oakland where economic, social, and physical stressors make residents especially vulnerable to the effects of climate hazards. These vulnerabilities are further discussed in Section 3.3, Social Vulnerability and Climate Hazard Exposure.

To build a robust and responsive climate-hazard mitigation strategy, one of Oakland's most important assets is its existing network of emergency response operations, planning, and personnel. According to the 2021 Emergency Operations Plan (EOP), "Emergency management coordination in the City of Oakland is based on a bottom-up approach to response and recovery resource allocation. Local response efforts precede County response efforts, then state response efforts, and finally federal government assistance with each level exhausting its own resources prior to elevation to the next level of government." This section will identify opportunities for the City of Oakland to coordinate between existing emergency response operations, local, and regional organizations and agencies.

The 2021 EOP also assumes that "Residents living within the City of Oakland boundaries are encouraged to develop a family disaster plan and maintain the essential supplies to be self-sufficient for a minimum of 72 hours and up to 2 weeks." However, as discussed in Chapter 4, historically disadvantaged communities might find it harder to reach for support in emergencies and therefore may be less likely to prepare in advance or participate in City emergency planning recommendations. In response to this issue, the City of Oakland should identify, support, and fund existing community-based mutual aid networks to reach Oakland residents in an inclusive and community-centered manner.

Community driven initiatives such as the Resilience Leadership Training, convened in 2021 by NorCal Resilience Network with support from Urban Sustainability Directors Network, and groups such as the Allendale Neighbors Network, demonstrate the capacity of grassroots organizations to gather adaptation and resilience resources and build trust between cities and historically marginalized communities. To build on these efforts and strengthen community-based adaptive capacity and resiliency, the City is developing its first municipal resilience hubs in West Oakland and Lincoln Square. These networks will enhance Oakland's existing emergency response operations and help ensure all Oakland residents have access to the support and resources they need to respond and adapt to climate hazards and emergencies.

5.2 Adaptation Priorities by Climate Change Impact

This section identifies gaps in the City of Oakland's climate adaptation and hazard mitigation planning and provides potential strategies and partners to address missing pieces. The strategies are grounded in the evidence-based conclusions of this assessment and input from stakeholder engagement. This section also discusses adaptation priorities in terms of their implications for socially vulnerable populations in the City of Oakland. Table 5-1 outlines and summarizes these adaptation priorities by climate change impacts for the City of Oakland.

TEMPERATURE INCREASES AND EXTREME HEAT

Establishing and Identifying Air-Conditioning Equipped Facilities

Establishing and identifying air-conditioning equipped facilities in Oakland is a key adaptation priority to respond to extreme heat hazards. During past extreme heat events, the City has established emergency cooling centers in public facilities such as government buildings, senior centers, and libraries. However, as stakeholders noted, information identifying the geographic distribution of these facilities is not well organized, and cooling centers are not located according to the distribution of more socially vulnerable populations. Unhoused individuals are particularly vulnerable to extreme heat, and stakeholders underscored the need for responsively located, supportive facilities to ensure unhoused individuals have access to water and cooling facilities during extreme heat events. To address the gaps between distribution of cooling centers and meeting the needs of the most vulnerable populations, the City should conduct a City-wide survey of HVAC equipped facilities operated by the City of Oakland or community partners willing and able to provide cooling services to the broader community during extreme heat events.

Equitable Tree Canopy and Green Infrastructure Distribution

As stakeholders described in environmental justice focus groups, the inequitable distribution of Oakland's tree canopy and urban green spaces exacerbates the urban heat island effect in historically under-resourced neighborhoods in Oakland. Green infrastructure is an important tool to mitigate the harmful effects of increased temperature and urban heat islands. According to the US EPA "Trees, green roofs, and vegetation can help reduce urban heat island effects by shading building surfaces, deflecting radiation from the sun, and releasing moisture into the atmosphere."[251] The network of vegetated buffers formed by urban tree canopy and other green infrastructure is also a tool to alleviate the impacts of air pollution, which is exacerbated under climate-change driven wildfire events. To mitigate the disproportionate effects of urban heat and air pollution on vulnerable populations, green infrastructure should be prioritized near sensitive receptors (schools, low-income neighborhoods, churches, etc.).

An equitably distributed urban tree canopy alongside additional forms of green infrastructure will involve coordination across multiple City departments and community organizations. According to the requirements of the recently reissued Municipal Regional Stormwater Permit (MRP), the City must retrofit five acres of impervious surfaces with green stormwater infrastructure (GSI). This generally includes vegetated areas and some trees, which will help enhance the existing urban tree canopy and green infrastructure network. However, as stakeholders noted, consistent funding for green infrastructure construction and maintenance can be challenging to establish. Therefore, the City also relies on the Department of Transportation streetscape projects to incorporate GSI where feasible and meet regulatory requirements set by the Water Quality Control Board through the MRP. In consideration of past and ongoing funding challenges, the City should consider partnerships with private industry and green infrastructure requirements for new development as strategies to expand its network of vegetated buffers.

The City may also benefit from pursuing funding opportunities such as CAL FIRE's Urban and Community Forestry Grant Program, which provides local governments and nonprofit organizations with funding to improve the urban forest. Because special consideration is given to projects serving disadvantaged and/or low-income communities, these grants could help Oakland address the inequitable distribution of its urban tree canopy. The California Natural Resources agency offers a similar grant program for urban greening projects. In 2018, the City of Oakland was awarded a $970,000 CAL FIRE grant for a Citywide Tree Inventory and Equity-Focused Urban Forest Master Plan, which is expected to be completed in 2023 and will set goals and rationale for future urban forestry initiatives, such as tree planting, maintenance, and stewardship. Urban tree canopy is one feature of a robust network of vegetated buffers, and the expansion of that network is an essential component of Oakland's climate resiliency and adaptation strategy. However, this process currently lacks clear agency ownership or well-defined funding strategies, and challenge ahead will be to balance community need and organizational capacity.

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[251] US EPA. "Reduce Urban Heat Island Effect | US EPA." *US EPA*, 22 May 2019, www.epa.gov/green-infrastructure/reduce-urban-heat-island-effect.

Air-Conditioning Options and Building Electrification

Annual home electricity demand in California is projected to increase due to the growing use of air conditioning (AC) units.[252]

While conventional AC systems are less expensive upfront than electric heat pumps (HP), they are much more energy intensive than HPs, which also provide fossil fuel-free heating in winter that AC systems cannot. HPs can save households up to 25 percent on energy bills.

As part of its building electrification strategy as called for in the ECAP, with a goal of eliminating all fossil ("natural") gas use in all Oakland buildings by 2040, the City is encouraging Oaklanders to replace gas-powered furnaces with electric heat pumps. In the case of buildings that lack AC, this replacement eliminates gas used for space conditioning and adds cooling capacity. In the case of buildings that have package AC units, installing a HP maintains cooling capacity and replaces two appliances with one, reducing combined operating costs as well as maintenance. By eliminating gas use and providing efficient cooling, HP deployment is both a climate change mitigation and adaptation strategy. The City is leveraging billions of dollars in State, regional, and federal funding currently available for HP incentives and rebates to encourage Oakland homes and businesses to make this upgrade. However, these subsidies are still insufficient to enable all frontline communities to electrify their homes.

In lower-income communities, and particularly older homes, rental properties, and buildings with deferred maintenance, the presence of multiple structural challenges (inadequate insulation, seismic safety challenges, outdated electric infrastructure, mold, etc.) can substantially increase the total upfront cost of HP installation. Additionally, current energy rate structures do not account for the total societal cost of gas (in terms of increased health, safety, and climate risk). Thus, building owners switching from gas furnaces to HPs (where AC was not previously installed, and no onsite renewable energy is installed) risk experiencing increased energy bills. Oakland's *Building Electrification Roadmap*, as directed in the ECAP (Action B-2) and expected to be considered by City Council in July 2023, will explore these challenges in depth and offer solutions that can be implemented over the next two decades to equitably achieve the City's 2040 full-electrification target.

WILDFIRE

Accessible Wildfire Preparedness

The Oakland Fire Department and the Emergency Services Management Department will play a central role in wildfire hazard adaptation and mitigation. Existing initiatives and emergency preparedness plans to prepare for and adapt to fire hazard risk in Oakland are summarized in Table 5-2 and described in more detail later in this section. In terms of adaptation priorities and hazard mitigation, stakeholders proposed annual community wildfire preparation days, additional

[252] Bedsworth, L., Cayan D., Franco G., Fisher L., Ziaja S. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-013.

outreach around defensible space, home hardening, and home inspections as potential strategies the Oakland Fire Department could take to enhance wildfire hazard mitigation strategy.

Ecologically Sensitive Vegetation Management

Much of the development in the Oakland Hills intersects with Oakland's urban wildland interface. Ecologically sensitive response to vegetation management with urban Wildland Interface (UWI) zones can help reduce wildfire risk and can be coordinated through the Oakland Fire Department Wildfire District Vegetation Inspection and Maintenance Standards. However, stakeholders also acknowledged financial barriers presented by the cost of ecologically sensitive vegetation management, home-hardening and insurance policies incentivizing property owners to harden homes. In response, the City could provide rebates that help offset these costs.

Environmentally Adapted Emergency Response Fleet

Parallel efforts to assess and analyze evacuation routes in Oakland demonstrate that narrow roads in the Oakland Hills will present an additional challenge to emergency response operations. Stakeholders proposed that the Fire Department invest in a smaller fleet of EV vehicles better suited for the environment of the Oakland Hills as a potential solution, which would also help reduce emergency operations carbon emissions and reliance.

Establishing and Identifying Clean Air Facilities

Inequitable air quality distribution in Oakland will be further compounded by wildfire smoke. During previous wildfire events, Oakland has provided emergency clean air shelters, which are summarized in Chapter 4. However, the locations of these centers are not currently distributed according to the location of populations most vulnerable to air quality hazards, and these community-serving facilities should be targeted in poor air quality areas where need is greatest, such as West Oakland, Downtown, Eastlake/Fruitvale, and Central/East Oakland. Figure 3-14 identifies specific census tracts where socially vulnerable residents also experience the highest concentrations of poor air quality.

SEA LEVEL RISE AND FLOODING

Immediate Flood Disaster

In the event of an immediate flood-related disaster event, the City will rely on its core emergency response and mutual aid networks. However, to avoid worst-case scenarios, sea level rise and flood hazards will require proactive and ongoing mitigation strategies involving collaboration between multiple agencies, organizations, and community groups in Oakland. Many local organizations, such as those working together through the Oakland Climate Action Coalition, have been essential to Oakland's climate resilience and adaptation strategy, and ongoing funding and support for organizations working with the coalition can enhance community resilience and engagement on climate issues, including flood hazard resilience and adaptation. The City's Watershed and Stormwater Management Division works to expand green infrastructure to mitigate stormwater runoff polluting local creeks and to prevent localized flooding that can surface and spread pollutants. Additional organizations working around sea level rise and flood hazard risk are summarized later in this chapter.

The City is also developing a Storm Drainage Master Plan that will include a detailed and comprehensive examination, including condition and sizing, of its storm drainage system, model flooding conditions, and create a list of high priority capital projects for future work. Armed with this robust information, the City hopes to be able to better secure funding for stormwater capital work and ongoing maintenance to reduce these types of issues in the future. The storm drainage master plan project will develop conceptual plans for three regional green stormwater infrastructure projects that will be designed to help address flooding in areas with known flooding issues. Though green stormwater infrastructure cannot provide flood control for large flows, it can help address nuisance flooding issues.

Monitoring Groundwater Levels

Based on new and forthcoming research by the SF Bay Estuary Institute, UC Berkeley, and Pathways Climate Institute discussed in Chapter 4, continuous monitoring of groundwater conditions will be a key adaptation priority for the City of Oakland. Rising water tables caused by sea-level rise could result in previously unexamined hazards, which could cause harmful effects to residents and infrastructure before rising tides even overtop the shoreline. Moving forward, it is recommended that the City of Oakland stay abreast of research identifying specific regions in Oakland at risk of rising water tables.

Need for Sea Level Rise Building and Infrastructure Standards

The City currently does not maintain specific standards for sea level rise to which buildings and infrastructure should be designed. Table 2-6 summarizes a range of estimates for Bay Area sea level rise. However, the City of Oakland has yet to adopt one these scenarios for planning or other purposes, which limits the City's ability to proactively mitigate sea level rise hazards. To limit future development in high risk areas, the City should establish consistent standards according to best estimates that require new development to accommodate sea level rise. Additionally, the City should prioritize new development of affordable housing away from high flood hazard areas or ensure that new affordable housing development can accommodate projected sea level rise scenarios.

The distribution of storm drain systems in Oakland and lack of sufficient storm drain infrastructure in East Oakland, present environmental inequities in the event of flood hazards. One potential flood hazard mitigation strategy includes investment in equitable, nature-based adaptation infrastructure to capture excess stormwater in flood hazard zones. Green infrastructure provides multifaceted benefits, not only as mitigation and a tool for extreme heat but also as an adaptation tool for flooding and sea level rise. Chart 4-5, Planned and Potential Green Stormwater Infrastructure Projects in the 2045 Oakland General Plan Map Atlas, identifies planned and potential green stormwater infrastructure projects, many of which are planned for high flood hazard regions in Oakland with socially vulnerable populations.

SOURCE: City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2021

Table 5-1: Adaptation Priorities by Climate Change Impacts in the City of Oakland

Primary Impact	*Evidence-Based Need for Adaptation in Oakland*	*Potential Adaptation Strategies*
Temperature Increase	Inequitable distribution of Oakland's tree canopy and urban green spaces that exacerbate the urban heat island effects	Implement equitable nature-based adaptation and urban heat island greening solutions
	Distribution of AC cooling is limited in many East Bay homes. AC systems are costly to install and energy intensive.	Equip building facilities with heat pumps instead of energy intensive AC units
	The City lacks data on the distribution of existing air-conditioning equipped facilities and potential cooling centers.	Identify community-serving facilities in urban heat island zones to serve as designated cooling centers. Establish a minimum of three Resilience Hubs in frontline communities.
	Power outages caused by electricity grid overload or wildfire related shutoffs	Support community microgrids to help provide emergency power and cooling. Establish a minimum of three Resilience Hubs in frontline communities.
	Unhoused people are uniquely vulnerable to extreme heat.	Ensure access to water and public cooling centers for Oakland's unhoused population. Establish a minimum of three Resilience Hubs in frontline communities.
Wildfire	Inequitable distribution of $PM_{2.5}$ that can be further compounded by wildfire smoke	Identify community-serving facilities in poor air quality areas to serve as designated clean air centers. Establish a minimum of three Resilience Hubs in frontline communities.
	Development in the urban wildlife interface (UWI) is at increased risk of wildfire hazard.	Integrate ecologically-sensitive vegetation management within UWI zones to reduce wildfire risk
	Narrow streets in Oakland hills will impede fire department emergency response capacity.	Invest in EV's for City fleet vehicles, smaller fire engines to traverse more narrow streets in the hills
	Evacuation challenges for those without transportation	Work with emergency response teams and the Oakland Fire Department to identify and support Oakland residents without access to transportation in the event of fire emergency
	Cost-burden associated with home hardening, fire insurance, vegetation management	Provide rebates and grants to offset fire-preparedness related expenses
Sea Level Rise and Flooding	Range of estimates for Bay Area sea-level rise may require an array of adaptation interventions	Implement equitable nature-based adaptation and coastal greening solutions. Establish specific standards according to best estimates that require new development to accommodate sea level rise.
	Lack of data on the impacts of rising groundwater on urban flooding	Conduct continuous monitoring of groundwater conditions and urban greening solutions
	Lack of storm drain systems in East Oakland which create environmental inequities	Implement equitable nature-based adaptation infrastructure to capture excess stormwater in flood hazard zones (e.g., green infrastructure)

5.3 Relevant Agencies and Initiatives

Effective collaboration of agencies, organizations, and community-based groups is essential to build adaptive capacity and climate resilience successfully and equitably in the City of Oakland. Researchers have identified the "governance gap" between climate hazard risks and the implementation of solutions, which arises when various stakeholders must engage in multi-level cooperation, even though agencies already understand the problem and solutions. As Lubell (2017) states, "While regional cooperation is beginning to emerge, most stakeholders see a critical need for shared learning, coordination, and planning."[253]

There are several tools that increase adaptive capacity, including emergency response and hazard response services, the collection and distribution of climate-relevant information, and infrastructure maintenance. The following is a discussion of federal, State, regional, and local agencies that are responsible for activities related to climate change adaptation as required under SB 379. These agencies represent sources of adaptative capacity from which the City of Oakland can coordinate and collaborate with in order to effectively respond to climate change impacts. Though not a comprehensive list, this section identifies key agencies, organizations, and initiatives advancing climate adaptation and hazard mitigations strategies within Oakland.

FEDERAL AGENCIES

The Federal Emergency Management Agency (FEMA) manages national-level response to disasters and implements programs designed to help local authorities respond to and mitigate the impacts of disasters, including the extreme weather events associated with climate change. FEMA conducts mapping of flood zones and administers the National Flood Insurance Program. The National Flood Insurance Program aims to reduce the socioeconomic impact of flooding on private and public structures through the provision of flood insurance and by encouraging communities to adopt and enforce floodplain management regulations. FEMA also provides general disaster response and hazard mitigation assistance through such entities as the Hazard Mitigation Grant Program, the Flood Mitigation Assistance Program, the Pre-Disaster Mitigation Program, and the Fire Management Assistance Grant Program.

The National Oceanic and Atmospheric Administration (NOAA) provides information about long-term climate patterns. NOAA promotes public understanding of climate science and provides tools designed to help decision makers integrate information about climate risks, vulnerability, and resilience into their decision-making processes.

[253] Lubell, M. (2017). The Governance Gap: Climate Adaptation and Sea-Level Rise in the San Francisco Bay Area. University of California, Davis.

The U.S. Army Corps of Engineers maintains the nation's infrastructure, including dams, levees,[254] and some energy facilities. Under the Flood Control and Coastal Emergency Act, the Corps provides disaster preparedness and response services and advanced planning services designed to reduce the amount of damage caused by a disaster. The Levee Safety Program works with local levee sponsors and stakeholders to assess and manage levee quality and communicate flood risks to residents and businesses. The Flood Risk Management Program employs levees, floodwalls, land acquisition, and flood proofing to reduce the risks associated with flooding. Additionally, the Responses to Climate Change program is slated to provide planning and engineering guidance to ensure that future infrastructure is designed to be sustainable and robust to a range of potential climate impacts.

The U.S. Department of Energy (DOE) administers programs pertaining to energy efficiency and renewable energy. Key energy efficiency programs include Energy Saver, which assists with cost-effective energy efficiency in homes and businesses, and the activities of the Office of Energy Efficiency & Renewable Energy, which support the development of solar and hydropower programs. The DOE's Weatherization Assistance Program (WAP) provides grants to states, territories, and Indian tribes to improve the energy efficiency of low-income homes.

The United States Environmental Protection Agency (EPA) serves as the nation's primary body regarding regulations for air, land, and water quality. The EPA's Air and Energy Research Program studies the relationship between climate change, air pollution, and the energy sector. The Sustainable and Healthy Communities Research Program works at the intersection of environmental quality and public health, specifically in the context of the management of hazardous sites and materials, and the development of healthy and resilient communities. Within the EPA, the Center for Environmental Solutions and Emergency Response plans, coordinates, and conducts research and development programs to improve decision making by federal, State, tribal, and local agencies. Key research activities include groundwater characterization and remediation, materials management, land remediation, and work in water infrastructure.

STATE AGENCIES

The California Department of Transportation (**Caltrans**) owns or controls 350,000 acres of Right of Way, maintains 15,133 centerline miles of highway and 13,063 miles of state highway, and inspects more than 12,200 local bridges. Caltrans engages in climate-related initiatives to protect these critical assets. It conducts climate change vulnerability assessments to identify segments of the State highway system vulnerable to climate change impacts including precipitation, temperature, wildfire, storm

[254] There are no levees under City jurisdiction, however, there are FEMA accredited levees under Alameda County Flood Control District jurisdiction near Oakland Airport.

surge, and sea level rise. The results of these assessments are used to guide analysis of at-risk assets and develop adaptation plans.

The California Air Resources Board (CARB) protects the public from the harmful effects of air pollution and develops programs to help fight climate change. CARB runs the Community Air Protection Program, which aims to reduce exposure to air pollutants in communities most impacted by air pollution. CARB works closely with local air districts, community groups, community members, environmental organizations, and regulated industries to develop a community-focused action framework for community protection. CARB is also involved in the State's cap-and-trade program, Low Carbon Fuel Standard Program, and Advanced Clean Cars Program.

The California Environmental Protection Agency (CalEPA) contains the CalEPA Emergency Response Management Committee, which coordinates preparedness for and responses to environmental emergencies in California. CalEPA's climate-related work includes analysis of the State's cap-and-trade program, studying urban heat islands, and operating the CalEPA Environmental Justice Taskforce. The Task Force coordinates the compliance and enforcement work of CalEPA's boards, departments, and offices in areas of California that are burdened by multiple sources of pollution and are disproportionately vulnerable to its effects.

The California Department of Forestry and Fire Protection (CAL FIRE) manages fire prevention and response for the State of California. CAL FIRE oversees enforcement of California's forest protection regulations, implements fuel management projects, participates in forest conservation and management, and provides training and educational programs. CAL FIRE also engages in general emergency response activities.

The California Department of Public Health contains the Emergency Preparedness Office, which maintains and manages the Medical and Health Coordination Center, distributes funds to local health departments for disaster planning, and operates the California Health Alert Network. The Department also manages the Climate Change & Health Equity Program, whose goal is to systematically integrate work from climate change planning and public health planning with policies and principles that promote equity. The Department works with local, State, and national partners to assure that climate change mitigation and adaptation activities have beneficial effects on health while not exacerbating preexisting health disparities.

The California Department of Water Resources engages in flood management and flood emergency response programs. It developed the Flood Emergency Response Information Exchange to improve flood emergency preparedness, response, and recovery. The Department also implements the Sustainable Groundwater Management Act and administers the California Statewide Groundwater Elevation Monitoring Program.

The California Governor's Office of Emergency Services (Cal OES) responds to and aids in the recovery from emergencies within the State of California under the authority of the California Services Act, California Disaster Assistance Act, and the Stafford Act. Cal OES is responsible for managing disaster recovery and aiding local governments, special districts, certain nonprofit organizations, individuals, businesses, and agricultural communities impacted by disasters. It provides technical support to reduce the costs and streamline the process of recovery efforts and serves as a liaison with local, State, federal agencies, legislators, nonprofit organizations, and the public. Cal OES develops and maintains state-level emergency plans, assists local governments in developing their own plans, and is also responsible for the design, installation, and repair of the statewide public safety radio communication system.

The California Natural Resources Agency leads and coordinates the administration's climate adaptation policy and its natural resources climate policy and has helped guide the State's efforts towards increasing the resilience of water system.

The California Office of Environmental Health Hazard Assessment is the leading State agency for the assessment of health risks posed by environmental contaminants. It assesses the health effects of toxic air contaminants and conducts research tracking the impacts of climate change on California's weather, water, ecosystems, agriculture, and public health. The office has conducted studies on the mortality and morbidity of heat exposure, as well as the interactions of environmental pollutants, such as particulate matter and ozone, with heat and their combined impacts on vulnerable populations. The office developed and updates CalEnviroScreen, a screening methodology that can be used to help identify California communities that are disproportionately burdened by multiple sources of pollution.

The California Public Utilities Commission enforces rules and regulations to ensure that energy infrastructure and utility companies run a safe and reliable electric or communication system. The Commission reviews the wildfire mitigation plans of utilities and transmission owners.

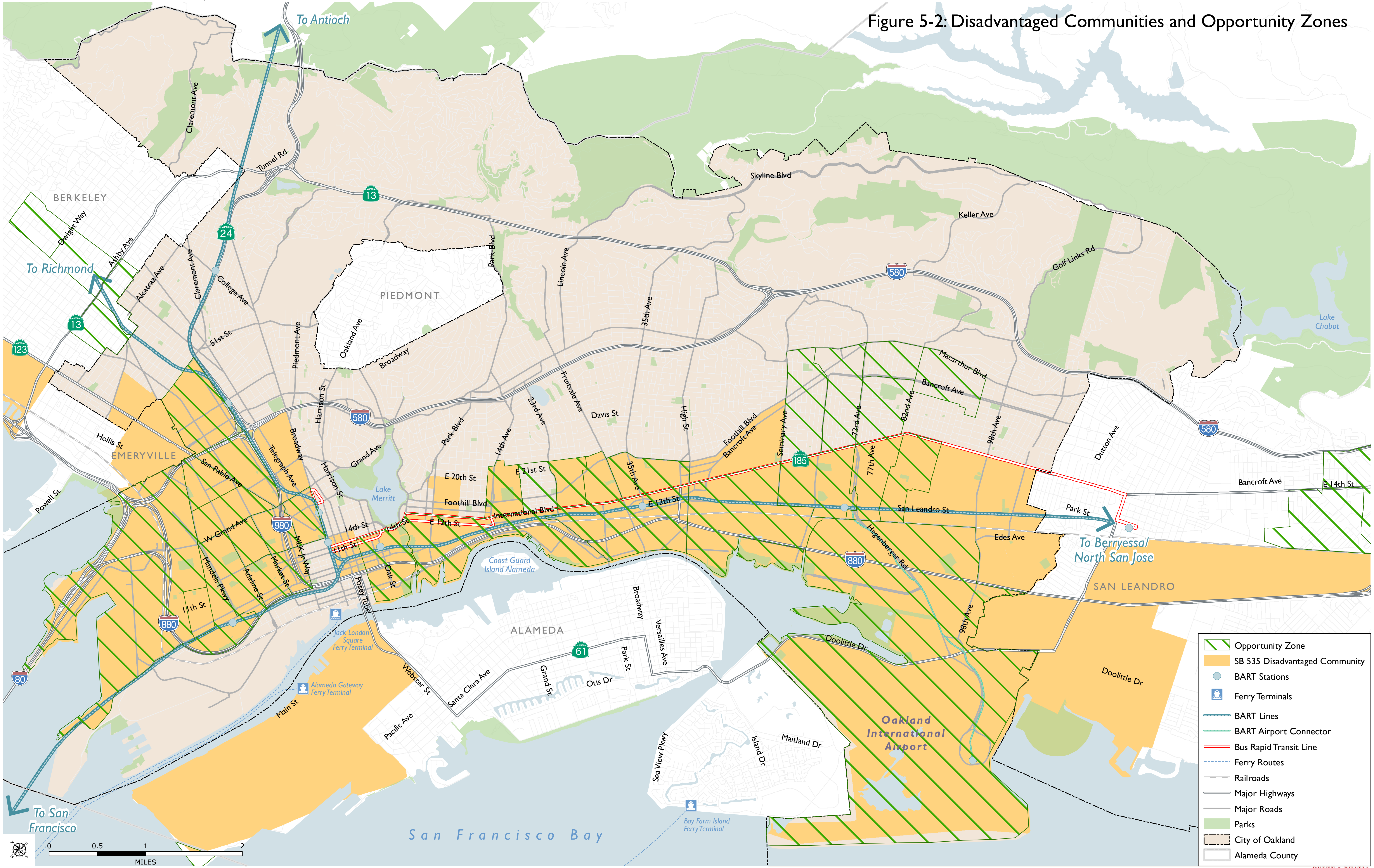
The State Water Resources Control Board engages in climate change-related actions, including the expansion of recycled water to increase drought resilience, adoption of regulations to increase the capture of urban stormwater, and efforts to reduce flood risk. The Control Board has been involved in the Central Valley Region Climate Change Work Plan. Key focus areas of this plan include addressing impacts due to drought and flooding, issues related to groundwater quality, and changes in surface water supply, with a focus on disadvantaged communities.

San Francisco Bay Regional Water Quality Control Board issues the Municipal Regional Stormwater Permit, which requires the City to implement a robust program to prevent stormwater pollution in the Bay and other waterways in Oakland. The Stormwater Permit also requires municipalities to add green stormwater infrastructure to remove pollutants from stormwater.

STATE PROGRAMS

Areas designated as Disadvantaged Communities by state Senate Bill 535 are specifically targeted for investment of proceeds from the State's cap-and-trade program. These investments are aimed at improving public health, quality of life, and economic opportunity, while reducing pollution that causes climate change. California Opportunity Zones, established in the Tax Cuts and Jobs Act of 2017, provide tax incentives for investment in designated census tracts. California Opportunity Zones support new investments in environmental justice, sustainability, climate change, and affordable housing. Oaklands's Disadvantaged Communities and Opportunity Zones are shown in Figure 5-2.

Figure 5-2: Disadvantaged Communities and Opportunity Zones



SOURCE: Department of Finance, 2020; CalEPA, 2022; City of Oakland, 2021; ALAMEDA County GIS, 2021; Dyett & Bhatia, 2022

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LOCAL AND REGIONAL AGENCIES AND PARTNERSHIPS

Alameda County Flood Control & Water Conservation District plans, constructs, and maintains Western Alameda County's flood control systems such as creeks, channels, levees pump stations, reservoirs, and dams. It also performs hydrologic, geotechnical, and environmental studies, and enforces waterway pollution control regulations.

The Bay Area Air Quality Management District adopts regulation and oversees policies regarding sources of air pollution in every county that surrounds the San Francisco Bay.

The Bay Area Climate Adaptation Network (BayCAN) is a collaborative network of local government staff and partnering organizations, including the City (through Alameda County) working to help the Bay Area region to respond effectively and equitably to the impacts of climate change. BayCAN focuses on adaptation challenges in water supply, sea level rise, wastewater and stormwater management, wildfires, ecosystems, and public health. BayCAN collaborates with current initiatives in these sectors to maximize impact and build on existing knowledge.

The Emergency Management Services Department (ESMD) The Emergency Management Services Department (ESMD) exists within the Oakland Fire Department and is the primary agency responsible for responding to, recovering from, and mitigating against any hazard that affects the City of Oakland.

The Oakland Fire Department is the primary emergency response service provider for the City of Oakland, and provides comprehensive strategies and training in fire prevention, fire suppression, emergency medical services, all risk mitigation, emergency preparedness, 9-1-1 services and community-based fire services.

The San Francisco Bay Restoration Authority is a regional agency that oversees the allocation of Measure AA funding, a 20-year parcel tax passed in 2016 that will raise approximately $25 million annually to fund restoration projects in the Bay. The Governing Board, comprised of local elected officials from around the Bay Area, oversees the allocation of fund, though the City of Oakland does not have a representative member. The Authority has funded projects such Oakland Gateway Shoreline Restoration and Public Access Project as well as the Shoreline Leadership Academy. Co-founded with the West Oakland Environmental Indicators Project, this program is designed to educate a cohort of residents about environmental and social issues along the Oakland shoreline. Through a community-led planning process, the cohort of residents develop shoreline restoration projects in Alameda County.

The **Vegetation Management Unit (VMU)** within the Oakland Fire Department serves to inspect properties in the Oakland Hills, much of which is designated as a Very High Fire Hazard Severity Zone (VHFHSZ). The VMU works under the Oakland Fire Department's Fire Prevention Bureau. The VMU is responsible for the inspections of over 20,000 homes and vacant parcels in the VHFHSZ. The purpose of these inspections is to identify and mitigate hazards that could contribute to the spread, growth, and intensity of wildfire. The VMU conducts inspections annually, and property owners are required to actively maintain their parcels in a fire-safe condition year-round.

LOCAL ORGANIZATIONS, COMMUNITY GROUPS, AND INITIATIVES

Organizations and Community Groups

Asian Pacific Environmental Network (APEN) brings together Asian immigrants and refugees in Oakland and Richmond to advance environmental justice through work advocating for community-owned renewable energy resources, affordable housing, and local cooperatives owned and governed by community members.

Black Cultural Zone addresses the disparate impact that decades of disinvestment in East Oakland and more recent displacement of Black People and Black Businesses from their legacy communities in Oakland by centering Black Arts and Culture within a community development framework. The East Oakland Black Cultural Zone Collaborative (the "Collaborative") was formed by the Eastside Arts Alliance and several non-profit organizations located in East Oakland to develop the East Oakland Black Cultural Zone.

Communities for a Better Environment aims to improve the health of the community through access to clean air and healthy food. CBE concentrates on building a more resilient community in Oakland. That means a community with the resources to rebound from such disasters as the economic downturn, an earthquake, or events linked to climate change, like heat waves. CBE is collaborating with allies to develop a three-part Community Resilience Series, and CBE's Cleaning Up and Greening Up program aims to make the City's unused vacant lots available for community gardens and other green community projects.

The East Oakland Collective works toward economic and racial justice, primarily for Black residents. Their work includes addressing food insecurity in Oakland through food supply and distribution, providing homeless services and economic empowerment, and organizing policy efforts to increase housing options for low- and no-income residents. The East Oakland Collective also advocates for neighborhood and transportation plans that are receptive to BIPOC community engagement, provide for healthy and equitable community economic development, and revitalize key East Oakland corridors. The East Oakland Collective's Power the People: Martin Luther King Jr. Shoreline Access Study is a project exploring the feasibility of a new zero emissions bus route along 73rd Ave and other clean mobility options that will bring East Oakland residents from 94603, 94605 and 94621 zip codes to the Martin Luther King Jr. Shoreline Park.

Friends of Sausal Creek is a volunteer-based, nonprofit, community organization dedicated to promoting awareness, appreciation, and stewardship of Oakland's Sausal Creek Watershed, which drains to the San Francisco Bay. Friends of Sausal creek facilitates educational programs, involves the community in environmental stewardship, and collaborates with agencies and other nonprofits to positively impact the local ecosystem.

The Greenlining Institute connects community leaders with policymakers, researchers, and the private sector. They design and support policies relating to clean transportation, inclusive energy economies, and climate resilience.

Greenbelt Alliance identifies climate risks and nature-based resilience opportunities to drive climate leadership, delivers equitable nature-based policy solutions for land use and urban growth, and advocates for climate SMART development—Sustainable, Mixed, Affordable, Resilient, and Transit-oriented.

HOPE Collaborative (Health for Oakland's People and Environment) works to advance economic, racial, and health equity in Oakland through food justice and community investment. HOPE's efforts include supporting healthy food sources in underserved areas, partnering with the Oakland Unified School District to improve food quality in schools, and working with City to create Healthy Development Guidelines.

Mycelium Youth Network focuses on preparing youth by giving them the resources and training they need to thrive in a climate-challenged world. They run events such as climate resilience education programs for students.

Oakland Climate Action Coalition (OCAC) is a majority volunteer-run coalition dedicated to racial and environmental justice. OCAC is a collaboration of more than thirty organizations striving to ensure that those who stand to be hit first and worst by climate change impacts benefit from efforts to address climate change in Oakland, CA. Founded in 2009, OCAC has advanced its social equity and climate justice goals by engaging community-based organizations and impacted residents in climate action, adaptation, and resilience planning in Oakland. The coalition partnered with the City of Oakland to develop Oakland's Energy and Climate Action Plan, adopted in December 2012, and was part of the Equity Facilitator consultant team that worked with the City in developing the 2030 ECAP.

Planting Justice works to address structural inequalities embedded in the industrialized food system by establishing edible gardens, urban farms, and training centers. Planting Justice supports the well-being of marginalized communities and supports holistic community health by providing access to nutritious affordable food, dignified jobs, education, green space, and safety & mobility

Public Health Institute and its programs improve health, equity and wellness by discovering new research, strengthening key partnerships and programs, and advancing sound public health policies. PHI strengthens the work of public health and builds community power through three key roles: as a fiscal sponsor, as a thought leader and as a partner.

San Francisco Estuary Institute provides scientific support and tools for decision-making and communication through collaborative efforts to improve the health of the waters, wetlands, wildlife and landscapes of San Francisco Bay, the California Delta and beyond. SFEI's team of 50 scientists and experts provides data, technology and tools that empower government, civic and business leaders to create cost-effective solutions for complex environmental issues. The Resilient

Landscapes team develops innovative, long-range, nature-based strategies to improve shoreline health in cities.

Save The Bay is a regional organization that works to protect and restore the San Francisco Bay by advocating for regional, state, and federal funding to restore wetlands.

SPUR is a nonprofit public policy organization based in San Francisco, San José, and Oakland. SPUR is recognized as a leading civic planning organization focusing on housing, transportation, land use, economics, food access, sustainability, and resilience. SPUR also focus on governance because it is how communities organize themselves to achieve collective goals and because we believe in the power of government as a force for good.

Trees for Oakland (TfO) is a component of the Oakland Parks & Recreation Foundation, uses volunteer-run operations to plant and maintain trees throughout the City. The organization aims to combat climate change and provide an equitable distribution of trees in Oakland. The "Trees for the Oakland Flatlands" project to provide new trees for Oakland residents is part of California Climate Investments, a statewide program that puts billions of Cap-and-Trade dollars to work reducing GHG emissions, strengthening the economy, and improving public health and the environment – particularly in disadvantaged communities.

The West Oakland Environmental Indicators Project is a resident-led organization that aims to create resilient communities through environmental justice. Among other projects, this organization is currently working with Bay Area Air Quality Management District to improve community health by reducing disparities in air pollution exposure.

Past and Ongoing Adaptive Capacity Enhancement Initiatives and Resources

CAL FIRE Urban and Community Forestry Grant Program provides local governments and nonprofit organizations with funding to improve urban forest. This grant gives special consideration is given to projects serving disadvantaged and/or low-income communities and has been utilized in conjunction with the Urban Forestry Master Plan referenced in Chapter Four and table 1-1.

Community Emergency Response Team Training [CERT] is the free community emergency preparedness and response training program provided by the City. CERT prepares Oakland residents with basic medical aid skills, search and rescue training, and additional emergency response training to provide immediate emergency support in advance of professional first responders.

California Natural Resources Agency Urban Greening Program funds projects that reduce greenhouse gases while also transforming the built environment into places that are more sustainable, enjoyable, and effective in creating healthy and vibrant communities. These projects will establish and enhance parks and open space, using natural solutions to improve air and water quality, reduce energy consumption, and create more walkable and bikeable trails. Grant Funds are awarded to a city, county, special district, or nonprofit organizations.

East Oakland Neighborhoods Initiative (EONI) is a partnership between the City of Oakland Planning Bureau and twelve community-based organizations focused on equity-based planning for Deep East Oakland. EONI conducted a year of community outreach to identify the primary concerns, goals, and priorities for East Oakland residents and stakeholders.

Preliminary Sea Level Rise Road Map was developed as part of Resilient Oakland, a coordinated effort to align resources, plans, and actions in support of a thriving and resilient community. Oakland was competitively selected in December 2013 to join 100 Resilient Cities, an initiative Pioneered by the Rockefeller Foundation that aims to help cities around the world build resilience to the social, economic, and physical challenges of the 21st century. Through this initiative, an Oakland Resilience Strategy was developed through a two-phase process. Phase 1 involved an initial resilience baseline assessment. Phase 2 involves strategic planning and technical analysis to better understand the underlying issues and identify solutions to some of Oakland's most critical resilience challenges. The Plan is being revised in 2023 by the Sustainability Resilience Division of the City Administrator's Office.

Resilient Fruitvale Initiative which conducted a neighborhood-level risk hazard and vulnerability assessment, launched a mini-grant program to fund disaster preparedness training, and established a neighborhood-level community outreach network in preparation for all types of emergencies. In 2017, a group of Fruitvale non-profits, small businesses, faith-based organizations, residents, and City Agency stakeholders joined forces to leverage available services and deepen resident engagement in vulnerable communities.

West Oakland Community Action Plan will serve as a blueprint for improving air quality in the City of Oakland. Owning Our Air, the West Oakland Community Action Plan's report outlines 89 strategies for emissions reduction in West Oakland. Following years of research, advocacy, and collaboration, the plan was developed under the West Oakland Environmental Indicators Project (WOEIP) in partnership with the Bay Area Air Quality Management District.

Appendix: Understanding Cal-Adapt and Key Scenario Assumptions

Material in this section is adapted from technical support information provided by Cal-Adapt and available on the Cal-Adapt website (www.cal-adapt.org).

Understanding Climate Projections

The data presented in Cal-Adapt tools are projections of future climate. They are not weather predictions and should not be treated as such. Weather is the behavior of the atmosphere over short periods, such as days and weeks. Climate is the long-term behavior of the atmosphere, and it is almost always expressed in averages—for example, average annual temperature, average monthly rainfall, or average water equivalent of mountain snowpack at a given time of year.

Climate projections cannot predict what will happen on a given date in the future. But they can provide information about what to expect from the future climate in general. Climate projections can also predict how much more often (or less often) extreme events such as heat waves and heavy rainfall are likely to occur in the future. However, they cannot predict when those events will actually occur.

How Climate Projections Are Produced

Climate scientists create projections of future climate using powerful tools called global climate models. Global climate models are complex pieces of computer software that crunch through thousands of mathematical equations representing the scientific theory of how the climate system works. They can be used to simulate climate over past periods or to run experiments, in which scientists impose certain conditions on the model to see how the climate system responds. A future climate projection is the product of global climate model experiments in which scientists impose upon the model some scenario of the future atmospheric concentration of greenhouse gases.

When climate scientists run a climate model, they divide the area of study into a grid, and the model performs calculations for each individual cell within the grid. The output from those calculations can then be visualized on a map.

The grid cells in most global climate models are very large—from 100 to 600 kilometers squared. This coarse resolution is OK when scientists are studying climate on the global scale, but it is not very useful when trying to understand climate change on smaller scales. Present-day climate varies greatly from region to region in California, and so future climate will vary accordingly. But that detail is lost in the global climate models, in which all of California may be represented by just a few grid cells. To be able to plan for the future, higher-resolution projections of future climate are needed. Climate scientists can create these high-resolution projections by using various techniques to "downscale" global climate model output to finer spatial scales. The data in Cal-Adapt is taken from a selection of global climate models and downscaled to about 7-kilometer resolution.

Cal-Adapt allows users to visualize climate changes under any of ten Global Climate Models (GCMs) selected by California's Climate Action Team for performance in California. Four of these models, HadGEM2-ES (Warm/Dry), CNRM-CM5 (Cooler/Wetter), CanESM2 (Average), and MIROC5 (Complement), are designed as priority models. These GCMs are part of the Climate Model Intercomparison Project version 5 and were developed to support the work of the United Nation Intergovernmental Panel on Climate Change (IPCC). Modeled data available on Cal-Adapt represent statistically downscaled GCMs using localized constructed analogs (LOCA) method by Scripps Institution of Oceanography as part of State of California's 4th Climate Change Assessment.

About the Greenhouse Gas Scenarios

The main driver of human-caused climate change is emissions of carbon dioxide and other greenhouse gases into the atmosphere. Greenhouse gases are so called because they trap heat in the atmosphere, causing it to warm over time. Atmospheric warming in turn leads to other changes throughout the earth system. How much climate changes in the future depends in large part on the amount of greenhouse gases emitted now and in the future. However, since emissions of greenhouse gases depend on a variety of different social, political, and economic factors, it is difficult to predict how they will change. However, scientists can formulate educated guesses about how greenhouse gas emissions might change and use those scenarios to create future climate projections.

Each tool in Cal-Adapt shows outcomes for two different greenhouse gas scenarios: a high-emissions scenario in which greenhouse gas emissions continue to rise over the 21st century, and a low-emissions scenario in which greenhouse gas emissions level off around the middle of the 21st century and by the end of the century are lower than 1990 levels.

To address the uncertainty in future emissions of greenhouse gases and aerosols, Cal-Adapt allows users to visualize climate projections based on either of two possible emissions scenarios used in California's 4th Climate Assessment, originally appearing in the Fifth Intergovernmental Panel on Climate Change (IPCC). The 4th Climate Assessment uses so-called Representative Concentration Pathways (RCPs), which encapsulate different possible future greenhouse gas and aerosol emission scenarios. RCP 4.5 is a "medium" emissions scenario that models a future where societies attempt to reduce greenhouse gas emissions, while RCP 8.5 is a higher baseline emissions scenario. Key assumptions underlying the RCP 8.5 scenario include rising emissions through 2050, which plateau around 2100. RCP 8.5 is commonly understood as a business-as-usual (BAU) scenario that would result in atmospheric CO_2 concentrations exceeding 900 parts per million by 2100 and a temperature increase of 4-7 °C. RCP 4.5 is a scenario where GHG emissions rise until mid-21st century and then decline, resulting in a CO_2 concentration of about 550 ppm by 2100[255] and a temperature increase of 2-4°C[256].

Sources of Uncertainty in Climate Projections

As with any statement about the future, there is no way to be certain that climate projections are accurate. One source of uncertainty in future climate projections is human greenhouse gas emissions. Projected climate data may not prove to be accurate if the actual emissions pathway differs from the scenarios used to make the projections.

Another source of uncertainty in climate projections is the fact that different climate models—the tools used to simulate the climate system and produce future climate data—may produce different outcomes. There are more than 30 global climate models developed by climate modeling centers around the world, and they have different ways of representing aspects of the climate system. In addition, some aspects of the climate system are less well understood than others. Climate scientists are constantly working to improve their theories of the climate system and its representation in climate models. In the meantime, one way to account for model differences is to look at projections from as many different models as possible to get a range of possible outcomes. Scientists can then take the average of the values across the different models, and this average value is a more likely outcome than the value from any single model. The default visualizations in Cal-Adapt are based on the average values from a variety of models.

[255] Bedsworth, L., Cayan D., Franco G., Fisher L., Ziaja S. (California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-013.

[256] Pierce D. W., Kalansky J.F., Cayan D.R., (Scripps Institution of Oceanography). 2018. Climate, Drought, and Sea Level Rise Scenarios for the Fourth California Climate Assessment. California Fourth Climate Change Assessment, California Energy Commission. Publication Number: CNRA-CEC-2018-006.

OAKLAND 2045
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