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Delta Adapts: Creating a Climate Resilient Future

Public Review Draft

Delta Stewardship Council
A CALIFORNIA STATE AGENCY

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DELTA ADAPTS: CREATING A CLIMATE RESILIENT FUTURE

Sacramento-San Joaquin Delta Climate Change Vulnerability Assessment

Public Review Draft – January 2021

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Delta Adapts Project Team

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The Delta Adapts team would like to thank the members of the Stakeholder Workgroup that participated in the Delta Adapts Climate Change Vulnerability Assessment and provided valuable input and feedback to the study.

ACRONYMS AND ABBREVIATIONS

AB	Assembly Bill
ART	Adapting to Rising Tides
AS	Adaptation Strategy
BCDC	San Francisco Bay Conservation and Development Commission
CCVA	Climate Change Vulnerability Assessment
cfs	cubic feet per second
Council	Delta Stewardship Council
CVFPP	Central Valley Flood Protection Plan
CVP	Central Valley Project
DLIS	Delta Levees Investment Strategy
DPC	Delta Protection Commission
DRMS	Delta Risk Management Strategy
DWR	Department of Water Resources
GCM	General Circulation Model (or Global Climate Model)
GHG	Greenhouse Gas
ICARP	Integrated Climate Adaptation and Resiliency Program
IPCC	Intergovernmental Panel on Climate Change
LOCA	Localized Constructed Analogs
MHW	Mean High Water
MHHW	Mean Higher High Water
MLW	Mean Low Water
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
NHA	National Heritage Area
OES	Office of Emergency Services
OPC	Ocean Protection Council
OPR	Governor's Office of Planning and Research

PDO	Pacific Decadal Oscillation
RCP	Representative Concentration Pathway
SFEI	San Francisco Estuary Institute
SGMA	Sustainability Groundwater Management Act
SLR	Sea Level Rise
SWP	State Water Project
SWRCB	State Water Resources Control Board
USGS	United States Geological Survey
WARMER	Wetland Accretion Rate Model of Ecosystem Resilience
WNMF	Wet, non-farmable, and marginally farmable
WWTP	Wastewater Treatment Plant

Executive Summary

The time to act is now. Climate change is already altering the physical environment of the Sacramento-San Joaquin Delta and Suisun Marsh (Delta), and we will continue to experience its effects through hotter temperatures, more severe wildfires, and prolonged droughts. Over the long term, climate change in the Delta is expected to harm human health and safety, disrupt the economy, diminish water supply availability and usability, shift ecosystem function, compromise sensitive habitats, and increase the challenges of providing basic services. Many of these impacts will disproportionately affect vulnerable communities.

Although the exact future extent and timing of these impacts is uncertain, this vulnerability assessment phase of Delta Adapts will help the Delta Stewardship Council (Council) understand specific regional climate risks and vulnerabilities.

Regional, collaborative adaptation strategies rooted in science are more critical than ever. The next phase of Delta Adapts, preparing an Adaptation Strategy, will identify ways to address the risks and vulnerabilities.

We did not go at this alone. The Council conducted the climate change vulnerability assessment in coordination with a diverse group of stakeholders over the last two years. The Council worked with agency partners at the local, regional, State and federal levels to obtain data, expand upon existing technical work, and ensure that our climate studies complement other ongoing work. The Council also coordinated with stakeholders representing various Delta interests including community-based organizations, service providers, reclamation districts, water districts, and environmental groups to gather input, to verify results, and to structure the outreach program and technical materials to reach a wider audience.

Considers a broad range of climate futures. Delta Adapts aligns with state guidance and best practices, leverages best available data sources, and conducts targeted analyses to expand our knowledge of climate impacts in the Delta. This vulnerability assessment considers climate impacts at three planning horizons: 2030, 2050, and 2085. It also considers a broad range of potential hydrologic conditions including river inflows, sea level rise, storm surge, and tides.

The assessment considers climate stressors, or chronic changes in climate conditions that may stress Delta systems, including changing temperatures, precipitation and hydrologic patterns, and sea level rise. Climate hazards or acute events that may impact assets and resources include flooding, extreme heat, wildfire smoke, and drought.

Our analysis considers the most vulnerable populations. Delta Adapts defines vulnerability as the intersection of exposure to climate hazards, sensitivity to those hazards, and adaptive capacity, or the ability to recover from and adapt to climate hazards. Delta Adapts identifies the communities with the highest social vulnerability to climate hazards, meaning the communities with high sensitivity and low adaptive capacity to flooding, extreme heat, wildfire, and drought.

Key Takeaways

Flooding will continue to get worse. Flood risk is one of the most pressing threats to the Delta and will continue to worsen in the future with changes in sea levels, precipitation, hydrology, and temperatures. These impacts will continue to affect the central and southern Delta the most, with a concentration in the Stockton area. Flooding in the northern part of the Delta is not expected to be as great a concern due to the numerous investments that have already been made to the flood infrastructure system. Assuming Delta levees remain at current conditions (i.e., no improvement or degradation), by 2050, approximately 10% of the Delta population (including more than 42,000 residents who live in areas with high social vulnerability), 33% of Delta land, and 148,000 acres of agriculture could be exposed to flooding from levee overtopping during a 100-year event, totaling more than $10 billion in exposed agricultural, residential, commercial, and infrastructure assets and nearly $2 billion in economic activity. These figures will double by 2085, when approximately 21% of the Delta population (including 71,200 residents in areas with high social vulnerability) and 68% of Delta land totaling $22 billion in assets and over $5 billion in annual economic activity will be similarly exposed. Future flooding is also anticipated to expose life safety facilities (fire stations, police stations and hospitals), schools, water infrastructure, flood infrastructure and wastewater treatment facilities, as well as hundreds of miles of critical infrastructure supporting energy, utilities, and transportation, potentially resulting in economic disruption that would extend throughout and beyond the Delta. This anticipated flooding underscores the importance of continued, and potentially elevated, levels of investment in Delta levee maintenance and improvements.

Climate change will not impact Delta residents equally. Approximately 65% of the Delta's population could be exposed to the 100-year flood by 2050 resides in areas with high concentrations of socially vulnerable residents. Vulnerable residents may lack the resources to adequately prepare for flood events, lack a vehicle to evacuate during an emergency, or not be aware of flood risks due to linguistic isolation. The communities of Stockton, Pittsburg, Antioch, Isleton, Terminous, Thornton, and Walnut Grove will experience disproportionate impacts, as greater than 80% of the exposed population within these communities is located within highly socially vulnerable block groups.

Increases in the number of extreme heat days, due to climate change, will also disproportionately affect certain populations, such as outdoor workers and people experiencing homelessness, who are more exposed to heat effects. Older adults, young children, and infants are highly sensitive to extreme heat events, as well as individuals suffering from chronic illnesses. While people with greater exposure, heightened sensitivity, or reduced adaptive capacity to extreme heat live and work throughout the Delta, the communities identified as most vulnerable to extreme heat are located in the cities of Stockton and Tracy.

Delta water exports will be less reliable in the future. Climate change will reduce Delta exports in all year types, but impacts will be greater in dry years. Climate change will also reduce reservoir storage in all years, meaning less water can be carried over from one year to the next, increasing the water supply system's vulnerability to droughts and impacts when they occur. In addition, the type of extreme drought that California experienced in 2012-2016 will be five to seven times more likely to occur by 2050. All of this will result in greater water shortages, especially in dry years, and generally, lower reliability of Delta water exports. Reduction in Delta exports will have far ranging consequences for municipal, industrial, and agricultural water users throughout the State. It is critical for Delta water users to continue planning for future drought conditions, because when Delta water is needed the most, it will likely be less available.

The existing water supply system does not provide enough storage to capture anticipated increases in runoff due to more variable precipitation. Among climate stressors, higher temperatures pose the greatest risk to water supply. More variable precipitation is especially impactful during dry periods, and sea level rise is of less concern for water supply relative to other factors. With higher temperatures, more precipitation will occur as rain and less as snow, which results in more runoff during core winter months when rain cannot be captured in reservoirs because of the need to provide flood protection. More variable precipitation means there will be more wet years, more dry years, and fewer average precipitation years. However, additional wet years do not provide much benefit with the system that exists today because additional runoff cannot be captured, and the additional dry years intensify and expand drought-like conditions. Adaptation of our existing water supply system will require significant modifications in order to accommodate the expected changing climate conditions while maintaining water supply reliability.

In-Delta water uses may be threatened by episodic water quality declines. Delta agriculture thrives on the rich organic soils of the Delta and a high quality, reliable water supply. Salt water from the San Francisco Bay is kept out of the Delta by high freshwater flows in winter and reservoir releases of stored water in the summer and fall, enforced through a number of water quality and flow regulations. Higher temperatures, changing precipitation and runoff patterns, and sea level rise all make maintaining Delta water quality more challenging. In general, even with up to two feet of sea level rise, water quality regulations will be able to be maintained in the Delta through 2050. However, during severe drought conditions, which are expected to become more frequent and more severe, water shortages will occur that require trade-offs. In the past, Delta water quality has been compromised during droughts, allowing salinity to penetrate further into the Delta. Future droughts may expose more acres of Delta agriculture to more saline water than has historically occurred.

Delta ecosystems are vulnerable to climate change. As the vast majority of Delta ecosystems have been lost over the previous two centuries, the ecological health of the Delta is already compromised. This reduces ecosystem resilience to climate change stressors and hazards. By 2085, rising sea levels will cause all critical remaining tidal wetland ecosystems in the Delta to transition to different plant communities or drown completely. Of the ecosystems currently protected by levees, 73% are at risk of flooding due to levee overtopping resulting from a combination of sea level rise and storm events. This risk is especially high in the Central Delta and Suisun Marsh. Projected reductions in spring and fall precipitation and increased inter-annual precipitation variability will stress Delta species, favor less diverse species assemblages, and lead to increased presence of non-native species. Increases in both average air temperatures and extreme heat days, especially when these occur sequentially, will stress Delta plant and wildlife species and alter ecosystem dynamics. With intentional, extensive, and timely habitat restoration and management, we can increase nature's resilience to climate change.

Agricultural production trends will shift with climate change. Agriculture is the prevailing land use in the Delta, serving as the cultural backbone and economic driver of the region. The majority of Delta crop yields are projected to decrease due to longer, hotter summers, and increases in the frequency and duration of extreme heat days may lead to additional crop losses. Warmer winters with fewer chilling hours will reduce yields of most fruit and nut trees in the Delta. However, the greater Central Valley is projected to be 2°F warmer than projections for the Delta, and as a result the Delta may serve as a thermal refuge for crops relative to the Central Valley.

By 2050, flooding due to sea level rise, changing Delta inflows, and storm events will expose 148,000 acres of agricultural lands (35% of land currently being farmed), $72 million in agricultural assets, and $79 million in annual agricultural economic activity. Agricultural operations in Sacramento and San Joaquin counties will be most vulnerable to flood risk. Approximately 257,000 acres (62%) of agricultural lands will be exposed by 2085, sending a strong signal that landowners, farmers, and the State will need to develop policy and adaptation strategies to address the threat of climate change to Delta agriculture.

Bringing it All Together

While many of these findings were expected, we now know where the greatest climate impacts will occur to people, places, recreation, agriculture, and infrastructure, and we understand the respective economic impacts. This underscores the importance of future levee investments targeted to protect communities and assets. We understand where the most socially vulnerable communities are located, and where future investments should be prioritized so that climate change adaptation is equitable.

This assessment provides the data and information from our modeling efforts and equity analysis to guide how we address these vulnerabilities in the important next step of Delta Adapts, preparation of an adaptation strategy. An effective plan for adaptation in the Delta will take teamwork and require input from a diverse range of stakeholders. We invite you to join us.

CHAPTER 1. INTRODUCTION

1.1 Purpose

California relies on the Sacramento-San Joaquin Delta in many ways. It supplies a portion of the drinking water for 27 million Californians, fuels California's $3 trillion economy, and is a biodiversity hotspot for more than 750 plant and animal species. It is home to more than 627,000 people spread across rural agricultural communities, legacy communities, and urban areas including Sacramento, West Sacramento, Stockton, Lathrop, Manteca, and the east Bay Area. Projected changes in California's climate put the state's water supply, economy, biodiversity, and Delta residents at risk.

As California continues to feel the pressures of climate change – including sea level rise, changes in precipitation patterns, and warming temperatures – regional adaptation rooted in science-based decision-making is more critical than ever. Individual jurisdictions in the Delta and Suisun Marsh have led their own climate vulnerability assessments and adaptation plans, but the Delta and Suisun Marsh have not been evaluated comprehensively until now.

The **Delta Adapts: Creating a Climate Resilient Future** study is a comprehensive, regional approach to climate resiliency that cuts across boundaries and commits to collaboration across state, local, and regional levels for the Delta and Suisun Marsh (collectively, "the Delta"). The Delta Stewardship Council (Council) initiated Delta Adapts in 2018 to improve the Council's understanding of regionally specific climate change vulnerabilities and risks and address how Delta communities, infrastructure, and ecosystems can adapt to future conditions. This assessment includes a planning horizon of 2100 while recognizing the 2050 planning horizon used for the Delta Plan and proposed amendments.

The findings of the Delta Adapts initiative will help inform future work at the Council, prioritize future actions and investments, provide climate information for local governments, and serve as a framework for future work by the Council and others.

Background

The Delta Stewardship Council is conducting the Delta Adapts initiative as a two-phase effort:

- A climate change vulnerability assessment (CCVA) to improve the understanding of regional vulnerabilities in order to protect vital resources the Delta provides to California and beyond with state interests and investments top of mind; followed by
- An adaptation strategy (AS) detailing strategies and tools that state, regional, and local governments can use to help communities and ecosystems thrive in the face of climate change, while protecting critical infrastructure and economic activities from damage and loss.

Delta Adapts supports the following:

- The Delta Reform Act, passed by the California Legislature in 2009, which mandates the consideration of "the future impact of climate change and sea level rise" in restoration planning and identifies a restoration planning horizon of 2100.
- The Delta Plan, adopted by the Council in 2013, which serves as California's roadmap for the region in support of the coequal goals of a reliable statewide water supply and resilient Delta ecosystem. Climate change science has advanced significantly since the Delta Plan's adoption, with important implications for the Council as it seeks to fulfill its mission of furthering the coequal goals—which will be continuously impacted by future climate change.
- Executive Order B-30-15, signed by Governor Brown in April 2015, which requires California state agencies to incorporate climate change into planning and investment decisions. It also requires agencies to prioritize natural infrastructure and actions toward climate preparedness among the most vulnerable populations.
- Executive Order N-82-20, signed by Governor Newsom in October 2020, which, among other things, sets a goal for the State to conserve at least 30 percent of California's land and coastal waters by 2030 to boost near-term climate resilience efforts.

As an agency of experienced planners, engineers, scientists, and communicators, the Council is uniquely equipped – and authorized – to steward the Delta region toward resiliency. The Council regulates actions of State and local agencies in the Delta to ensure they support statewide water supply reliability and Delta ecosystem restoration, and has the resources needed to guide climate adaptation in the region. Through strong working relationships with government agencies on the federal, state, regional, and local levels, the Council can influence action in the Delta to improve resilience over time and communicate the statewide implications of anticipated regional impacts.

The Council's role in Delta Adapts has three core elements. The Council is:

- The **initiator** of a regional planning process,
- The **convener** bringing various partners together to work as part of a broader team, and
- An **active participant** collaborating with a robust group of experts and interested stakeholders to gather and synthesize existing research and data, identify knowledge gaps, develop methods to fill data gaps, complete technical analyses, and summarize results.

Goals and Process

The overall goal of Delta Adapts is to build resilience to climate change in the region, with specific goals to:

- Inform future work at the Council,
- Provide local governments with a toolkit of information to incorporate into their planning and regulatory documents,

- Integrate climate change into the state's prioritization of future actions and investments, and
- Serve as a framework to be built upon by the Council and others in years to come.

The Council is pursuing these goals across the two phases, while following the statutory requirements outlined in the Delta Reform Act of 2009. Delta Adapts considers climate change impacts that are expected to occur and impact the people, places, land uses, infrastructure, ecosystems, and water supply reliability of the Delta.

The first phase, the findings of which are summarized in this report, is a climate change vulnerability assessment characterizing the vulnerability of Delta people, assets, and resources to climate change stressors and hazards. The second phase is an adaptation strategy that will be developed in 2021.

1.2 Geographic Setting

The Delta is located at the convergence of the State's two largest rivers – the Sacramento River flowing from the north and the San Joaquin River flowing from the south (Figure 1-1). The Delta lies between the Sierra Nevada to the east and the Coast Range to the west. Rainfall and snowmelt in the mountains collect in tributaries that flow into these rivers and ultimately support the Delta, along with brackish water carried by tides from San Francisco Bay. The Delta is situated 40 miles inland from the Pacific Ocean, connecting to San Francisco Bay via the narrow Carquinez Strait, west of Suisun Marsh. The Delta's warm temperate climate and access to fresh water and rich alluvial soils provide excellent components for life to thrive. This fertile landscape evolved in response to California's dynamic annual precipitation variability, through periods of drought and flood. The Delta covers approximately 1,300 square miles and is made up of a network of channels, levees, subsided islands, sloughs, rivers, and tributaries across six counties including Yolo, Sacramento, Solano, San Joaquin, Contra Costa, and Alameda. The Delta Adapts project area includes the legal Delta and Suisun Marsh. Existing conditions in the Delta are described in more detail in Chapter 2.

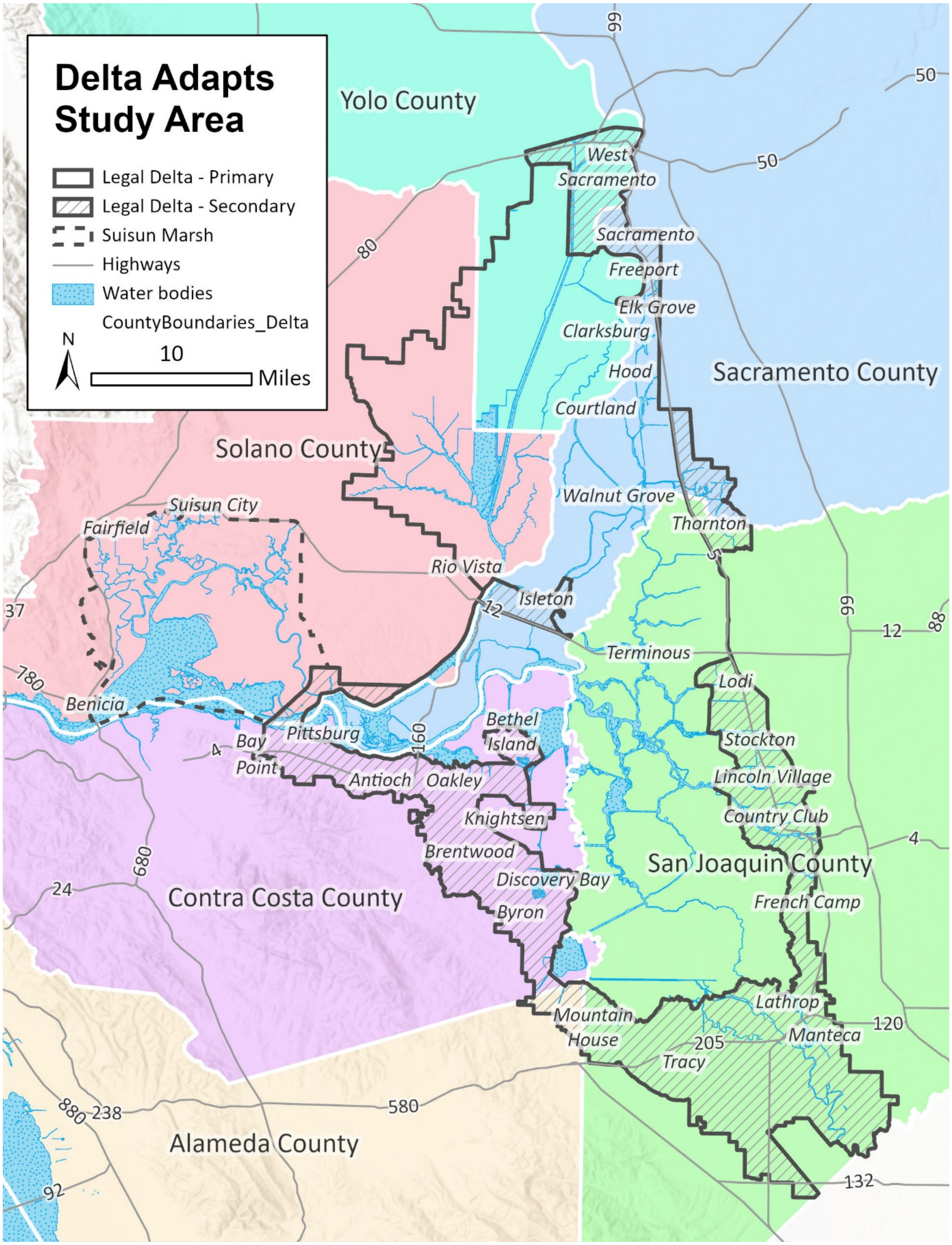

Figure 1-1. Location map showing the Delta and Suisun Marsh

1.3 Planning and Regulatory Setting

Within California and in the Delta, a multitude of federal, state, regional, and local authorities have begun to integrate climate change and sea level rise considerations into their policy frameworks (Table 1-1). These agencies are at varying stages of planning for climate change and sea level rise. Their roles and authority to plan for climate change adaptation within the Delta also vary (see Planning Context Technical Memorandum for a summary of each agency's role in the Delta and current climate change planning status). Understanding agency roles and responsibilities supports the Council's role as the convener of Delta Adapts, bringing various partners together to work as part of a broader team. Documenting the range of assets and infrastructure in the Delta that agencies maintain and manage ensures that the vulnerability assessment phase of the project provides information that is salient to the Council's partners. Finally, understanding agency progress on planning for climate change helps the Council identify opportunities to leverage partner research and fill gaps in information and plan implementation where they exist.

Table 1-1. Agencies with Climate Change Related Roles in the Delta

Agency Type	List of Agencies
Federal Agencies	Federal Emergency Management Agency (FEMA) Federal Energy Regulatory Commission (FERC) National Oceanic and Atmospheric Administration (NOAA) U.S. Army Corps of Engineers (USACE) U.S. Environmental Protection Agency (EPA) U.S. Department of the Interior (USDOI) U.S. Fish and Wildlife Service (USFWS) U.S. Geological Survey (USGS) U.S. Bureau of Reclamation (USBR)
State Agencies	Department of Fish and Wildlife (CDFW) Department of Food and Agriculture (CDFA) Department of Public Health (CDPH) Department of Transportation (Caltrans) Department of Water Resources (DWR) California Energy Commission (CEC) Natural Resources Agency (CNRA) Public Utilities Commission (CPUC) Central Valley Flood Protection Board (CVFPB) California Strategic Growth Council (SGC) Delta Protection Commission (DPC) Delta Stewardship Council (DSC) Governor's Office of Emergency Services (CalOES) Governor's Office of Planning and Research (OPR) Ocean Protection Council (OPC)

	Sacramento San Joaquin Delta Conservancy (Delta Conservancy) San Francisco Bay Conservation and Development Commission (BCDC) State Water Resources Control Board (SWRCB)
Regional Agencies	Sacramento Area Council of Governments (SACOG) Sacramento Metropolitan Air Quality Management District (SMAQMD) Yolo-Solano Air Pollution Control District (YSAPCD) San Joaquin Council of Governments (SJCOG) San Joaquin Valley Air Pollution Control District (SJVAPCD) Metropolitan Transportation Commission (MTC) Association of Bay Area Governments (ABAG) Bay Area Air Quality Management District (BAAQMD)

As part of the Delta Adapts initiative, the Council reviewed the agencies with roles in the Delta and the policy and planning frameworks employed by each to better understand how governance and policy related initiatives can address vulnerabilities identified in the CCVA. This analysis provides one of the first comprehensive reviews of climate policy and governance capacity within the Delta and provides a starting point for understanding gaps and prioritizing the Council's climate change efforts moving forward.

The Council found that plans, policies, requirements, and resources at various levels of government accomplish the following: (1) provide awareness of climate change vulnerabilities and risks, (2) provide guidance on how to characterize vulnerabilities, (3) identify best available science at the state level, (4) acknowledge that climate change will disproportionately affect the state's most vulnerable populations, (4) provide grants to support reduction of greenhouse gas emissions, and (5) publish resources and guidance on how to adapt to climate change. However, the review also found that significant opportunities remain to improve the application of scientific information to policy and planning instruments, and to coordinate among jurisdictional boundaries and across levels of government. The Council aims to address some of these gaps through the Delta Adapts initiative.

1.4 Resilience Goals

As part of the Delta Adapts initiative, the Council developed a set of Climate Change Resilience Goals (resilience goals) to provide a long view toward Delta regional values and priorities. The resilience goals are used by the project team to focus Delta Adapts methods and recommendations. The resilience goals will also be used by the Council, stakeholders, and other decision-makers to evaluate adaptation options, identify tradeoffs and synergies across goals, and ultimately prioritize adaptation actions that increase Delta assets' resilience to climate change.

What is resilience?

Resilience is the capacity of any entity – an individual, a community, an organization, or a natural system – to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience (Guidebook for State agencies in Planning and Investing for a Resilient California (OPR 2018a)).

These resilience goals build upon the Council's coequal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. Delta Adapts also incorporates the sustainability framework used by the San Francisco Bay Conservation and Development Commission (BCDC) Adapting to Rising Tides (ART) regional climate change adaptation planning program. This framework is organized around the following themes: water, environment, society and equity, economy, and governance.

The resilience goals will be revisited prior to initiating the Adaptation Strategy to ensure alignment with planning issues and to ensure that they continue to reflect agency, organization, and community values and visions, as well as regional interests in a balanced, holistic manner.

Water

- Promote statewide water conservation, water use efficiency, and sustainable water use (Public Resources Code 85020(d)).
- Improve water quality to protect human health and the environment consistent with achieving water quality objectives in the Delta (Public Resources Code 85020(e)).
- Improve the water conveyance system and expand statewide water storage (Public Resources Code 85020(f)).

Environment

- Restore the Delta ecosystem, including its fisheries and wildlife, as the heart of a healthy estuary and wetland ecosystem (Public Resources Code 85020(c)).
- Restore critical physical and biological processes; connectivity; complexity and diversity; redundancy; at large scales with a long time horizon in mind.

Society and Equity

- Protect and enhance the unique cultural, recreational, and agricultural values of the California Delta as an evolving place (Public Resources Code 85020(b)).
- Reduce risks to people, property, and state interests in the Delta by effective emergency preparedness, appropriate land uses, and investments in flood protection (Public Resources Code 85020(g)).
- Increase the resilience of Delta communities, especially those with characteristics that make them more vulnerable to climate risk due to physical (built and environmental), social, political, and/or economic factors. These factors include, but are not limited to, race, class, sexual orientation and identification, national origin, and income inequality (OPR 2018).
- Prioritize actions that protect the most vulnerable populations (EO B-30-15).

Economy

- Maintain and improve local economic vitality and access to diverse employment opportunities by preserving and growing, where appropriate, key economic and employment drivers and associated infrastructure that support the Delta economy and communities.

- Promote the development of urban growth strategies that reduce climate risks by focusing new development in more resilient areas, enhancing the Delta ecosystem, and supporting resilient farming and recreation activities.
- Improve and enhance the resilience of the Delta transportation network while supporting the achievement of regional and statewide greenhouse gas reduction targets.

Governance

- Foster collaboration and build capacity among federal, state, and local agencies, non-governmental and private organizations, and communities in the Delta.
- Commit to working cooperatively to identify and mitigate climate change impacts and risks.
- Improve coordination among regulatory agencies to reduce program or legal barriers to addressing current and future flood, drought, wildfire, and other risks that will be exacerbated by climate change.
- Incorporate climate change into state and local Delta planning and investment decisions (EO B-30-15).
- Prioritize actions that incorporate natural and green infrastructure solutions (EO B-30-15).
- Define the Council's role in coordinating adaptation responses in the Delta.

1.5 Conceptual Framework

The framework for the Delta Adapts initiative acknowledges state agency guidance on climate change from agencies including the Governor's Office of Planning and Research (OPR), the Ocean Protection Council (OPC), the Natural Resources Agency (Resources 2018), and Governor's Office of Emergency Services (OES), and incorporates sea level rise guidance issued by the Ocean Protection Council (OPC) for local and regional government engagement and planning (OPC 2018). In addition, lessons learned from the San Francisco Bay Conservation and Development Commission (BCDC) ART program in the San Francisco Bay and Eastern Contra Costa County are applied. Delta Adapts incorporates input from the Council, a Technical Advisory Committee, a Stakeholder Work Group, and a broad array of Delta stakeholders. For more information regarding stakeholder input, please refer to the Outreach and Engagement Summary Technical Memorandum. The project also integrates best available science (as described in Delta Plan Appendix 1A), including information from the recent California Fourth Climate Change Assessment (https://www.climateassessment.ca.gov/).

Delta Adapts applies guidance from the Intergovernmental Panel on Climate Change (IPCC 2012) to evaluate exposure and vulnerability to climate hazards and the potential impacts. OPR describes the dimensions of vulnerability as "the degree to which natural, built, and human systems are at risk of exposure to climate change impacts, the sensitivity to climate change, and the adaptive capacity and resources to cope with, adapt to, or recover from climate impacts" (OPR 2018b). The Delta Adapts initiative considers vulnerability along these dimensions.

Delta Adapts considers vulnerability to climate change across a broad range of assets, sectors, and systems within the Delta, including:

- Delta as an Evolving Place (people, places, agriculture, recreation, and infrastructure)
- Protection, Restoration, and Enhancement of the Delta Ecosystem
- Water Supply Reliability
- Economics

The Delta Adapts vulnerability and adaptation conceptual framework is shown in Figure 1-2.. This vulnerability assessment presents Steps 1-4: (1) Review Science (Chapter 3), (2) Inventory Assets and Resources (Section 2.2), (3) Assess Vulnerability, and (4) Assess Risk (Chapter 4 and Chapter 5). The subsequent Adaptation Strategy will address Steps 5-7.

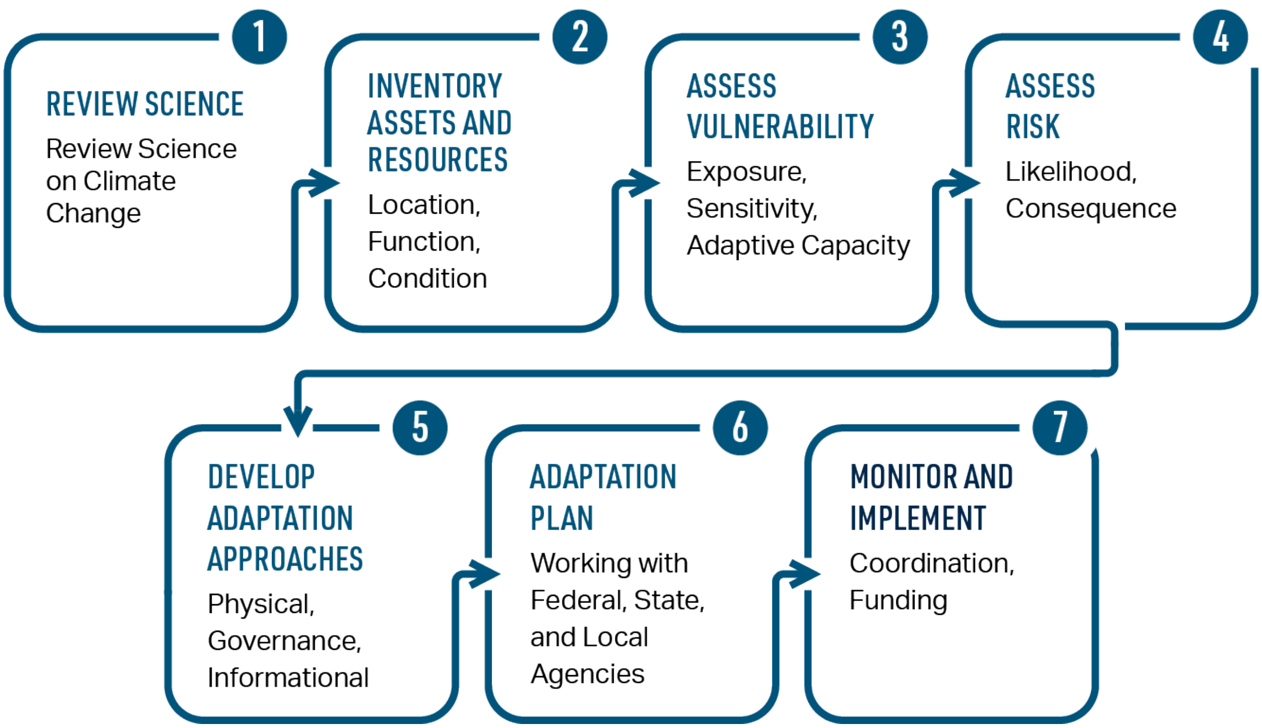

Figure 1-2. Climate change vulnerability and adaptation conceptual framework applied in the Delta

1.6 Equity Considerations

Equity is just and fair inclusion into a society in which all can participate, prosper, and reach their full potential (OPR 2018a; PolicyLink 2018). OPR identifies the following equity challenges for climate change policy: "addressing the impacts of climate change, which are felt unequally; identifying who is responsible for causing climate change and for actions to limit its effects; and, understanding the ways in which climate policy intersects with other dimensions of human development, both globally and domestically" (OPR 2018a). Climate equity means acknowledging that those who have benefitted least from the economic activities that cause greenhouse gas emissions are often most vulnerable to the impacts of climate change (IPCC 2014; Roos 2018; Shonkoff et al. 2011; Stallworthy 2009).

By Executive Order, state agencies must consider the most vulnerable populations when incorporating climate change into planning and investment decisions (EO B-30-15). Local agencies have similar requirements to incorporate equity and address climate change in their general plans. Compliance with Senate Bill (SB) 1000 requires local agencies to identify goals, policies, and objectives to reduce risks to *disadvantaged communities*, defined as areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure, or environmental degradation, or with concentrations of people that are of low income, high unemployment, low levels of homeownership, high rent burden, sensitive populations, or low levels of educational attainment (*Cal. Health & Saf. Code* § 39711). Compliance with SB 379 requires local agencies to identify the risks that climate change poses, the geographic areas at risk, and feasible climate adaptation and resiliency strategies to avoid or minimize those risks (*Cal. Gov. Code* § 65302). While some local agencies within the Delta have already met these obligations by adopting environmental justice elements or updating safety elements in their general plans, others are still working toward compliance with this new set of requirements. The State's Integrated Climate Adaptation and Resiliency Program (ICARP) Technical Advisory Council developed and adopted the following definition to assist local and state agencies in implementing the Executive Order (OPR 2018a):

> Vulnerable populations are "those which experience heightened risk and increased sensitivity to climate change and have less capacity and fewer resources to cope with, adapt to, or recover from climate impacts. These disproportionate effects are caused by physical (built and environmental), social, political, and/or economic factor(s), which are exacerbated by climate impacts. These factors include, but are not limited to, race, class, sexual orientation and identification, national origin, and income inequality."

The Council has incorporated equity into the Delta Adapts initiative by identifying the communities and populations that are most vulnerable to climate hazards in the Delta (see Section 4.3 and the Equity Technical Memorandum) and the potential impacts of those hazards. In combination with stakeholder input, the results of this analysis will be used to inform the development of equitable adaptation strategies.

CHAPTER 2. EXISTING CONDITIONS AND CHALLENGES

This chapter provides an overview of existing conditions in the Delta and Suisun Marsh, with particular focus on characteristics that may exacerbate the vulnerability of the Delta to future climate change and challenges to adaptation (Section 2.1). In addition, the existing conditions summary highlights what is at stake in terms of vulnerability to climate stressors and hazards over the next century, including the important populations, assets, and resources within the Delta. This chapter does not provide an exhaustive review of existing conditions but rather is focused on the discussion noted above. Section 2.2 describes the asset and resources inventory that was conducted by the Delta Adapts team to inform the vulnerability assessment.

2.1 Existing Conditions Summary

Over the past 150 years, the Delta's landscape has been greatly modified for agricultural, industrial, and urban purposes, including water withdrawals and diversions, land conversions, levee building, groundwater pumping, and channel deepening for shipping. In addition, widespread introduction of non-native and invasive species has resulted in unintended impacts across the landscape. Beginning in the 1800s, levee systems were constructed to reclaim land for agricultural purposes and control the flow of water through the Delta. Through this reclamation process, a complex network of distributary streams and sloughs were channelized and hundreds of thousands of acres of seasonally and tidally flooded wetlands were converted into fertile agricultural fields (Figure 2-1). As a result of these actions, over 95% of the native ecosystems of the Delta and the fish and wildlife that comprise them were destroyed. Today the Delta remains home to diverse communities of people and a prominent agricultural sector, with remnant areas of native habitats consisting of native plants and wildlife distributed throughout its landscape. Delta waterways and islands also serve a critical role for migrating birds and remnant spawning salmonid populations. However, these changes have resulted in challenges that have had lasting effects on the landscape that exacerbate the vulnerability of the Delta to future climate change. These challenges are discussed in more detail in the sections that follow to set the context for the vulnerability assessment.

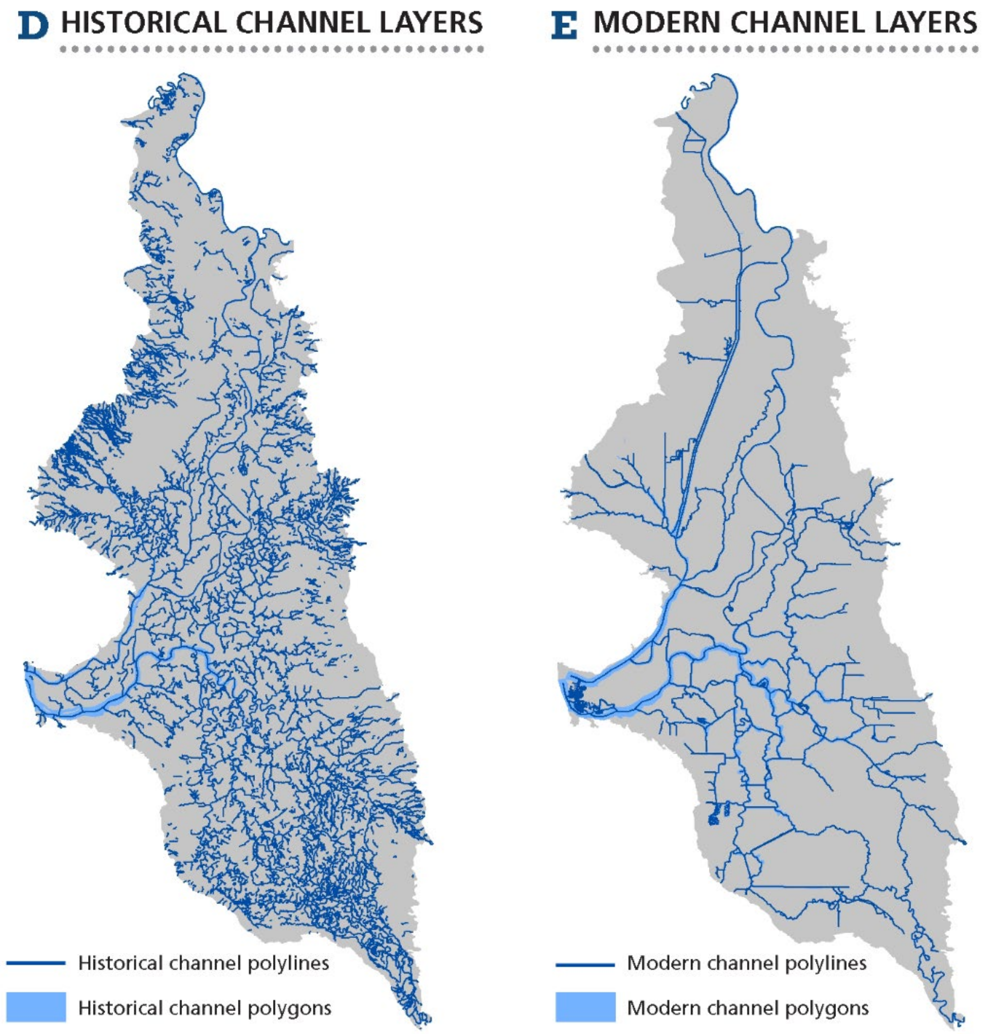

Figure 2-1. Historical and modern channels in the Delta

Source: SFEI (2014) A Delta Transformed

2.1.1 Delta as an Evolving Place

The Delta is divided into three legally recognized areas (Figure 1-1.) – the Primary Zone, the Secondary Zone, and Suisun Marsh. The Primary Zone is the largest, covering 490,050 acres, and is located at the heart of the Delta. It comprises mainly rural farmland and a few small towns. The Secondary Zone includes 247,320 acres surrounding the Primary Zone. It also includes farmland but is dominated by the region’s cities and suburbs. Suisun Marsh lies northwest of the Delta, encompassing 108,570 acres primarily consisting of managed wetlands. Within these three zones is a unique setting distinguished by its legacy communities, rural and agricultural setting, vibrant natural ecosystems, reliable water supplies, and mix of economic activities. The following sections describe the Delta’s characteristics as a place with an emphasis on their evolution through time, how they could be affected by a changing climate, and existing challenges to climate adaptation.

2.1.1.1 People and Community

Human activity in the Delta coincided with its formation over 6,000 years ago when indigenous populations, including Miwok, Yokut, and Maidu tribes from the adjacent Sacramento and San Joaquin Valleys expanded into the region. Through the use of controlled burning and other land use practices, they actively managed the landscape to improve the harvest of Delta plant, animal, and mineral resources needed to support their communities (Helzer 2015; Keeley 2002; Anderson 2005). Although the Delta sustained a large number of indigenous peoples, the culture placed a great value on maintaining a broad diversity of species and environments in the natural landscape, limiting degradation of the ecosystems.

In the mid-1800s, the California gold rush dramatically changed the landscape and population. In the span of a few years, there was a large influx of European settlers, deltaic streams were channelized for steamboat navigation, new communities were established along the waterways, and hydraulic mining in the Sierra Nevada foothills quickly degraded the local water quality and surrounding ecosystems. These changes had a devastating effect on the area's local tribes, resulting in the death of 75 percent of the region's indigenous people and effectively ending widescale indigenous landscape management (Cook 1955; Castillo 1978).

The Delta today has a population of approximately 627,000 people (2018 American Community Survey data) of diverse ethnic backgrounds. Only three percent of the population lives in the Delta's Primary Zone while the remaining 97% of the population lives in the Delta's Secondary Zone. Approximately 18% of people in the Delta live below the poverty line and may be disproportionately impacted by climate change (see Section 4.3.2). Legacy communities of historical significance are primarily located in the Primary Zone. These culturally significant communities and resources may be exposed to more frequent and severe extreme heat days and increased likelihood of flooding as a result of future climate change (see Section 5.2.2).

The Delta's urban communities are primarily located around the periphery of the Delta, which is undergoing rapid urbanization and population growth, with an estimated 26,000 acres expected to undergo urbanization in the future (DPC 2012). Development and population growth within the Delta will increase the number of residents located in areas that may be exposed to climate hazards such as extreme heat, flooding, drought, and wildfire (see Section 5.2.1).

2.1.1.2 Agriculture

Agriculture is the dominant land use in the Delta, providing jobs to residents, a sense of community and place, and over $4.5 billion in economic output (DPC 2020). Approximately 45 percent of Delta farmland (approximately 377,000 acres) is considered prime farmland. Unique farmland, farmland of statewide or local importance, or farmland of potential local importance comprise another 112,000 acres (DOC 2016).

Delta agriculture is primarily composed of corn, alfalfa, irrigated pasture, wine grapes, processing tomatoes, and wheat. Almonds and vineyards cover an increasing portion of croplands and the Delta is projected to continue seeing increases in the fraction of high-value crops in the coming decades (DPC 2020).

Changing climate, including warming air temperatures, more frequent and severe extreme heat events and droughts, and flood hazards will stress Delta agriculture in the future. Other factors such as land use changes, oxidation of peat soils, subsidence, water quality degradation, salinity intrusion, and wind erosion may also stress Delta agriculture in the future, depending on future management actions (see Section 0 and the Crop Yield and Agricultural Production Technical Memorandum).

2.1.1.3 Recreation and Tourism

The Delta is a popular recreation destination within California and is valued for its wide-open spaces, interconnected waterways, historic towns, and lifestyle. In recognition of these values the Delta was designated as a National Heritage Area (NHA) in 2019. The Delta NHA is the first National Heritage Area in California and one of only 55 nationally. The Delta's waterways, marshes, parks, and historic communities support recreation and tourism activities for residents and visitors. Many recreational facilities, such as boat launches, docks, and marinas, are water-dependent and may be impacted by climate change effects such as increased frequency and severity of flooding, low streamflow conditions due to drought, and degradation of water quality (see Section 5.2.4).

Public lands, including parks, wildlife areas and refuges, and preserves, comprise approximately ten percent of Delta lands. Public recreation facilities consist of recreation areas (e.g., Brannan, Franks Tract), State Parks properties managed by the Department of Fish and Wildlife, the State Lands Commission, and the California Department of Water Resources (e.g., Delta Meadows), and county, regional, and city parks. A number of public access trails also pass through the Delta, including the American Discovery Trail, Mokelumne Coast-To-Crest Trail, and the in-development Great Delta Trail. These trails currently support or will provide public access for a variety of recreation activities, including hiking and biking.

Heritage tourism in the Delta includes legacy communities and other historic sites. Museums, nature centers, and interpretive programs draw visitors and provide information about the Delta's many natural and cultural resources. Local and regional festivals and events attract visitors to the region's farms and wineries, and its diverse ethnic heritage supports food, wine, and cultural tourism attractions (DSC 2018c).

Changing climate, including more frequent and severe extreme heat events, droughts, and flood hazards will stress Delta recreation and tourism activities and the assets and resources that support these activities in the future.

2.1.1.4 Utilities and Infrastructure

The Delta contains a network of infrastructure, much of it aging, that is critical to the functioning of the Delta and the state – including energy and utilities, transportation, solid and hazardous waste, flood management, and water supply infrastructure. Five highways, three railroads, two deep-water shipping channels, hundreds of miles of natural gas and high-voltage transmission lines, oil and gas wells, and numerous other infrastructure assets are located in the Delta. Delta agriculture depends on local and county roads for transporting crops to market and for local circulation of goods. The Stockton and West Sacramento Ports are important links for maritime commerce. Water supply infrastructure, including forebays, pumps, and water control structures are key to the functioning of the Central Valley Project and State Water Project and aqueducts and other facilities serve the East Bay Municipal Utility District, Contra Costa Water District, and other areas. Infrastructure located in areas exposed to climate change-related flooding may be damaged and temperature-sensitive assets may be affected by increased frequency and severity of extreme heat events in the future (see Section 5.2.5). In addition, existing risks such as levee stability and seismic risk remain as underlying factors.

2.1.1.5 Economy

The Delta's economy is diverse, expanding, and regionally integrated. It is primarily urban and service oriented with important sectors being transportation, warehousing, utilities, construction, housing, and real estate. The top employment sectors are retail, education, healthcare, and accommodations. The Primary Zone economy is less diverse and depends primarily on agriculture, and somewhat on recreation and tourism (DSC 2018c). Agriculture is an important contributor to the Delta economy and including value-added manufacturing, the statewide impact of Delta agriculture is over 23,000 jobs, more than $2 billion in value added, and $4.5 billion in economic output (DPC 2020). Recreation and tourism are also important contributors to the Delta's economy providing an estimated 3,000 jobs with $100 million in wages in the Delta counties, $312 million in annual direct expenditures in the Delta by anglers, hunters, boaters, picnickers, campers, hikers, bicyclists, and other recreators, and a total of $175 million in value added to the regional economy. Statewide, Delta recreation and tourism support 5,200 jobs and contribute $348 million (DSC 2018c). Climate change related hazards including flooding, extreme heat, drought, and wildfire smoke will affect the Delta's economy in the coming decades.

2.1.2 Water Supply

The Delta watershed (Figure 2-2) provides all or a portion of water supplies to more than 27 million California residents throughout the State and more than 3.7 million acres of agriculture. A number of in-Delta users also divert water directly from the Delta's channels and sloughs. Many of these uses take advantage of the Delta's consistent water availability but depend on upstream water releases from state and federal reservoir operations to manage the salinity of Delta water during summer and fall. In addition, inflows serve important functions for the Delta ecosystem. The Delta serves as a hub for water transfers to other areas of the state and while only eight percent of the state's water supply is exported from the Delta, this represents a substantial proportion of supply for some regions and water suppliers. The Delta's system of channels, aqueducts, gates, pumps, and treatment plants are critical to meeting California's water needs.

Interannual variability in California precipitation is a perennial challenge for in-Delta and statewide water supply. Historically, California has experienced alternating periods of warm and dry conditions punctuated by extremely wet years – both of which stress the water supply system. Climate change will affect air temperature and hydrologic patterns within the Delta's watersheds, increase the frequency and severity of drought, and cause sea level rise in the Bay (see Chapter 3) – all of which will impact Delta water supply reliability in the future (see Section 5.4 and the Water Supply Technical Memorandum). Further, as annual surface water supplies become more variable and less reliable, water users in the Delta and throughout California may increasingly rely on groundwater to provide a buffer against water shortages and meet demands. The Sustainable Groundwater Management Act (SGMA) will play an important role in facilitating effective and sustainable management of groundwater supplies in the future in the Delta and its contributing watersheds.

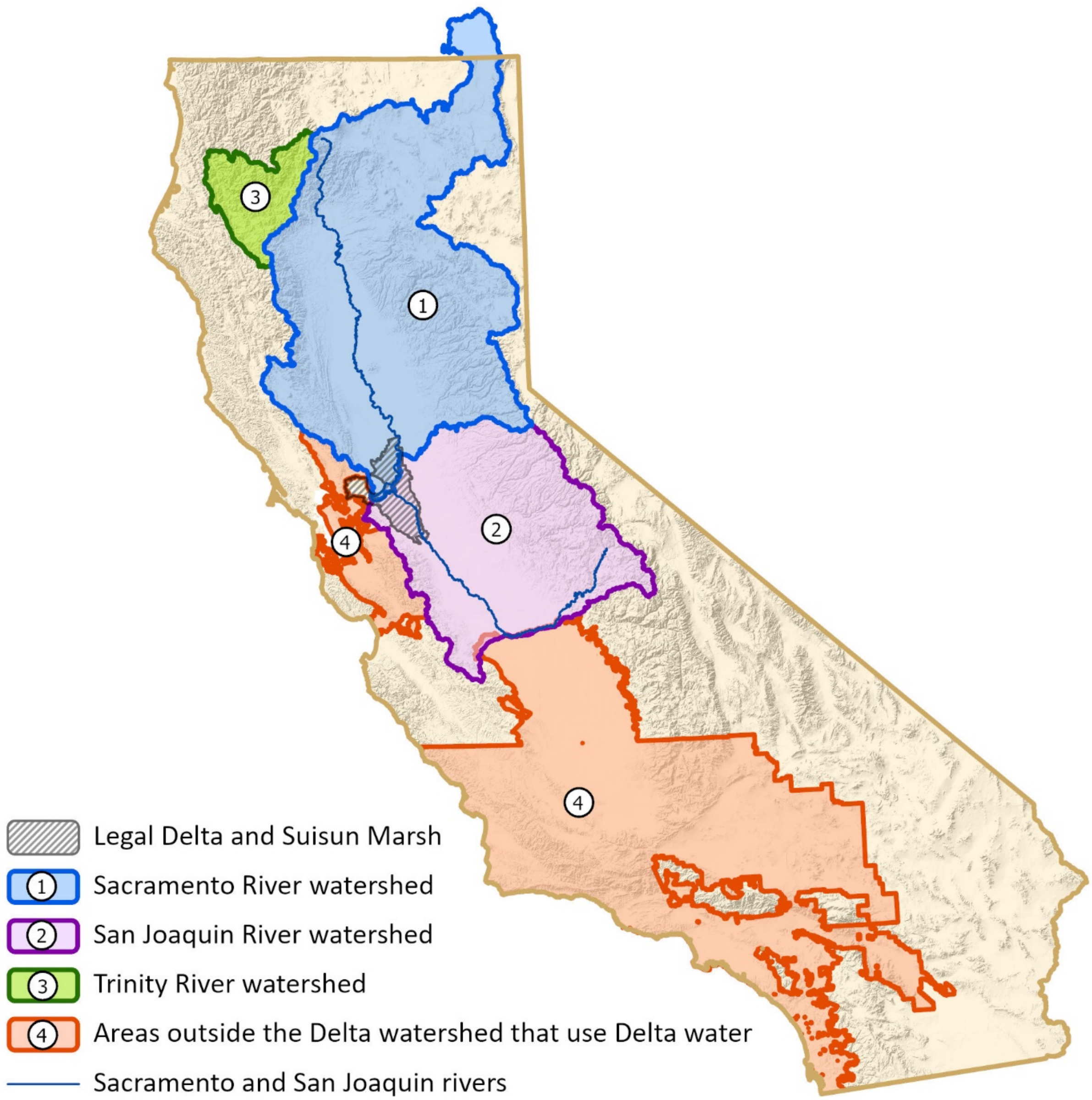

Figure 2-2. Map of the Delta watershed and areas of California that use Delta water

2.1.3 Ecosystems

The Delta ecosystem is characterized by a Mediterranean climate, extraordinary biodiversity, and endemism that persists despite substantial human modifications to the landscape that have occurred since reclamation began in the 1800s. These modifications have altered the Delta's ecosystem to one that is highly managed yet remains productive.

Existing Delta habitats include waters—tidal and fluvial mainstream channels, smaller channels, open water, freshwater ponds, and lakes; freshwater emergent wetlands—brackish, tidal and non-tidal; willow thickets; willow riparian scrub and shrub systems; valley foothill riparian; seasonal wetlands; vernal pools; dunes; grasslands; managed wetlands; agricultural lands; and urban/ruderal areas. These habitats host a wide range of endemic plant communities, while supporting important migratory corridors for native fish, wildlife, and birds. The Delta is an important stop along the Pacific Flyway for hundreds of species of migratory and overwintering birds. The Suisun Marsh and Yolo Bypass are designated as Important Bird Areas of global importance and the Delta is designated as an Important Bird Area of state importance by the National Audubon Society. Waterfowl are abundant in the seasonal wetland and agricultural areas of the Delta and regularly flooded agricultural lands support tens of thousands of shorebirds and hundreds of thousands of waterfowl.

Land reclamation, levee building, river channelization and diversion, and land use conversions have altered much of the historical Delta landscape and resulted in habitat loss, fragmentation, and disconnection of wetlands, rivers, floodplain terraces, and upland areas. These alterations have reduced the natural resiliency of the aquatic and terrestrial species that inhabit the Delta's riparian and wetland ecosystems (SFEI-ASC 2015; SFEI-ASC 2016). Further, impacts to both the upstream watershed and the Pacific Ocean and San Francisco Bay have resulted in degraded freshwater flows, water quality, and critical habitats necessary for various life stages of species outside the Delta. Non-native invasive species have also become more problematic due to habitat fragmentation and modification in the Delta. Delta ecosystems are stressed under current conditions and climate change will further stress species as climate variability exceeds conditions that species have adapted to over time (see Section 5.3). In addition, restoring natural conditions and providing adequate habitat for species to adapt will be challenging given the substantial land use changes that have occurred historically, presence of deeply subsided Delta islands, competing demands for freshwater flows, and urbanization in the Delta.

2.1.4 Water Quality and Salinity

Water quality in the Delta is influenced by many factors, including freshwater inflows and outflows, water temperatures, dredging, tides, point source inputs of pollutants, nonpoint source inputs of pollutants, in-Delta water use, and export diversions and operations (DSC 2018c). Located at the head of the San Francisco Bay estuary, the Delta and Suisun Marsh serve as a transition zone from fresh riverine water to saline ocean water. Due to Delta inflows and salinity and flow management activities in the Delta, freshwater typically extends across most of the Delta, to the Delta's west side near Pittsburg. During the wet season when runoff is high, freshwater extends even further west into Suisun Marsh and beyond. During the dry season and during drought conditions, reservoir releases are often used to limit salinity's eastward intrusion into the Delta to maintain water quality for in-Delta water users and ecosystem functions (DSC 2018a). Warming air and water temperatures, sea level rise, and changes in hydrologic patterns due to climate change will affect water quality in the Delta in the future and may require changes in in-Delta water use patterns and upstream reservoir management.

2.1.5 Flood Management

The Delta is an inherently flood prone area and low-lying rural and urban communities are protected from flooding by a complex system of levees within the Delta and by multipurpose reservoirs in upstream tributaries. Approximately 1,330 miles of levees in the Delta and Suisun Marsh reduce flood risk for approximately 740,000 acres of land, including residential, commercial, industrial, agricultural, and ecological uses. In addition to reducing flood risk, Delta levees provide a critical role in maintaining conveyance channels and hydrodynamic conditions suitable for the operation of the State and Federal water projects and maintenance of Delta salinity conditions, which allow freshwater to be withdrawn from the central and south Delta. Delta levees also protect wildlife habitat areas for waterfowl and other species that depend on the levees for effective habitat management (see Section 5.3.6).

Many Delta levees were initially constructed more than a century ago using primitive equipment and non-engineered fill material excavated from adjacent channels, sloughs, and marshes. Over the past century, there have been more than 140 levee failures and island inundations; however, very few have occurred over the past 30 years since state and local agencies adopted an active role in supporting the maintenance and enhancement of the levees. Besides the Council, the Central Valley Flood Protection Board, Department of Water Resources, U.S. Army Corps of Engineers, and local reclamation districts all play a role in Delta flood risk management. Levee maintenance and improvement activities over the last few decades have focused on raising crest elevations to meet freeboard requirements, achieve modern standards of flood protection, and improve levee stability. Climate change is projected to result in sea level rise and changes in hydrologic patterns that will increase flood elevations within the Delta. These changes will reduce levee freeboard in the near- to mid-term and may result in levee overtopping or seepage and stability failures in the mid- to long-term.

Delta levees face numerous other threats in addition to higher water levels during floods, including wind-generated waves in open water areas, earthquakes, and subsidence. While seismic risk is not evaluated by Delta Adapts, the Delta Levee Investment Strategy (DSC 2017) evaluated the probability of hydraulic and seismic flooding of Delta levees and found that islands in the western and central Delta tend to have the highest probability of seismically induced flooding. Future raising of levees to address increasing flood elevations due to climate change may increase the likelihood of seismic-related failures in the future as well.

2.1.6 Subsidence

Subsidence is a key aspect of the Delta landscape's vulnerability to climate change. Since the initiation of intense land management practices in the 1850s, half of the volume of organic peat soils in the Delta has been lost due to disturbance and oxidation (Deverel and Leighton 2010;

Mount and Twiss 2005), resulting in substantial greenhouse gas emissions and the lowering of some Delta islands by as much as 25 feet below sea level. Subsidence rates have decreased substantially from early 20th century values and range from a few millimeters per year to approximately 2 centimeters per year today (Deverel et al. 2016).

Subsidence of Delta islands creates height differences between the land and adjacent water surface elevations in channels. These height differences amplify forces against the levees and drive flow through and underneath levees into the subsided islands. Irrigation water further contributes to the accumulation of water in island drainage ditches, where it is routed to pumps and returned to adjacent channels. Subsidence of Delta islands due to continued agricultural practices will increase the Delta's overall vulnerability to climate change. Increasing water surface elevations due to sea level rise, hydrological changes, subsidence, and drainage ditch deepening will increase pressure on levees and increase rates of seepage onto Delta islands (Mount and Twiss 2005, Deverel et al. 2014). These effects will increase the probability of levee failure over time (Deverel et al. 2015, 2016). Permanent flooding of Delta islands, if they occur, will alter circulation and salinity dynamics in the Delta and create deep, open water habitats that do not resemble any historical state of the ecosystem.

2.2 Asset and Resources Inventory

This vulnerability assessment is structured according to key Delta assets and resources and organized by themes corresponding to the chapters of the Delta Plan, including Delta as an Evolving Place, Ecosystems, Water Supply Reliability, and Risk Reduction (i.e., flood hazards).

The Delta Adapts team conducted an asset and resources inventory and developed a geospatial database to organize data describing people, places, land use, infrastructure, and ecosystems within the Delta as input to the vulnerability assessment. The Delta Levees Investment Strategy (DLIS) asset database is used as a starting point and updated to include more recent data layers, where available, and supplemented with additional datasets to meet the needs of Delta Adapts. The assets and resources compiled include the following categories:

- People
  - Population
- Places
  - Parcel boundaries
  - Cultural resources (legacy communities, historic places, landmarks)
  - Buildings and properties (critical facilities, government buildings)
  - Commercial and industrial areas
  - Recreation (parks, campgrounds, marinas, scenic highways, trails)
- Land Use and Land Cover
  - Agricultural land use

  - Vegetation classification and mapping
- Infrastructure
  - Energy and utilities (energy generation, substations, transmission/pipelines, natural gas)
  - Communications (facilities and cell towers)
  - Transportation (roads, rail lines and stations, bike paths, airports, shipping ports, and bridges)
  - Solid/hazardous waste facilities, contaminated sites
  - Flood management infrastructure (levees, channels, pump stations, rock stockpiles, evacuation routes)
  - Water supply infrastructure (intakes, canals, aqueducts)
  - Critical infrastructure (fire and police stations, schools, hospitals, prisons, wastewater treatment plants, flood depots, evacuation routes)
- Ecosystems
  - Habitats
  - Preserves and wildlife areas
  - Protected areas
  - Planned restoration areas
  - Conservation easements

Chapter 3. Climate Stressors and Hazards in the Delta

3.1 Applying Global Climate Change Science

The global climate is experiencing rapid changes compared to the pace of natural variations observed throughout Earth's history. Widespread evidence now exists to demonstrate deviations in natural climate trends. Scientists have documented increases in atmospheric and oceanic temperatures, melting of glaciers, reduction of land ice sheets and snowpack, shifting rainfall patterns, intensification of storm events, and rising sea levels (Jay et al. 2018; US EPA 2016). Observations from across the State of California and the Delta confirm similar changes are also occurring at a local scale (Barnett et al. 2008; Williams et al. 2015) with earlier runoff, higher sea levels, and a greater frequency and intensity of extreme events (Fritze et al. 2011; Kunkel et al 2013; Pierce et al. 2013; Dettinger 2016; Dettinger et al. 2016). As the climate continues to evolve, similar effects are projected to intensify over the coming century (Jay et al 2018).

This chapter discusses primary and secondary climate stressors that will affect the Delta in the coming century and reviews the best-available climate science for the Delta region. The assessment uses the Intergovernmental Panel on Climate Change's (IPCC) definition of stressors—events and trends that have an important effect on the system that can increase vulnerability to climate-related risk. The assessment focuses on the primary climate stressors of air temperature, sea level rise, and precipitation and the secondary stressors of wind and fog (Figure 3-1). This chapter also discusses potential physical hazards (extreme heat, flooding, drought, and wildfire) posed by these stressors to the ecosystem, people, infrastructure, water supply, flood risk management, and economy of the Delta region. These hazards are evaluated in Chapters 4 (Vulnerability Assessment Approach) and 5 (Vulnerability Assessment Findings).

Climate Stressors and Hazards

Stressor: an event or trend, often not climate-related, that has an important effect on the system exposed and can increase vulnerability to climate-related risk.

Hazard: the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. In this report, the term refers to climate-related physical events or their physical impacts.

Source: IPCC

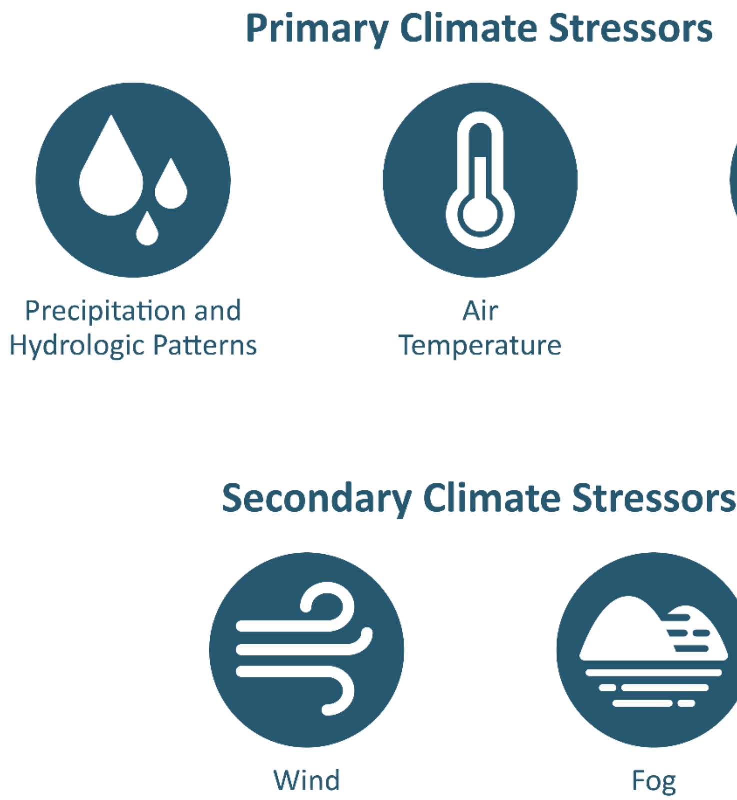

Figure 3-1. Primary and secondary climate stressors in the Delta

3.1.1 Interpreting Climate Change Projections

Changing climate conditions at the global and local scale are a result of the accumulation of heat-trapping greenhouse gases (GHG) in the atmosphere—primarily carbon dioxide, methane, nitrous oxide, and ozone. Future atmospheric concentrations of GHGs could follow a range of pathways depending on a combination of natural (e.g., volcanic activity) and human (e.g., international and local efforts to limit or reduce emissions) influences. To project and plan for future climate conditions, the IPCC has developed a suite of possible trajectories, or scenarios, of atmospheric GHG concentrations, referred to as Representative Concentration Pathways (RCPs) (IPCC 2013). Each RCP represents future conditions that may be created by a combination of factors, including population, economic development, environmental changes, technology, and policy decisions that could influence GHG concentrations. Each RCP is defined in terms of the total "radiative forcing" at 2100, measured in Watts per square meter, and represents the net balance of incoming and outgoing energy in the Earth-atmosphere system due to the heat trapping effects of factors such as atmospheric GHG concentrations. For the purposes of the CCVA, climate conditions corresponding to multiple RCPs are considered in order to evaluate a range of potential future climate conditions and the vulnerabilities that may arise in the Delta under each future scenario.

Two RCPs (RCP 8.5 and RCP 4.5) are considered in the CCVA to represent a range of potential climate conditions that may occur over the next century (Figure 3-2). The higher of the two (RCP

8.5), sometimes referred to as a "business-as-usual" scenario and the trajectory we are currently trending towards, represents rapid economic growth with little effort to limit or reduce emissions, reaching atmospheric GHG concentrations exceeding 900 parts per million (ppm) by 2100. RCP 4.5 represents a more moderate scenario, with atmospheric GHG concentrations increasing through mid-century, reaching a concentration of 550 ppm, followed by stabilization (Van Vuuren et al. 2011). While climate projections for both RCPs are reported in this chapter, in general, the hazard assessment in the CCVA (e.g., extreme heat and flooding) focuses on RCP 8.5 because it most closely resembles current emissions trends and presents a more precautionary approach.

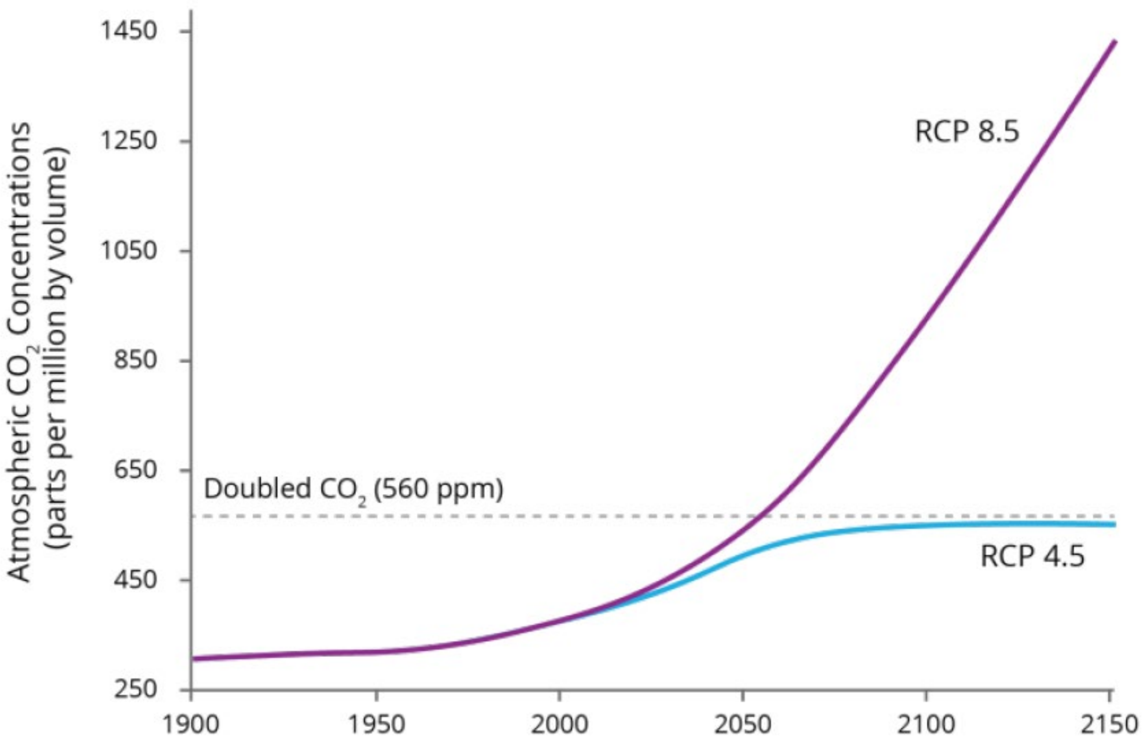

Figure 3-2. Emission of carbon dioxide under the RCP 4.5 and 8.5 scenarios

Source: Modified from van Vuuren et al. (2011)

Each RCP is used as input for General Circulation Models (GCM) (sometimes called global climate models – see callout box below) to assess the influence of increases in radiative forcing on climate variables such as temperature and precipitation. GCMs incorporate the inter-related physical processes of the atmosphere, ocean, and land to simulate the response of the climate system to changing conditions. The models are based on well-established physical principles and have been demonstrated to reproduce observed changes of past climate, providing confidence that they may be useful in understanding future climate as well.

Use of downscaled climate data in vulnerability assessments. GCMs provide estimates of future climate conditions at a spatial resolution that is typically too coarse for detailed vulnerability assessments. Multiple approaches have been used to address this issue and provide more detailed and place-based projections at the regional and local level. One common approach is to "downscale" GCM model output using detailed observed information and statistical techniques. For the Delta region, GCM simulations have been downscaled using a statistical technique called Localized Constructed Analogs (LOCA) (Pierce et al. 2014). This approach relies on quantitative relationships between large-scale climate stressors and local conditions. Coarse-scale (200 kilometer resolution) GCM projections of climate variables (e.g., precipitation, temperature) and fine-scale (six kilometer resolution) physiographical and meteorological features (e.g., topography land use, temperature, and precipitation) are input into a statistical model to estimate the corresponding local changes in climate characteristics (Figure 3-3).

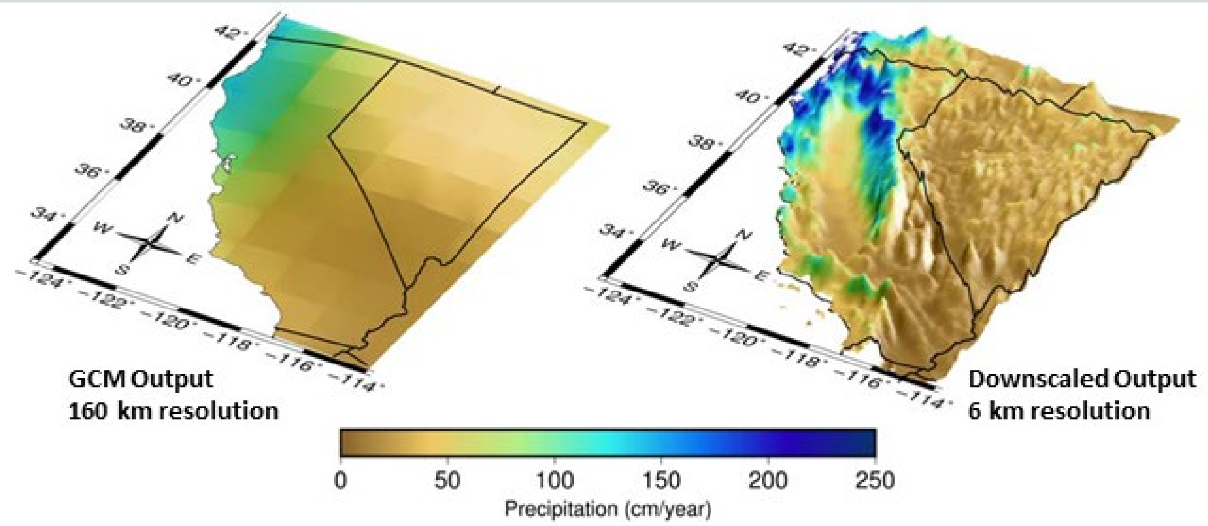

Figure 3-3. Example GCM output resolution and downscaled climate data analysis

Source: modified from Pierce et al. 2018

While downscaled climate model data can provide inputs for vulnerability assessments, planners and decision makers often struggle with the selection of projections/scenarios and their associated likelihoods due to the large uncertainty and sensitivity to modeling and analysis assumptions. One approach that addresses this dilemma is "decision scaling", which evaluates the performance of a system (such as a water supply system) by stress testing the system to better understand its sensitivities to changes in key climate stressors (such as temperature or precipitation) (Brown et al. 2019). A probabilistic framework is then applied to characterize the climate information and better inform decision making in the face of uncertainty. This CCVA uses LOCA downscaled climate change projections and applies sensitivity analyses and decision scaling-based approaches to develop and present findings in ways that may resonate better with the diverse stakeholders who seek to understand potential future climate impacts in the Delta.

3.1.2 State Climate Change Guidance and Resources

California has developed a series of guidance documents and studies to enhance the understanding of climate change impacts on a regional scale and directly inform vulnerability assessments and adaptation strategies. To the extent possible, the CCVA relies on and adopts these state-published resources and datasets as best-available science for the assessment. Table 3-1 summarizes state resources used for assessment of climate stressors in the Delta area.

Table 3-1. State of California Climate Change Guidance and Resources

Study/Date	Summary
California's Fourth Climate Change Assessment and Regional Reports (Ackerly et al. 2018; Houlton and Lund 2018; Westerling et al. 2018; Schwarz et al. 2018; Wang et al. 2018)	The assessment summarizes academic and technical reports discussing climate change projections for a suite of climate stressors, including temperature, sea levels, snowpack, annual precipitation, precipitation intensity, frequency of drought, frequency and intensity of Santa Ana winds, marine layer clouds, and wildfire. Potential impacts also are described for a variety of sectors (e.g., land use and development, biodiversity and ecosystems, water supply, forest health, transportation, and public health). Regional reports for the Sacramento Valley, San Joaquin Valley, and the San Francisco Bay Area include the Delta region, emphasizing specific effects and potential adaptation options.
Ocean Protection Council Sea Level Rise Guidance Update (OPC 2018)	This guidance update compiles, reviews, and summarizes the latest research on sea level rise and presents the latest peer-reviewed projections of sea level rise, describes an extreme scenario for sea level rise caused by rapid ice sheet loss from the West Antarctica ice sheet, and presents scenario selections using a risk-based (probabilistic) approach. The guidance also provides recommendations to state agencies on preferred approaches to planning and adaptation for vulnerable assets, natural habitats, and public access.
Cal-Adapt (https://cal-adapt.org)	To satisfy a key recommendation of the 2009 California Climate Adaptation Strategy, Cal-Adapt was developed to provide an interactive geospatial tool for localized climate projections in California. The tool allows users to explore projected changes in temperature, extreme heat, precipitation, snowpack, wildfire, and sea level rise across the state, based on a variety of climate models and future emission scenarios. The updated version of the tool, Cal-Adapt 2.0, also includes high-resolution, local climate projections, using LOCA downscaling methods and emission

Study/Date	Summary
	scenarios that align with the Intergovernmental Panel on Climate Change's Fifth Assessment Report.
Paying it Forward: The Path Toward Climate-Safe Infrastructure in California (CSIWG 2018)	This report responds to AB 2800, which is intended to make California communities safer. The report highlights the findings of a state-convened panel of scientists, engineers, and architects to help the State of California understand how it can best incorporate climate information into infrastructure planning, design, and implementation. The report outlines an action-oriented approach to move from vision to implementation and provides recommendations to create climate-safe infrastructure investments that will decrease the overall infrastructure risk of failure regardless of future climate conditions.
Planning and Investing for a Resilient California: A Guidebook for State Agencies (OPR 2017)	The California Governor's Office of Planning and Research (OPR) developed this document in response to Executive Order B-30-15, which requires each agency to prioritize adaptation actions, prioritize natural infrastructure approaches, and protect the state's most vulnerable populations. The guidance assists state agencies with meeting these requirements by providing a process for determining how to integrate climate considerations into state planning and investment decisions. The guidance introduces climate hazards, common practices for analyzing risk, and principles to guide decision making in the context of climate change, social equity, and community resilience.
30 by 30: Innovative Strategies to Use California Land to Fight Climate Change, Conserve Biodiversity and Boost Climate Resilience (Executive Order N-82-20)	This Executive order directs state agencies to establish strategies to store carbon in the state's natural and working lands and remove it from the atmosphere. The order also sets a first-in-the-nation goal to conserve 30 percent of the state's land and coastal water by 2030 to fight species loss and ecosystem destruction. Specifically, state agencies are directed to pursue innovative actions, strategies and partnerships to maximize the full climate benefits of our natural and working land, through: • Healthy soils management, including planting cover crops, hedgerows and compost applications; • Wetlands restoration to protect coastal areas; • Active forest management to reduce catastrophic risk and restore forest health; and • Boosting green infrastructure in urban areas like trees and parks.

3.2 Primary Stressors

With a variety of microclimates, variable rainfall, dependency on snow-fed mountain water supply, and an extensive length of leveed riverbanks and shorelines, the physical climate of the Delta will be affected by climate change in complex ways. This section examines recent historical trends of observed changes in the primary climate stressors of air temperature, sea level rise, and precipitation and hydrologic patterns and projected changes across the 21st century.

3.2.1 Air Temperature

Warming due to climate change will affect average annual and seasonal temperatures as well as extreme temperatures during extreme heat events and heat waves. Projected changes to average temperature (Section 3.2.1.1) and extreme heat (Section 3.2.1.2) are discussed below.

3.2.1.1 Average Temperature

Like most of California, the Delta is characterized by a mild, Mediterranean climate, defined by cool, wet winters and dry, hot summers. Air temperature variability in the Delta is strongly influenced by its proximity to the San Francisco Bay, with seasonal air temperature ranges dampened by cool afternoon sea breezes (Lebassi et al. 2009). Despite the buffered temperature regimes, the Delta commonly experiences summer heat waves (i.e., four consecutive days of extreme heat conditions with temperatures over the 98th percentile of historical summer daily maximums; Cal-Adapt 2017). Local temperature variations that currently exist in the Delta and Suisun Marsh will persist and likely become amplified in the future. Sub-regional climate regime differences will be impacted by warming – lower elevation regions are projected to warm more slowly than those at higher elevation and locations further inland (Dettinger et al. 2016; Lebassi at al. 2009; Wang et al. 2014). The Suisun Marsh is and will remain cooler than the rest of the Delta, and the north Delta will be cooler than the South Delta (current average annual maximum temperatures: Suisun Marsh 72.9°F, Yolo Bypass 74.2°F, and Stockton 74.5°F; DSC 2018a).

Change in air temperature is a key indicator of climate change and typically responds directly to cumulative GHG concentrations in the atmosphere. Across California, present-day temperatures (1986-2016) are warmer than observations from the early 20th century (1901-1960). The change in annual temperature has exceeded 1°F in most parts of the state with some areas exceeding 2°F. To put this temperature increase into context, Sacramento has an average annual maximum temperature of 77.8°F, whereas, Fresno, California currently has an average annual maximum temperature of 79.7°F (Cal-Adapt 2017). By the end of the century, Sacramento is projected to have summer temperatures that are more in line with those of current day Tucson, Arizona (99.6°F as opposed to current Sacramento summertime temperatures of 91.5°F; Climate Central 2020).

Nearly all GCMs indicate that temperatures will continue to increase through the end of this century. By the end of the century, models indicate that average daily maximum temperatures in the Delta could increase by 5.1°F (RCP 4.5) to 8.1°F (RCP 8.5) relative to historical temperatures (Bedsworth et al. 2018). Table 3-2 shows projected average daily maximum temperatures for mid-century and end-of-century conditions for the Delta based on analysis of downscaled temperature data from 10 GCMs available on Cal-Adapt. Similar trends exist for nighttime low temperatures with the average daily minimum temperature projected to increase by 4.9°F (RCP 4.5) to 8.2°F (RCP 8.5). This approximate equal rate of increase between average daily minimum and maximum temperatures in the Delta contrasts with the general trend of faster warming nighttime temperatures in other parts of the country.

Table 3-2. Projected Changes in Average Daily Maximum Temperature for the Delta and Suisun Marsh

Time Horizon	Emission Scenario: RCP 4.5	Emission Scenario: RCP 8.5
Historical (1961-1990)	73.8°F	73.8°F
Mid-Century Model Average (2035-2064)	+3.9°F	+4.9°F
Mid-Century Model Range (Min, Max)	+3.2°F to +4.8°F	+4.0°F to +5.8°F
End-of-Century Model Average (2070-2099)	+5.1°F	+8.1°F
End-of-Century Model Range (Min, Max)	+3.6°F to +6.3°F	+6.5°F to +9.6°F

Notes: Annual average values are calculated for each 30-year time period for 10 of the 32 LOCA downscaled GCMs under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt for the Delta and Suisun Marsh.

Although air temperatures are projected to increase across the Delta and the Delta watershed, localized effects based on variations in topography and proximity to the coast may cause spatial variations in projected temperature changes (Figure 3-4). Greater warming inland may enhance cooling Delta breezes and thereby partially offset temperature increases within the Delta and Suisun Marsh. Within the broader Central Valley, the annual average maximum daily temperature by 2100 is projected to warm by about 2.0°F more than the warming expected to occur in the Delta and Suisun Marsh (Cal-Adapt), reinforcing the regional importance of the Delta as a potential vegetation refugia under hotter/drier projected conditions in the future, which may also benefit fish and wildlife in the region (Thorne et al. 2020; see Section 5.3 for additional discussion).

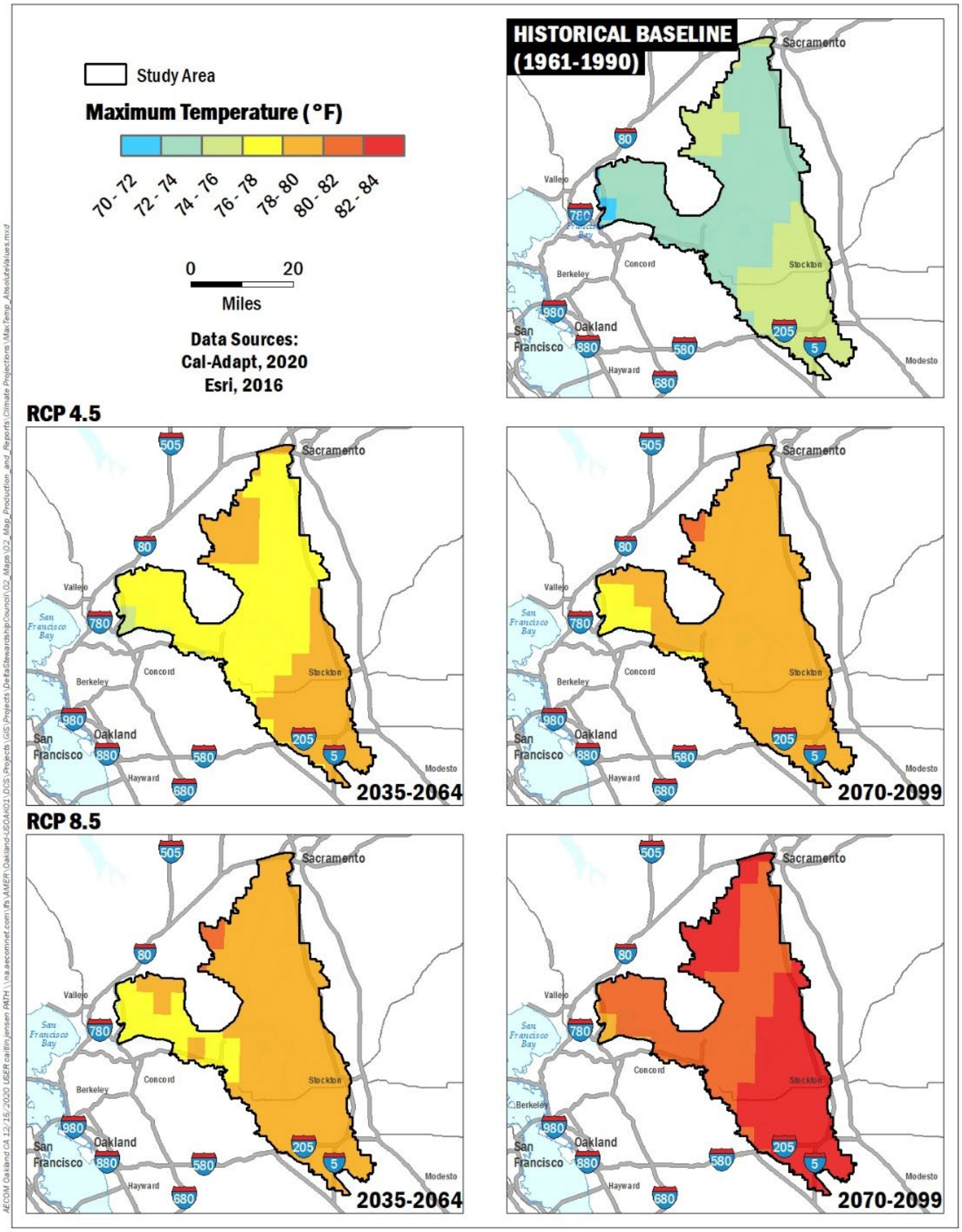

Figure 3-4. Spatial variability of projected changes in absolute average daily maximum temperature in the Delta

Note: Annual average maximum values are calculated for each 30-year time period for 10 of the 32 LOCA downscaled GCMs under RCP 4.5 (middle images) and RCP 8.5 (bottom images) using data obtained from Cal-Adapt.

This trend of rising air temperatures also extends to the Sierra Nevada east of the Delta, which includes the snowy portions of the Sacramento and San Joaquin watersheds. Temperatures in the Sierra Nevada mountains are projected to rise by 1.8°F by 2025, between 3.6°F and 4.5°F by 2055; and between 6.3°F and 7.2°F by 2085 (Dettinger et al. 2016). In addition, the watersheds that feed the Delta stretch east to the crest of the Sierra Nevada, north to Oregon and south to the San Joaquin Valley which can also experience significant heat events and can result in warm surface waters and increased fire risk in the Delta’s upland watersheds (Dettinger et al. 2016). Rising air temperatures in the Sierra Nevada mountains will have a large influence on the Delta, increasing the portion of precipitation that falls as rain instead of snow, which in turn will impact peak runoff events, snowpack volumes, and spring melt timing (Dettinger et al. 2016). Changes in snowpack and snowpack runoff will also have substantial impacts on reservoir storage and Delta water supply. See Section 3.2.3 for more information on precipitation and hydrologic patterns in the Delta and the Delta watershed; see Section 5.4 and the Water Supply Technical Memorandum for more information about water supply impacts.

3.2.1.2 Extreme Heat

An increase in average annual temperatures within the Delta also affects extreme heat conditions. For much of California, climate models project an increase in the magnitude and frequency of extreme heat events. Extreme heat days are defined by temperatures that exceed the 98th percentile of observed historical temperatures for a local area. For much of the Delta, the 98th percentile temperature corresponds to days with temperatures in excess of 100 degrees. Over the latter half of the 20th century, the Delta experienced approximately 4 or 5 extreme heat days per year on average. By mid-century, the number of extreme heat days in the Delta is projected to increase to approximately 22 days per year on average for a high emissions scenario (RCP 8.5). By end-of-century, the number of extreme heat days in the Delta is projected to increase to approximately 24 to 41 days per year on average, depending on future emissions (Table 3-3; Cal-Adapt 2017). Some portions of the Delta – particularly Yolo and San Joaquin Counties – may see even greater numbers of extreme heat days each year due to spatial variations in extreme heat patterns across the Delta (Table 3-3). The projected increase in the number of extreme heat days relative to historical conditions will strain Delta communities, residents, businesses, and infrastructure. Extreme heat impacts to Delta residents and communities are discussed in Section 5.2.1.

Table 3-3. Projected Average Number of Extreme Heat Days Each Year in the Delta

Planning Horizon	Emission Scenario: RCP 4.5	Emission Scenario: RCP 8.5
Historical (1961-1990)	4 to 5 days	4 to 5 days
Mid-Century (2035-2064)	13 to 23 days (Delta-wide average of 17 days)	16 to 29 days (Delta-wide average of 22 days)
End-of-Century (2070-2099)	17 to 31 days (Delta-wide average of 24 days)	28 to 53 days (Delta-wide average of 41 days)

Source: Cal-Adapt LOCA-derived extreme heat projections.

Note: Annual average values are calculated for each 30-year time period using LOCA downscaled GCM data for the four priority models identified in Cal-Adapt. Reported range at each planning horizon is due to the geographic variability in the occurrence of extreme heat events across the Delta. Averages represent Delta-wide average of extreme heat projections for Census blocks located within the Delta.

3.2.2 Sea Level Rise

Global sea level rise is primarily caused by thermal expansion of warming ocean water and melting of land ice as air temperatures increase. Recent research has also focused on potential large-scale ice sheet collapse in West Antarctica, which would rapidly raise ocean levels worldwide (DeConto et al. 2016; Oppenheimer, et al. 2016). Regional rates of sea level rise are variable, depending on vertical land motion (i.e., uplift and subsidence), winds, and large-scale ocean circulation patterns. Since its installation in the mid-1850s, the San Francisco tide station, located near the Golden Gate Bridge at the mouth of San Francisco Bay, has recorded an 8-inch increase in local sea levels over the past century, with other tide stations in the Bay Area showing comparable rates of sea level rise. Analysis of satellite altimetry data also indicates a recent acceleration of global sea level rise rates since 2011 (Nerem et al. 2018). This recent acceleration follows decades of suppressed sea level rise along the west coast of the United States (relative to rates of sea level rise elsewhere in the Pacific Ocean basin), which may be linked to variations in the Pacific Decadal Oscillation (PDO) (Bromirski et al. 2011). It is unclear how long this recent accelerated trend of sea level rise will continue, but near-term variations in local sea level will largely depend on patterns of shorter (e.g., El Niño Southern Oscillation) and longer (e.g., PDO) modes of Pacific climate variability.

Local sea level trends for the Delta region are further complicated by regional and local land subsidence. Decomposition of drained and converted marsh and peat soils within diked Delta islands have caused much of the Delta region to lie below sea level—in some places by as much as 15 to 20 feet (Deverel et al. 2020). Continued land subsidence may increase the relative rate of locally observed sea level change for the Delta area when comparing water levels to local land elevations.

Table 3-4 shows the State of California Sea Level Rise 2018 Guidance (OPC 2018) projections for the San Francisco tide station. The San Francisco tide station, although not located within the Delta, provides an ocean boundary that is considered representative of regional oceanic sea level conditions that will influence local sea level rise and peak water level response in the Delta. Response of daily and peak Delta water levels to sea level rise at the Golden Gate is discussed in Section 4.2. Based on the OPC Guidance, sea levels in the San Francisco Bay-Delta Estuary are likely (66% probability) to rise between 0.6 to 1.1 feet by 2050, with an upper range (1-in-200 chance) projection of 1.9 feet. By 2100, sea levels are likely to rise between 1.2 to 3.4 feet, with an upper range projection of 6.9 feet. The combination of extreme rates of ice-sheet loss and complex feedback mechanisms could result in sea level rise of up to 10.2 feet by the end of the century (OPC 2018). The OPC Guidance provides recommendations for selecting appropriate sea level rise scenarios for future planning. The range of values recommended for low, medium-high, and extreme risk aversion are identified in Table 3-4. Section 4.2 describes how the full range of potential sea level rise projections are considered in the CCVA flood hazard assessment, Section 4.4 describes how sea level rise projections are used in the ecosystem analysis, and Section 4.5 describes how sea level rise projections are used in the water supply analysis.

Table 3-4. Sea Level Rise Projections for the San Francisco Bay-Delta

		Median *50% probability sea level rise meets or exceeds*	Likely Range *66% probability sea level rise is between*	1-in-20 chance *5% probability sea level rise meets or exceeds*	1-in-200 chance *0.5% probability sea level rise meets or exceeds*	H++ Scenario *Extreme scenario not associated with a probability*
Emission Scenario	Year	N/A	Low-risk aversion	N/A	Medium-high risk aversion	Extreme risk aversion
RCP 8.5	2030	0.4	0.3 to 0.5	0.6	0.8	1.0
RCP 8.5	2050	0.9	0.6 to 1.1	1.4	1.9	2.7
RCP 4.5	2070	1.3	0.8 to 1.7	2.1	3.2	5.2
RCP 8.5	2070	1.4	1.0 to 1.9	2.3	3.5	5.2
RCP 4.5	2100	1.8	1.2 to 2.7	3.5	5.8	10.2
RCP 8.5	2100	2.5	1.7 to 3.4	4.4	6.9	10.2

Notes: Probabilistic projections are based on the Kopp et al. 2014 methodology. Projections are shown for the San Francisco tide station. California state guidance recommends using sea level rise projections for RCP 8.5 through 2050 due to the current emissions trajectory.

3.2.3 Precipitation and Hydrologic Patterns

Precipitation affects the Delta region at two primary geographic scales: local rainfall within the Delta (Section 3.2.3.1) and, to a larger extent, precipitation in the greater Sacramento-San Joaquin watersheds (Section 0). The majority of California precipitation occurs during the cooler and wetter months from October through April and most of the annual precipitation occurs during discrete storms or atmospheric river events, which can be separated by extended dry periods (Section 3.2.3.3). Precipitation in the Delta and the Delta watershed is highly variable year-to-year and the region is often characterized as one of the most dynamic in the country (Ackerly et al. 2018). This high interannual variability of precipitation in the region makes it difficult to detect a strong signal in recent data or future projections. Furthermore, precipitation is one of the least certain aspects of climate models, especially when applied at the regional level, because climate models do not resolve many of the fine-scale and complex interactions that occur locally – such as orographic intensification of precipitation in higher elevation areas and rain shadowing by the coast range.

3.2.3.1 Precipitation within the Delta

Precipitation trends vary considerably across the Delta. The Suisun Marsh and North Delta regions experience the greatest amounts of precipitation (22 inches/year on average), while the South Delta only receives 8 inches/year on average (Figure 3-5.).

Downscaled modeled precipitation results show a relatively small signal of average annual precipitation increasing by approximately 1.5 inches for RCP 4.5 and 3.0 inches for RCP 8.5 by end-of-century when compared to historical conditions in Suisun Marsh and the Delta (Figure 3-5.; Table 3-5). However, these changes are nearly imperceptible relative to the high interannual variability in Delta precipitation, characterized by a range of almost 50 inches in total rainfall between the driest and wettest years (Ackerly et al. 2018).

Table 3-5. Projected Changes in Annual Precipitation in the Delta

Planning Horizon	Emission Scenario: RCP 4.5	Emission Scenario: RCP 8.5
Historical (1961-1990)	15.0 inches	15.0 inches
Mid-Century Model Average (2035-2064)	15.6 inches	15.8 inches
Mid-Century Model Range (Min, Max)	-2.3 to +4.7 inches	-2.6 to +3.8 inches
End-of-Century Model Average (2070-2099)	15.8 inches	16.5 inches
End-of-Century Model Range (Min, Max)	-2.8 to +3.5 inches	-2.7 to +4.5 inches

Notes: Annual average values are calculated for each 30-year time period for 10 of the 32 LOCA downscaled GCMs under RCP 4.5 and RCP 8.5 emission scenarios using data obtained from Cal-Adapt.

Although annual precipitation trends show slight, but uncertain, increases across the Delta, localized effects due to topography and proximity to the coast cause spatial variations in projected trends (Figure 3-5.). The Suisun Marsh and North Delta are projected to experience the largest increases, particularly for end-of-century, while the Central and South Delta regions are projected to experience little to no change in precipitation.

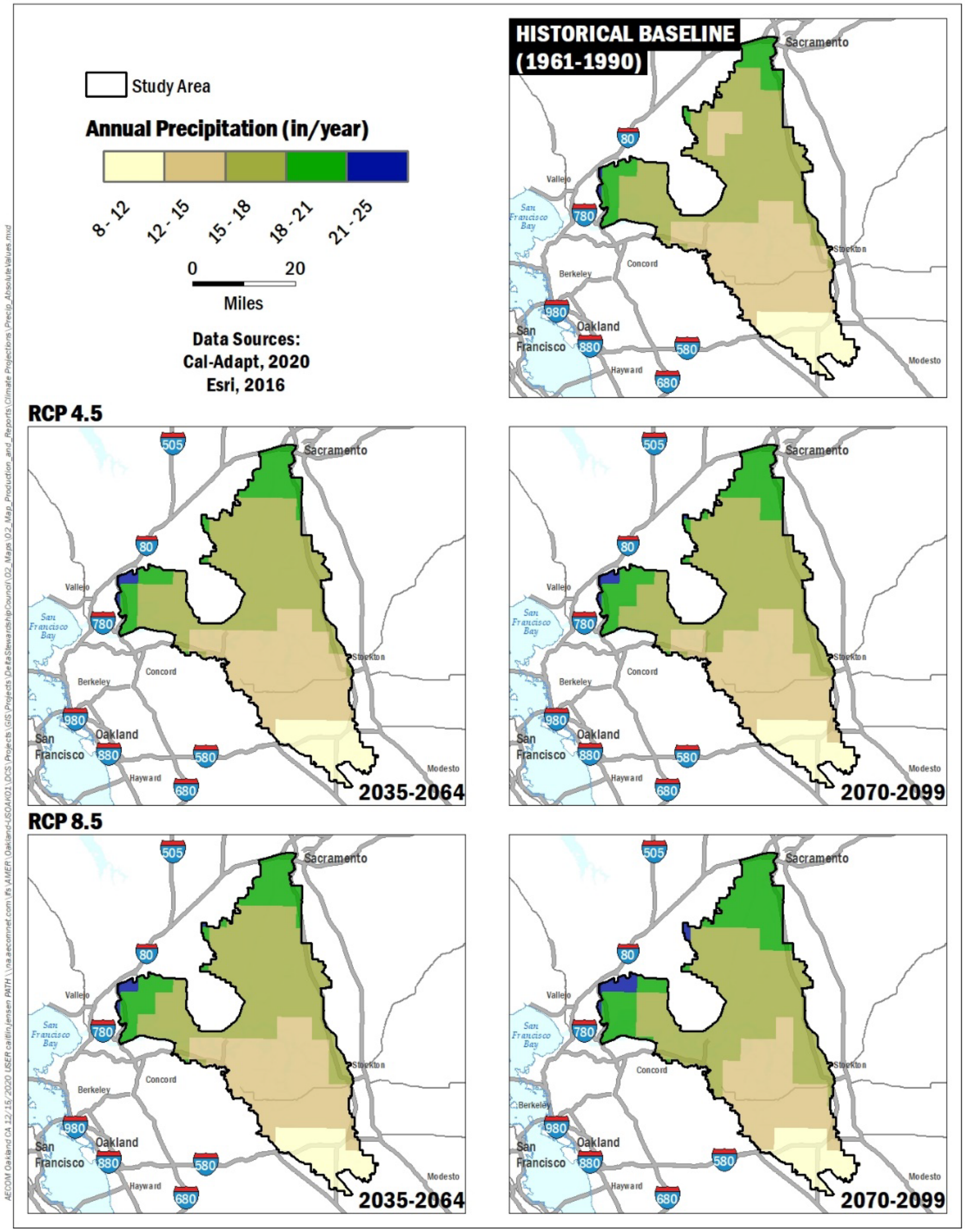

Figure 3-5. Spatial variability of projected changes in annual average precipitation in the Delta

Note: Annual average maximum values are calculated for each 30-year time period for 10 of the 32 LOCA downscaled GCMs under RCP 4.5 (middle images) and RCP 8.5 (bottom images) using data obtained from Cal-Adapt.

3.2.3.2 Delta Watershed Precipitation

The Delta's hydrology is predominately governed by precipitation and runoff within the broader Sacramento-San Joaquin watershed, which receives much of its precipitation in the form of snow in the Sierra Nevada (DSC 2018a). Small changes in average annual precipitation, particularly throughout the Delta watershed as opposed to within the Delta, may mask more significant changes in interannual precipitation variability that have significant implications for flood risk and water supply. The water supply analysis (Section 4.5 and Water Supply Technical Memorandum) evaluates the impacts to both the change in average precipitation and changes in the variability of precipitation, and the flood risk analysis (Section 4.2) evaluates changes in peak water levels as a result of changes in Delta watershed hydrology. Although average annual total precipitation amounts are not expected to change significantly across the Sierra Nevada range, interannual variability may increase and warming air temperatures are projected to cause a higher portion of precipitation to fall as rain rather than snow, thereby decreasing the annual snowpack and increasing the frequency and intensity of higher runoff events into the Delta (Dettinger et al. 2018). Observations from the last decade already exhibit a downward trend in the northern Sierra's snow fraction that may be caused by anomalous increases in Pacific sea surface temperatures (Hatchett et al. 2017). These findings foreshadow the continued shift from snow to rain that is likely with climate change.

Water storage in the form of mountain snowpack is important for the Delta region, as it serves as a natural reservoir to alleviate seasonal fluctuations in rainfall. Warming temperatures will likely shift the timing and volume of snowmelt to earlier in the spring, which could decrease the watershed's stream flows during the dry summer and fall months (Bedsworth et al. 2018; Ackerly et al. 2018; Schwartz and Hall 2017). Since this early season runoff cannot be captured in reservoirs due to flood management operations, this extra runoff will be released in winter and early spring and not be available to help meet summer and fall water demands (Wang et al. 2018, Schwarz et al. 2018).

With or without a change in average annual precipitation, a warming climate will likely have large implications for the region's hydrological patterns, water supply, and flood risk. A large portion of California's annual precipitation falls over a small number of wet days. Climate models suggest that this characteristic of California's hydrology will be amplified by climate change, with the wettest days contributing an even larger portion of annual precipitation in the future (Dettinger 2016) (see Section 3.2.3.3).

3.2.3.3 Extreme Precipitation

There is growing evidence that the frequency and intensity of precipitation extremes will increase in a warming climate, even where projected changes in mean precipitation are minimal and/or uncertain (Dettinger et al. 2016). In addition, the occurrence of extreme wet and extreme dry conditions and drastic transitions between the two – referred to as "climate whiplash" – may increase (Swain et al. 2018; see callout box). Precipitation extremes in the Delta and the Delta watershed are dominated by atmospheric river events, which transport large quantities of water vapor and cause extreme precipitation in the high elevation watersheds of the Delta due to orographic effects. Atmospheric rivers are responsible for up to half of the state's annual precipitation and account for more than 80% of flood damages, including levee breaches in the Delta (Corringham et al. 2019; Florsheim and Dettinger 2015). Studies have demonstrated a link between increasing intensity of atmospheric rivers along with warmer air and sea surface temperatures, which support greater atmospheric moisture and wetter, longer, and wider atmospheric rivers that can lead to higher precipitation rates (Dettinger et al. 2018). Models also indicate that the number of atmospheric rivers making landfall in California may increase and the peak season in which most atmospheric river events occur is projected to lengthen in the future (Dettinger et al. 2011). The outsized effect of atmospheric river events on precipitation and streamflow may be exacerbated by a warming climate, as a higher portion of mountain precipitation falls as rain instead of snow. In cases where atmospheric rivers deliver substantial rain in watersheds with ripe snowpacks (i.e., close to the melting point), substantial increases in peak streamflow and inflow to the Delta could result (Davenport et al. 2020). Increases in local precipitation intensity in developed urban areas may also increase flood risk, especially for local streams and stormwater systems that discharge to tidally influenced areas where higher water levels due to sea level rise may impede drainage or back-up into storm drain systems.

Climate Whiplash

Recent research has examined the potential for hydrological cycle intensification as a result of climate change. This so-called "climate whiplash" refers to rapid transitions from extreme dry to extreme wet conditions (Swain et al. 2018). While future projections of California's precipitation indicate fairly small to modest increases in average annual precipitation, the occurrence of extreme wet and extreme dry conditions and drastic transitions between the two may increase, as follows (Swain et al. 2018):

- Increase in the frequency of very wet rainy seasons (similar to 2016-2017) that historically have occurred about four times per century. These events may become about 2.5 times more frequent by 2100.
- Increase in the frequency of very dry rainy seasons (similar to 1976-1977) that historically occurred about once per century. These events may become about twice as frequent by 2100.
- Increase in the likelihood of extreme prolonged precipitation events (similar to the Great Flood of 1862). These events may become about five times more frequent by 2100.
- Increase in the frequency of "precipitation whiplash" events. These events may be about 25% more frequent by 2100.

Analysis of future Delta watershed hydrology conducted as part of the Central Valley Flood Protection Plan (CVFPP) found that Sacramento River watersheds may experience increases in 100-year inflows of 10 to 30% (average of projections across watershed). High elevation San Joaquin River watersheds may experience increases in 100-year inflows of 60 to 70% (average of projections across watershed; DWR 2017). Analysis of future conditions streamflow prepared by the U.S. Geological Survey (USGS) as part of the CASCaDE project and analyzed in the CCVA (see

Section 4.2) suggest that peak inflows to the Delta, across the six major tributaries to the Delta, may increase by approximately 45% by mid-century and by 80% by end-of-century. As warmer storms produce more rainfall in higher elevation watersheds in the southern Sierra Nevada, relatively large increases in the frequency and magnitude of high discharge events on the San Joaquin River may occur. Higher streamflows in the Sacramento and San Joaquin Rivers will increase the frequency and magnitude of high inflow events to the Delta. These high inflow events, combined with higher Bay water levels due to sea level rise, will increase the frequency and magnitude of peak water level events in the Delta compared to historical conditions. The CVFPP and USGS projections represent the best-available science regarding information about future regulated runoff behavior across the Delta watershed. However, it should be noted that this is still an area of active research and the methods have limitations that may over- or underestimate the actual future changes.

3.3 Secondary Stressors

Secondary climate stressors are variables indirectly affected by the complex interactions between primary climate stressors (e.g., temperature, precipitation, sea level rise) and other physical factors in the environment. This section summarizes recent historical trends of observed changes in the secondary climate stressors of wind and fog and projected changes in the 21st century. While these stressors may exacerbate, or be exacerbated by, primary climate drivers, Delta Adapts does not explicitly evaluate their impact on Delta resources.

3.3.1 Wind

California's climate is dominated by complex large-scale atmospheric and oceanic features, including the coastal ocean and continental weather patterns. Small changes in these features can create large variations in the Delta's climate and associated weather patterns.

The Central Valley of California is surrounded by continuous mountain ranges—Klamath to the northwest, Cascades to the northeast, Sierra Nevada to the east, and the Coastal Range to the west. Low elevation inlets from the ocean into the Sacramento Valley allow for a channeling of cool, marine airflow, which passes through the Golden Gate Gap—a passage from the San Francisco Bay east into the Delta. Once this cool air enters the Delta, it splits north to the Sacramento Valley and south to the San Joaquin Valley, resulting in enhanced daytime onshore winds caused by the temperature differential between the cool coastal air and warm inland valley areas. The reverse process occurs in the evenings with offshore land-breezes originating inland due to the land cooling faster than the sea (Lebassi et al. 2009).

Studies indicate that projected warming of summer air temperatures in the inland valleys may produce enhanced cool-air sea breeze activity due to a larger temperature gradient across the land-sea interface. This enhanced wind effect may have the ability to offset localized summer temperatures in the Delta (Lebassi et al. 2009).

3.3.2 Fog

Tule fog, named after the tule wetlands, is a dense ground fog that commonly forms in the Delta and Central Valley area from late fall through early spring when temperatures are sustained around 44 degrees (F). Fog formation occurs on calm nights typically following a rain event when there is relatively high humidity. Once formed, the fog creates a microclimate of cooler local temperatures, known as winter chill, by shielding the ground from incoming solar radiation. This phenomenon is of significance to the region's fruit and nut agricultural industry, which accounts for 95% of U.S. production, as "winter chill" conditions are necessary to achieve dormancy during the winter months (Baldocchi and Waller 2014) (see Section 0 and Crop Yield and Agricultural Production Technical Memorandum.

Fog formation is highly variable from year to year due to the required complex meteorological conditions. Drought years (e.g., 1990-1991 and 2012-2013) tend to have the lowest number of fog days due to limited moisture available to condense from the air. Similarly, extremely wet years also have a limited number of fog days because there are few cold and clear nights when the fog can form (Baldocchi and Waller 2014).

Although characterized by interannual variability, fog frequency has experienced dramatic changes over the past century, increasing by 80% from 1930 to 1970 followed by a 75% decrease since 1980. The cause for this decline is an area of active research, but air pollution has been found to be a primary driver of long-term trends in fog frequency. Particulates associated with poor air quality provide a nucleus for fog to form. Paralleling the fog frequency trends, air pollution increased in the Central Valley through 1970 prior to the emission regulations of the Clean Air Act, then decreased since 1980 due to the introduction of air pollution control measures (Gray et al. 2019). Studies also indicate that climate variables, such as increasing air temperatures, are also found to affect short-term (annual) variability in fog frequency (Baldocchi and Waller 2014; Gray et al. 2019). Warming air temperatures due to climate change, decreasing emissions and pollution, and decarbonization of California's energy and transport sectors will result in continued improvements in air quality, which may continue the decreasing trend of fog frequency in the future.

3.4 Climate Hazards

As the accumulation of GHGs in the atmosphere continues to exert a large-scale influence on top of natural variations of climate stressors, these climate changes will interact with human systems, which are currently based around a narrow range of historical and existing climate conditions. As *climate stressors* begin to negatively impact human health, livelihoods, the economy, valued ecosystems, infrastructure, and environmental resources, they transform to *climate hazards* that are associated with a range of physical and social impacts.

Climate hazards are complex and result from the interactions between multiple climate stressors. For example, a flood hazard experienced in a low-lying coastal community may be attributed to the compounding effects of increases in extreme precipitation, intensifying coastal storms, and sea level rise. Figure 3-6. shows the relationship between the primary climate stressors discussed above and the resultant climate hazards that are evaluated in the CCVA.

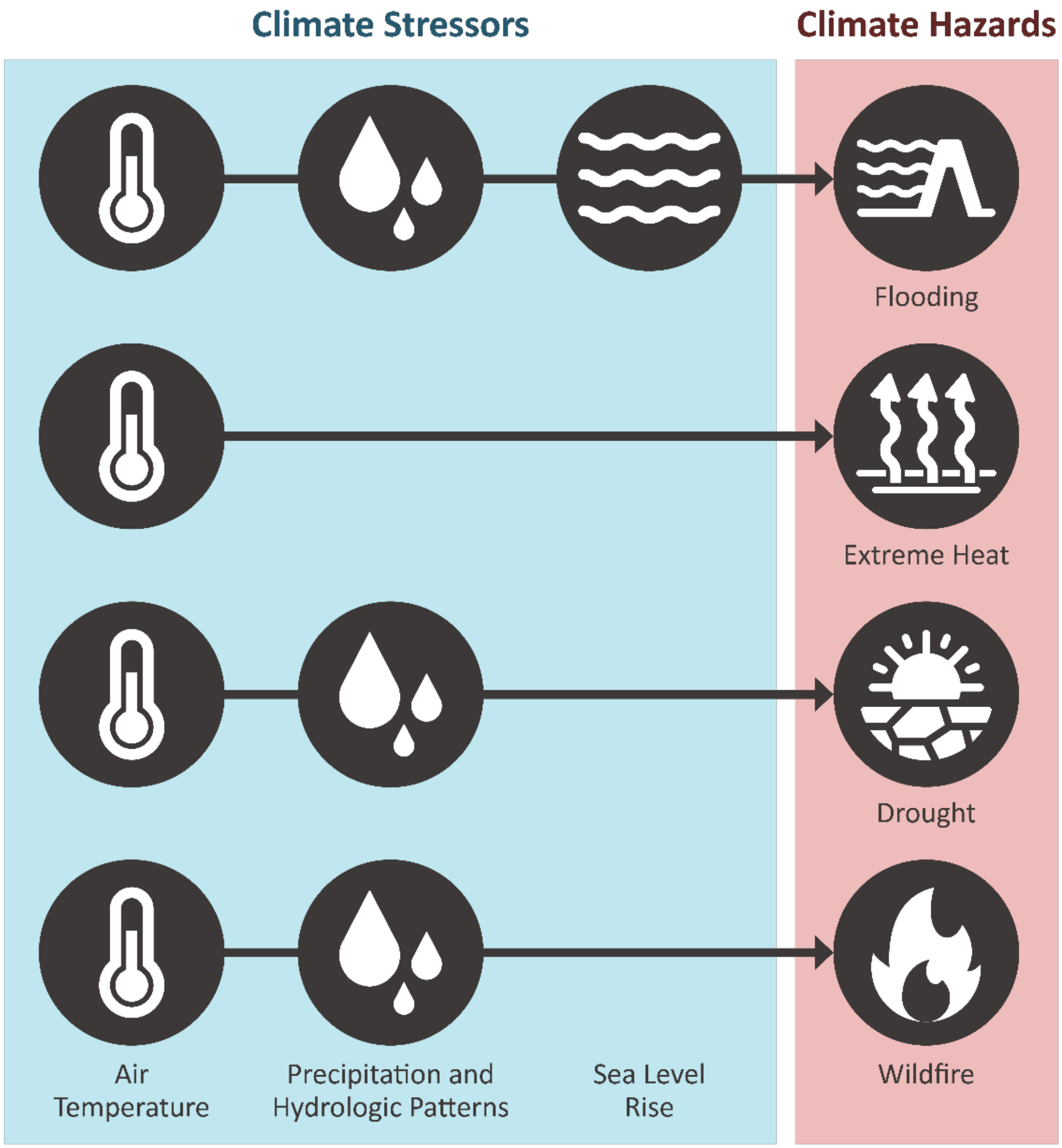

Figure 3-6. Relationship between climate stressors and hazards evaluated in the Delta climate change vulnerability assessment

The CCVA evaluates climate hazards to the Delta's people, assets, and resources. Four climate hazards, directly influenced by the primary climate stressors described in Section 3.2 and 3.3, are identified as having increasing impacts to the Delta: flooding, heat, drought, and wildfire. Descriptions of these four hazards are provided in Table 3-6.

Table 3-6. Description of Delta Climate Hazards Considered in the CCVA

Climate Hazard	Contributing Climate Stressors	Description of Hazard and Potential Impacts
Flooding	Sea level rise, precipitation and hydrologic patterns, air temperature	Flooding in the Delta may result from the combination of high tides, sea level rise, changes in precipitation and hydrologic patterns, warming temperatures in the Delta's watershed, and an increase in the frequency and magnitude of intense precipitation events. Depending on location within the Delta, high riverine inflows, elevated Bay water levels driven by a combination of sea level rise, storm surge, and tide, or both can lead to overtopping or other levee failures resulting in flooding of Delta islands and low-lying areas. Potential impacts of flooding include impairment of physical infrastructure, displacement of residents, drowned habitats, and damaged agricultural crops. Assessment of future flood hazards is presented in Section 4.2 (Flooding), and flood hazard impacts to Delta people, assets, and resources are presented in Chapter 5.
Extreme Heat	Air temperature	The Delta will experience both an increase in average air temperatures and more frequent and severe extreme heat events. Increases in average temperatures and the frequency and duration of extreme heat events can cause risks to human health, affect water demand and quality, and may stress ecosystems, agricultural productivity, energy demands, and physical infrastructure. Assessment of future extreme heat hazards is presented in Section 3.4 (Extreme Heat), and extreme heat impacts to Delta assets and resources are presented in Chapter 5.
Drought	Air temperature, precipitation and hydrologic patterns, sea level rise	Drought has no standard definition, but usually refers to episodic occurrences of prolonged below average rainfall, streamflow, or water supply. Because of the Delta's unique position draining nearly 50 percent of the state's land, nearly all the state's snowpack, and as a tidal estuary that serves as a hub of California water supply, it can experience drought in a number of ways. When droughts occur, they affect agricultural productivity, water supply,

		and ecosystems. A warming climate, reduction in snowpack, changes in the timing of spring snowmelt, and increased reservoir releases to counter salinity intrusion will all contribute to increased severity and frequency of drought in the future. Assessment of future drought and water supply impacts is presented in Section 4.5, Section 5.4, and the Economic Assessment Technical Memorandum.
Wildfire	Air temperature, precipitation and hydrologic patterns	Wildfire frequency and severity throughout California are expected to increase in the future as a result of increased temperatures and atmospheric aridity (Williams et al. 2019), more frequent and severe droughts, and altered precipitation patterns. Wildfires will primarily impact the Delta by reducing local air quality caused by smoke from remote fires in other parts of the state. Wildfires occurring within the Delta watershed will also affect potential sediment loads due to the denuding of slopes and increased erosion following fire events, which could affect Delta ecosystems and water quality. Wildfire impacts on air quality and Delta residents and workers are presented in Section 5.2.1.

CHAPTER 4. VULNERABILITY ASSESSMENT APPROACH

4.1 Assessment Framework

This vulnerability assessment provides insight into the varied effects that future climate conditions pose for the Delta's people, places, ecosystems, infrastructure, and services (assets and resources). It also presents information describing the potential timing, extent, and consequences of climate stressor and hazard impacts. Overall, the CCVA identifies Delta populations, assets, resources and systems (such as water supply) that are most vulnerable to climate change and will inform development of strategies that integrate climate considerations into Delta planning, policies, and ongoing operations. This section describes the overall approach to assessing Delta-wide climate vulnerability, expressed in terms of *exposure*, *sensitivity*, and *adaptative capacity* (see callout box). Refinements to this approach for specific asset types and systems are described in Sections 4.2 through 4.6. Chapter 5 presents high level risk considerations (i.e., consequences) and summarizes the potential consequences that could occur due to exposure to climate hazards. Each component of vulnerability and risk considered in the assessment is described below.

Key Vulnerability Terms

- **Exposure** – signifies the assets, populations, or resources that are within locations most likely to experience climate hazard impacts
- **Sensitivity** – describes characteristics that make an asset or population susceptible to harm from climate hazards
- **Adaptive Capacity** – an asset or population's ability to adjust to changing climate conditions and moderate potential damages in order to maintain functionality or well-being
- **Vulnerability** – describes the how and why assets, populations, or resources can be expected to be affected by climate hazards
- **Consequence** – illustrates the extent of potential impacts or losses that could occur for the asset, population, or greater region if exposure to hazard occurs

4.1.1 Exposure

Exposure describes the degree to which a population, asset, or resource is located in an area that may be impacted by a climate stressor or hazard. While the exposure assessment provides information about when a climate stressor or hazard may begin to affect an asset, it does not provide information about the degree to which the asset will experience damage or loss, as it does not consider site specific conditions (e.g., flood-proofed buildings, well-insulated and air-conditioned homes) that may prevent or limit impacts.

The Delta Adapts team assessed exposure for current conditions and at two future time horizons: mid-century and end-of-century. The projections for climate stressors at these two future periods and the scientific background of these projections are described in Chapter 3.

The exposure assessment evaluates the following climate hazards posed to Delta people, assets, and resources:

- Flooding – Both coastal and riverine flood hazards are analyzed to estimate peak water levels projected to occur through the end of the century. These water levels are used to map potential flood extents, as described in Section 4.2.2, which are overlaid onto Delta asset locations to assess their likelihood of exposure (Section 4.3).
- Extreme Heat – Extreme heat projections obtained from Cal-Adapt are analyzed to project changes in the intensity and duration of extreme heat events across the Delta. For most asset categories, exposure to extreme heat is assessed uniformly across the Delta. However, the localized effects of urban heat islands are considered for population impacts, as discussed in Section 5.2.1.
- Other Climate Impacts (e.g., wildfire, drought, etc.) – Wildfires will primarily impact the Delta through a reduction in local air quality caused by smoke from remote fires in other parts of the state. Exposure for all assets is considered qualitatively with poor air quality impacts assumed to be equally distributed across the Delta.

  Droughts are evaluated from the perspective of water supply reliability (Section 4.5) and Delta ecosystems (Section 4.4). To understand future drought conditions, the drought analysis considers event severity and frequency using past conditions as a proxy for future drought events (see the Water Supply Technical Memorandum for additional detail). Exposure of the Delta's water supply system is assessed quantitatively in terms of resulting reductions in water supply reliability. Exposure of the Delta's ecosystems is assessed qualitatively with drought conditions assumed to be uniform across the Delta.

In addition to evaluating exposure to climate hazards, some Delta assets and resources (e.g., agriculture, ecosystems [Section 4.4], and water supply reliability [Section 4.5]) are assessed for exposure and impacts related to chronic changes in primary climate stressors:

- Air temperature – For the ecosystems and agriculture assessments, increases in average daily maximum and seasonal temperatures from Cal-Adapt are tabulated for the project area and used to assess exposure of ecosystem types and agricultural crops to climate change-related air temperature changes. For the water supply reliability and the flood risk analyses, air temperature changes in the Delta's watersheds are considered for how they may change snowpack accumulation and runoff patterns.
- Precipitation – For the ecosystems and agriculture assessments, increases in average annual precipitation and seasonal precipitation from Cal-Adapt are tabulated for the Delta and used to assess exposure of ecosystem types and agricultural crops to climate change-related precipitation changes. For the water supply reliability assessment, changes in average annual precipitation and precipitation variability in the Delta's watersheds are considered. For the flood risk assessment, changes in precipitation are

considered for how it may affect runoff patterns and the frequency and intensity of high inflow events to the Delta.

- Sea level rise – Exposure of hydrologically connected Delta ecosystem asset types to long-term changes in sea levels is evaluated using estimated changes in future tidal datums (Section 4.2.1), which represent local average tide conditions throughout the Delta. For tidal wetlands, future tidal datums are input to a wetland accretion model that projects tidal ecosystem evolution in response to sea level rise. The water supply reliability analysis considers sea level rise up to two feet. The flood risk assessment considers sea level rise up to 10 feet but focuses evaluation of flood exposure in response to sea level rise ranging from 0.2-0.8 ft at 2030, 0.2-1.9 ft at 2050, and 0.5-6.9 ft at 2085. The ecosystems flood exposure analysis overlays the location of levee-protected ecosystem assets with the flood exposure maps (Section 5.3.6).

4.1.2 Sensitivity

Sensitivity examines the degree to which an asset is affected by its exposure to a given climate stressor or hazard. For the CCVA, sensitivity to climate stressors and hazards is considered at the asset category level (i.e., not for individual assets) and is done qualitatively based on a set of considerations unique to each asset type that affect its susceptibility to the evaluated climate hazard. Sensitivity levels considered for each asset category (except people) include not sensitive, low, moderate, and high, as defined in Table 4-1. Sensitivity considerations are developed based on literature review and interviews with technical specialists familiar with the asset types evaluated. For people, the literature review is used to identify quantitative indicators of sensitivity. These indicators are included in a social vulnerability index, representing combined sensitivity and adaptive capacity levels as moderate, high, and highest (see Section 4.3.2 and the Equity Technical Memorandum).

Table 4-1. Sensitivity Considerations for Delta Assets and Resources

Rating	Not Sensitive	Low	Moderate	High
Definition	No impact to asset function	Short-term, minor, or reversible damage to asset or function	Significant but reversible damage to asset or function	Irreversible damage to asset and permanent loss of function

4.1.3 Adaptive Capacity

Adaptive capacity examines the degree to which strategies or conditions exist to mitigate potential climate impacts to an asset or allow an asset to cope with anticipated impacts from climate change. Adaptive capacity for infrastructure assets and managed systems considers not only an asset's operational ability to adapt, but also the managing agency's ability to respond to and mitigate vulnerabilities through other social, economic, and technological means (DWR

2019). Adaptive capacity for most assets and resources is considered qualitatively based on characteristics that apply to each asset type that would affect the capacity of an asset to adjust to climate stressors and hazards. The people analysis uses quantitative indicators of adaptive capacity based on characteristics that affect individuals', households', and communities' ability to respond to and recover from climate impacts. These indicators were included in a social vulnerability index, representing combined sensitivity (discussed above) and adaptive capacity levels as moderate, high, and highest (see Section 4.3.2 and the Equity Technical Memorandum). The ecosystems assessment also considers inherent adaptive capacity for ecosystem types. An asset's adaptive capacity is characterized as none, low, or high, as defined in Table 4-2 depending on the capacity of the asset type to respond to and recover from climate impacts.

Table 4-2. Adaptive Capacity Considerations for Delta Assets and Resources

Rating	None	Low	High
Existing characteristics that provide ability for asset to adapt in order to mitigate climate impacts	No ability to adapt asset or possible adaptations do not mitigate impacts	Ability to adapt asset to partially mitigate impacts; or full mitigation is possible but extremely costly or difficult	Ability to adapt asset to fully mitigate impacts; full mitigation is possible at reasonable cost and effort

4.1.4 Consequences

Consequences consider the magnitude of the impact that may occur if an asset or system is damaged, inoperable, or suffers decreased reliability or performance due to climate stressor or hazard exposure. The interconnected nature of many Delta assets is likely to cause cascading or cumulative consequences, threatening the region's economy, health and well-being, and natural environment. By better understanding the cascading nature of climate impacts, the Council will be better able to plan, adapt, and manage risks. Consequences are generally discussed qualitatively (Table 4-3.) from the perspectives of social and environmental impacts posed to the Delta, and quantitatively in terms of the value of exposed assets and economic activity as described in Section 4.6.

- Economic – potential effects to infrastructure, services, local businesses, tourism, or private property values; economic consequences are characterized for flood hazards from the perspective of the value of assets and economic activity exposed to flooding at each planning horizon
- Social – potential impacts to the well-being of Delta residents, workforce, and tourists with regard to public health, public safety, and impacts to culturally-significant sites or assets
- Environmental – potential impacts that alter natural resources, damage native habitats and green space, contaminate water, or harm fisheries or native wildlife

Table 4-3. Consequence Considerations for Delta Assets and Resources

Rating	Negligible	Minor Impacts	Moderate Impacts	Major Impacts	Catastrophic
Definition	Asset is resilient	Inconvenient or temporary effects; easy and not costly to restore	Widespread impacts resulting in loss or setback of asset or system; costly, but possible to restore	Significant and long-lasting loss or setback; very costly to restore	Extensive loss; likely irreversible/not cost feasible to restore

4.2 Flood Hazard Analysis

4.2.1 Analysis Approach

A primary goal of Delta Adapts is to develop a better understanding of the effects of sea level rise and changing Delta inflows on local water levels. Water levels throughout the Delta are driven primarily by sea level, astronomical tides, meteorological effects (precipitation, pressure, and wind), and streamflow from rivers and tributaries to the Delta. In some localized areas of the Delta, water supply and flood control operations may also affect water levels. Climate change will increase mean sea level and sea level extremes in San Francisco Bay, change oceanic and coastal processes that influence the Bay and Delta, and change the nature of streamflows into the Delta (including the timing and magnitude of inflow).

The Delta is a complex system and climate change will not affect all areas in the same ways. Changes in sea level will drive flood exposure in Suisun Marsh and the western and central Delta while flood exposure of other areas will be driven by changes in river inflows. Leveed areas that experience a flood event may be reclaimed after floodwaters recede; however, impacts would be significant. Areas not protected by levees, such as tidal wetlands, will be exposed to higher tide levels and more frequent (or permanent) inundation and in some areas will drown while in other areas will evolve and adapt over time (see Section 5.3.5 that discusses impacts to ecosystems).

Two different analyses are conducted as part of Delta Adapts to evaluate flood exposure – peak water levels and tidal datums:

- **Peak Water Level Analysis.** The peak water level analysis evaluates the effects of sea level rise and changes in the timing, magnitude, and spatial distribution of peak inflows to the Delta. Results are used in the flood hazard mapping to inform the asset, resources, and economic exposure assessments. This analysis builds on, expands, and improves previous analyses conducted for the Delta Risk Management Strategy (DRMS 2008a, DRMS 2008b) and Delta Levees Investment Strategy (DLIS 2017) and incorporates improved streamflow data from the Central Valley Flood Protection Plan Update 2017 (DWR 2017). The analysis is designed to explore the ways in which climate change – in the form of higher sea levels and larger streamflows – will increase exposure to flooding and how those climate-related changes will interact with storm surge, tides, and existing flood risk throughout the Delta. For more information about the peak water level data, methodology, and analysis please refer to the Flood Hazard Analysis Technical Memorandum.

- **Tidal Datums Analysis.** The tidal datums analysis evaluates the effect of sea level rise on future daily water levels throughout the Delta to understand how tidal datums – such as mean sea level and mean high water – will change throughout the Delta in the future. This information is important for evaluating impacts to Delta and Suisun Marsh habitats. As sea level rises, existing marsh and intertidal habitat may convert to lower marsh or subtidal open water habitat. Upland transition areas will become more frequently exposed to inundation and existing tidal habitats may migrate upslope where space is available. Dudas et al. (2016) is used as the reference dataset for existing conditions tidal datums and additional modeling is conducted by Delta Adapts to derive tidal datum adjustment factors to estimate future conditions tidal datums at a range of future sea levels. The results of this analysis are used as inputs to the ecosystems assessment (Section 4.4). For more information about the tidal datums data, methodology, and analysis please refer to the Flood Hazard Analysis Technical Memorandum.

Tidal Datums in the Delta

Tidal datums are standard reference elevations defined by a particular phase of tide. They are commonly used for measuring local sea levels and specifying elevations of features such as adjacent terrain, navigation depths, habitats, and infrastructure. Commonly referenced tidal datums in the Delta include:

- **Mean Higher High Water (MHHW):** Average of the higher of the two daily high water elevations
- **Mean High Water (MHW):** Average of all high water elevations
- **Mean Sea Level (MSL):** Arithmetic mean of water levels
- **Mean Low Water (MLW):** Average of all low water elevations
- **Mean Lower Low Water (MLLW):** Average of the lower of the two daily low water elevations

4.2.2 Mapping Approach

Delta Adapts evaluates flood hazards throughout the Delta under current conditions and three future planning horizons: 2030, 2050, and 2085. Each planning horizon combines the impacts of sea level rise and changes in watershed hydrology expected at that time horizon and provides information about the likelihood of a flood event occurring that would overtop levees at each location throughout the Delta (flood analysis and mapping scenarios are summarized in Table 4-4.).

Table 4-4. Summary of Flood Hazard Mapping Scenarios Used for Asset Exposure Analysis

Planning Horizon	Sea Level Rise Distribution	Watershed Hydrology (TDI Distribution)	Figure Number
Current Conditions	N/A	Historical	4-1
2030	RCP 8.5 2030	Historical	4-2
2050	RCP 8.5 2050	Mid-Century (2035-2064) RCP 8.5	4-3
2085	RCP 8.5 2085	End-of-Century (2070-2099) RCP 8.5	4-4

Each flood hazard map combines information from two million simulations of the Delta system. These simulations consider a range of flood events that could occur in each year (including wet, average, and dry years), assuming two million years with stable climate conditions at that planning horizon, to estimate the likelihood of experiencing flooding of varying magnitudes. This method of flood exploration and mapping provides important information about flood likelihood and the different ways in which sea level rise, tides, storm surge, and river inflows during a storm event can combine to cause high water levels in different areas of the Delta. Each map shows which islands would be overtopped and flooded at five levels of frequency or likelihood:

1. Less than a 10-year event, which is an event that has a 10 percent chance of occurrence in each year and would have a 65 percent chance of occurring at least once over a 10-year period. ***This level of flood frequency would be acceptable only for wetland, riparian, or subtidal open water habitat.***
2. Between a 10-year and 50-year event, which is an event that has between a 2 and 10 percent change of occurrence in each year and would have an 18 to 65 percent chance of occurring at least once over a 10-year period. ***This level of flood frequency would likely be too high to support agricultural investment and too low to support wetland development.***
3. Between a 50-year and 100-year event, which is an event that has between a 1 and 2 percent change of occurrence in each year and would have a 10 to 18 percent chance of occurring at least once over a 10-year period. ***This level of flood frequency is likely acceptable for agricultural investment of non-permanent crops.***
4. Between a 100-year and 200-year event, which is an event that has between a 0.5 and 1 percent change of occurrence in each year and would have a 5 to 10 percent chance of

occurring at least once over a 10-year period. ***This level of flood frequency is likely acceptable for existing rural population protection and investment in permanent crops.***

5. Greater than 200-year, which is an event that has less than a 0.5 percent change of occurrence in each year and would have less than a 5 percent chance of occurring at least once over a 10-year period. ***This level of flood frequency is considered acceptable for protection of urban populations.***

The Delta Adapts flood hazard exposure assessment results reported in this report for people, places, ecosystems, and infrastructure are based on the exposure to flooding corresponding to probability levels 1 through 3 as described above (i.e., flooding that has an equal or greater likelihood of flooding to a one percent annual chance of occurring given the range of sea level rise and hydrologic conditions at a given planning horizon). Exposure results are tabulated for all probability levels and are archived with the Delta Adapts initiative documentation.

In addition to the flood hazard mapping scenarios listed in Table 4-4, four additional flood hazard maps are developed to show expected flood exposure with a one percent annual chance of occurrence (also referred to as a 100-year event) at specified levels of sea level rise. These maps are similar to traditional flood risk maps showing what would be "in or out" of a 100-year floodplain when considering levee overtopping alone. These maps are not directly used for the asset, resources, and economic exposure analysis and can be found in Appendix A. One of these maps, showing flood exposure throughout the Delta with 3.5 feet of sea level rise and late-century hydrology conditions, may be particularly useful for planning purposes as it aligns with the Ocean Protection Council's sea level rise principles (OPC 2020).

The flood hazard mapping compares modeled local peak water levels throughout the Delta (for each of the likelihood levels described above) to adjacent levee crest or land surface elevations and projects floodwaters landward. Topography is represented using Delta-wide elevation data gathered in 2017 and released in 2019 by USGS and DWR. The Delta Adapts team conducted extensive stakeholder review with Delta levee engineers and local city and county staff familiar with recent and ongoing levee improvement projects to ensure the levee dataset accurately represents conditions on the ground. Levee elevations used for future conditions flood hazard assessments (2030, 2050, and 2085) do not include potential future subsidence, slumping, failure, or degradation of levees nor do they include potential future investments that could improve levee crest elevations or stability.

The flood hazard maps identify islands and tracts that are exposed to flooding by overtopping of levees for each future planning horizon. Other modes of levee failure such as seepage, stability, or seismic failure are not evaluated; thus, the likelihood of flooding shown in these maps may under-estimate the likelihood of levee failure across all failure modes. Changes to local water levels and flood risk caused by unreclaimed island flooding (i.e., islands that flood and permanently become open water) are also not considered in these maps. Unreclaimed islands could lower flood water levels in adjacent channels by providing additional storage but could also increase flood risk by creating open water conditions that increase wind wave and other erosive processes. The flood hazard modeling also does not account for overbank flows and floodplain storage that may be especially important along the San Joaquin River as it enters the

Delta. Additional information about the flood hazard scenarios and flood hazard mapping processes can be found in the Flood Hazard Analysis Technical Memorandum.

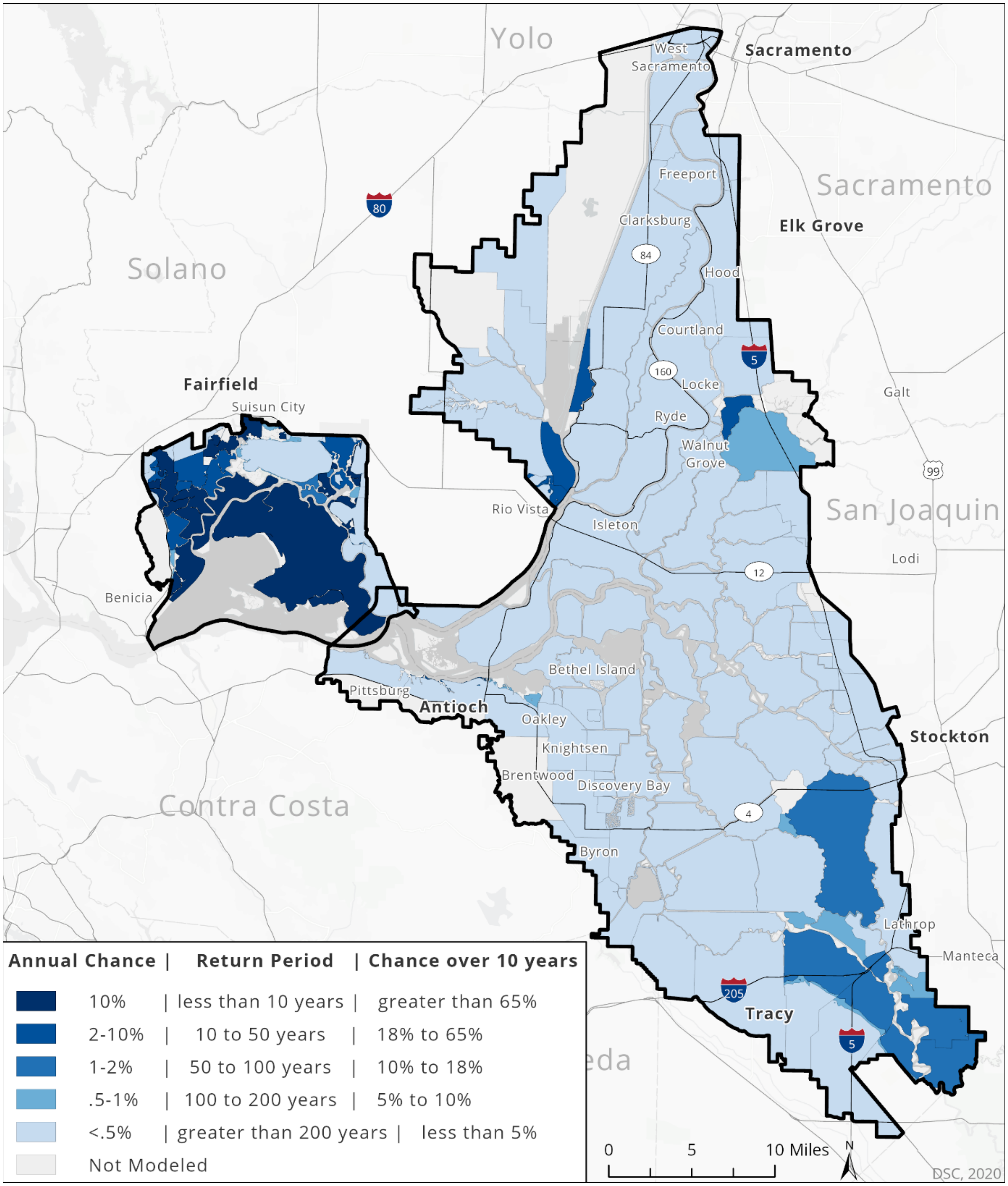

Figure 4-1. Flood hazard map for Existing Conditions

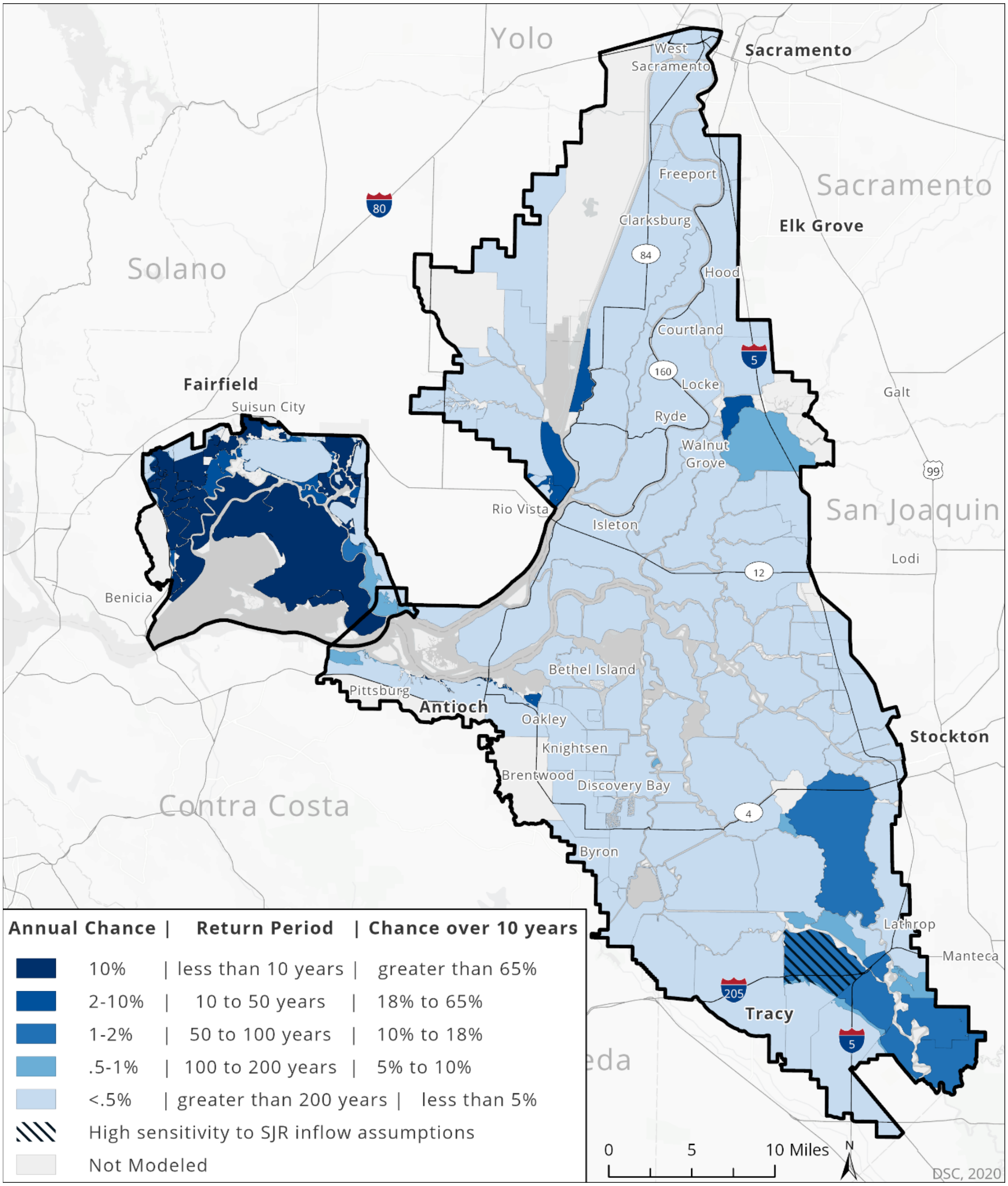

Figure 4-2. Flood hazard map for 2030 Conditions

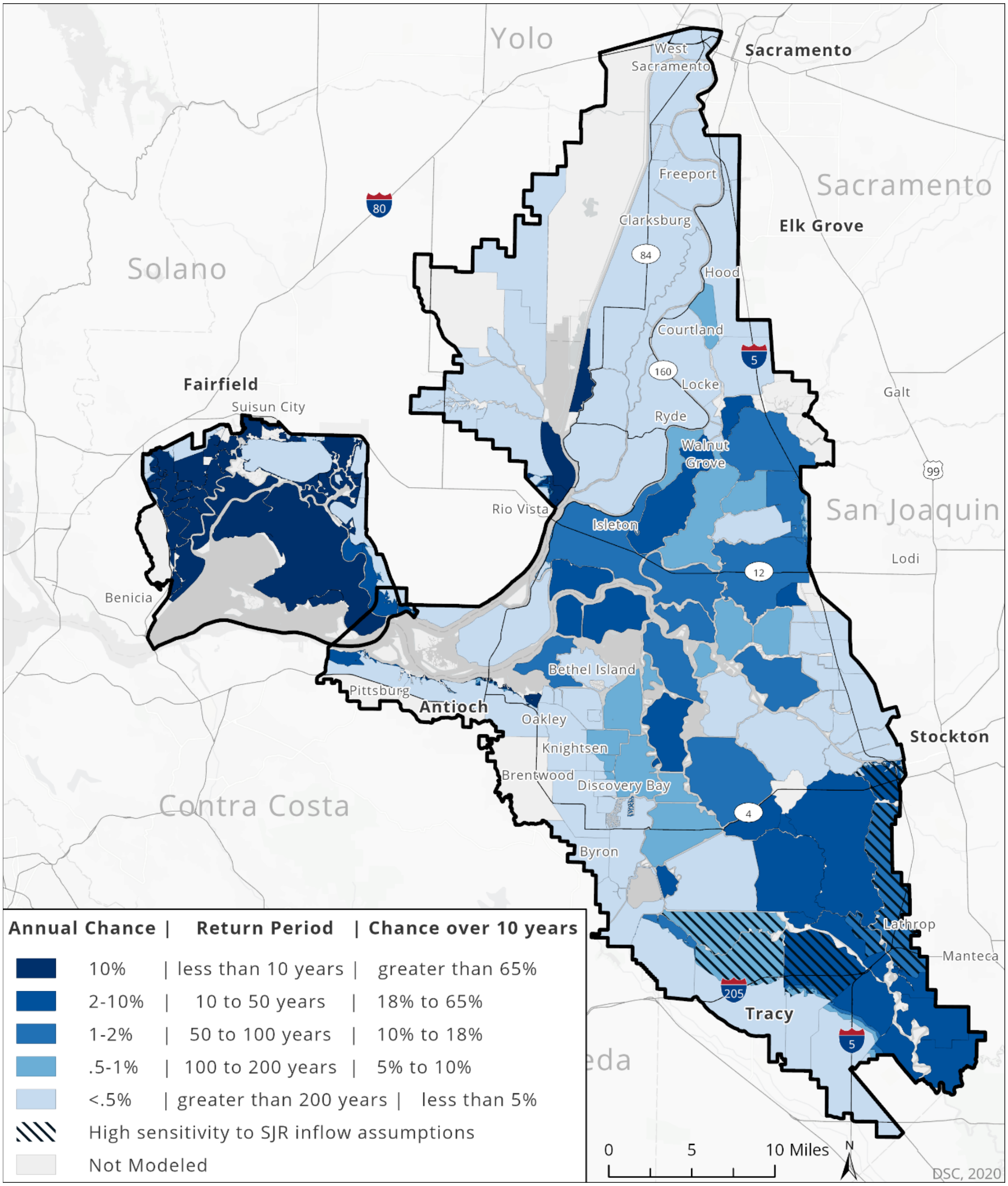

Figure 4-3. Flood hazard map for 2050 Conditions

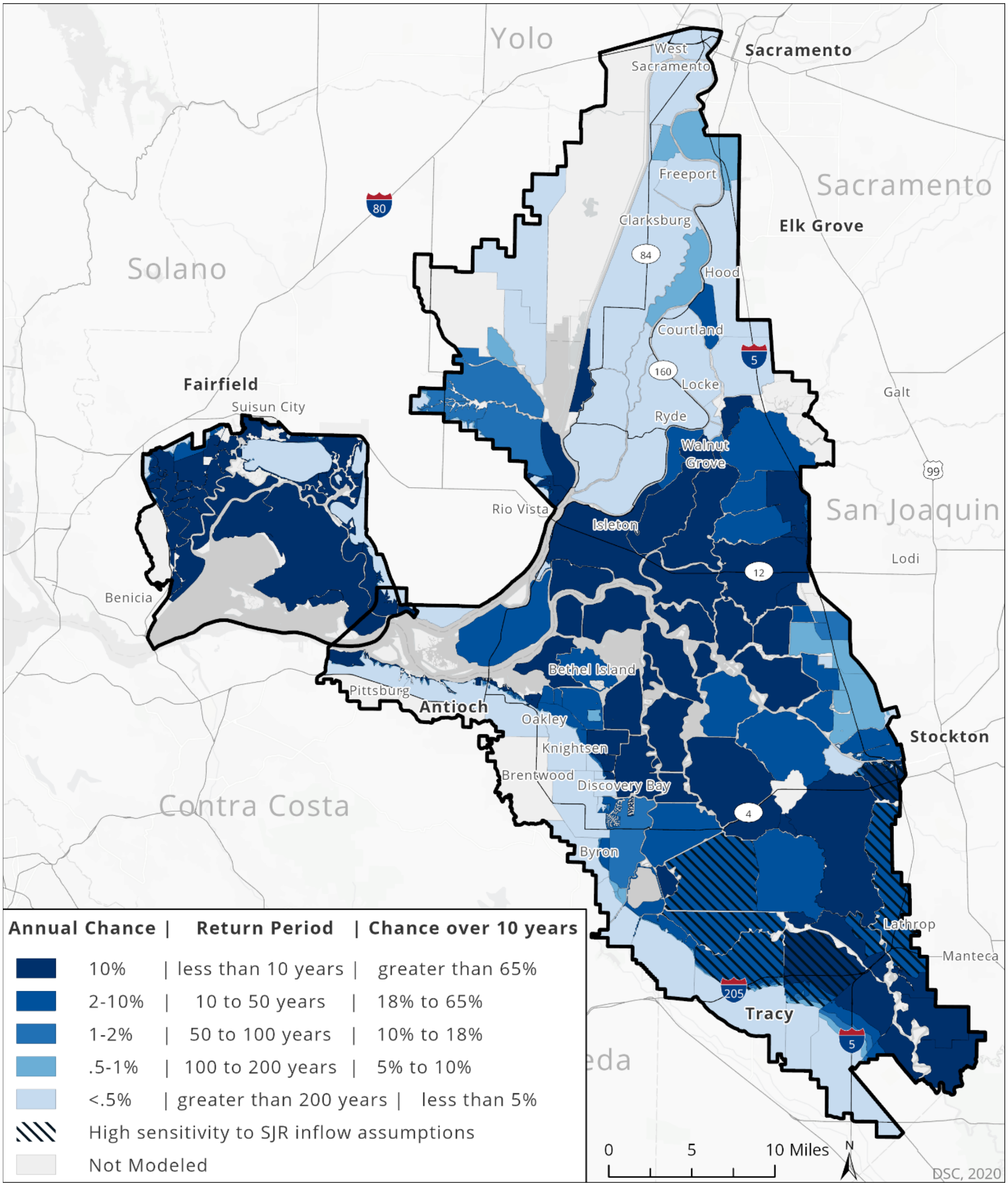

Figure 4-4. Flood hazard map for 2085 Conditions

4.3 Delta as an Evolving Place

The vulnerability assessment for the Delta as an evolving place evaluates the vulnerability of the people, places, and assets within the Delta to climate change hazards, primarily flooding and extreme heat. Vulnerability to drought and wildfire are discussed qualitatively where applicable to each asset category. The assessment considers the following Delta assets and resources:

- People
- Places (cultural resources, critical facilities, and residential, commercial, and industrial areas)
- Agriculture (crops and agricultural assets)
- Recreation (parks, campgrounds, marinas, scenic highways, trails)
- Infrastructure (energy and utilities, transportation, solid/hazardous waste, flood management, and water supply)

The approaches to assessing exposure, sensitivity, and adaptive capacity are described in the following sections.

4.3.1 Exposure

Flood exposure for Delta populations, places, and assets is evaluated using the flood hazard maps described in Section 4.2.2 by overlaying the flood exposure layers on the geospatial locations of various assets and resources compiled in the asset inventory (Section 2.2). Exposure to flooding is tabulated for each asset category for near-term (2030), mid-century (2050), and end-of-century (2085) timeframes. Results are generally presented at the Delta-wide or county level, with the exception of people, which is presented at the county, city, and census designated place level to provide additional geographic granularity to Delta stakeholders to better understand potential impacts within their communities. Exposure to extreme heat hazards is considered to be geographically uniform throughout the Delta because analysis of projected changes in number of extreme heat days showed little spatial variation across the Delta (i.e., while the absolute temperature threshold that defines an extreme heat day does vary throughout the Delta, there are only small geographic differences in the projected changes to the number of extreme heat days throughout the Delta; see Section 3.2.1.2). As a result, spatially varying exposure to changing extreme heat hazards is not discussed.

4.3.2 Sensitivity and Adaptive Capacity

Sensitivity and adaptive capacity considerations are presented for Delta populations, places, and assets for each climate hazard and are incorporated into the key findings statements presented in Chapter 5. The approach to assess sensitivity and adaptive capacity for people and assets and resources is discussed below.

People

Some individuals may have physiological or socioeconomic characteristics that increase their sensitivity to a particular climate change hazard (Raval et al. 2019). Similarly, some individuals, neighborhoods, or communities may have greater ability or opportunity to adjust to future hazards or respond to the consequences of those hazards than others (IPCC 2014). In this assessment, the characteristics that affect people's sensitivity and adaptive capacity to climate change are described qualitatively and captured quantitatively at the community level using a social vulnerability index.

The social vulnerability index is developed and mapped at the block group scale (Figure 4-5) based on ability status, educational attainment, linguistic isolation, household vehicle access race/ethnicity, tenancy, poverty, and the prevalence of young children, older adults living alone, and health disparities such as asthma and cardiovascular disease. Block groups with high concentrations of individuals or households that meet these criteria indicate communities with higher social vulnerability to climate hazards. The index begins at *moderate* and increases to *highest* to reflect that even in areas that do not exhibit the highest concentrations of residents that meet the indicator criteria above, residents with greater sensitivity or lower adaptive capacity may still live in these areas. Block groups in the highest category of social vulnerability are located in Antioch, Pittsburg, Tracy, Sacramento, Stockton, West Sacramento, and unincorporated areas of San Joaquin County.

While this vulnerability analysis treats exposure separately from social vulnerability, ample research demonstrates that the physical environment has been shaped by policies and attitudes towards particular socioeconomic groups. Redlining (the practice of denying a creditworthy applicant a loan for housing in a certain neighborhood even though the applicant may otherwise be eligible for the loan; Federal Reserve 2008) and discrimination, reinforced by market forces, have created conditions in which many low-income communities and communities of color reside and work in more hazardous environments (Bartlett 1998; CSIWG 2018; Rothstein 2017; Shonkoff et al. 2011) and experience significant health disparities (McCall 2018; OPR 2018b). Thus, overall vulnerability is also closely linked to place (Raval et al. 2019). See the Equity Technical Memorandum for additional details on the social vulnerability index.

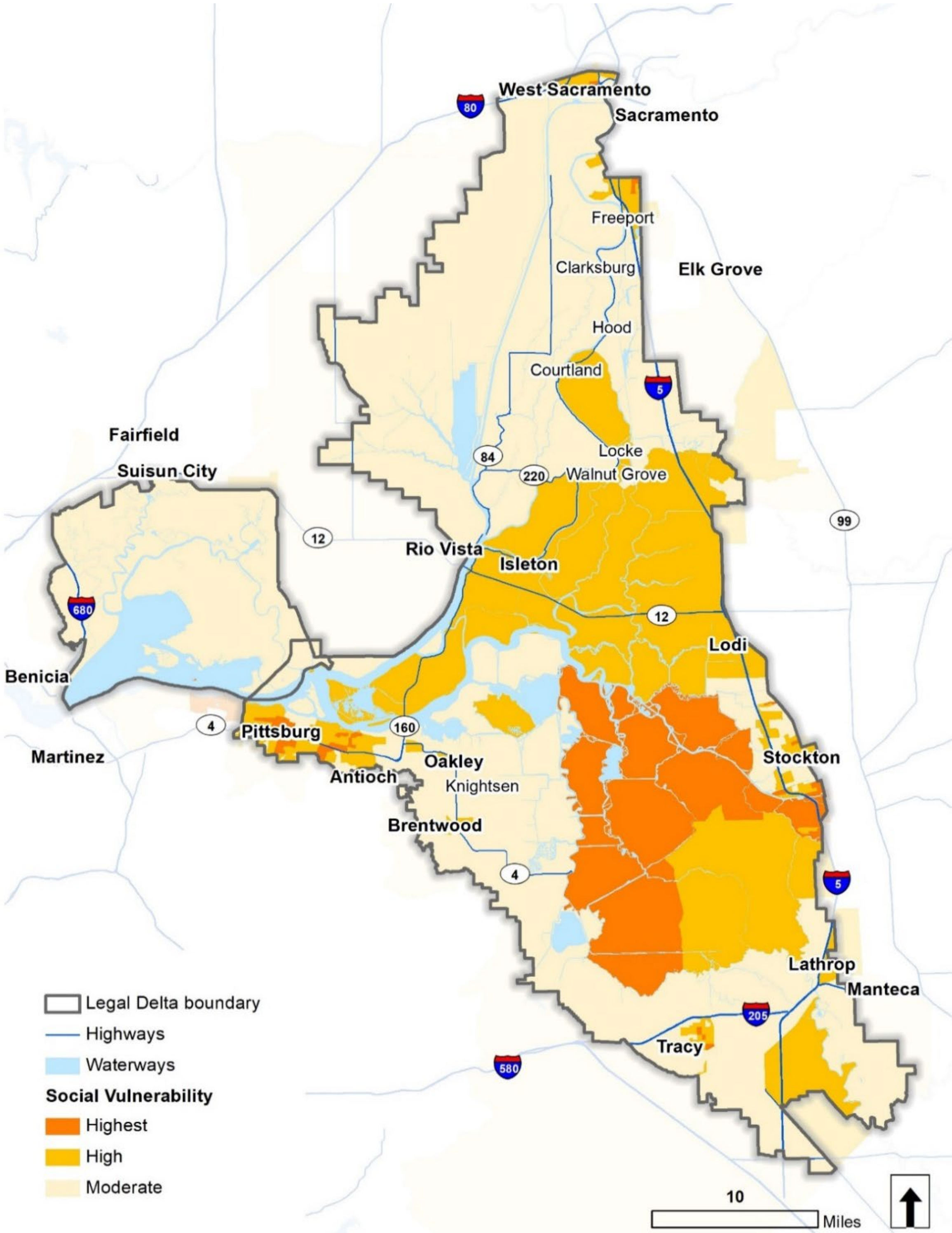

Figure 4-5. Social Vulnerability in the Delta

Note: Moderate = block groups with 0 to 3 indicators; High = block groups with 4 to 7 indicators; Highest = block groups with more than 8 indicators

Assets and Resources

A common set of factors that affect the sensitivity and adaptive capacity of assets and resources to flooding and extreme heat are listed in Table 4-5. Unique factors that affect the sensitivity and adaptive capacity of specific asset categories to specific climate hazards are discussed qualitatively within Chapter 5. The discussion of sensitivity and adaptive capacity provides additional context as to how characteristics of a given asset or resources category may increase its vulnerability to each climate hazard. Sensitivity and adaptive capacity for agriculture assets is considered at the crop type level in terms of how different crops may respond to climate stressors and hazards, including changes in air temperature, precipitation, salinity intrusion due to sea level rise or reduced freshwater inflow.

Table 4-5. Factors That Affect Asset Sensitivity and Adaptive Capacity of Assets and Resources

Hazard	Sensitivity Factors
Flooding	• Electrical equipment *(flooding or inundation of electrical equipment may lead to operation malfunction or damage to the asset)* • Corrosive material *(surface structures required for conveyance of water, sewer, natural gas, and electrical utilities may be composed of materials that could corrode prematurely if exposed to saltwater)* • Susceptible to increased frequency, duration, or depth of saltwater inundation *(some assets have a narrow tolerance of water depth changes and may experience damage or complete loss of function)* • Susceptible to erosion/scour events *(flood event may cause erosion/scour under the asset)* • Buildings present *(some buildings house equipment on lower floors that could be damaged if exposed to flooding)*
Extreme Heat	• Electrical equipment *(temperatures may exceed the design threshold, causing the asset to overheat or have a reduced useful life)* • Dependence on regional power supply *(asset may lose functionality without regional power grid that can be stressed during extreme heat events, causing inconsistent power supply)* • Asphalt *(material is more likely to experience shoving, or ripple across a pavement surface, during extreme heat events)* • Narrow tolerance for temperatures *(narrow tolerance for temperature variations)* • Made of dark colored material *(more sensitive due to increased heat gain)*
Hazard	**Adaptive Capacity Factors**
Flooding or Extreme Heat	• Electrical equipment *(existing assets can easily be raised to reduce its exposure to flooding, or have electrical components raised out the reach of temporary flooding)* • Ability to relocate infrastructure *(asset can be easily moved to higher elevation or outside of floodplain to protect it from flood damage)*

	• **Redundancy** *(there are multiple access paths to the asset, the presence of a back-up generator or other means that could provide asset substitution)* • **Ability to retrofit/upgrade** *(asset can be easily retrofitted with air-conditioning/cooling system units or with water proofing material)*

4.3.3 Consequences

Consequences for Delta as an evolving place populations, assets, and resources are generally discussed qualitatively in the key findings (Chapter 5) for each asset category, with the exception of economic consequences. The economic analysis provides estimates of the economic value of physical assets and economic activity that are exposed to flooding at 2030 and 2050. The economic exposure analysis approach is discussed in Section 4.6.

4.4 Ecosystems

A key goal of the Delta Adapts CCVA is to gain a clear understanding of the climatic projections and subsequent impacts on Delta ecosystems. This section presents the analyses and approach taken to assess the exposure and sensitivity of Delta and Suisun Marsh ecosystem asset types (dominant habitats) to climate drivers, including primary and secondary climate stressors and hazards.

4.4.1 Ecosystem Asset Types

Ten Delta ecosystem asset types are evaluated in the vulnerability assessment. Asset types are further distinguished as being protected by levees ("leveed") or not protected by levees ("un-leveed") for the sea level rise and flood hazard analyses (Table 4-6 and illustrated in Figure 4-6). Descriptions of the ecosystems are in Table 4-7 (*A Delta Transformed*, SFEI-ASC 2014). To determine the ecosystem asset types, Vegetation Classification and Mapping Program maps (Boul et al. 2018; Kreb et al. 2019; VegCAMP) are matched with the asset types specified in *A Delta Transformed* and described in greater detail in the Ecosystems Technical Memorandum.

Table 4-6. Ecosystem Assets Types Protected and Not Protected by Levees

Un-Leveed Ecosystem Asset Types	Leveed Ecosystem Asset Types
Grasslands	Wet Meadow or Seasonal Wetland
Riparian and Willow Ecosystems	Alkali Seasonal Wetland complex
Tidal Brackish Emergent Wetland	Non-tidal Freshwater Wetland
Freshwater Emergent Wetland	Managed Wetland
-	Agricultural areas providing wildlife resources

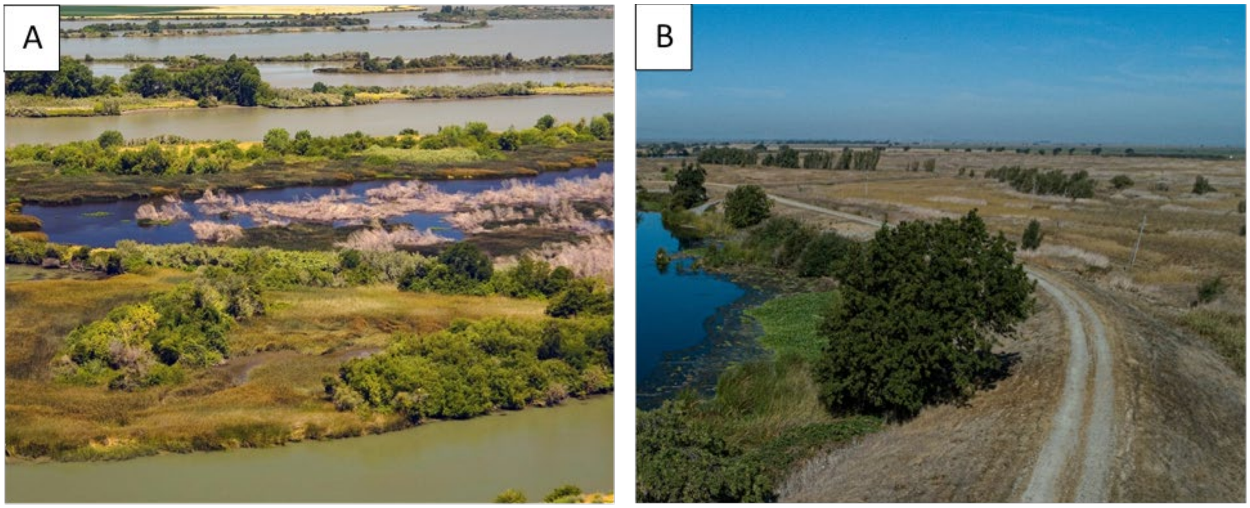

Figure 4-6. Un-leveed ecosystems are connected to Delta waterways (Panel A). Leveed ecosystems are disconnected from Delta waterways (Panel B).

Note: Images from California Department of Water Resources

Table 4-7. Ecosystem Asset Types Evaluated in Vulnerability Assessment

Habitat Type	Photo	Description
Emergent Wetlands	  	*Tidal freshwater emergent wetland*: Perennially wet, high water table, dominated by emergent vegetation. Woody vegetation (e.g., willows) can be a significant component, particularly the western-central Delta. Wetted or inundated by spring tides at low river stages (high tide levels). *Non-tidal freshwater emergent wetland*: Temporarily to permanently flooded, permanently saturated, freshwater non-tidal wetlands dominated by emergent vegetation. In the Delta, these occupy upstream floodplain positions above tidal influence. *Tidal brackish emergent wetland*: Intertidal emergent wetland at the confluence of fresh and saltwater dominated by grasses, forbs, and shrubs and tolerant to moderate salinities.

Willow Thicket		Perennially wet, dominated by woody vegetation (e.g. willow). Emergent vegetation can be a significant element. Generally located at the "sinks" of major creeks or rivers as they exit alluvial fans onto the valley floor.
Willow Riparian Scrub or Shrub		Riparian vegetation dominated by woody scrub or shrubs with few to no tall trees. This habitat type generally occupies long, relatively narrow corridors of levees along rivers and streams.
Valley Foothill Riparian		Mature riparian forest usually associated with a dense understory and mixed canopy, including sycamore, oaks, willows, and other trees. Historically occupied the supratidal natural levees of larger rivers that are occasionally flooded.
Wet Meadow or Seasonal Wetland		Temporarily or seasonally flooded, herbaceous communities characterized by poorly drained, clay-rich soils. These often comprise the upland edge of perennial wetlands.

Alkali Seasonal Wetland complex		Temporarily or seasonally flooded, herbaceous or scrub communities characterized by poorly drained, clay-rich soils with a high residual salt content. These often comprise the upland edge of perennial wetlands.
Grassland		Low herbaceous communities occupying well-drained soils and composed of forbs and annual and perennial grasses and usually devoid of trees. Few to no vernal pools present.
Agricultural/Ruderal/ Non-native		Cultivated lands, including croplands and orchards. This ecosystem type also includes areas dominated by non-native vegetation and ruderal lands.
Managed wetland		Areas that are intentionally flooded and managed during specific seasonal periods, often for recreational uses such as duck clubs.

Source: Habitat descriptions derived from SFEI's A Delta Transformed (SFEI-ASC 2014); photos from SFEI's A Delta Transformed, Department of Water Resources, Annika Keeley of the Delta Stewardship Council, and Ellen Dean with UC Davis.

4.4.2 Climate Stressors and Hazards

The CCVA evaluates exposure and sensitivity of ecosystem asset types to climate stressors and hazards to assess vulnerability (Table 4-8). Climate stressors influence Delta ecosystem assets over long time periods that can lead to gradual, yet meaningful, shifts in species composition and eventual ecosystem decoupling, whereas climate hazards are discrete events that may lead to catastrophic failures or ecosystem impacts within the Delta.

Table 4-8. Primary and Secondary Climate Stressors and Climate Hazards Evaluated in Ecosystems Assessment

Climate Drivers	Primary: Local Precipitation	Primary: Air Temperature	Primary: Sea Level Rise	Secondary: Wind	Secondary: Water Temperature
Climate Stressors	Change over time in amount and timing of rainfall	Change over time in air temperature, seasonal changes, maximum air temperature used as proxy	Increase in sea level	Change in wind patterns over time, proximity to the Central Valley and the coast	Change over time in water temperature, directly corresponds to air temperature – dependent on atmospheric forcing, riverine flows and tidal dispersion
Climate Hazards	Extreme precipitation events/ drought	Extreme heat events	Flooding/ levee overtopping	No wind hazards assessed	No water temperature hazards assessed

4.4.3 Analysis Approach

The approach to assess exposure, sensitivity, and adaptive capacity for leveed and unleveed ecosystem asset types is described below. Refer to the Ecosystems Technical Memorandum for more detailed information regarding the climate data, methodology, and analyses.

4.4.3.1 Exposure

For the primary climate stressors of air temperature and local precipitation, downscaled climate projections are evaluated for the Delta and Suisun Marsh using Cal-Adapt data for mid-century and end-of-century planning horizons and for two emissions scenarios (RCP 4.5 and RCP 8.5). For sea level rise, flooding of leveed habitats is assessed using the flood hazard maps and response of unleveed habitats is assessed using the results of the tidal datums analysis and sedimentation modeling. Secondary climate stressors and climate hazards are assessed using peer-reviewed literature and qualitative assessment.

Air Temperature

Air temperature in the Delta and Suisun Marsh is assessed using the following metrics:

1. Change in average annual air temperature (stressor): Average annual air temperature in the Delta is evaluated to understand how thermal changes (namely thermal stress) may gradually affect the vulnerability of ecosystem assets over time.
2. Change in seasonal average temperature (stressor): Average seasonal temperature changes are evaluated to understand how projected changes may gradually affect the vulnerability of ecosystem assets over time. Vegetative communities, fish and wildlife species, and physical processes all depend on certain thermal ranges throughout the year in order to function properly and persist into the future.
3. Extreme heat (climate hazard): The ecosystems assessment includes a high-level discussion of extreme heat impacts based on literature review and analysis of projections of average extreme heat days per year from Cal-Adapt.

Local Precipitation

Local precipitation in the Delta and Suisun Marsh is assessed using the following metrics:

1. Change in average annual local precipitation (stressor): Average annual precipitation changes are evaluated to understand how local annual rainfall changes may gradually affect the vulnerability of ecosystem assets over time.
2. Change in average annual seasonal precipitation (stressor): Average seasonal precipitation changes are evaluated to better understand potential phenological (i.e., biological life cycle) impacts to ecosystem asset types due to altered precipitation regimes. Changes in seasonal precipitation trends may result in changes in phenology – for example, the timing of flowering or bird migrations.
3. Extreme precipitation and drought (hazard): The ecosystems assessment includes a high-level discussion of extreme precipitation and drought hazards based on literature review.

Sea Level Rise and Flooding

Sea level rise in the Delta and Suisun Marsh is assessed spatially across five Delta Regions (Central Delta, North Delta, South Delta, Suisun Marsh, and Yolo-Cache Slough Complex; Figure 4-7) and considering the following metrics:

1. Sea level rise (stressor): Future tidal datum projections for each sea level rise scenario are obtained from the tidal datums analysis (see Section 4.2.1) and used to evaluate potential impacts to un-leveed ecosystems. For un-leveed tidal freshwater and brackish wetlands, the Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) is used to evaluate future evolution of un-leveed wetlands considering inorganic and organic sedimentation and sea level rise response (Swanson et al. 2015). Two sea level rise scenarios for mid-century (1 and 2 feet sea level rise by 2050) and three sea level rise scenarios for late-century (2 and 3.5 feet of sea level rise by 2085 and 6 feet sea level rise

by 2100) were evaluated under a constant, declining, and increasing sediment supply scenarios (results for the constant sediment supply scenario are presented in the CCVA).

2. Flooding (hazard): Flood exposure of leveed Delta habitats is assessed using the flood hazard maps at each planning horizon (see Section 4.2.2). Acreage of exposed habitats are tabulated for each planning horizon.

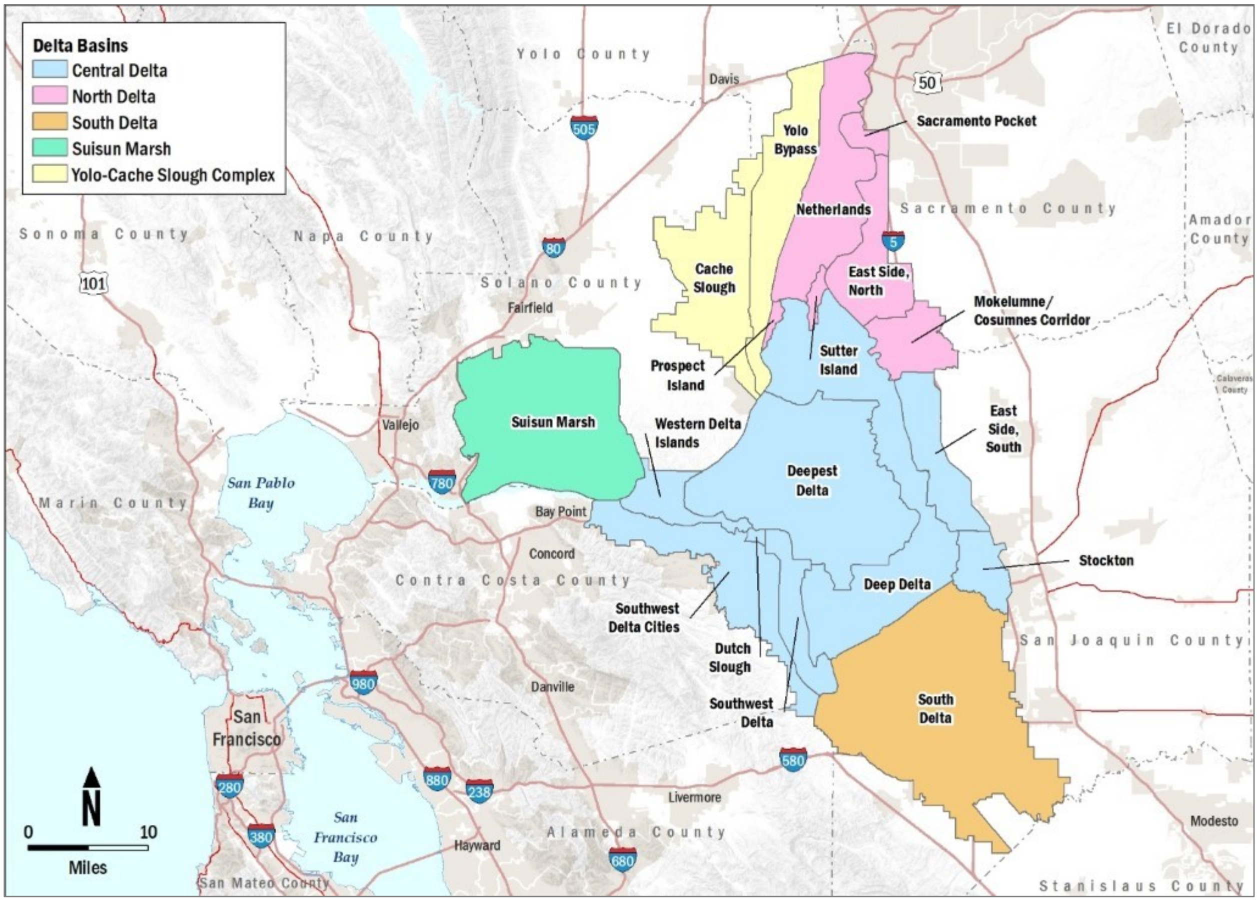

Figure 4-7. Delta regions considered for sea level rise in the ecosystems assessment (Yolo-Cache Slough, North Delta, Central Delta, South Delta, and Suisun Marsh)

4.4.3.2 *Sensitivity*

For this assessment, sensitivity factors are selected based on primary ecosystem functions of the assets outlined in Table 4-9. Sensitivity is qualitatively assessed for each ecosystem asset type based on the natural history, associated species, and foundational physical processes (such as soil moisture content, evapotranspiration, sedimentation/accretion, water quality, and tidal exchange) according to the expert knowledge of scientists familiar with Delta ecology (through the Delta Adapts Technical Advisory Committee) and peer-reviewed literature.

Table 4-9. Asset Sensitivity Scale to Climate Variables and Secondary Impacts

Asset Type	None - No impact to asset function	Low - Asset still functional	Moderate - Asset function compromised	High - Asset no longer functional
Ecosystems	Negligible or no change to ecosystem function	Short term, minor but reversible interruption to ecosystem function	Significant but not permanent loss of ecosystem function	Widespread and permanent loss of ecosystem function

4.4.3.3 *Adaptive Capacity*

For natural systems, adaptive capacity can be divided into natural adaptive capacity and institutional adaptive capacity. The sensitivity analysis considers natural adaptive capacity (each ecosystem asset's inherent ability to adjust to changes in air temperature, local precipitation, and sea level rise in order to maintain its ecosystem structure and function). Institutional adaptive capacity is separately and qualitatively considered in Section 4.1.3.

4.5 Water Supply Reliability

The complex system of watersheds, rivers, reservoirs, levees, pumping plants, regulations, and operations that allow water from the Sacramento and San Joaquin river watersheds to be stored, conveyed, and delivered to meet the needs of California water users is one of the most complex and sophisticated water systems in the world (Ray et al. 2020). The 45,600 square mile Delta watershed provides all or a portion of water supplies to more than 27 million California residents and more than 3.7 million acres of agriculture. The Delta serves as a hub in water transfers to other areas of the state; approximately eight percent of the state's water supply is exported from the Delta. A primary goal of Delta Adapts is to develop a better understanding of the effects of climate change on the water supply system that depends on the Delta's watershed and provides water supply to both in-Delta uses and uses statewide. This section describes the analyses conducted as part of Delta Adapts to assess the vulnerability of the water supply system to climate change.

The Delta Adapts water supply analysis evaluates the vulnerability of the water supply system to primary climate stressors including air temperature, precipitation (both the amount of precipitation and interannual variability), and sea level rise. The vulnerability assessment focuses on the projected near and medium-term (i.e., occurring over the next 10 to 30 years) shift in these climate stressors over the Delta's watershed (for temperature and precipitation changes) and within the Delta (for sea level rise). Projections beyond 2050 are not analyzed because of modeling limitations and compounding uncertainties associated with climate change, system operations, water demands, and regulations. Changes in watershed temperature and precipitation will affect surface runoff to the system (in terms of amount, seasonal timing, and interannual variability), while sea level rise will affect the operations of the water supply system (including management of upstream reservoir storage and releases, management of water quality requirements in the Delta, and exports of water from the Delta). The assessment also evaluates short-term conditions such as droughts, which could become more frequent and severe due to climate change. Secondary climate stressors such as wildfire and fog are not evaluated quantitatively as part of Delta Adapts.

The Delta Adapts water supply reliability assessment conducted three primary analyses in support of the vulnerability assessment. The first component of the vulnerability assessment is a sensitivity analysis of the water supply system that applies a bottom-up approach, known as *decision scaling*, that explores the system performance in response to changes in the primary climate stressors. This sensitivity analysis sought to understand the response of the system to each climate stressor in isolation. The second component of the vulnerability assessment recognizes that climate change will drive multiple simultaneous changes to the climate stressors in the coming decades. Changes to one stressor will likely reinforce or exacerbate changes driven by other stressors, making the impacts to the system greater than the sum of the individual stressors alone. System performance (i.e., response of the key water supply metrics) is evaluated for the likely range of climate change for the primary stressors at 2050. The third component of the vulnerability assessment assessed how climate change would affect the frequency and severity of extreme droughts (such as the one that occurred in 2012 to 2016) that may occur in the future.

What is decision scaling and how is it used in Delta Adapts?

Decision Scaling is a “bottom-up” analysis approach to better understand the uncertainties of climate change and how complex systems (such as the water supply system) behave in response to changes in climate variables. This approach helps decision makers understand which climate variables – temperature, precipitation, or sea level rise – exert the greatest effect on future water supply system performance, in order to better inform stakeholders in future decision making and monitoring. It differs from a traditional, scenario-based approach, where a discrete number of climate models and/or projections are selected to evaluate impacts. In addition, decision scaling allows decision makers to consider how the system may behave whether projected climate change occurs in the next five years, 50 years, or in 2100 because its results are more flexible to incorporate changing climate projections.

All three components of the analysis evaluate system performance in terms of the response of four key water supply metrics: Delta exports, North of Delta April and September reservoir storage, and system shortages:

- **Delta exports:** provides a measure of the water supply available to south of Delta water users

- **North of Delta storage:** provides measures of the volume of stored water at the end of the runoff season (April storage) and at the end of the irrigation season (September storage). April storage is important for water deliveries and reservoir releases for environmental purposes in the summer and fall and September storage is important for year-to-year drought resilience and downstream river water temperature control for salmonids.
- **System shortages:** provides a measure of the frequency and severity of shortages in which there is not enough water available to meet all system requirements. The system shortages metric may also serve as a proxy metric indicating potential impacts to in-Delta water uses.

The vulnerability of the water supply system is assessed through the evaluation of the four metrics discussed above. Results are presented in Section 5.4 for the climate stressor sensitivity analysis and system vulnerability for projected likely 2050 climate conditions. Projected changes in each metric are presented across the full range of dry, average, and wet years to assess system performance under typical and more extreme conditions. In addition, the frequency and severity of future droughts is evaluated under future conditions with warmer temperatures, higher sea levels, and more variable precipitation.

More details on the methods and results of the analysis can be found in the Water Supply Technical Memorandum.

4.6 Economic Exposure Analysis

The Delta Adapts CCVA considers two aspects of economic exposure to climate change related flooding in the Delta: (1) economic value of physical assets exposed and (2) agricultural and commercial economic activity exposed. In addition, an evaluation of the potential economic impacts of climate change-related disruptions to Delta water exports is performed. This assessment considers how impacts to the movement and supply of water through the Delta to the State's two major water supply projects may influence municipal, industrial, and agricultural economic activity derived from those supplies. Economic exposure analysis for Delta Adapts considers future planning horizons of 2030 and 2050 and results are presented for 2050 in this CCVA. Economic exposure for planning horizons beyond 2050 is not evaluated in Delta Adapts because of the uncertainty in water supply regulations, operations, cropping patterns, water use, technology, and economic values.

See the Economic Assessment Technical Memorandum for details on the methods, assumptions, and results of the economic exposure and impact analysis.

4.6.1 Economic Value of Assets Exposed to Flooding

The estimation of asset value and economic activity exposed to flooding is intended to quantify the value and economic significance of Delta assets and activities that are at risk to flooding, as opposed to quantifying the specific damages that might occur as a result of a particular future flood event. This approach is taken to highlight the substantial economic investments that exist in the Delta that may be vulnerable to future flooding and the significance of the Delta economy for the region and the state.

The economic values of physical assets are tabulated for the Delta assets and resources identified in the asset and resources inventory (Section 2.2). Asset values are compiled on a unit cost basis at the asset category level (e.g., replacement cost per fire station, per mile of highway, per wastewater treatment plant, etc.) using the DLIS unit cost values as a starting point and filling in data gaps for assets included in Delta Adapts that were not included in the DLIS assessment. Asset values are escalated to 2020 values for the Delta Adapts assessment.

Economic exposure is evaluated by tabulating the number of assets within each asset category that are exposed to flooding for each planning horizon using the results of the flood hazard analysis (Section 4.2.2). Exposed asset values are tabulated for the following categories: agricultural assets, residential structures, commercial and industrial structures, critical facilities, communications, transportation, water, energy, and utilities. Where economic exposure information supports the key vulnerability findings summarized in Chapter 5, it is included at the asset category level (for example, value of exposed residential property, transportation assets, energy infrastructure, etc.) – otherwise, economic exposure estimates are discussed at the Delta or county level.

4.6.2 Economic Activity Exposed to Flooding

Economic activity exposed to flooding for each scenario is tabulated for commercial and agricultural activities. Economic activity data for commercial and industrial enterprises are obtained from the IMPLAN model and ArcGIS Business Analyst to estimate the value of economic activity within the Delta that would be interrupted due to flood exposure and associated impacts at each planning horizon. IMPLAN is an economic analysis tool that is used to value economic sectors that considers impacts to components of the economy such as industry or economic output, gross regional product, employment, income, and taxes. Flood exposure of Delta agricultural production is estimated for the more than thirty crop types present in the Delta, based on average gross revenues per acre from agricultural commissioner crop reports for each county and total acreage exposed to flooding under each scenario.

See the Economic Assessment Technical Memorandum for details on the methods and results of the economic exposure analysis.

4.6.3 Economic Exposure to Delta Water Supply Impacts

An analysis of annual economic impacts of changes to Delta water exports due to future climate change is conducted. The assessment considers potential water supply impacts due to reduced water deliveries to south of Delta water users under future climate conditions, including typical annual conditions and a severe drought scenario. In addition, economic impacts of a temporary diversion outage (assumed to last six months) as a result of a climate-related event that impedes exports (for example, failure of a number of Delta islands due to flooding and/or widespread salinity intrusion into the south Delta) is also evaluated. The changes in water deliveries are translated into economic impacts in terms of replacement cost to acquire new sources of water, replace consumed water reserves, and/or lost economic activity as follows:

- For agricultural users: Reduced deliveries result in reduced irrigated acreage and production and costs to replenish groundwater reserves. Economic impact of reduced Central Valley Project (CVP) and State Water Project (SWP) deliveries to Central Valley agriculture in Kern, Tulare, Kings, Fresno, Madera, Merced, and Stanislaus Counties is considered.
- For urban agencies (municipal and industrial uses): Reduced deliveries result in costs to obtain additional alternative supplies (either by water transfers or developing new local supplies) and costs from unmet shortages created by curtailments. For temporary Delta diversion outage events, it is assumed that south of Delta water agencies would rely on emergency supplies to meet water demands during the outage so economic impacts represent the cost of replacing emergency supplies in subsequent years (after Delta operations are restored).

The economic analysis incorporates the outputs of the water supply reliability analysis (see Section 4.5), which considers the effect of future changes in interannual precipitation variability and air temperature across the Delta watershed and sea level rise within the Delta. The probabilistic projections of changes in Delta exports in response to climate change consider the full range of potential changes in precipitation variability, air temperature, and sea level rise. Impacts to water deliveries are considered in terms of changes to average annual deliveries at each planning horizon. In addition, changes in water deliveries under future drought conditions are evaluated at 2030 and 2050 under a scenario that considers conditions similar to the 2012 to 2016 drought, were it to occur under future climate conditions (i.e., warmer climate, higher sea levels, and more variable precipitation).

CHAPTER 5. VULNERABILITY ASSESSMENT KEY FINDINGS

This chapter summarizes the key findings of the vulnerability assessment. Findings are presented for Changing Climate Stressors and Hazards (Section 5.1), Delta as an Evolving Place (Section 5.2), Ecosystems (Section 5.3), and Water Supply Reliability (Section 5.4). More detailed discussion of results can be found in the supporting Technical Memoranda for each topic.

5.1 Changing Climate Stressors and Hazards

This section summarizes the key findings related to projected changes in air temperature, precipitation, sea level rise, flooding, and extreme heat. See Chapter 3 for more detailed discussion of climate stressors and hazards in the Delta.

5.1.1 Air Temperature

Air temperatures in the Delta are projected to increase by +3.2°F to +5.8°F by mid-century and +3.6°F to +9.6°F by end of century, depending on future mitigation efforts and the climate's response to increased atmospheric greenhouse gas concentrations.

Given current global emissions, the temperature projections for mid-century are more likely to reflect the RCP 8.5 (business-as-usual emissions) scenario, for which models project average annual daily maximum air temperature increases in the Delta of +4.0°F to +5.8°F, with a model average of +4.9°F. End of century projections depend on global mitigation actions over the coming decades. Air temperature projections for the RCP 4.5 (moderate emissions stabilization) scenario are +3.6°F to +6.3°F, with a model average of +5.1°F. Air temperature projections for the RCP 8.5 scenario are +6.5°F to +9.6°F, with a model average of +8.1°F. Projected changes in air temperature will affect all aspects of life in the Delta, especially crop productivity and ecosystems (see Sections 0 and 5.3).

Air temperature increases in higher elevations within the Delta's watershed may be greater than within the Delta itself, with warming greatest at elevations between 5,000 to 8,000 feet (UCLA Center for Climate Science). This differential warming will have important implications for snowpack and water supply (see Section 5.4 and the Water Supply Technical Memorandum).

5.1.2 Precipitation

Climate models project that average annual precipitation may increase slightly across the Delta in the future; however, the magnitude of changes is uncertain and small relative to typical year-to-year variability. There is greater consensus among models that interannual variability in precipitation will increase as a result of climate change.

Projected precipitation trends are the least certain aspects of climate models, as the models are not able to resolve many of the fine-scale and complex interactions that occur locally. Although trends suggest increases in annual precipitation across the Delta (with considerable variability among the models), localized effects due to topography and proximity to the coast may cause variations. The Suisun Marsh and North Delta typically receive higher amounts of precipitation annually and are also projected to experience the largest increases, particularly for an end-of-century high emissions scenario, while the Central and South Delta regions are projected to experience little to no change in precipitation. It is noted that the magnitude of projected changes in annual precipitation is small relative to the typical year-to-year variability historically experienced in California.

While climate models differ on projected changes in average annual precipitation, there is reasonable consensus that future precipitation will become more variable year-to-year. Additionally, precipitation will be concentrated within fewer days of precipitation each year and the large storms that do occur may be more intense (Dettinger et al. 2016). Changes in interannual variability in precipitation will affect Delta ecosystems and water supply (see Section 5.3 and 5.4).

Climate whiplash events—the rapid transition from extreme dry to extreme wet conditions—are projected to occur approximately 25% more often by the end of the century. In addition, it is projected that the frequency of very dry or very wet years will approximately double.

Recent research (Swain et al. 2018) examined the potential for hydrological cycle intensification as a result of climate change. This so-called “climate whiplash” refers to rapid transitions from extreme dry to extreme wet conditions (Swain et al. 2018). While future projections of California’s precipitation indicate fairly small to modest increases in average annual precipitation, the occurrence of extreme wet and extreme dry conditions and drastic transitions between the two may increase. This may result in increased frequency of climate extremes (i.e., very wet or very dry years), increased likelihood of extreme prolonged precipitation events, and increased frequency of precipitation whiplash events.

5.1.3 Sea Level Rise

Sea level rise in San Francisco Bay will affect daily tide and peak storm water levels throughout the Delta. Scientists estimate that sea levels could rise by up to 1.9 feet by 2050 and 6.9 feet by 2100.

Based on current projections, an increase in sea level of 0.6 to 1.1 feet is likely by 2050, with an upper range estimate of 1.9 feet. Beyond 2050, sea level rise depends partly on emissions over the coming decades and the planet’s response to a warmer climate. Under a moderate emissions scenario, an increase in sea level of 1.2 to 2.7 feet is likely, with an upper range estimate of 5.8 feet. Under a high emissions scenario, an increase in sea level of 1.7 to 3.4 feet is likely, with an upper range estimate of 6.9 feet.

Daily tide levels will respond to sea level rise differently across the Delta and Suisun Marsh, depending on the amount of sea level rise, proximity to the Bay, and local hydrodynamic conditions.

In some parts of the Delta, high tide datums (MHHW and MHW) are projected to increase at a faster rate than MSL or the low tide datums (MLLW and MLW) in response to sea level rise (see Flood Hazard Assessment Technical Memorandum). This suggests that the tide range in the Delta may also increase as a result of sea level rise. For 1 foot of sea level rise, this effect is most pronounced in the south Delta, where the tide range is projected to increase by more than 20%. The tide range amplification is progressively less in the north Delta (approximately 10 to 15%) and central Delta (approximately 5%) and negligible in strongly tidally influenced areas such as Suisun Bay, Rio Vista, and lower Yolo Bypass. Changes in mean sea level and tidal dynamics will affect tidal habitats in the Delta (see Section 5.3.5).

5.1.4 Flooding

Climate change will concentrate high runoff events within the core winter months, increasing the likelihood that large inflow events may coincide with high astronomical Bay tide levels during the winter months.

Delta Adapts analysis of future streamflow projections found that future peak inflow events to the Delta are projected to become increasingly concentrated in the core winter months – particularly January and February when king tides typically occur. This concentration of peak inflow events increases the likelihood that a large inflow event would co-occur with a higher than normal astronomical tide. For the RCP 8.5 scenario, the likelihood of peak annual inflow events occurring in January and February increases from 43% historically to 56% by mid-century and 65% by end-of-century.

Climate change will increase the frequency of large runoff events from Delta watersheds and increase peak water levels throughout the Delta. It is estimated that storm runoff to the Delta during extreme events may increase by 44% by mid-century and by 77% by end-of-century.

As discussed in Chapter 3, a warmer climate may contribute to increased frequency and magnitude of atmospheric rivers and a shift in precipitation from snow to rain in higher elevation areas of the Delta's watersheds. These factors will contribute to larger potential runoff and inflows to the Delta during storm events. Analysis of USGS projections of Delta inflows suggest an increase in the 100-year inflow of +44% by mid-century and +77% by end-of-century. This corresponds to an increase in the 100-year total Delta inflow from 632,000 cubic feet per second (cfs) historically to 913,000 cfs by mid-century and 1.1 million cfs by end-of-century.

Due to the high elevation of the San Joaquin basin, it is more sensitive to warming air temperatures, and the rate of increase in San Joaquin runoff will outpace increases in other Delta watersheds such as the Sacramento basin. For an end-of-century high emissions scenario, 100-year inflow to the south Delta from the San Joaquin River may increase by +140% versus a +70% increase for the north Delta from the Sacramento River. These changes could have large implications for future flood risk in different parts of the Delta – for example in the south Delta where peak water levels and flooding are particularly sensitive to inflows from the San Joaquin River.

Climate change will affect peak water levels differently in each region of the Delta. Peak water level changes in the western and central Delta will be driven by sea level rise. Peak water level changes in the north and south Delta will be driven by changes in watershed hydrology.

Delta Adapts performed simulations to identify areas of the Delta where water level changes will be driven primarily by changes in riverine flows versus locations where water level changes will be driven primarily by sea level changes.

Figure 5-1. shows the strongest climate change influence on peak water levels throughout the Delta – either riverine, sea level rise, or transition areas. Transition areas are regions of the Delta where both riverine and sea level rise will influence future peak water levels. Understanding the climate change stressors that will drive flooding and vulnerability is important for adaptation planning and future monitoring of climate changes in the Bay and Delta watersheds. Areas annotated as "riverine" influenced may benefit from investments and adaptations in the Delta watershed, if these investments and adaptations result in reduced peak inflows. Those watershed investments and adaptations will do little for the areas annotated as "sea level rise" influenced. In these areas, adaptation to rising sea levels must be the focus of exposure reduction. In areas annotated as "transition" influenced, adaptation and consideration of both sea level rise and riverine inflows will be important.

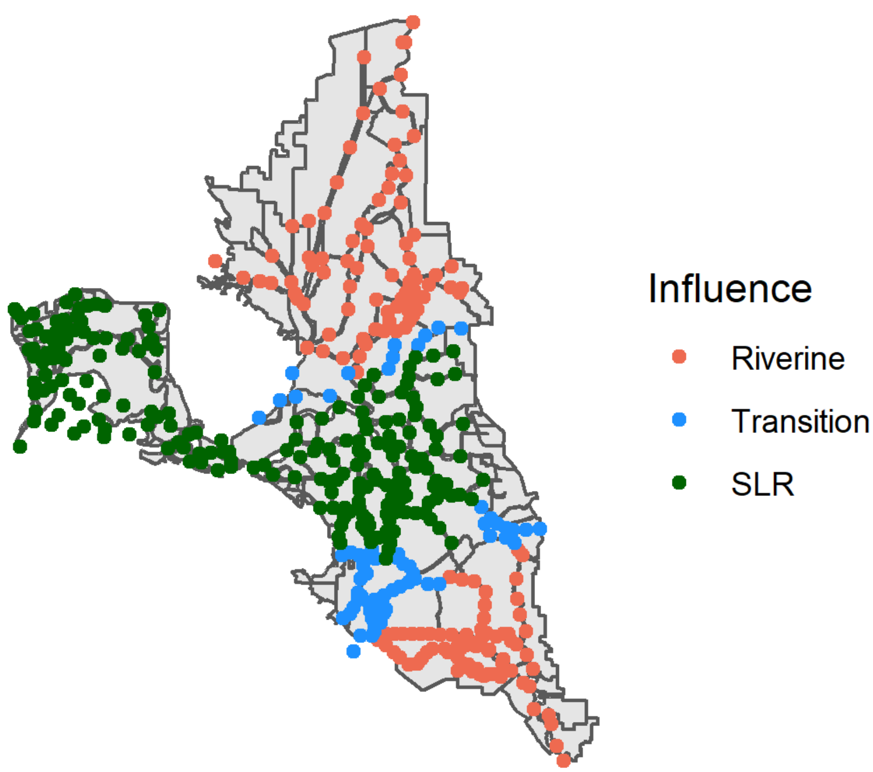

Figure 5-1. Primary climate change influence on peak water levels throughout the Delta.

Sea level rise and changes in hydrologic patterns in Delta watersheds will increase peak water levels and flooding in the Delta in the coming decades, exposing up to 250 square miles of land to flooding by mid-century and up to 600 square miles of land by end-of-century.

Approximately 85 of 1,312 square miles of Delta and Suisun Marsh lands are exposed to flooding under existing conditions by levee overtopping during an event with a 1-percent annual chance of occurrence, primarily in Solano County (Table 5-1). In some places, the existing system of levees that currently protect the Delta from flooding includes up to several feet of freeboard above the 100-year event, providing much of the Delta a buffer against changing hydraulic conditions due to climate change. This freeboard, while effective in reducing existing flood risk, will decrease and potentially be exceeded in the future as peak water levels increase in response to climate change (assuming no future improvements in levee crest elevations).

Table 5-1. Land Area Exposed to Flooding by Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	Existing Area (square miles)	2030 Area (square miles)	2050 Area (square miles)	2085 Area (square miles)
Alameda	0	0	0	<1
Contra Costa	<1	1	16	59
Sacramento	3	3	22	66
San Joaquin	<1	4	121	375
Solano	83	87	92	96
Yolo	<1	<1	<1	<1
Total	86	94	252	596
Increase in exposed area relative to existing conditions	N/A	8	165	510

By mid-century, peak water levels are projected to increasingly exceed existing levee elevations in some parts of the Delta, increasing the likelihood of overtopping and flooding. By 2030, the effects of sea level rise on Delta water levels will expose an additional 8 square miles to flooding. By 2050, the combined effect of sea level rise and changes in riverine inflows exposes an additional 165 square miles to flooding relative to existing conditions. The majority of the increased land area exposed is in unincorporated San Joaquin County. By end-of-century, an additional 510 square miles has a high likelihood of exposure to flooding relative to existing conditions.

5.1.5 Extreme Heat

A warming climate will increase the number of extreme heat days in the Delta. Delta-wide, communities may see six times as many extreme heat days by mid-century and six to 10 times as many extreme heat days by end-of-century, depending on location and future global emissions.

Over the latter half of the 20th century, the Delta experienced approximately four to five extreme heat days per year on average. By mid-century for RCP 8.5, the number of extreme heat days is projected to increase from 4 days per year to 22 days per year on average across the Delta, with a range of 16 to 29 days per year, depending on location. By end-of-century, the number of extreme days is projected to increase to 41 days per year on average across the Delta, with a range of 28 to 53 days per year, depending on location. Yolo and San Joaquin Counties and the cities of Manteca, Rio Vista, Stockton, Tracy, and West Sacramento, and the unincorporated communities of Clarksburg, Country Club, and Lincoln Village are projected to experience the greatest increase in number of extreme heat days. However, the projected increase in the number of extreme heat days relative to historical conditions will affect all Delta communities, and poses risk to residents, businesses, and infrastructure. Projected extreme heat days in Delta Counties, Cities, and Census Designated Places are shown in Table 5-2 through Table 5-4.

Table 5-2. Projected Number of Extreme Heat Days in Delta Counties for RCP 8.5

County	Threshold Temperature (deg F)	Mid-Century (2035-2064) (days)	End-of-Century (2070-2099) (days)
Alameda County	99	19	34
Contra Costa	101	20	36
Sacramento	103	22	40
San Joaquin	102	24	46
Solano	101	21	37
Yolo	102	25	46
Average	**101**	**22**	**41**

Note: Communities have historically been exposed to four to five extreme heat days per year on average.

Table 5-3. Projected Number of Extreme Heat Days in Delta Cities for RCP 8.5

City	Threshold Temperature (deg F)	Mid-Century (2035-2064) (days)	End-of-Century (2070-2099) (days)
Antioch	100	20	37
Benicia	97	17	32
Brentwood	101	20	37
Fairfield	100	18	33
Isleton	104	22	40
Lathrop	103	20	39
Manteca	103	24	44
Oakley	101	20	37
Pittsburg	101	18	34
Rio Vista	104	25	45
Sacramento	104	22	40
Stockton	102	25	47
Suisun City	102	21	37
Tracy	103	24	43
West Sacramento	101	24	44

Note: Communities have historically been exposed to four to five extreme heat days per year on average.

Table 5-4. Projected Number of Extreme Heat Days in Delta Census Designated Places for RCP 8.5

Place	Threshold Temperature (deg F)	Mid-Century (2035-2064) (days)	End-of-Century (2070-2099) (days)
Bay Point	101	17	31
Bethel Island	104	22	40
Byron	101	21	38
Clarksburg	103	28	49
Country Club	102	25	48
Courtland	101	24	43
Discovery Bay	102	22	40
Freeport	103	21	39
French Camp	103	23	43

Hood	101	24	43
Knightsen	101	21	38
Lincoln Village	102	25	48
Mountain House	103	23	41
Terminous	102	24	44
Thornton	102	24	44
Walnut Grove	101	24	43

Note: Communities have historically been exposed to four to five extreme heat days per year on average.

5.2 Delta as an Evolving Place

Delta as an Evolving Place includes the people, places, agriculture, recreation, and infrastructure assets within the Delta. An overview graphic is provided for each asset category, with additional detail provided in key findings statements and supporting narrative. Key findings are discussed for the relevant climate stressors and hazards for each asset category.

5.2.1 People

Climate change related flooding, extreme heat, and other hazards will affect all aspects of life for Delta Populations. The People category focuses on the Delta's communities (counties, cities, and towns), residents, and workers. Figure 5-2 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections.

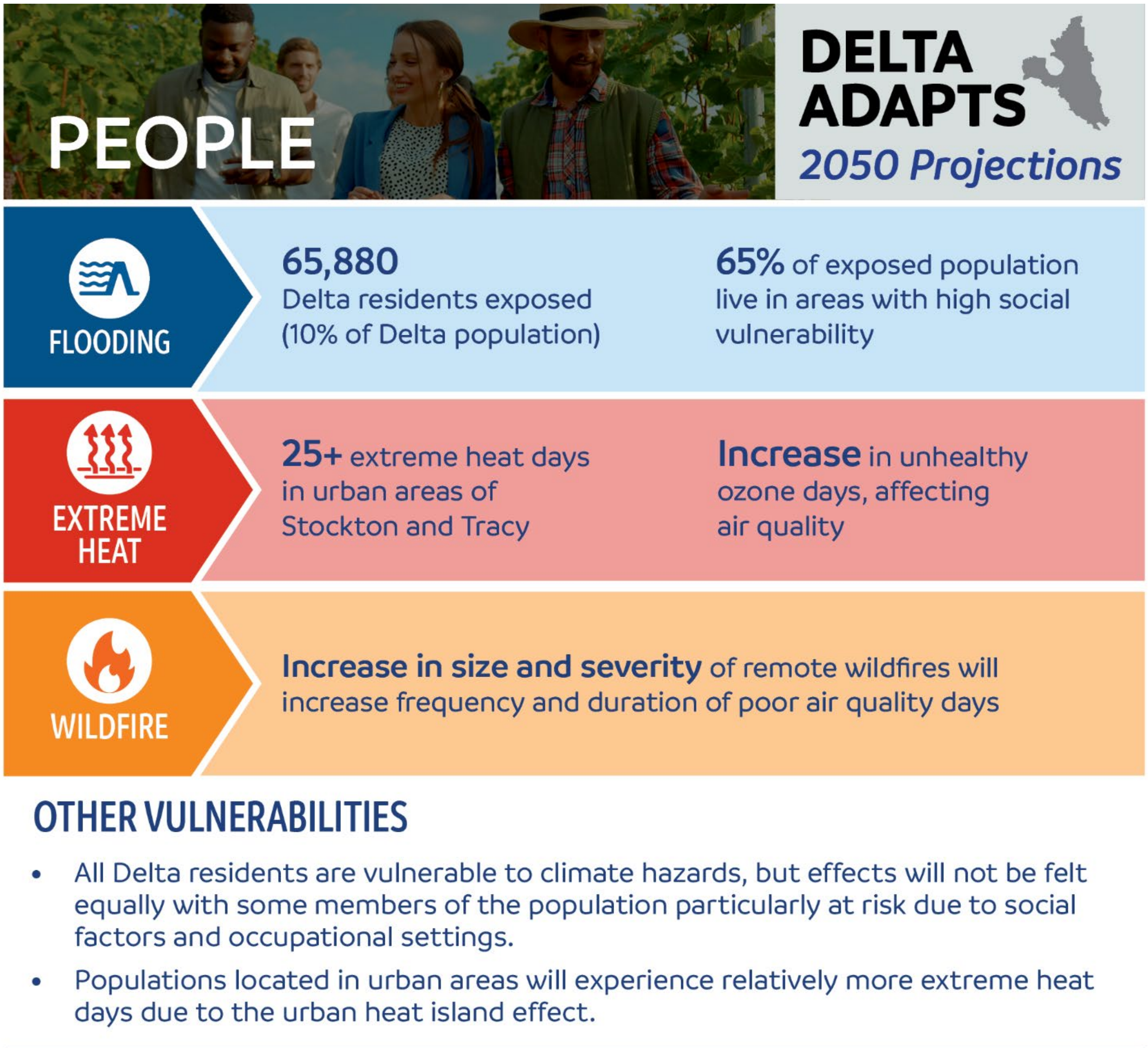

Figure 5-2. Summary of Delta Adapts key findings for people at 2050

Flooding

Approximately 66,000 residents will be exposed to flooding by mid-century, and 133,000 residents will be exposed by end-of-century.

Much of the Delta is protected from flooding by levees, and under current conditions, fewer than 10,000 Delta residents are exposed to flooding by levee overtopping during an event with a 1 percent annual chance of occurrence (primarily in unincorporated San Joaquin County). Sea level rise and changes in hydrologic patterns are not expected to have a significant effect on residents' exposure in the next decade (through 2030), but as sea levels rise and high-flow events become more common, the likelihood of levee overtopping will increase. By 2050, the combined effect of sea level rise and changes in riverine inflows will expose an additional 56,000 residents (approximately 65,880 total) to flooding relative to existing conditions, including an additional 11,440 residents in Lathrop and 29,550 residents in Stockton. By end-of-century, approximately 132,700 Delta residents will be exposed to flooding, including 55,690 residents in Stockton and 11,920 residents in Lathrop. Across all time periods, San Joaquin County residents make up most of the Delta population that is exposed to flooding.

Table 5-5. Population Exposed to Flooding Due to Levee Overtopping During an Event with a 1-Percent Annual Chance Occurrence by County at Each Planning Horizon

County	Existing Population Exposed	2030 Population Exposed	2050 Population Exposed	2085 Population Exposed
Alameda	0	0	75	75
Contra Costa	282	460	2,955	20,315
Sacramento	0	0	1,390	1,730
San Joaquin	9,480	9,480	61,310	109,680
Solano	90	90	155	900
Yolo	0	0	0	0
Total	9,855	10,035	65,880	132,700
Increased population relative to existing	N/A	180	56,030	122,845
Total residing in High and Highest Socially Vulnerable Block Groups	3,230	3,230	42,810	71,170
Percentage of exposed population residing in High and Highest Socially Vulnerable Block Groups	33%	32%	65%	54%

Table 5-6. Population Exposed to Flooding Due to Levee Overtopping During an Event with a 1-Percent Annual Chance of Occurrence by City at Each Planning Horizon

City	Existing Population Exposed	2030 Population Exposed	2050 Population Exposed	2085 Population Exposed
Antioch	280	280	420	1,180
Isleton	-	-	150	150
Lathrop	480	480	11,920	11,920
Manteca	-	-	2,640	2,640
Oakley	-	180	290	3,975
Pittsburg	-	-	1,060	2,000
Rio Vista	50	50	50	50
Stockton	-	-	29,550	55,690
Suisun City	20	20	30	80
Tracy	1,710	1,710	2,225	9,165

Note: See Figure 1-1 for location map. The following cities are found to not have any population exposed to flooding from levee overtopping for the scenarios examined: Benicia, Brentwood, Fairfield, Sacramento, and West Sacramento.

Table 5-7. Population Exposed to Flooding Due to Levee Overtopping During an Event with a 1-Percent Annual Chance of Occurrence by Census Designated Places at Each Planning Horizon

Place	Existing Population Exposed	2030 Population Exposed	2050 Population Exposed	2085 Population Exposed
Bethel Island	-	-	-	1,627
Byron	-	-	-	70
Country Club	-	-	-	9,770
Discovery Bay	-	-	1,040	8,330
Knightsen	-	-	-	1,610
Terminous	-	-	10	10
Thornton	-	-	285	285
Walnut Grove	-	-	100	210

Note: The following places are found not to have any population exposed to flooding from levee overtopping for the scenarios evaluated: Bay Point, Clarksburg, Courtland, Freeport, French Camp, Hood, Lincoln Village, and Mountain House.

Exposure to flooding is particularly disruptive and dangerous for those living in areas with high concentrations of socially vulnerable populations that may have very limited resources for flood impact preparedness and recovery.

Analysis of Delta Adapts flood maps and social vulnerability data indicate that a substantial portion of the Delta's population that is exposed to flooding have a high sensitivity to the hazard. Although all Delta residents are susceptible to floods, block groups with high concentrations of socially vulnerable residents are particularly sensitive. Residents of communities with high or highest social vulnerability (see Section 4.3.2) make up 65% of the population that will be exposed to flooding by mid-century. By end-of-century, 54% of the exposed population resides in highly socially vulnerable communities (Table 5-5). The communities of Stockton, Pittsburg, Antioch, Isleton, Terminous, Thornton, and Walnut Grove would experience a disproportionate impact of flooding, as greater than 80% of the exposed population within these communities is located within highly socially vulnerable block groups. Compared to the Delta as a whole, where 43% of the population is located within block groups with high concentrations of socially vulnerable residents, this represents a disproportionate impact to vulnerable populations.

In communities with lower levels of education and income, residents may lack the resources to adequately prepare for flood events, thereby lowering their adaptive capacity to the hazard (Bell et al. 2016). Linguistically isolated households may not be as aware of flood risks or receive timely warnings (Bell et al. 2016). Households that include young children, older adults, people with disabilities, or lack access to a vehicle may have more difficulty or need additional time to evacuate during an emergency. In addition, people living in nursing homes, prisons, and other institutions have less ability to evacuate on their own and are therefore more vulnerable (Bell et al. 2016; OPR 2018b; Roos 2018).

Extreme Heat

People with greater exposure, heightened sensitivity, or reduced adaptive capacity to extreme heat are more likely to experience adverse health effects during extreme heat events. These include outdoor workers, older adults, young children, people experiencing homelessness, people with certain existing health conditions, among others, and incarcerated populations.

Exposure to extreme heat can cause cramps, fainting, edema, and heat exhaustion, which are all readily treatable conditions if a person is able to quickly relocate to a cool environment and rehydrate. If a person does not have immediate access to a cooler environment at the onset of heat stress and exhaustion, and is not able to recover, these conditions may become more serious and progress to heat stroke, which can cause death from cardiac failure, suffocation, and kidney failure (McCall 2018). Individuals that lack health insurance may face more difficulty accessing care for these conditions (Fowler et al. 2010; OPR 2018b).

People that work in outdoor occupations, such as emergency response, agriculture, and construction, are more exposed to extreme heat and are more sensitive because body temperatures are elevated during strenuous activity (Gamble et al. 2016). Heat stress can be a particularly high occupational hazard in the Delta's agricultural industry. There is a significant proportion of the Delta's agricultural workforce characterized by diverse ethnic backgrounds and language and cultural barriers may impact workplace safety during extreme heat days (Hansen et al. 2013). In addition, extreme heat accelerates ozone formation and creates air stagnation that can trap air pollutants at ground level (Shen et al. 2016), exposing outdoor workers to poor air quality and unhealthy working conditions (McCall 2018).

Older adults, people with mental illness, children and infants, and individuals suffering from chronic illnesses are also more sensitive to the effects of extreme heat (Hajat et al. 2007; Knowlton et al. 2009; Kovats et al. 2004; Gamble et al. 2016; OPR 2018b; Ebi & Paulson 2007; Gamble et al. 2016). Existing health disparities among low-income communities and people of color result in these group also being disproportionately impacted by extreme heat (OPR 2018b; Shonkoff et al. 2011).

The primary adaptation strategy for individuals is to use air conditioning or to evacuate to a cooling center or other, cooler location. Therefore, Delta residents without access to air conditioning have a lower adaptive capacity to extreme heat conditions. For example, individuals experiencing homelessness, incarcerated populations without adequate air conditioning, renters without an option to install air conditioning, low-income people who may not be able to afford using air conditioning during peak demand, and households without access to a vehicle are all more vulnerable to extreme heat events (OPR 2018b; Montanya & Valera 2016; Gamble et al. 2016; Shonkoffet al. 2011).

The communities most vulnerable to extreme heat are located in Stockton and Tracy. These communities have high urban heat island effects and high concentrations of people who are more socially vulnerable to heat impacts. By mid-century, these communities are projected to experience approximately 25 extreme heat days per year compared to 5 days per year currently – a five-fold increase.

While people with greater exposure, heightened sensitivity, or reduced adaptive capacity to extreme heat live and work throughout the Delta, the population characteristics that increase vulnerability are more concentrated in some communities. Communities within the cities of Antioch, Pittsburg, Stockton, Tracy, West Sacramento, and unincorporated San Joaquin County have higher incidences of asthma, disabilities, poverty, linguistic isolation, and other factors that have been found to increase vulnerability to the health impacts of extreme heat. Of these, the cities Stockton and Tracy are projected to experience the highest number of extreme heat days per year by mid-century.

The built environment also plays a significant role in extreme heat events. In urban areas, impervious surfaces and scarcity of vegetation create urban heat islands – regions that are hotter than surrounding rural areas (Altostratus Inc. 2015; Oke 1989; Oke 1982). Low-income communities and communities of color are overrepresented in urban areas that have higher rates of impervious cover and less tree cover and are therefore more likely to be exposed to the urban heat island effect (Shonkoff et al. 2011). In the Delta, the urban heat island effect is greatest in Tracy and South Stockton and along the Highway 4 corridor in East Contra Costa County.

Other Climate Hazards

Although climate change is not expected to greatly affect the frequency or severity of wildfires in the Delta, projected changes in wildfire risk in other parts of the state and the western U.S. will increase the occurrence of hazardous air quality conditions in the Delta.

Wildfire smoke is a significant source of fine particulate matter, carbon monoxide, ozone, and toxic chemicals (Lipsett et al. 2008; McCall 2018). Toxic chemicals in wildfire smoke, such as formaldehyde and benzene, are believed to contribute to long-term adverse health impacts such as heart and lung disease and cancer (Stone et al. 2019). Infants, children, pregnant women, older adults, and people with existing heart and lung conditions are particularly sensitive to these air pollutants. As with the other climate change hazards described in the CCVA, existing health disparities among low-income communities and people of color result in these groups having a higher sensitivity and being disproportionately impacted by poor air quality (Stone et al. 2019).

Reducing exposure to wildfire smoke involves adaptation measures similar to those recommended for extreme heat: staying indoors, using air conditioning (or air filters), or evacuating (Stone et al. 2019), which may not be possible for some Delta residents. Thus, these same populations face increased exposure and reduced adaptive capacity to wildfire smoke: outdoor workers, individuals experiencing homelessness, low-income households, renters, households that lack vehicle access, and some racial and ethnic groups (Stone et al. 2019).

5.2.2 Places

Climate change related flooding, extreme heat, and other hazards will impact the places of the Delta, including cultural resources (legacy communities, historic places, and landmarks), critical facilities, residential areas, and commercial and industrial areas. Figure 5-3 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections.

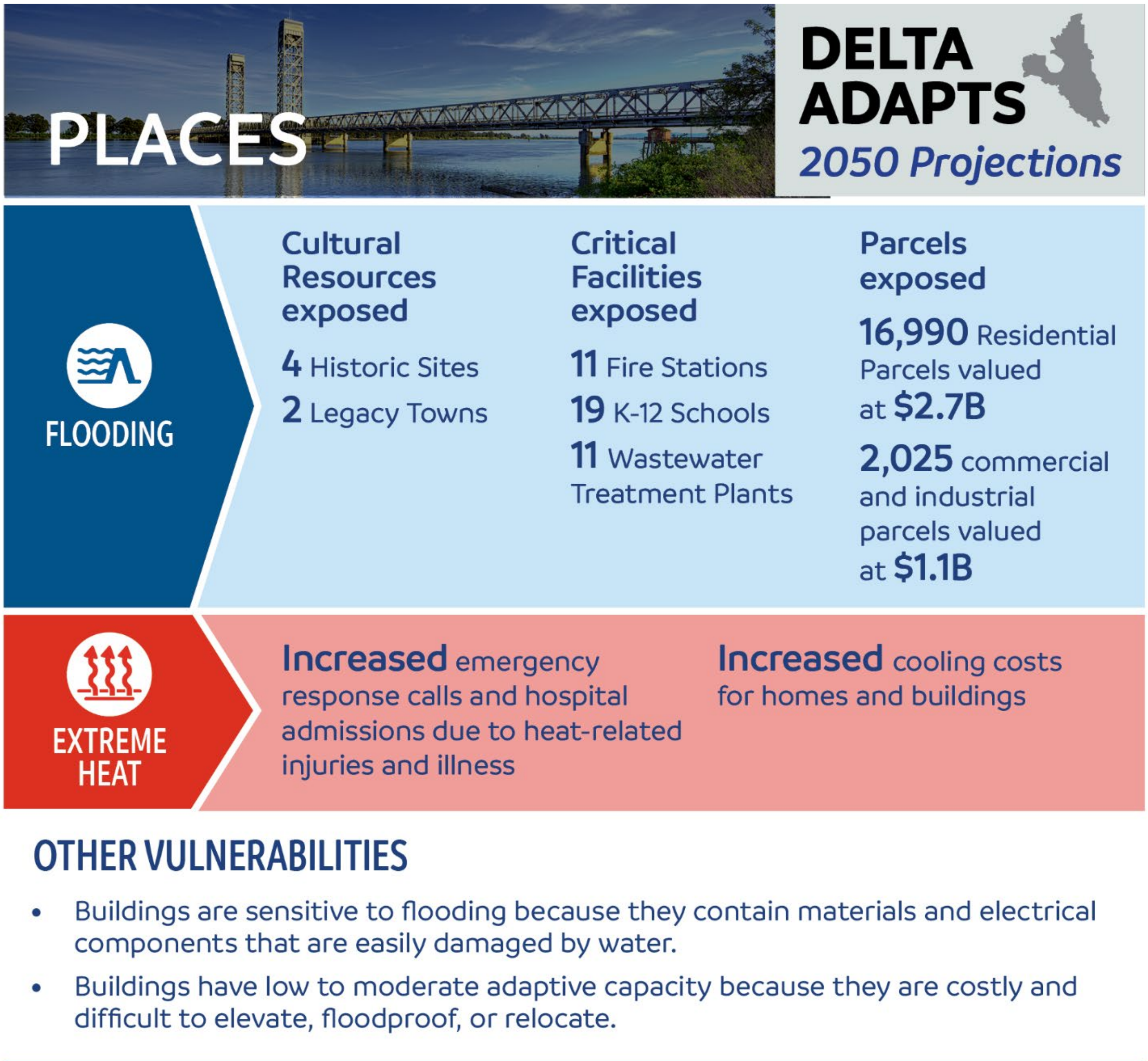

Figure 5-3. Summary of Delta Adapts key findings for places at 2050

5.2.2.1 Cultural Resources

Cultural resources include the legacy communities of Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Rio Vista, Ryde, Locke, and Walnut Grove, historic places, and landmarks.

Flooding

Flood impacts to the Delta’s cultural resources could damage or destroy landmarks that played a pivotal role in the region’s history.

Cultural resources have an intangible value. They provide links to the history and culture of the Delta. Many cultural resources in the Delta are already in need of preservation, irrespective of flood risk. Sites identified as legacy communities, historic places, and landmarks are particularly vulnerable to flooding. They typically consist of buildings with materials and electrical components that are easily damaged by floodwaters, giving them a moderate to high sensitivity to flooding. Elevating or floodproofing poses challenges for any structure, but historic structures have unique challenges and limited adaptive capacity. Even when it is physically possible to protect a cultural or historic asset, such changes may degrade the details that inform interpretation of its history or limit its accessibility to the public. Their loss due to flood damage would eliminate a source of history of the Delta and its residents, resulting in major or catastrophic consequences of flood exposure for these assets and resources.

Six culturally significant sites will be exposed to flooding by mid-century and 12 culturally significant sites will be exposed by end-of-century.

Four historic places, including the Terminous Culling Chute, Sperry Office Building, and Sperry Union Flour Mill in San Joaquin County, and the Isleton Chinese and Japanese Commercial Districts in Sacramento County will be exposed to flooding by levee overtopping by 2050. Legacy communities exposed to flooding by levee overtopping by 2050 include Rio Vista and Isleton. By end-of-century, an additional five historic places are exposed to flooding, with four located in San Joaquin County

Culturally Significant Sites Exposed to Flooding by Mid-Century

Terminous Culling Chute – Former site of a three-story, wood-frame culling chute constructed by the Western Pacific Railroad in 1927 on the banks of Little Potato Slough in San Joaquin County. The chute was used to load celery, potatoes, onions, and asparagus onto trucks for transport to area farms.

Sperry Office Building and Sperry Union Flour Mill – 19^{th} century red brick commercial building constructed in 1888 and former site of a mill owned by the Sperry Flour Company, both located in Stockton. Named after Austin Sperry, a pioneer grain miller who founded a small barley and graham flour mill in 1852 in Stockton which went on to become the Sperry Flour Company, the largest flour miller in California at the end of the 19^{th} century, shipping products throughout the nation and worldwide.

Isleton Chinese and Japanese Commercial Districts – The latter half of the 19^{th} century and early 20^{th} century saw an influx of Chinese and Japanese workers to the Isleton area. Primarily agricultural workers initially, merchants followed and helped establish a bustling and prosperous Asian-American community that grew dramatically into the 1920s up until the outbreak of World War II. Today the district retains connections to the past through local families, businesses, and architecture.

and one in Contra Costa County. The Legacy Town of Bethel Island is also exposed by end-of-century, as shown in the Cultural Resources flood exposure maps in Appendix B.

Extreme Heat

Without modifications to accommodate extreme heat conditions, the continued use of many Delta historic buildings is at risk.

Historic and cultural sites have a low sensitivity to extreme heat because they are unlikely to experience damage during a heat wave; however, cultural and historic sites typically have a low adaptive capacity to extreme heat, particularly when compared to more modern buildings that can be easily retrofitted (e.g., replacement of windows, adding insulation, cool roof, etc.) to increase the energy efficiency of the cooling system. This means that people's ability to gather and use these sites during extreme heat days will become increasingly limited, particularly for sensitive health groups. There are more restrictions on modifying historic buildings due to the need to preserve the historic character of the site, which can restrict actions to improve the building's ability to maintain a comfortable interior temperature. Extreme heat exposure of cultural sites will have minor to moderate consequences, primarily related to the comfort of staff and visitors for indoor and outdoor facilities. These sites will also likely experience an increase in cooling costs if strategies to increase building energy efficiency are unable to be put in place due to restrictions necessary to preserve the site's historic character.

Other Climate Hazards

No other climate hazards for cultural resources were evaluated by Delta Adapts.

5.2.2.2 Critical Facilities

Critical facilities provide essential services to the Delta community. In order to provide ongoing services, the structures, utilities, and staff of critical facilities must remain operational even during extreme events. Critical facilities include life safety facilities (fire stations, police stations, and hospitals), schools (public and private), wastewater treatment plants, and prisons. Note that only one Delta prison – the Deuel Vocational Institution – is exposed to flooding under the scenarios evaluated and it is slated for closure in 2021.

Flooding

Eleven life safety facilities (fire stations, police stations, and hospitals) will be exposed to flooding by mid-century and 19 life safety facilities will be exposed by end-of-century.

Flooding of life safety critical facilities due to levee overtopping during an event with a 1-percent annual chance of occurrence would disrupt core community services and adversely affect public health and safety. By mid-century, eleven fire stations with an estimated total replacement cost exceeding $25 million – including stations in Isleton, Lathrop, Oakley, Rio Vista, Stockton, and Terminous – will be exposed to flooding by levee overtopping. By end-of-century, an additional six fire stations, one police station, and one hospital (Dameron Hospital in Stockton) will be exposed to flooding by levee overtopping. Exposed life safety facilities are shown in the Critical Facilities flood exposure maps in Appendix B.

Older buildings may contain electrical equipment and materials on the first floor that could be damaged by flood exposure, depending on flood depths and conformity with modern building codes, making them moderately to highly sensitive to flooding. Hospitals house people with existing health conditions, who are highly sensitive to equipment and operational failures during flooding. Hospital patients are further vulnerable because they have less ability to evacuate on their own (Bell et al. 2016; OPR 2018b; Roos 2018).

Life safety facilities have moderate adaptive capacity. Floodproofing at building entryways or perimeter floodwalls can prevent damage from temporary flooding conditions; however, floodproofing individual buildings in deeply subsided Delta islands may not be a feasible approach to provide redundant protection for these facilities. Elevating or waterproofing electrical and mechanical equipment, or installing backup power sources, can reduce operational vulnerabilities. However, emergency response operations are also dependent on clear access routes from the ground floor entrance and connections to the region’s transportation network. If a life safety facility, such as a fire station, is temporarily inoperable, it is common practice for the closest station to assume responsibility for covering the service population, providing some built-in redundancy. However, this will increase the distance between essential services and response times as well as limit the capacity of staff and facilities able to respond.

Nineteen schools will be exposed to flooding by mid-century and 41 schools will be exposed by end-of-century.

The majority of schools (public and private) exposed to future flooding due to levee overtopping during an event with a 1-percent chance annual chance of occurrence are located in the City of Stockton and the larger San Joaquin County area. Schools are highly sensitive to flooding because floodwater entering the building could cause damage to the building and affect the safety of staff and students. Flood exposure would likely force schools to close until floodwaters recede and repairs could be made to the building to ensure safe occupancy. Schools have moderate adaptive capacity because students could be temporarily or permanently redistributed to neighboring districts, use temporary trailers, or use remote learning capabilities to continue their education. School buildings could also be retrofitted with flood proofing techniques to withstand temporary flood events; however, floodproofing individual buildings in deeply subsided Delta islands may not be a feasible approach to provide redundant protection for these facilities. Exposed schools are displayed in the Critical Facilities flood exposure maps in Appendix B.

Exposure to flooding has the potential to have catastrophic consequences for schools. The greatest concern is for the safety of students and staff, which may be compromised by episodic flood events. Direct exposure to floodwaters could also damage the building, requiring costly repairs or replacement. Many schools are also designated emergency shelters and loss of schools could reduce the number of shelters available during emergencies.

Eleven wastewater treatment plants will be exposed to flooding by mid-century and 17 plants will be exposed by end-of-century.

Wastewater treatment plants (WWTP) protect public health and the health of adjacent waters. WWTPs tend to be located at low elevations near waterways, to facilitate collection and discharge of treated wastewater. The majority of Delta WWTPs exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence by mid-century are in San Joaquin County, where eight of the eleven exposed facilities are located. By end-of-century, the greatest number of additional exposed WWTPs is distributed between San Joaquin County (nine) and Contra Costa County (six). WWTPs contain numerous pumps and other electrical and mechanical equipment, as well as treatment basins. Each component of a WWTP has varying sensitivity to flooding. Individual pumps may have backup power generation available, providing some redundancy and supporting continued operation. However, flooding of a treatment basin may overwhelm the system and cause sewage overflows. WWTP operations may also be affected even if levee overtopping does not occur if floodwaters overwhelm pump capacity or prevent outfalls from functioning. Exposed WWTPs are depicted in the Critical Facilities flood exposure maps in Appendix B.

Adaptive capacity of an entire WWTP is low to impractical. Although there is some ability to adapt WWTPs to temporary flood events through floodproofing specific plant components and entryways, there is typically no alternate facility to continue treating wastewater if the WWTP has lost service or exceeded its capacity. Damage to WWTPs could have catastrophic consequences, such as local and systemwide backups and overflows of untreated sewage into adjacent neighborhoods and waterways, which would cause serious public health and environmental impacts. In addition, WWTPs are high value assets that may be prohibitively expensive to rebuild or relocate – the 11 WWTPs exposed to flooding by 2050 have an estimated replacement cost exceeding $3 billion.

Extreme Heat

Extreme heat will impact the Delta’s critical facilities, particularly the emergency response facilities of fire, police, and hospitals.

Buildings associated with most critical facilities generally have a higher sensitivity to extreme heat than other building types (e.g., residential) because they often face restrictions that compromise thermal regulation. For example, the structural design of hospitals may need to consider safety protocols (e.g., restricting the opening of windows). Similarly, firehouses may be restricted by fire apparatus station designs to minimize dispatch times (e.g., leaving station bay doors open and relying on industrial fans for cooling). Industry-specific regulations may reduce the adaptive capacity of critical facilities, but there are some retrofits (e.g., added insulation and light-colored roofs) that can be implemented to increase energy efficiency of the building’s cooling system.

Without adaptation, extreme heat conditions will have moderate consequences across the Delta. Extreme heat may impair the functionality of hospitals, affecting the thermal comfort of patients and staff and ability to efficiently store medicines. Extreme heat days are also likely to increase the number of emergency response dispatch calls and hospital admissions related to heat-related injuries, placing an increased demand on emergency response facilities and resources.

Other Climate Hazards

No other climate hazards for critical facilities were evaluated by Delta Adapts.

5.2.2.3 Residential Areas

Residential areas include Delta residential property parcels and physical housing structures. The Delta is characterized by a combination of rural and urban residential areas and structure types including single family units, apartment buildings, condominiums, and mobile homes.

Flooding

Flooding due to climate change will directly impact the households of Delta residents. By mid-century, 17,000 residential parcels with structure improvements valued at $2.7 billion will be exposed to flooding. By end-of-century, 37,500 residential parcels will be exposed to flooding.

As noted in Section 5.2.1, existing exposure to flooding from levee overtopping is relatively low. By 2030, exposure of residential property to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence is expected to increase marginally to 1,220 parcels, with structural improvements valued at $200M. The number of dwelling units exposed is likely much higher, as apartment buildings, condominiums, and mobile home parks typically have multiple units on a single parcel. Residential exposure increases significantly by mid-century to 17,000 parcels with structural improvements valued at approximately $2.7 billion. At mid-century, more than 90% of exposed parcels are located in San Joaquin County (primarily Stockton, Lathrop, Manteca, and Tracy). By end-of-century, 37,500 residential parcels are exposed to flooding, with 74% in San Joaquin County and 24% in Contra Costa County (primarily Discovery Bay, Oakley, Antioch, and Pittsburg).

Table 5-8. Residential Parcels Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	Existing Parcels Exposed	2030 Parcels Exposed	2050 Parcels Exposed	2085 Parcels Exposed
Alameda	0	0	4	4
Contra Costa	69	77	968	8,894
Sacramento	0	0	635	713
San Joaquin	1,119	1,119	15,352	27,813
Solano	23	24	29	64
Yolo	0	0	0	0
Total	1,211	1,220	16,988	37,488

Residential structure vulnerability to flooding depends on the age of the building, construction techniques, foundation type, building materials, and other characteristics. Newer structures are more likely to be adapted in their design to allow flood waters to pass beneath unimpeded or elevated to a height above flood waters. Therefore, elevated structures that are exposed to flooding are less likely to have irreparable damage compared to slab-on-grade structures, making them less sensitive to the hazard. Mobile homes are particularly vulnerable to flooding due to the physical characteristics of the structures. Factors increasing the sensitivity of mobile homes include the use of unreinforced piers (dry-stacked blocks), lack of corrosion-resistant materials, and limited anchoring to foundations. Out of the 79 mobile home parks within the Delta, 19 are exposed to flooding by mid-century, and 35 by end-of-century. Of the mobile home parks that are exposed by mid-century, many are located in unincorporated areas - including six on Brannan-Andrus Island, four on New Hope Tract, and four on various islands in the South Delta. By end-of-century almost all mobile home parks outside of West Sacramento and the coastal cities of Contra Costa County are exposed to flooding. Residential units and parcels have moderate ability to adapt through the elevation of individual structures. However, it is a costly option that many homeowners are unable to afford.

Extreme Heat

See discussion of extreme heat impacts to Delta residents in Section 5.2.1.

Other Climate Hazards

No other climate hazards for residential areas were evaluated by Delta Adapts.

5.2.2.4 Commercial and Industrial Areas

Commercial and industrial areas include the physical assets used to carry out commercial activities in the Delta such as commercial storefronts, warehouses, and offices.

Flooding

Flooding due to climate change will directly impact commercial and industrial activities in the Delta, including buildings, facilities, and economic activity. By mid-century, 2,000 commercial and industrial parcels with structural improvements valued at $1.1 billion and $1.8 billion in annual net revenues will be exposed to flooding. By end-of-century, 3,800 commercial and industrial parcels will be exposed to flooding.

Exposure to flooding will impact both the physical structures within the Delta that support commercial and industrial activities as well as disrupt economic activity associated with these businesses. Table 5-9 shows the economic value of commercial buildings and structures exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence at 2030 and 2050. Table 5-10 shows the annual commercial economic activity exposed to flooding. Exposed commercial activity at 2030 is relatively low compared to the Delta's annual economic activity of $33 billion; however, exposed commercial economic activity increases dramatically by 2050. Nearly all of the exposed commercial activity is in San Joaquin County, where more than $1 billion in annual commercial economic activity is exposed.

Table 5-9. Economic Value of Commercial Buildings and Structures Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	2030	2050
Alameda	None	<$1M
Contra Costa	$4M	$14M
Sacramento	None	$21M
San Joaquin	$34M	$1.05B
Solano	$5M	$5M
Yolo	None	None
Total	**$43M**	**$1.09B**

Note: Value of commercial property includes buildings and physical infrastructure but does not include the value of the land itself.

Table 5-10. Commercial Activity (Annual Net Revenues) Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	2030	2050
Alameda	None	None
Contra Costa	$47M	$180M
Sacramento	None	$82M
San Joaquin	$117M	$1.48B
Solano	$18M	$23M
Yolo	None	None
Total	**$182M**	**$1.76B**

Commercial and industrial areas have a high sensitivity to flooding. Warehouses, storefronts, and office buildings typically include electrical equipment and building materials that may experience widespread structural damage to even temporary flood exposure. Products and materials housed inside commercial buildings are also likely sensitive to flooding, posing cascading economic impacts to the facility and dependent economic activities. Buildings associated with commercial and industrial areas have limited adaptive capacity because they are not easily elevated or relocated; however, it is possible to flood proof points of entry (e.g., doors and vents) to eliminate or reduce potential flood pathways during temporary flood events.

Extreme Heat

See discussion of extreme heat impacts to Delta workers in Section 5.2.1.

Other Climate Hazards

No other climate hazards for commercial and industrial areas were evaluated by Delta Adapts.

5.2.3 Agriculture

Agriculture is the prevailing land use within the Delta and its cultural backbone, driving the economy and surrounding communities and providing the majority of employment in the Delta's Primary Zone (Medellín-Azuara et al. 2012). The majority of the Delta is considered Prime Farmland, and a significant remainder of the land is considered Farmland of Statewide Importance, or Farmland of Local Importance. Dozens of crops are currently grown in the Delta, covering approximately 55% of its land. Warming temperatures, extreme precipitation events, increased flood levels, subsiding land, and levee seepage currently pose and will continue to increase and further pose unique challenges for Delta agriculture in the future. The Delta Adapts Crop Yield and Agricultural Production Technical Memorandum reviews anticipated biophysical impacts of climate change on Delta crop production and suitability and discusses agro-social and agro-economic considerations for the Delta. Figure 5-4 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections.

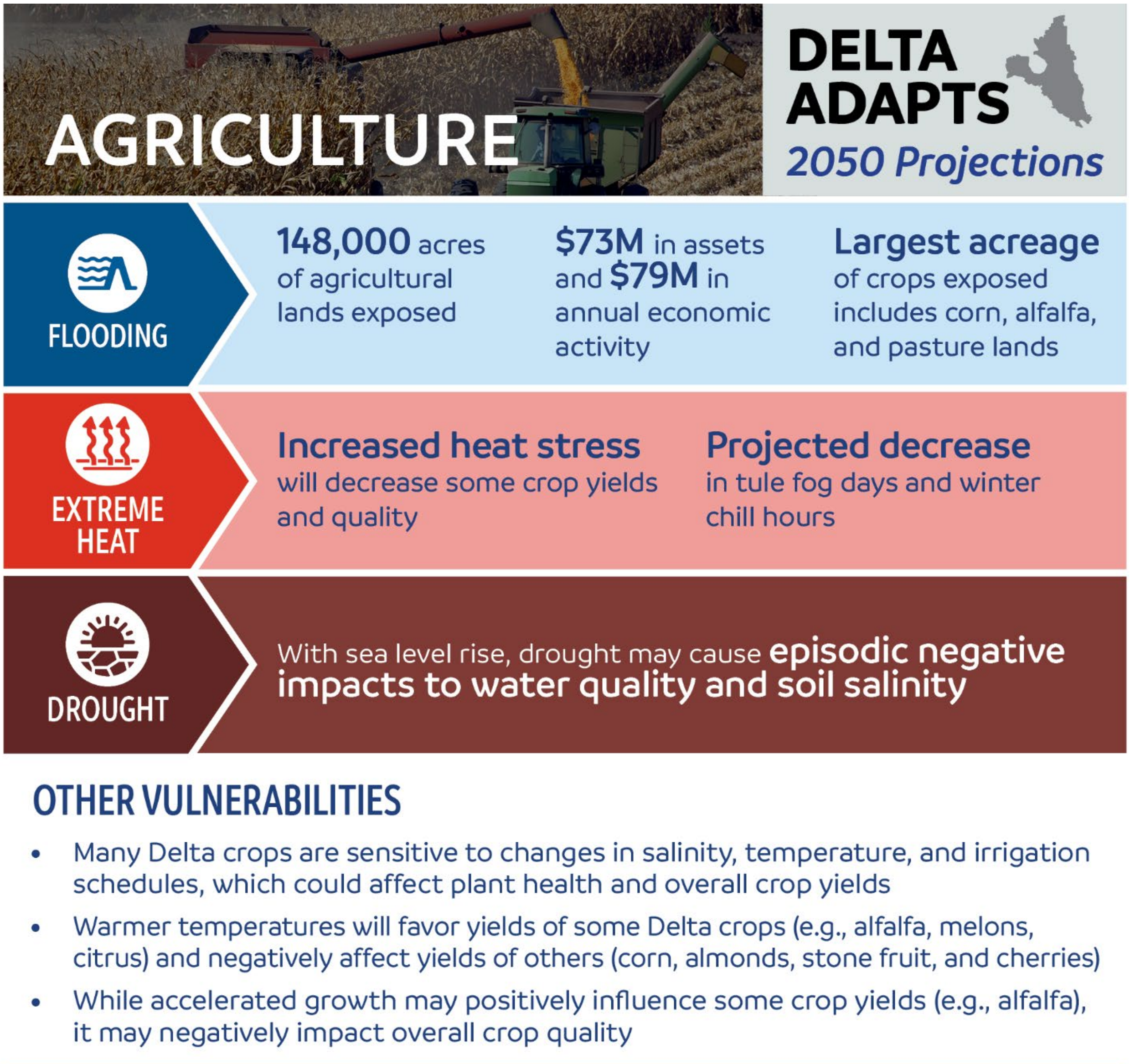

Figure 5-4. Summary of Delta Adapts key findings for agriculture at 2050

5.2.3.1 Climate Stressors

Temperature

Some Delta crop yields will respond positively and others negatively to longer, hotter summers as a result of climate change; however, warming temperatures, increased temperature variability, and temperature-related water stress will decrease yields for the majority of Delta crops.

Current agricultural practices in the Delta are optimized, through irrigation, to California's wet winters and dry, hot summers but may be negatively impacted by climate change induced warming through 2100. Delta crops have varying sensitivities to changes in air temperature.

Temperatures influence metabolic processes and photosynthesis rates, which impact evapotranspiration and water needs, overall growth, leaf morphology, development, nutritional quality, flavor, flowering and pollination timing, and fruit production (Cavagnaro et al. 2006). Longer and hotter summers will influence each crop differently (with winners and losers), but generally will result in overall reduced yields and quality of the current crop assemblage in the Delta.

Crops projected to experience a medium decline in yields (10% to 20% decrease) due to warmer temperatures include almonds, asparagus, carrots, cucurbits (e.g. melon, pumpkin, squash, cucumber), and some truck crops (Medellín-Azuara et al. 2018; Lobell and Field 2011; Pathak et al. 2018). Fruits are highly sensitive to hotter summers, especially during development. Crops projected to experience a large decline in yields (more than 20% decrease) due to warmer temperatures include cherries and other stone fruit (Lobell and Field 2011). It is important to note, however, that these predictions are derived from studies in the greater Central Valley, which is projected to be approximately 2.0°F warmer than projections for the Delta (Cal-Adapt 2017). In this way, the Delta and Suisun Marsh may serve as a thermal refuge for crops that would otherwise be subject to more temperature stress elsewhere in the Central Valley.

Some crops such as alfalfa, forage grass, and tomatoes are expected to experience small increases in yields (up to 10%) due to warmer temperatures and hotter summers; however, quality may be reduced (Pathak et al. 2018; Izaurralde et al. 2011; Medellín-Azuara et al. 2018). Other crops such as wine grapes, almonds, and walnuts have limited temperature sensitivities and are expected to experience little change in yields due to warming summer temperatures (Lobell et al. 2006, Webb et al. 2012).

Agriculture in the Delta has some inherent ability to adapt to temperature changes. Some crops may benefit from increased irrigation to offset the effects of warmer temperatures while more extreme measures, such as switching to crops with lower temperature sensitivities, may also be considered.

Warmer winters with fewer chilling hours as a result of climate change will reduce yields of most fruit and nut trees in the Delta.

Yields of most fruit and nut orchards grown in the Delta are highly sensitive to winter chill hours (winter temperatures below 45 degrees) to achieve sufficient dormancy to develop buds, flowers, and fruit (Campoy et al. 2011; Luedeling 2012). Sustained winter temperatures below 45 degrees are largely maintained in the Delta by prolonged periods of radiative tule fog, the occurrence of which has been decreasing since the early 1980s due to a combination of reduced air pollutants (which enhance the development of the fog) and increasing air temperatures caused by climate change (Gray et al. 2019). A reduction in the number of tule fog days will increase the amount of sunlight orchards will receive, thereby increasing the maximum air temperature experienced during the day and reducing the number of accumulated winter chill hours (Baldocchi and Waller 2014).

Reduction in winter chilling hours will have detrimental effects on yield of fruit and nut trees, which are high value crops in the Delta. By mid-century, the Delta climate may still be suitable for almond, fig, olive, persimmon, pomegranate, chestnut, pecan, and quince trees, but not pear, cherry, apple, apricot, kiwifruit, peach, nectarine, plum, or walnut trees (Luedling et al. 2009). By 2100, the Delta is not likely to have sufficient chilling hours to ensure success of many orchards. The end of the century is projected to only permit almond, fig, olive, persimmon, and pomegranate tree success (Luedling et al. 2009).

Precipitation and Hydrologic Patterns

Delta farmers will face increased uncertainty and impacts due to extreme precipitation events and increased interannual variability in precipitation.

Rainfall in the Delta is projected to become more unpredictable and variable in the future due to climate change. Unexpected downpours and winter atmospheric river events may disrupt agricultural schedules or compound with other winter water impacts (Pathak et al. 2018), later spring extreme precipitation events can wash away pollen on fruit trees during flowering (Pathak et al. 2018), and successive rainfall events on fully saturated soil may lead to additional soil erosion and nutrient loss. Lack of rainfall during dry years may impact effective soil salinity management in parts of the Delta (Aegerter and Leinfelder-Miles 2016).

Sea Level Rise

Sea level rise may increase salinity exposure of crop and range lands in some regions of the Delta, especially during droughts.

Salinity is not a new stressor for Delta agriculture and farmers appropriately match irrigation methods and time irrigation with soil type, draining conditions, and twice daily tidal changes. However, some Delta soils have low permeability and shallow groundwater, making soil salt accumulation a problem for some farmers, especially in the summer season (Aegerter and Leinfelder-Miles 2016). At present, in-Delta irrigation water salinity varies by region and water year type, and consequently, crops that are more vulnerable to salinity, such as vineyards and nut trees, are grown in the northern Delta rather than the somewhat saltier southern Delta (Chaudhry et al. 2020).

Sea level rise will continue to place additional stress on the operation of the State Water Project and Central Valley Project, and the ability of the projects to continue to meet water quality requirements in the Delta. However, the system already has some adaptive capacity built into the operations through anticipated mid-century conditions. Modeling conducted for Delta Adapts shows that current regulatory water quality requirements, including salinity requirements, can be met in most year types for future conditions up to at least two feet of sea level rise (through mid-century and potentially longer, depending on the amount of sea level rise), though this requires trade-offs with impacts to water storage and Delta exports. Short-term and potential extreme increases in salinity intrusion into the Delta during droughts are likely to increase as described below in Section 5.4.

Existing Delta crops range from salt-tolerant to sensitive, with the highest acreage considered moderately sensitive (Chaudhry et al. 2020). Truck crops, corn, alfalfa, melons, and squash are moderately sensitive to salt, while vineyards, fruit and nut orchards, berries, and beans are sensitive, and grains, field crops, and olives tend to be moderately tolerant (Chaudry et al. 2020).

Towards end-of-century, increases in salinity or salinity variability may encourage transitions in some regions from more sensitive higher value truck and vineyard crops to less sensitive lower value crops at the same time levee maintenance and pumping costs increase.

Sea level rise and land subsidence will increase rates of levee seepage, raise groundwater levels on islands, and expand wet, non-farmable, and marginally farmable areas in the Delta.

Sea level rise will raise in-channel water levels throughout the Delta in the future. Coupled with land subsidence on the interior of Delta islands, sea level rise will increase seepage onto islands and increase under-seepage exit gradients in drainage ditches adjacent to levees, which can detrimentally affect levee stability. It is estimated that most of the increased seepage onto islands will be the result of thinning of organic soils and compensatory drainage-ditch deepening. Groundwater modeling of future conditions indicates that island groundwater level change associated with a projected sea level rise of 12 inches will be about 2 to 4 inches by 2050 (Deverel et al. 2015).

In addition to increased seepage, exit gradients, and the potential effects on levee stability, Deverel et al. (2017) concluded that future subsidence and sea level rise will cause increased seepage and drain flows on subsided Delta islands. In response, more pumping will be required in the future to deal with increased rates of seepage and farmers will face larger impacts from seepage inside levees. Moreover, Deverel et al. (2015) used available data to estimate the expansion of wet, non-farmable, and marginally farmable (WNMF) areas in the Delta from 1984 to 2012 and developed a conceptual model to assess expansion of WNMF in the Delta due to future sea level rise and subsidence. This research suggests a doubling of the existing WNMF areas from 6,900 acres in 2012 to 15,500 acres by 2050 as a result of future sea level rise and ongoing subsidence.

5.2.3.2 Climate Hazards

Flooding

Approximately 148,000 acres of agricultural lands, $73 million in agricultural assets, and $79 million in annual agricultural economic activity will be exposed to flooding by mid-century. Approximately 257,000 acres of agricultural lands will be exposed by end-of-century.

Approximately 43,000 acres of agricultural lands in the Delta and Suisun Marsh are exposed to flooding due to levee overtopping during an event with a 1-percent chance annual chance of occurrence under existing conditions, representing approximately 10% of the 418,000 acres of Delta agricultural lands. The largest acreages of exposed agricultural lands under existing conditions are Delta alfalfa (10,000 acres) and corn (8,000 acres) crops. Projected sea level rise at 2030 does not substantially increase the acreage of exposed agricultural lands. However, by mid-century, the exposed acreage more than triples to 148,000 acres, representing approximately 35% of Delta agricultural lands. The largest acreages of exposed agricultural lands at mid-century are corn (50,000 acres), alfalfa (23,000 acres), and vineyards (10,000 acres). By end-of-century, the exposed acreage is six times more than existing conditions – 257,000 acres – representing approximately 60% of Delta agricultural lands. The largest acreages of exposed agricultural lands at end-of-century are corn (76,000 acres), alfalfa (42,000 acres), pasture (25,000 acres), tomatoes (16,000 acres), and vineyards (15,000 acres). By end-of-century, greater than 75% of the acreages of the following current Delta and Suisun Marsh crops are projected to be exposed to flooding: corn, olives, bush berries, asparagus, potatoes, turf farms, carrots, grain and hay, mixed pasture, and wheat.

Table 5-11 shows the economic value of agricultural buildings and structures exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence at 2030 and 2050 and Table 5-12 shows the annual agricultural economic activity exposed. Exposed agricultural activity at 2030 ($0.3 million) is relatively low compared to the Delta's annual economic activity of $33 billion; however, exposed agricultural economic activity increases dramatically by 2050 to $79 million. Nearly all the exposed agricultural activity is in Sacramento and San Joaquin Counties, where approximately $22 million and $49 million, respectively, in annual agricultural economic activity is exposed to flooding.

Table 5-11. Economic Value of Agricultural Buildings and Structures Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	2030	2050
Alameda	None	None
Contra Costa	None	$1M
Sacramento	<$0.1M	$22M
San Joaquin	$17M	$49M
Solano	$0.2M	$0.2M
Yolo	None	None
Total	**$0.3M**	**$73M**

Note: Value of commercial property includes buildings and physical infrastructure but does not include the value of the land itself.

Table 5-12. Agricultural Activity (Annual Net Revenues) Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

County	2030	2050
Alameda	None	<$0.1M
Contra Costa	<$0.1M	$1M
Sacramento	<$0.1M	$8M
San Joaquin	$21M	$69M
Solano	$0.3M	$0.3M
Yolo	None	None
Total	**$21M**	**$79M**

Extreme Heat

Increases in the frequency and duration of extreme heat days may lead to crop losses due to heat stress, water stress, and early development.

Delta crops are highly sensitive to extreme heat conditions. Heat stress reduces the rate of photosynthesis and increases respiration, resulting in reduced plant growth and decreased quality (Pathak et al. 2018). The impact of extreme heat on crop yields may depend on the timing of extreme heat events, especially those that occur during germination or reproductive stages (e.g. pollination, fruit set) (Medellín-Azuara et al. 2018). As a result, heat waves early in spring or summer can be more detrimental than later in summer (Jackson et al. 2011). Prematurely hot days can damage plants early in development or spur rapid bolting, which can create a mismatch with pollination and affect crop quality. Early or repeated heat waves cause yield decreases in corn, rice, sunflowers, and tomatoes (Jackson et al. 2011; Pathak et al. 2018). Even crops that are expected to have yields negligibly affected by average temperature changes, such as wine grapes, are still highly sensitive to extreme heat, which can negatively impact the flavor, aroma, and color (Nicholas et al. 2011). Crops have limited ability to adapt to extreme heat conditions, but changes to the irrigation schedule may offset impacts related to an increased rate of evapotranspiration.

Drought

In the tidally influenced parts of the Delta, water quality may decline during droughts due to low flow conditions and salinity intrusion.

Modeling conducted for Delta Adapts indicates that significant water shortages will occur more frequently and will be more significant as droughts become more frequent and severe (see

Section 5.4 and the Water Supply Technical Memorandum). During these droughts, water shortages will force water managers to make difficult choices about how to manage very limited water supplies. In most of the Delta, even during the most severe droughts, water availability is not affected; however, because of the Delta's tidal influence, water quality may decline during drought years if water quality regulations in the Delta are relaxed, freshwater flows are reduced, and seawater penetrates further into the Delta. If future episodes are handled similarly, these salinity intrusions could cause significant loss of productivity and potential damage to agricultural production.

Delta crops are sensitive to stress during water shortages; however, impacts may be restricted to a limited region.

Water stress impacts crop germination and growth rate, total vegetative growth, and reproduction. Stressed plants tend to have reduced leaf size and limited stem and root growth (Farooq et al. 2009). Yield response to water stress depends on timing, severity, and co-occurrence with other stresses (Plaut 2003). For example, insects and diseases can take advantage of crops that are in a water-stressed state (Pathak et al. 2018).

Most Delta agriculture is not limited by water availability due to shallow groundwater and riparian water rights, but some areas in the upslope fringes of the Delta may have to institute stress irrigation in dry years. Delta crops with a high water demand and evaporation rates have the highest sensitivities and include alfalfa, tomatoes, pasture, rice, and corn (Jackson et al. 2011). Orchards typically require a large amount of water and cannot be fallowed, or left unattended, during conditions of water shortage; however, much of the existing orchards in the North Delta are not water limited. The quality of wine grapes benefits from reduced water applications, but significant water shortages combined with elevated temperatures can reduce vegetative growth and grape yield (Kizildeniz et al. 2015).

5.2.4 Recreation

The Delta region's mix of land and water offers diverse recreation experiences including fishing, boating, birdwatching, hunting, and hiking. These activities are supported by a network of recreation assets consisting of parks, campgrounds, marinas, scenic highways, and trails. Figure 5-5 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections.

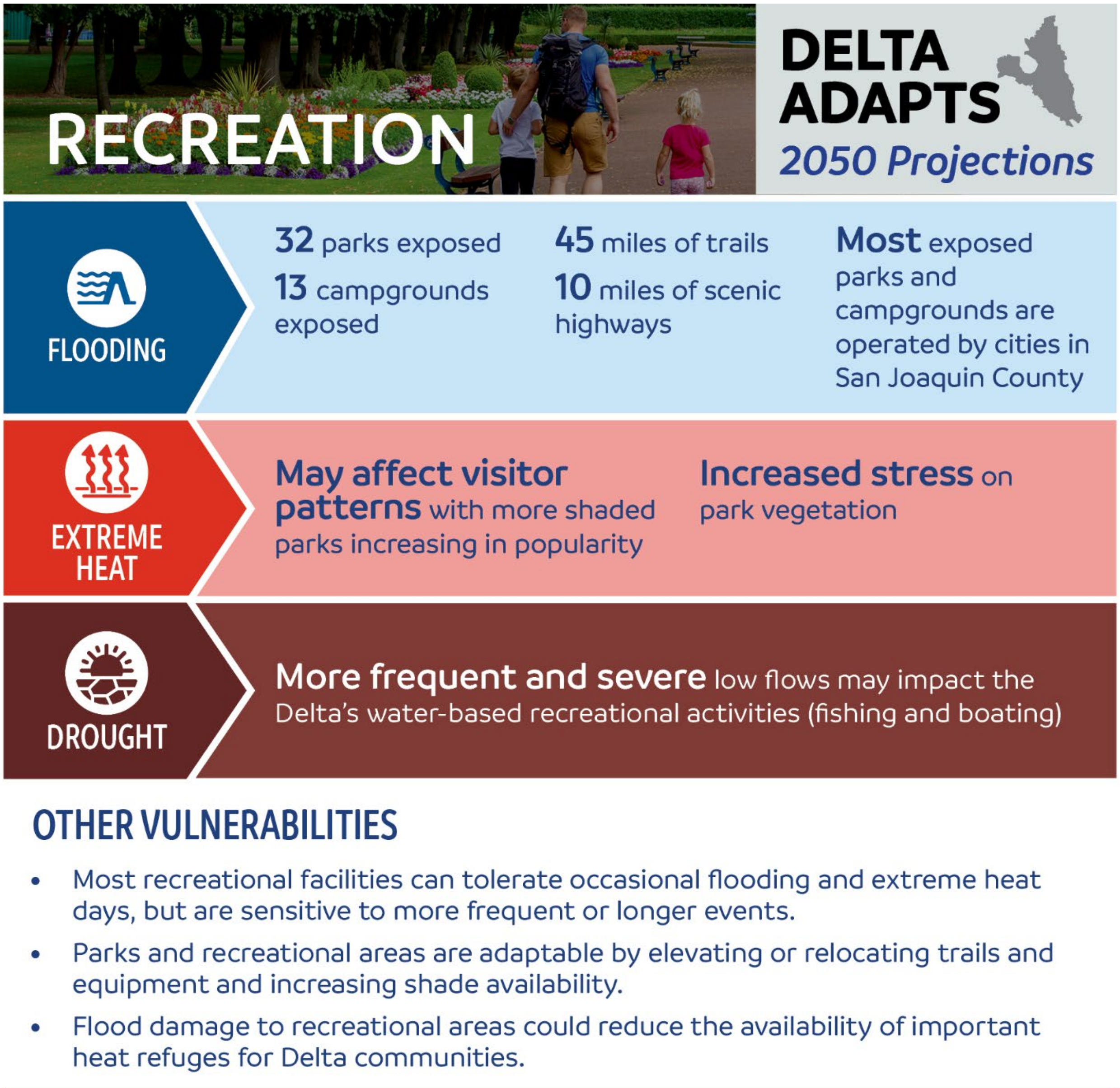

Figure 5-5. Summary of Delta Adapts key findings for recreation at 2050

Flooding

Forty-five parks and campgrounds will be exposed to flooding by mid-century and 69 parks and campgrounds will be exposed by end-of-century. Flooding of Delta recreational facilities would further limit the availability of already scare low-cost recreation opportunities for Delta residents and surrounding communities.

By mid-century, 13 campgrounds, 32 parks, 45 miles of trails, and 10 miles of scenic highways would be exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence. Most of the exposed campgrounds and parks are owned and operated by the municipalities of Stockton (eight) and Lathrop (nine) in San Joaquin County, while the majority of trail and scenic highway exposure occurs in Sacramento County. By end-of-century, an additional five campgrounds, 19 parks, 28 miles of trails, and nine miles of scenic highway will also be exposed. These exposed sites are shown in the Recreation flood exposure maps in Appendix B. Recreational facilities within the Delta also include numerous marinas that are likely to be affected by changing water levels associated with future flood events. However, the sensitivity of flooding of marinas will depend on site-specific factors not assessed in Delta Adapts, such as height of the docks, whether they are fixed or floating, and the elevation of gangplanks/approaches to the dock structures.

The sensitivity of recreation assets to flooding is low to moderate, depending on the degree of flood exposure. For example, minor flooding may only require temporary closure and cleanup of minor debris after floodwaters recede; however, regular or major flooding may completely erode or wash out trails, scenic highways, and campground facilities, prohibiting future use until repairs are made.

The adaptive capacity of recreation assets is high, particularly when compared with other built infrastructure in the Delta, because it is relatively easy to relocate or elevate (e.g., using fill material or boardwalks) trails and marinas or transition a recreation area to adopt different activities based on the changing climate. In fact, there are many examples worldwide where park and open space areas are designed to accommodate flooding and reduce flood impacts to adjacent areas. Scenic routes are an exception and have a lower adaptive capacity. While it is possible to elevate roadways above the flood elevation to maintain access, doing so is associated with high costs and engineering feasibility challenges.

Damage to recreation areas will have moderate consequences for the Delta and surrounding communities. The greatest concern is the loss of already limited public recreational access for Delta communities, particularly in the south Delta. Recreation areas provide outdoor access to the area’s unique wetland and open water areas with other 1,000 miles of waterways. Further, these areas increase the Delta’s appeal as a place to live and visit. These areas offer free and low-cost options for recreation such as fishing, paddling, hiking, and camping, making them of particularly high value for low-income households that may not be able to easily replace these activities with other options.

Extreme Heat

Increases in the occurrence of extreme heat events could affect visitor patterns, reduce availability of heat refuge, and alter the use of the Delta’s recreational sites.

Recreation facilities generally have a low sensitivity to extreme heat, but park vegetation may be affected, requiring increases in frequency or duration of irrigation. Recreation facilities have a high ability to adapt to extreme heat – for example, by increasing shade or canopy coverage throughout recreation areas to reduce temperatures or provide shelter for visitors. Operational changes to recreation areas, such as adjusting irrigation schedules and/or changing plants to native or drought-tolerant species can also increase the resilience of vegetation to accommodate future temperatures.

Specific impacts to recreational sites due to extreme heat conditions will vary across the Delta, but the largest impacts will likely be changes in visitor patterns. For example, recreation areas with an abundance of shade or river access may experience an increase in visitors during heat waves. Conversely, recreation areas with limited shade and no river access may experience a decline in visitors, particularly during more frequently occurring extreme heat days.

Green spaces and water access associated with recreation areas play an important role in the Delta by providing a cooling oasis for many visitors from Delta neighborhoods and adjacent urban areas, particularly during summer heat waves. Therefore, recreation areas that receive major damage or closure from flood hazards may create a cascading effect of increasing the Delta’s vulnerability to extreme heat conditions by reducing the availability of recreational opportunities.

Other Climate Hazards

An increasing frequency and duration of drought conditions will impact the Delta’s water-based recreation activities such as fishing and boating.

The Delta’s recreational fishing and boating sectors are highly sensitive to water levels and water quality in the Delta. Low water levels experienced during drought conditions can prevent boat access at marinas and boat launch areas, which occurred during the 2012-2016 drought. Past droughts have also contributed to conditions ideal for harmful algal blooms and exotic aquatic plants that overrun marina areas of the Delta and prevent boat passage (Durand et al. 2018). Drought impacts on the Delta’s recreational opportunities can also create disproportionate losses in rural areas of the Delta dependent on supporting marina operations (including lodging, food, and retail) as a livelihood. Although the Delta’s water-based recreation activities have limited ability to adapt to future drought conditions, changes to recreational management during drought events, including removal of aquatic weeds and restoring vulnerable fish stocks may offset impacts.

5.2.5 Infrastructure

The Delta relies on a variety of infrastructure types to support local communities and the economy. Additionally, Delta infrastructure includes facilities that transport people and products throughout the Delta to the Sierra Nevada to the east, the Bay Area to the west, the Sacramento Valley to the north, and the San Joaquin Valley to the south. Infrastructure assets include energy and utilities, transportation, solid/hazardous waste facilities, flood management infrastructure, and water supply infrastructure. Figure 5-6 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections.

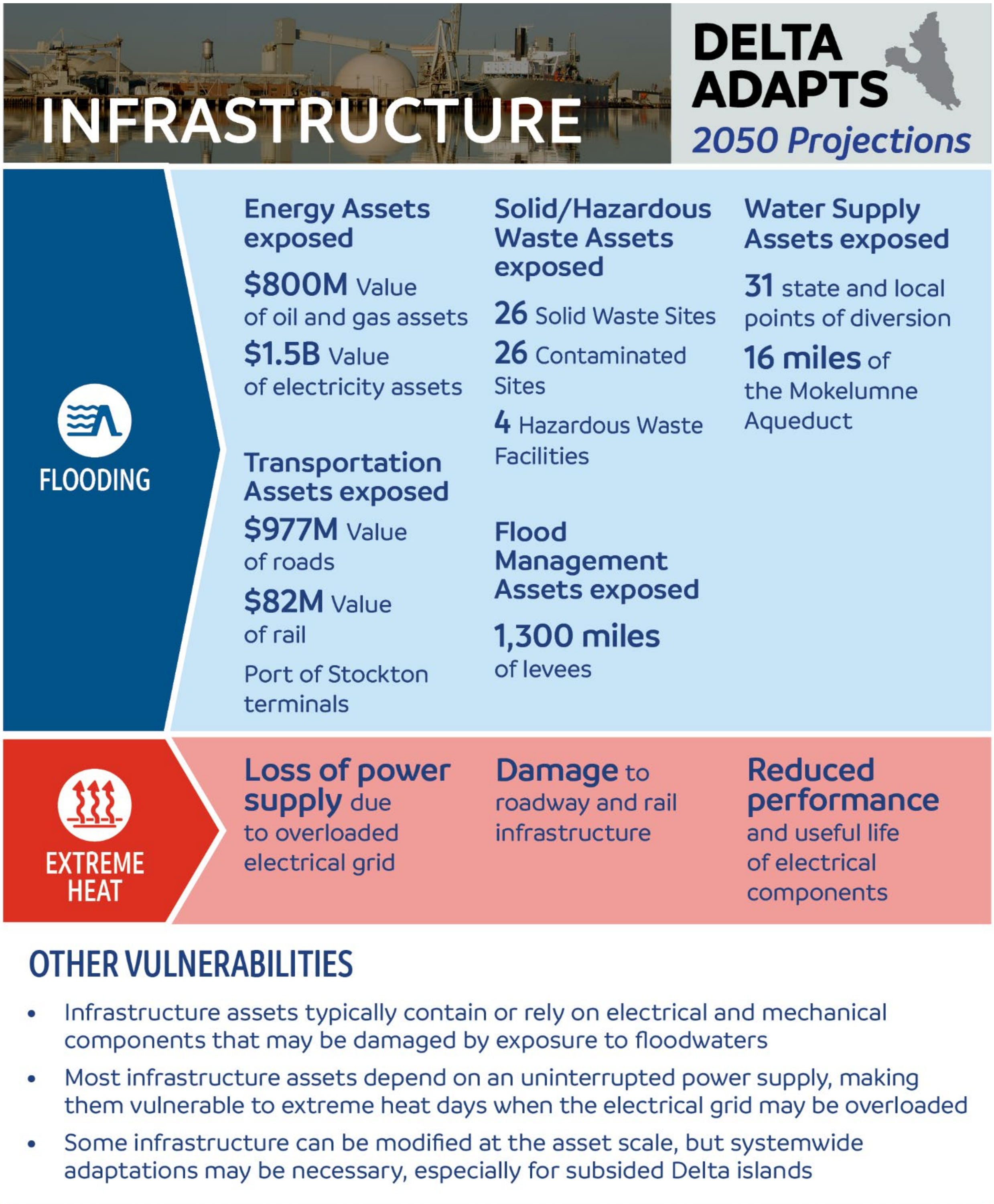

Figure 5-6. Summary of Delta Adapts key findings for infrastructure at 2050

5.2.5.1 Energy and Utilities

The energy and utilities sector include asset categories of energy generation, substations, transmission pipelines, and natural gas.

Flooding

Much of the Delta's energy industry, a critical source of electricity and gas for Delta communities, may be exposed to flooding in the future, with the greatest number of exposed assets located in San Joaquin County.

The Delta's energy industry is composed of various natural gas, petroleum, and electricity facilities. By mid-century, 24 natural gas stations, 89 miles of natural gas pipelines, 33 miles of oil pipelines, and 297 oil and gas wells will be exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence. These oil and gas energy assets have an estimated value of $800 million. Most of the natural gas assets exposed are located in San Joaquin and Sacramento Counties while the majority of exposed oil pipeline is located in Solano County. Active oil and gas wells that may be exposed to flooding are mostly located on Brannan-Andrus Island and Twitchell Island in Sacramento County. By end-of-century, 64 natural gas stations, 210 miles of natural gas pipelines, 43 miles of oil pipelines, and 449 oil and gas wells will be exposed to flooding. These exposed assets are shown in the Energy and Utilities flood exposure maps in Appendix B.

Electrical facilities located in areas exposed to flooding by levee overtopping by mid-century are mostly located in San Joaquin County and include 17 substations, 5 power plants, 642 transmission towers, and 168 miles of transmission lines. These energy assets have an estimated value of $1.5 billion. By end-of-century, 32 substations, 1,401 transmission towers, and 366 miles of transmission lines will be exposed to flooding by levee overtopping (no additional power plants are exposed).

Energy infrastructure is highly sensitive to flooding and exposure could result in substantial and cascading impacts to the Delta's public health, safety, and economy.

Energy infrastructure has a high sensitivity to flooding. Associated facilities are typically complex with many electrical and mechanical components that are susceptible to flood damage. Even sealed wells, which have a low sensitivity to temporary flood events, will have operational effects because they are dependent on adjacent electrical controls that may be located near the ground level and could be damaged by flood exposure. Energy facilities also rely on a network of at- or sub-grade pipelines and transmission lines to distribute sources of heat and power throughout the region. Large flood events may cause scouring or removal of sediment around pipelines, creating support issues or damage. Submergence of pipes can also cause them to 'float' or become displaced due to buoyancy effects. Depending on the materials, exposure to saltwater flooding may corrode transmission pipes, requiring replacement before the end of the project's design life and or impediments to access for maintenance and inspections. Although components of energy infrastructure can be adapted to resist flooding (e.g., raising or flood-proofing electrical equipment, control panels, and pipelines), the complexity of the facilities and need for reliable site access may require costly flood protection strategies (e.g., raised levee, flood barrier with elevated access roads or relocation), resulting in lower adaptive capacity.

Damage to the Delta's energy infrastructure could have catastrophic consequences in addition to the monetary value of individual assets. A reliable and consistent power supply is critical for the operation and functioning of most Delta assets and facilities (e.g., wastewater treatment plants, hospitals, fire stations, schools, traffic lights, etc.). If electrical infrastructure is flooded and service is interrupted for any amount of time, cascading social (e.g., limited services for residential communities), environmental (e.g., wastewater overflows), and economic (e.g., lost work time) consequences will occur across the Delta. Much of the Delta's energy infrastructure is also focused on the energy source extraction of natural gas and oil. Flood damage to this infrastructure is also likely to have major impacts due to environmental contamination of adjacent waterways, safety hazards posed to on-site employees by flood-damaged equipment, and economic losses due to a loss in production time.

Extreme Heat

An increase in the frequency and duration of extreme heat events will place increased demand on the energy grid, affecting regional power supply.

Elevated air temperatures can reduce the ability to transmit power, making "brown-outs" or power outages throughout the Delta more common due to an overloaded electrical grid. Because all energy and utility assets are dependent on an uninterrupted power supply, they are highly sensitive to extreme heat days. Extreme heat can also affect the performance and longevity of exposed electrical equipment (e.g., control panels), which is designed to operate within a specified temperature for optimal performance. Large-scale energy and utility facilities have low adaptive capacity for system-wide modifications to accommodate extreme heat. Specific components could be retrofitted to increase shade and airflow, reduce heat absorption, or increase redundancy using a backup power supply.

Other Climate Hazards

Increased frequency and severity of wildfires within and outside the Delta may impact the region's power supply in the future.

Power supply throughout the Delta is dependent on regional transmission and distribution lines that may traverse wildfire-prone areas of the state. Distribution lines that traverse heavily treed and wildland areas may be prone to increasingly more frequent and severe wildfires in the future due to climate change. Power transmission lines are sensitive to wildfires and direct exposure to can cause widespread damages to power lines, causing line outages and widespread service disruption for customers in the Delta. In addition, preventative public safety power shutoffs (as occurred in 2019 and 2020) may increase in frequency and duration as conditions conducive to wildfire growth become more frequent and severe in the future. Adaptive capacity of energy infrastructure for wildfires is low (due to the large geographic areas spanned by distribution lines and distance between power sources and customers), but possible through hardening, increased vegetation management, placing existing transmission lines underground, or relocating transmission lines to lower risk fire zones.

5.2.5.2 Transportation

The transportation sector includes asset categories of roadways, bike paths, railroads, seaports, bridges, evacuation routes, and airstrips.

Flooding

Climate change-related flooding will impact key regional transportation routes in the Delta, including roads, highways, rail, and evacuation routes.

By mid-century, 38 miles of mainline rail track, 63 miles of state/federal highways, 17 miles of county routes, 10 miles of scenic highways, and almost 1,200 miles of local roads will be exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence, affecting critical access routes, the ability to respond to emergencies, and everyday life for Delta residents and goods movement (Table 5-13). The estimated value of roads and highways exposed to flooding by mid-century is $977 million and the value of exposed rail is $82 million. By end-of-century, 48 miles of mainline rail track, 89 miles of state/federal highways, 25 miles of county routes, and more than 1,900 miles of local roads will be exposed to flooding by levee overtopping. Impacted highways include CA-4, CA-120, CA-12, I-205, and I-5. Exposed routes and facilities can be viewed in the Transportation flood exposure maps in Appendix B.

Table 5-13. Transportation Assets Exposed to Flooding Due to Levee Overtopping During an Event with a 1-percent Annual Chance of Occurrence

Transportation Assets	Length of Asset Exposed (Miles) Existing	Length of Asset Exposed (miles) 2030	Length of Asset Exposed (miles) 2050	Length of Asset Exposed (miles) 2085
Interstates and State Highways	19	19	63	89
County Routes	5	5	17	25
Local Roads	470	485	1,097	1,916
Railroads	18	20	38	48

Note: Mileage for divided highways is included for both directions separately.

Beyond the direct and indirect impacts within the Delta, these widespread impacts to vital transportation corridors would likely result in significant economic impacts throughout the western United States. For example, I-5 is the main north-south interstate highway on the west coast, connecting major cities such as San Diego, Los Angeles, Sacramento, Portland, and Seattle. By mid-century, I-5 is vulnerable to flooding in multiple places, including a stretch near Thornton on the New Hope Tract and an almost 8-mile stretch running through the City of Lathrop and Paradise Junction.

Degradation of roadway and rail surfaces and subsurface materials from repeated flood events may require additional road maintenance and repairs.

According to Caltrans' district-level Climate Vulnerability Assessments, pavement, the substructure of rail lines, and bridges can be damaged by intermittent flooding, making them moderately sensitive to flooding depending on factors such as flood depth, velocity, frequency of flooding, and structural characteristics. For example, if roads are submerged by more than a few inches, it may cause delays or stop traffic, but may be able to resume movement after floodwaters recede. However, long-term effects of flooding can damage the roadway itself. Further, rising groundwater could inundate components that are not built for saturated soil conditions and higher water levels and peak flows could increase scour effects on bridge structural elements. High flows can strip rail, rail ties, and ballast off of railroad bridges and rail lines if they are exposed (FHWA 2019). These impacts during storm events will cause increased wear and tear on infrastructure, increasing maintenance costs and disruptions during construction and repair activities.

Transportation infrastructure has moderate adaptive capacity, because there may be built-in redundancy in routes (although some routes provide sole points of ingress/egress to islands) and traffic could use alternate routes during flood events. It is also possible to elevate roadways and rail above projected flood elevations to maintain access – particularly for those routes on existing levees; however, this is likely to be associated with high costs or infeasible for routes that traverse subsided Delta islands.

Disruption of Delta ports by climate-related flooding may result in loss of jobs and impact businesses that rely on port operations.

Ports are particularly vulnerable to flooding because they depend on the waterfront and have limited ability to relocate. Even if a port is not identified as exposed to flooding in this assessment, depending on the elevations of specific piers, cranes, and other infrastructure, portions of the port may be disrupted prior to widespread flooding of sensitive infrastructure. According to the Delta Adapts flood analysis and mapping, the Port of West Sacramento is not exposed to flooding even by end-of-century. However, most terminals of the Port of Stockton are exposed to flooding by mid-century and the entire port is exposed by end-of-century. The Port of Stockton is the State's fourth busiest port, generating economic activity that provides more than 10,000 jobs and generating $77.7 million in state and local taxes annually (Port of Stockton, 2019). 2017-2019 set tonnage records at the Port and recent capital investment has totaled approximately $288 million, indicating that the Port is a vital and growing component of Stockton's economy and that widespread temporary or permanent inundation could have significant economic impacts.

In Contra Costa County, all ten working piers in the cities of Antioch and Pittsburg are exposed to flooding by mid-century. However, based on available data, several of these piers appear to experience only intermittent use and temporary flooding of these structures would likely result in minimal disruption to the regional economy.

Extreme Heat

Extreme heat may increase maintenance and repair needs for transportation infrastructure as assets are placed under increased heat stress in a warmer climate.

The average maximum temperature over seven consecutive days is a required measure for pavement design. According to Caltrans' district-level Climate Vulnerability Assessments, the Delta region is likely to experience a 6-8°F increase in this measure by mid-century and a 10-12°F increase by end-of-century. Roadway materials are composed of asphalt, which is sensitive to prolonged periods of extreme heat. Exposure to extreme heat may cause the roadway to soften and experience deformation, cracking, or splitting, thereby increasing the need for maintenance and repairs. Roadways have a high ability to adapt to extreme heat conditions because the asphalt mix can be modified to withstand higher temperatures or cooling pavement techniques can be painted onto the existing surface to reduce the absorption of solar radiation.

Rail systems are also sensitive to extreme heat. Rail lines may expand during extreme heat conditions, causing the rail to buckle. In a worst-case scenario, this could cause a derailment leading to deaths or injuries. To address this, freight and commuter trains can run at slower speeds during extreme heat events, suggesting that rail operations have some adaptive capacity to extreme heat; however, as these events increase in frequency and duration, delays and interruptions in service will likely become more and more frequent.

In addition to direct damage to infrastructure, heat will also impact maintenance worker and driver safety. High temperature can increase health and safety risk as well as engine and equipment heat stress for road maintenance vehicles. Risk of accidents also increases with extreme heat conditions due to slowed reaction times and loss of alertness.

Other Climate Hazards

Roadway and rail networks traversing the Delta and connecting to the greater region could be impacted by wildfires.

While the vulnerability of transportation assets in the Delta to direct damage from wildfires is relatively low, wildfires change the land in ways that may increase the sensitivity of road and railbeds. For example, loss of vegetation due to wildfire could make soil along transportation corridors more susceptible to erosion and less able to absorb rainfall. This could exacerbate rates of runoff and increase the chances of local flooding. Burned vegetation may also generate debris that can clog culverts, increasing the risk of road or railway overwashing, or damage the supports of bridges during extreme precipitation events. With the exception of increasing vegetation control, roads and railways have limited adaptive capacity to wildfires.

5.2.5.3 Solid/Hazardous Waste

The solid/hazardous waste sector includes three categories of waste sites: 1) solid waste sites such as landfills, composting, scrap metal yards, and tire facilities; 2) contaminated sites; and 3) hazardous waste facilities.

Flooding

Numerous solid waste facilities, contaminated areas, and hazardous waste sites will be exposed to flooding in the coming decades, potentially mobilizing and transporting contaminants to adjacent areas and waterways.

The Delta has 26 solid waste sites, 26 contaminated sites, and 4 hazardous waste facilities projected to be exposed to flooding due to levee overtopping during an event with a 1-percent annual chance of occurrence by mid-century. By end-of-century, 31 solid waste sites, 53 contaminated sites, and 6 hazardous waste facilities are projected to be exposed to flooding from levee overtopping. These exposed sites can be reviewed in the Solid/Hazardous Waste flood exposure maps in Appendix B. For both time horizons, most exposed sites are in San Joaquin County, with a concentration in and around Stockton. This is likely an underestimate, because the evaluated data do not include locations of businesses where hazardous materials may be used or stored.

Release of toxic substances and trash may occur when floodwaters come into contact with solid and hazardous waste sites, making these sites highly sensitive to flooding. Sites may also be sensitive to mobilization of contaminated soil caused by scour from high-velocity surface flows or rising groundwater tables associated with increased flooding. The adaptive capacity of solid and hazardous waste sites is generally low and limited to increased monitoring and ongoing maintenance of identified vulnerabilities, or implementation of costly remediation measures. Site-wide adaptation would require considerable and costly interventions, additional protective measures, or removing contaminants from the site.

Flood exposure of hazardous materials, trash, or other pollutants poses major and cascading risks to the health and safety of Delta residents and ecosystems. Release of potentially toxic materials from sites can cause chronic effects in the Delta, impacting native species, access to recreational facilities, local economies dependent on tourism and water activities, and the long-term health of residents.

Extreme Heat

Extreme heat hazards to solid and hazardous waste sites were not evaluated as part of Delta Adapts.

Other Climate Hazards

No other climate hazards for solid and hazardous waste sites were evaluated by Delta Adapts.

5.2.5.4 Flood Management Infrastructure

Flood management infrastructure includes levees, pump stations, and flood fighting materials stockpiles.

Flooding

Sea level rise and changes in hydrologic patterns in Delta watersheds will place greater stress on the Delta's flood management infrastructure, such as Delta levees and upstream reservoirs.

The Delta's 1,300 miles of levees protect more than 800,000 acres of land and play a critical role in conveying water supply through the Delta. By mid-century, overtopping of Delta levees by an event with a 1-percent annual chance of occurrence may result in the exposure of over $1.8 billion in annual agricultural and commercial economic activity and $10.5 billion in agricultural, residential, commercial, and infrastructure assets. Most of the Delta's flood management infrastructure, including levees and upstream reservoirs, are designed to operate under historical sea level and hydrologic conditions that do not consider potential future climate change. Changing climatic conditions will place greater stress on the flood management system in the future.

Urban Development and Flood Risk

New development behind levees has increased the consequences of flooding by increasing the number of lives and properties facing potential flood hazards. Future urbanization and development within the Delta will further exacerbate this risk in the future while peak water level events increase in frequency and severity due to climate change. Overtopping or failure of levees and pumps may result in catastrophic consequences, depending on the scale of the storm and damage, with risks of damage posed to nearly every aspect of Delta life.

Delta levees are highly sensitive to extreme storm events, which could scour the waterside slope, or cause breaches, overtopping, or other types of failure. Emergency materials stockpiles are located throughout the Delta for flood fighting and emergency repairs of levee damage. Although the current locations of stockpiles are not exposed to flooding, access routes to stockpiles or at-risk levees may be inaccessible during a flood event.

Flood management infrastructure has moderate adaptive capacity to climate change through raising and fortifying levees, increasing the use of pumps for groundwater and seepage removal, elevating sensitive electrical pump station components, and relocating emergency stockpiles to be more accessible during and following flood events; however, there are engineering, cost, and environmental challenges to continued raising of Delta levees in the future.

Extreme Heat

Extreme heat hazards for flood management infrastructure were not evaluated as part of Delta Adapts.

Other Climate Hazards

No other climate hazards for flood management infrastructure were evaluated by Delta Adapts.

5.2.5.5 Water Supply Infrastructure

Water supply infrastructure includes conveyance facilities, such as pipelines and channels, pumps, siphons, gates, and associated infrastructure used to divert and store freshwater within the Delta.

Flooding

Sixteen miles of the Mokelumne Aqueduct will be exposed to flooding by mid-century and nearly 50 miles of water conveyance infrastructure will be exposed by end-of-century. The Delta's 31 state and local water diversions and over 3,400 private points of diversion may be impacted by flooding of Delta islands.

Nearly 16 miles of the Mokelumne Aqueduct in San Joaquin County will be exposed to flooding by levee overtopping by mid-century. By end-of-century, nearly 40 miles of the Aqueduct will be exposed as well as 10 additional miles of other water conveyance infrastructure, including the Contra Costa Canal, Victoria Canal, Delta Mendota Canal, North Bay Aqueduct, California Aqueduct, and Los Vaqueros Pipeline. These exposed water supply assets are shown in the Water Supply Infrastructure flood exposure maps in Appendix B.

The State Water Project and Central Valley Project pumping plants in the South Delta, as well as other public and private diversions located throughout the Delta, depend on the conveyance of freshwater through the Delta. Sea level rise and changes in watershed hydrology will increase the risk of levee failure and flooding of Delta islands in the future that may result in temporary or permanent changes to Delta hydrodynamics and salinity regimes. In addition, increased frequency and severity of drought conditions and salinity intrusion may impact the functioning of these assets in the future (see Section 5.4).

Individual diversion points such as pumps contain electrical and mechanical components and other supporting infrastructure that are sensitive to flooding. Pumps and siphons may be damaged by high velocity flood flows, scour, or inundation. While sensitive electrical and mechanical components of pump stations can be elevated or floodproofed to accommodate higher water levels, equipment located on subsided Delta islands may be more difficult to adapt or recover after a flood event.

Flood exposure of water supply infrastructure poses major consequences for users that rely on that water. The Delta's water supply system is critical to water users throughout the Delta and the State. Water from the Delta serves two thirds of California's population and provides irrigation for much of the State's agricultural industry. Flooding of water supply infrastructure, even if temporary, has the potential to disrupt the complex water supply delivery system that millions of Californians depend on.

Extreme Heat

Extreme heat hazards to water supply infrastructure were not evaluated as part of Delta Adapts.

Other Climate Hazards

No other climate hazards to water supply infrastructure were evaluated as part of Delta Adapts.

5.3 Ecosystems

The ecosystems assessment evaluated climate change vulnerability of ecosystem habitat types within the Delta to primary and secondary stressors and climate hazards. Figure 5-7 provides an overview of the key vulnerabilities identified by Delta Adapts. Additional detail on the key findings is provided in the following sections and the Ecosystem Technical Memorandum.

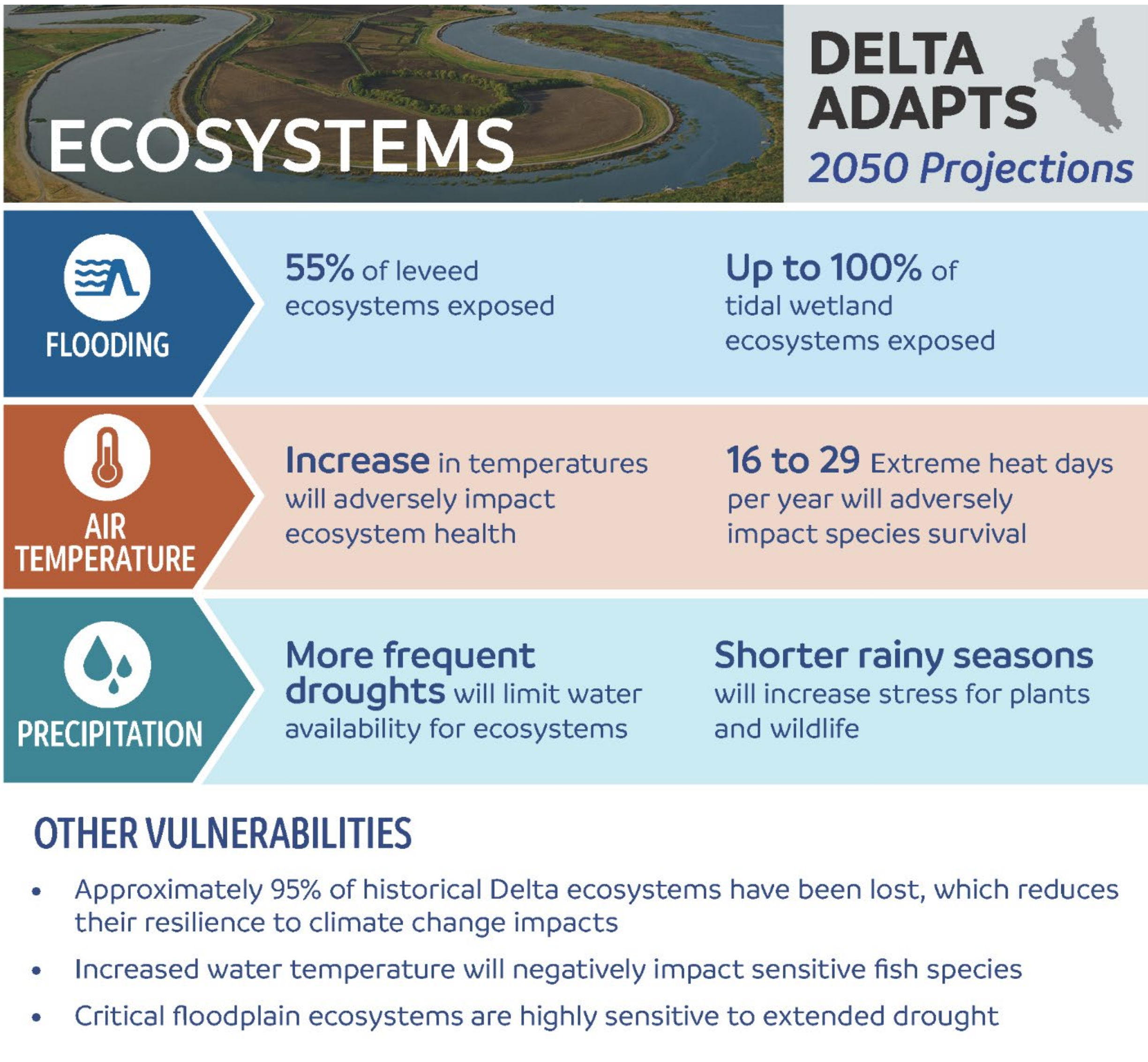

Figure 5-7. Summary of Delta Adapts key findings for ecosystems at 2050

5.3.1 General Findings

Delta ecosystems that are already highly diminished, disturbed, and fragmented will be most vulnerable to changes in climate stressors and hazards.

Delta ecosystems have declined by as much as 95% from their historical extents (DSC 2018; SFEI 2014). These sharp declines are largely driven by the conversion of natural ecosystems to agriculture and urban development. Large losses and fragmentation of habitats greatly compromise overall ecosystem health and function and threaten the ability of ecosystems to respond to climate change impacts and other environmental disturbances (Opdam and Wascher 2004). Impacts of historical alteration contribute to population declines, loss of biodiversity, and modifications to both community structure and ecosystem function (Didham 2010), all of which are evident in the Delta's ecosystems.

Wildlife in the Delta are vulnerable to the impacts of climate change. Protecting, restoring, and managing the Delta's ecosystems will reduce vulnerability and increase resilience to climate change.

The Delta Adapts team (Dybala et al. 2020) assessed the climate vulnerability of Delta bird communities as a proxy for vulnerability of Delta wildlife to climate change. The assessment found that bird communities in the Delta are most vulnerable to the cascading impacts of climate change (e.g., subsidence, salinity intrusion, drought, flooding, and reduced snowpack) which are likely to cause degradation and loss of habitats including tidal marsh, the tidal-terrestrial transition zone, managed wetlands, agriculture, and riparian vegetation. Additionally, a mismatch between the timing of biological and climate events (phenology) may result from changing air temperature and precipitation patterns. In order to reduce the vulnerability of Delta bird communities, tidal wetlands, wetland to upland transition zones, seasonal wetlands, and managed wetlands with a diversity of water depths must be protected and expanded. These changes will also impact other wildlife species, and ecosystem management must account for the needs of multiple wildlife species. Increasing the acreage of natural ecosystems through restoration and management will provide greater access to habitat and reduce wildlife vulnerability to climate change.

The Delta will persist as a unique and significant system despite anticipated transformations as a result of climate change.

Despite the impacts of climate change, the Delta will continue to be an important and dynamic region within California and along the Pacific Flyway bird migration route (Dybala et al. 2020). Even under a range of climate change scenarios, the Delta will continue to support aquatic ecosystems due to its extensive watershed and tidal connections. Tidal and riverine ecosystems and the connectivity between them will continue to provide habitat for a diversity of species assemblages.

The Delta ecosystems of the future will never resemble historical conditions, but adaptive management of restoration and conservation initiatives will allow the Delta's unique ecosystems to persist and expand. If adequate resources are available and climate change adaptation strategies are integrated, restoration will help improve ecological function, structure, identity, and process, producing robust multi-benefit outcomes. This will reduce climate vulnerability and allow the region to serve as a refuge for species in the face of future climate change.

Floodplains and the species that occupy them are highly vulnerable to extended drought periods and changing flood patterns.

Floodplains provide critical ecosystem services, including flood risk reduction, filtration of surface water, and groundwater recharge. They also support high levels of biodiversity, serving as fish nurseries, and contributing to the aquatic food web. Floodplain adaptive capacity is limited by available water at the watershed scale. Projected increases in the frequency and severity of drought (see Section 5.4.4) will decrease the frequency and duration of floodplain inundation. In addition, floodplain forests along the Cosumnes River are sensitive to low groundwater levels that are likely to be caused by a combination of extended drought cycles and increased groundwater extraction during periods of low surface water supplies.

5.3.2 Air Temperature

Increases in average annual and seasonal air temperatures will cause adverse and cascading impacts to Delta ecosystems.

Warming air temperatures will increase evapotranspiration and decrease soil moisture content, which may lead to premature drying of seasonal wetlands (Ordonez et al. 2014). Ecological effects will include increased thermal stress and physiological impacts on Delta organisms. This will amplify competition for limited water supplies, shift the phenology of vegetation and wildlife communities, and modify species dynamics and composition (Hegland et al. 2009).

All organisms can survive in a species-specific temperature range, but thrive in a narrower, optimal range. As air temperatures are increasing with climate change, species need to function at the higher end of their operating thresholds. To avoid mortality, species will need to adapt to the new conditions through behavioral or physiological changes or move to locations where the climate conditions are more favorable, which may disrupt food web relationships. Increasing temperatures may also allow for an increase in abundance of already present non-native species or the establishment of new invasive species that have broader temperature and precipitation tolerances, putting native species further at risk.

Species that rely on freshwater sources or habitats that are more likely to dry out, aquatic species that are more sensitive to temperature increases, and species that are rarer or have already experienced population declines as a result of human activities are at greater risk to climate impacts.

Increased occurrence of extreme heat days, especially when occurring consecutively, will impact Delta plant and wildlife species and alter ecosystem dynamics.

Extreme heat events in the Delta (generally corresponding to temperatures exceeding 100°F, depending on location within the Delta) are projected to occur more frequently and last longer compared to historical conditions. Annual occurrence of extreme heat days will increase from 4 to 5 historically to 24 days per year by mid-century and 41 days per year by the end of the century under RCP 8.5 (Cal-Adapt 2017). Extreme heat events can cause mass-mortality events for vegetation and wildlife within the Delta, shift species distributions, reduce reproductive success and fitness, and intensify disease outbreaks (Stillman 2019).

The risk of negative effects on organisms in the Delta is particularly acute during heat waves when multiple consecutive days of extreme heat intensifies temperature stress. If organisms cannot adjust through behavioral changes such as moving to cooler areas, heatwaves will cause mass mortality events that can have cascading effects on the rest of the ecosystem.

Over a century of human pressures on the natural systems of the Delta have severely reduced the extent and quality of suitable habitat and consequently greatly diminished population sizes. This renders them vulnerable to additional stresses caused by climate change, limiting the potential for adaptation. Increasing shade by expanding the extent of riparian vegetation throughout the Delta would be a nature-based solution to increase the inherent adaptive capacity of organisms to respond to extreme heat.

5.3.3 Local Precipitation

Projected reductions in spring and fall precipitation and increased inter-annual precipitation variability may stress Delta species, favor less diverse species assemblages, and lead to increased presence of non-native species.

By mid-century, climate models show a reduction in the total number of rainy days and decreases in both fall and spring precipitation. These changes will likely be accompanied by an increase in the intensity and frequency of large storm and atmospheric river events during the winter. Decreases in spring and fall precipitation may impact freshwater availability, increase competition for limited water supply, and shift the phenology of species who are dependent on seasonal rainfall for reproduction, growth and survival (Mauger et al. 2015). Although the ecosystem response to changes in intra- and inter-annual precipitation variability remains uncertain, data suggests that increased variability in precipitation will likely favor less diverse species assemblages and invasion of non-native species (Liu et al. 2020; Parton et al. 2012).

The Delta's growing season is determined by its Mediterranean climate – rains in late fall, winter, and spring followed by dry summers. As the climate changes and the rainfall season becomes shorter, freshwater and groundwater availability may be diminished. As a result, species adapted to a longer growing season and available freshwater sources may be negatively impacted. If species cannot tolerate or adapt to new precipitation patterns they may experience increased mortality rates.

Ecosystem types that have evolved to accommodate historical inter-annual variability in local precipitation and groundwater levels are highly vulnerable to changes in local precipitation patterns.

Wet meadows and seasonal wetlands, including alkali seasonal wetlands, are dependent on local rainfall and groundwater sources in order to persist. Although these ecosystem asset types are adapted to a Mediterranean climate regime, forecasted increases in precipitation variability will increase stress. Increased wildfire risk, loss of suitable habitat, and loss or redistribution of biodiversity are all possible results of increased precipitation variability in the Delta. More frequent drought conditions in combination with higher rates of evaporation due to higher temperatures may impact key ecological functions of wet meadow and seasonal wetlands.

5.3.4 Water Temperature

Warming water temperatures in Delta waterways will decrease dissolved oxygen, increase nutrient loads, stress aquatic species adapted to present-day conditions, and alter ecosystem dynamics.

Increasing air temperatures have direct impacts on water temperatures in the Delta and Suisun Marsh. Water temperatures are also dependent upon wind, riverine flows, and tidal dispersion – all of which are projected to be impacted by climate change (Vroom et al. 2017). By the end of the century, the Sacramento River water temperatures could warm as much as 5.4 to 10.8°F (Wagner et al. 2011). Warming water temperatures will vary spatially and may affect species by directly inducing stress or by decreasing dissolved oxygen levels. When coupled with decreased water supply, warming water temperatures could lead to higher risk of eutrophication, increase the occurrence of harmful algal blooms, cause higher disease risk in fish and wildlife species, impact predator-prey dynamics and lead to phenological mismatches between spawning events and prey availability, and lower weights in juvenile salmonids (Beer and Anderson 2013; Jeffries et al. 2016; Moyle et al. 2013; Wagner et al. 2011;). Operational flow management will need to be modified to at least partially offset these changes (Dettinger et al. 2016; DSC 2018a).

5.3.5 Sea Level Rise

Rising sea levels will cause tidal wetlands to transition to different plant communities or drown completely.

For tidal freshwater and brackish wetlands in the Delta and Suisun Marsh, vulnerability is defined as either the transition from high marsh to low marsh or complete drowning in response to sea level rise. Persistence of mid- to high marsh in the Delta and Suisun Marsh depends on a variety of factors, including rate of sea level rise, sediment availability, vegetation type, salinity regime, and availability of upland transition space. The habitat evolution projections for Delta and Suisun Marsh tidal marshes based on the results of the WARMER modeling are shown in Table 5-14. For mid-century (2050) sea level rise scenarios, high marsh tidal wetlands will not be at risk of habitat transitions or drowning under one foot of sea level rise. Under two feet of sea level rise, tidal freshwater wetlands in the Delta will be at risk of transitioning to low marsh, but brackish tidal wetlands in Suisun Marsh will persist and keep pace with sea level rise.

For late-century (2085) scenarios, tidal wetlands will not be at risk of transitioning to low marsh under two feet of sea level rise but will be at risk of transitioning under 3.5 feet of sea level rise. Under the more extreme end-of-century scenario (6 feet sea level rise by 2100), all tidal wetlands in the Delta and Suisun Marsh are at risk of drowning.

In addition, high water storm and king tide events are likely to impact resident species, particularly where upland transition and high tide refugia are not available. Planning and rapidly implementing restoration projects with substantial connections to upland transition space is critical for creating multi-benefit tidal wetland investments that will persist past 2100. However, upland transition space is rare in the Delta (Siegel and Gillenwater 2020; SFEI-ASC 2014). Restoring tidal wetlands with upland connection transition space as soon as possible will allow species to maintain their habitat elevation through natural processes and reduce the risk of loss. Restoration potential (based on areas with appropriate elevations to support tidal wetlands) varies sub-regionally within the Delta; it is higher in the northern part of the Delta and along the eastern edges. See Appendix C for maps of existing tidal marsh habitat and potential areas of sea level rise accommodation space within the Delta (defined as areas within 10 feet above today's MHHW) and see the Ecosystem Technical Memorandum for additional discussion of accommodation space considerations within the Delta.

Table 5-14. Predicted habitat changes of unleveed freshwater and brackish high/mid marsh in the Delta and Suisun Marsh under different sea level rise scenarios

Year	Sea Level Rise Scenario	Delta Freshwater Marsh	Suisun Brackish Marsh
2050	1 foot	High/Mid Marsh Persists	High/Mid Marsh Persists
2050	2 Feet	Conversion to Low Marsh	High/Mid Marsh Persists
2085	2 feet	High/Mid Marsh Persists	High/Mid Marsh Persists
2085	3.5 Feet	Conversion to Low Marsh	Conversion to Low Marsh
2100	6 Feet	Drowned	Drowned

Managed wetlands in the Suisun Marsh are highly likely to flood even under current conditions, which contributes to their high vulnerability to sea level rise.

As sea level and storm event frequency increase, flooding events are likely to become more common, putting strain on Delta levee systems that protect managed wetlands. If Suisun Marsh levees are overtopped but not breached with significant damage, water control infrastructure currently used to maintain managed wetland water levels will facilitate water drainage. However, if these flooding events persist for an extended period, or occur from storm events such as atmospheric rivers that damage levees, there is a risk of ecosystem change through deep and permanent flooding. Waterfowl, the primary target of managed wetlands, may be negatively impacted if these areas transition to tidal brackish wetland (Coates et al. 2012), and wildlife species such as black rails that require high-tide refuge will suffer habitat loss (Overton et al. 2015). However, permanent flooding of diked wetlands could also lead to the creation of productive aquatic or intertidal ecosystems, provided they are not too deeply subsided.

Riparian and willow ecosystems are projected to be resilient to sea level rise, and the shade they provide can help fish and wildlife species persist despite higher temperatures.

Only 18% of riparian and willow ecosystems not protected by levees are at risk with 3.5 feet of sea level rise by 2085. Riparian and willow ecosystems may be quite resilient to sea level rise, because they occur at higher elevations, likely can maintain their elevations relative to higher sea levels through natural processes, and can withstand periodic flooding.

Shade provided by trees may help fish and wildlife species cope with warming temperatures (Justice et al. 2017). In the present landscape, most riparian and willow ecosystem patches are very narrow and small. Restoring larger riparian forests and wider riparian areas lining rivers and sloughs with minimal gaps would reduce their vulnerability and improve ecological function.

5.3.6 Flooding

55% of leveed ecosystems will be exposed to flooding by mid-century and 73% of leveed ecosystems will be exposed by end-of-century. Ecosystems on deeply subsided islands in the Central Delta and managed wetlands in Suisun Marsh have the highest risk of flooding due to levee overtopping resulting from the combination of sea level rise and storm events.

By mid-century, 55% of leveed ecosystems may be exposed to flooding by levee overtopping during an event with a 1 percent annual chance of occurrence. By end-of-century, 73% of leveed ecosystems will be exposed. If natural ecosystems on deeply subsided islands flood, they may transition to open water if flooded islands are not reclaimed, making leveed ecosystems highly sensitive to flooding. However, levee maintenance and multi-benefit nature-based solutions such as levee setbacks and subsidence reversal wetlands can reduce the likelihood of flooding (Jongman 2018). Setback levees increase channel conveyance and decrease flood levels while creating in-channel riparian habitat. Subsidence reversal wetlands can reduce the likelihood of levee failure by raising land surface elevations in island interiors while also providing valuable habitat for avian and other species (Miller et al. 2008).

5.4 Water Supply Reliability

27 million Californians and more than 3.7 million acres of agricultural lands receive a portion of their water from the Delta and its watersheds. The Delta serves as a hub for water transfers to other parts of the state and is an area of critical importance for local water use by people, agriculture, and ecosystems. Climate change will place greater stress on the water supply system in the future. Climate change in the Delta and its contributing watersheds will affect water supply and demand, which will impact the reliability and performance of the water supply system in the future. Water supply and runoff will be affected by warming temperatures, decreased snowpack, shifts in the timing of inflows, and increased interannual precipitation variability. Water demand and system operations will be affected by increased crop consumptive use due to warmer temperatures and increased water releases to repel salinity due to sea level rise, particularly in dry years. This section discusses the sensitivity of the Delta's water supply system to future climate stressors and summarizes projected impacts to key water supply

reliability metrics, including Delta exports, North of Delta storage (April and September), and system shortages.

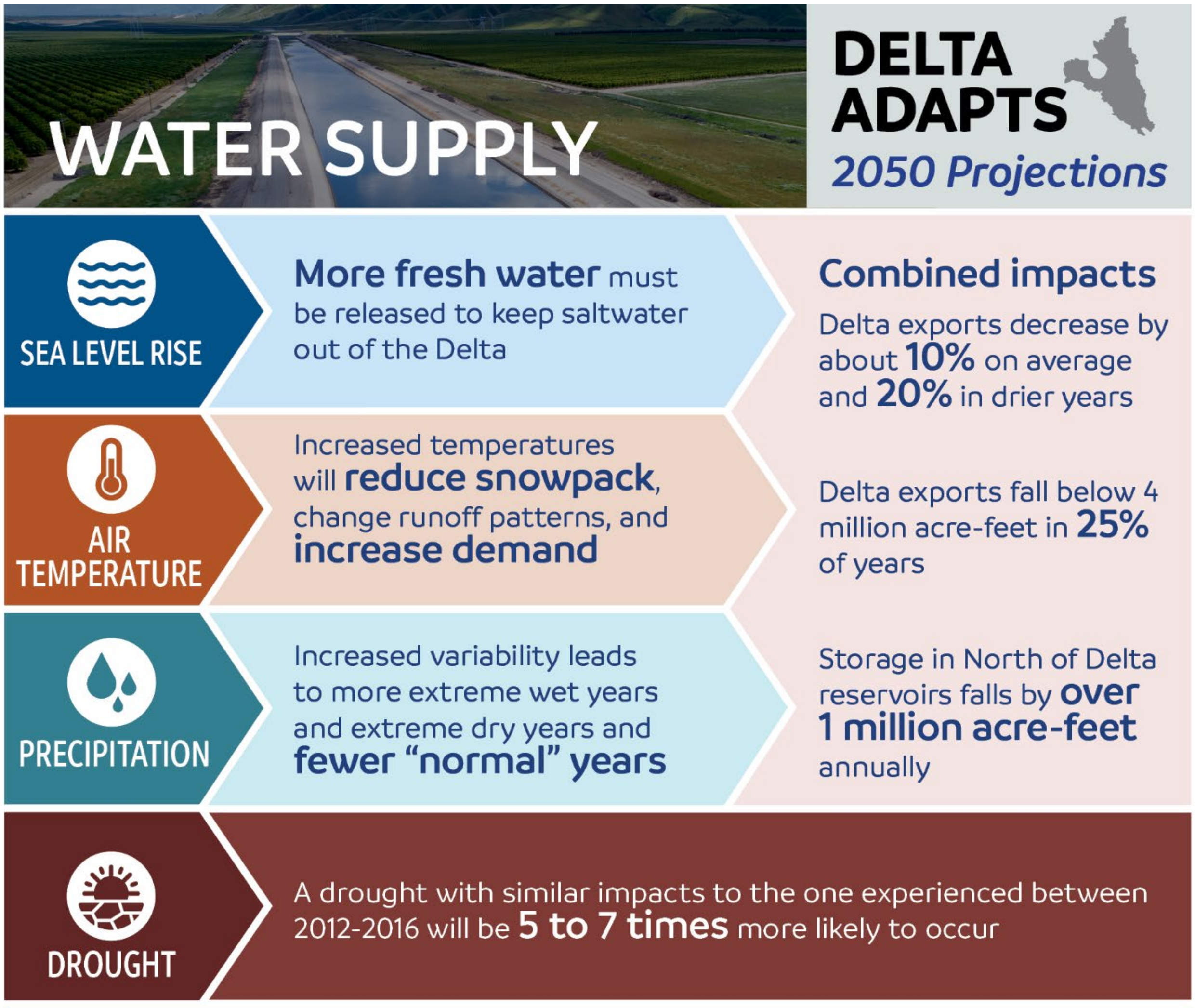

Figure 5-8. Summary of Delta Adapts key findings for water supply at 2050

5.4.1 General Findings

The Delta and its contributing watersheds will be impacted by warming temperatures, decreased snowpack, shifts in the timing of runoff, increased interannual precipitation variability, and sea level rise. These changes will alter the timing, magnitude, and reliability of runoff from Delta watersheds and further stress the water supply system in the future.

Climate projections show a broad consensus in substantial warming trends in the Delta and its watershed over the coming century. Climate projections consistently show that warmer temperatures will result in a transition of precipitation from snow to rain and earlier melting of snowpack, which will alter runoff patterns to reservoirs. By end-of-century, under a high emissions scenario, the mid-point of total runoff is projected to advance by approximately 50 days from the end of April to the end of February, on average (Figure 5-9.). Runoff that shifts to the core winter months is less likely to be captured and stored in reservoirs under current operating rules due to a lack of storage and flood management operations that reserve capacity during the winter to protect downstream areas from flooding.

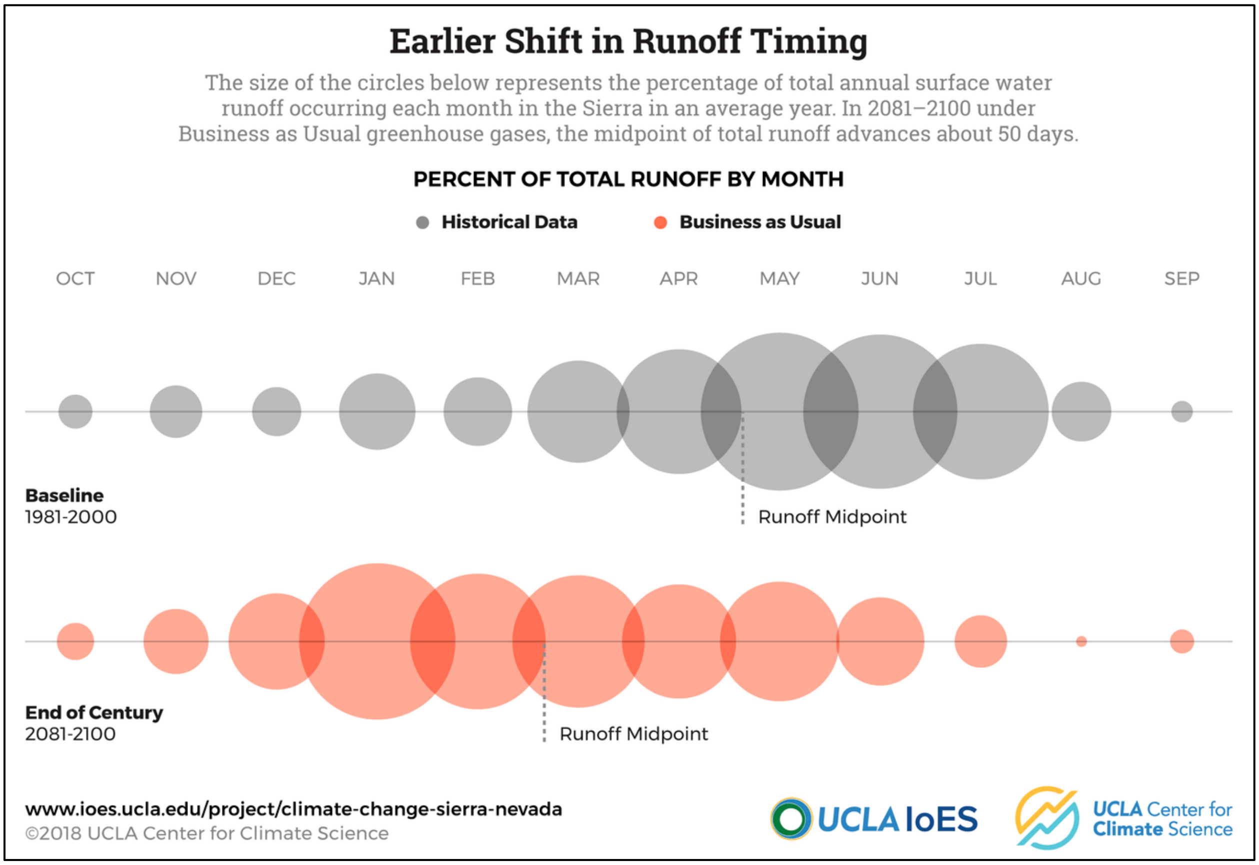

Figure 5-9. Projected shift in end-of-century Sierra runoff for high emissions scenario (RCP 8.5)

Changes in watershed runoff to reservoirs, coupled with reservoir operations that may pass high inflows through reservoirs to maintain winter flood storage capacity, will contribute to higher winter inflows to the Delta. Analysis of future projected streamflows conducted for Delta Adapts identifies a concentration of peak Delta inflow events within the core winter months (January, February, and March) due to future climate change. A study by the U.S. Bureau of Reclamation (2016) found that applying current reservoir operations rules to future hydrologic conditions could actually increase flood risk during the winter while reducing water supply later in the year.

California's climate has historically been characterized by large changes in precipitation from year to year. Recent research by Swain et al. 2018 suggests an increased occurrence of years with rapid transitions from extreme dry to extreme wet conditions. Increased interannual variability may further stress the water supply system and reduce its reliability in the future. Analysis of downscaled precipitation projections conducted for Delta Adapts indicates that it is likely that year-to-year variability in annual precipitation will increase in the future due to climate change – by approximately 15 percent by 2050 and 20 percent by 2085 – while projections of changes in average annual precipitation are less certain (i.e., some models predict an increase in annual precipitation and others predict a decrease).

5.4.2 System Sensitivity

Key water supply performance metrics (Delta exports, North of Delta April storage, North of Delta September storage, and system shortages) have varying degrees of sensitivity to key climate stressors, including air temperature, average annual precipitation, interannual precipitation variability, and sea level rise. Overall, key water supply metrics are found to have high sensitivity to changes in annual precipitation, moderate sensitivity to changes in temperature and interannual variability, and low sensitivity to sea level rise.

The Delta water supply system is highly sensitive to changes in the amount of annual precipitation, with performance across all metrics improving substantially with increasing annual precipitation and degrading substantially with decreasing annual precipitation (Table 5-15). However, projected changes in the amount of average annual precipitation is the most uncertain aspect of climate change and managers should continue to monitor evolving climate science and new research on projected precipitation changes within the Delta's watershed. A change in average annual precipitation of just 10 percent in either direction (i.e., increase or decrease) would result in substantial changes to annual Delta exports (488,000 acre-feet), April storage (462,000 acre-feet), and carryover storage (660,000 acre-feet).

The Delta water supply system is found to be moderately sensitive to changes in average annual air temperature, with substantial reductions in Delta exports and carryover storage (Table 5-15). Because of the high certainty that temperatures will increase in the future, the temperature impact of climate change on the Delta water supply system should be of special concern to water managers and decision makers. Increased temperatures will result in more precipitation falling as rain instead of snow during the winter months, which will help fill reservoirs to similar levels as observed historically by April. However, warmer temperatures will result in reduced winter snowpack and diminished spring and summer runoff from higher elevation areas, which will decrease carryover storage at the end of the irrigation season. Reduced storage in the summer and fall will have broad ranging impacts on ecosystem health, water supply, and drought hedging. For each 1° C of warming, Delta exports are projected to decrease by approximately 210,000 acre-feet per year on average and carryover storage is projected to decrease by 291,000 acre-feet per year on average.

The Delta water supply system is found to be moderately sensitive to changes in interannual variability in precipitation (Table 5-15), with the most significant impacts occurring during dry years. This means that in the driest years that already place the most stress on water users because of low Delta export levels, an increase in interannual variability will even further exacerbate reductions in water supply and may contribute to increased frequency and severity of system shortages. On average, for each 20% increase in precipitation variability, Delta exports are projected to decrease by 169,000 acre-feet per year, April reservoir storage will decrease by 331,000 acre-feet per year, and carryover storage will decrease by 273,000 acre-feet per year.

The Delta water supply system is found to be relatively insensitive to sea level rise in all but the most extremely dry years (Table 5-15), at least up to the 2 feet threshold analyzed for Delta

Adapts. In general, sea level rise will increase salinity intrusion eastward into the Delta unless additional freshwater is released from reservoirs or export pumping is reduced. Within this range of sea level rise, water managers can maintain required flow and salinity conditions in the Delta in most years. During exceptional dry years, sea level rise may be a compounding factor that leads to large system shortages that would cause substantial impacts to in-Delta water users and ecological resources in the Delta. On average, each 10 centimeter increase in sea level is projected to decrease Delta Exports by 34,000 acre-feet per year.

Table 5-15. Sensitivity of Key Water Supply System Performance Metrics to Climate Stressors

Performance Metric	Annual Precipitation	Temperature	Interannual Precipitation Variability	Sea Level Rise
Delta exports	High	Moderate	Moderate	Low
April storage	High	Low	High	Low
September storage	High	Moderate	Moderate	Low
System shortages	Moderate	Low	Moderate	Low

5.4.3 System Vulnerability

While the system sensitivity analysis described above is instructive in providing a better understanding of how the system performance may improve or decline in response to individual climate stressors, climate change will drive multiple simultaneous changes that may act cumulatively to exacerbate impacts. The following section summarizes impacts for climate conditions at 2050. The analysis considers a wide range of potential climate projections at 2050, giving more weight to conditions where more models agree but still considering more extreme outcomes projected by fewer models. The range of outcomes spans from 1 degree C to 3.5 degrees C with a median around 2 degrees of warming, -20% change in variability of precipitation to +40% with a median around 13%, and up to 24 inches of sea level rise (see Water Supply Technical Memorandum for additional discussion of the range of climate projections considered).

5.4.3.1 Delta Exports

There is a very high likelihood that annual Delta exports will be reduced at 2050 relative to historical levels, with projected average decreases of 10 to 20 percent. Reductions in Delta exports will have considerable economic impacts to municipal, industrial, and agricultural activities throughout the State.

Delta exports average approximately 5.5 million acre-feet per year under current conditions. There is a very high likelihood that annual Delta exports will be reduced at 2050 relative to historical levels. Based on the range of future climate projections, it is likely that Delta exports will be reduced by approximately 10 to 20 percent annually by 2050 relative to current conditions, with more severe reductions to exports occurring during the driest years. Additionally, the frequency with which Delta exports fall below 4 million acre-feet (approximately the 20^{th} percentile of exports for current conditions) will increase from about 12 percent of years under current climate conditions to nearly 25 percent of years by 2050.

Municipal and industrial water users outside the Delta that rely on CVP and SWP exports may experience economic losses as a result of reductions in Delta exports due to climate change. Reductions in CVP and SWP exports may cost urban agencies approximately $237 million per year on average by 2050 to replace losses in water deliveries (e.g., through water transfers or alternate supplies). In 2050, a complete loss of Delta exports due to a temporary diversion outage as a result of a climate-related (or non-climate related) event that impedes exports would cost urban agencies approximately $1.6 billion to replace emergency water supplies consumed during the outage.

Agricultural water users outside the Delta that rely on CVP and SWP exports may also experience economic losses as a result of reduced agricultural production and groundwater replacement costs due to reductions in Delta exports as a result of climate change. Average annual reductions in water deliveries may result in approximately 115,000 acres of croplands being fallowed by 2050 relative to existing production, exposing approximately $126 to $285 million per year in agricultural production to water supply vulnerabilities. In 2050, a complete loss of Delta exports due to a temporary diversion outage as a result of a climate-related event such as widespread Delta island flooding and salinity intrusion could expose approximately $962 million to $1.2 billion in agricultural production to water supply vulnerabilities due to reduced water supply and costs of groundwater replacement.

5.4.3.2 April Storage

Increases in interannual precipitation variability are projected to result in greater frequency of lower end-of-April storage conditions and exacerbate low storage during below average runoff years.

Future North of Delta end-of-April reservoir storage is predicted to be most sensitive to changes in interannual precipitation variability as opposed to temperature and sea level rise. Increases in interannual variability will result in more years with runoff either below or above average conditions and fewer years in which runoff is near average conditions. During low runoff years (approximately the 25th percentile of April storage), it is projected that April storage would decrease by 450,000 acre-feet (approximately five percent). During high runoff years (approximately the 75th percentile of April storage), it is projected that April storage would change very little. This is because higher runoff during the winter months may not be able to be captured in reservoirs due to existing operations and rule curves that limit reservoir levels during the winter to reduce downstream flood risk.

5.4.3.3 September Storage

There is a very high likelihood that end-of-September storage will be reduced at 2050 relative to historical levels, with projected average decreases of 10 to 25 percent and larger declines during the driest years.

Projected changes to North of Delta end-of-September "carryover" storage are similar to changes predicted for Delta exports. There is a very high likelihood that carryover storage will be reduced at 2050 relative to historical levels. Reduction in snowpack translates to reductions in late season reservoir refill, (i.e., the reduction of flows that enter reservoirs during late spring and early summer and will likely substantially reduce the amount of water stored in reservoirs at the end of each irrigation season). Projected increases in interannual precipitation variability will exacerbate the sensitivity of North of Delta carryover storage to temperature increases which result in less snowpack. Based on the range of future climate projections, it is likely that North of Delta carryover storage will decline by 10 to 25 percent by 2050. Moreover, declines of over one million acre-feet of annual carryover storage are predicted to occur in all future years, with larger declines predicted during the driest years. The lowest storage operational target of 1.5 MAF for North of Delta carryover storage during the driest year conditions is projected to be eight times more likely to occur by 2050.

5.4.3.4 System Shortages

Climate change will increase the frequency and severity of rarely occurring system shortages, which may result in potentially damaging water shortages.

System shortages – years in which there is not enough water to meet all operational requirements – primarily occur during extreme and rare events. Sea level rise appears to be an important factor in conditions that lead to especially large system shortages that would cause the greatest impacts to in-Delta water users and ecological resources in the Delta. While current water management and operations can effectively manage increases in sea level rise generally, the chronic impacts of higher sea levels create greater vulnerability to severe impacts in the form of system shortages when extremely dry conditions occur. Comparison of the most severe conditions expected under current climate conditions with the most severe conditions expected under 2050 conditions shows that system shortages are projected to increase by 1200 percent in the driest two percent of years. These results suggest that climate change will lead increasingly to rare conditions that result in large water shortages in which minimum environmental flow targets and Delta water quality may be compromised.

5.4.4 Drought Impacts

Rarely occurring drought events – such as the drought that occurred between 2012 to 2016 – will become more frequent and severe in the future. Reductions in Delta exports during future similar droughts will have considerable economic impacts to municipal, industrial, and agricultural activities throughout the State.

Water supply drought frequency and intensity are projected to increase in the future. The most recent 2012-2016 water supply drought was a rare event and one of the driest and warmest in history. By 2050, increased temperatures, increased precipitation variability, and sea level rise are projected to result in drought conditions like 2012-2016 occurring 5-7 times more often.

Pervasive reductions in carryover storage are expected under future climate conditions across all water year types, especially during abnormally dry years. Under current conditions, simulations demonstrate that 8 million acre-feet of water are typically carried over from September into the first year of a water supply drought (as defined in the Water Supply Technical Memorandum). Projected carryover storage prior to the first year of the drought would be reduced by nearly 10 percent in 2050. These reductions will contribute to increasing drought severity and reduced Delta exports in the future. For example, Delta exports during a drought like 2012-2016 would be approximately 20 percent less were that drought to occur in 2050.

Municipal and industrial water users outside the Delta that rely on CVP and SWP exports may experience economic losses due to future droughts above and beyond the annual losses discussed above due to average changes in climate conditions. Additional economic losses during a drought similar to 2012 to 2016, were it to occur under 2050 climate conditions, may cost urban agencies an additional $17 billion due to curtailment of economic activities as a result of water restrictions and conservation during the latter years of the drought. Reductions in CVP and SWP water deliveries to agricultural water users outside the Delta during such a drought, may result in an additional 243,000 acres of croplands being fallowed relative to projected 2050 production, resulting in exposure of an additional $762 to $921 million per year in agricultural production to water supply vulnerabilities due to reduced water supply and costs of groundwater replacement during and after the drought.

5.4.5 In-Delta Water Supplies

In-Delta water users will likely face reduced reliability of diversions in the future due to climate change, primarily due to low inflow conditions coupled with sea level rise, which may allow salinity intrusion into the Delta. While these events have been rare under current water system operations, they may become more common in the future, and when they do occur, the shortages will be significantly larger than historical conditions.

In-Delta water users have historically faced reductions and reduced reliability of diversions in years in which the water delivery system as a whole is stressed and water supplies are limited. The primary limit on in-Delta diversions is salinity intrusion into the Delta during low inflow conditions, especially during the summer and fall months of drought years. While these conditions have historically been rare due to operation of the State and Federal Water Projects, climate change may result in these events becoming more common in the future. When they do occur, shortages will be significantly larger. Projected changes to the water supply system due to climate change may require more substantial trade-offs between beneficial uses and potentially longer periods during which normal regulations and requirements are relaxed.

CHAPTER 6. CONCLUSIONS

The Delta Adapts Climate Change Vulnerability Assessment is an important step in the Council's efforts to develop a comprehensive, regional approach to climate resiliency in the Delta and Suisun Marsh. The CCVA helps the Council and Delta communities better understand regionally significant climate vulnerabilities and risk in the Delta and lays the foundation for future adaptation planning efforts by the Council and stakeholders.

Climate change is already altering the Delta's physical environment and the people, assets, and resources of the Delta will continue to experience the effects of climate change in the coming decades. This assessment evaluated a range of potential climate stressor and hazard impacts and identified a broad set of key findings to inform future adaptation planning efforts. Representative key findings include:

- Climate change will not impact Delta residents, assets, and resources equally
- The risk of flooding in the Delta will get worse
- Delta water exports will be less reliable and impact urban, industrial, and agricultural users statewide
- In-Delta water users may be threatened by episodic water quality declines
- Delta ecosystems will be stressed by changes in temperature, precipitation, and sea level rise
- Agricultural production trends will shift with a changing climate
- There is still time to act to lessen the impacts of climate change in the Delta

Although the exact extent and timing of these impacts is uncertain, the vulnerabilities identified in this assessment highlight the need to act now. The next phase of Delta Adapts, preparing an Adaptation Strategy, will identify ways to address these vulnerabilities and risks and provide a more reliable water supply for California, protect, restore, and enhance the Delta's ecosystem, and protect the values of the Delta as an evolving place.

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CHAPTER 8. SUPPORTING APPENDICES

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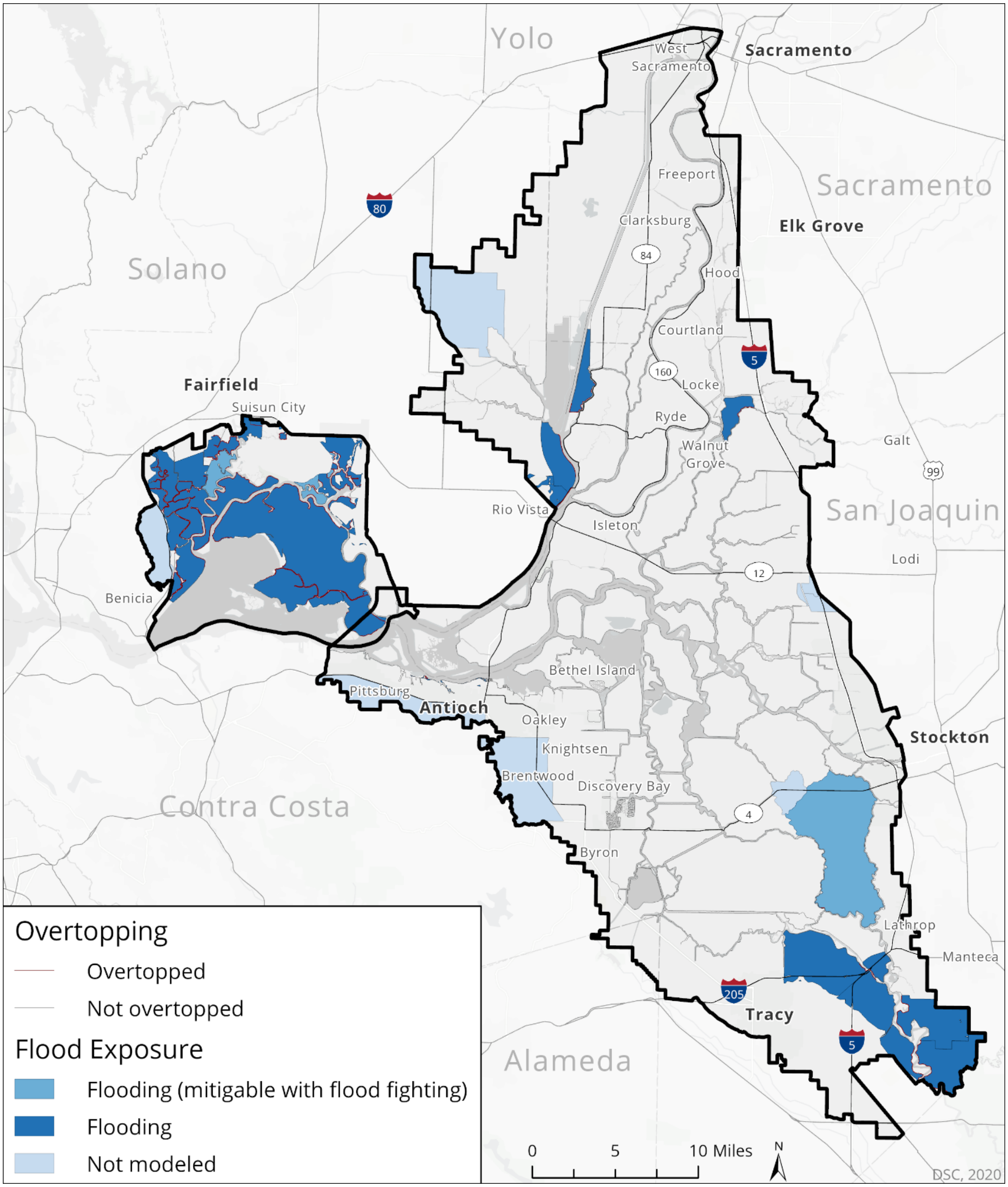
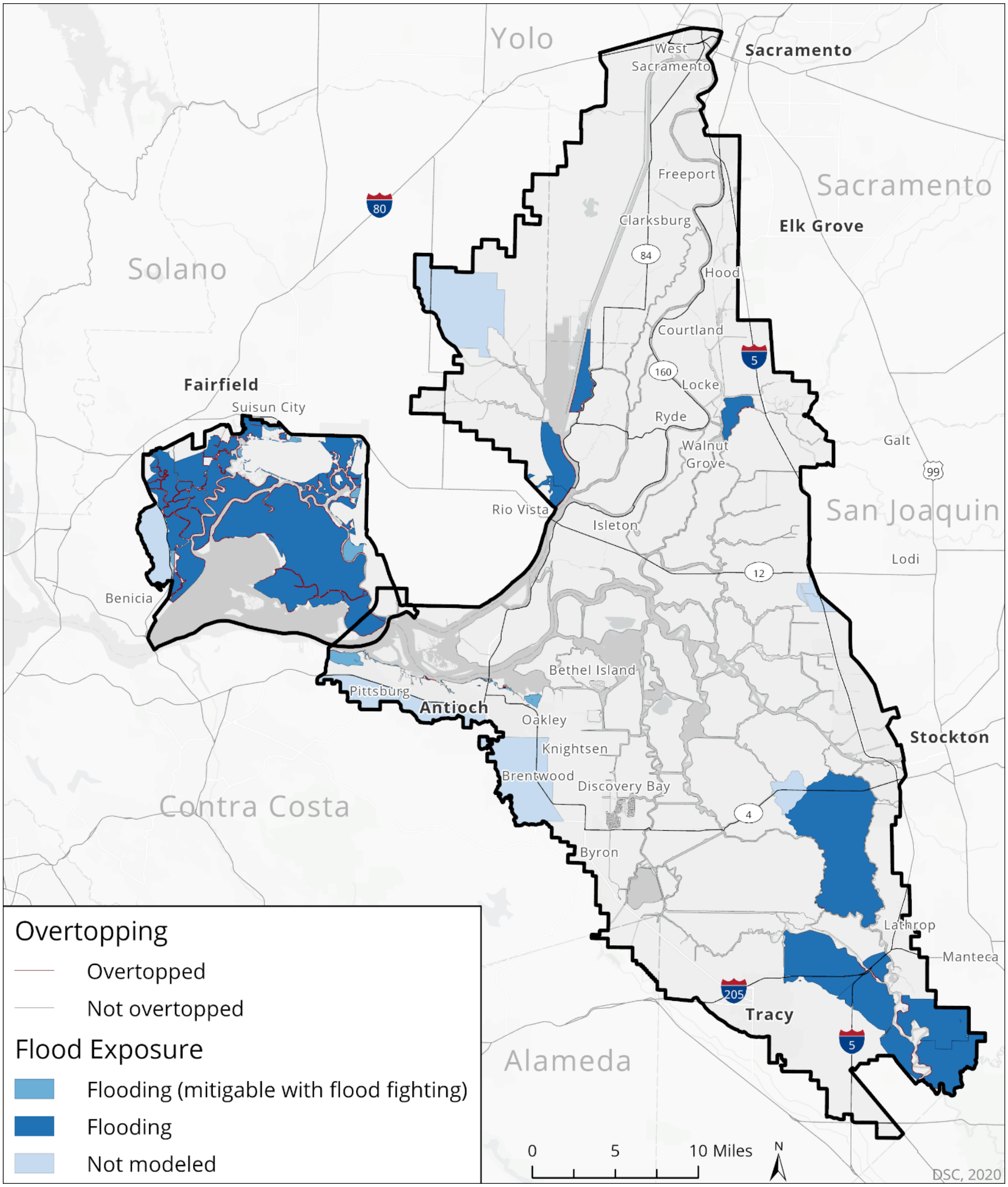
Appendix A. Deterministic Flood Maps

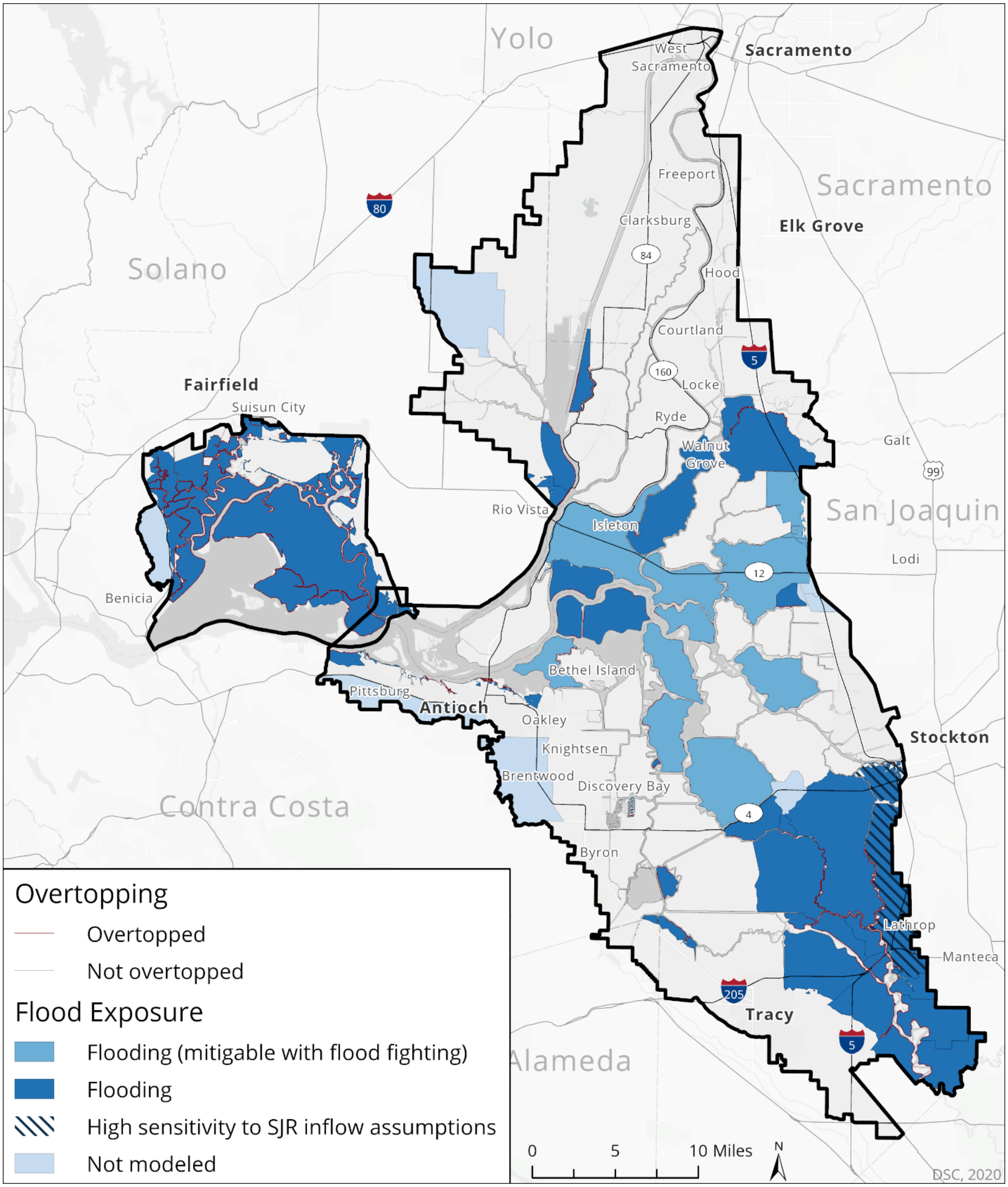
Existing Conditions: 100-year Flood with 0 inches of Sea Level Rise



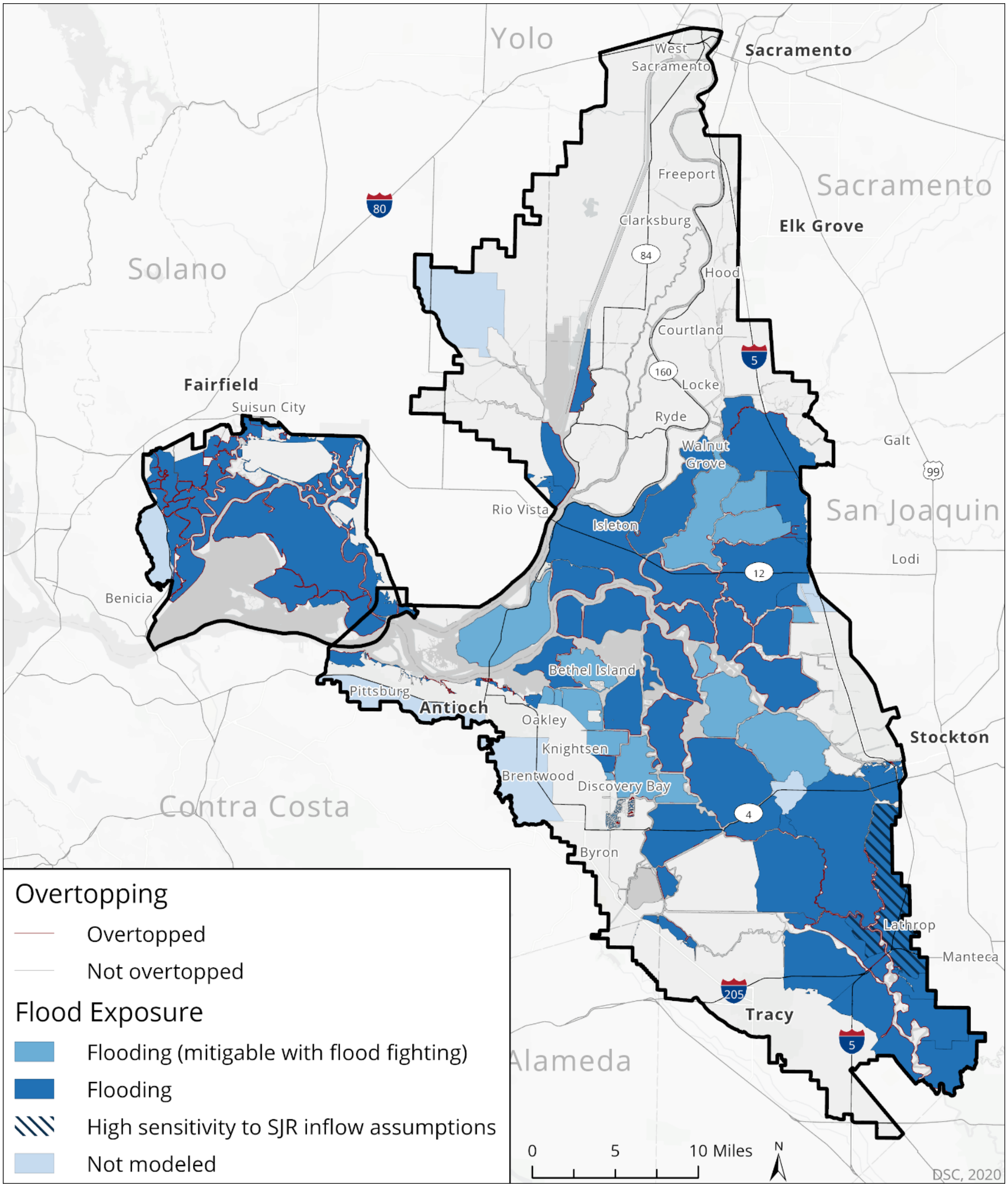
2030: 100-Year Flood with 6 Inches of Sea Level Rise



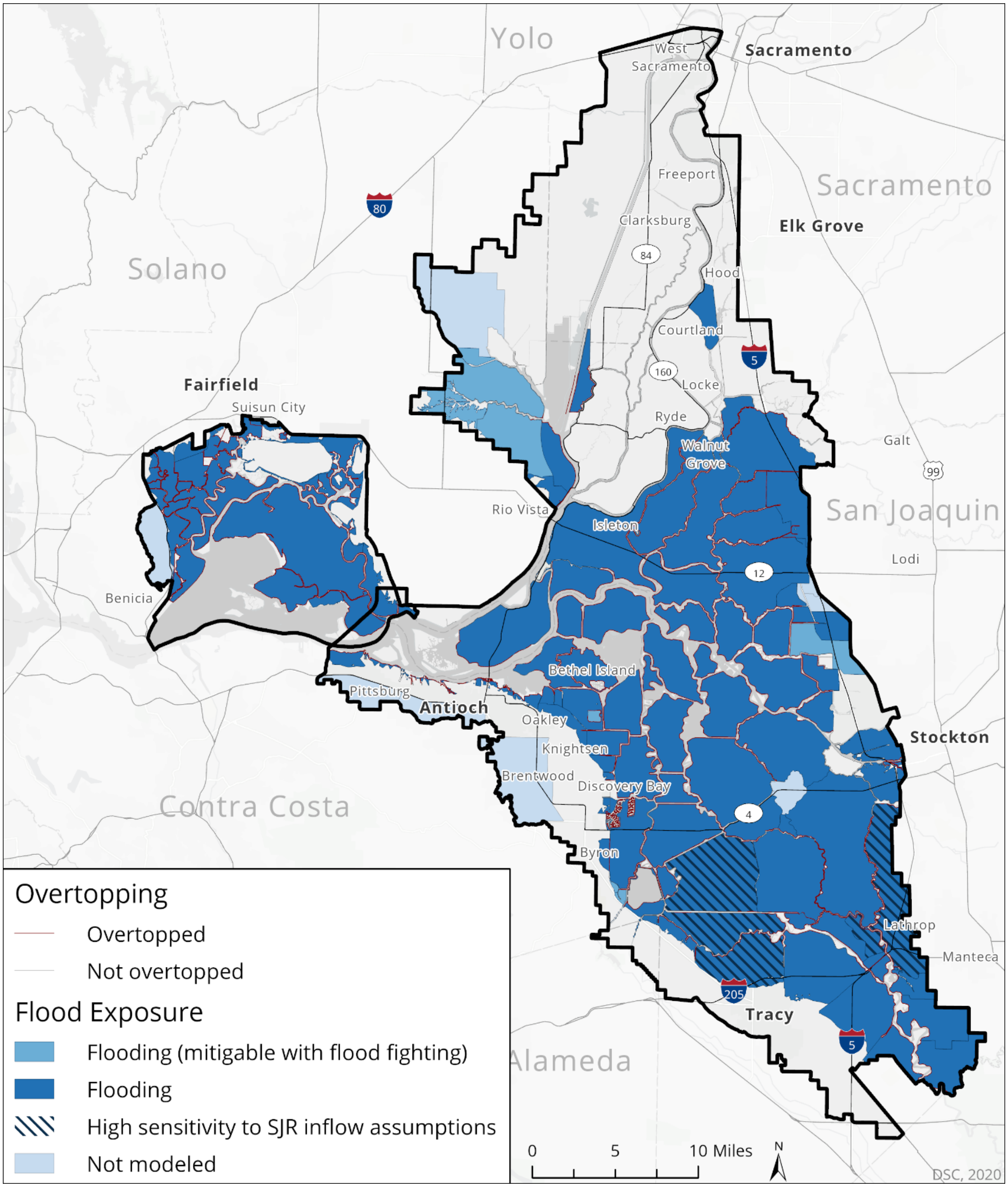
2050: 100-Year Flood with 12 Inches of Sea Level Rise



2050: 100-Year Flood with 24 Inches of Sea Level Rise

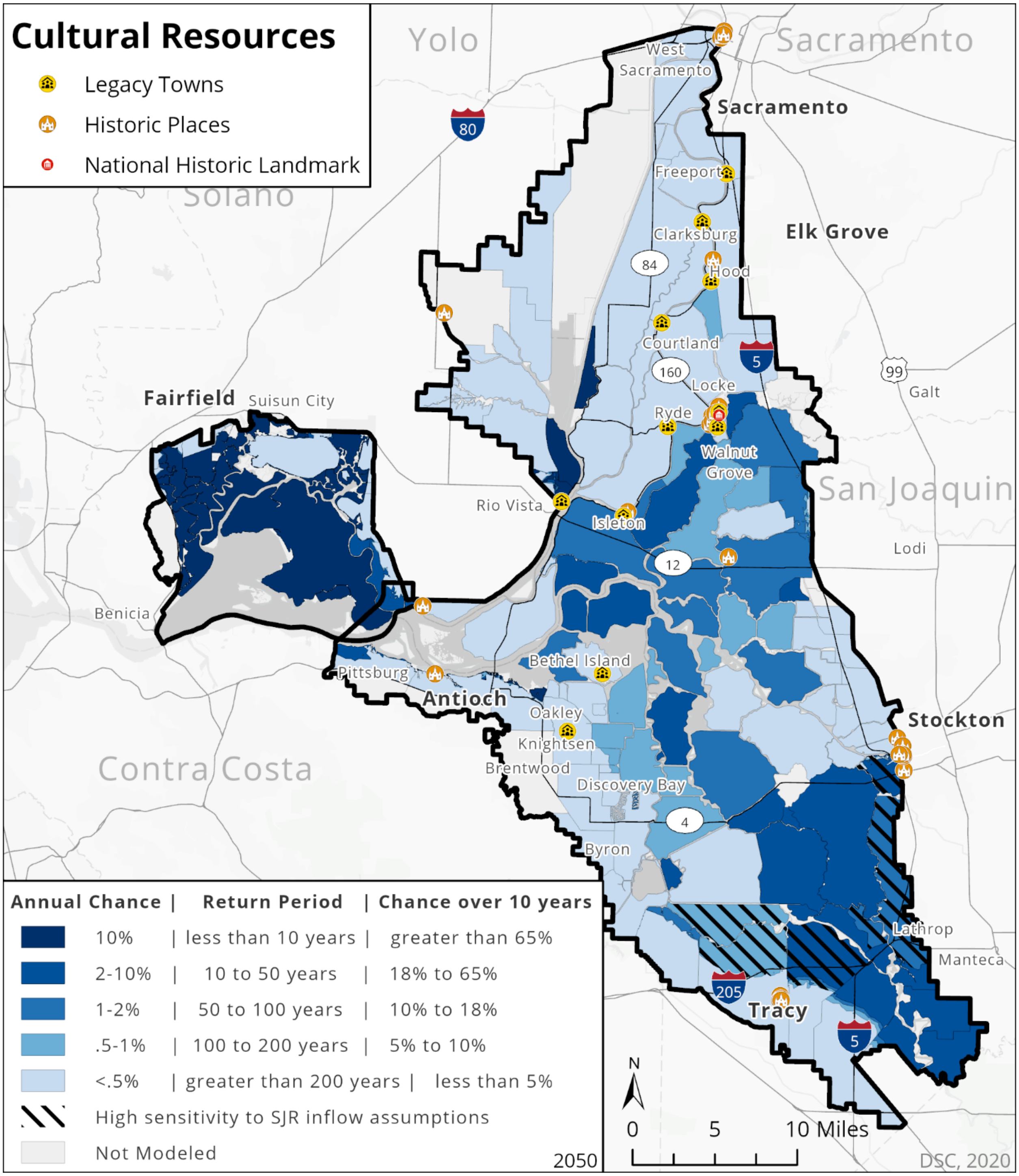


2050+: 100-Year Flood with 42 Inches of Sea Level Rise

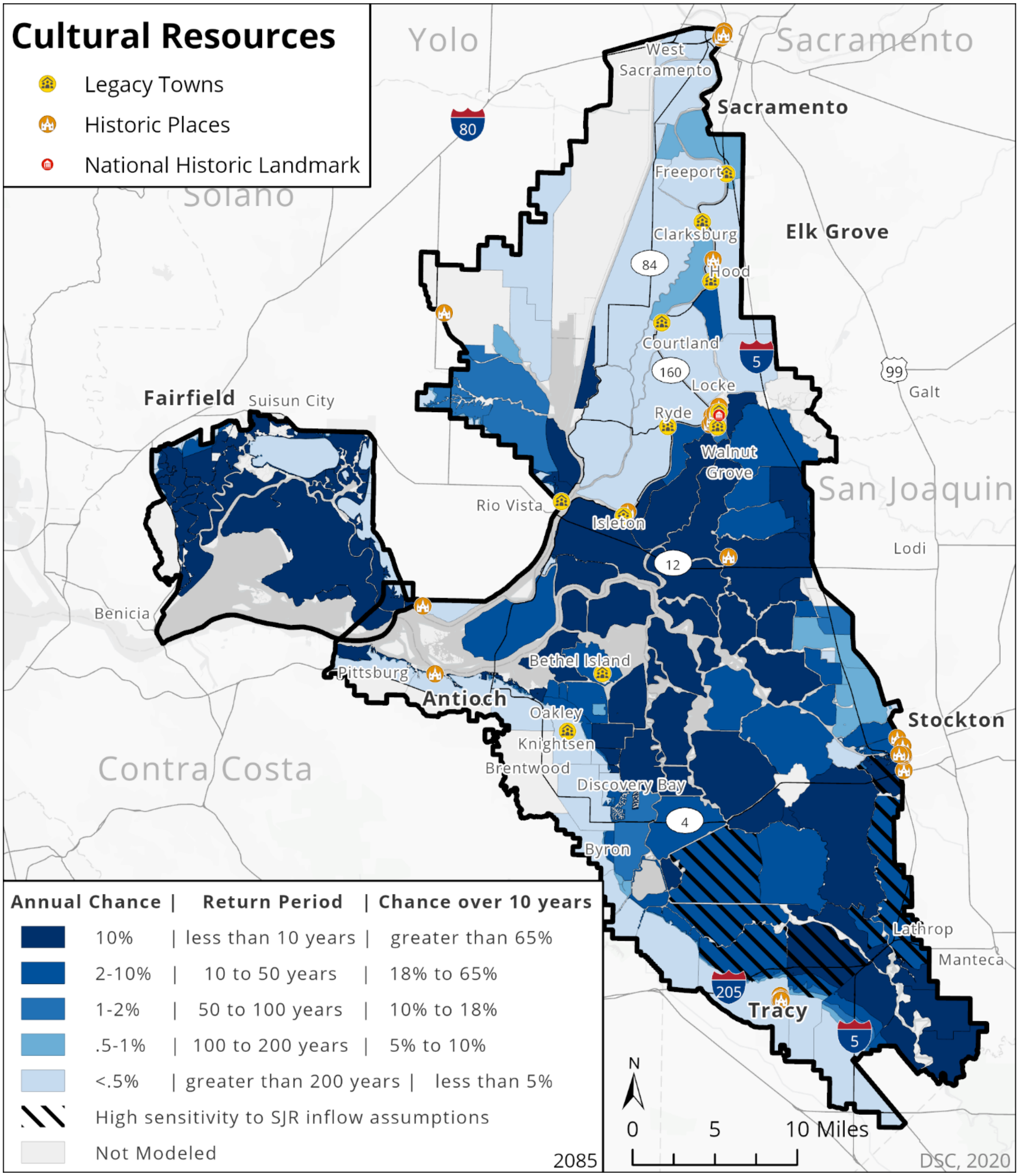


Appendix B. Asset Flood Exposure Maps

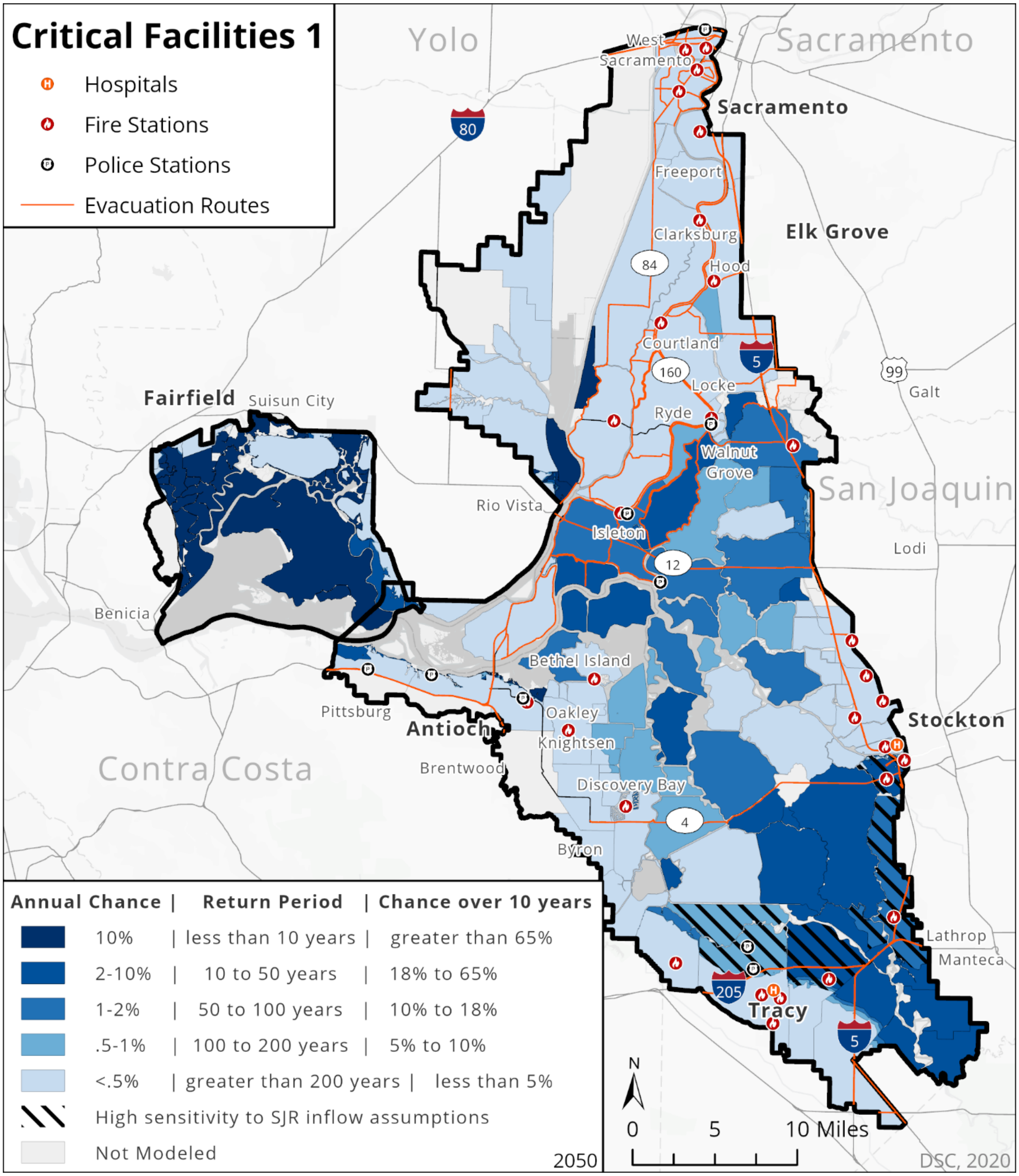
2050: Cultural Resources Flood Exposure Map



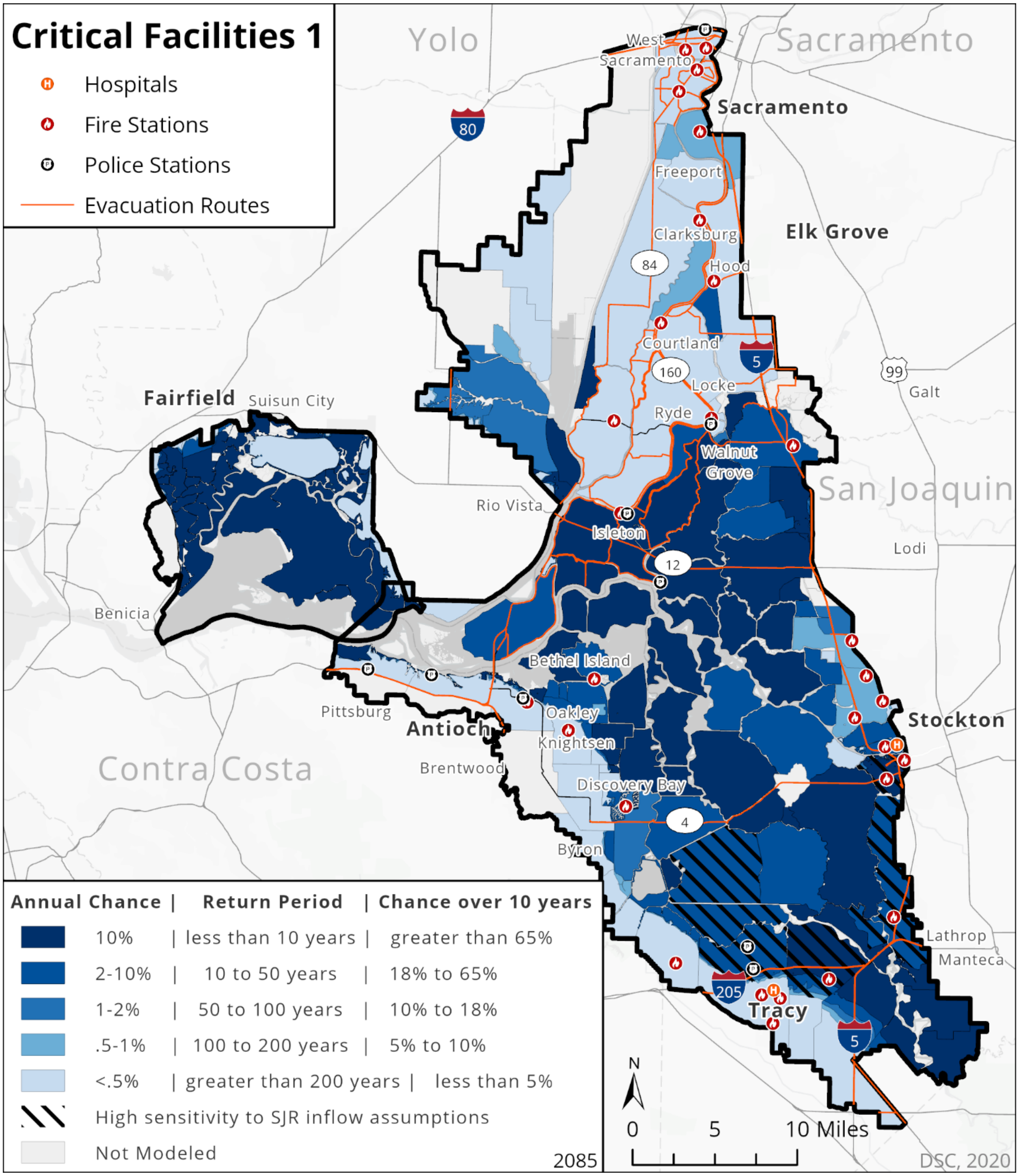
2085: Cultural Resources Flood Exposure Map



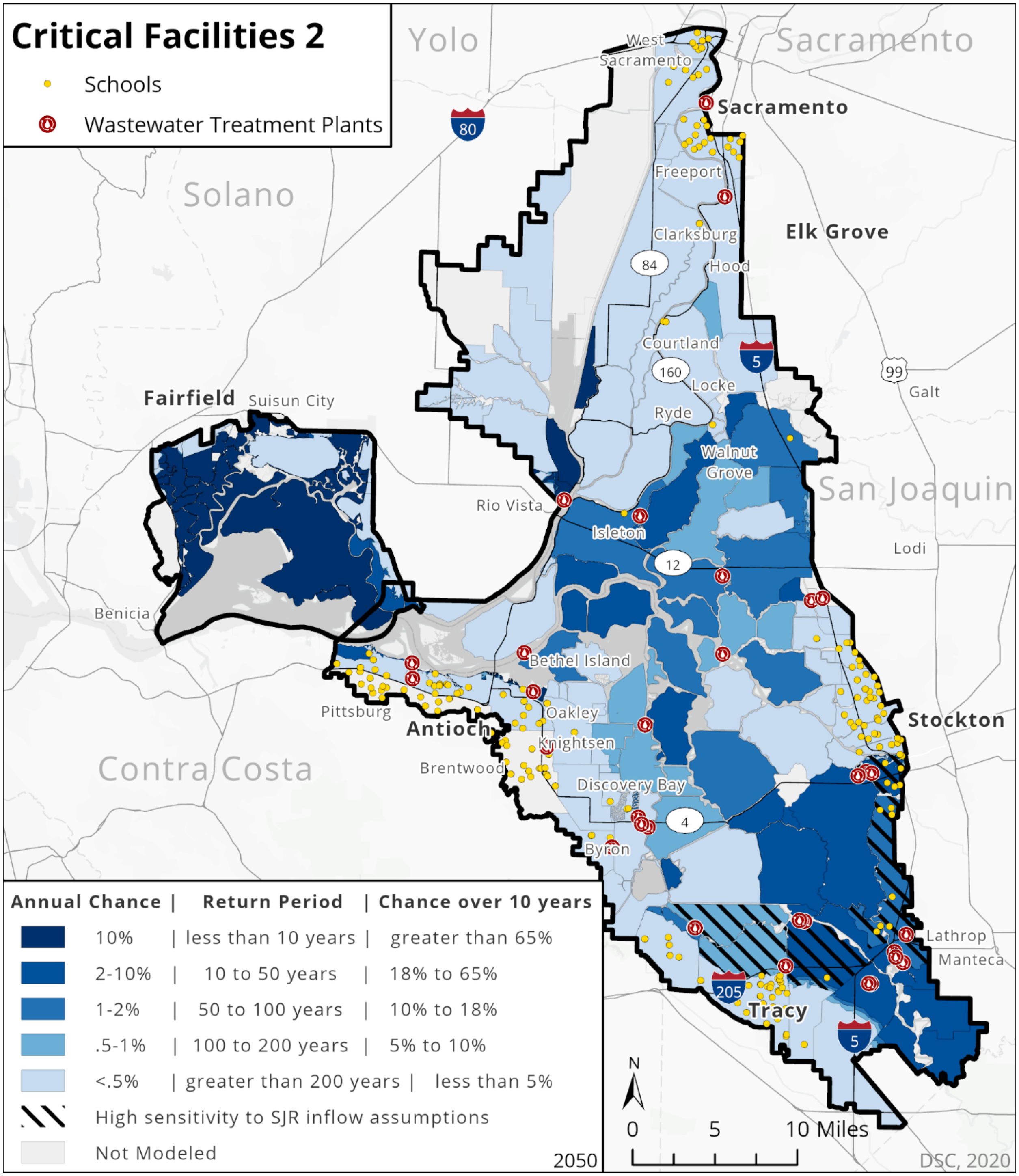
2050: Critical Facilities Flood Exposure Map #1



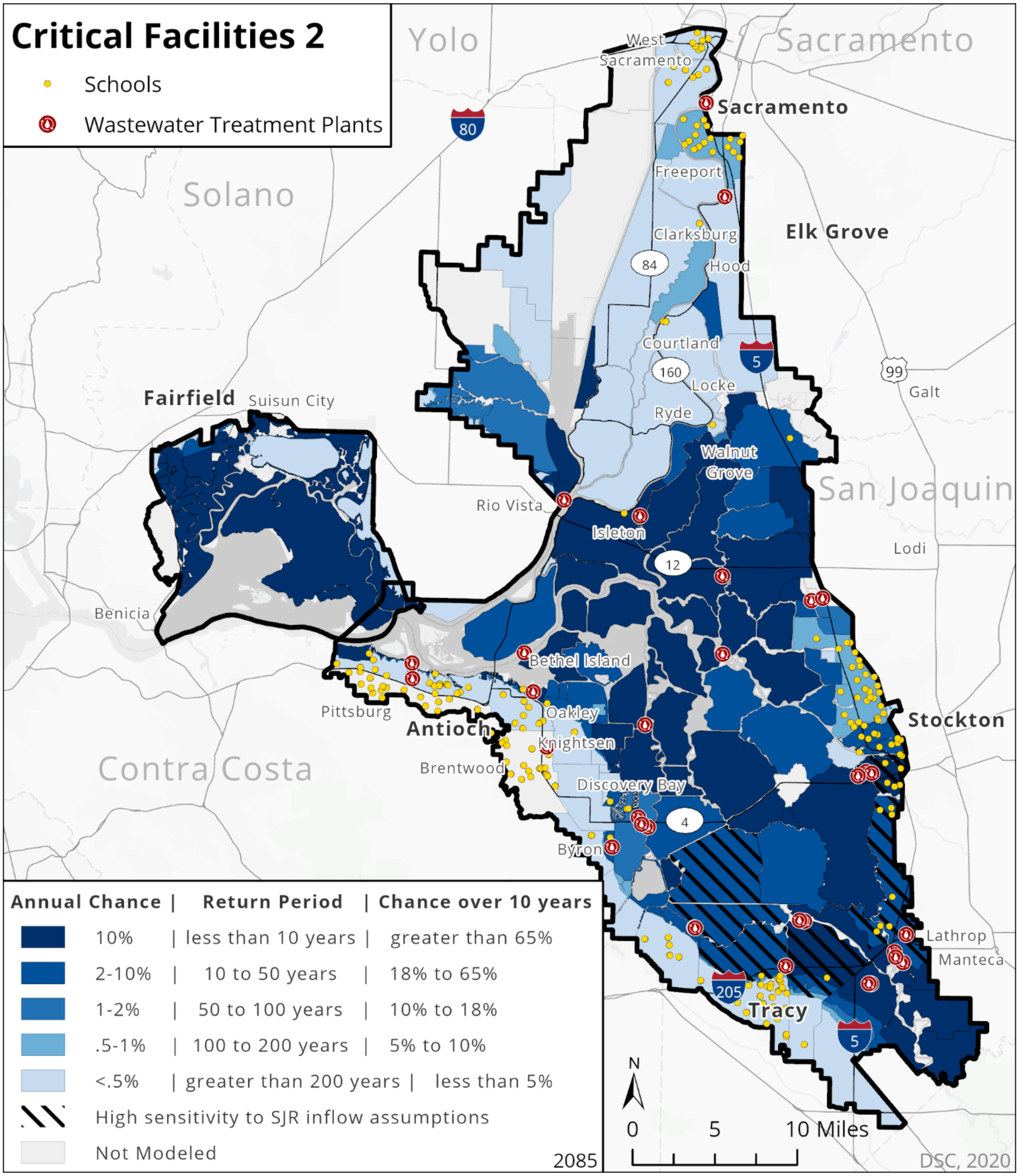
2085: Critical Facilities Flood Exposure Map #1



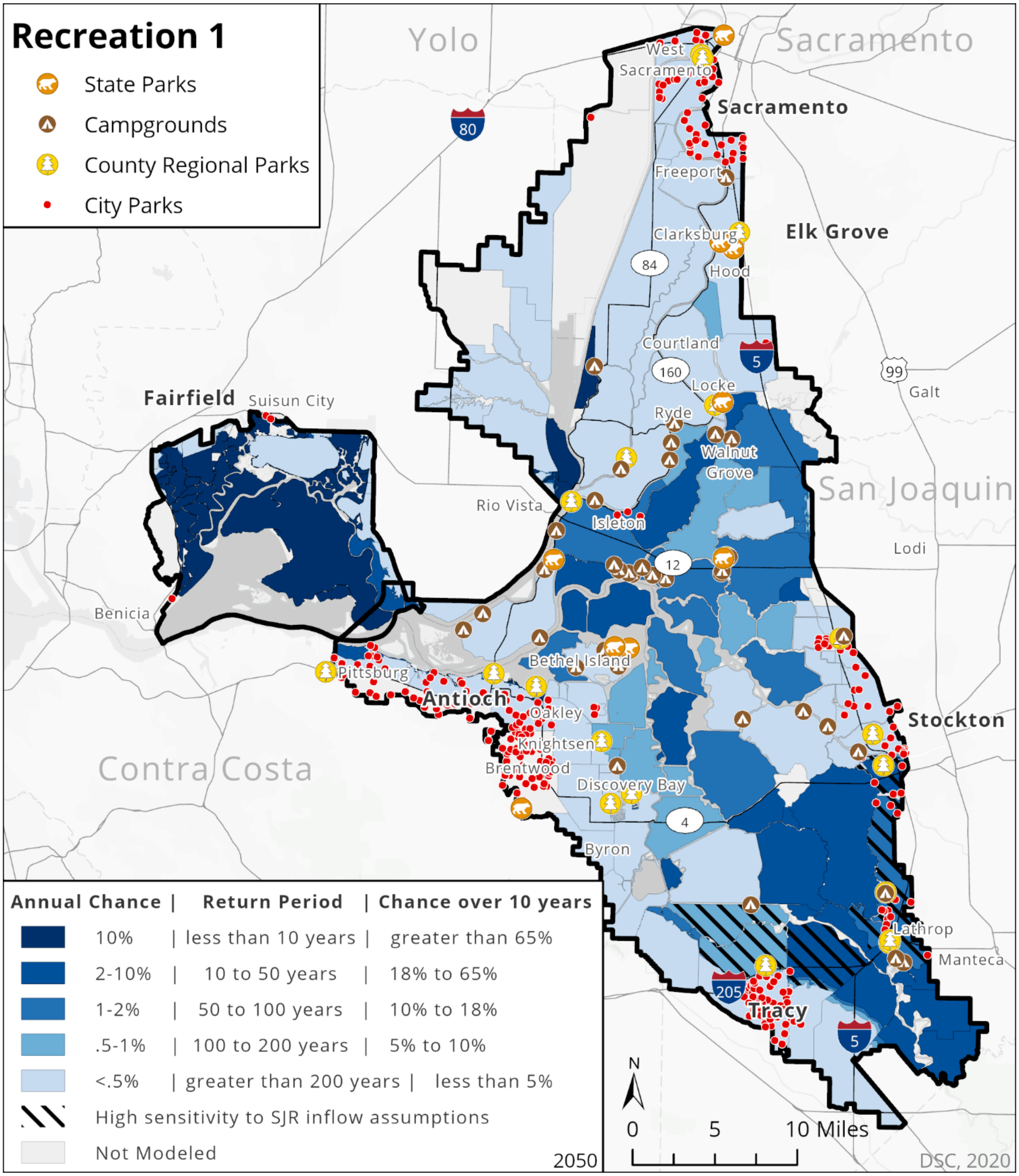
2050: CRITICAL FACILITIES FLOOD EXPOSURE MAP #2



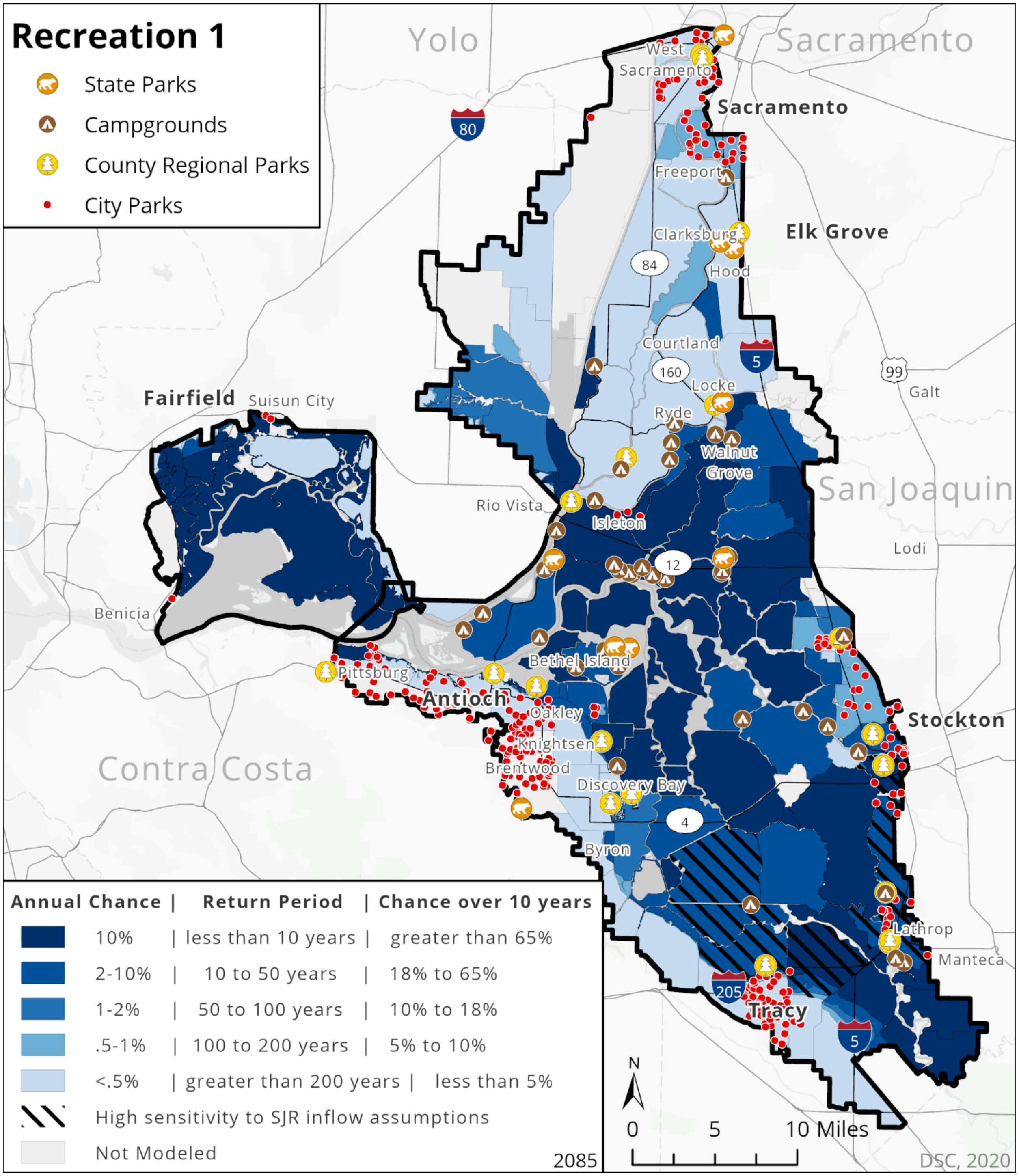
2085: CRITICAL FACILITIES FLOOD EXPOSURE MAP #2



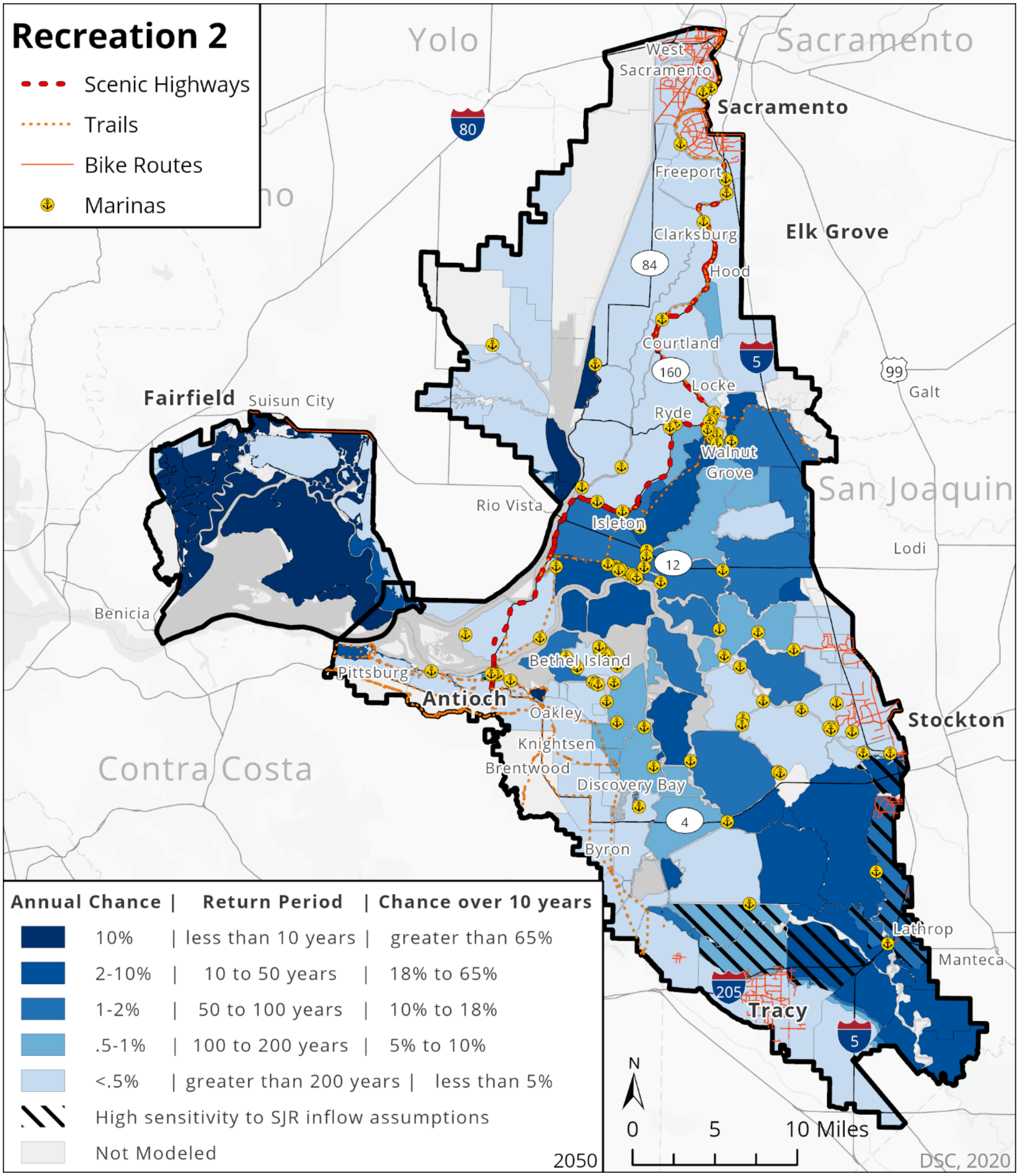
2050: Recreation Flood Exposure Map #1



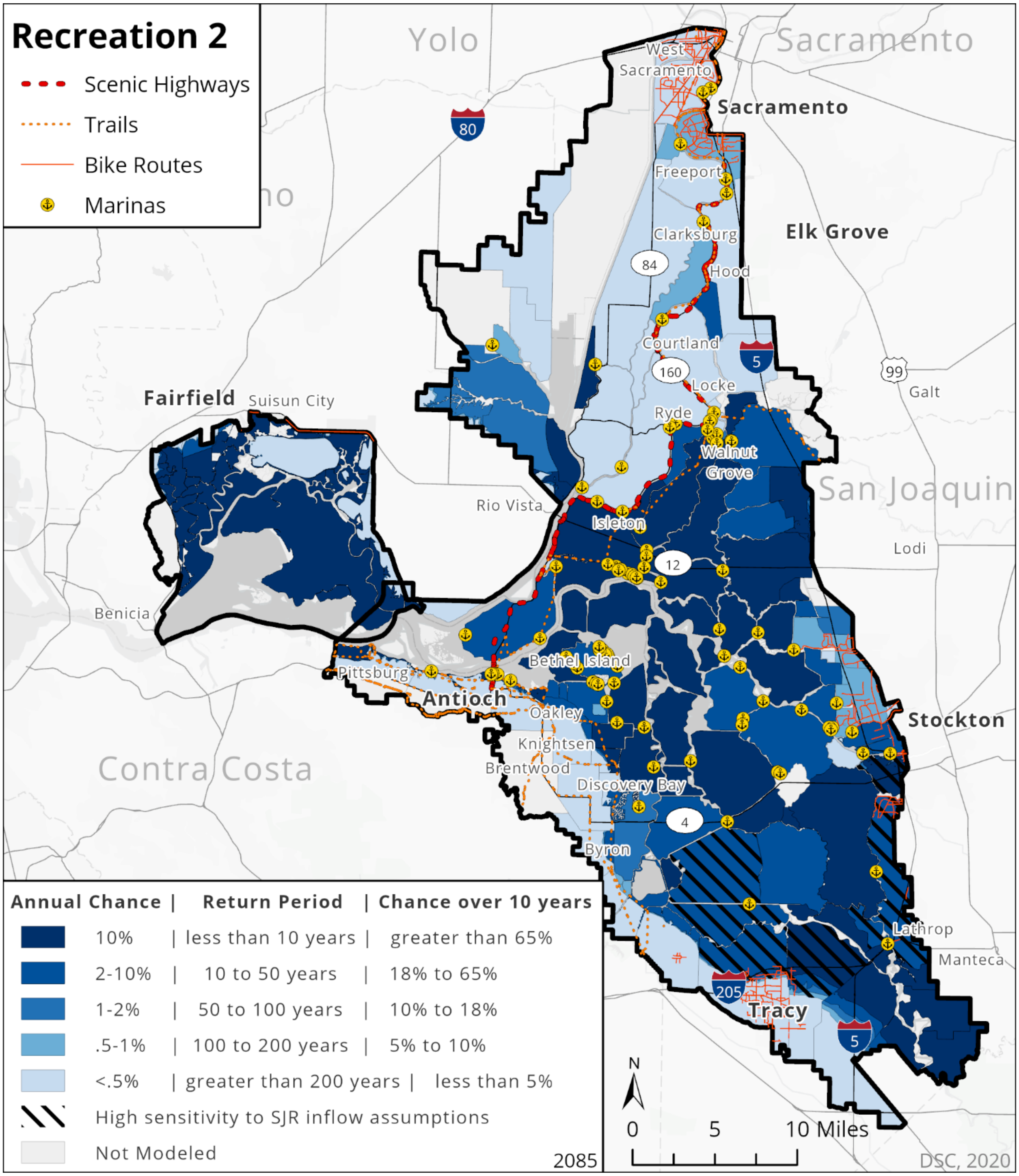
2085: Recreation Flood Exposure Map #1



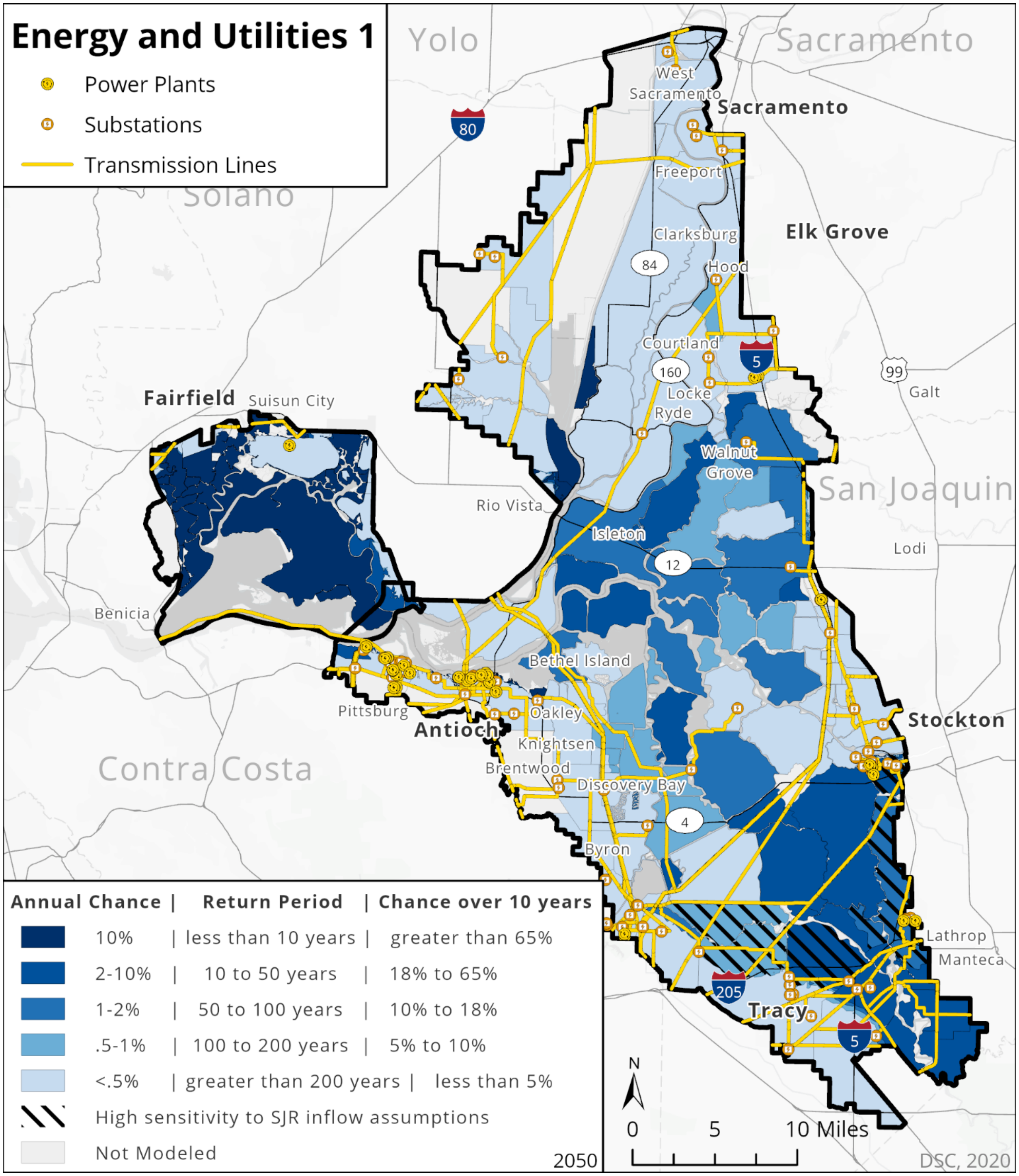
2050: Recreation Flood Exposure Map #2



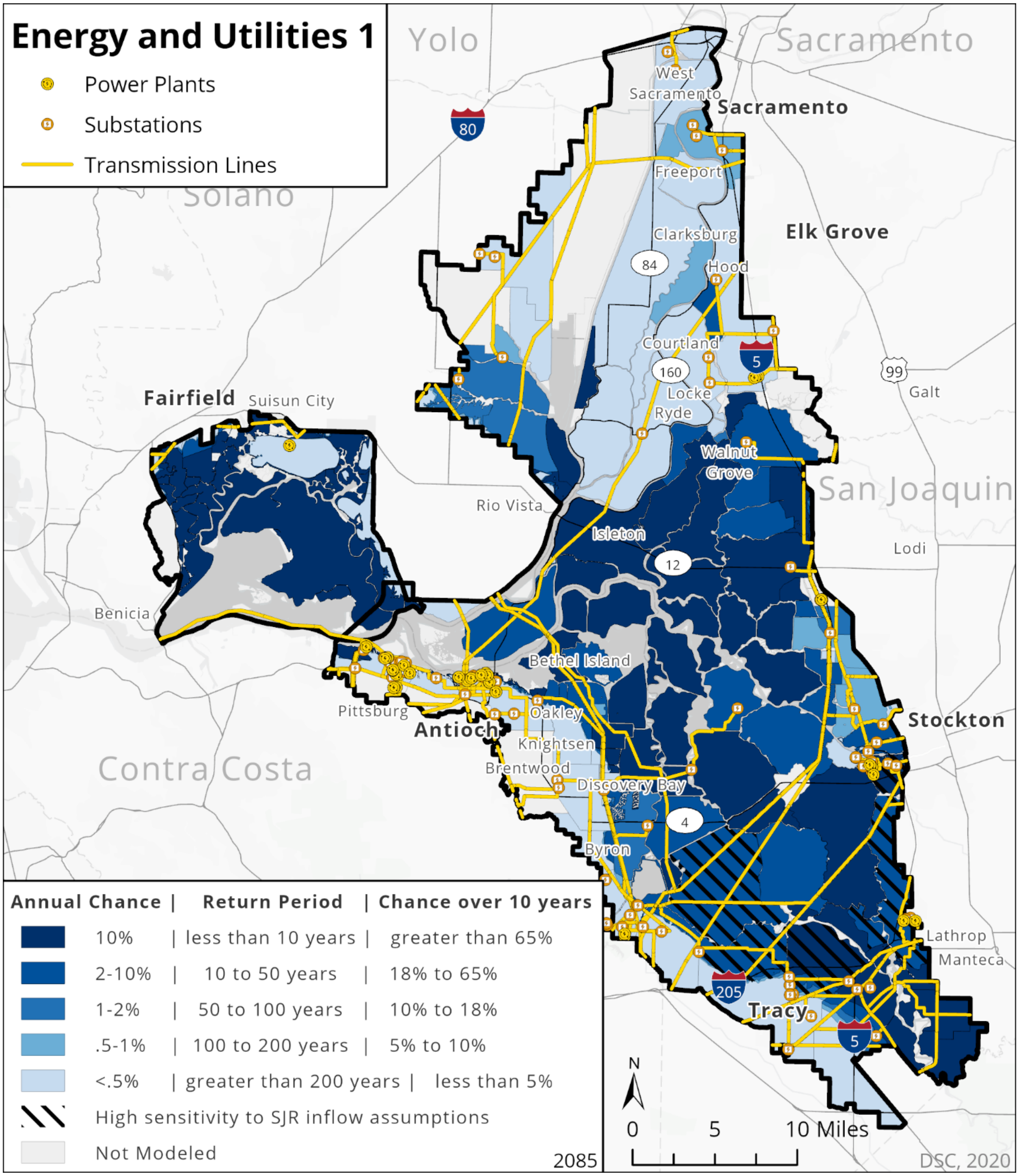
2085: Recreation Flood Exposure Map #2



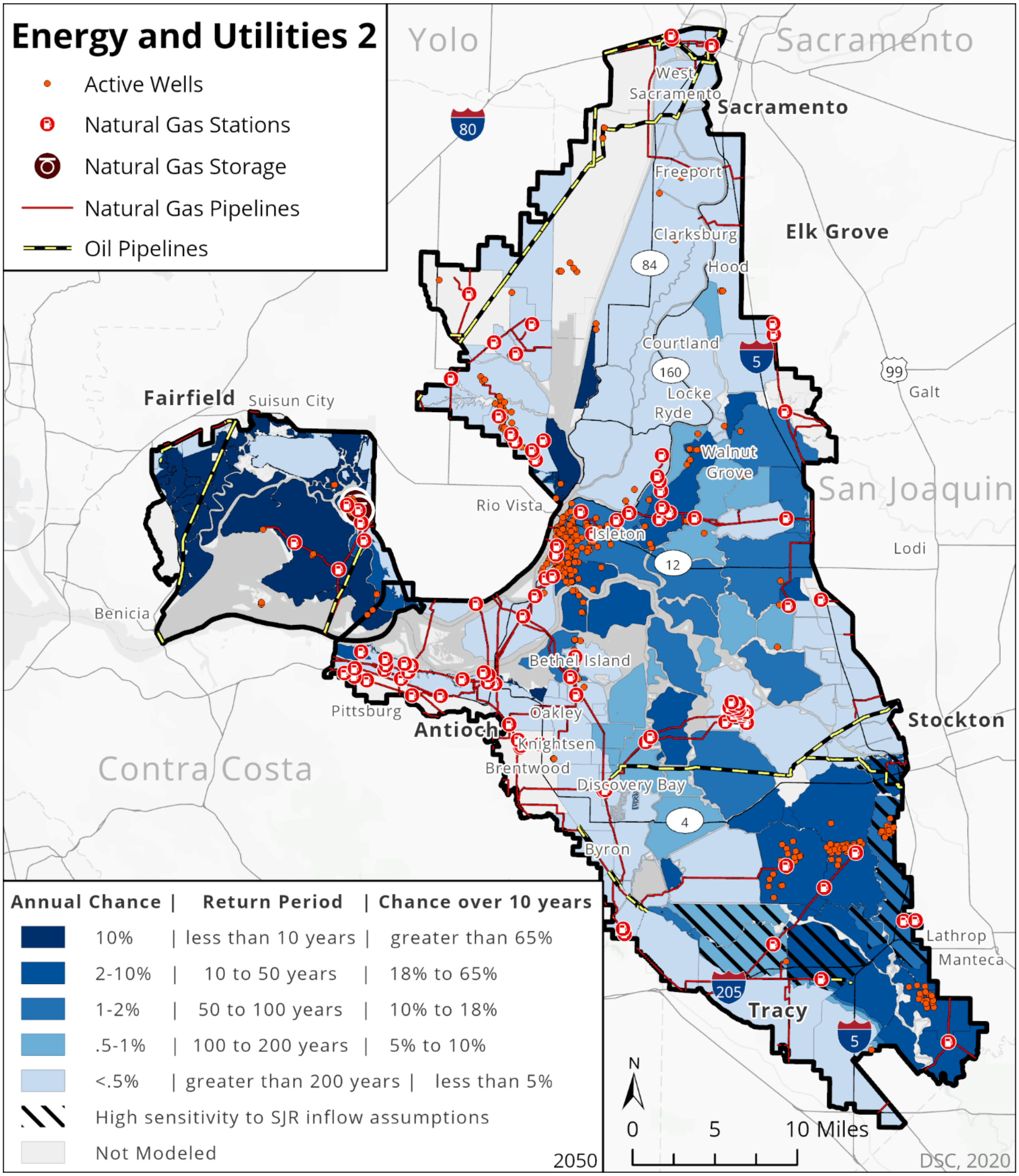
2050: Energy and Utilities Flood Exposure Map #1



2085: Energy and Utilities Flood Exposure Map #1



2050: ENERGY AND UTILITIES FLOOD EXPOSURE MAP #2



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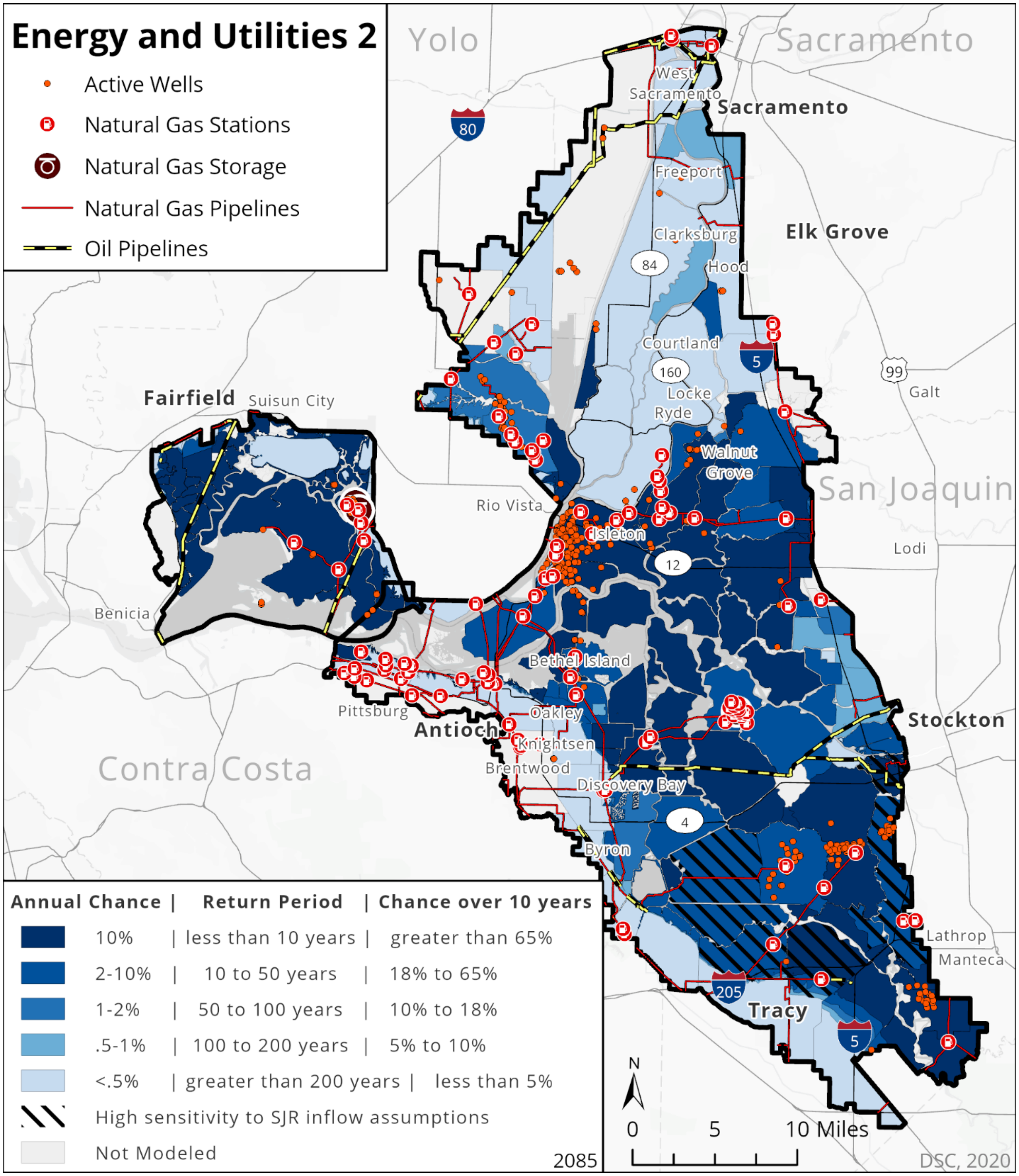
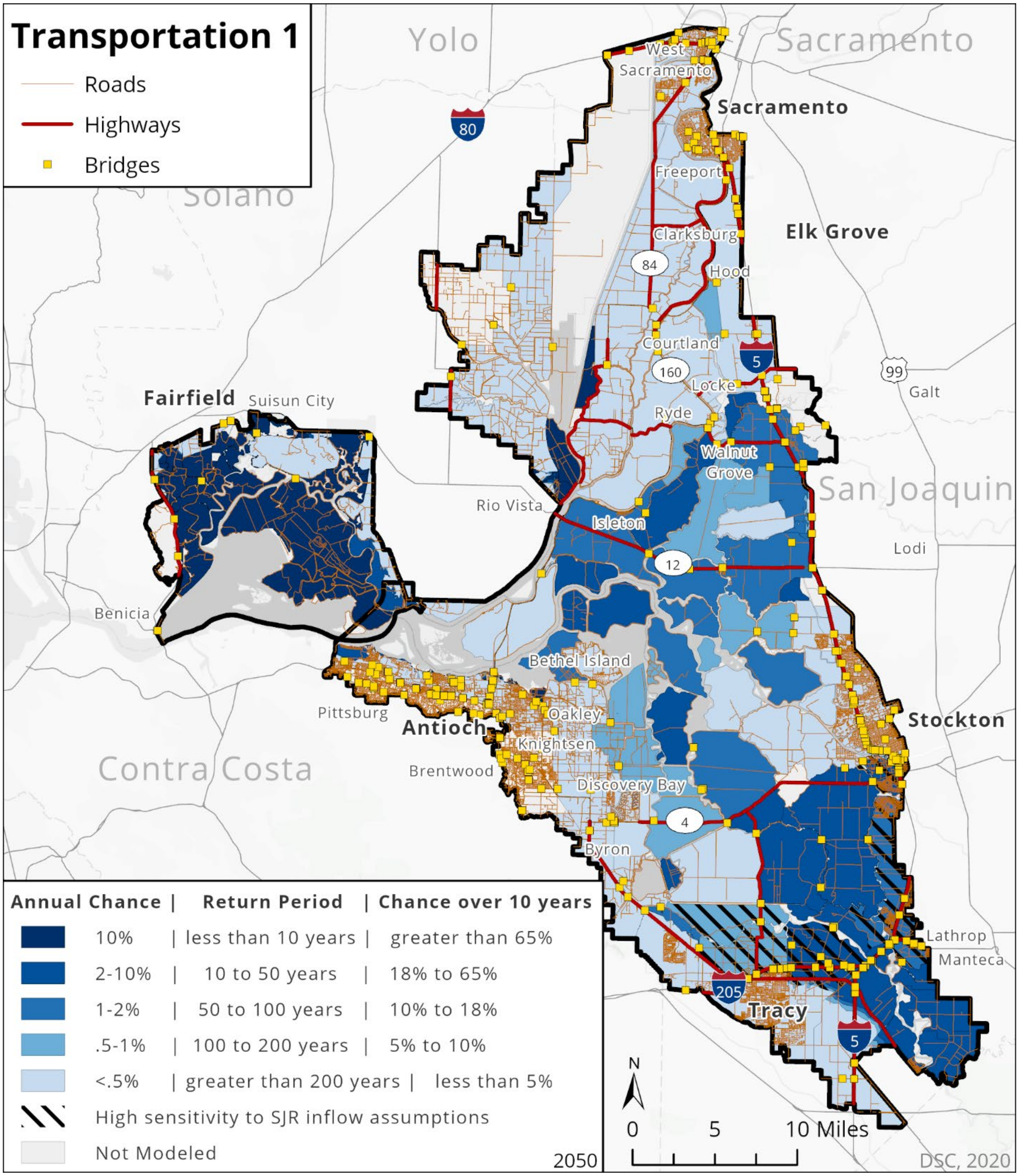
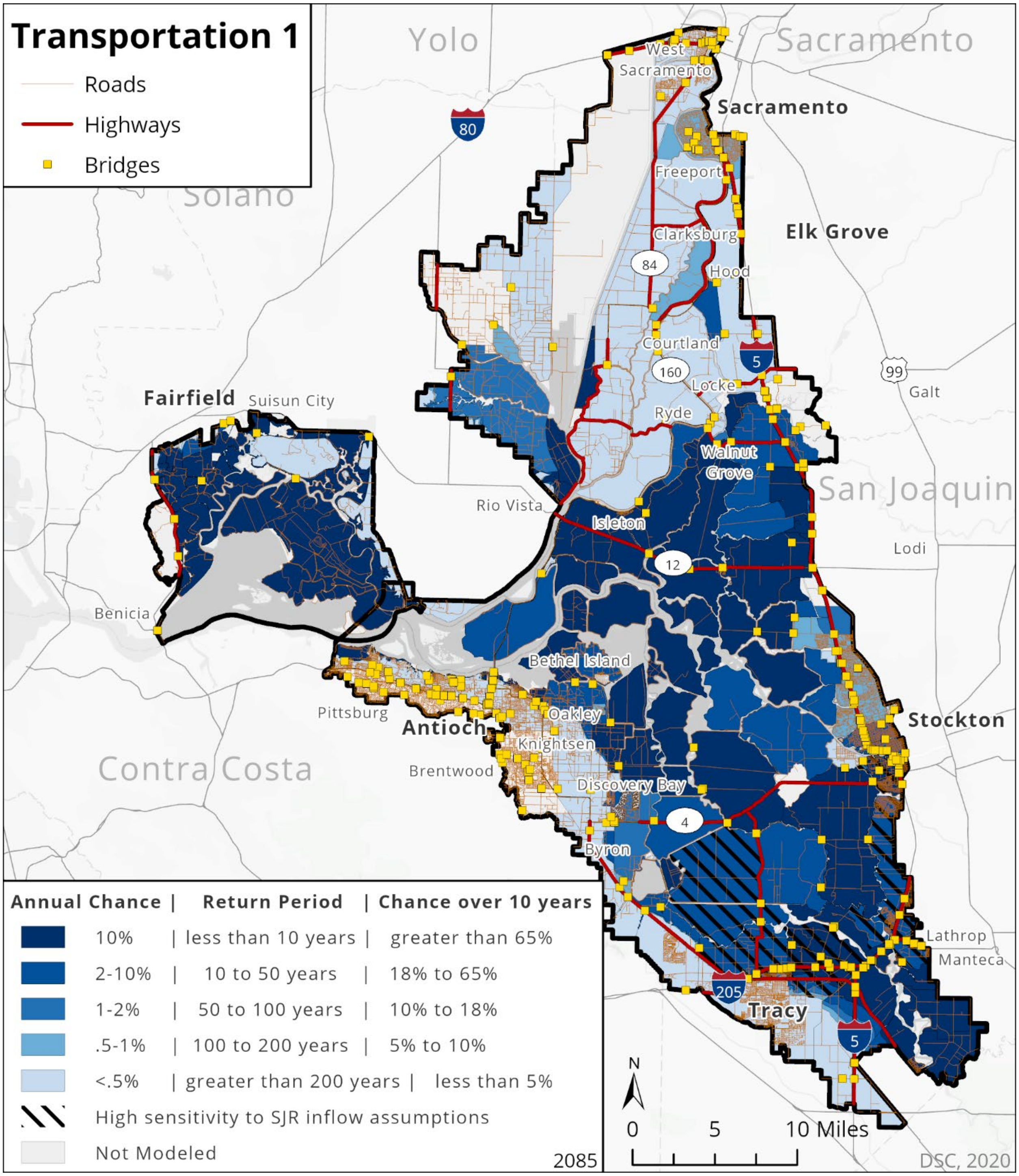


2050: TRANSPORTATION FLOOD EXPOSURE MAP #1



2085:TRANSPORTATION FLOOD EXPOSURE MAP #1



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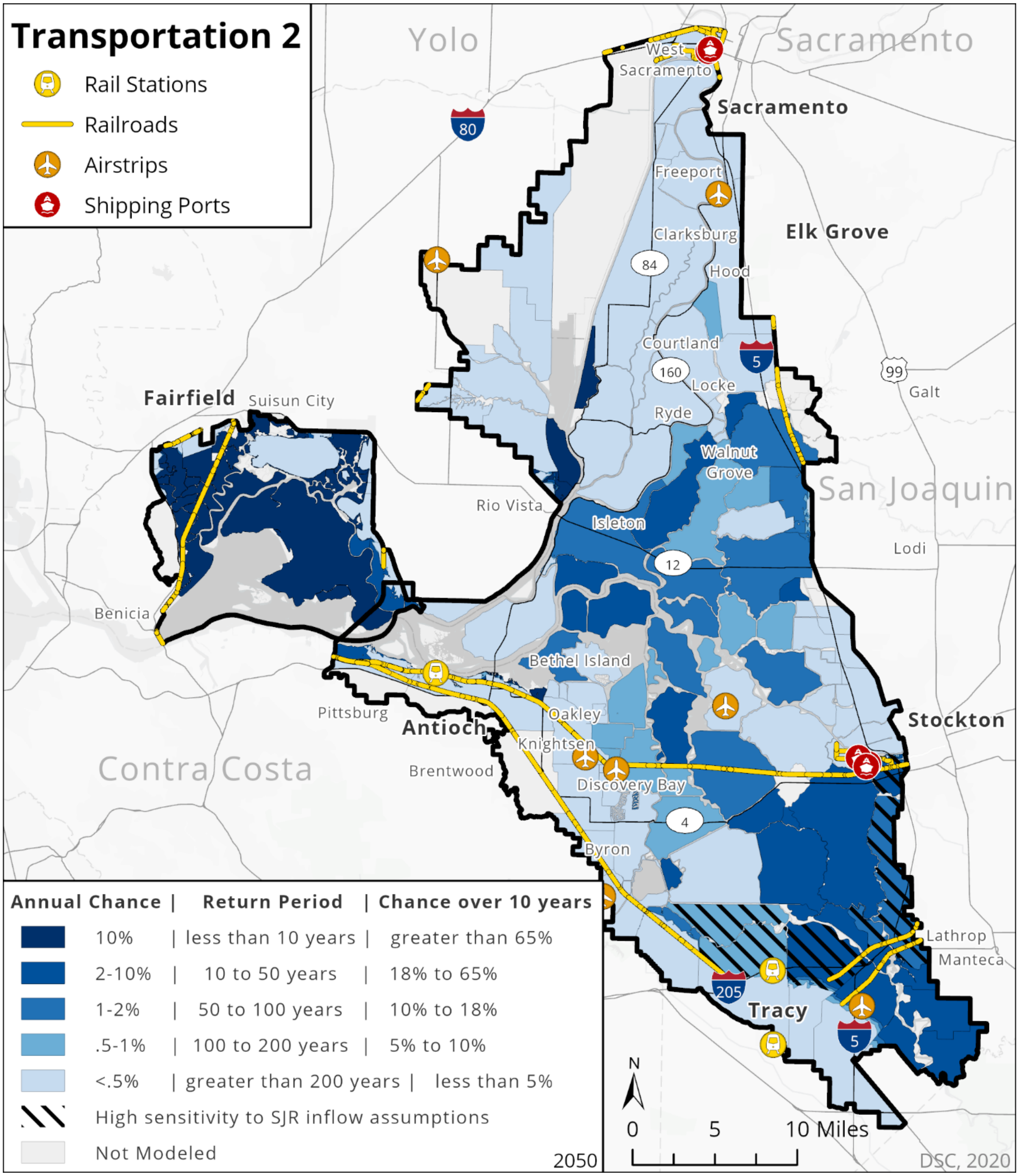

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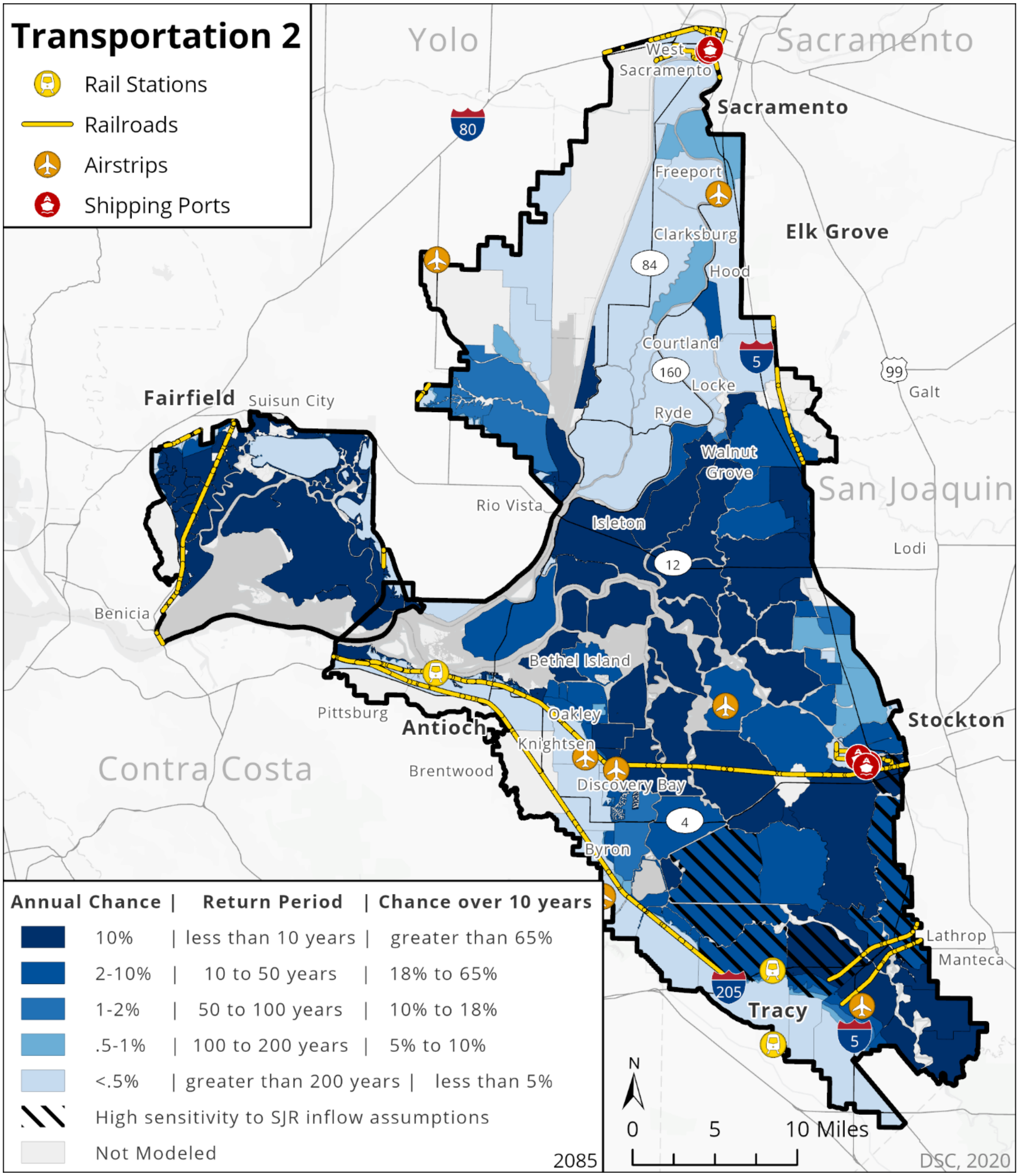
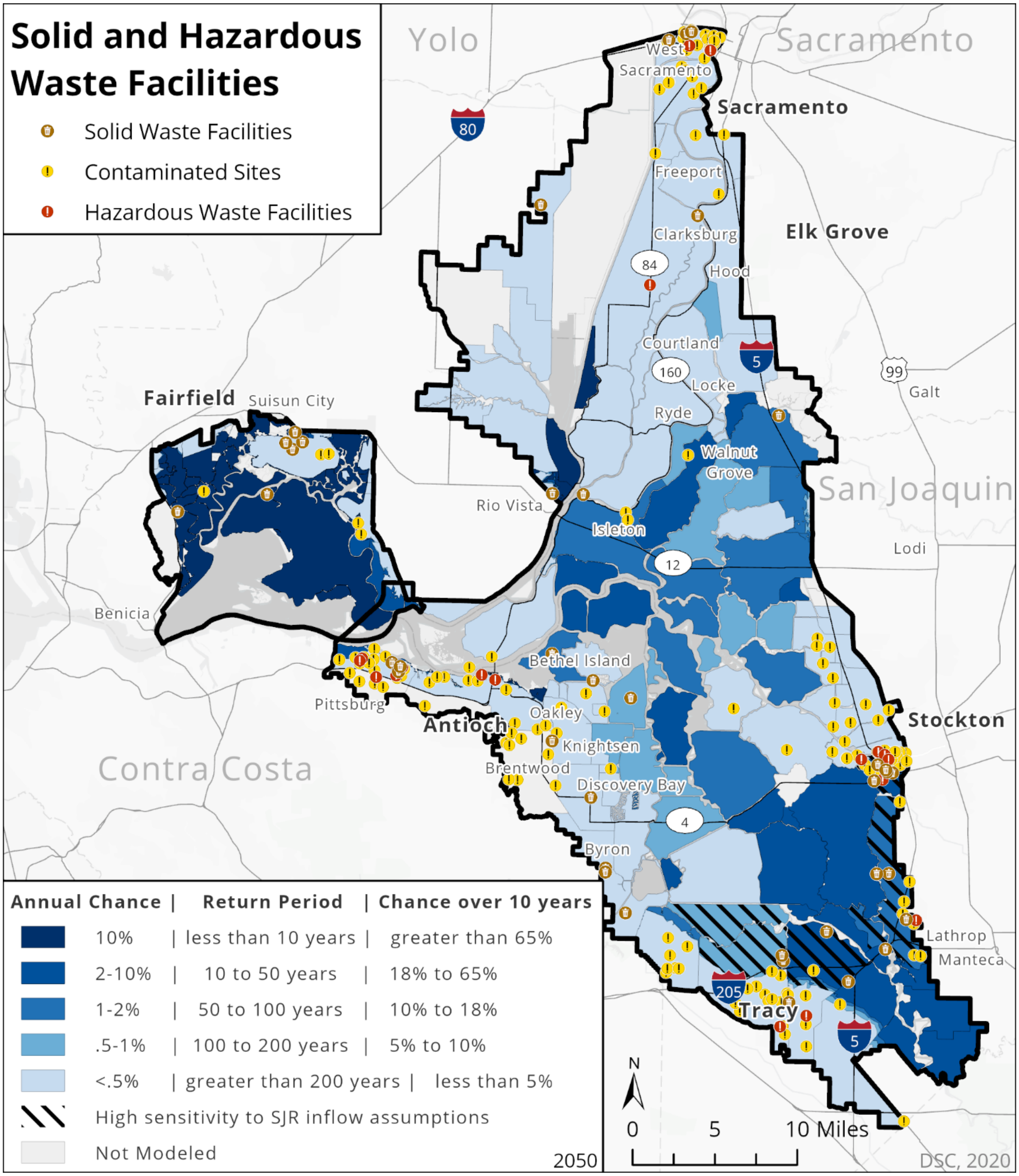
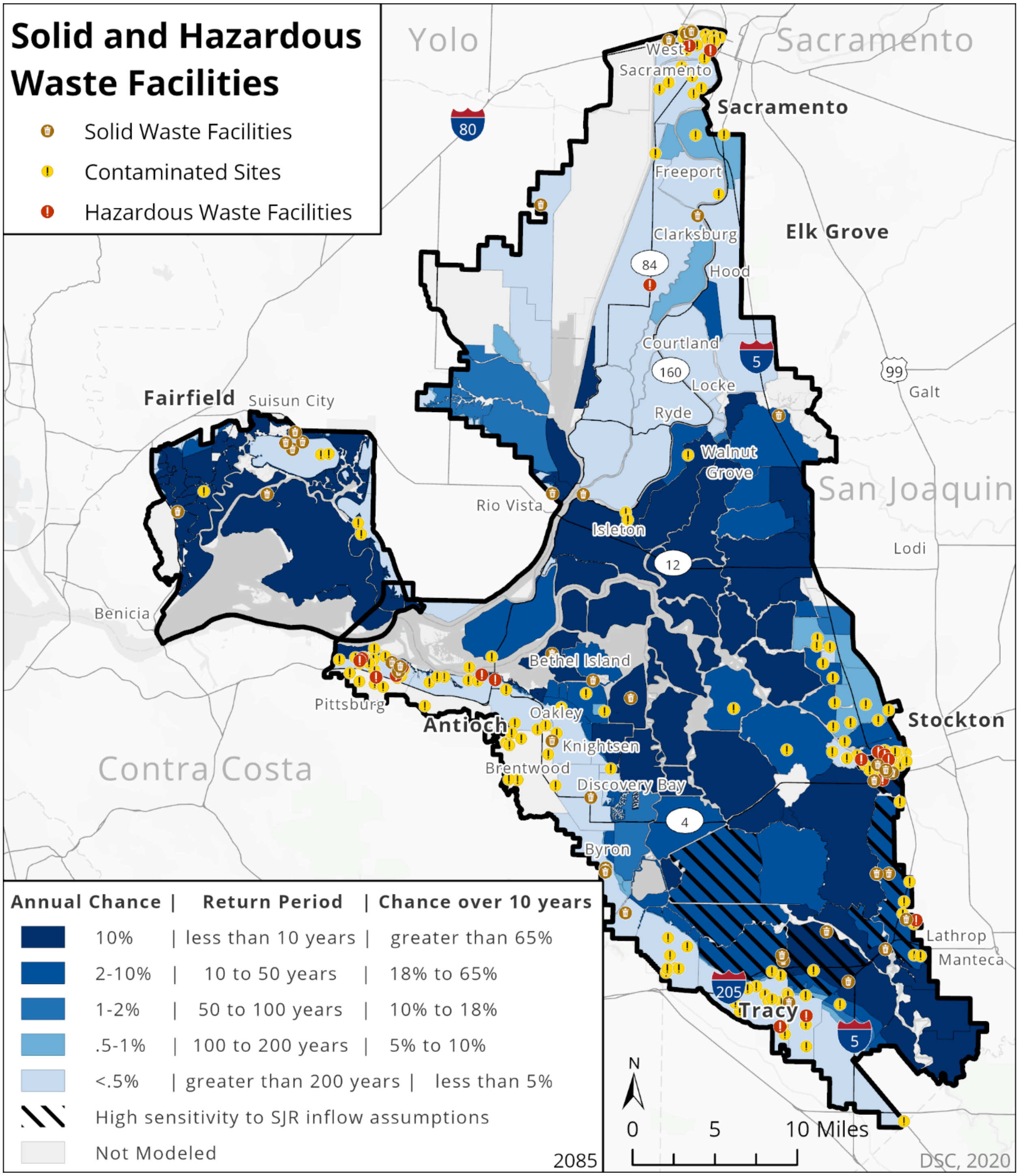


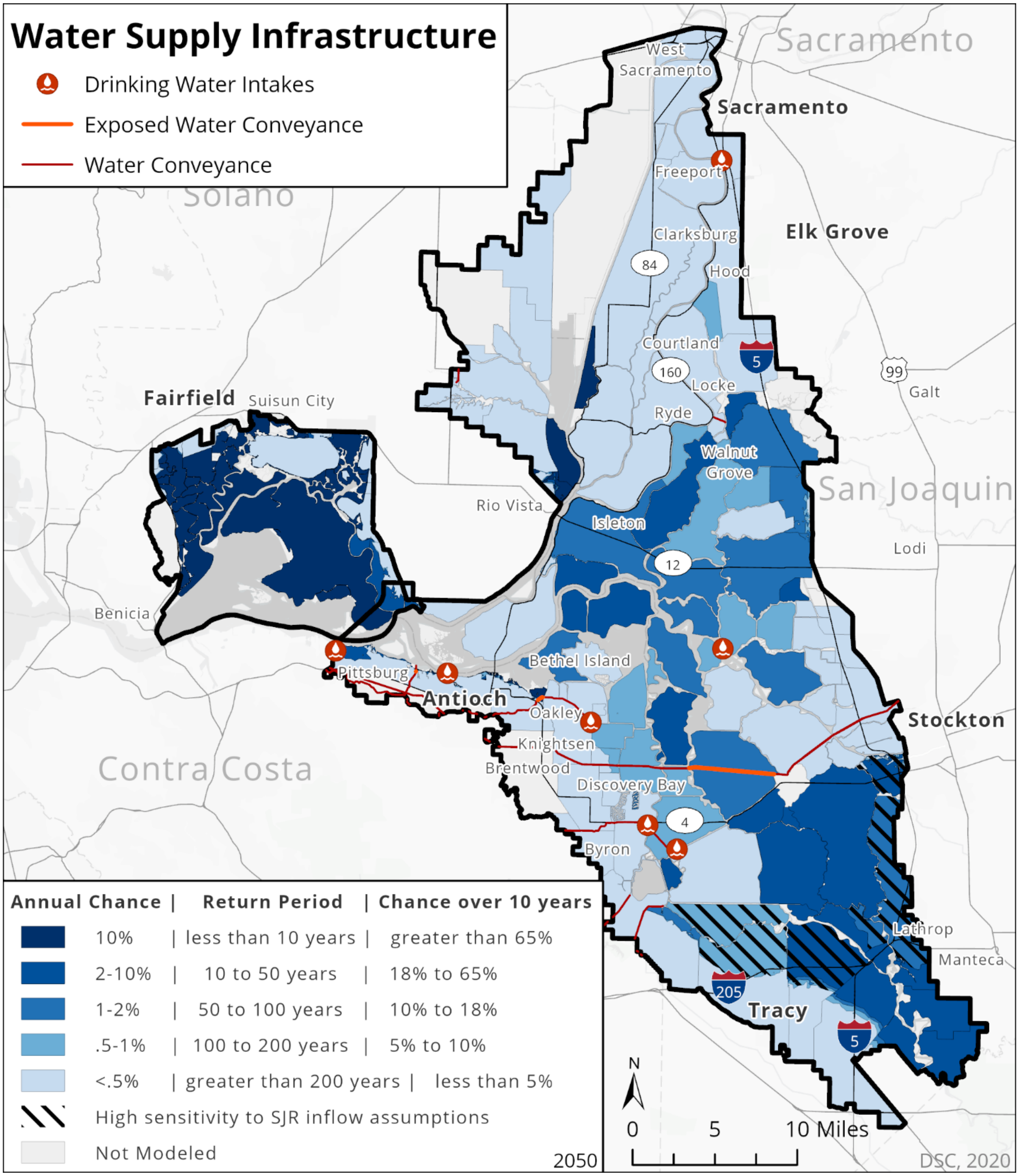
2050: Solid and Hazardous Waste Facilities Flood Exposure Map



2085: Solid and Hazardous Waste Facilities Flood Exposure Map



2050: Water Supply Infrastructure Flood Exposure Map



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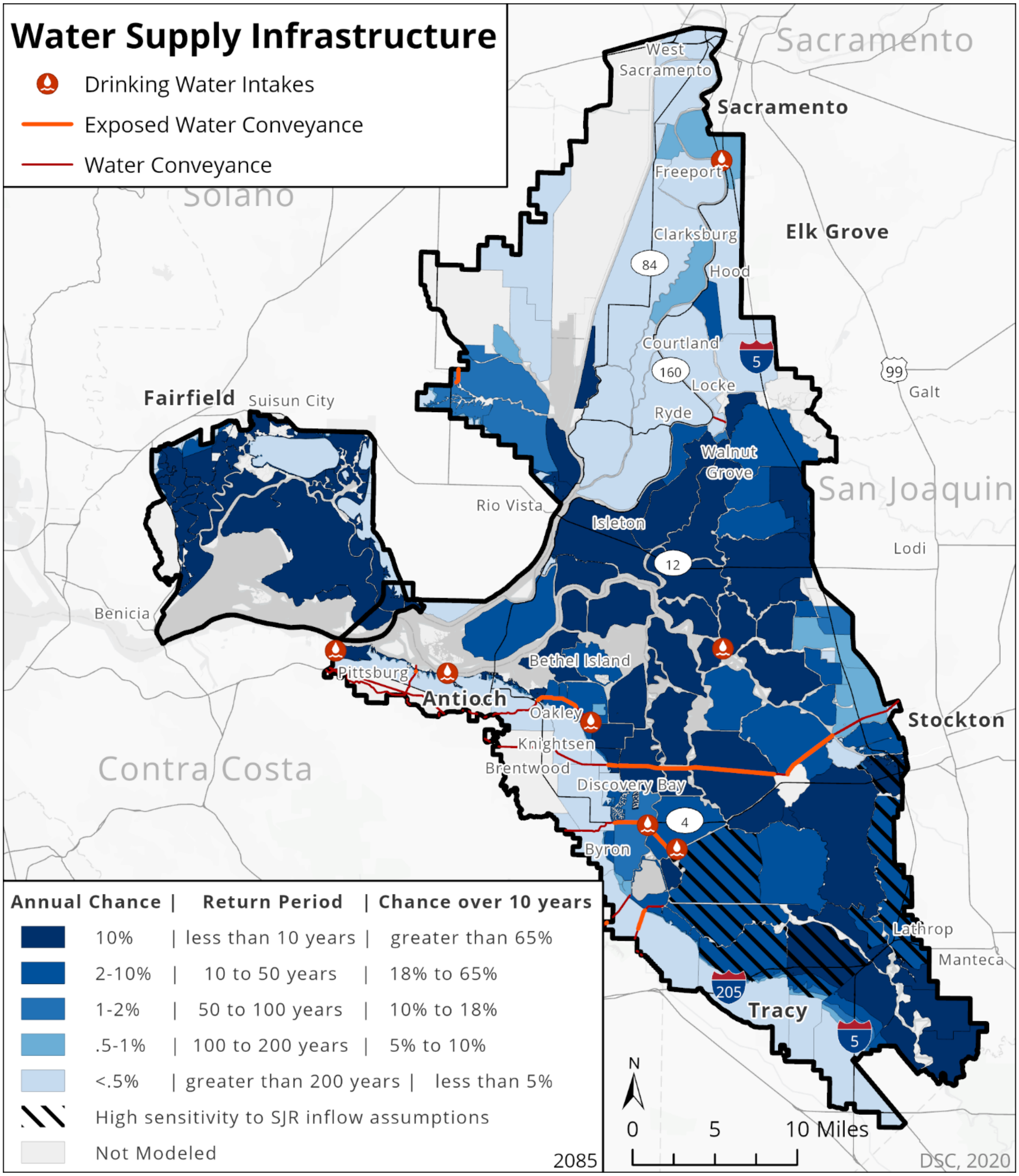
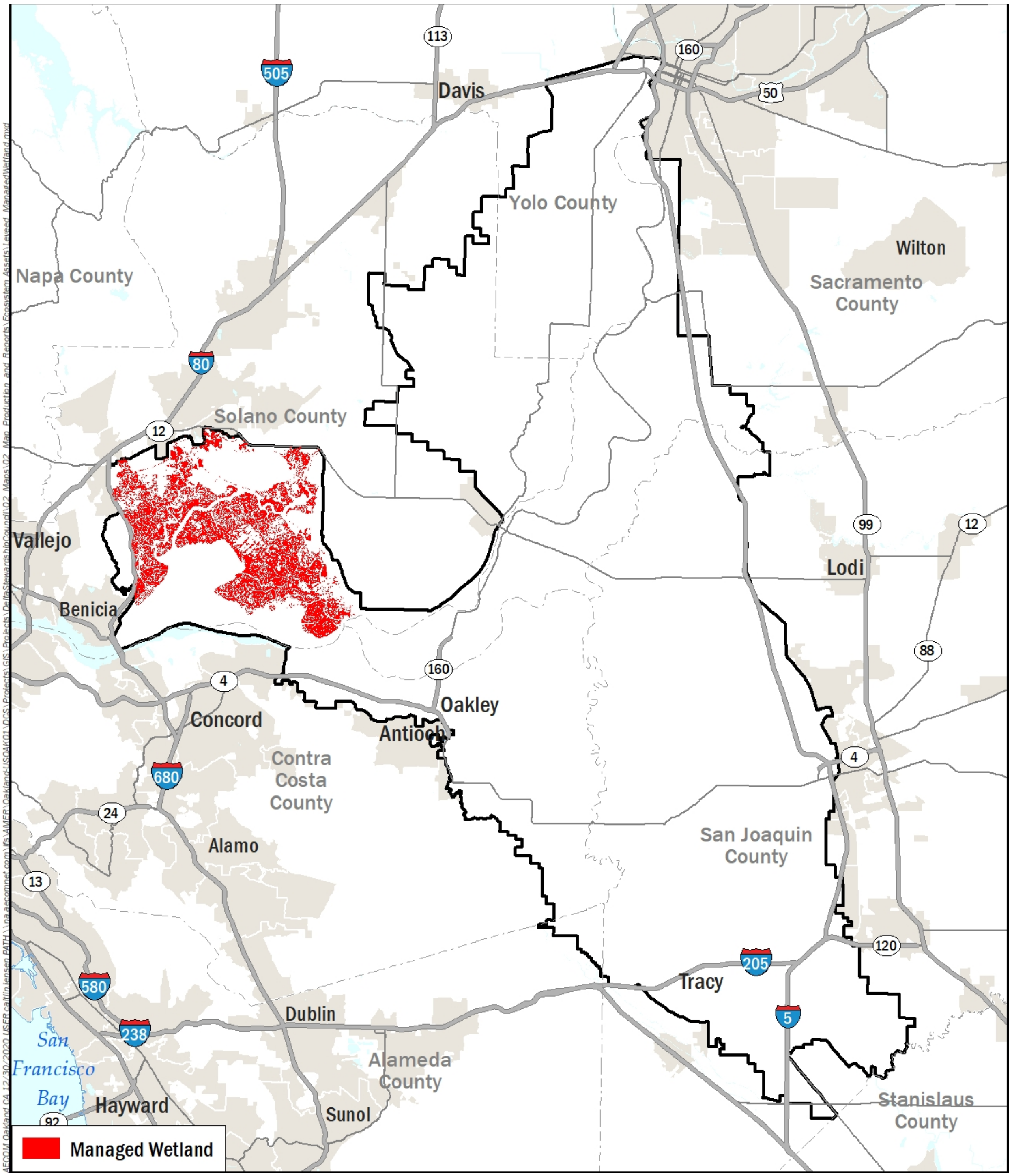
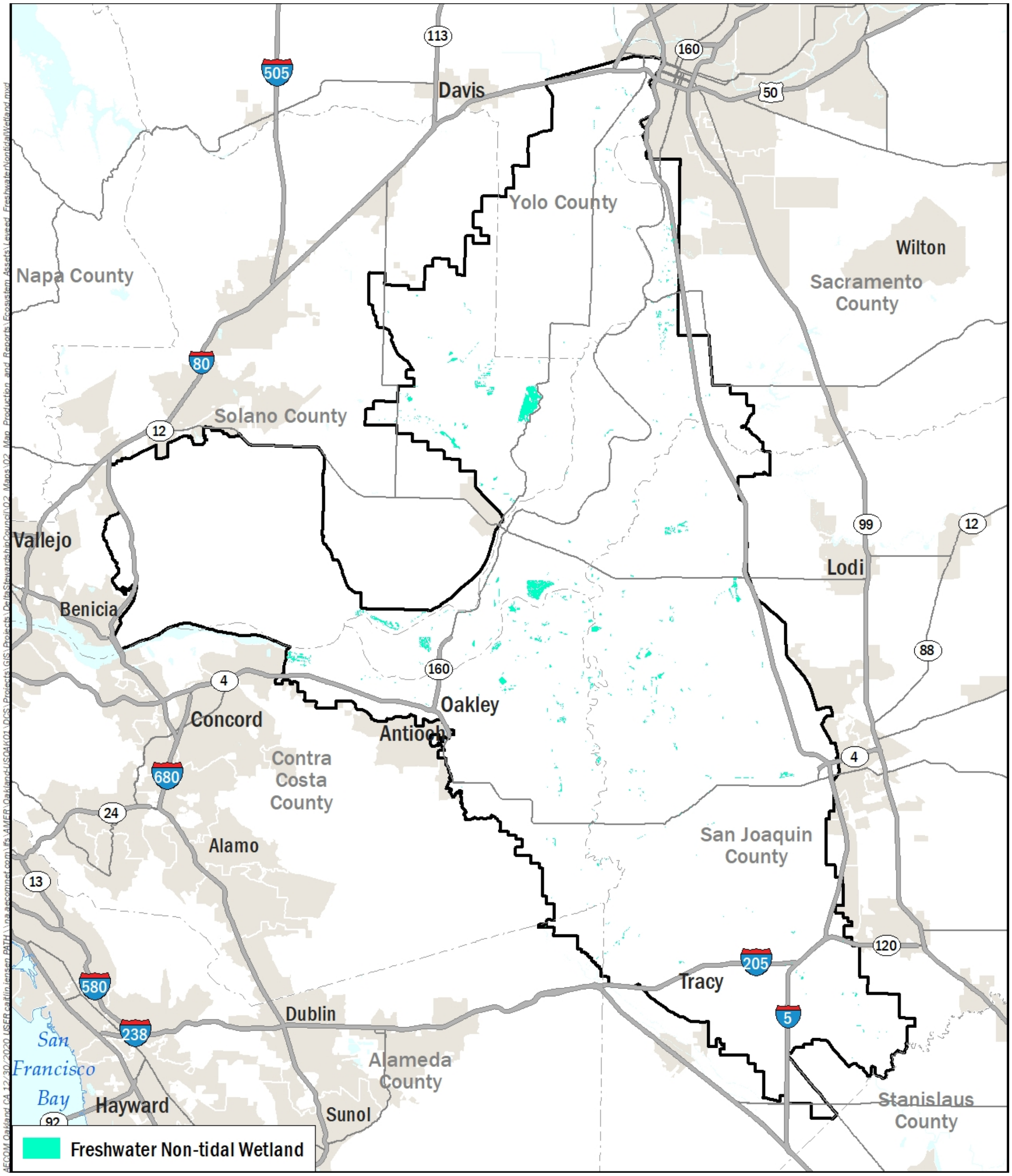


Appendix C. Supporting Ecosystem Assessment Maps

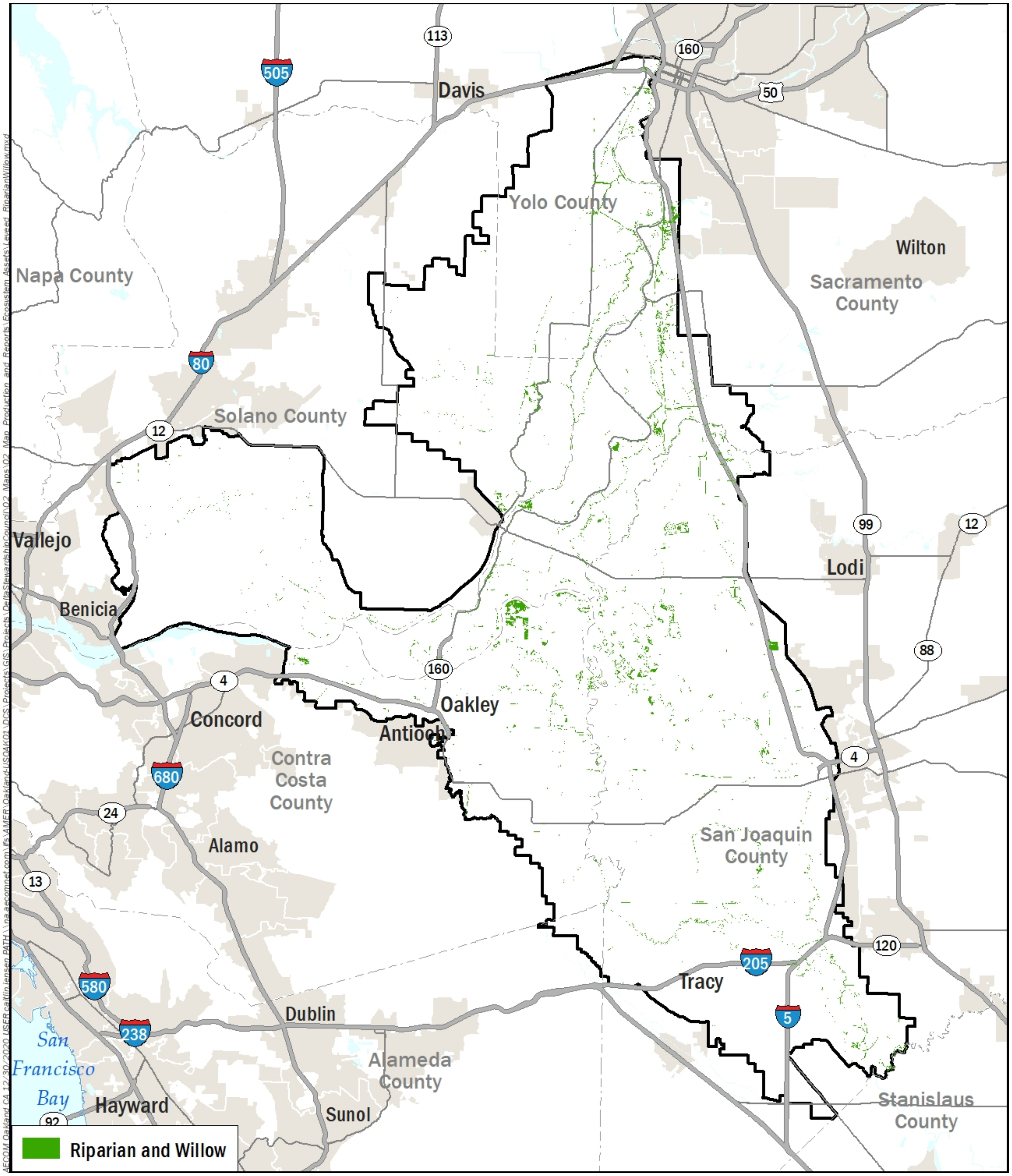
EXISTING LEVEED HABITATS: MANAGED WETLAND



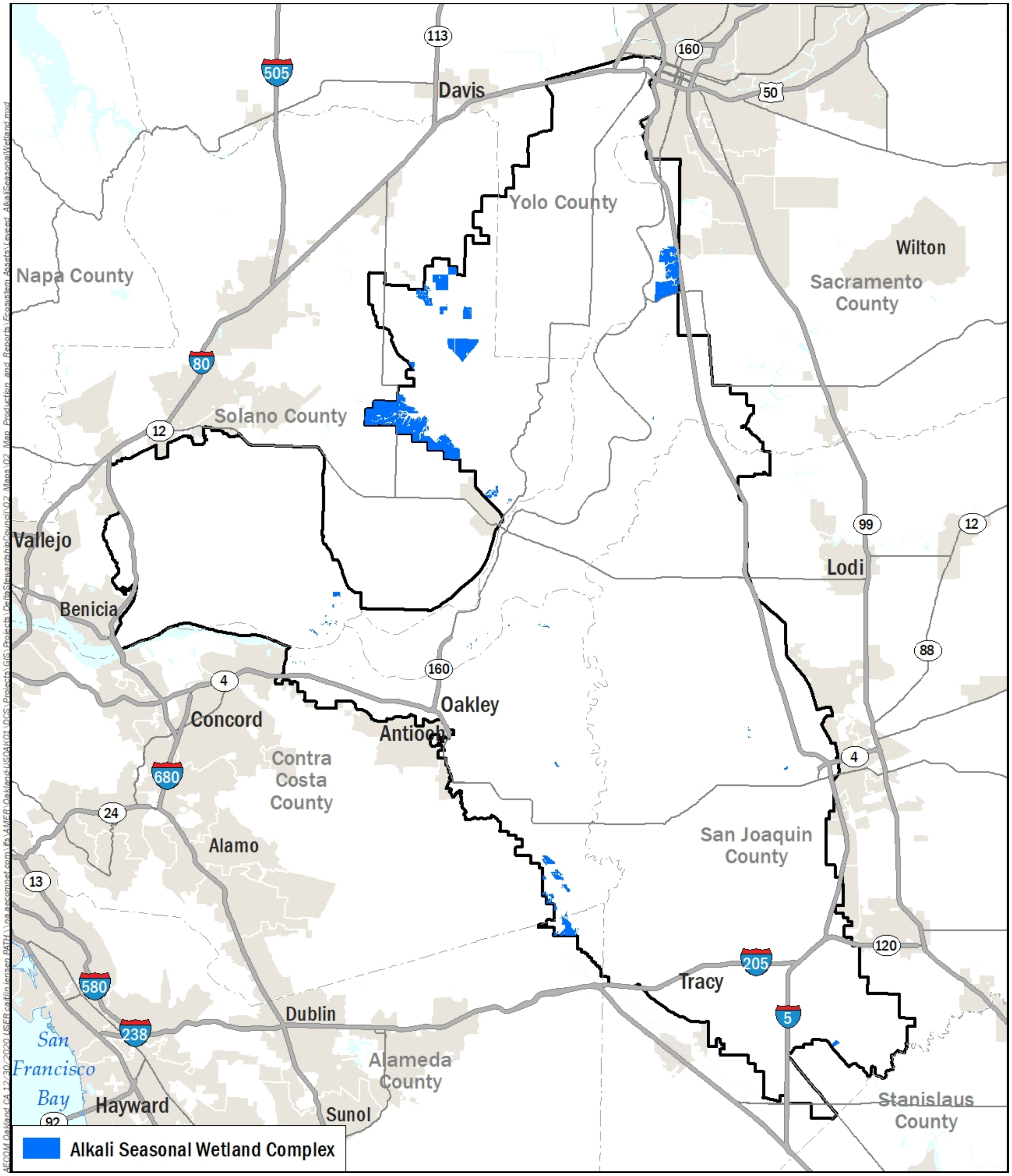
Existing Leveed Habitats: Freshwater Non-Tidal Wetland



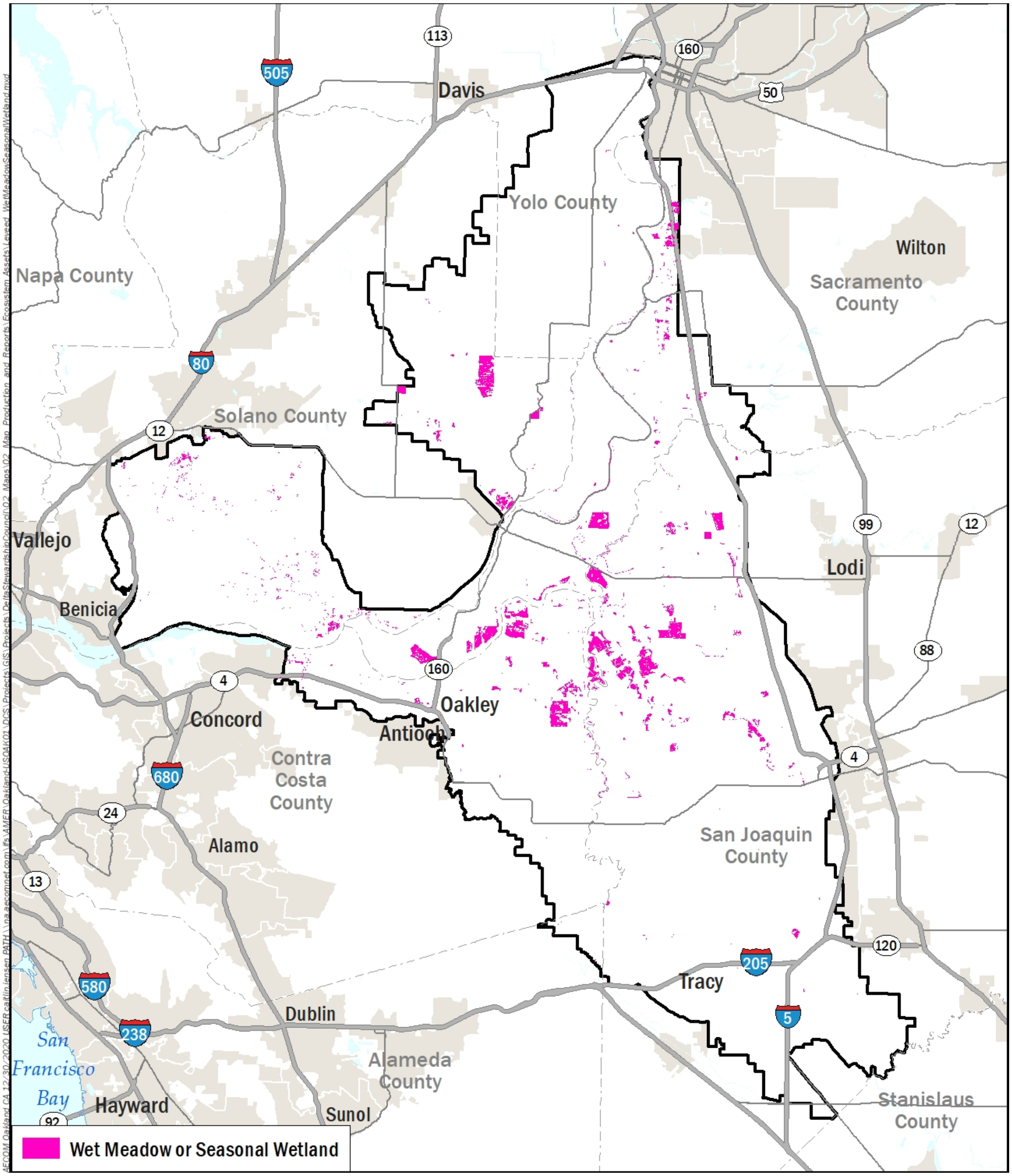
Existing Leveed Habitats: Riparian and Willow



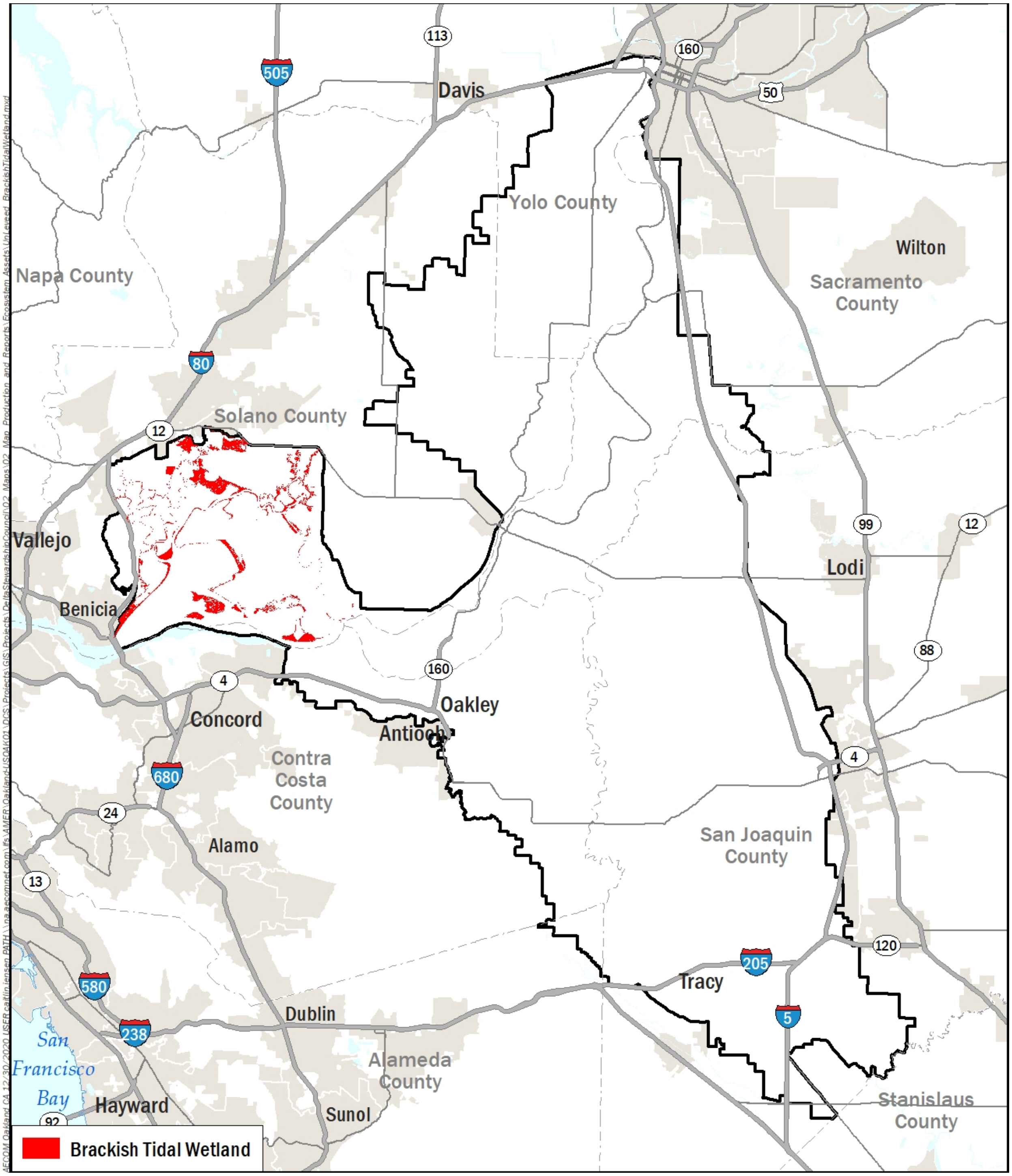
EXISTING LEVEED HABITATS: ALKALI SEASONAL WETLAND COMPLEX



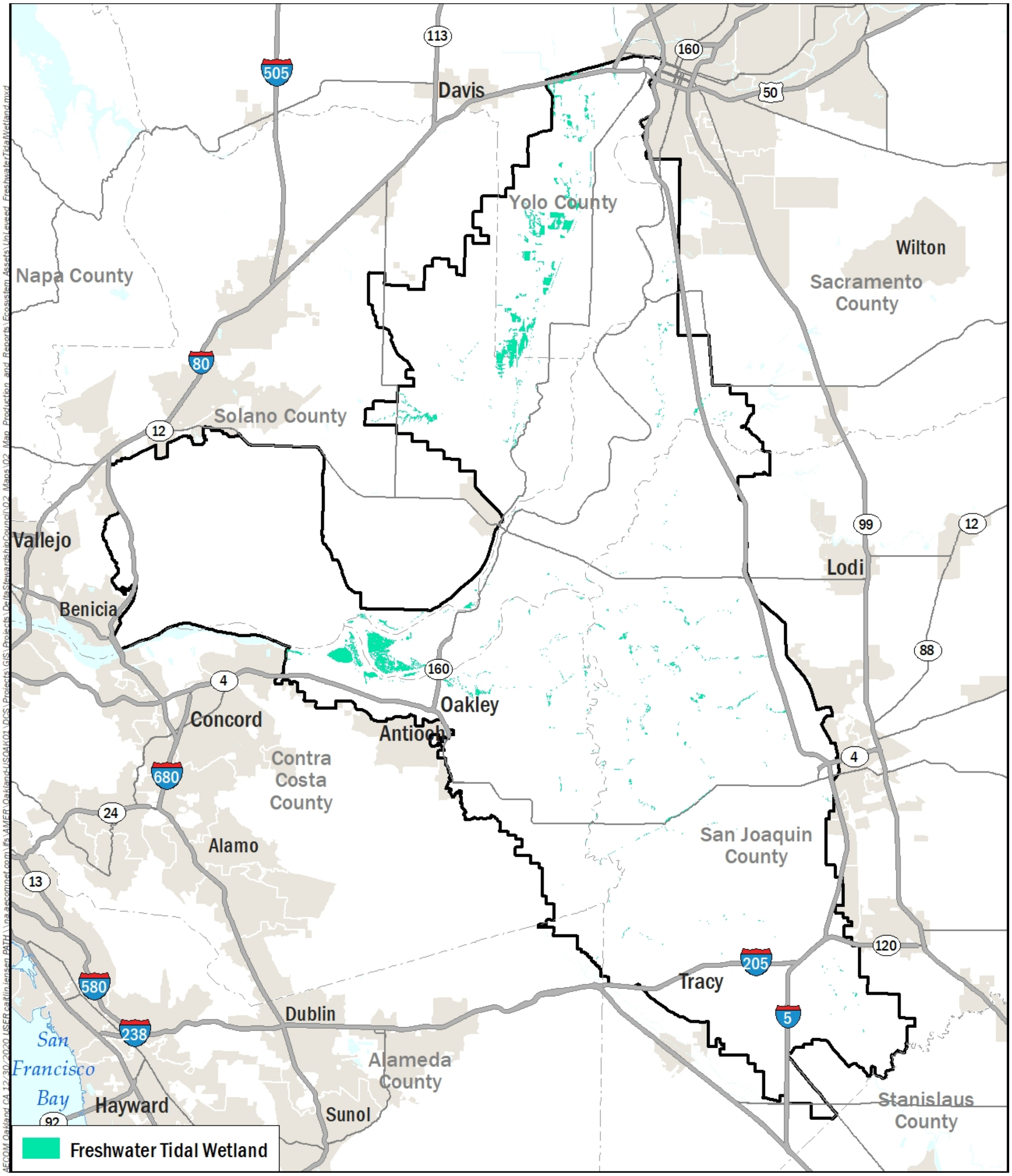
Existing Leveed Habitats: Wet Meadow or Seasonal Wetland



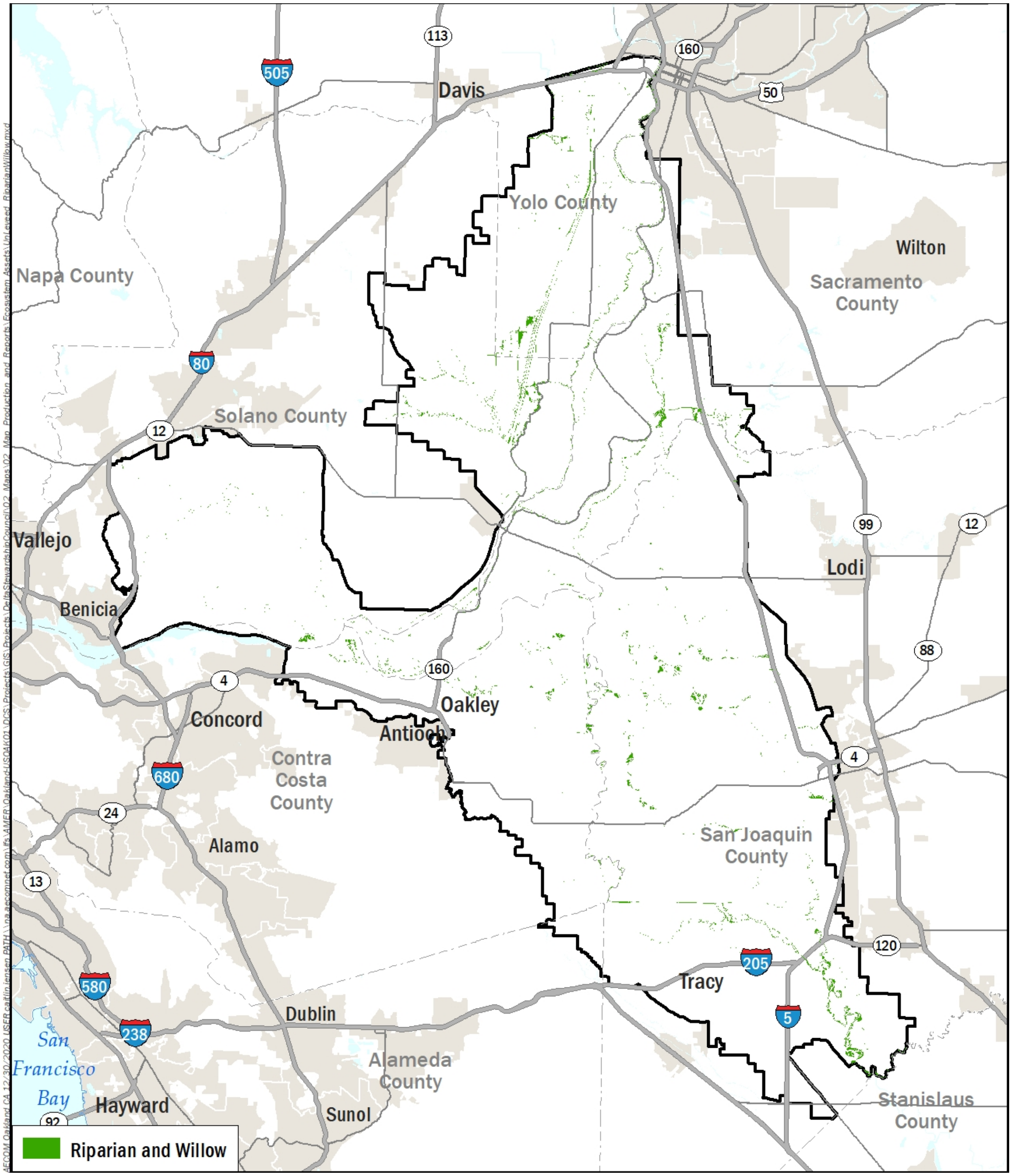
Existing Unleveed Habitats: Brackish Tidal Wetland



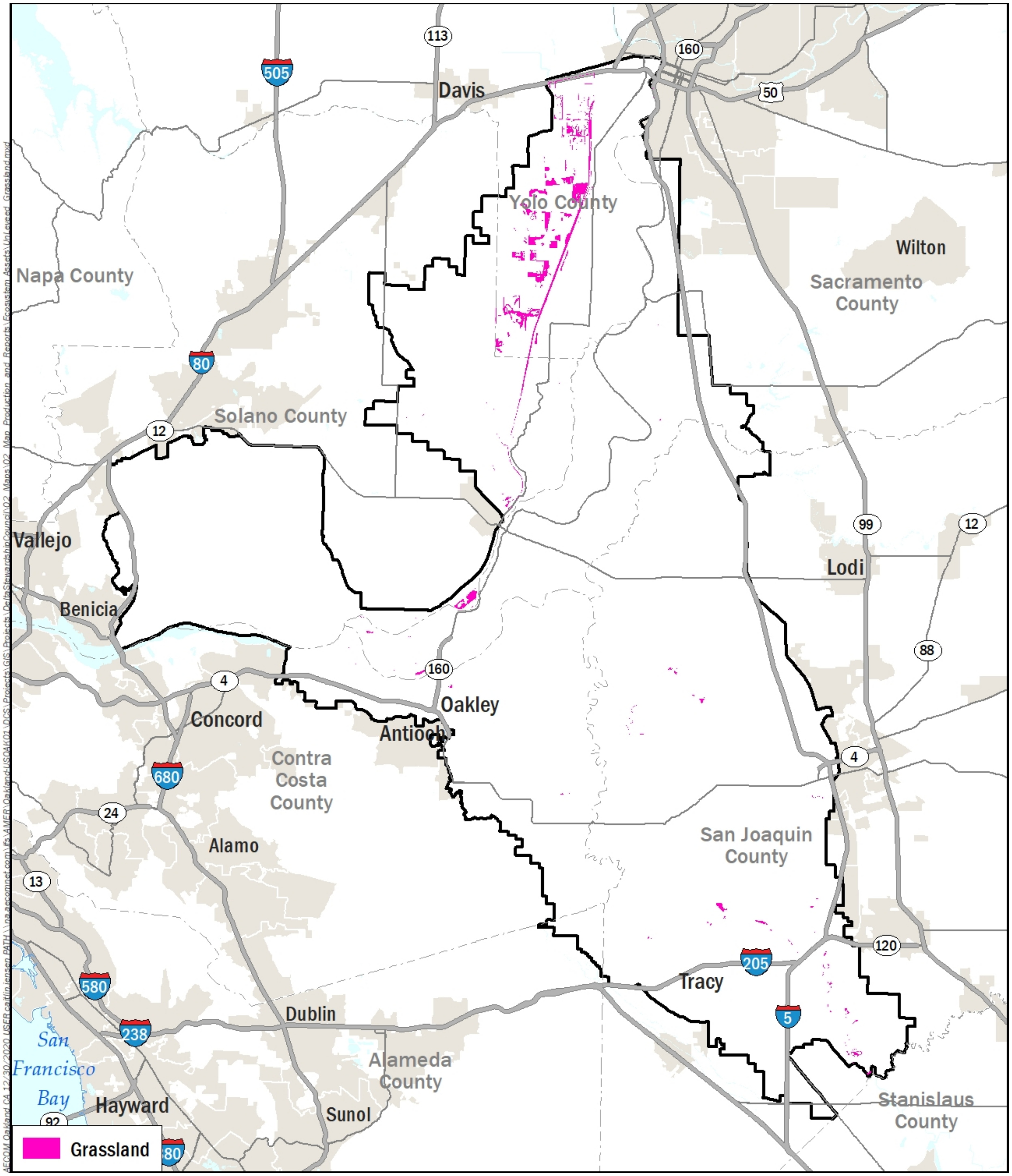
EXISTING UNLEVEED HABITATS: FRESHWATER TIDAL WETLAND



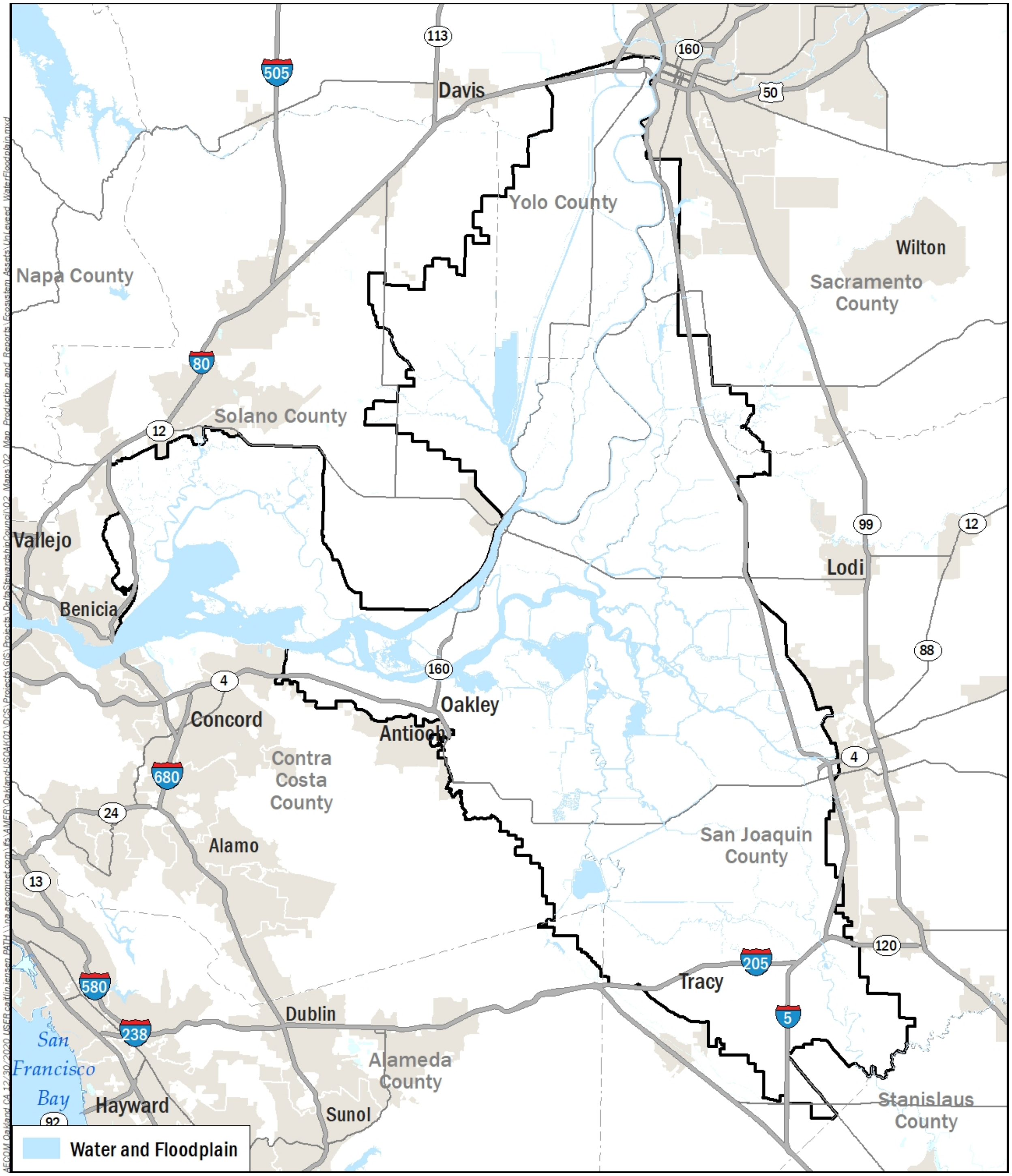
Existing Unleveed Habitats: Riparian and Willow



Existing Unleveed Habitats: Grassland

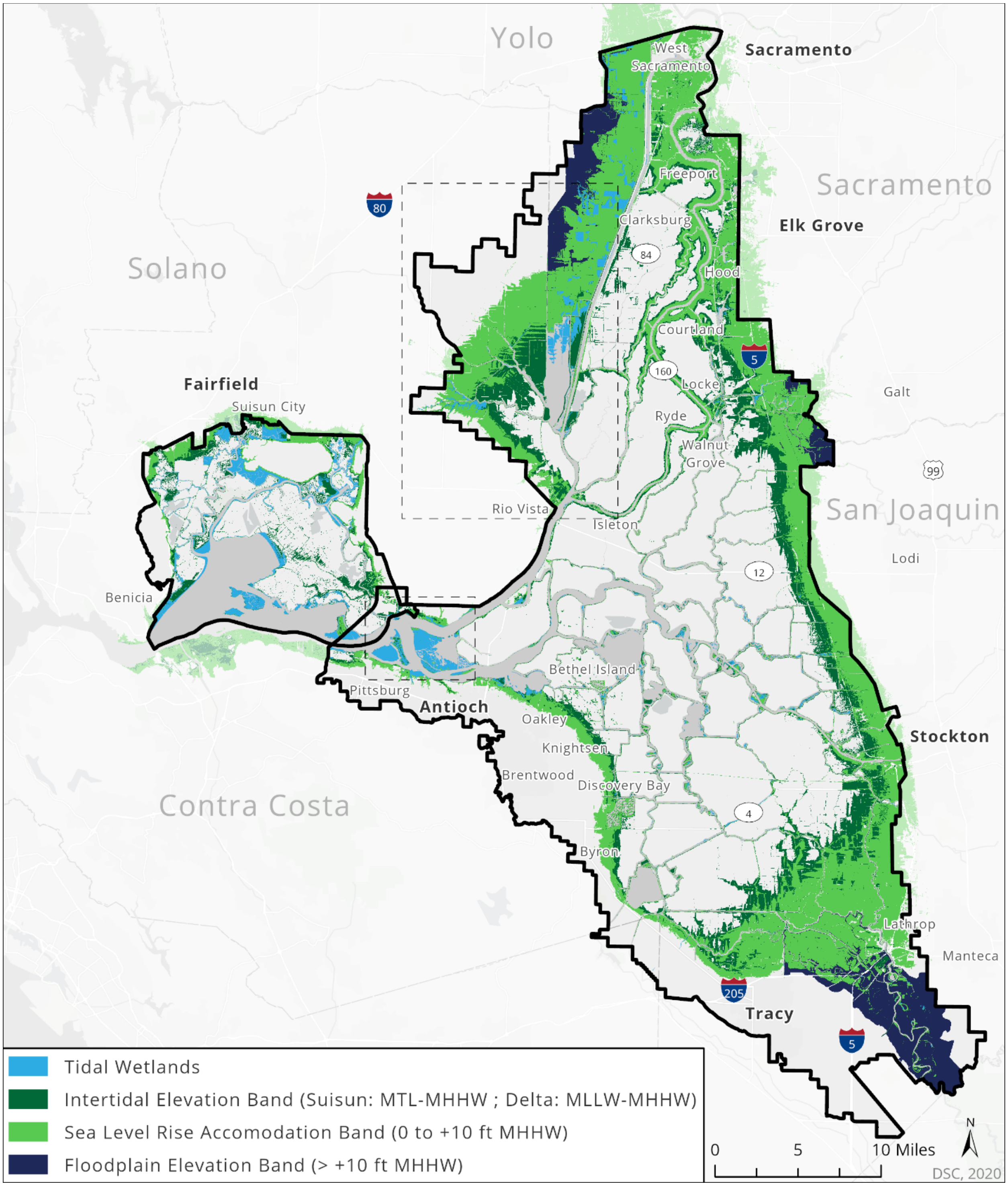


EXISTING UNLEVEED HABITATS: WATER AND FLOODPLAIN



Sea Level Rise Accommodation Space in Delta and Suisun Marsh

Delta-wide sea level rise accommodation space and extents of zoom-in figures in Cache Slough/Yolo Bypass and central Delta areas (shown on next page).



Sea level rise accommodation space for tidal wetlands is present in the Cache Slough Complex tidal freshwater wetlands (left panel) but absent in Central Delta tidal wetlands (Browns Island, Winter Island, and Sherman Lake) (right panel).