



Climate Change in the Sacramento-San Joaquin Delta

A State Agency Report for:

California's Fifth Climate Change Assessment

Prepared by:

Delta Stewardship Council, Delta Protection Commission, Sacramento-San Joaquin
Delta Conservancy



**Delta
Stewardship
Council**
A CALIFORNIA STATE AGENCY



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About California's Fifth Climate Change Assessment

California's Climate Change Assessments are the state's scientific foundation for understanding future climate-related vulnerability across California's regions and systems. Senate Bill 1320 (Stern, 2020) requires the State to report the impacts and risks of climate change across California at least every five years, beginning with California's Fifth Climate Change Assessment (Fifth Assessment). Building on decades of climate research and previous Assessments, the Fifth Assessment presents new findings about California's climate future, with a dedicated focus on Tribal partnerships, public engagement, and communities most vulnerable to climate impacts.

The Fifth Assessment's research and tools are designed to fill knowledge gaps about California's climate future, inspire strategic climate actions, and shape planning, investments, and policies at the state, regional, and local scales. Guided by research priorities identified by state, Tribal, and local leaders, community representatives, and subject matter experts, its findings are designed to help illuminate potential climate futures, the challenges they may present, and the opportunities to build resilience through adaptation pathways.

For the full suite of Fifth Assessment research products, please visit: www.ClimateAssessment.ca.gov.

DISCLAIMER:

State Agency reports are new Assessment contributions that complement the Assessment's suite of products, which include a Statewide Summary report, Regional and Statewide Topical reports, and original research. Note that State Agency Reports are reviewed by the contributing agency and are not included in the Assessment's Editorial Board peer review process.

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Executive Summary

The Sacramento-San Joaquin Delta (Delta) is essential to California's water, agricultural, ecological, and cultural systems. It supplies a portion of the water used by more than 27 million Californians, supports a \$4.6 billion agricultural economy, and sustains habitat for more than 750 plant and animal species. Yet it is also one of the most climate-vulnerable regions in the state, facing higher relative sea level rise than the San Francisco Bay Area due to land subsidence and its position at the confluence of California's two largest rivers.

Recognizing that California's Fifth Climate Change Assessment does not include a synthesis focused solely on the Delta (three Climate Assessment regions span this area: Sacramento Valley, San Joaquin Valley and the San Francisco Bay Area), the Delta Stewardship Council, in partnership with the Delta Protection Commission, and Sacramento-San Joaquin Delta Conservancy (Delta Conservancy), developed this State Agency-led report to fill that gap. It compiles the best available data on climate change in the Delta, including relevant findings from other Fifth Climate Change Assessment reports, summarizes the Delta agencies' and the Delta Independent Science Board's regional adaptation planning work, and identifies major investment needs to ensure the region's long-term resilience. The report also reflects the Delta agencies' commitment to ensuring that adaptation planning meaningfully involves and represents marginalized and historically excluded communities.

This summary is intended to inform federal and State partners, Tribes, local governments, researchers, and communities as we collectively work to create a climate-resilient future for the Delta. As the centerpiece of California's water system and a region of immense ecological, cultural, and economic importance, the Delta's resilience is inseparable from that of the state itself.

Significance of the Delta to the Rest of the State

The Delta is the heart of California's water system, a tidal inland estuary where the Sacramento and San Joaquin Rivers meet before flowing to San Francisco Bay. It provides water to millions of Californians, supports farms across the Central Valley, and sustains diverse ecosystems that underpin the state's environmental health. Because so many of California's water, agricultural, and ecological systems depend on the Delta, the resilience of the Delta is directly tied to the state's overall climate resilience.

The Delta is a cultural and historical landscape and an ancestral homeland to Native Peoples including the Bay Miwok, Coast Miwok, Plains Miwok, Maidu, Nisenan, Ohlone, Patwin, Pomo, Wappo, Wintun, and Yokuts, whose stewardship has shaped



the region's ecology for millennia. European-American colonizers forcibly displaced Native Peoples in the Delta, and today, many descendants of the Delta's original inhabitants live on reservations or rancherias outside of the Delta or belong to Tribes that do not have federal recognition. Settlers drained the Delta's wetlands to access its fertile soils, permanently altering the landscape by converting the vast majority to farmland. In 2019, Congress designated it as California's first National Heritage Area, recognizing its ongoing role as an "evolving place" of natural and cultural significance.

The Delta's fertile peat soils and extensive levee network support a \$4.6 billion agricultural economy, producing crops such as corn, alfalfa, and wine grapes. Its waterways and wetlands provide habitats for more than 750 species, including migratory birds and endangered fish. Protecting these habitats advances the State's coequal goals for the Delta—a reliable water supply and a restored ecosystem—and statewide efforts such as the California Climate Adaptation Strategy, Nature-Based Solutions Climate Targets, and 30x30 Initiative.

The Delta is a culturally significant region and a statewide lifeline where California's environmental, economic, and cultural priorities converge. Its protection and adaptation are essential to maintaining water supply reliability, agricultural vitality, and ecological health across the state.

Threats Posed by Climate Change

Climate change is already reshaping the Delta's physical environment and putting pressure on its communities, ecosystems, and infrastructure. The Climate Stressors and Hazards section of this report provides detailed scientific projections; this Executive Summary highlights the key vulnerabilities identified in the Delta:

Flooding and Levee Risk

Flooding is among the Delta's most significant threats, which is compounded by sea level rise and subsidence. Over 150,000 acres of land in the Central Delta are deeply subsided with land elevations as much as 20 feet below sea level. The processes that cause subsidence result in significant greenhouse gas emissions, further contributing to global climate change. Sea level rise, subsidence, and stronger storm events will heighten water levels and strain the region's aging levee network. A major flood could inundate islands, displace residents, increase salinity (or saltwater) intrusion, and disrupt critical transportation and Delta water conveyance that serves much of California.

Water Quality and Supply Reliability

Rising sea levels and longer dry periods are contributing to salinity intrusion in Delta channels, threatening both local and statewide water supplies. Small and rural water



systems are particularly at risk of degradation because they often lack the resources to treat or replace compromised wells. Declining water quality also reduces the reliability of water deliveries to regions dependent on Delta exports. If a catastrophic levee failure were to occur, water conveyance through the Delta would be threatened by significant salinity intrusion, potentially disrupting water supply to 27 million people and millions of acres of farmland.

Impacts on Communities and Social Equity

Certain Delta communities, particularly in Stockton, Antioch, Pittsburg, West Sacramento, and unincorporated areas of San Joaquin County, are disproportionately vulnerable to climate change due to socioeconomic conditions such as limited income, vehicle access, and English proficiency. These factors compound exposure to flooding, heat, and poor air quality. Equitable investment and community-driven planning are crucial to ensure that resilience efforts reach those most at risk.

Ecosystem and Agricultural Stress

More frequent flooding, salinity intrusion, and temperature shifts are altering the Delta's ecological balance. Wetland and riparian habitats, already reduced by more than 95%, are becoming increasingly fragmented, limiting their ability to support native species. Meanwhile, invasive species continue to thrive under changing conditions, further displacing native flora and fauna. Agriculture faces its own vulnerabilities: subsidence, flood risk, and salinity all reduce productivity and threaten long-term crop yields.

Collectively, these vulnerabilities illustrate that the Delta's challenges are interconnected, spanning public safety, water supply, environmental stewardship, and social equity. Addressing them will require regional, coordinated adaptation strategies that protect the Delta's people, ecology, infrastructure, and culture.

Adaptation Strategies

The Delta Stewardship Council and its partners are leading a coordinated, science-based effort to build regional resilience. Through Delta Adapts: Creating a Climate-Resilient Future, the first comprehensive framework addressing climate risks across the Delta, the Council developed a [Climate Change Vulnerability Assessment](#) in 2021 and an [Adaptation Plan](#) in 2025.

The Adaptation Plan emphasizes integrating the best available science, prioritizing equitable engagement, highlighting the needs of the most socially vulnerable communities, coordinating regionally, and pursuing multi-benefit projects that serve both people and nature. It identifies near-term actions, such as levee maintenance and emergency planning, alongside long-term strategies focused on ecosystem restoration, climate-smart agriculture, and water management.



Across the region, State and local entities are already working on adaptation activities such as levee upgrades, subsidence reversal, floodplain restoration, and community-based planning. Collectively, these efforts require continued coordination and investment to advance the adaptation priorities outlined in the plan and ensure the Delta's resilience.

Investment Needs

Achieving climate resilience in the Delta will require sustained investment in infrastructure and natural systems, especially Delta levees and ecosystems. The Delta's approximately 1,100 miles of levees protect communities, farmland, and statewide water infrastructure, but were not built for future climate conditions. Top priorities for the levee system include expanding and modernizing the Delta Levees Maintenance Subventions Program, administered by the Department of Water Resources and the Central Valley Flood Protection Board; investing in climate-adaptive levee designs; and diversifying funding for levee maintenance and updates. Upgraded levees can support multi-benefit flood management projects that enhance both safety and habitat. Adapting the levee system to mid-century sea level rise and river inflows is expected to cost between \$3.2 and \$3.3 billion (DSC, 2025b).

Restoring tidal marshes, managed wetlands, riparian corridors, and floodplains, as well as re-wetting highly organic, deeply subsided peat soils through rice cultivation and restoration, will strengthen natural buffers, improve biodiversity, and advance statewide climate goals. The cost of implementing ecosystem restoration projects such as these across 60,000 to 80,000 acres is expected to range between \$2.5 and \$5.2 billion (DSC, 2025b).

Investing in resilient levees and restored ecosystems will be a significant capital need, but doing so will reduce disaster risk, safeguard the state's water conveyance system, and ensure that the Delta continues to support California's people, economy, and environment in a changing climate. Prioritizing adaptation now will avoid future costs, including economic losses, damage, and cleanup costs after a disaster.

In addition to capital investment needs, continued scientific research and data collection are critical to understanding how the Delta is affected by and responding to climate change. Major uncertainties in scientific understanding remain regarding precipitation changes, drought recurrence, infrastructure vulnerabilities, ecosystem tipping points and transitions, water supply and quality modeling, and trade-offs between halting subsidence and reducing greenhouse gas emissions. Further, focus on the social sciences is needed to center people in environmental science and management and understand how people live, work, and play in the Delta.



Adaptation Governance

Adaptation governance determines the process by which organizations plan, fund, implement, and manage climate adaptation within existing and evolving legal frameworks and authorities. Climate adaptation in the Delta relies on collaboration among a multitude of parties, including Tribes and Tribal communities, federal, State, and local agencies, academic institutions, and communities. Moving forward, sustained collaboration and funding will be essential to turn plans into action.

The Delta Plan Interagency Implementation Committee (DPIIC) brings together 18 State and federal agencies engaged in Delta management to align planning efforts, share data, and implement the region's long-term management plan, the Delta Plan (Water Code, § 85204.). Continued interagency leadership will be key to securing a resilient and equitable future for the Delta. The Delta Adapts initiative and an emerging Delta Climate Adaptation Team further strengthen these partnerships, promoting shared priorities and knowledge exchange across the full range of entities operating in the Delta, including not only agencies but also Tribes, community-based organizations, academic institutions, local jurisdictions, and private businesses.

Recent efforts, including the Council's Tribal and Environmental Justice Issue Paper, strengthened how the Council and its partner agencies convene, communicate with, and include marginalized groups in adaptation planning. This work has informed broader engagement practices across Delta initiatives, ensuring that equity and inclusion remain central to climate resiliency. Fostering a regional network of diverse adaptation practitioners will improve data sharing and strengthen local capacity, accelerating project delivery and ensuring that adaptation benefits reach those most in need.



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Introduction

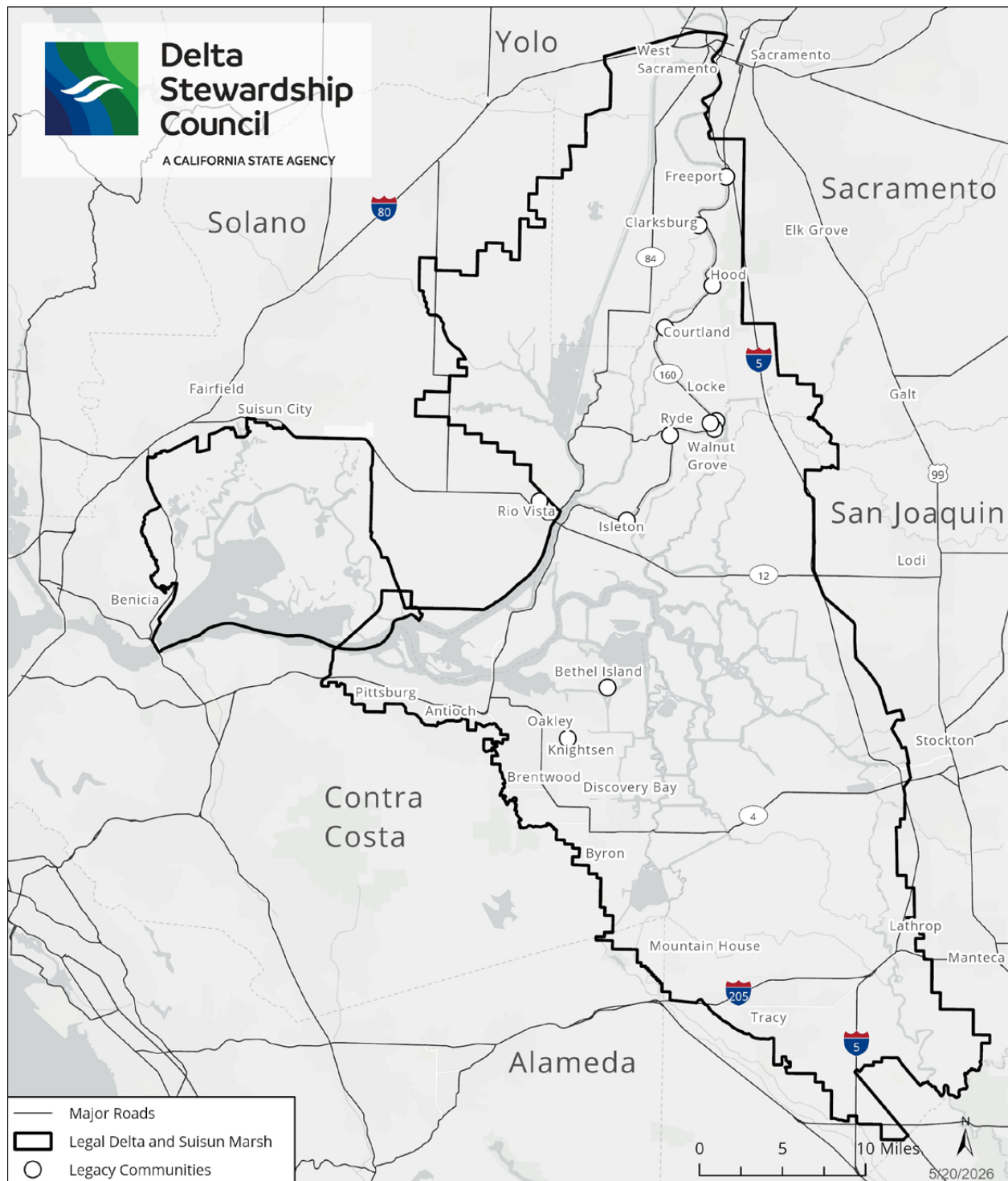
What is the Delta?

The Sacramento San Joaquin Delta (Delta) (**Figure 1**) is located where the state's two largest rivers – the Sacramento and San Joaquin – meet before they flow through the Carquinez Strait and Suisun Marsh into San Francisco Bay and ultimately the Pacific Ocean. These rivers are fed by rainfall and snowmelt from their watersheds upstream (see **Figure 3**). The freshwater carried into the Delta mixes with saltwater pushed inland by the tides. The Delta spans five counties and is home to more than 650,000 people across urban areas, rural agricultural communities, and legacy towns.

Indigenous Peoples, including the Bay Miwok, Coast Miwok, Plains Miwok, Maidu, Nisenan, Ohlone, Patwin, Pomo, Wappo, Wintun, and Yokuts, have inhabited and stewarded the lands and waters of the Delta since time immemorial. These ancestral homelands remain landscapes of cultural and traditional significance for Native Peoples today, despite the devastating impacts of colonization and European-American settlement, which displaced many Indigenous communities and dramatically altered the land and waterscapes of the Delta as settlers drained marshlands for agriculture (DSC, 2025). Today, the Delta is supported by over 1,100 miles of levees that protect the Delta islands, which are primarily used for agriculture. The U.S. Congress recognizes it as California's first National Heritage Area, created to protect the historical, cultural, natural, and recreational resources of the Delta's dynamic and living landscape (DPC, 2025).

The Delta is vital to supporting California's water supply and agriculture, as well as the ecosystems that are critical for species. It is also one of the most climate-vulnerable regions of the state, with most of the Delta experiencing higher relative sea level rise than San Francisco (Baranes et al., 2023). Most people living in areas susceptible to flooding in the Delta are highly socially vulnerable to climate change and have fewer resources available to respond and adapt (DSC, 2021a).

Figure 1. Legal Delta Boundary and its Cities and Counties





California's Fifth Climate Change Assessment

California's Fifth Climate Change Assessment (Fifth Assessment) produced regional reports for nine regions, three of which cover the Delta, as delineated in **Figure 2** below. However, there is no regional report solely for the Delta. This State Agency report, developed by the Delta Stewardship Council (Council), Sacramento-San Joaquin Delta Conservancy, and Delta Protection Commission, provides a much-needed regional focus on the unique characteristics, vulnerabilities, and needs of the Delta. It shares new, best-available climate data from the Fifth Assessment, highlights several ongoing efforts to implement a regional approach to adaptation, and underscores the significant investment need in the Delta to ensure its continued resiliency.

Figure 2. Fifth Assessment Regions and Delta Boundaries



The Delta (shown in a thick black outline) covers the San Francisco Bay Area, the Sacramento Valley, and the San Joaquin Valley, as defined by the Fifth Assessment.



State Policy and Initiatives

The climate change initiatives outlined in this report advance and support several statutory requirements and policy priorities for the Governor's Office and State government. This includes promoting a climate-resilient water system, incorporating climate change into planning and investment decisions in support of both the Governor's Water Resilience Portfolio and Executive Orders N-10-19 and B-30-15, and fostering diversity and equity in government processes per Executive Order N-16-22. The work also informs and feeds into State strategies, programs, and plans, including but not limited to:

- The California Climate Adaptation Strategy
- California's Nature-Based Solutions Climate Targets (as required by Assembly Bill 1757; C. Garcia, 2022)
- The California Natural Resource Agency's (CNRA) Natural and Working Lands Climate Smart Strategy
- The "30x30" initiative codified in Senate Bill 337 (D. Min, 2023), which sets a goal of conserving at least 30% of the state's land and coastal waters by 2030
- The Central Valley Flood Protection Plan 2022 update
- California Air Resources Board (CARB) Scoping Plan updates
- California Department of Food and Agriculture's (CDFA) Climate Resilience Strategy for California Agriculture

Report Organization

The report is organized into five main parts, beginning with the statewide significance of the Delta and the role of the Delta Reform Act and Delta agencies in stewarding it. Part two is a summary of the best available science documenting the Delta's climate vulnerabilities and emerging threats, drawing from recent research and projections from California's Fifth Assessment. Part three provides a summary of adaptation planning and programming to address the Delta's climate vulnerabilities. Part four addresses capital cost estimates associated with adaptation projects in the Delta and the need for further investment in the region for on-the-ground projects and scientific research to benefit Delta communities and the state. Part five summarizes the state of adaptation governance in the Delta, including key players and what is necessary to move from adaptation planning to implementation collectively.



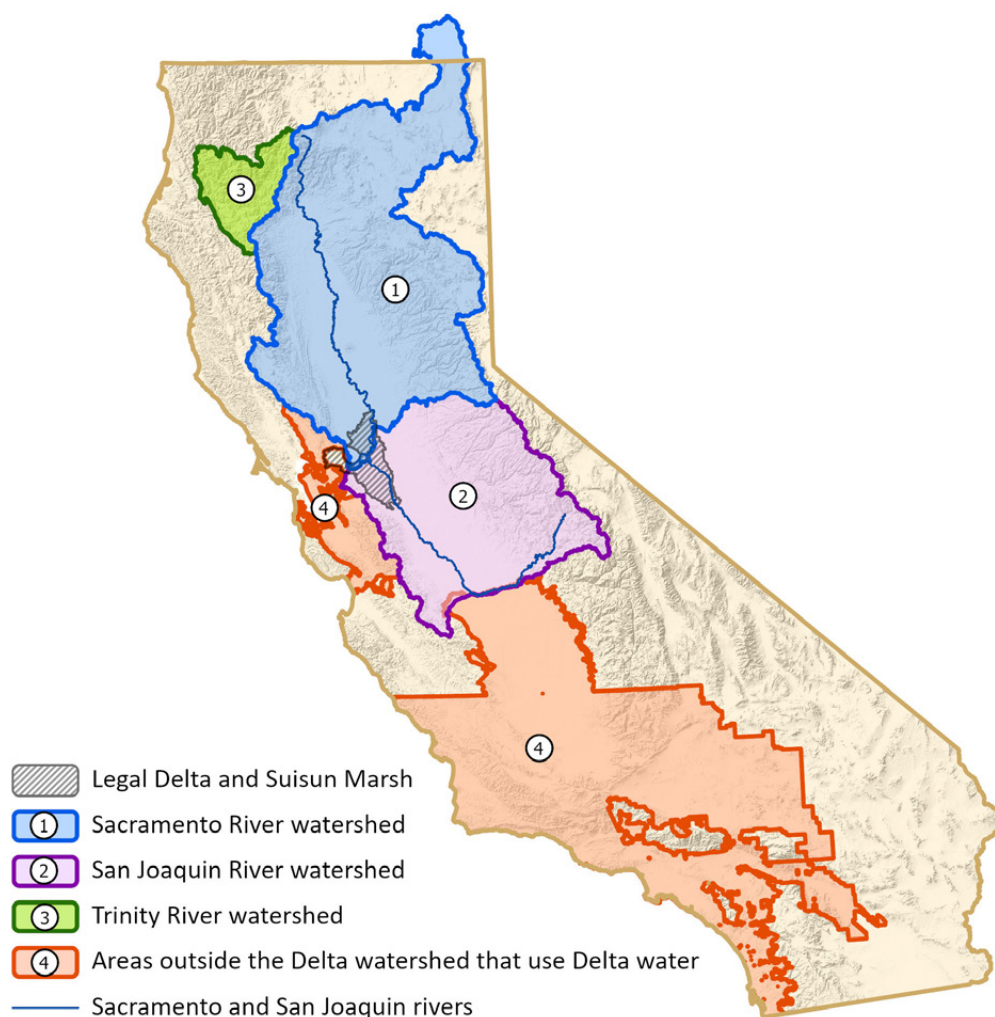
I. Statewide Significance of the Delta

California Relies on the Delta

The Delta is of critical importance to California's people, ecosystems, and economy. The region is a crucial stop for migratory fish and bird species as well as a fertile agricultural landscape that supports \$4.6 billion in agricultural output statewide (DPC, 2020). The Delta is also the heart of the state's water system. 40% of California's runoff flows into the Delta, where it is used to support ecosystems, diverted for irrigation and uses in the Delta, and exported to other parts of the state (Mount, 2022; DSC, 2021c). Two water conveyance projects, the State Water Project and the Central Valley Project, pump water from the southern Delta to approximately two-thirds of Californians living in the Bay Area and Central and Southern California and about one-third of California's farmland (DWR, n.d. a; DSC, 2024a). See **Figure 3** for a map of the watersheds upstream of the Delta and downstream diverters, or areas outside the Delta and its watersheds that use Delta water.

The Delta's rich peat soils, built by the deposition of organic-rich sediment during seasonal flooding over thousands of years, provide fertile ground for growing. However, making the land suitable for growing crops comes with trade-offs. The Delta has experienced soil loss, increased greenhouse gas (GHG) emissions, and subsidence over 150,000 acres due to the breakdown of peat soils when exposed to air. As soil carbon is converted to carbon dioxide, land elevation decreases, and large amounts of GHGs are released into the atmosphere. Worldwide, highly organic soil occupies only about 3% of the land surface but stores 20% of the terrestrial carbon. Hence, the Delta has the potential to store carbon but is currently a major carbon source. The Delta has lost roughly half of its peat and continues to release about 1.2 million metric tons of carbon dioxide equivalents into the atmosphere each year (Vaughn et al., 2024). This process is referred to as oxidation-driven subsidence. Some locations in the Delta have subsided by as much as 20 feet below sea level, adding pressure on levees and increasing the risk of flooding and saltwater intrusion into statewide water supplies conveyed through the Delta (Deverel et al., 2020).

Figure 3. Regions of the State Influenced by the Delta



The Delta – like the entire state – is facing the accelerating impacts of climate change. Rising sea levels, extreme heat, flooding, drought, changes in precipitation, and upstream wildfires and air quality impacts from smoke all threaten the people, ecology, industry, agriculture, recreation, infrastructure, economy, and culture of the Delta. Flood events could overtop or damage levees, endanger communities, destroy agricultural land, and disrupt the Delta’s conveyance and water supply infrastructure that provides a portion of the water used by 27 million Californians and millions of acres of farmland across the Central Valley (DSC, 2021a). Droughts and saltwater intrusion from sea level rise already disrupt harvests and could affect the long-term viability of the agricultural economy (DSC, 2021a). Further, climate change impacts threaten more than 750 plant and animal species, including critical and endangered migratory birds and salmon, as well as the livelihoods of more than half a million people living in the Delta (DSC, 2021a).



The Delta Reform Act and the Coequal Goals

Improving the Delta's resilience to climate change impacts is critical to support the mission of the Sacramento-San Joaquin Delta Reform Act of 2009 (Act) which established the state's coequal goals (see callout box), created the Council, the Delta Conservancy, and the Office of the Delta Watermaster (Water Code, §§ 85200, 85230; Pub. Res. Code, §32320.).¹ The Act called for fundamental reorganization of state resources to manage challenges in the Delta watershed. The Delta agencies each have an important role in the Delta.

The Coequal Goals

The state's coequal goals for the Delta are to 1) **provide a more reliable water supply for California**; and 2) **protect, restore, and enhance the Delta ecosystem**. These goals are to be achieved in a way that **protects and enhances the Delta's unique cultural, recreational, natural resource, and agricultural values** as an evolving place (Water Code, § 85054.). The goals pose a challenge to reconcile what are often considered disparate objectives – water supply and restoration – yet highlight opportunities to apply science-based approaches to decision-making.

Delta Agencies

The Delta Stewardship Council

The Council is an independent state agency with the authority, responsibility, accountability, scientific support and funding to achieve the State's coequal goals. (Water Code, § 85001, subd. (c).). The Council is comprised of seven members, supported by a dedicated staff of over 70 employees, including the Planning & Performance Division and the Delta Science Program. It is charged with adopting and implementing a legally enforceable "Delta Plan" the state's long-term and science-based management plan for the Delta, that is built upon the principles of adaptive management. (Delta Stewardship Council Cases (2020) 48 Cal.App.5th 1014, 1038.). The Delta Plan has regulatory policies that protect land for restoration and agriculture, manage flood risk, and improve water supply reliability. The Delta Reform Act directs the Council to coordinate and regulate the actions of more than 200 state and local agencies in the Delta through the DPIIC to ensure the Delta Plan is implemented (Water Code, § 85204.).

The Delta Reform Act also established the Delta Independent Science Board (Delta ISB) (CA Water Code, § 85280.). The Delta ISB is composed of prominent scientists with diverse expertise in topics relevant to supporting adaptive management of

¹ The Delta Protection Commission was created by the Delta Protection Act of 1992.



the Delta through independent review (see callout box). Over the years, the Delta ISB has produced numerous influential reports on topics such as restoration, water quality, food webs, and levee hazards, and has provided valuable input on critical science documents to inform decision-making. Findings and recommendations from Delta ISB reports have informed the development and implementation of the Council's Delta Plan and the Delta Science Plan, which serves as a shared framework for better coordinating science in the Delta. The Delta ISB also identifies key science gaps, including those related to assessing the impacts of climate change and extreme events.

Adaptive Management

Adaptive management is a framework and flexible decision-making process for ongoing knowledge acquisition, monitoring, and evaluation leading to continuous improvements in management planning and implementation of a project to achieve specified objectives (Water Code, § 85052.). As conditions continue to shift in the Delta due to climate change, adaptive management provides a valuable framework to ensure that management decisions are responsive and reflect advancements in our understanding.

In 2018, the Council kicked off its climate adaptation initiative, Delta Adapts: Creating a Climate Resilient Future (Delta Adapts). Delta Adapts included two phases: a Climate Change Vulnerability Assessment and an Adaptation Plan, both of which are described in later sections. At the same time, the Council compiled and adopted a Tribal and Environmental Justice Issue Paper, which identifies general and Council-specific recommendations to address the disproportionate environmental burdens faced by Tribal and local communities in the Delta. The paper highlights, among other injustices, the disproportionate vulnerability of certain Delta communities to climate impacts and the need to invest in the communities most vulnerable to climate change while considering equity in climate adaptation. The foundations of the Council's work on climate science and resilience are regional planning, convening and communicating with partners and experts, conducting technical analyses, and synthesizing best available science (Water Code, §§ 85001(c), 85020(h).).

The Sacramento-San Joaquin Delta Conservancy

The Act also created the Delta Conservancy, for which the governing statute was established by the Sacramento-San Joaquin Delta Conservancy Act (Public Resources Code §§ 32300-32381.). The Delta Conservancy is one of California's 10 State conservancies that provide vital funding and resources for projects that serve communities and protect natural resources. State conservancies support communities by connecting them to State funding for projects that protect resource lands and regional economies while improving environmental conditions, and by bringing



partners together to solve local resource challenges.

The Delta Conservancy's mission is to lead efforts to preserve, protect, and restore the natural resources, economy, and agriculture of the Delta and Suisun Marsh primarily through internal programs and grant-funded projects. It collaborates with Tribes, State and federal agencies, local communities, interested groups, and science experts to accomplish this mission. The Conservancy is a non-regulatory entity governed by a board of 11 voting members, composed of appointed public members, county supervisors, and representatives from local non-profits, special districts, and State and federal agencies. Since its creation in 2010, the Delta Conservancy has provided over \$130 million in State and federal funding for more than 140 projects that improve recreation opportunities, drive tourism, fund locally supported restoration and climate resilience projects, and support Delta agriculture. In addition to grant-funded projects, environmental, cultural, and historical education are important to the Conservancy's overall mission.

The Delta Protection Commission

The Commission was created by the Delta Protection Act of 1992 with a charge to protect, maintain, enhance, and enrich the overall quality of the Delta environment and economy. This is carried out by implementing Land Use and Resource Management Plan policies for agriculture, recreation, and cultural and natural resources. The Delta Reform Act included amendments to the Delta Protection Act directing the Commission to develop and update a regional Economic Sustainability Plan with recommendations to inform policy development for the long-term health of the Delta economy. The Plan's topics included levees and public safety, addressing sea level rise and risk management. It also recommended development and tracking of indicators for infrastructure and socioeconomic status, leading to the development of a Socioeconomic Indicators Report (2025), which lends added depth to the Delta Plan's Performance Measures and prioritization tools such as the Delta Levees Investment Strategy.

The 15-member Commission consists of elected representatives of the five Delta counties and cities, representatives of the North, Central and South Delta reclamation districts, and representatives of the State Lands Commission and Secretaries of Natural Resources, Food and Agriculture, and Transportation Agencies. The Commission also coordinates the [Delta National Heritage Area](#), leads the development of the [Great California Delta Trail system](#), and supports the [Delta Leadership Program](#), a project of the Delta Regional Foundation. The Commission advocates for the preservation of agriculture, promotes recreation and Delta legacy communities while remaining mindful of the importance of the Delta to all Californians, and contributes to preserving the Delta as an evolving place.



Office of the Delta Watermaster

Lastly, the Delta Reform Act created the Office of the Delta Watermaster (CA Water Code § 85230.). The Watermaster is an independent officer of the State, appointed to a four-year term by the State Water Resources Control Board (State Water Board), which provides reports to the State Water Board and to the Council. The Watermaster is responsible for overseeing the day-to-day administration of water rights in the Delta, and, when necessary, taking enforcement action related to water diversions. The Watermaster also confers with and assists both the State Water Board and the Council as they carry out their respective legislative mandates within the constraints of the existing water rights system and of the Delta as an evolving place.



II. Climate Change in the Delta

The Council's Delta Adapts initiative began with a [Climate Change Vulnerability Assessment](#), which summarized existing conditions in the Delta, climate stressors and hazards, and vulnerabilities to Delta people, places, ecosystems, agriculture, recreation, and infrastructure. This section updates the Council's 2021 Vulnerability Assessment using best available data and information from the Fifth Assessment to update climate projections and our understanding of climate vulnerabilities in the Delta. It also draws on other best available sources, including the 2023 Delta Residents Survey, the State of Bay Delta Science, Delta ISB reviews (e.g., subsidence), and symposia (e.g., the Emerging Climate Science Symposium). The chapter is organized into the following core sections: 1) a methods section that summarizes the data, emissions scenarios, and models commonly used in climate research and projections, 2) climate stressors and hazards, 3) social vulnerability to climate change, and 4) key climate vulnerabilities in the Delta region.

Methods

The Council's 2021 Vulnerability Assessment relied on climate data from California's Fourth Climate Change Assessment (Fourth Assessment). Wherever possible, this report incorporates new data from the sixth Coupled Model Intercomparison Project (CMIP6), downscaled for the state through the Fifth Assessment. These data were developed by researchers from Scripps Institution of Oceanography at UC San Diego and researchers from the University of California, Los Angeles through funding by the California Energy Commission. These datasets underpin California's Fifth Assessment research and are accessible via the [Cal-Adapt Analytics Engine](#).

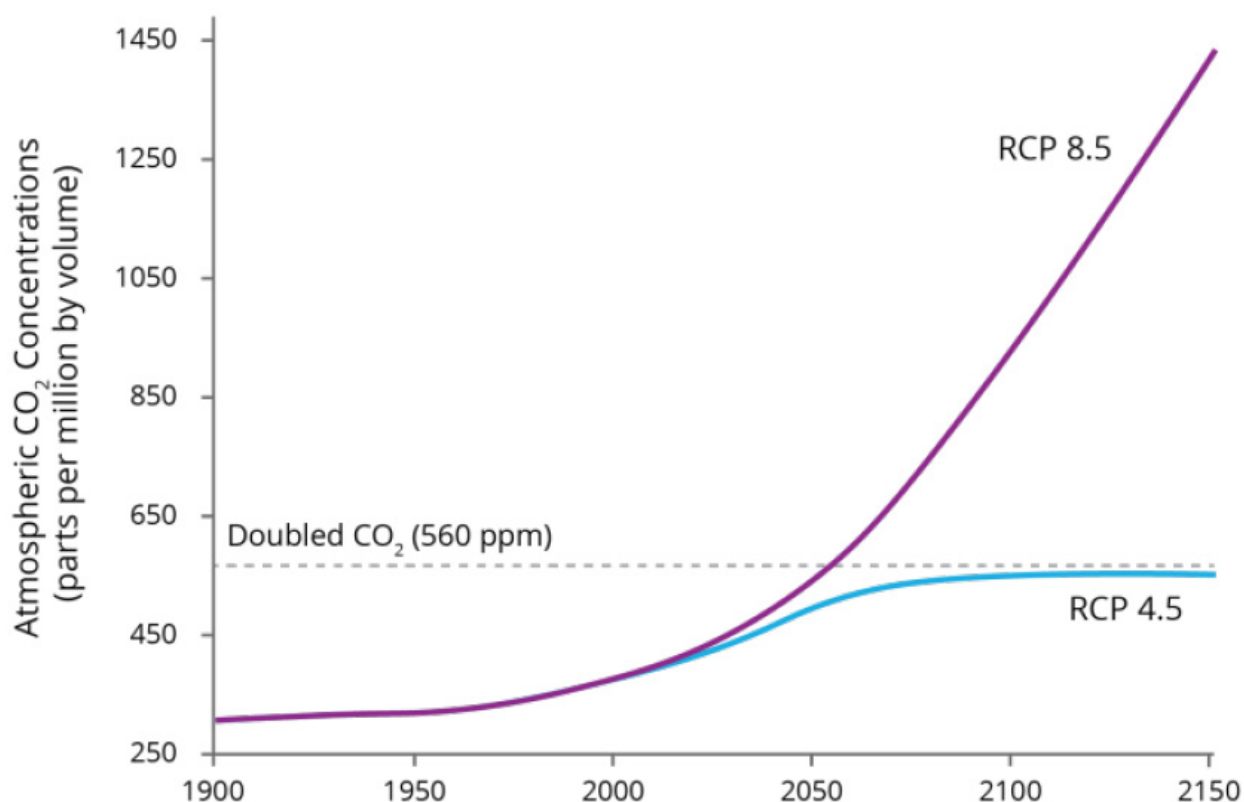
Some projections from the Vulnerability Assessment were not updated as they relied on a secondary model that has not yet been re-run with new inputs; this is the case for the streamflow and flood hazard modeling reported from the Vulnerability Assessment.² Any data reported from the Vulnerability Assessment is appropriately cited and refers to the GHG emissions scenarios used exclusively at the time: the Representative Concentration Pathways (RCP).

The RCPs are climate scenarios used to define the radiative forcing, or change in atmospheric energy, which the Earth will experience in 2100 (IPCC, 2023). They are RCP 2.5, RCP 4.5, RCP 6.0, and RCP 8.5, where the numbers refer to greater radiative forcing (IPCC, 2023). Two RCPs are commonly used to represent future GHG conditions: RCP 8.5 and 4.5. RCP 8.5 represents little effort to limit or reduce

2 The Council intends to update its flood hazard modeling using new streamflow data and a two-dimensional model of the Delta. Council staff are evaluating options to develop a two-dimensional model in-house that suits the requirements of this analysis and other Council needs.

emissions coupled with rapid economic growth (DSC, 2021a). RCP 4.5 represents more moderate GHG concentrations, increasing through mid-century and then stabilizing (DSC, 2021a). See **Figure 4** for a summary of atmospheric carbon dioxide concentrations under each scenario.

Figure 4. Atmospheric Carbon Dioxide Concentrations Under RCP 4.5 and 8.5



The Fifth Assessment uses new emissions pathways applied by the Intergovernmental Panel on Climate Change (IPCC) called the Socioeconomic Pathways (SSP). Unlike the RCPs, the SSPs incorporate socio-economic trends that could influence climate actions in the coming century (IPCC, 2023). Five SSPs cover a range of population growth, income, land use, resource consumption, and technological outcomes (IPCC, 2019). The SSPs can also be paired with RCPs to estimate the amount of climate mitigation achievable in that scenario (IPCC, 2023). Data from the Fifth Assessment is provided for three SSPs coupled with a RCP, representing intermediate (SSP 2-4.5), high (SSP 3-7.0), and very high (SSP 5-8.5) emissions. See **Table 1** for a summary of these three pathways.



Table 1. Summary of the SSPs Used in the Fifth Assessment and the Emissions They Represent

Scenario Name	Descriptive Term	Narrative Summary	Emissions Summary
SSP 2-4.5	Intermediate	A “middle of the road” trajectory that shows improvements toward meeting GHG mitigation targets. Assumes medium population growth and income, technological and consumptive patterns follow past trends, and inequality reduces gradually (IPCC, 2019).	Global annual CO ₂ emissions decrease from 2000 to 2100 but do not reach zero. Average temperature rises by about 2.1 to 3.5°C (3.8 to 6.3°F) by 2100 (IPCC, 2023).
SSP 3-7.0	High	A less optimistic “business as usual” pathway that assumes current emissions continue through the end of the century. Assumes high population growth, low income, resource-intensive consumption, slow technological growth, and continued inequality (IPCC, 2019).	Global annual CO ₂ emissions roughly double from 2000 to 2100. Average global temperature rises by about 2.8 to 4.6°C (5.0 to 8.3°F) by 2100 (IPCC, 2023).
SSP 5-8.5	Very High	An unlikely, “worst case scenario” pathway. Assumes a peak then a decline in population, high income, resource-intensive consumption, and reduced inequalities (IPCC, 2019).	Global annual CO ₂ emissions roughly triple from 2000 to 2100. Average global temperature rises by about 3.3 to 5.7°C (5.9 to 10.3°F) by 2100 (IPCC, 2023).

General Circulation Models (GCM) (or Global Climate Models) use emissions scenarios such as these to generate projections for how different climate variables such as temperature and precipitation will change in response to GHG emissions. California’s Climate Change Assessments produce GCM simulations downscaled to



California; datasets produced through the Fifth Assessment used a hybrid (LOCA2-Hybrid) downscaling approach to generate temperature, precipitation, wind, and humidity projections (Pierce, 2025).³ Data reported in the Council's 2021 Vulnerability Assessment relied on GCM data collected for the Delta region from Cal-Adapt for 10 of the 32 GCMs available.⁴ Updated data reported from the Fifth Assessment are drawn from 15 GCMs chosen based on their good performance across California.⁵ Data is provided in 30-year averaged periods: historical (1981-2010), mid-century (2041-2070), and late-century (2071-2100).⁶

Climate Stressors and Hazards

Stressors are defined by the IPCC as "events and trends, often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate-related risk" (IPCC, 2023). The primary stressors in the Delta are air temperature, sea level rise, and precipitation. The Council's 2021 Vulnerability Assessment analyzed these stressors in the context of physical hazards they pose to Delta assets including ecosystems, people, infrastructure, water supply, flood risk management, and economy. Projections for the climate stressors most relevant to the Delta are summarized below; wherever possible, new projections from the Fifth Assessment are provided.

Air Temperature and Extreme Heat

Air Temperature

The Delta's climate is characterized by cool, wet winters and hot, dry summers. While the primary drivers of air temperatures are incoming solar radiation and weather, local factors such as proximity to the Pacific Ocean (a heat sink) and inland urban areas (a heat source) can influence the range of variability (Mahardja et al., 2025). Fifth Assessment modeling of observed trends demonstrates that the Delta has already experienced noticeable warming since the 1970s (see **Figure 5**). As summarized by Dr. Paul Ullrich (UC Davis) during the Delta ISB's 2025 Emerging Climate Science Symposium (Delta ISB Climate Symposium), the years 2014, 2020, and 2024 were the hottest on record, and no year since 2011 has been cooler than the average between 1981 to 2020 (Delta ISB, 2025a).

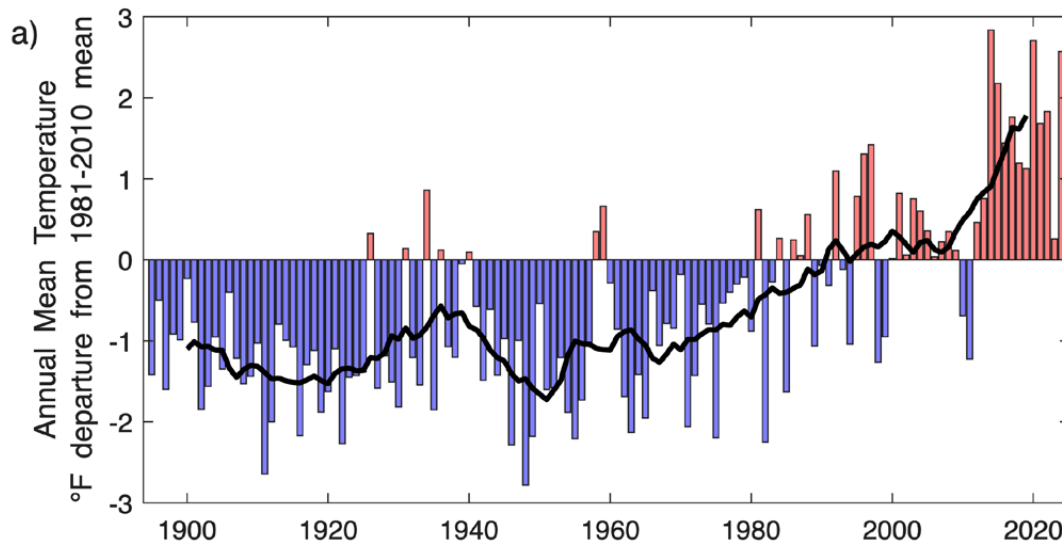
3 This approach is referred to as "hybrid" as it is a statistical approach based on dynamically downscaled data.

4 These were HadGEM2-ES, CNRM-CM5, CanESM2, MIROC5, ACCESS1-0, CCSM4, CESM1-BGC, CMCC-CMS, GFDL-CM3, HadGEM2-CC.

5 These models are ACCESS-CM2, CESM2-LENS, CNRM-ESM2-1, EC-Earth3, EC-Earth3-Veg, FGOALS-g3, GFDL-ESM4, HadGEM3-GC31-LL, INM-CM5-0, IPSL-CM6A-LR, KACE-1-0-G, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0, TaiESM1

6 The Council used slightly different planning horizons in its original Vulnerability Assessment: Historical (1961-1990), Mid-Century (2035-2064), and End-of-Century (2070-2099).

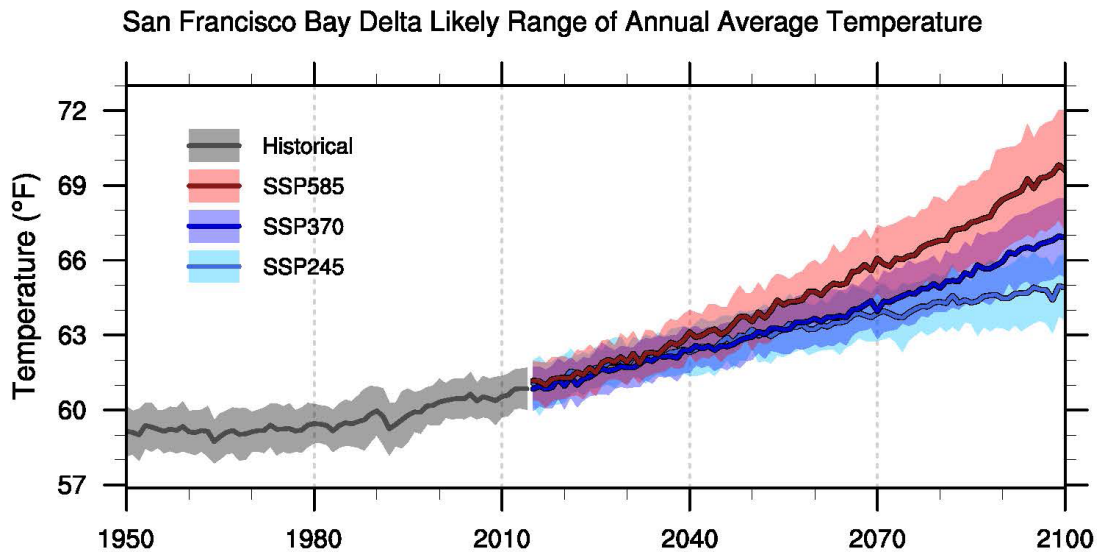
Figure 5. Observed Trends in Annual Temperature in the Delta.



Observed historical change in average annual (January to December) temperature for the Delta region, reported as anomalies from the historical period (1981 - 2010). The black line shows the 11-year centered moving average. Data is from the National Oceanic and Atmospheric Administration's (NOAA) monthly nClimgrid averaged across the geography of the Delta (Abatzoglou, 2025).

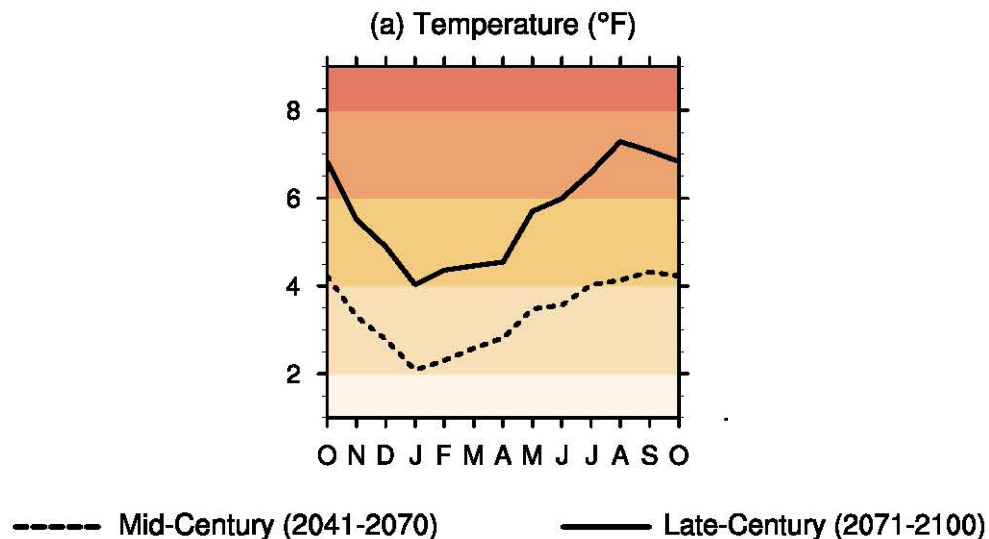
Fifth Assessment modeling of future average annual temperatures across the Delta all show various levels of warming (see **Figure 6**). Per Dr. Ullrich's Delta ISB Climate Symposium presentation, temperature projections are similar enough that they are statistically indistinguishable through mid-century, then begin to diverge (Delta ISB, 2025a). By late-century, average annual temperatures are expected to be 3.5°F, 5.5°F, and 7.5°F above present temperatures for the SSP 2-4.5, SSP 3-7.0, and SSP 5-8.5 scenarios, respectively (Delta ISB, 2025a). **Figure 7** provides a snapshot of projected changes in absolute monthly average temperatures by mid-century and late century.

Figure 6. Likely Range of Average Annual Temperature in the Delta.



Average annual temperature likely range estimated by LOCA2 downscaled GCMs for California under three scenarios: SSP 5-8.5, SSP 3-7.0, and SSP 2-4.5. Historical trends are shown until 2014 (Ullrich, 2025).

Figure 7. Projected Changes in Absolute Monthly Average Temperature.



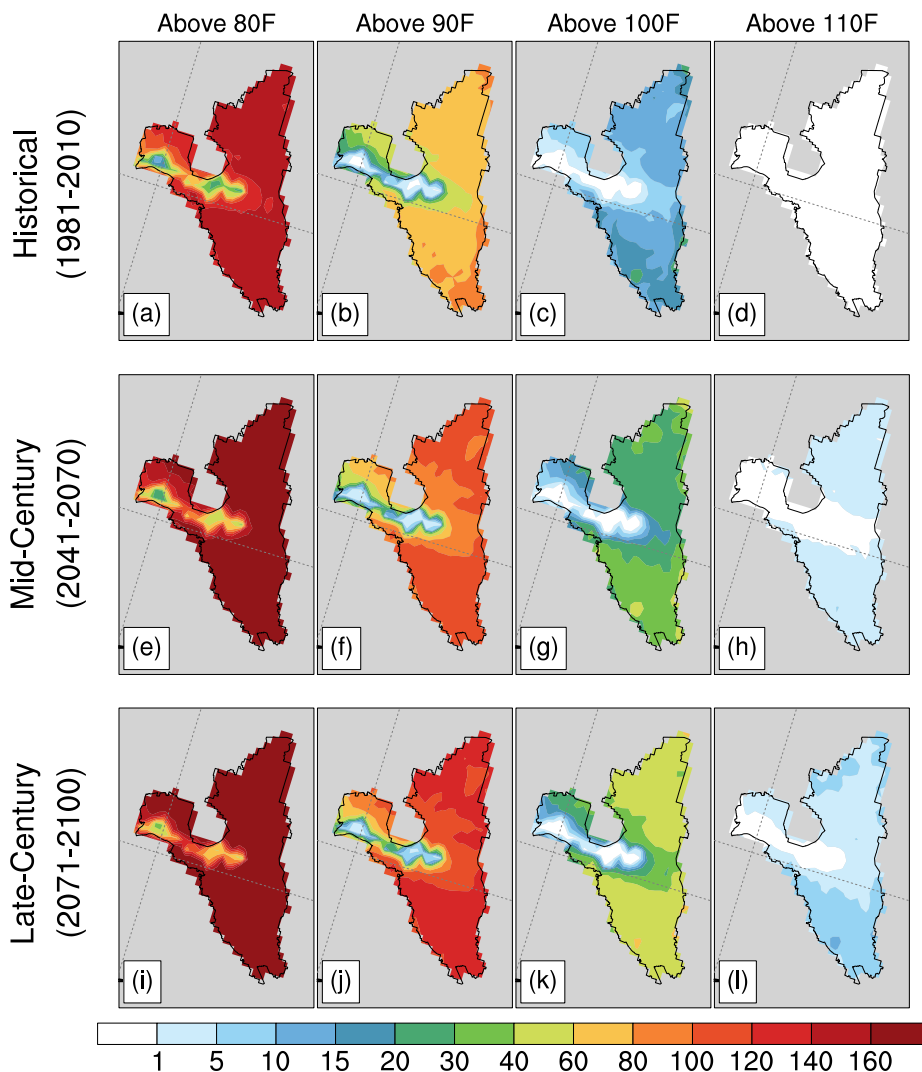
Seasonal change in future average monthly temperature (°F) for mid-century (2041-2070) and late century (2071-2100) from historical (1981-2010). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Ullrich, 2025).



Extreme Heat

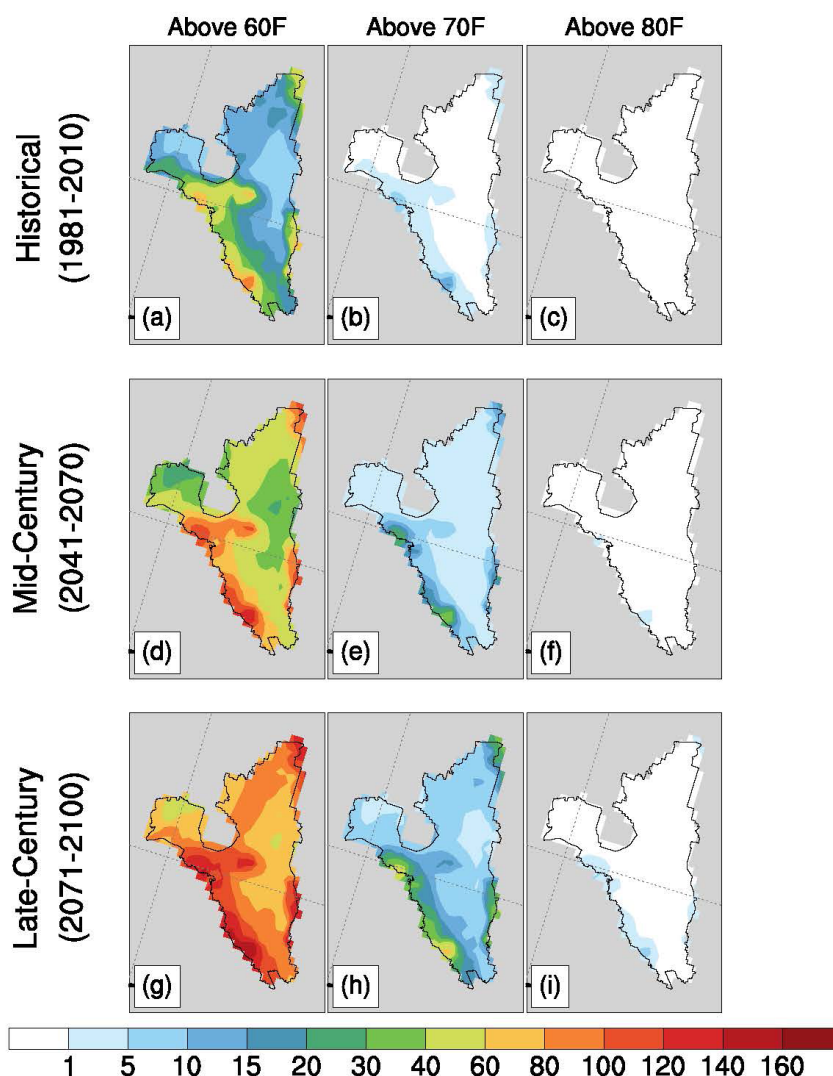
Rising average annual temperatures will increase extreme heat event severity and frequency. As shared by Dr. Ullrich during the Delta ISB Climate Symposium, most of the Delta will experience daily temperatures above 80°F for the majority of the year by mid-century, including five to 10 days per year when the Delta will experience daily average temperatures above 110°F (see Figure 8) (Delta ISB, 2025a).

Figure 8. Average Number of Days per Year Where the Maximum Daily Temperature is Above a Threshold Temperature.



Change in the future average number of days per year where daily maximum temperature exceeds one of four high temperature thresholds at mid-century (2041-2070) and late century (2071-2100) as compared to the historical period (1981-2010). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Ullrich, 2025).

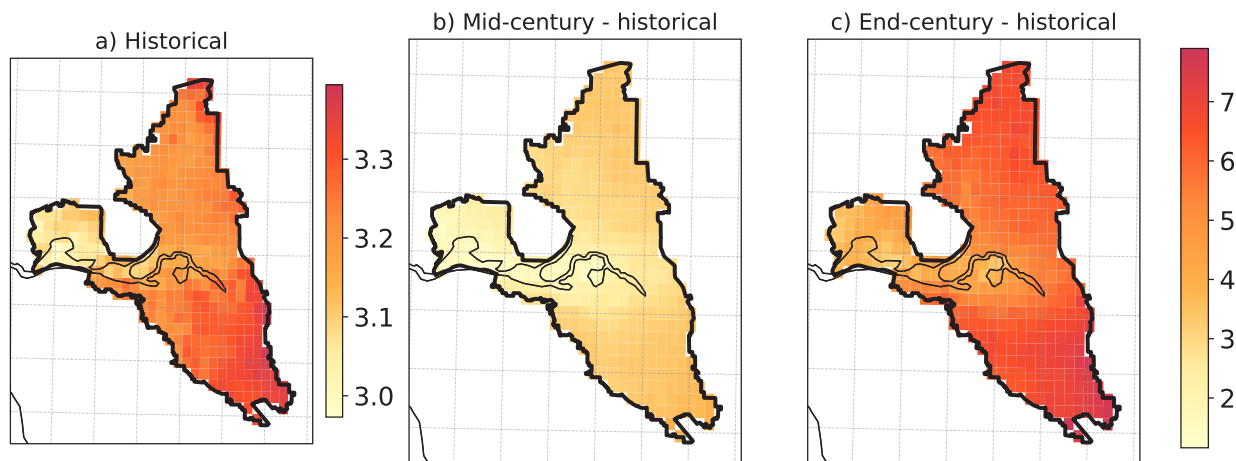
Figure 9. Average Number of Days per Year Where the Minimum Daily Temperature is Above a Threshold Temperature.



Change in the future average number of days per year when daily minimum temperatures (warm nights) exceed a high temperature threshold at mid-century (2041-2070) and late century (2071-2100) as compared to the historical period (1981-2010). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Ullrich, 2025).

Extreme heat days are defined as days that experience temperatures exceeding the 98th percentile of observed historical temperatures for a location (see **Figure 32** in the Appendix). On average, the longest annual heat wave in the Delta was historically about three days (see **Figure 10**). Based on future projections from the Fifth Assessment, the average duration of heat waves in the Delta is expected to increase to six days by mid-century and nine days by late-century (see **Figure 10**).

Figure 10. Projected Change in Length of Heat Waves (in Days).



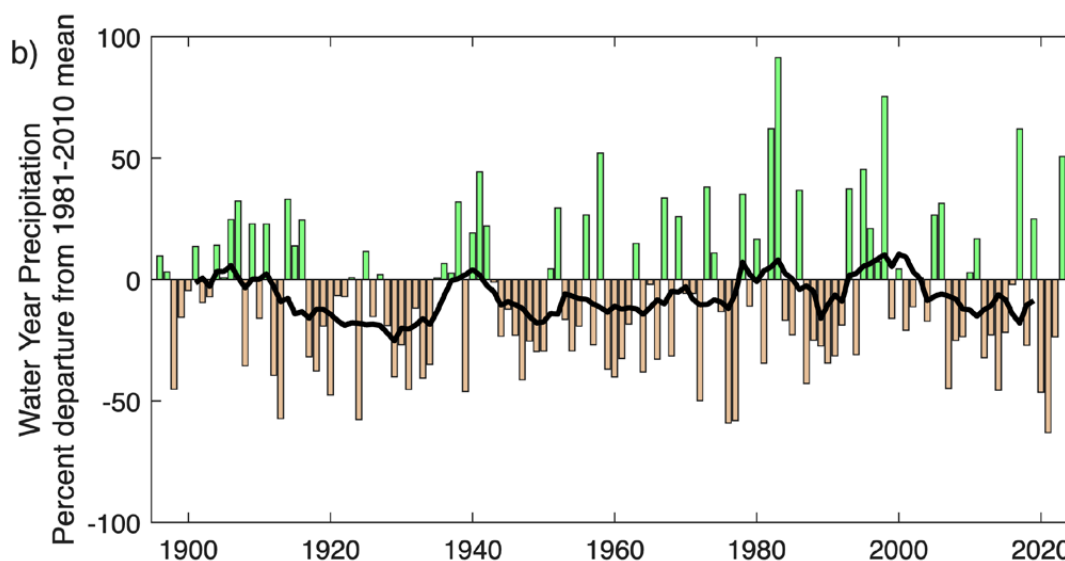
Change in the average longest annual heat wave at mid-century (2041-2070) and late century (2071-2100) as compared to the historical period (1981-2010). A heat wave is defined as the number of consecutive days with temperatures above the 98th percentile of historical temperature distribution across the region. Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Stevenson, 2025).

Precipitation, Hydrologic Patterns, and Drought

Precipitation and Hydrologic Patterns

Precipitation in the Delta, like the rest of the state, is variable. It is not uncommon in California to experience an extremely wet year followed by a multi-year drought. Projected precipitation trends are the least certain aspects of climate models, as the models cannot resolve many of the fine-scale and complex interactions that occur locally. Precipitation affects the Delta at two geographic scales: rain that falls inside the Delta and precipitation in the Delta's upstream watersheds. Snow is uncommon in the Delta but has historically been the primary form of precipitation in the Delta's upstream watersheds, forming snowpack and a source of water later in the year (DSC, 2021c). The accumulation of snow usually peaks in late March to early April and then begins to melt throughout spring (DSC, 2021c). This snow melt typically peaks earlier in the Sacramento River Basin and later in the San Joaquin River Basin, staggering inflow to the Delta that is important to water supply in the drier seasons (DSC, 2021c). See **Figure 11** for observed trends in annual precipitation across the Delta.

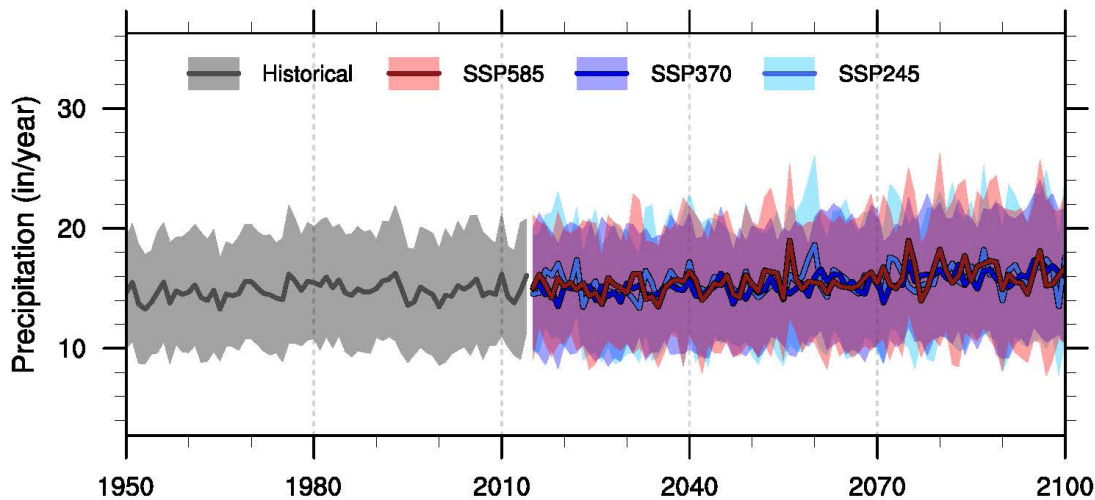
Figure 11. Observed Trends in Annual Precipitation in the Delta.



Observed historical change in water year (October – September) precipitation anomalies for the Delta region, reported as anomalies from the historical period (1981 – 2010). The black line shows the 11-year centered moving average. Data is from NOAA’s monthly nClimgrid average across the geography of the Delta (Abatzoglou, 2025).

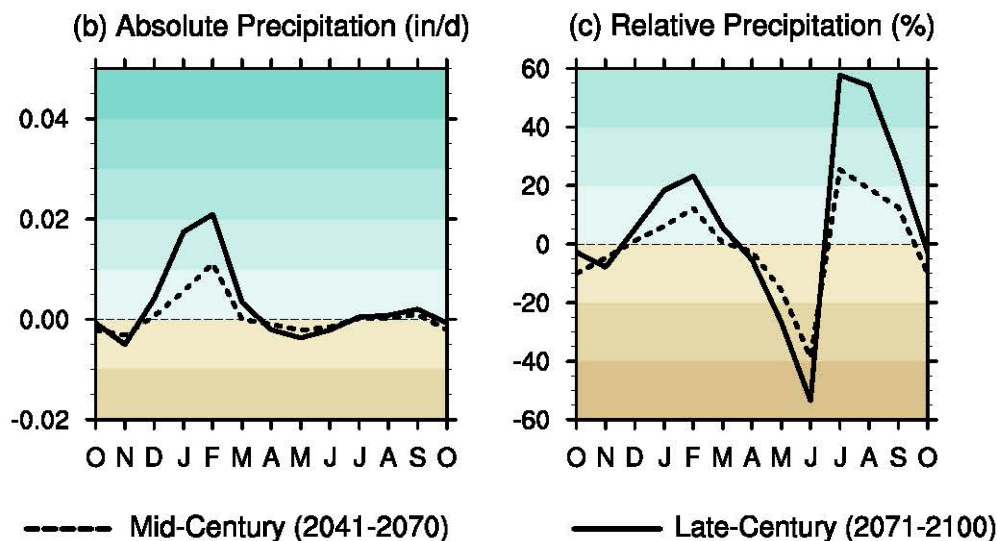
Fifth Assessment precipitation projections show that average annual precipitation in the Delta is expected to increase slightly, by 4% through mid-century and by 8% through late-century, above average annual historical precipitation of about 10 to 20 inches per year (Delta ISB, 2025a) (see **Figure 12**). Projections of seasonal changes in precipitation show that absolute precipitation is expected to increase in the winter and relative precipitation (the percentage of historical precipitation) is projected to decrease in drier months (see **Figure 13**). As presented by Dr. Ullrich in the Delta ISB Climate Symposium, variability of precipitation is expected to increase, with more extremely wet and dry years occurring under all scenarios (Delta ISB, 2025a). Higher river inflows during wet years can increase in-Delta water levels, which can damage or overtop levees.

Figure 12. Likely Range of Annual Average Precipitation.
San Francisco Bay Delta Likely Range of Annual Average Precipitation



Average annual precipitation likely range estimated by LOCA2 downscaled GCMs for California under three scenarios: SSP 5-8.5, SSP 3-7.0, and SSP 2-4.5. Historical trends are shown until 2014 (Ullrich, 2025).

Figure 13. Projected Changes in Absolute Monthly Average Precipitation.



Seasonal change in future monthly precipitation (inches/year) and relative precipitation (percentage of 1981-2010 inches per year) for mid-century (2041-2070) and late-century (2071-2100) from historical conditions (1981-2010). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Ullrich, 2025).

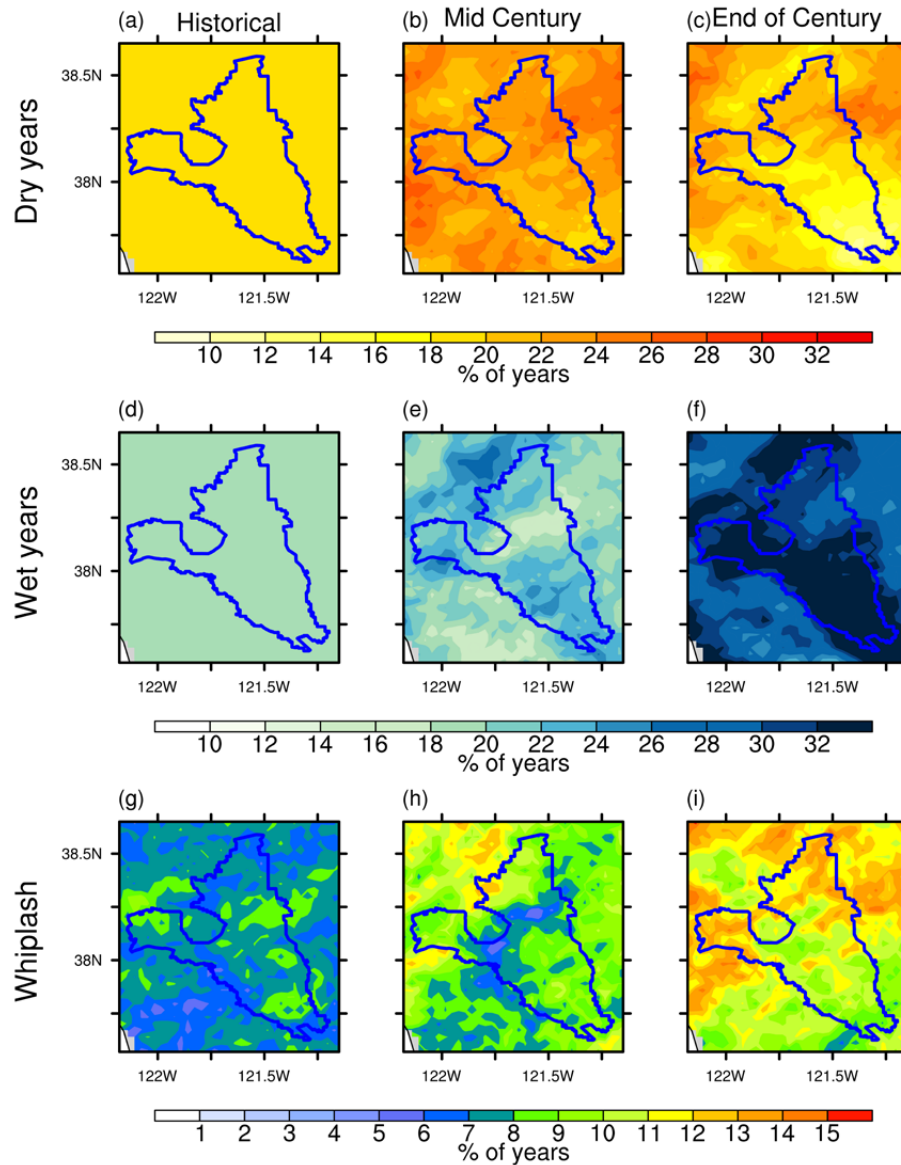


Model projections suggest that while overall precipitation rates may increase, the portion of precipitation falling as snow will decrease, leading to greater runoff and higher peak flows during extreme events (Baranes et al., 2023). In addition, more rainfall, and more rain falling on snow, will lead to earlier snowmelt in the spring and lower stream flows during hot, dry months (Schwartz et al., 2017). Earlier snowmelt often cannot be captured in surface reservoirs due to flood management requirements and thus diminishes the state's natural water storage for the spring and summer months (DSC, 2021c; Schwartz et al., 2017). Measurements already demonstrate a downward trend in snowpack in the Sierra Nevada (Hatchett et al., 2017).

The 2025 Delta ISB Climate Symposium featured discussions on how climate change is rapidly transforming hydrological extremes in the Delta region and its upstream watersheds (Delta ISB, 2025a). As noted by Dr. Ben Hatchett (Colorado State University), there will be fewer but more intense storms (Delta ISB, 2025a). Specifically, atmospheric rivers, which are responsible for the wettest events in California, are projected to become more intense, especially the most extreme ones (Gershunov et al., 2025). Storms may also have greater clustering, meaning they occur closer together in time.

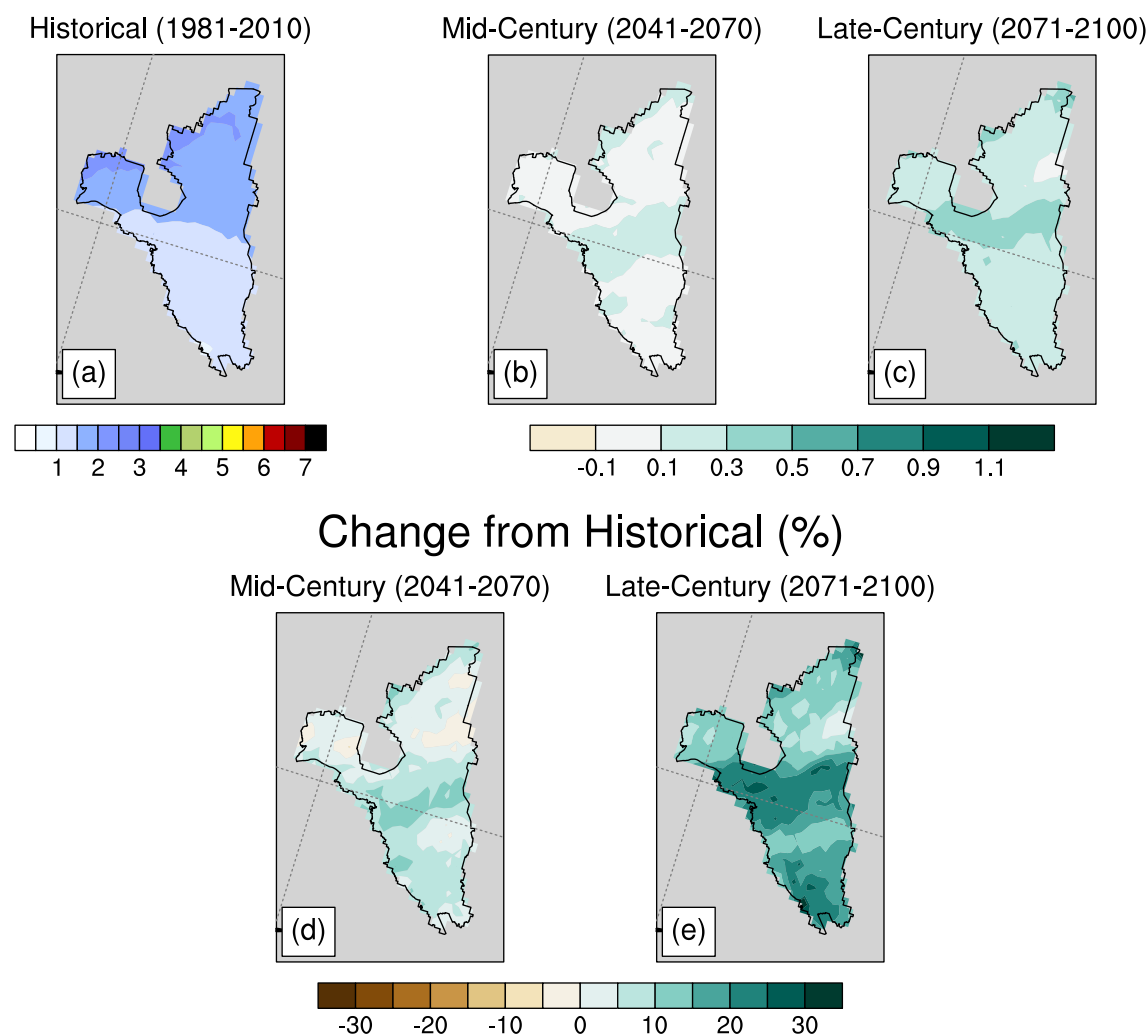
As shown in **Figure 14**, projections from the Fifth Assessment suggest that both dry and wet years are projected to become more prevalent across the Delta. The percentage of dry years is highest in the mid-century period and percentage of wet years is highest in the late-century period, in which up to 32% of years could be wet. The frequency of whiplash, or dry and wet years happening one after the other, is also expected to increase across the Delta (see **Figure 14**). The wettest day in mid-century is expected to be 5 to 10% wetter than historical conditions and expected to be 15 to 25% wetter than historical conditions in late century (see **Figure 15**) (Delta ISB, 2025a).

Figure 14. Projected Change in Variability of Annual Precipitation.



Top row: Frequency of dry years (below local 20th percentile historical); Second row: Frequency of wet years (above local 80th percentile historical); Bottom row: Frequency of whiplash (consecutive occurrence of dry and wet years, using same definitions). Shown for (left) historical, (middle) mid-century, (right) late-century (Norris, 2025).

Figure 15. Change in the Average Rainiest Day of the Year.



Map of absolute (top) and percent (bottom) change in the rainiest day of the year in inches per day by mid-century (2041-2070) and late century (2071-2100) as compared to the historical period (1981-2010). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Ullrich, 2025).

Streamflow

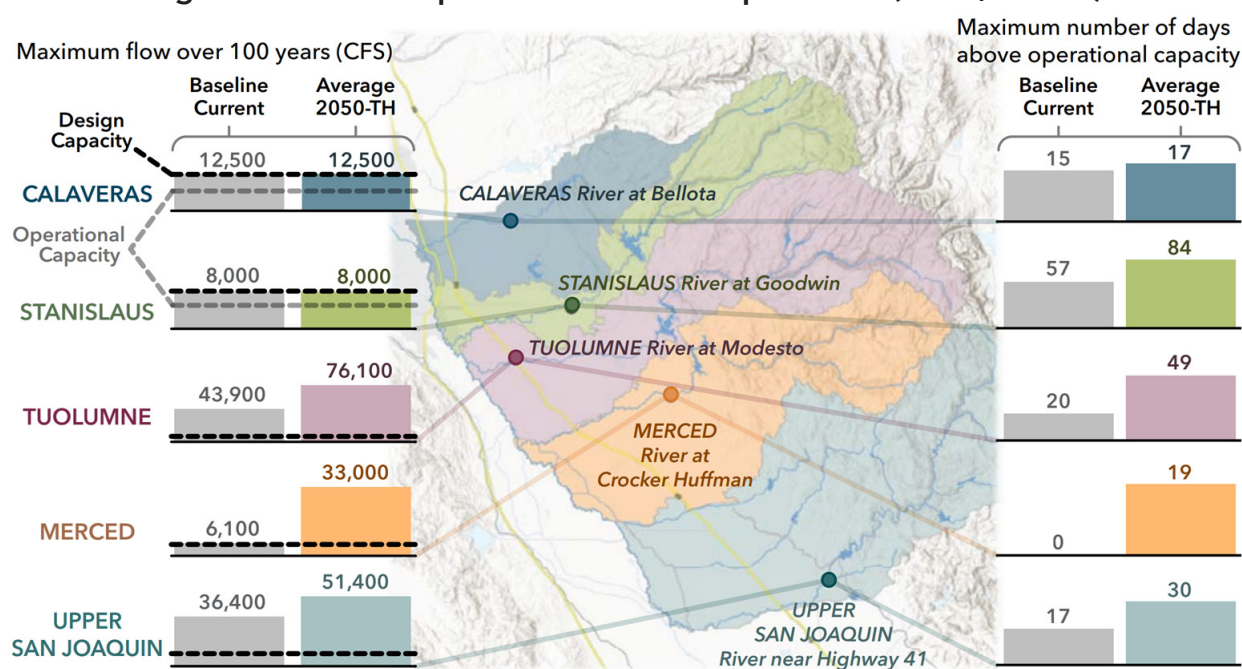
Climate change is causing dramatic swings between extreme precipitation events and severe droughts (DWR, 2025b). Higher peak flows from heavy precipitation in wet years can threaten dams and reservoirs that are at or near full capacity in the Delta's upstream watersheds, leading to emergency releases of water through spillways and bypasses.

A recent analysis conducted by the California Department of Water Resources (DWR)



(DWR, 2025b) evaluated the effects of climate change on watersheds in the San Joaquin Basin specifically, including potential changes to peak flows, flood events, and the effectiveness of management responses. The San Joaquin Basin is one of the highest flood risk regions in the nation and relies heavily on groundwater, making it uniquely vulnerable to both wet years and periods of drought. The analysis found that peak flows in the basin could increase by up to 400%, with large flood events becoming more common. **Figure 16** shows maximum projected flows by mid-century across the five San Joaquin Basin watersheds. Without adaptation, reservoir capacity is expected to be exceeded across all watersheds during a maximum flood event for 17 to 84 days per year. DWR evaluated two options for Forecast-Informed Reservoir Operations (FIRO) and Managed Aquifer Recharge (MAR) to improve reservoir retention, recharge groundwater, and reduce flood risk. Both strategies would mitigate flood risk and alleviate groundwater overdraft in the basin. See the “FIRO and Flood-MAR in the San Joaquin Basin” case study in the Water Supply Reliability section to learn more.

Figure 16. Flood Impacts in the San Joaquin Basin (DWR, 2025b)



Notes: Dashed lines denote channel capacity. Average 2050-TH = Average Future Climate Change 2050-time horizon; cfs = cubic feet per second.

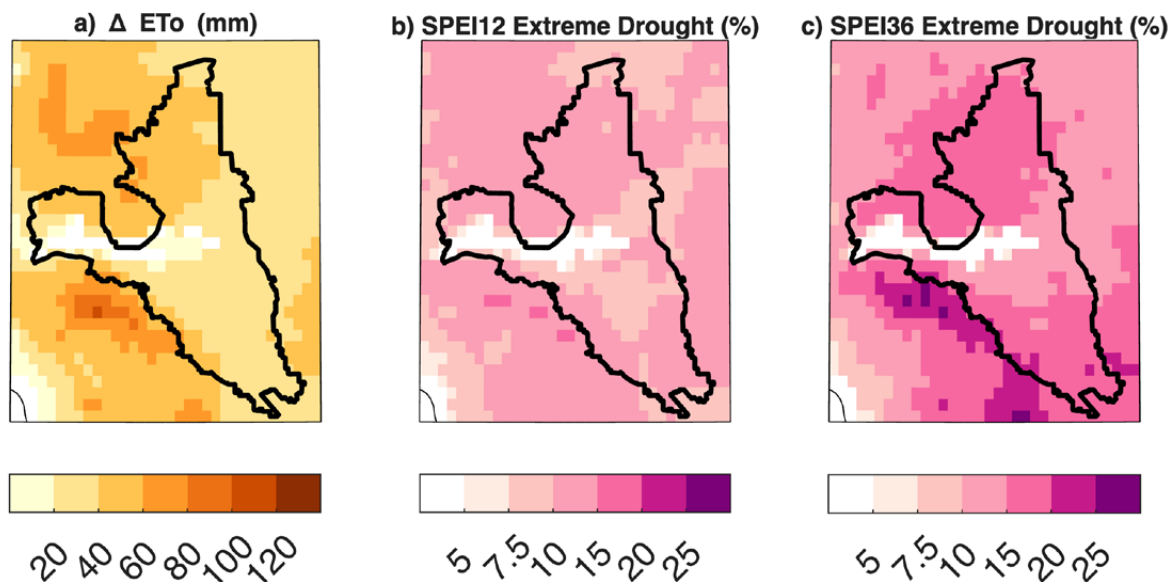
The 2021 Vulnerability Assessment analysis of future streamflow projections found that future peak inflow events in the Delta are projected to become increasingly concentrated in the core winter months—particularly in January and February when king tides typically occur (DSC, 2021a). Concentration of peak inflow events in this

time frame increases the likelihood that a major event could occur alongside a higher-than-normal astronomical tide, increasing in-Delta water levels and flood risk (DSC, 2021a).

Drought

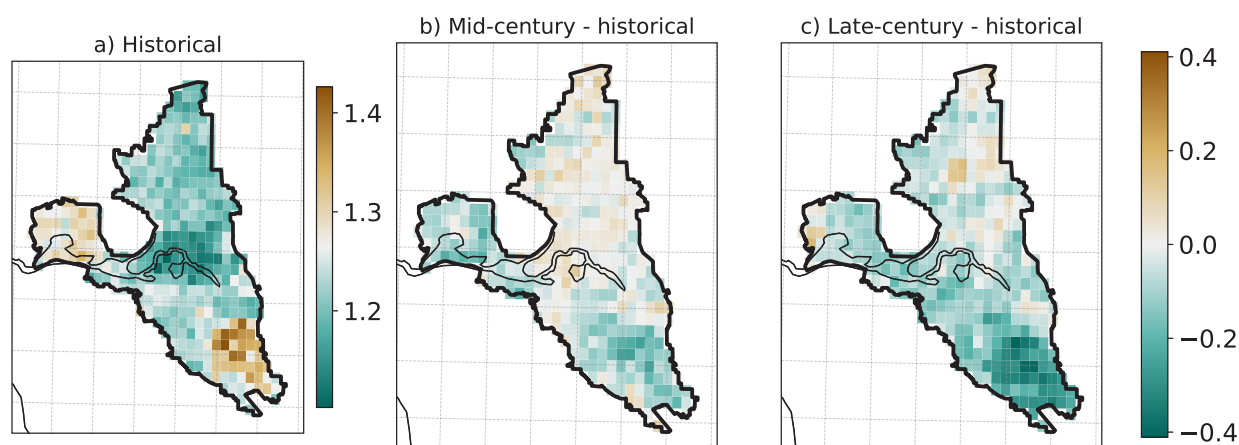
Climate model projections from the Fifth Assessment indicate that severe droughts will likely become more frequent in the future but may decrease in duration. **Figure 17** demonstrates that overall evaporative demand, or the loss of water from the Earth's surface, is projected to increase across the Delta by mid-century. The likelihood of extreme drought may also increase in the Delta region by mid-century, by 15 to 25% depending on the index used (see panels b and c of **Figure 17**). Updated projections provide a window into how the length of periods of drought may change. By mid-century, drought lengths could increase in the North Delta and decrease in the South Delta (see **Figure 18**). By the end of the century, projections across the Delta demonstrate an overall decrease in drought length (see **Figure 18**).

Figure 17. Change in Agricultural Drought Measures.



Multi-model average (a) change in annual evaporative demand (ETo) and the likelihood of extreme drought realized through the (b) 12-month Standardized Precipitation-Evapotranspiration Index (SPEI), and (d) 36-month SPEI for mid-century (2041-2070) as compared to the historical period (1981-2010). Projections are shown for a subset of GCMs downscaled for California using LOCA2 and the SSP2-4.5 scenario (Abatzoglou, 2025).

Figure 18. Projected Change in Duration of the Longest Drought (in Years).



Change in the duration of the longest drought at mid-century (2041-2070) and late century (2071-2100) as compared to the historical period (1981-2010) in units of years. A drought was defined as water year precipitation below the 10th percentile of the historical distribution. Projections are shown for GCMs downscaled for California using LOCA2 and the SSP 3-7.0 scenario (Stevenson, 2025).

In addition to the increased frequency of drought conditions, sea level rise will push saline (i.e., salty) water further into the Delta, degrading water quality. Saline water can affect regional water quality for Delta communities and lead to reduced and poorer quality Delta water exports. The DWR 2023 State Water Project Delivery Capability Report found that projected climate conditions are expected to reduce State Water Project export capability by approximately 13 to 22% by 2043 due to extreme hydrology, rising sea levels, and shifting precipitation patterns (DWR, 2024). The report highlights several statewide adaptation strategies, most notably the use of FIRO, as essential tools for maintaining water supply reliability under these conditions.

Sea Level Rise and Flooding

Sea Level Rise

As temperatures rise, the Earth's oceans are warming and expanding and ice on land is melting, causing sea levels to rise around the world. While this is a global phenomenon, regional rates of sea level rise will vary because of vertical land motion (e.g., land rising or falling), winds, and ocean circulation patterns. In the Delta, historical marshland was dredged and diked for agriculture. Agriculture, in turn, exposed what were once partially submerged peat soils to the air, triggering the natural process of microbial oxidation and ultimately leading to the loss of soil and subsidence of the land. As a result, most of the Delta now lies below sea level by as much as 20 feet (Deverel et al., 2020).



Levees managed by a mix of local, federal, and state entities protect land and communities below sea level from flooding and are critical to protecting water quality and supply. However, continued oxidation-driven subsidence and sea level rise can put additional pressure on levees, increasing the risk of levee failure, groundwater seepage, and flooding. Oxidation-driven subsidence contributes substantially to long-term land surface lowering across Delta islands, but its relevance to levee performance depends on proximity to the levee. Subsidence within approximately 400 to 500 feet of the landside toe can influence geotechnical stability and hydraulic loading (Hopf, 2011; DWR, 2016). Subsidence farther inland affects flood depth and associated consequences following a breach. Levee condition is a critical concern in the Delta especially in the face of these ongoing challenges as levee failures can lead to altered in-Delta flow dynamics and increased salinity and nutrient concentrations that affect water quality. Specifically, flooding of Delta islands would impact flows and nutrient loading that can lead to toxic algae blooms as well as cause salinity intrusion in the interior Delta, putting California's water supply at risk.

The 2021 Climate Change Vulnerability Assessment relied on State of California Sea Level Rise 2018 Guidance prepared by the Ocean Protection Council (OPC) to identify sea level rise scenarios for the San Francisco tide station. Projections from the San Francisco tide station were used to understand sea level rise heights at the mouth of the Delta; the OPC did not produce projections for tide gauges in the Delta. The assessment considered sea level rise scenarios for 2030, 2050, 2070, and 2100 under RCPs 8.5 and 4.5 and assuming a range of probabilistic projections of sea level rise based on rates of ice sheet loss and other physical processes (e.g., 50% probability of sea level rise meeting or exceeding a certain threshold). Since then, OPC has updated these projections, expressing a higher degree of certainty regarding how much sea level rise is expected by mid-century (OPC, 2024). Sea level rise projections from the State of California Sea Level Rise Guidance: 2024 Science and Policy Update are summarized below.

The OPC's updated sea level rise scenarios are defined using a target value of global average sea level rise at end of century (2100) generated from probabilistic projections created by the IPCC. The new scenarios are not associated with a specific RCP or other emissions pathway, rather they span the full, potential range of future sea level rise under all global futures. For example, the Low scenario is associated with one foot (0.3 meters) of global sea level rise by 2100, which assumes that the current rate of sea level rise will continue. At the other end of the spectrum, the High scenario is 6.6 feet (2.0 meters), which is only possible with high future emissions and warming, and rapid ice sheet loss, representing a "worst case" scenario. OPC recommends evaluating at least the Intermediate, Int-High, and High scenarios to inform sea level rise planning and project decisions (OPC, 2024). See Table 2 for a summary of OPC's 2024 sea level rise projections by year and scenario at the San Francisco tide station, including heights modeled in a flood hazard mapping exercise



conducted by the Council for the 2021 Vulnerability Assessment.⁷

Table 2. Median Values (in Feet) of 2024 Sea Level Rise Scenarios for San Francisco.

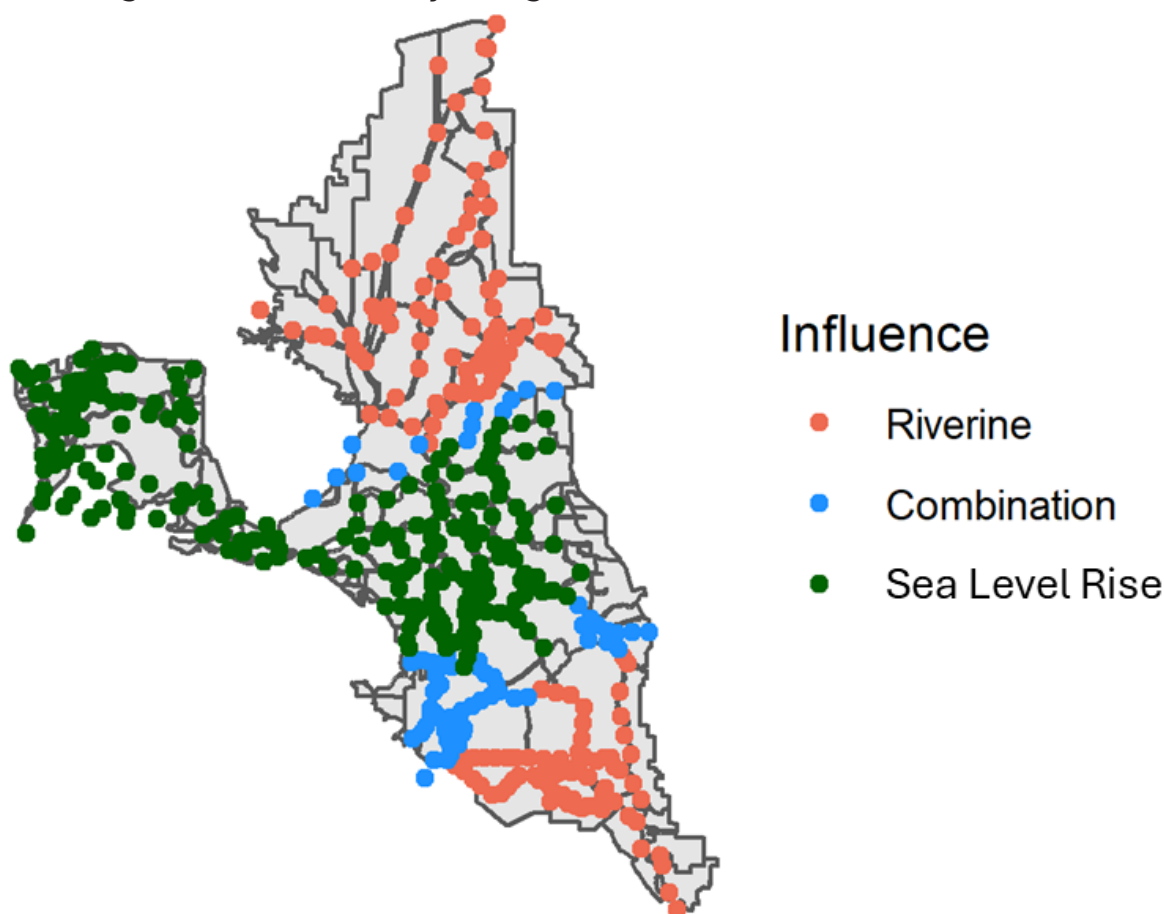
Year	Low	Int-Low	Intermediate	Int-High	High
2020	0.2	0.2	0.2	0.3	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.3
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	2.9
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.8	5.3
2100	1.0	1.6	3.1	4.8	6.5

Bolded values indicate those that were modeled in Delta Adapts flood hazard mapping. Localized sea level rise values account for local vertical land movement at the San Francisco tide station.

Sea level rise and stream flows will both affect Delta flood risk by increasing peak water levels, but their influence will vary geographically. The effect of sea level and tidal fluctuations decreases further inland in the Delta (Baranes et al., 2023). Peak water level changes in the western and Central Delta are expected to be driven primarily by sea level rise, whereas peak water level changes in the North and South Delta will be driven mainly by changes in riverine inflows (see **Figure 19**) (DSC, 2021a).

⁷ The Council's flood hazard mapping considered 0, 0.5, 1.0, 2.0, and 3.5 feet of sea level rise. 0.5 and 1.0 feet are projected by mid- to late-century in the Low and Int-Low OPC scenarios. The analysis considered at least one corresponding sea level rise height by mid-century for each of the recommended OPC scenarios (Int, Int-High, and High). The flood hazard assessment also looked at a 3.5-foot option, which does not have a corresponding OPC scenario and year, but would be surpassed by the end of the century under the Int-High and High scenarios.

Figure 19. Dominant Hydrologic Influence on Peak Water Levels



Flood Hazard Mapping

Both coastal and riverine flood hazards were analyzed by the Council to estimate peak water levels projected to occur through the end of the century. These water levels were used to map potential flood extents in the Delta in the years 2030, 2050, and 2085 under a range of sea level rise heights. Each scenario assessed the combined impacts of sea level rise and changes in the Delta's upstream watershed hydrology to model the likelihood of water levels overtopping levees throughout the Delta during a 100-year storm event, assuming levee heights remain the same and do not fail (e.g., no seepage or erosion).

The 2021 Vulnerability Assessment generated flood hazard scenarios using a specific amount of sea level rise, from 0 to 3.5 feet, and a range of Delta water inflow possibilities developed using GCM projections from the Fourth Assessment (see Table 3 for a summary of inputs used to develop each scenario).



Table 3. Summary of Scenarios Used for Flood Hazard Analysis and Mapping

Time Period	Sea Level Rise (feet)	Watershed Hydrology	Storm Event
Historical	0	Historical	100-year water level
2030	0.5	Historical	100-year water level
2050	1.0	Mid-century (2035-2064) RCP 8.5	100-year water level
2050	2.0	Mid-century (2035-2064) RCP 8.5	100-year water level
2085	3.5	End-of-century (2070-2099) RCP 8.5	100-year water level

See **Figure 20** and **Figure 21** for projected flood hazard exposure under one and two feet of sea level rise and a 100-year storm. **Figure 20** shows modeled flood extents under one foot of sea level rise, equivalent to projected sea level rise by 2100 under OPC's Low scenario, by 2070 under the Int-Low scenario, and by approximately 2060 in the Intermediate scenario (OPC, 2024). **Figure 21** shows modeled flood extents under two feet of sea level rise, or the projected sea level rise height by 2060 under the High scenario (OPC, 2024). Both figures incorporate streamflow data from GCM data downscaled in California's Fourth Assessment and have not been updated with Fifth Assessment data.⁸ Areas designated as "mitigable with flood fighting" could flood from water levels of less than six inches, indicating some flood management activities can be taken to reduce the risk of flooding. Areas shown as having "High sensitivity to SJR (San Joaquin River) inflow assumptions" are especially sensitive to overbank flows and floodplain storage along the San Joaquin River as it enters the Delta.

⁸ For more information on the 2021 Vulnerability Assessment flood hazard assessment, see the [Delta Adapts Flood Hazard Assessment Technical Memorandum](#). Flood hazard extents modeled for the 2021 Vulnerability Assessment can also be viewed on an online platform, [here](#).



Figure 20. Flood Hazard Mapping for One Foot of Sea Level Rise in the Delta with a 100-Year Storm Event (OPC 2024 Int-High by 2050)

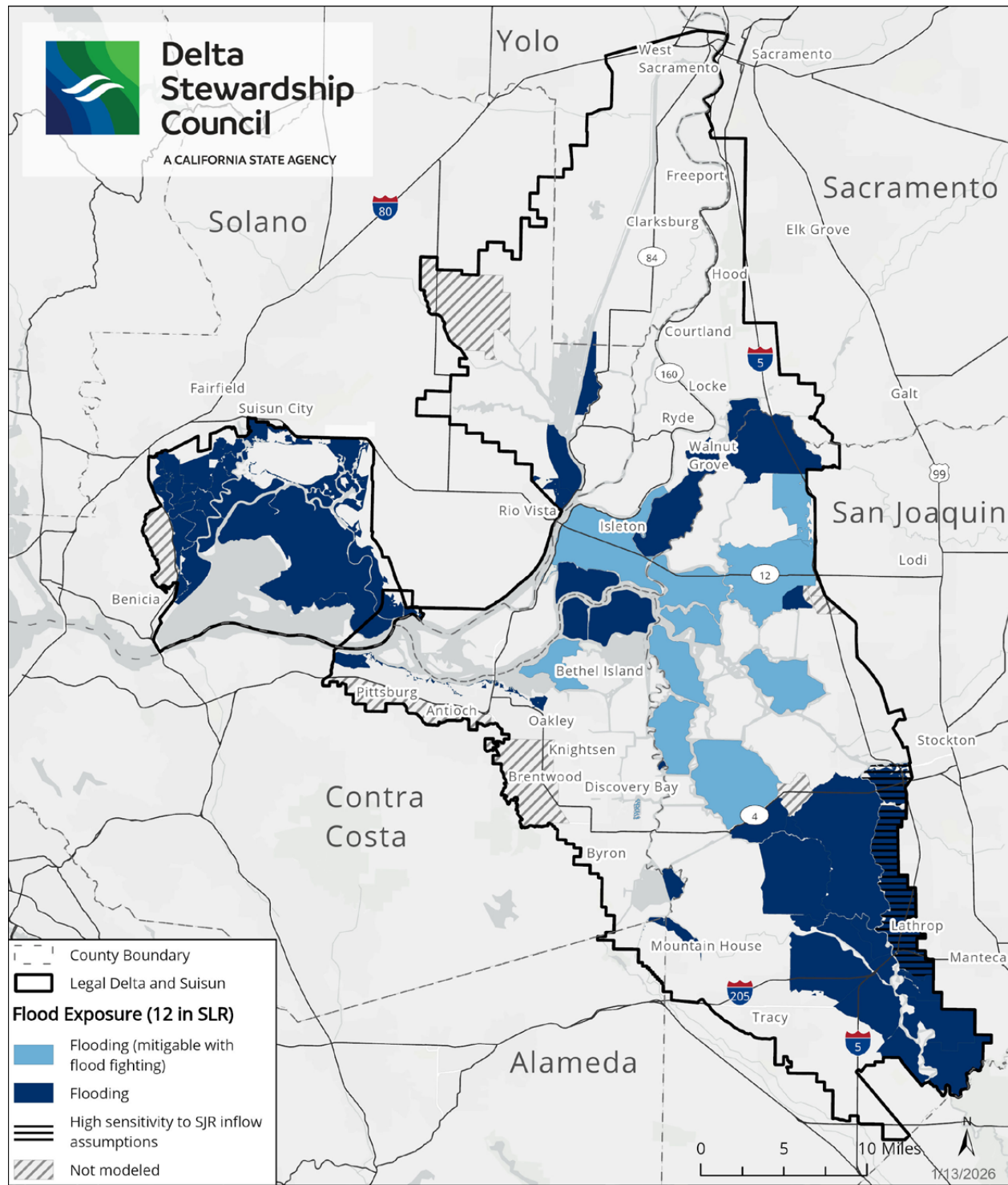
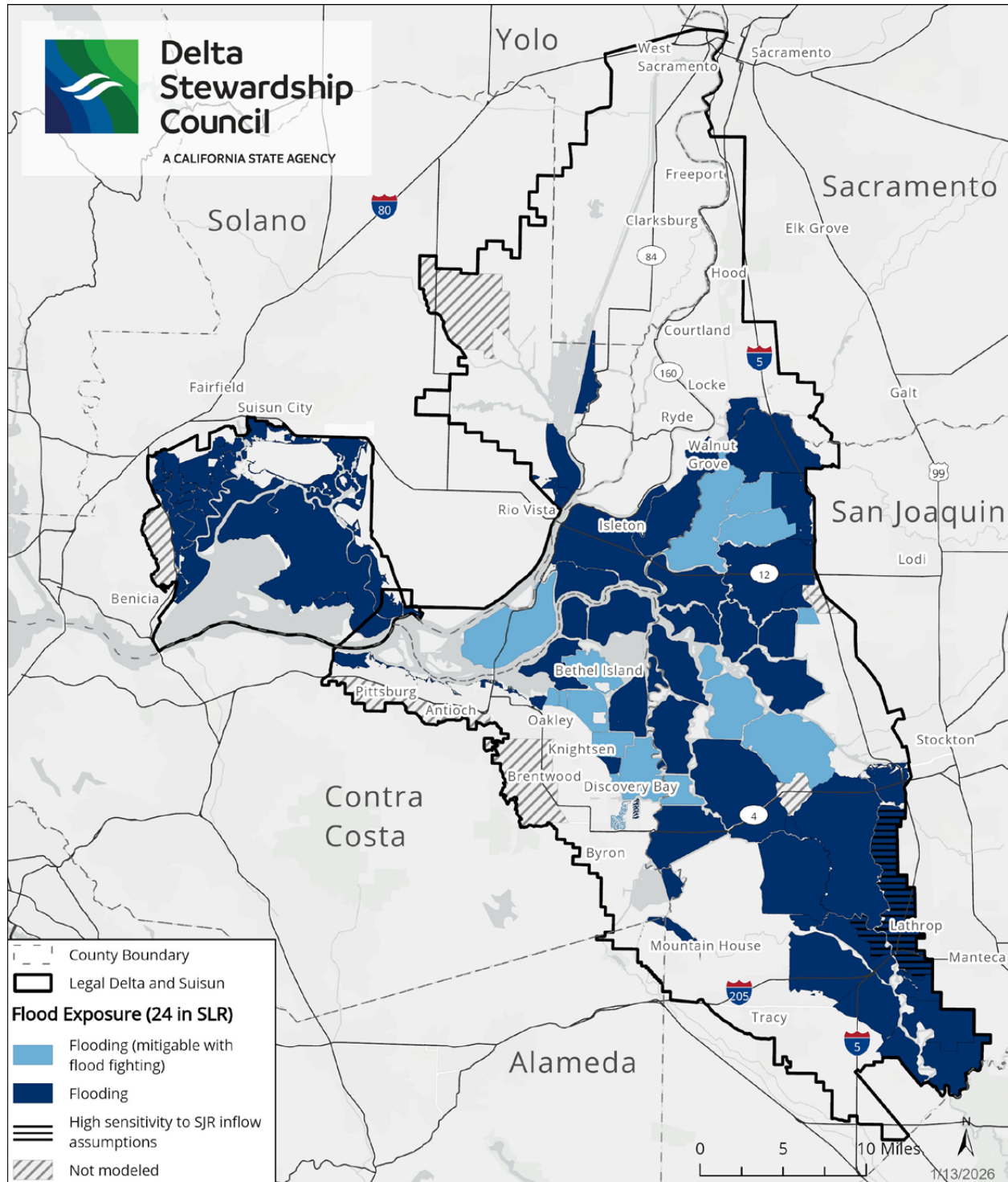




Figure 21. Flood Hazard Mapping for Two Feet of Sea Level Rise in the Delta with a 100-Year Storm Event (OPC 2024 High by 2060)





Vertical Land Motion and Relative Sea Level Rise

Water levels across the Sacramento–San Joaquin Delta are heavily influenced by coastal conditions and river flows, but these are not the only factors that control water level variability in the Delta. Over longer time scales, sea level rise at the coast raises the baseline from which these influences act, leading to higher overall water levels in the Delta. Water levels in deltas and rivers are affected by coastal water level trends and variability, river flow changes, spatially varying vertical land motion, human modifications (e.g., dredging, structures), astronomical tidal variability, tidal evolution, and the interaction between river flow and tides (Baranes et al., 2023).

In the Delta, relative sea level rise is strongly influenced by vertical land motion from subsidence, which is occurring at rates of 3 to 20 millimeters per year (mm/yr), or 0.1 to 0.8 inches per year (in/yr), depending on location (Baranes et al., 2023). Across most of the Delta, relative sea level rise is exceeding the rate of sea level rise observed at San Francisco and along the California coast due to vertical land motion (Baranes et al., 2023). These findings are reinforced by historical records evaluating long-term water-level trends in the Delta. Relative rates of sea level rise vary greatly and are location-dependent across the Delta, ranging from -0.1 to 0.5 in/yr (-2.8 to 12.9 mm/yr) (Baranes et al., 2023).

It is important to note that the subsidence affecting vertical land motion and relative sea level rise in the Delta is caused by different mechanisms than the oxidation-driven soil loss that is prevalent across Delta islands due to exposure of peat soils to air. Because tide gauges are mounted on piers or alluvial levees, not on peat soils, the oxidation process does not directly affect their elevation. Instead, the land motion observed at tide-gauge locations reflects deeper and broader geologic processes, such as consolidation of underlying sediments due to groundwater level changes, tectonic or glacial isostatic adjustments, and localized deep subsidence associated with historical natural gas extraction (Baranes et al., 2023). Recent analysis (Baranes et al., 2023) found that these tide-gauge-derived vertical land motion rates in the Central and South Delta have a median value of approximately 0.1 in/yr (or 2.5 mm/yr), as compared to oxidation-driven island interior subsidence of about 0.1 to 0.8 in/yr (or 3 to 20 mm/yr).

Understanding this dual nature of Delta subsidence is critical for managing flood risk, as spatially variable vertical land motion interacts with sea level rise projections. Relying solely on projections from San Francisco or another Bay tide station can underestimate true sea level rise in the Delta and overlook local variability. When planning projects or designing assets in the Delta, it is critical to incorporate spatial variability rather than depending on a single tide gauge. Increasing average and extreme water levels in the Delta can lead to greater levee seepage, higher overtopping likelihood, and increased risk of levee failure (Baranes et al., 2023).



Wildfire

Wildfires were a focus of the 2025 State of Bay-Delta Science, the Delta ISB's 2025 Emerging Climate Science Symposium, and the State of the Estuary Conference in October 2025. Wildfire frequency and severity across the State of California are expected to increase in the future because of increased temperatures and arid conditions (Williams et al., 2019), more frequent and severe droughts, and changing precipitation. Mega-fires, defined as burning areas greater than 10,000 hectares (or larger than 25,000 acres), are becoming increasingly large, frequent, and severe in California (Dahm et al., 2025). According to Dahm et al. (2025), the eight largest wildfires in California in recorded history occurred between 2018 and 2024, and each was at least partially within the Delta's upstream watersheds (Dahm et al., 2025). For example, the August Complex Fire was the largest fire to date (418,000 hectares) and occurred in 2020 when ~4% of the state's land burned.

Significant water quality impairments, such as loss of dissolved oxygen, can occur when storms mobilize debris avalanches from burn scar materials in tributaries in the upper watershed (Curtis et al., 2025; Dahm et al., 2025). Because ~80% of the state's drinking water supply passes through reservoirs, and little is known about the contamination of reservoirs that capture debris avalanches, post-fire water quality monitoring is a priority area of research and investment (Dahm et al., 2025). Within the legal Delta, wildfires are often used as a beneficial management tool to encourage tidal wetland plant growth (Hankins, 2025). However, peat fires that smolder for long periods of time (especially during a severe drought) can lead to peat collapse, fundamentally altering wetland ecosystem health (Jones et al., 2022).

Management efforts are focused on reducing the risk of harmful fires while promoting beneficial fires, requiring improved tools for planning, prediction, and detection. As highlighted by Dr. Carrie Levine (Spatial Informatics Group) at the Delta ISB's Climate Symposium, several tools and initiatives are currently being used or developed to address wildfire risk and resilience, including (1) PyreCast (near-term wildfire risk and behavior forecasting tool), (2) Planscape (linking multiple open source models to optimize fuel treatment impacts on wildfire behavior), and (3) AI Collaborative: Wildfire (a strategic initiative by Google to coordinate artificial intelligence (AI) collaborators to address the wildfire problem space) (Delta ISB, 2025a).

Based upon the 2021 Vulnerability Assessment, wildfire risk is not anticipated to greatly increase within the legal Delta boundary (DSC, 2021a). However, wildfires around the state can affect residents of the Delta through poor air quality from smoke. Since 2018, the state has experienced a surge in wildfire activity and impacts driven by compounding factors including extreme fire weather, dry and abundant fuels, and wind direction (LCI, 2026). Vegetation is drying out and fire seasons are getting longer as temperatures rise and the state experiences decreased summer precipitation, and



these trends are expected to continue (LCI, 2026). For more information on statewide wildfire trends and changes in climate and extreme fire weather on wildfire risk, see the California Fifth Climate Change Assessment Statewide Summary Appendix on climate change and wildfires in California (LCI, 2026).

Social Vulnerability

Climate change will affect communities in the Delta differently depending on location, susceptibility, and ability to adapt, with some being disproportionately vulnerable to climate hazards. Vulnerability, as defined by the IPCC, is: “The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2023). Considering the disproportionate impacts to certain Delta communities based on their susceptibility to harm and adaptive capacity was an important component of the 2021 Vulnerability Assessment, and the Delta Adapts initiative overall. Understanding inequities in how communities experience climate change is also important to protecting the Delta as an evolving place where people live and work.

The Integrated Climate Adaptation and Resiliency Program defines vulnerable communities as those who “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, ethnicity, class, gender, sexual orientation, national origin, income inequality, and disability. People facing multiple forms of marginalization and inequality will confront more intense climate change impacts and barriers to recovery” (LCI, 2025).

These factors and others influence community vulnerability to climate change for a variety of reasons. Climate change disproportionately affects low-income communities of color due to a lack of representation in political decisions that affect them, less financial stability to respond to impacts, and the compounding impacts of climate hazards on top of existing stresses (U.S. EPA, 2021).⁹

Vulnerable Communities in the Delta

To identify vulnerable populations in the Delta, the Council developed a weighted vulnerability index in 2021 used to combine multiple indicators into one vulnerability score per community. This **Social Vulnerability Index (SoVI)** was developed using

⁹ See the Council’s Tribal and Environmental Justice Issue Paper to learn more about how environmental hazards, and climate change in particular, negatively affect certain communities, including but not limited to Tribes, low-income communities, and communities of color in the Delta (DSC, 2025).

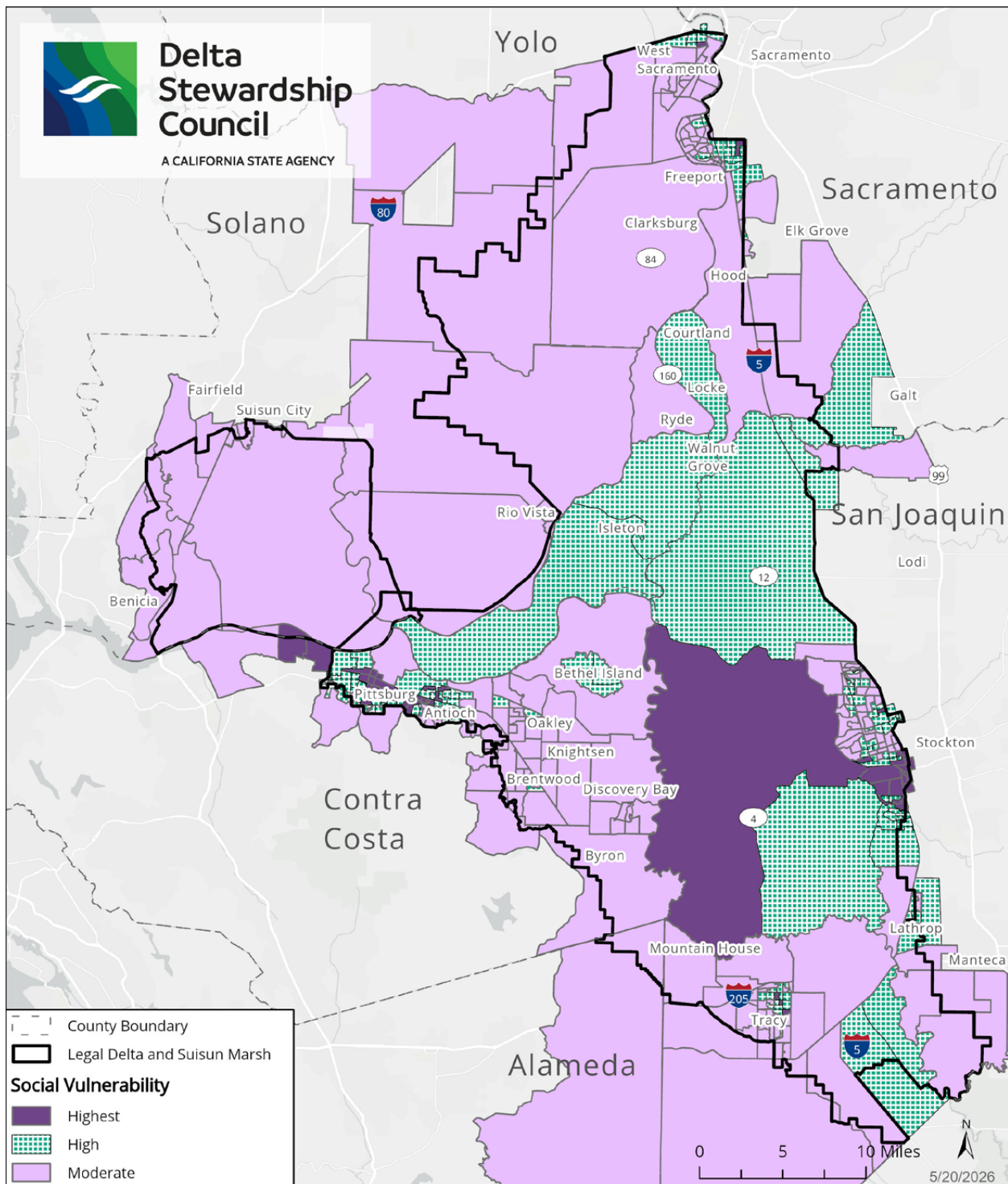


a combination of socioeconomic characteristics that are correlated to negative outcomes in the event of flooding, extreme heat, and wildfire. These indicators were identified through a review of more than 40 similar frameworks and interviews with community leaders (DSC, 2021b). A weighting scheme was used to combine the various indicators into a single score. To conduct the weighted analysis, an individual block group or tract was assigned a score based on the number of indicators for which the community is in the 70th percentile or higher. See the [Delta Adapts Equity Technical Memorandum](#) for the full list of indicators and a complete description of methodology, including how socioeconomic factors were selected, how they influence vulnerability to flooding, heat, and wildfire, and the weighting scheme.

Communities that scored the highest in the SoVI are in Stockton, Antioch, Pittsburg, West Sacramento, Sacramento, and Tracy. Each of these communities scored above the 70th percentile on at least seven social vulnerability indicators. Other rural communities scored very highly as well, with six indicators above the 70th percentile, including Ryde, portions of Walnut Grove, and large unincorporated areas in San Joaquin County. **Figure 22** shows the results of the weighted scoring analysis, with block groups organized into three categories: moderate, high, and highest social vulnerability. Moderate areas had zero to three indicators above the 70th percentile, high block groups had four to seven, and the highest scoring block groups had eight to 11 (DSC, 2021b).



Figure 22. Social Vulnerability Ratings for Communities in the Delta



Council staff use the SoVI to prioritize socially vulnerable communities in outreach and engagement, the Delta Levees Investment Strategy (a risk-based prioritization



strategy for levee investments in the Delta), and when considering projects for funding through the Delta Research Awards. Moving forward, Council staff anticipate using the recently released Governor's Office of Land Use and Climate Innovation **Vulnerable Communities Platform**, which integrates social vulnerability and physical vulnerability to extreme heat, drought, sea level rise, and flooding, as the best available information for understanding social vulnerability to climate change in the Delta.¹⁰

This work emphasizes that in addition to physical infrastructure, social infrastructure is an important part of climate adaptation and community resilience specifically. Hatch et al. (2026) recommend complementing investments in physical infrastructure with investments in social infrastructure, such as boosting social connectedness, supporting cultural knowledge, and investing in the humanities.

Climate Vulnerabilities

This section summarizes how changing climate stressors and hazards affect the Delta's people, places, ecosystems, agriculture, recreation, and infrastructure.

Flooding and levee vulnerability are major threats to the Delta

Flood risk is one of the most pressing threats to the Delta today, due in part to ongoing oxidation-driven subsidence resulting in land elevation as deep as 20 feet below sea level. This risk will continue to grow in the future as sea levels rise and the Delta experiences more frequent and larger inflows from storm events. At current water levels, a 100-year storm or seismic event has the potential to damage or overtop Delta levees and cause significant flooding and saltwater intrusion, potentially affecting 9,000 Delta residents and 41,000 acres of Delta agricultural lands, and interrupting California's centralized water supply (Mount and Twiss, 2005; DSC, 2021a). Assuming levees remain at current heights, under one foot of sea level rise and a 100-year storm, approximately 33% of land, dozens of historical sites and critical facilities, over 55 solid waste, contaminated, or hazardous waste sites, miles of trails and scenic highways, and 148,000 acres of agriculture could be exposed to flooding in the Delta from levee overtopping. Flooding of these assets could total more than \$10 billion in exposed agricultural, residential, commercial, and infrastructure assets and nearly \$2 billion in economic activity (DSC, 2021a).

In addition to affecting communities, ecosystems, agriculture, and infrastructure, flooding can limit access to recreational opportunities, including parks, trails, and campsites. Furthermore, the loss of soil from oxidation-driven subsidence could contribute to the seepage of groundwater up through peat soils, which is detrimental

¹⁰ See the **Delta Adapts Equity Technical Memorandum** for more information on social vulnerability to climate change. SoVI results can also be viewed in a virtual web platform here: https://deltascience.shinyapps.io/Delta_vulnerability_map/



to farming operations and especially concerning if this were to occur at solid and hazardous waste sites. Mobilized toxic substances and trash from flood waters, whether from levee overtopping or seepage, could affect water quality and pose risks to public health and safety (DSC, 2021a).

Sea level rise and subsidence also have implications for levee integrity. Increasing water levels in the Delta can lead to greater levee seepage, higher overtopping likelihood, and increased risk of levee failure (Baranes et al., 2023). Levee design standards, such as the Public Law 84-99 standard requiring a minimum of 1.5 feet of freeboard above the 100-year flood stage, are rapidly being compromised by subsidence. And subsidence driven by oxidation can affect levee stability when it occurs within 400 to 500 feet of the levee base (Hopf, 2011; DWR, 2016).

Seismic Hazard and Delta Levee Vulnerability: Current Understanding

Early assessments of Delta seismic risk, including Mount and Twiss (2005), played an important role in elevating concern about the potential for widespread levee failure during an earthquake. Their analysis warned that a large Bay Area earthquake could trigger multiple simultaneous levee breaches leading to rapid island flooding, disruption of water exports, and major economic and ecological consequences. These early findings were intentionally conservative, and they are best interpreted as foundational, preliminary estimates.

The Delta Risk Management Strategy (DRMS, 2007–2009) provided the first comprehensive, systemwide evaluation of seismic risk to Delta levees (Delta ISB, 2016). DRMS concluded that earthquakes represented the most significant single hazard to Delta levee integrity (Delta ISB, 2016), estimating high 25-year probabilities of failure (53% to over 84%) across many deeply subsided central and western islands (Deverel et al., 2014). A 2016 Delta ISB workshop highlighted substantial uncertainties in the DRMS hazard calculations, particularly the ground motions assumed for large, distant Bay Area earthquakes. Despite finding that DRMS shaking intensity was overstated, the ISB reaffirmed that liquefaction of nonengineered levees remains the most likely mode of seismically induced failure.

Research conducted after the ISB workshop has further refined the understanding of Delta seismic risk (Brandenberg et al., 2022; Delta ISB, 2016). These studies generally find more rapid dissipation of ground motions into the interior Delta than previously assumed (Delta ISB, 2016). At the same time, post-2016 analyses underscore that seismic vulnerability remains strongly dependent on local geotechnical conditions, levee material variability, and liquefaction susceptibility (Brandenberg et al., 2022). As a result, while updated hazard models provide a more refined and, in some cases, lower estimate of seismic loading (Liu, 2024), the primary determinants of failure potential continue to lie in the engineering properties of individual levees and islands (Brandenberg et al., 2022).



Certain Delta communities will be disproportionately affected by climate change

While climate change affects everyone, it does not impact everyone equally. Highly socially vulnerable communities often live in harm's way and may lack adequate resources to respond to climate-related impacts. For example, families and individuals who are linguistically isolated may not be able to understand and respond to emergency notifications. Households without vehicles or older adults living alone will have a more difficult time evacuating in the event of a flood. In the Delta, the most socially vulnerable communities include Stockton, Antioch, Pittsburg, West Sacramento, Sacramento, Tracy, and unincorporated areas of San Joaquin County (DSC, 2021b). Flooding and extreme heat present the greatest threats to these communities (DSC, 2021a).

About 66,000 or 10% of people in the Delta could be affected by flooding from a 100-year storm under one foot of sea level rise, most of which (65%) live in socially vulnerable communities primarily in San Joaquin County (DSC, 2021a). Under 3.5 feet of sea level rise, the number of people exposed to flooding rises to 133,000, about half of which are in socially vulnerable neighborhoods (DSC, 2021a).

Certain populations are more vulnerable to illness (heat exhaustion or stroke) from extreme heat due to direct exposure and physical susceptibility, including outdoor workers, older adults, young children, people experiencing homelessness, people with existing health conditions (e.g., asthma), and incarcerated people. Delta communities with higher rates of characteristics tied to disproportionate heat vulnerability live in Antioch, Pittsburg, Stockton, Tracy, West Sacramento, and unincorporated San Joaquin County (DSC, 2021a). The urban areas of Stockton and Tracy will experience greater warming than surrounding areas due to the urban heat island effect (DSC, 2021a). In addition, rising air temperatures combined with smoke from wildfires can affect air quality and disproportionately affect socially vulnerable communities in the Delta, who have higher instances of health disparities (DSC, 2021a; Stone et al., 2019).

Water quality may decline for Delta communities and water exports will be less reliable

Higher temperatures, changing precipitation and runoff patterns, and sea level rise make maintaining Delta water quality and exports more challenging. Modeling conducted for the 2021 Vulnerability Assessment found that current water quality regulations can be maintained with up to two feet of sea level rise, but higher sea level rise coupled with low inflow conditions from drought may allow salinity intrusion into the Delta (DSC, 2021a). The most affected Delta communities will be those with small water systems or private wells (DSC, 2021a). These water sources are the most likely to experience degraded water quality because they lack the same oversight



as larger, public water utilities (Feinstein et al., 2017). Delta communities already experience poor drinking water quality, with eight drinking water systems failing Human Right to Water standards and 20 systems at risk of failing (out of 82 systems assessed) as of December 2025 (SWRCB, 2025). Out-of-Delta water users who rely on Delta exports will also be affected by poorer water quality. And, droughts can affect water affordability for all users, as water usage declines and water suppliers increase rates to make up for lost revenue (Feinstein et al., 2017). Droughts can also have major impacts on farmers and agriculture, leading to lost income and jobs (Michael et al., 2010; Greene, 2018). Finally, drought conditions contribute to the occurrence of cyanobacterial harmful algal blooms (CHABs).

CHABs have been a recurring nuisance in the Delta over recent decades, affecting water quality, ecosystem function, and public health in numerous ways (Preece et al., 2024). Water quality impairment due to cyanotoxin contamination is of particular concern. Delta CHABs are frequently dominated by *Microcystis* (Preece et al., 2024), a genus of cyanobacteria that produces the potent hepatotoxin microcystin (Harke et al., 2016), which affects humans, pets, livestock, fish, and wildlife (McLellan & Manderville, 2017). Potential human exposure pathways include drinking water, irrigation water, recreational and subsistence fishing, water contact recreation, and even inhalation via microcystin aerosolization (Kudela et al., 2023). The main environmental drivers of Delta CHABs are residence time, water column stratification, water temperature, irradiance, salinity, and nutrient concentrations (Kudela et al., 2023). Climate change is expected to intensify many of these drivers. For example, rising air temperatures will warm surface waters, providing a competitive advantage to cyanobacteria versus other phytoplankton and extending the bloom season (Visser et al., 2016). More frequent droughts and reduced flows will likely increase water temperatures, increase residence time, and reduce vertical mixing, again to the advantage of cyanobacteria (Visser et al., 2016). And while extremely wet years do retard CHAB activity, they do not necessarily suppress it entirely (Lehman et al., 2022; Bouma-Gregson et al., 2024). Indeed, episodic high-flow pulses of nutrients into the system followed by prolonged drought and increasing temperatures could create conditions that are particularly favorable for CHABs (Paerl, 2018). Finally, rising temperatures are likely to alter CHAB composition and might increase their toxicity (Visser et al., 2016), while the distribution of different bloom-forming phytoplankton could change in response to salinity gradient changes (Kudela et al., 2023). Overall, without effective management and mitigation strategies, drought-related climate change impacts are likely to cause more frequent, more severe, and longer-lasting CHABs in the Delta.

In addition to water quality impacts in the Delta, climate change will reduce upstream reservoir storage and exports as more precipitation falls as rain instead of snow, running off in winter months when reservoirs are too full to store it (DSC, 2021c). If this happens, less water can be carried over from one year to the next, which is



an important backstop to California's water supply in times of drought. The current water supply system in California offers little flexibility to capture runoff in wet years, intensifying stress on the water supply in dry years.

Delta ecosystems are compromised and lack resilience to climate change

Today, most of the Delta's once extensive natural wetlands are gone. Approximately 95% of the Delta's historical wetlands have been converted to agricultural land over the past two centuries, and remaining natural wetlands are fragmented (DSC, 2021a). This loss of natural wetlands has reduced the Delta's capacity to absorb flood waters, filter water pollutants, and sequester carbon, among other ecosystem services (DSC, 2025b; Vaughn et al., 2024). Though some types of agricultural land can provide supplementary habitat for certain species, generally the conversion of natural lands leaves less room for aquatic and terrestrial habitats and species to migrate, making them more susceptible to a changing climate. Impacts on wetland habitats also affect recreational opportunities such as fishing, hunting, and bird watching.

The Delta Adapts Vulnerability Assessment (DSC, 2021a) found that approximately half of ecosystems protected by levees will be exposed to flooding by mid-century. With 3.5 feet of sea level rise by late century, un-leveed, or tidally influenced, wetland ecosystems will be at risk of transitioning to low marsh. Under the more extreme end-of-century scenario (6 feet of sea level rise by 2100), all tidal wetlands are at risk of drowning. If sea level rise increases salinity in the system, tidal wetland ecosystems may be subject to changes in plant community composition that would further compromise their ability to keep pace with sea level rise.

Wetlands that cannot keep up with the pace of sea level rise and are submerged will provide limited habitat for wetland species, such as the endangered Salt Marsh Harvest Mouse, and not produce the full range of ecosystem services, such as flood mitigation and carbon sequestration, that wetlands are known to provide. In addition, high water storm and king tide events are likely to impact resident species, particularly where upland transition zones and high tide refugia are not available. Planning and rapidly implementing restoration projects with substantial connections to upland transition zones is critical for creating multi-benefit tidal wetland investments that will persist past 2100. However, upland transition zones are rare in the Delta. Restoring tidal wetlands with upland transition zones as soon as possible will allow species to maintain their habitat elevation through natural processes and reduce the risk of loss. Areas with appropriate elevations to support tidal wetlands vary sub-regionally within the Delta and are more common in the northern part of the Delta and along the eastern edges.

In addition to flood impacts, rising temperatures and more frequent extreme heat



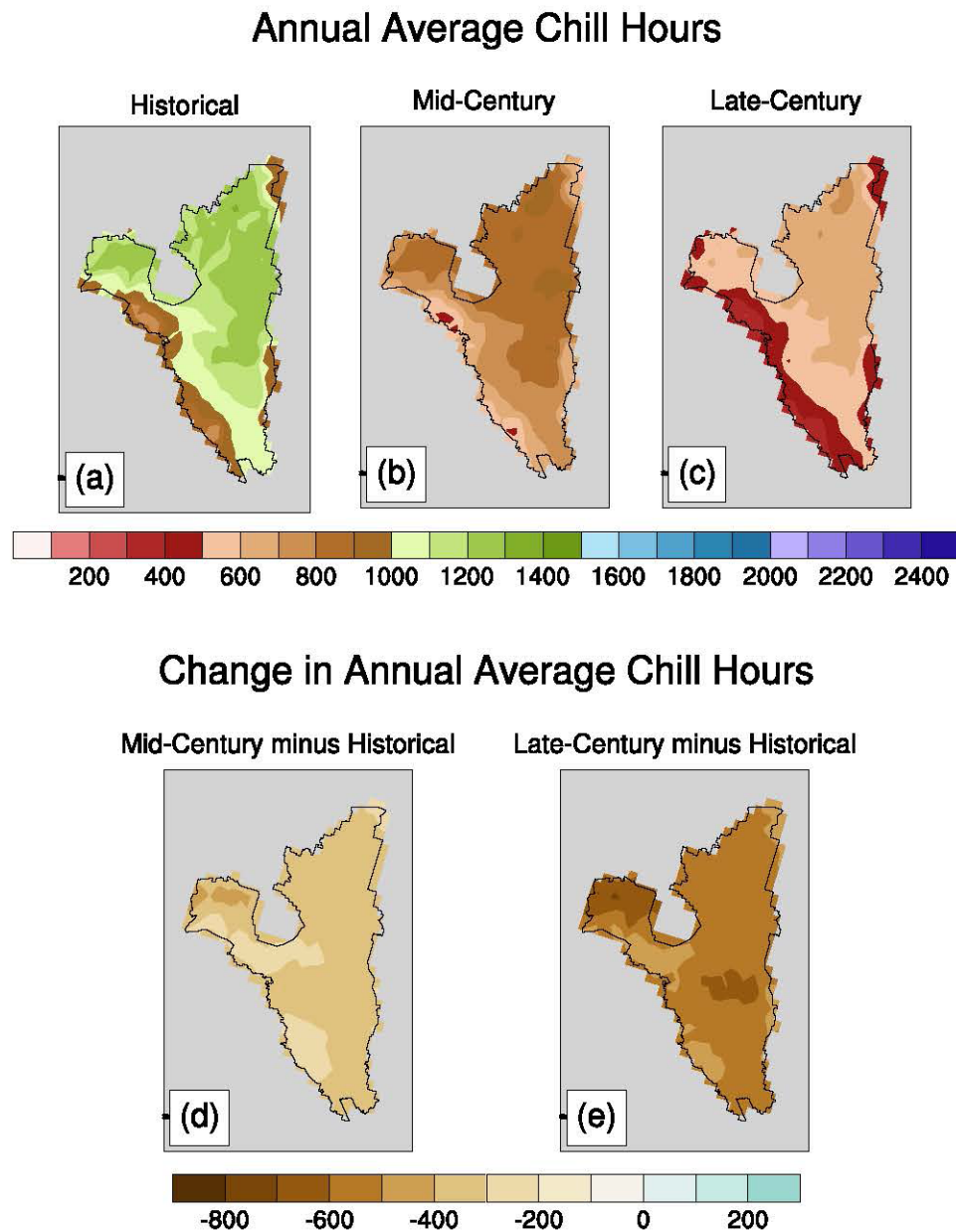
events can further stress plants and animals in the Delta. Impacts are expected to be seen at all levels of the aquatic ecosystem including aquatic plants, phytoplankton, zooplankton, and fishes (Mahardja et al., 2025). This is especially the case for sensitive fish species which require cooler water temperatures for survival. For example, the spawning season of Delta smelt appears to coincide with water temperature, with spawning success decreasing in water temperatures over 20°C, or 68°F (Damon et al., 2017). As water temperatures rise, Delta smelt and other sensitive fish species can have their reproductive seasons shortened and experience altered ecosystem interactions including increased competition, parasitism, and disease (Mahardja et al., 2025). Warmer waters and droughts can also affect freshwater availability, especially for floodplain ecosystems, and increase the presence of CHABs. Restoration projects in the Delta will be critical to improving “ecological function, structure, identity, and process, producing robust multi-benefit outcomes” and driving California’s climate resilience and carbon neutrality goals (DSC, 2021a).

Climate change will have variable effects on Delta crops, but generally will lead to reduced yields

Projected impacts to crops from climate change are from heat stress, drought, flooding, sea level rise, and poor water quality. While warmer temperatures may end up increasing yields for some crops, like alfalfa, melons, and citrus, most crop yields are expected to decrease (DSC, 2021a). Almonds, asparagus, carrots, and cucurbits (e.g., melons, pumpkins, squashes, cucumbers) are all expected to experience a 10 to 20% decrease in yields due to warmer temperatures (Medellín-Azuara et al., 2018; Lobell and Field, 2011; Pathak et al., 2018). Other crops that will be negatively affected by rising temperatures include corn, almonds, stone fruit, and cherries (DSC, 2021a). Higher minimum temperatures and early heat waves may also decrease rice yields (DSC, 2021d).

One of the reasons for decreased yields for certain crops is the loss of chill hours, or the total number of winter hours where temperatures are between 32 and 45°F (OEHHA, 2023). Fruit and nut trees require a certain number of chill hours for the trees to bloom at the right time of year (OEHHA, 2023). Based on Fifth Assessment data, chill hours are projected to decrease across the Delta, with some of the greatest decreases occurring in Suisun Marsh and the Central Delta (see **Figure 23**).

Figure 23. Average Annual and Projected Change in Average Annual Chill Hours.



Top: Average annual chill hours for the mid-century (2041-2070), late century (2071-2100), and historical periods (1981-2010). Bottom: Change in average annual chill hours as compared to the historical period. Projections are shown for GCMs downscaled for California using LOCA2 and SSP3-7.0 (Ullrich, 2025).



Farmer Interviews

Through meetings and interviews held in 2022, the Delta Stewardship Council heard directly from farmers about their concerns related to environmental changes, including climate change. Farmers reported their common struggles to track regulatory and market changes, hire staff amidst labor shortages, purchase expensive equipment, and maintain levees that the Delta relies on. On top of these daily challenges, farmers expressed that they are concerned about additional pressure from climate change, including increasing salinity exacerbated by droughts, rising temperatures, flooding, and more invasive species.

Flooding from precipitation runoff and sea level rise will threaten agricultural lands in the Delta from levee overtopping or seepage. Under current conditions, 41,000 acres of land could flood from levee overtopping during a 100-year storm. With one foot of sea level rise, this number could grow to 148,000 acres, and with 3.5 feet, 257,000 acres (or 62% of all agricultural lands in the Delta) (DSC, 2021a). In addition to flood risk, sea level rise can contribute to higher salinity in Delta waters, affecting farming operations already grappling with soil salinity.

Despite these challenges, the Delta could end up being a refuge for agriculture when compared to other parts of the state, which will get even hotter, such as the Central Valley (DSC, 2021a). Farmers will have some flexibility to adapt to climate change by using climate-smart farming strategies, transitioning crop types to ones more tolerant to higher temperatures and salinity, and converting crops to rice. Agricultural lands can also be used for habitat by waterfowl, fish, and other species with the implementation of specific land management practices. For example, growers who flood their fields during the winter provide proxy wetlands along the Pacific Flyway. Many of these strategies will also contribute to achieving California's climate goals by reducing GHG emissions, including the Nature-Based Solutions Climate Targets.¹¹

Invasive species will continue to flourish as the climate changes

The Delta is one of the world's most heavily invaded estuaries, with at least 185 non-native species present and more species likely to arrive. As noted in the Delta ISB's 2021 review on non-native species, climate change is altering habitats in the Delta, shifting species susceptibility and risk (Delta ISB, 2021). Extreme events like floods and droughts can disturb ecosystems and facilitate invasions (Diez et al., 2012). Pathways of invasion may also change, and vulnerability to non-native species will vary across habitats and taxonomic groups. For instance, invasive aquatic species often benefit from climate change more than native species (Sorte et al., 2013), and

¹¹ To learn more about climate-smart farming techniques suitable for the Delta, see the [Climate-Smart Catalog](#) produced by UC Davis Environmental Policy and Management graduate students in partnership with the Council.



non-native fish generally tolerate warmer waters better than native species. Moyle et al. (2013) found that 82% of native fish are vulnerable to climate impacts, compared to just 19% of non-natives. Some species, like the common reed (*Phragmites australis*), are highly adaptable to climate-related changes, showing genetic variation and trait plasticity, or “the ability of an organism to modify its physical traits, behavior, or structure in response to environmental changes, without altering its genetic makeup” across environments (Sheposh, 2024; Eller et al., 2014). Moreover, interacting climate stressors and multiple invaders can have combined and negative effects (Pyšek et al., 2020; Gaertner et al., 2014).

The Delta ISB has called for a forward-looking, ecosystem-level approach to managing non-native species, emphasizing the need to anticipate and prevent invasions (Delta ISB, 2021). Climate change, through sea level rise, warming, and extreme events, will shift habitats, promote range expansions, and create new opportunities for invaders. Forward-looking climate research to support invasive species management is more critical than ever, especially in light of recent Delta invaders, such as nutria and golden mussel, which pose significant threats to the Delta’s water supply reliability and ecosystem health.



III. Delta Adaptation: Creating a Path Forward

The Delta Adapts Adaptation Plan proposes strategies to adapt Delta communities, infrastructure, and ecosystems to climate change. These regional adaptation strategies were informed by community outreach and developed in partnership with subject matter experts and federal, Tribal, state, and local decision makers to reduce climate vulnerabilities from flooding and to water supply, agriculture, and ecosystems. The strategies and specific actions in the Plan were developed through regional collaboration and covered a range of topics and sectors, but they are not the only adaptation strategies identified for the Delta. For example, DWR has been pursuing multiple adaptation initiatives in the region and recently developed an Adaptation Strategy for the State Water Project. This section summarizes key topics and strategies from the Delta Adapts Adaptation Plan and highlights several case studies of other adaptation initiatives underway.

Tribal Collaboration and Traditional Knowledges

Outreach conducted for the Adaptation Plan included early pre-consultation and a formal consultation process with three Tribes to understand their perspectives on climate adaptation priorities, concerns, and considerations surrounding Traditional Knowledges (TK) in the Delta.¹² Key feedback heard in consultation with Tribal partners on these topics included the following (DSC, 2025b):

- That the entire Delta is a culturally significant landscape, and projects can have a cultural impact regardless of if they affect a specific site or archaeological resource,
- Social issues and climate change are interwoven – you cannot address one without the other, and,
- Commercial agriculture and Tribal land stewardship are different and often opposed practices, and it is important to be mindful of these differences when considering how Tribes can co-manage or influence projects with an agricultural component.

TK is “a body of observations, oral and written knowledge, innovations, practices, and beliefs that promote sustainability and the responsible stewardship of cultural and natural resources through relationships between humans and their landscapes. [It] cannot be separated from the [Indigenous] people inextricably connected to that

¹² The Tribes consulted have been left anonymous here. The Council recognizes that feedback and perspectives heard from these partners cannot be extrapolated to be that of all Indigenous Peoples of the Delta.



knowledge” (Daniel et al., 2022). Tribes and knowledge holders may also refer to TK as Indigenous Knowledge and/or use the term Traditional Ecological Knowledge, which is the “direct application and utilization of Traditional Knowledges having to do with ecology, ecosystems, or the environment,” though each term can hold different meanings among Tribes and knowledge holders (OCCRI, 2025). See the Fifth Assessment Tribal and Indigenous Communities Report for more information on these knowledge systems.

Case Study: Ecocultural Restoration of Webb Tract

The Metropolitan Water District of Southern California (Metropolitan) and an Ecocultural Working Group made up of Tribal partners are leading an innovative, multi-benefit restoration project at Webb Tract, located in Contra Costa County in the central Delta. Webb Tract is one of several Delta islands owned by Metropolitan, historically used for conventional agriculture, like corn, which led to severe soil loss and increased carbon emissions (Meadows, 2025a). Restoration work on Webb Tract will transform the island into wetlands and rice farms that will slow or stop subsidence, create additional habitat, reduce greenhouse gas emissions, and provide opportunities to study carbon storage (Metropolitan, 2026). Another long-term goal for Webb Tract is to open the site for access so that Tribal partners can practice ceremony and actively steward and harvest natural resources (Meadows, 2025a).

Co-chaired by Plains Miwok cultural practitioner Don Hankins and Northern Sierra Mewuk cultural bearer Austin Stevenot, the Ecocultural Working Group is made up of various Indigenous knowledge holders, including basket weavers and healers (Meadows, 2025). The working group was formed early in project planning to ensure that Indigenous perspectives could meaningfully shape the project, including the selection of native plants for creating wetland habitat. Tribal partners selected plants that Indigenous people use for survival, including for food, baskets, and medicine, and plants important for pollinators. As Stevenot describes, “We’re paying attention to not just what we need but what other critters need” (Meadows, 2025a). The Webb Tract Project is a unique case study for demonstrating how Tribal perspectives and TK are integral to successful restoration project design in the Delta.

The adaptation strategies developed through Delta Adapts recognize that partnerships with Tribes with ancestral ties to the Delta are critical to their implementation, especially regarding the application of TK by knowledge holders. For example, restoration projects should be planned and designed in partnership with Tribes to engage Tribal knowledge holders, support Indigenous-led ecocultural stewardship practices, and intentionally increase Tribal access to restored areas



for traditional uses and cultural resources. Conducting multi-benefit projects in partnership with Tribes with ties to the Delta presents numerous opportunities to improve ecological and cultural outcomes, as in the case of the Webb Tract Project. These partnerships can even lead to the return of ancestral lands to Tribal governments for long-term, sustainable management.

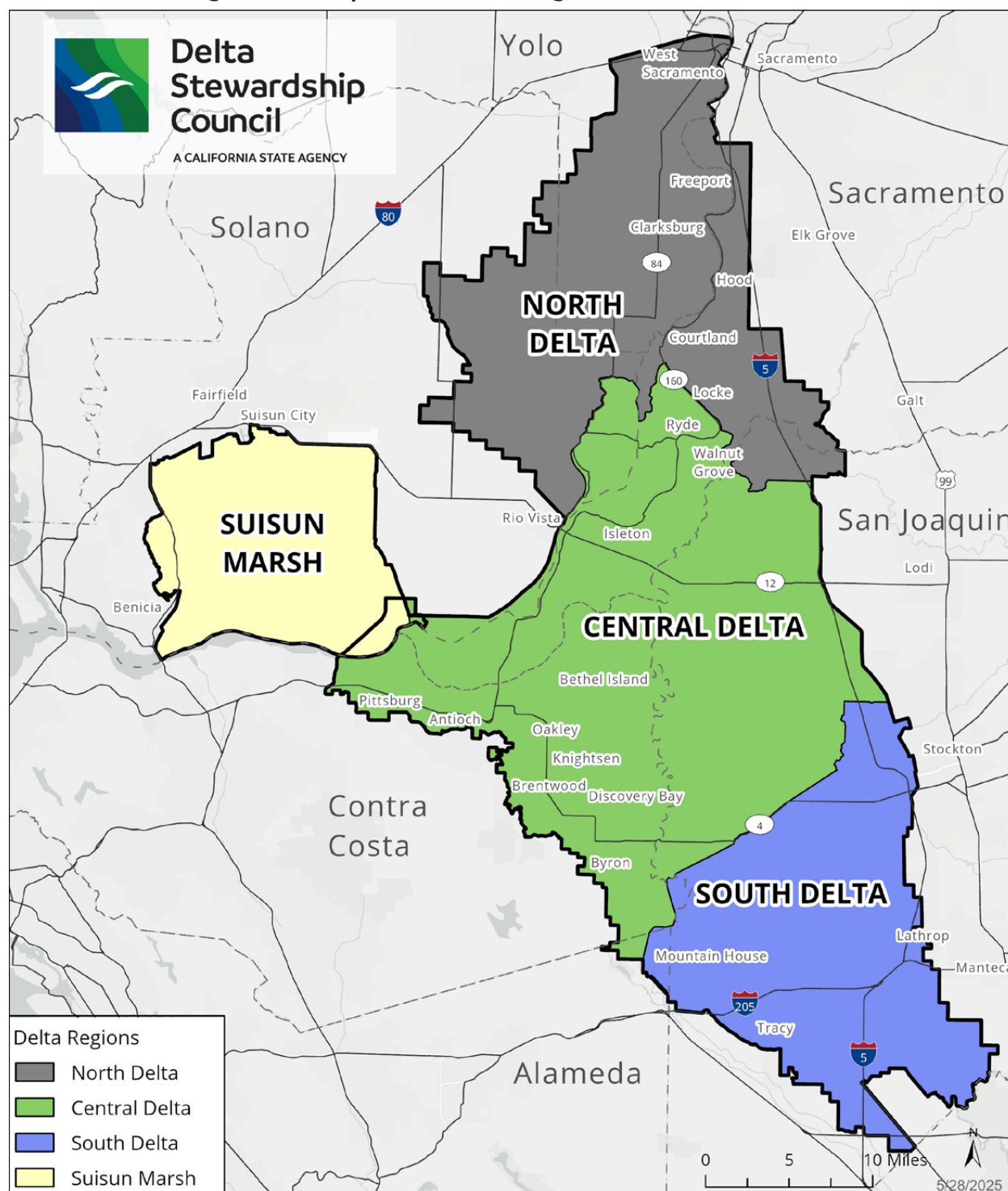
Regional Differences and Approaches

The Delta and Suisun Marsh share many common challenges, but regions within the Delta also have unique challenges, considerations, priorities, and appropriate adaptation strategies (see **Figure 24** for the Delta regions). For example, the North Delta offers opportunities for multi-benefit restoration projects that incorporate farming practices, while activities in the Central Delta must prioritize halting subsidence. Salinity management is a priority for the South Delta and Suisun Marsh, as is the protection of transition zones and enhanced wetland management. Other strategies including aquifer recharge, increasing regional water supply self-reliance, and habitat restoration should be implemented in areas outside the Delta.

The Adaptation Plan addresses some of these regional tradeoffs and considerations, though the adaptation strategies are generally applicable across the Delta. The North Delta – primarily rural, agricultural, and composed of many legacy communities – currently experiences water quality issues due to high levels of organic carbon and pollutants. Low flows during periods of drought could exacerbate these issues, affecting public health and agriculture. Relative sea level rise rates in the North Delta range from 4.7 to 8.9 mm/yr (about 0.18 to 0.35 in/yr) (Baranes et al., 2023). This area is well suited for integrated farming systems as well as ecological adaptation options. The Central Delta is experiencing significant and ongoing land subsidence, and its levees face the highest risk of overtopping and failure without maintenance. The South Delta hosts critical water supply infrastructure including the pumping plants for the State Water Project and Central Valley Project and experiences the compounding impacts of sedimentation, invasive species, and salinity. The build-up of sediment in the South Delta exacerbates flood risk and water availability issues, and dredging necessary to clear out collected sediment is expensive, with recent estimates averaging \$10 million per mile of channel (Meadows, 2025b). Relative sea level rise in the South Delta ranges from 3.2 to 7.9 mm/yr (0.12 to 0.31 in/yr) with some of the highest rates occurring at Venice Beach (9.9 mm or 0.39 in/yr), the Clifton Court intake (~0.4 in or 10.1 mm/yr), and Garwood Bridge near Stockton (0.43 in or 10.9 mm/yr) (Baranes et al., 2023). Lastly, Suisun Marsh – primarily made of up managed wetlands – is the transition zone from fresh water to saltwater. The marsh experiences high flood risk from incoming sea level rise from the San Francisco Bay.



Figure 24. Map of the Delta Regions and Suisun Marsh.





Adaptation Strategies

The [Delta Adapts: Adaptation Plan](#) identifies 22 adaptation strategies and over 100 specific actions to implement them. The Adaptation Plan identifies the climate hazards addressed by each strategy, additional co-benefits each strategy provides, proposed strategy leads and partners to advance implementation, and how the strategy aligns with California's Climate Adaptation Strategy adaptation priorities. Adaptation strategies are grouped into four focus areas: flood risk reduction, ecosystems, agriculture, and water supply reliability.

The Adaptation Plan considers how each strategy may support improved health, economic stability and prosperity, physical and emotional well-being, and social justice for vulnerable communities. Increasing representation of those who have been historically left out of government procedures and decision-making is also integrated within governance best practices. Equity considerations are embedded throughout the adaptation strategies and implementation actions.

Each adaptation strategy specifies actions for implementation through planning, coordination, research, project development, funding identification, and/or monitoring and evaluation. The Plan includes 30 *adaptation accelerator*¹³ actions that should be addressed first. Each adaptation accelerator meets the following two criteria:

1. **These actions need to happen now, before 2030:** Some actions must be taken sooner rather than later because they have a narrow implementation window. If the action is not started soon, it may be too late, either because the action is no longer possible or because the intended benefits may not be realized.
2. **These actions have widespread support:** These actions are already included in agency plans or existing initiatives and grounded in established science.

The following sections provide short summaries of the adaptation strategies and implementing actions the Council and its partners designed for the Delta, organized by focus area. Each section also shares project case studies and examples.

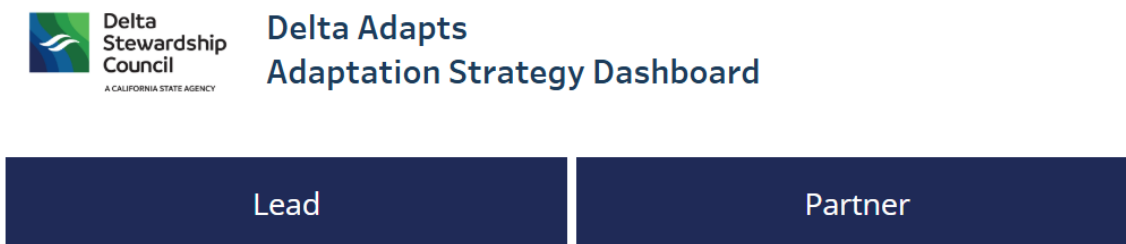
Adaptation Strategy Dashboard

The Council created an [Adaptation Strategy Dashboard](#) that allows partners and the public to sort and view the Adaptation Plan strategies and actions. Users can sort and view the strategies by lead and partner organization, focus area, hazards addressed, and co-benefits. For instructions on how to use the Dashboard, see the [Delta Adapts webpage](#).

¹³ This term is used in the field of adaptation when referring to initiatives, programs, or projects designed to speed up and scale up effective climate adaptation solutions and practices, often targeting vulnerable communities and regions.



Figure 25. Delta Adapts Adaptation Strategy Dashboard Developed by the Delta Stewardship Council



The “Delta Adapts” Adaptation Strategy Dashboard was developed by the Delta Stewardship Council (Council) to view and sort the adaptation strategies and implementing actions of the Council’s Delta Adapts Adaptation Plan. The Adaptation Plan proposes a suite of strategies under four focus areas: **flood risk reduction, ecosystem, agriculture, and water supply reliability**, developed in collaboration with Council partners, to create a more resilient Sacramento-San Joaquin Delta in the face of climate change. **For more information about Delta Adapts, and for instructions on how to navigate the Dashboard, visit our website:** <https://www.deltacouncil.ca.gov/delta-plan/climate-change>

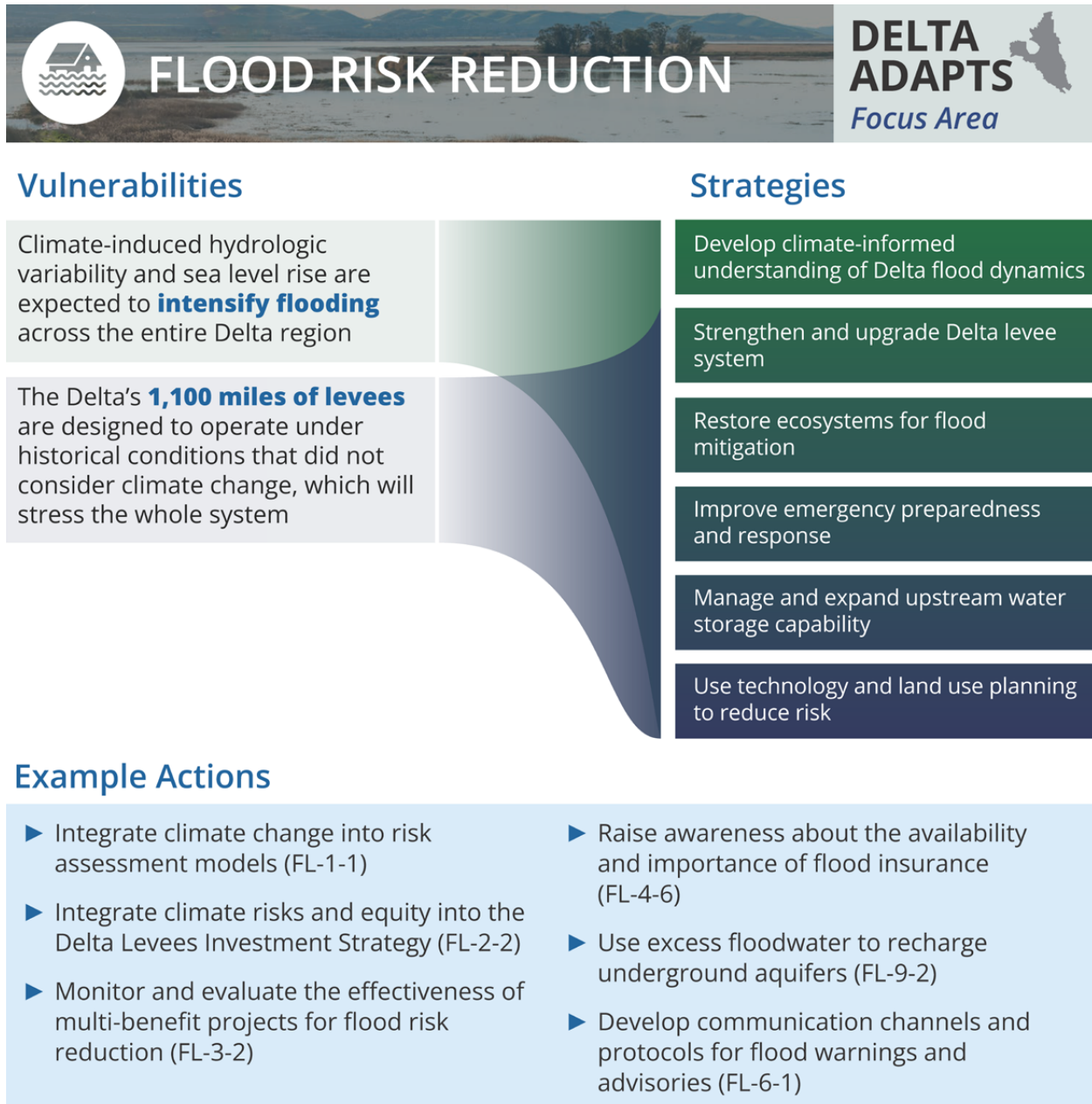
Adaptation strategies in the Dashboard are organized by recommended leads and partners, as identified in the Plan (see buttons above). **Recommended leads** are entities that are best positioned to convene, coordinate, and lead the implementation of a strategy. **Recommended partners** are entities with a role in the collaborative implementation of a strategy. Both designations are preliminary and subject to change.

Flood Risk Reduction

The Adaptation Plan seeks to reduce flood risk through a series of actions focused on in-Delta levee improvements and land use changes, nature-based solutions to support flood mitigation and ecosystem services, improved emergency preparedness and response, improved risk communication, and upstream management of reservoirs to control flood flows into the Delta. **Figure 26** provides a summary of the flood risk reduction strategies and how they address Delta climate vulnerabilities, with some example actions.



Figure 26. Delta Adapts Summary of Flood Risk Findings, Flood Risk Reduction Strategies, and Example Actions (DSC, 2025b)





Flood risk reduction adaptation accelerators:

- Integrate climate change and socioeconomic factors into flood risk management (FL-1-1)
- Strengthen collaboration and dialogue on flood risk reduction (FL-1-2)
- Integrate climate risks and equity into the Delta Levees Investment Strategy (FL-2-2)
- Consider future climate conditions in ongoing inspections and maintenance (FL-2-3)
- Support levee improvements and multi-benefit projects (FL-2-4)
- Provide 200-year protection for key islands and 100-year protection for others (FL-2-5)
- Prioritize levee improvements in socially vulnerable communities (FL-2-6)
- Appropriate funds for local agencies to upgrade levees (FL-2-8)
- Implement advanced monitoring technologies for inspections (FL-2-9)
- Identify emergency planning gaps and update response plans (FL-4-1)
- Raise awareness about flood insurance availability and importance (FL-4-6)
- Develop clear communication channels and protocols for timely flood warnings (FL-6-1)
- Improve flood risk communication and information dissemination (FL-6-2)

Case Study: Community Flood Risk Awareness

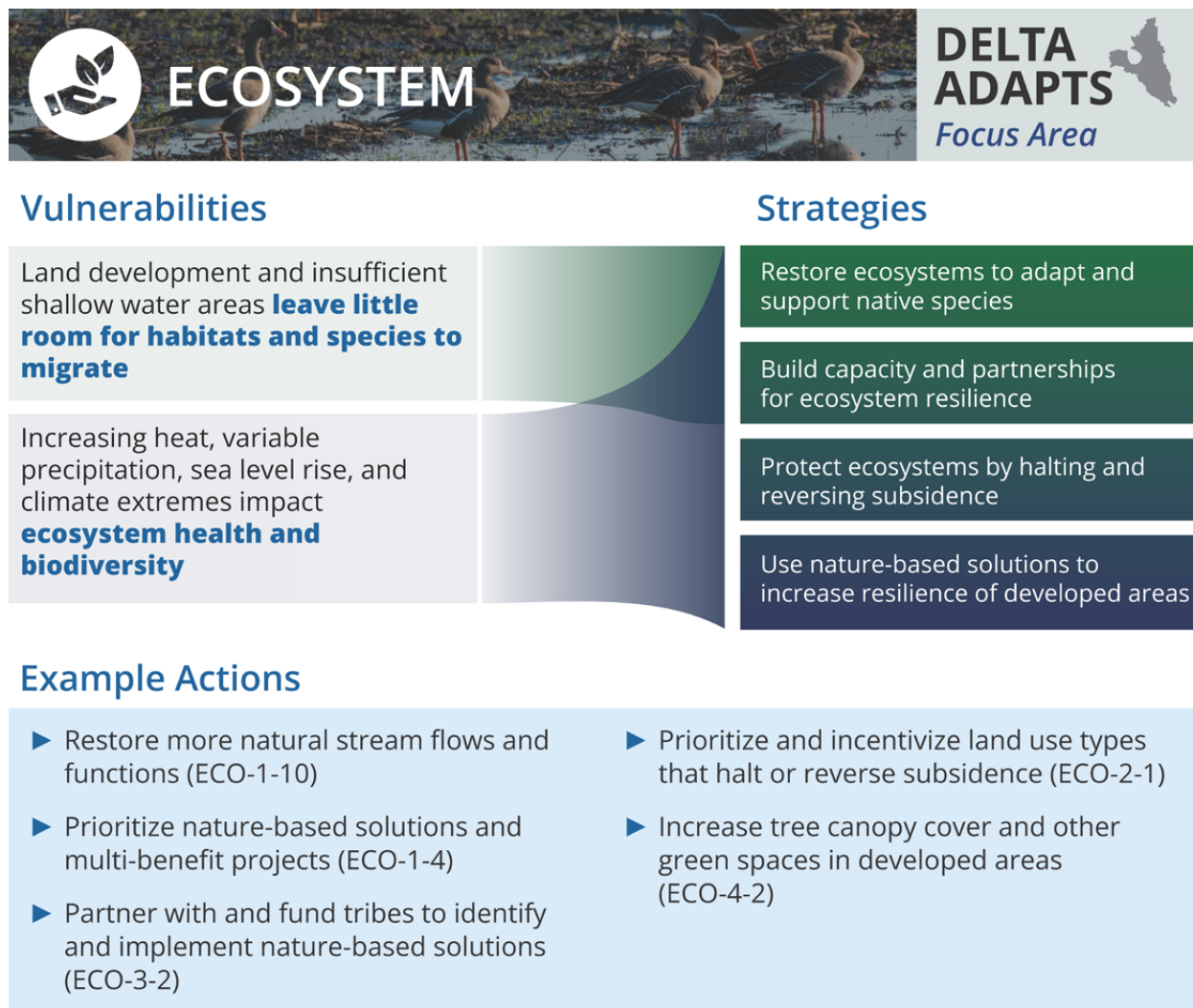
The Council, Delta Protection Commission, Sacramento Coalition to End Homelessness, DWR, UC Davis, and Stanford University collaborated in 2024 to produce a ["Planning for Post-Disaster Housing in Legacy Communities" Story Map](#). This resource highlights Delta communities with vulnerable populations at risk of needing long-term temporary housing in the aftermath of a flood.

Ecosystem

The Adaptation Plan's ecosystem strategies strengthen the adaptability of Delta ecosystems by restoring and connecting habitats to meet Delta Plan goals, implementing functional flows, halting or reversing land subsidence, and protecting native species and improving ecosystem health. These strategies provide a broad range of benefits including flood risk reduction, water quality improvement, increased Tribal and public access, and GHG mitigation. **Figure 27** provides a summary of the ecosystem strategies and the climate vulnerabilities they address, with some example actions.



Figure 27. Delta Adapts Summary of Ecosystem Vulnerability Findings, Adaptation Strategies and Example Actions (DSC, 2025b)





Ecosystem adaptation accelerators:

- Prioritize multi-benefit projects (ECO-1-4)
- Restore natural stream flows and functions (ECO-1-10)
- Incentivize land use that halts and reverses subsidence (ECO-2-1)
- Incentivize tidal wetland restoration at tidal elevations in the North Delta and Suisun Marsh (ECO-2-2)
- Work with Tribes to implement nature-based solutions and identify opportunities to co-manage restored public areas (ECO-3-2)
- Streamline environmental review and permitting while maintaining procedures for environmental protection; Establish program-level endangered species permitting tools (ECO-3-7)
- Expand public-private partnerships upstream of the Delta that provide ecosystem functions (ECO-3-10)
- Explore opportunities for a comprehensive ecosystem restoration, maintenance, and monitoring funding strategy (ECO-3-11)

Case Study: Carbon Credits

The Delta Conservancy also coordinated an effort to realize funding for development of a wetland carbon market protocol that was adopted by the American Carbon Registry and CARB. This protocol allows project proponents to obtain and sell carbon credits on the voluntary market for revenue. The protocol covers both rice and managed wetlands and was created with the intention of advancing the pace and scale of subsidence reversal projects in the Delta by providing landowners with a financial incentive. Three projects have successfully quantified and verified their credits using the protocol and plan to make them available on the market soon.

Case Study: Delta Carbon Team

To address Delta ISB subsidence review recommendations (Delta ISB, 2025b), the Delta Conservancy is co-leading a Delta Carbon Team with the Nature Conservancy that aims to bring people working on Delta carbon issues together to improve collaboration and make progress toward reversing subsidence and reducing associated GHG emissions within the Delta. Several action teams have been formed to make meaningful progress on key issues and outstanding research questions.



Case Study: Funding Multi-Benefit Approaches

The Delta Conservancy funded 34 multi-benefit ecosystem restoration projects using \$42 million from the 2014 Water Quality, Supply, and Infrastructure Improvement Act. These projects benefited more than 11,350 acres of habitat in the Delta, including restoration of riparian and wetland habitat, invasive species control and monitoring, and flood management.



Aerial view of Webb Tract, Source: DWR

The Delta Conservancy also funded four wetland restoration projects to stop or reverse subsidence on up to 11,000 acres and avoid about 110,000 tons of carbon dioxide emissions annually. These projects include the conversion of Webb Tract to a mosaic of wetlands and rice, creation of a wetland on the most deeply subsided portion of Staten Island, acquisition of a conservation easement on Bethel Island for future restoration, and an incentive program for farmers to convert existing row crops to rice.



Case Study: Delta Interagency Invasive Species Coordination Team

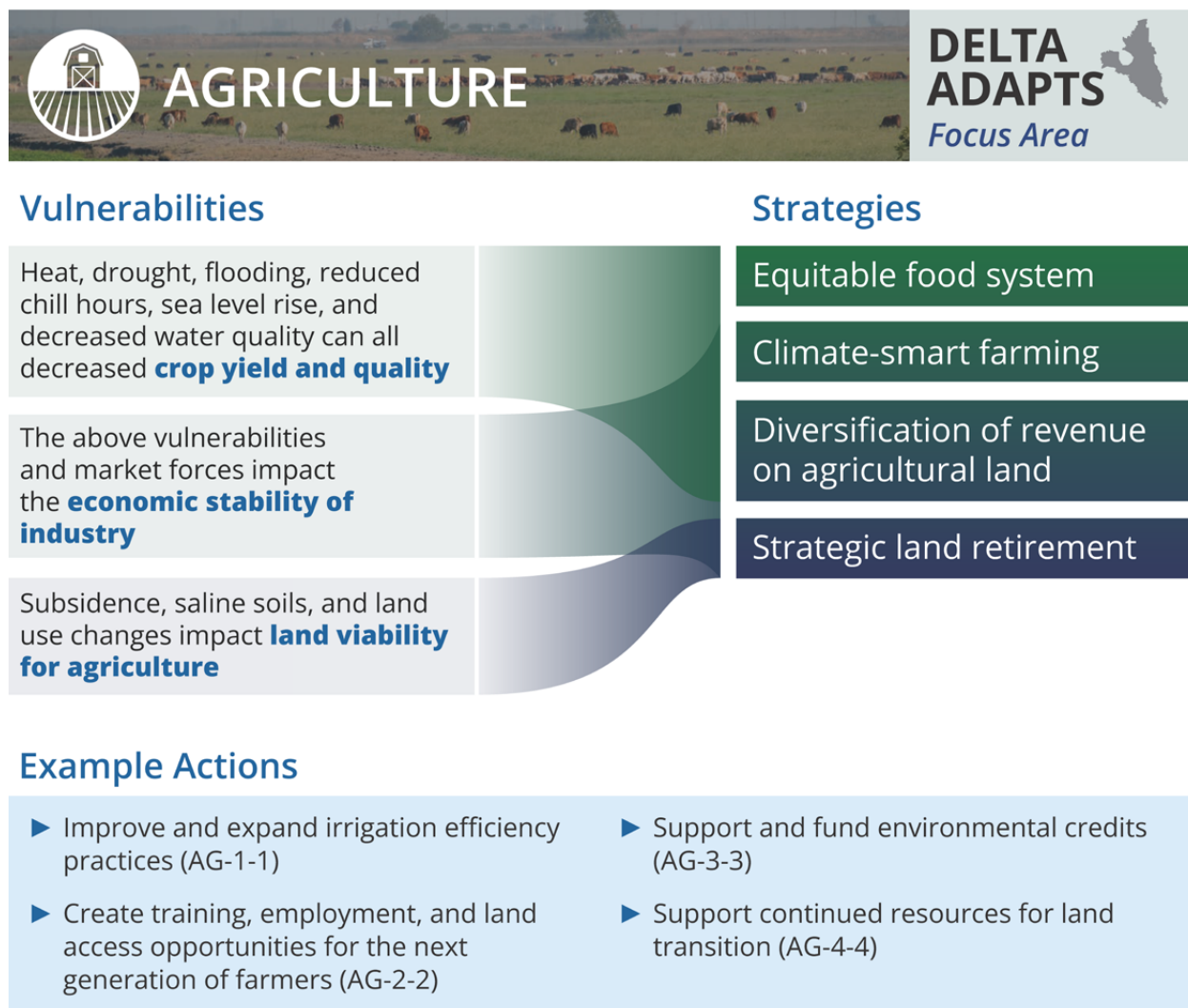
The Delta Interagency Invasive Species Coordination (DIISC) Team promotes opportunities to strengthen communication and collaboration among organizations and agencies involved in invasive species management in the Delta. The Delta Conservancy co-leads the DIISC to exchange information, coordinate activities, and identify research needs and funding sources. A DIISC Team working group is developing general guidance for adaptive management of invasive aquatic vegetation in tidal wetland restoration sites, expected for release in 2025.

Agriculture

The Adaptation Plan takes a holistic approach to agricultural resilience leading with actions that support the resilience of the Delta agricultural economy for the benefit of Delta farmers and communities. This includes actions that support more efficient agricultural water use, building healthier soils through actions for both peat and non-peat soils, and conversions to climate-resilient crops. These regional agricultural strategies can provide many co-benefits including increasing food security, strengthening the local economy, halting or reversing land subsidence, reducing GHG emissions, and providing habitat for a diverse range of species. **Figure 28** provides a summary of the agricultural strategies and the climate vulnerabilities they address, with some example actions.



Figure 28. Delta Adapts Summary of Agriculture Vulnerability Findings, Adaptation Strategies and Example Actions (DSC, 2025b)



Agricultural adaptation accelerators:

- Improve and expand irrigation efficiency management practices (AG-1-1)
- Create training, employment, and land access programs and opportunities for the next generation of farmers (AG-2-2)
- Support and fund environmental credits (e.g., carbon credits or wildlife-friendly farming incentives) (AG-3-3)
- Support continued resources for land transition (AG-4-4)



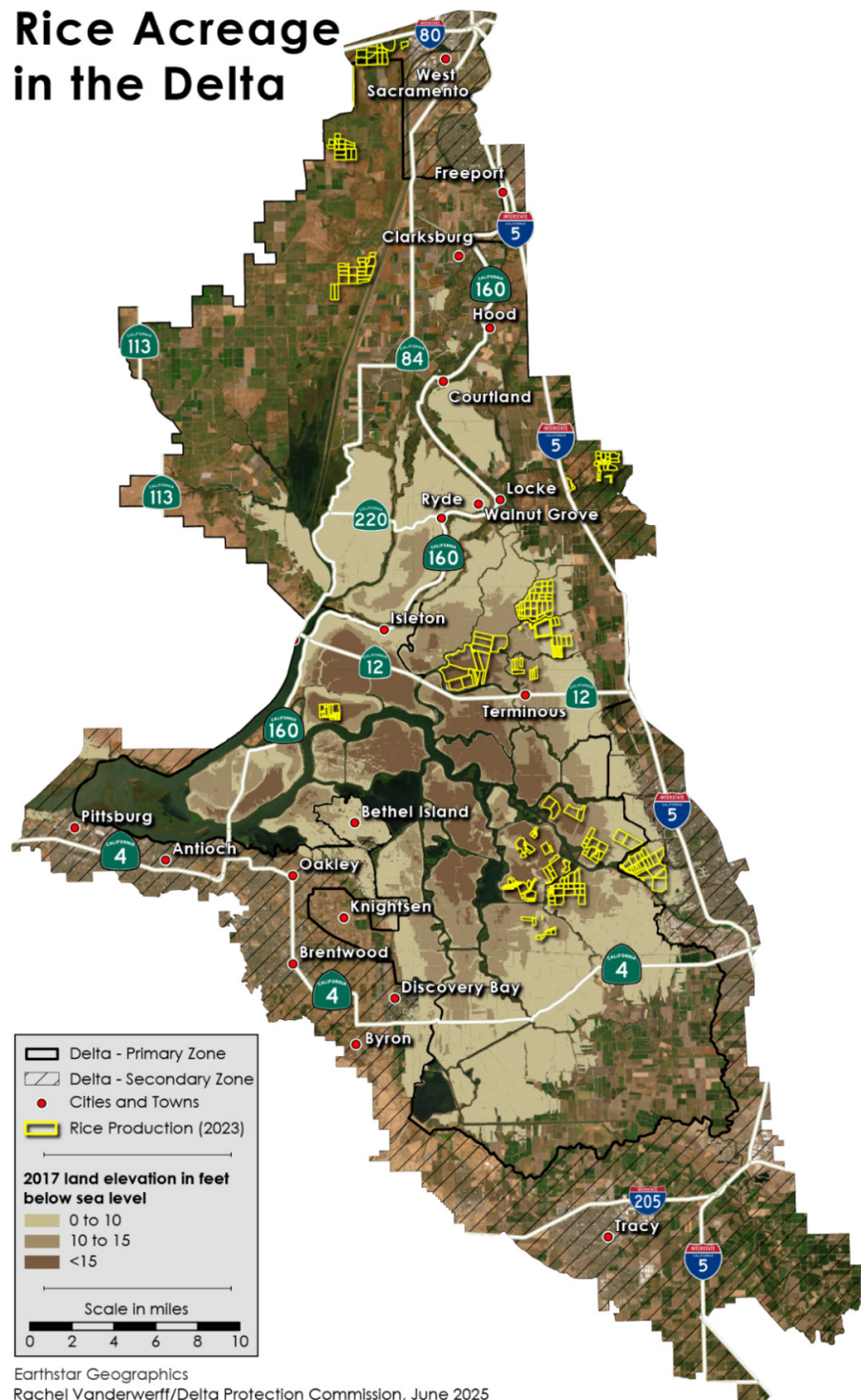
Case Study: Rice Cultivation for GHG Reduction, Resilience, and Wildlife

Delta farmers and landowners are increasingly switching to growing rice, which can mitigate subsidence, reduce carbon emissions, and provide benefits to wildlife. The acreage of rice grown in the Delta tripled between 2018 and 2022, while acres of corn fell (Heyser, 2025) (see Figure 29 for rice acreage in the Delta). The Delta Rice Incentive Program, conducted by the Nature Conservancy with funding from the Delta Conservancy, provides financial incentives to farmers to convert existing row crops to wildlife-friendly rice. Between 2024 and 2025, ten farmers enrolled and converted nearly 4,000 acres of existing row crops to rice, avoiding the emission of about 18,000 tons of carbon dioxide. The Nature Conservancy also provides technical assistance as needed to growers and supports the economic viability of growing rice in the Delta by assisting with the high upfront costs of conversion. Once the conversion is made, rice is a high-revenue crop that can be more profitable for farmers than corn (Heyser, 2025). The Healthy Soils Program from CDFA recently added conversion to rice in the Delta as an eligible practice for their program. Delta farmers also have access to the water needed to flood rice fields for part of the year, making the Delta an ideal location for growing rice, especially as other parts of the state face limited water availability in times of drought.

Growing rice in the Delta is a win-win for farmers and the environment. Re-wetting Delta soils by growing rice decreases the oxidation of soil and release of GHG emissions (Heyser, 2025). Decreasing oxidation of organic matter in soils also prevents or slows subsidence, which is affecting the long-term viability of farming in the Delta and can contribute to higher flood risk (Heyser, 2025). Flooded fields can also provide habitat for waterbirds, migratory birds like sandhill cranes, and other species, and provide zooplankton for fish species like endangered winter run chinook salmon (Heyser, 2025).



Figure 29. Rice Acreage in the Delta and Areas of Deep Subsidence (Source: Delta Protection Commission)



Earthstar Geographics
Rachel Vanderwerff/Delta Protection Commission, June 2025



Case Study: Understanding Agricultural Land Transitions

As part of its agricultural land use protection mandate, the Delta Protection Commission is completing an analysis of farmland conversion to ecosystem restoration and flood control projects and is developing a report evaluating acreage and effects of farmland conversions within the Delta. Potential future policy responses that could further inform adaptation actions may be considered based on the report's findings.



Organic rice harvesting at Tide's End Restoration Project, Source: DWR

Case Study: Delta Drought Response Pilot Program

The Delta Drought Response Pilot Program (DDRPP), funded by DWR and administered by the Delta Conservancy, was launched to test drought-resistant field management practices in the Delta Watershed given its unique hydrology. Under the program, farmers received financial incentives to reduce their water use and protect wildlife and water quality in the Delta. In 2024, the Conservancy released a final report on outcomes of the 2023 DDRPP program.

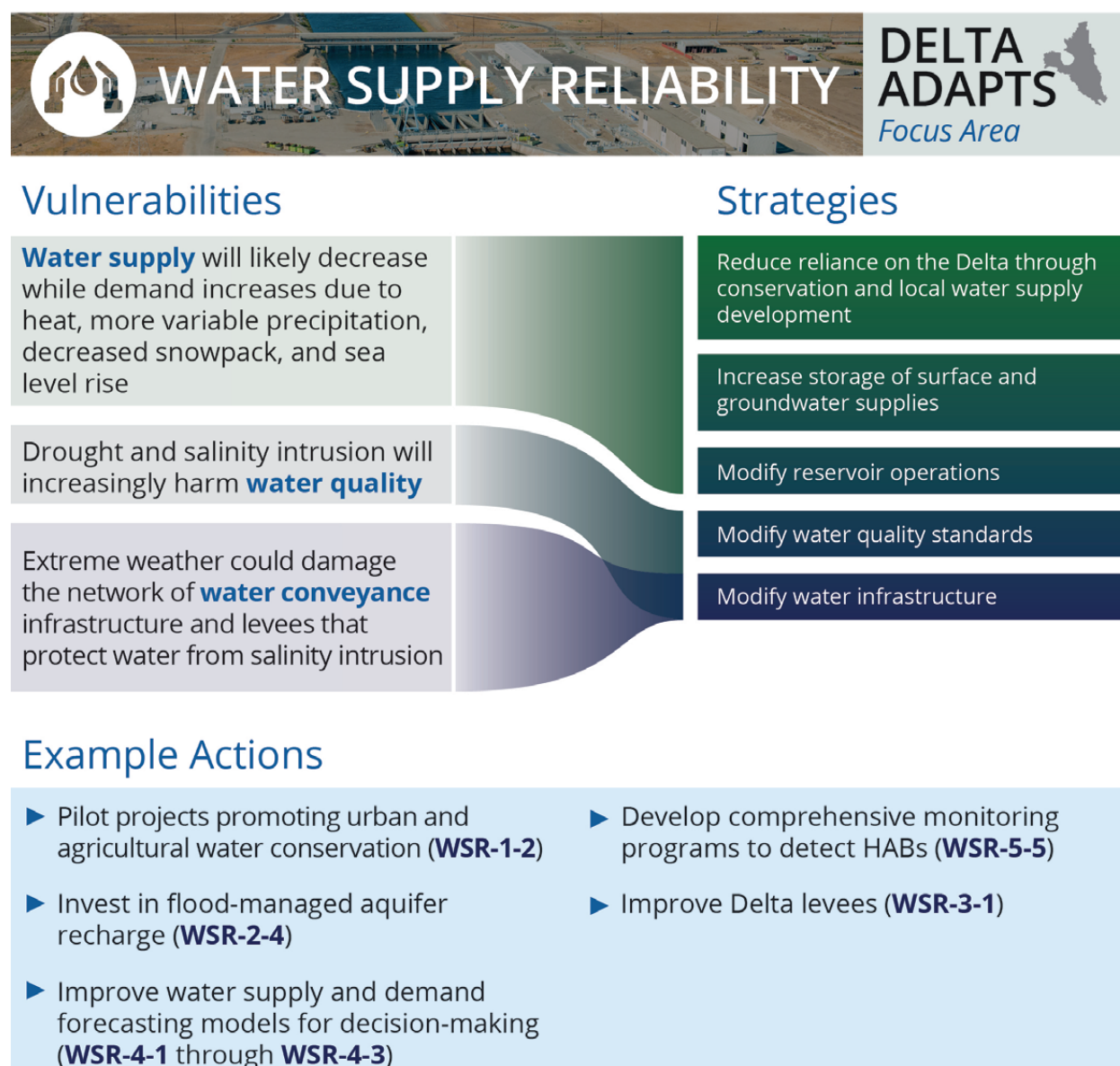
Water Supply Reliability

The Adaptation Plan's water supply reliability strategies re-double the state's efforts to reduce reliance on the Delta by working with partners to increase water conservation, expand surface and groundwater storage and regional water supplies, modernize



Delta conveyance systems, improve upstream reservoir operations, and update water quality standards to account for the impacts of climate change. These strategies are based on using best available and transparent science to inform decision-making, such as adopting FIRO and Flood-MAR strategies for reservoir operations. **Figure 30** provides a summary of the water supply reliability strategies and the climate vulnerabilities they address, with some example actions.

Figure 30. Delta Adapts Summary of Water Supply Vulnerability Findings, Adaptation Strategies and Example Actions (DSC, 2025b)





Water supply reliability adaptation accelerators:

- Support pilot projects (WSR-1-2)
- Invest in Flood-MAR (WSR-2-4)
- Improve Delta levees (WSR-3-1)
- Coordinate with U.S. Army Corps of Engineers (USACE) to review and update flood space reservation guidelines (WSR-4-1)
- Coordinate with all partners to review Bay-Delta Plan water quality standards (WSR-5-2)

The Delta faces chronic underinvestment relative to the need for its sprawling levee system, local communities and water systems, infrastructure, and fragmented habitats. More funding is needed to maintain the levee system and bring it up to recommended design standards; improve local drinking water quality for Delta communities; maintain and update Delta infrastructure; support statewide water funding needs, and a new but limited source of funding – the 2024 Climate Bond.

Case Study: Optimizing Monitoring Tools for Cyanobacterial Harmful Blooms

A research team¹⁴ is undertaking a project to develop and validate tools to monitor CHABs in the Delta better. Most CHABs in the Delta are formed by *Microcystis*, a cyanobacteria that produces a toxin called microcystin. Since the early 2000s, monitoring of CHABs has relied heavily on a visual scoring system called the *Microcystis Visual Index* (MVI). However, this system is subjective and does not provide quantitative data about bloom severity or toxicity. At various Delta locations, the researchers will take digital photographs of CHABs and collect field data on bloom density, toxin levels, and environmental conditions. They will use the data to create an image classification model that automatically ranks bloom severity from photos. They will also relate visual bloom characteristics to quantitative measures of biomass and toxicity. Ultimately, the project aims to develop a smartphone app to classify blooms and a public data dashboard to help disseminate CHABs information. Standardizing the MVI by removing observer bias and rendering it semi-quantitative will help water managers, Tribes, and communities track and respond to potentially harmful algal blooms that affect water quality and public health. This project is funded by the Delta Science Program and administered by California Sea Grant under the 2025 Delta Research Awards.

¹⁴ Comprising Dr Holly Bowers (Coastal Conservation and Research, Inc.), Dr Mine Berg (Coastal Conservation and Research, Inc.), Dr Ellen Preece (California Department of Water Resources), Laura Nickelhoff (Environmental Science Associates), and Spencer Fern (Restore the Delta).



Case Study: Forecast-Informed Reservoir Operations and Flood-Managed Aquifer Recharge in the San Joaquin Basin

DWR is advancing an integrated strategy that combines FIRO with MAR to improve climate resilience in the San Joaquin River watershed. DWR's San Joaquin Basin Flood-MAR Watershed Studies (DWR, 2025b) demonstrate how adaptive reservoir management and floodplain recharge can jointly reduce downstream flood risk while replenishing depleted aquifers. The FIRO-MAR approach uses real-time meteorological forecasts and hydrologic modeling to adjust reservoir storage and release decisions. During large runoff events, water is diverted from rivers using existing conveyance infrastructure and spread across agricultural fields and recharge basins, reducing peak flood flows while enhancing groundwater recharge.

At the core of this work is the *Integrated Forecast-Informed Resource Management* (I-FIRM) framework, which couples FIRO reservoir operations with MAR to optimize multiple objectives—flood control, water supply, and ecosystem management. DWR's modeling uses a suite of linked surface and groundwater tools to simulate forecast uncertainty, daily recharge capacity, and downstream channel constraints across five watersheds—Calaveras, Stanislaus, Tuolumne, Merced, and Upper San Joaquin. I-FIRM simulations show that coordinated FIRO-MAR operations substantially reduce the magnitude, frequency, and duration of high-flow events in the San Joaquin tributaries—particularly the Tuolumne, Merced, and Upper San Joaquin Rivers—while increasing groundwater storage by an average of approximately 410,000 acre-feet per year, roughly four times greater than recharge achieved under standalone MAR strategies. These operations nearly offset climate-driven groundwater overdraft in several subbasins and cut the number of downstream channel-capacity exceedances by up to half, returning peak flows closer to current conditions. While modeled flood risk reductions occur within the San Joaquin Basin, they provide meaningful benefits for the Delta by moderating tributary inflows that contribute to downstream flooding and stress on levees.

Beyond hydrologic benefits, the studies illustrate the value of intentional recharge placement to maximize social and ecological co-benefits. Priority recharge zones were identified near disadvantaged communities and subsidence-prone areas, while functional-flow management was incorporated to sustain habitat and salmon migration cues. The FIRO-MAR framework demonstrates a science-based, cross-sectoral adaptation strategy that links upstream reservoir operations with downstream Delta resilience, helping California manage more variable precipitation, sustain aquifers, and mitigate flood hazards in a warming climate.



IV. Delta Investment Needs

The Delta faces chronic underinvestment relative to the need for its sprawling levee system, local communities and water systems, infrastructure, and fragmented habitats. More funding is needed to maintain the levee system and bring it up to recommended design standards; improve local drinking water quality for Delta communities; maintain and update Delta infrastructure; support statewide water supply; and protect and restore Delta habitats. This funding need is expected to grow as the climate changes, placing additional pressure on these systems. Conserving and restoring ecosystems will be especially important moving forward, given the co-benefits these projects have for public health, flood management, water quality, GHG mitigation, economic opportunity, and overall climate resiliency. This section summarizes known and projected investment needs in the Delta, uncertainties related to funding needs, and a new but limited source of funding – the 2024 Climate Bond.

Funding Priorities

Levee Maintenance and the Subventions Program

The Delta's extensive levee system protects urban and rural communities, critical infrastructure, waterways, and precious habitats. Key infrastructure protected by the system includes critical state and federal water conveyance projects: the State Water Project and the Central Valley Project. These two systems convey water to a combined total of approximately 27 million Californians in the Bay Area and Central and Southern California and almost four million acres of farmland in the Central Valley (DWR, n.d. a; Maven's Notebook, 2024). For this reason alone, maintaining and protecting the Delta levee system is a matter of statewide significance.

Despite the system's importance, most Delta levees are overdue for maintenance and upgrades. The Delta's levee network includes both federally authorized "Project" levees and locally maintained "Non-Project" levees. Most of the levee network was built during the Reclamation Era, which spanned approximately 1850 to 1930, and many levees no longer meet today's design criteria (DSC, 2024b; DSC, 2025a). Current criteria include the Urban Levee Design Criteria developed in response to the Central Valley Flood Protection Act of 2008, the Delta Specific Public Law 84-99 standard (PL 84-99) established by the USACE, and DWR's Bulletin 192-82 standard, which is similar to PL 84-99 standards but with a higher design water level (DSC, 2024b). The Council tracks progress made towards achieving these safety standards in partnership with DWR. Of the 947 miles of levees monitored by DWR across the Delta, about 122 miles are in urban areas, and 825 are in rural areas. As of 2023, about 34% of urban levee miles met the Urban Levee Design Criteria, 17% of rural levee miles met PL 84-99 requirements, and half of rural levee miles met or exceeded Bulletin 192-82 (DSC, 2024b). These estimates demonstrate that there is still much



work to be done to bring the Delta levee system into compliance with state and federal standards.

In 2017, DWR estimated the total cost of Delta levee operations, maintenance, replacement, repair, and rehabilitation to be approximately \$13,000 per rural levee mile and \$18,000 per urban levee mile (DWR, 2017). Using these estimates along with the Delta levee mileage above, **total annual operational and upgrade costs are about \$17.5 million in today's dollars.**¹⁵ A 2025 DWR report found that for the portion of the levee system managed by local flood control districts, **about \$1.06 billion is needed to complete local levee upgrades over the next five years**, or about \$212 million annually over a five-year period (DWR, 2025a).¹⁶

The Delta agencies support funding adequate maintenance and improvements to Delta levees, especially given increased climate change-related risks. Adequate levee funding, however, remains an ongoing challenge, and there is a need to diversify funding sources to reduce the burden on local landowners. Currently, most of the Delta levee system is maintained by local public agencies, with the remainder managed by federal and state entities (DWR, 2025a; WEF, n.d.). When capital improvements are undertaken in partnership with the USACE, design and construction costs may be shared under the standard federal/non-federal cost split (e.g., 65% federal and 35% non-federal sponsor). At the same time, long-term operation and maintenance responsibilities remain with the local agency (USACE, 2025).

One of the few reliable sources of funding for local public agencies' levee maintenance is the Delta Levees Maintenance Subventions Program (Subventions), operated by DWR. The program provides cost-sharing for levee maintenance costs with levee maintenance agencies, who cover maintenance fees and then apply to DWR for reimbursement of eligible costs (DWR, 2016).¹⁷ Since 2006, with the passage of bond funds for the Program, the state has spent \$200 million to fix and improve the levee system, or about \$10.5 million annually (Maven's, 2024b).

Another funding source for levee projects and upgrades is the Delta Levees Special Flood Control Projects Program, also operated by DWR, which provides financial

15 Cost data were adjusted for inflation from 2014 dollars as provided in DWR, 2017.

16 "The cost estimate is the sum of proposed work that includes construction of multi-benefit projects, levee projects, studies, emergency planning, and additional protection, which can include rock slope protection, levee armoring, stability toe berms, setback levees, vegetation control, all-weather road improvements, seepage control, and raising utilities to maintain a sustainable levee standard. Any routine levee maintenance proposed within a Plan has been excluded from the summary of data in this report" (DWR, 2025a).

17 The Subventions Program is primarily for Non-Project levees; Project levees qualify if more than 50 percent of the island acreage is within the Delta primary zone. The Subventions Program does not fund levee projects in Suisun Marsh (DSC, 2024c).



assistance to local levee maintenance agencies to improve or rehabilitate levees in the Delta and portions of the Suisun Marsh (DSC, 2024c). It can fund up to 100% of project costs (DSC, 2024c).¹⁸ Since its establishment in 1988, the program has invested about \$300 million in the Delta for flood protection and multi-benefit projects that restore habitat (DWR, n.d. b). This comes to an average of \$8.1 million provided annually.

Both state and local officials recognize the success and importance of these programs, calling Subventions one of “the most successful infrastructure program(s) that the state of California has undertaken” (Maven’s Notebook, 2024b). However, there is no sustained funding source for either the Subventions or Special Projects programs (Maven’s Notebook, 2024b). They rely on bond act funding to continue, and local proponents must continually advocate for more money before funds run out (Bland, 2025). Furthermore, levee maintenance agencies must annually apply for funding from these programs and often take out loans to cover the upfront costs themselves, putting local agencies in a precarious fiscal situation year to year (Bland, 2025). Without more funding, these programs alone are not enough to meet the mounting financial needs of the Delta levee system.

Climate Adaptation for Levees and Habitats

The Delta Adapts Adaptation Plan evaluated the costs of implementing levee improvements and ecosystem restoration projects to adapt these systems to climate change through the year 2050. The analysis focused on levees and ecosystems, as they are the most expensive adaptation needs relative to the Plan’s other adaptation strategies and have supporting data. Project costs varied by location in the Delta, and estimates are provided in a range.

The Delta levee improvements assessment identified the costs associated with raising levee crests (or tops) to accommodate rising water levels (see Adaptation Plan Strategy FL-2). Future water levels were based on the 2021 Vulnerability Assessment. They assumed 1 foot of sea-level rise by 2050 (projected in the Int-High OPC scenario), changes to upstream watershed hydrology under RCP 8.5, and a 100-year storm event. Cost estimates were based on project planning, design, permitting, and construction, and the assumption that levees had already been brought to Bulletin 192-82 standards before climate adaptation-driven improvements were made (DSC, 2025). The Delta-wide cost estimate for adapting levees to one foot of sea level rise and changing inflows is between \$3.2 and \$3.3 billion (DSC, 2025). While this is a high price tag, this reflects only a fraction of the value of the assets and economy that Delta levees protect. Under one foot of sea level rise, more than \$10 billion in agricultural, residential, commercial, and infrastructure assets, and nearly \$2 billion in

18 Any local agency with a Project or Non-Project levee in the Delta Primary Zone, or a Non-Project levee in the Delta Secondary Zone, is eligible to apply for Special Projects funding (DWR, 2014).



economic activity could be exposed to flooding during a 100-year storm, if the levee system is not updated (DSC, 2021a).

The Delta habitat restoration assessment calculated the costs associated with meeting the Delta Plan and California's nature-based solutions climate targets to restore 60,000 to 80,000 acres by mid-century (see Adaptation Plan strategies ECO-1 and ECO-2).¹⁹ Restoration project types could include restoring tidal marshes, managed wetlands, riparian corridors, oak woodlands, and floodplains, as well as re-wetting highly organic, deeply subsided peat soils through rice cultivation. To estimate project costs, Council staff collected per-acre cost estimates from completed restoration projects and grant funding amounts for project planning, design, permitting, and construction. The Delta-wide cost estimate for restoring 60,000 to 80,000 acres of habitat is \$2.5 to \$5.2 billion (DSC, 2025b). Again, while the cost of meeting these restoration targets is high, studies have shown that nature-based solutions are cost-effective solutions for adapting to climate change and reducing disaster risk (Vicarelli et al., 2024).

See Table 4 for a summary of adaptation costs for levee improvements and habitat restoration projects, and the combined total cost range to implement these projects by 2050.

Table 4. Estimated Adaptation Costs for Levee Improvements and Habitat Restoration (DSC, 2025b)

Adaptation Strategy	Low-Cost Scenario	High-Cost Scenario
Improve levees (FL-2)	\$3.2B	\$3.3B
Restore habitats (ECO-1,2)	\$2.5B	\$5.2B
Total Costs	\$5.7B	\$8.5B

Though the funding need is substantial, the cost of inaction is far greater. Research has shown that preparing for disasters reduces the cost of recovery after a disaster strikes. For each dollar invested in adaptation and preparedness, about \$13 in economic costs, damages, and cleanup is saved (U.S. Chamber of Commerce et al., 2024). Because the benefits of adaptation are difficult to monetize, the actual economic benefits are likely even higher (Brandon et al., 2025).

¹⁹ The State's Nature Based Solutions climate targets call for restoration of 72,672 acres by 2045 (28,624 of brackish and freshwater tidal and 44,048 of managed wetlands and rice) (CNRA, 2024).



Case Study: Jones Tract Levee Breach

A powerful illustration of the cost and complexity associated with levee failure is the Jones Tract levee breach. In June 2004, a breach occurred on Upper Jones Tract under calm summer weather conditions, not during a high-flow event, storm, or extreme tide. Local emergency responders, state agencies, federal partners, and reclamation districts mobilized immediately to protect life, property, and regional water supply reliability.

Because Jones Tract sits within the heart of the Delta, the response required more than simply closing the breach. To protect statewide drinking water and agricultural supplies, DWR and the U.S. Bureau of Reclamation reduced pumping at the South Delta export facilities to avoid drawing salty Bay water into the inland water supply. Water was also released from upstream reservoirs to help stabilize salinity levels and maintain water quality standards in the Delta (DSC, 2021c). Meanwhile, DWR worked to reinforce interior levees to prevent secondary failures (DSC, 2021c).

Repairing the breach and pumping the island dry took more than six months and cost approximately \$90 million, or about \$155 million in today's dollars (DSC, 2021c). Importantly, this was the cost of one island, under favorable weather and flow conditions, and with no loss of life. The event demonstrated that a single failure could trigger ripple effects across California's water supply, agricultural economy, transportation networks, and local communities. Proactive levee investment is significantly more cost-effective than response and recovery.

Research and Data Gaps

Major scientific advances in the last five to ten years have improved sub-seasonal forecasting for extreme events (down to two to three weeks), provided better understanding of rare events driving system-wide changes, increased recognition of flash droughts and the connection to wildfires, and enhanced climate model reliability assessment (Delta ISB, 2025a). However, major research and data gaps remain, and scarce resources are available to address them. Some of these gaps are highlighted below.

Major Uncertainties & Needs

Despite recent advances in science, some major uncertainties remain, including (Delta ISB, 2025a):

- **Pacific Decadal Oscillation and El Niño Southern Oscillation changes under warming:** Climate models have historically suggested an El Niño-like trend in the tropical Pacific under climate change, meaning they predicted



greater warming in the eastern tropical Pacific compared to the west. However, real-world observations through 2025 have shown a La Niña-like trend, which is the opposite of what many models predicted. This discrepancy raises significant uncertainty about future changes in atmospheric circulation.

- **Dynamic vs. thermodynamic precipitation changes:** While the fundamental mechanisms governing moisture holding capacity are well understood (i.e., thermodynamic change), the large-scale drivers of storm patterns remain highly uncertain (i.e., dynamic changes)
- **Medieval drought recurrence potential:** The uncertainties surrounding the recurrence potential of Medieval droughts, or extremely rare droughts, center on the inability of current climate models and scientific understanding to explain their extreme persistence.
- **Infrastructure vulnerability assessment:** Assessing vulnerability is challenging due to aging, complex infrastructure, and location-specific factors. One major concern is the potential for cascading effects, which are difficult to predict and understand. For example, there is a significant risk that a major flood could occur within 18 months of an earthquake that weakens levees.
- **Ecosystem tipping points and forest transitions:** Around mid-century, the forests of the Sierra Nevada are predicted to transition out of their natural climate regime. They are projected to move into a climate regime more conducive to the shrublands and brushlands currently found in Southern California. The consequences of that transition after the tipping point occur are not well understood.

Furthermore, there is an urgent need to bridge the gap between science and decision-making. Several strategies to connect science to current operational practices include:

- **The need to consider the extremes and not rely on averages.** Extreme events are the new normal. More than ever, there is a need to avoid using average data to inform management.
- **The need for better engagement and co-production of knowledge with interested parties.** Engagement in adaptive management is crucial. In particular, “after-action reviews” by interested parties reveal the effectiveness of adaptations from multiple perspectives.
- **Insufficient cross-agency coordination.** There is a need to integrate model results in a way that is informative for multi-objective management. There are benefits to sharing capacity, which improve efficiency and avoid duplication of effort.
- **Limited integration of compound risks (climate, seismic, and subsidence).** Compound risks can be ignored but may be valuable for improving risk mitigation strategies or for understanding the benefits of isolated actions.



- **Lack of end-user focus on tool development.** Tools are not easy for all types of scientists to use. This has resulted in some tools being developed but not being used.

As climate threats intensify, improving coordination, aligning tools with user needs, and integrating science into daily operations will be critical for building resilience in the Delta. Without proactive action, the region risks being unprepared for the compounding and accelerating impacts of climate change. Luckily, some work is being done to address these gaps. As an example, CNRA funded a project through California's Fifth Assessment that assessed how flood potential from isolated atmospheric rivers and co-occurring events may evolve under warming, using multiple modeling approaches to examine changes in key flood drivers (precipitation, snowpack, and soil moisture) and their impacts on managed hydrologic systems in Northern California. Results indicate a ~15% increase in annual precipitation, with a larger share from more extreme and clustered events (Rhoades et al., 2026).

Decision-Making Under Deep Uncertainty

Decision-Making under Deep Uncertainty (DMDU) offers a framework for addressing complex situations characterized by limited historical precedent, multiple plausible futures, and high-stakes outcomes (Delta ISB, 2024). "Deep Uncertainty" is defined as unpredictable events or system variability that cannot be well characterized with existing data, models, and understanding. Often, there is little or no agreement among interested parties on how systems are likely to behave or the probabilities of occurrence of such events, including the duration, sequence, and co-occurrence of events (Delta ISB, 2024). This leads to disagreement over what to do with the modeling results. DMDU offers a path forward to achieving greater agreement on which extremes to plan for by focusing on the outcomes everyone wants to avoid.

Science Action Agenda

The Science Action Agenda (SAA) is a list of research priorities for the Delta developed by and for the Delta community. The SAA outlines 25 priority science actions needed to address six specific Delta management needs and to fill knowledge gaps. One focus of the SAA is to "assess and anticipate impacts of climate change and extreme events to support successful adaptation strategies." According to a recent progress summary, seven funded projects are contributing to this management need. One project, "FutureTracts: Leveraging Agent-Based Models to Forecast Land Use Changes in California's Central Valley," aims to explore strategic land-use modifications across different climate scenarios to meet socio-economic goals.



The current implementation of the SAA highlights progress and opportunities to continue investing in research that prioritizes critical gaps in the Delta. The cost of implementing the full 2022-2026 SAA is estimated at \$80 to 90 million, and so far, the Council and State Water Contractors have invested \$16 million in implementation. Researchers are encouraged to explore the research priorities in the SAA, explore collaborations in the Delta Science Tracker, and seek funding opportunities from the Council's Delta Science Program and other funding partners (e.g., [Delta Research Awards](#)).²⁰

Biogeochemistry of Greenhouse Gas Emissions and Carbon Sequestration

Reducing GHG emissions and enhancing carbon sequestration are important benefits that can be associated with efforts to halt and reverse land subsidence in the Delta. While the basic GHG chemistry of peat soils is well understood, uncertainties remain in predicting how these systems will respond to different management interventions (Windham-Myers et al., 2023). As highlighted by the Delta ISB (2025b), subsidence management strategies, such as rice cultivation, managed freshwater wetlands, and wetland restoration, present trade-offs among subsidence reversal, GHG emissions, and carbon sequestration potential. In addition to carbon dioxide (CO₂), two other GHGs of concern in peat soil management are methane (CH₄) and nitrous oxide (N₂O). Inundating peat soils generally reduces the microbial oxidation of organic matter that produces CO₂, but it can create conditions of low oxygen availability that contribute to the generation of CH₄ and N₂O - potent global warming gases (Delta ISB, 2025b). Nevertheless, some inundated sites can sequester N₂O, depending on soil carbon content and fertilization (Ye & Howard, 2016; Ye et al., 2016).

In its review of subsidence, the Delta ISB emphasized the need for a comprehensive portfolio of analysis and modeling to address critical questions about maximizing carbon sequestration and minimizing GHG emissions. Such tools are essential for enabling farmers and land managers to fine-tune practices on subsiding lands (Delta ISB, 2025b). Effective wetland management for GHG reduction requires a holistic approach that accounts for multiple GHGs rather than focusing solely on CO₂ (Stein & Lidstrom, 2024). Key priorities identified by the Delta ISB for advancing subsidence management in the near term include:

1. Improve understanding of the processes driving spatial and temporal variability in CH₄ and N₂O emissions, and how these processes evolve over time.
2. Develop land management strategies to enhance the accumulation and stabilization of organic carbon in wetland soils, especially those that also limit methane production.
3. Advance predictive modeling tools to assess land use and management scenarios, valuable for identifying where the climate benefits of carbon

20 Visit the Snapshot and Delta Science Tracker to learn more about projects funded by the DSP.



sequestration in managed freshwater wetlands outweigh the warming impacts of CH₄ emissions (Kroeger et al., 2017).

The Delta as an Evolving Place

The Delta Reform Act requires that the coequal goals of water supply reliability and habitat restoration “be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place” (Water Code, § 85054.). In a 2017 review, the Delta ISB found that research on the social and natural processes that sustain the unique values of the Delta as an evolving place is sparse and sporadic. The Delta ISB recommended an expanded, sustained commitment to research on the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place (Delta ISB, 2017). Decisions based solely on the natural sciences can fall short if they exclude perspectives from the social sciences and humanities, which are essential for understanding the full complexity of the region (Delta ISB, 2017). Disciplines like economics help assign value in monetary terms and should be recognized as integral parts of science.

Over the years, the Council has led critical advances in supporting the social sciences in understanding the Delta as an evolving place.²¹ For example, in 2023, a research team funded by the Council conducted a Delta Residents Survey to understand how residents in and around the Delta feel about where they live, their quality of life, and their concerns around climate change (Rudnick et al., 2023). The survey found that over three-quarters of respondents believe in climate change, and over half were concerned about the impacts of heat waves and droughts (Rudnick et al., 2023). However, relative to other issues in the Delta, such as aging infrastructure, limited transportation options, affordability, and public safety, climate change is not seen as a priority (Rudnick et al., 2023). The survey is a crucial step in understanding local perspectives, but more work is needed to involve Delta communities in science and decision-making.

Funding Future Climate Solutions

The State of California has advanced numerous funding initiatives to implement climate solutions. On November 5, 2024, California voters approved a \$10 billion general obligation climate bond: the Safe Drinking Water, Wildfire Prevention, Drought Preparedness, and Clean Air Bond Act of 2024, also known as the 2024 Climate Bond. Other funding sources that could support climate adaptation projects in the Delta include CDFA’s Healthy Soils Program, CDFA’s State Water Efficiency and Enhancement Program, Wildlife Conservation Board’s Streamflow Enhancement

21 More information about the Council’s work on integrating the social sciences can be found on the Council’s Social Science Integration webpage.



Program, CalFire's Wildfire Prevention Program, CNRA's Urban Greening Program, the Department of Conservation's Working Lands and Riparian Corridors Program, and more. However, funding is still insufficient to fill the financial gaps identified in this report.

The Delta Conservancy is working with the Delta community and its partner agencies to identify priority projects and seek additional funding sources to advance adaptation strategies. For example, the Conservancy is working with the Delta Resource Conservation Districts, California Conservation Corps, and state funders to implement projects in the Delta as soon as funding is available. The Delta Conservancy is also working toward increasing Tribal engagement in the Delta and seeking funding to support their leadership in restoration and adaptation projects. Finally, the Delta Conservancy is partnering with the Nature Conservancy to identify additional revenue streams to implement nature-based solutions and address subsidence at scale in the Delta.

Even with these ongoing efforts, the Delta requires significant additional investment to adapt to climate change. Implementing climate solutions in the Delta will have statewide benefits to water supply, water quality, agriculture, native species such as salmon, and more, whereas insufficient funding of adaptation in the Delta could dramatically impact the rest of the State. More investment in the Delta is needed to address existing deficits in infrastructure and ecosystem health, while also keeping pace with the changing climate. The Delta agencies are committed to communicating Delta funding priorities and furthering partnerships to support the region's continued resiliency.



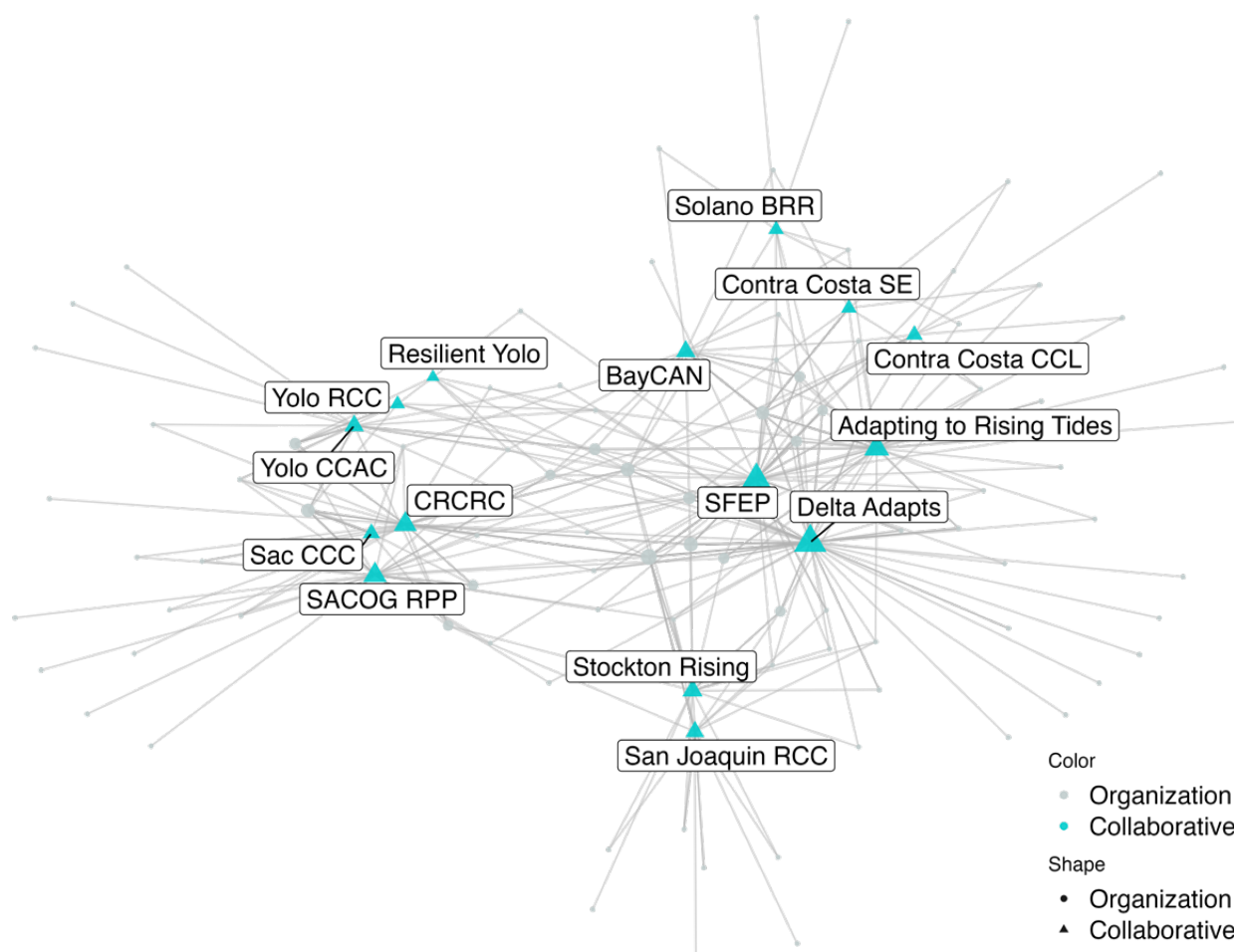
V. Adaptation Governance in the Delta

Adaptation governance determines the process by which organizations plan, fund, implement, and manage climate adaptation within existing and evolving legal frameworks and authorities. Resource management decisions in the Delta have been historically distributed across hundreds of agencies, institutions, and interested parties, often with conflicting visions. In recognition of the Delta's complex governance system, the Delta Reform Act created the Council to direct efforts across state agencies, and "establish and oversee a committee of agencies responsible for implementing the Delta Plan," known as the DPIIC (Water Code, §§ 85001, 85204.). DPIIC is comprised of 18 state and federal agencies and a restoration subcommittee, which are focused on increasing alignment of agency actions across the Delta, reducing barriers to restoration, and reporting Delta science and restoration expenditures, amongst other initiatives. To date, DPIIC membership has consisted solely of state and federal partners; however, the Delta Plan recommends that the restoration subcommittee include Tribal representation, and this is a recognized need for the committee moving forward (DSC, 2022).

While DPIIC serves a critical role in the Delta and interagency science efforts and collaboration in the Delta have improved in recent years to address climate change, they still fall short of what is needed to support science-driven policies and solutions (Delta ISB, 2019). The Delta faces complex, interconnected, and rapidly evolving management challenges that often cross the boundaries of individual agency mandates, requiring a more integrated and robust scientific approach. Recent work suggests that governance that is anticipatory, adaptive, and flexible is more effecting at addressing climate issues, including the scientific uncertainty of future projections (Colombano et al., 2025).

Pozzi et al.'s (2025) adaptation practitioner research reveals barriers and pathways to successful collaboration. The top barriers include competing visions for adaptation, limited capacity, and lack of political leadership (Pozzi et al., 2025). The Council was created in part to provide direction and facilitate coordination while advancing the coequal goals, and Delta Adapts already connects a significant portion of the adaptation practitioners in the region, ranking the highest in participation of 15 climate initiatives – see **Figure 31** (Pozzi et al., 2025).

Figure 31. Network Plot Illustrating Connections to Delta Adapts (Pozzi et al., 2025).



Network plot illustrating climate adaptation collaborative forum participation in the Delta and connections between each collaborative group/initiative, including connections with Delta Adapts (Pozzi et al., 2025).

In 2019, the Council adopted a set of Climate Change Resilience Goals at the onset of the Delta Adapts initiative, which builds on the state's coequal goals for the Delta and the Council's work to develop its Tribal and Environmental Justice Issue Paper, which recognizes how Tribes and Tribal and environmental justice communities have been marginalized and excluded from decision-making processes. Inclusive, accessible, authentic engagement and representation in decision-making processes²² and planning are a necessary step to distributional equity, which is the fair distribution of benefits and burdens across all segments of a community, prioritizing those with the greatest need (USDN, 2014). The Council's Climate Change Resilience Goals, specific

²² See Section 1.2 of the [Delta Adapts Adaptation Plan](#) for the full list of Resilience Goals and the [Tribal and Environmental Justice Issue Paper](#) for more context surrounding historical Tribal and environmental justice issues, including inadequate representation.



to governance and improving equitable representation, are to:

- Foster collaboration and build capacity among federal, State, and local agencies, Tribes and Tribal communities, and non-governmental and private organizations, in the Delta.
- Serve as a model for how to restore trust and participation of communities in government.
- Commit to working cooperatively to identify and mitigate climate change impacts and risks.
- Improve coordination among regulatory agencies to reduce programmatic or legal barriers to address current and future floods, drought, wildfire, and other risks that will be exacerbated by climate change (CA Water Code §§ 85001(c), 85020 (h)).
- Incorporate climate change into State and local Delta planning and investment decisions (Governor's Executive Order B-30-15).
- Prioritize actions that incorporate natural and green infrastructure solutions (Governor's Executive Order B-30-15).
- Explain the Council's role in coordinating adaptation responses in the Delta.

These resilience goals support the near-term creation of a work group centered around the Adaptation Plan's strategies and the implementation of adaptation across the Delta. The Council is planning to convene a Delta Climate Adaptation Team in 2026, consistent with procedural and representational equity, that would foster collaboration, build capacity, and provide scaffolding for more diverse and robust participation in adaptation discussions from federal, Tribal, State, and local entities in the Delta. The DCAT would expand participation beyond federal and State government by engaging with those who have been historically excluded from the public process, including Tribes and environmental justice communities.

California Relies on the Delta

This report brings together the Delta agencies' collective understanding of climate change in the Delta today – including projections, vulnerabilities, research gaps, and the funding and partnerships needed to support adaptation. Our agencies remain committed to advancing and applying science to help the Delta respond to a changing climate, benefiting current and future generations.

Climate change poses significant and growing risks to the Delta and the state as a whole – affecting Tribes with ancestral ties to the region, aging water infrastructure, fragile ecosystems, farmers, and numerous communities across the state that rely on Delta water. Addressing these challenges will require integrating diverse perspectives and knowledge systems to support coordinated, long-term resilience. The Delta



Stewardship Council's Delta Adapts Adaptation Plan provides one framework for addressing these challenges, and through its implementation, state and federal agencies, as well as regional and local entities, can collectively create a Delta ready for the future.

To learn more about this report or the Council's Delta Adapts initiative, please visit our website or contact the Council at climatechange@deltacouncil.ca.gov.



Terms Used Within this Report

Adaptation: An action or set of actions that reduces climate risk.

Climate model: Climate models use quantitative methods to simulate the interactions among the important drivers of climate, including the atmosphere, oceans, land surface, and ice. Climate models are used for a variety of purposes, from the study of the dynamics of the climate system to projections of future climate.

Climate scenario: A coherent, plausible, and internally consistent description of possible climatic conditions. It is not a forecast; instead, each scenario is one alternative image of how the climate can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions).

Downscaling: The general name for a procedure to take information known at large scales to make predictions at local scales. The two main approaches to downscaling climate information are dynamical and statistical.

Equity (climate): The state or quality of being just and fair in the way people are treated. The equity challenges for climate change policy involve several core issues: 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 how climate policy intersects with other dimensions of human development, both globally and domestically.

Evaporative demand: The loss of water from the surface of the Earth from plants, soil, and bodies of water (CNAP, 2022).

Hazard: “The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources” (IPCC, 2023).

Indigenous Stewardship: The act of tending to the environment and enhancing natural processes to create a functional social-ecological system which is sustainable and resilient through time, and supports or is informed by Indigenous leadership, knowledge, and practice.

Impact (climate): An effect of climate change on the structure or function of a system. For example, environmental consequences of climate change, such as extreme heat waves, rising sea levels, changes in precipitation resulting in flooding and droughts, intense hurricanes, and degraded air quality, impact the physical, social, and psychological health of humans.

Mitigation (climate change): A human intervention to reduce the human impact on the climate system; it includes strategies to reduce GHG sources and emissions and



enhance GHG sinks.

Resilience (climate): Resilience describes a state of readiness to face climate risks.

Risk (climate): The combination of an event, its likelihood, and its consequences – i.e., risk equals the probability of climate hazard multiplied by a given system's vulnerability.

Subsidence: Gradual sinking of an area due to land management practices such as groundwater pumping or agricultural cultivation, which causes oxidation and loss of organic soils material.

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” (IPCC, 2023).

Traditional Knowledge (TK): “a body of observations, oral and written knowledge, innovations, practices, and beliefs that promote sustainability and the responsible stewardship of cultural and natural resources through relationships between humans and their landscapes. [It] cannot be separated from the [Indigenous] people inextricably connected to that knowledge” (Daniel et al., 2022). Tribes and knowledge holders may also refer to TK as Indigenous Knowledge and/or use the term Traditional Ecological Knowledge, and each term may hold different meaning for different Tribes and knowledge holders. See the Tribal and Indigenous Communities Report for more information on these knowledge systems.

Traditional Ecological Knowledge (TEK): is sometimes used in collaborative or cross-cultural contexts to discuss the ecological dimensions of Indigenous or Traditional Knowledge, including long-standing understandings of fire behavior, hydrology, species interactions, phenology, soils, and ecosystem dynamics. TEK is inseparable from the communities, cultures, protocols, and responsibilities to place that sustain it. Sometimes referred to as Traditional Environmental Knowledge.

Vulnerability (climate): The degree to which natural, built, and human systems are at risk of exposure to climate change impacts. Vulnerable communities 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 factors, 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 (Vulnerable Communities Platform).

Vulnerable communities: Those that “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, ethnicity, class, gender, sexual orientation, national origin, income inequality, and disability. People facing multiple forms of marginalization and inequality will confront more intense climate change impacts and barriers to recovery” (LCI, 2025).

Watershed: “An area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel” (USGS, 2019). Sometimes used interchangeably with the terms drainage basin or catchment.

Watersheds upstream of the Delta: The large Sacramento and San Joaquin River watersheds, as well as smaller watersheds including the Cosumnes, Mokelumne, and Calaveras Rivers, which drain directly into the Delta.



References

- Abatzoglou, J. (2025). California Fifth Climate Change Assessment Regional Synthesis Reports Climate Analysis Coordination Workgroup. UC Merced.
- Baranes, H., Dykstra, S. L., Jay, D. A., & Talke, S. A. (2023). Sea level rise and the drivers of daily water levels in the Sacramento-San Joaquin Delta. *Scientific Reports*, 13(1), Article 22454.; <https://doi.org/10.1038/s41598-023-49204-z>
- Bland, A. (2025, April 9). *Miles of Delta levees are at risk of floods. Repairs could cost \$3 billion*. CalMatters. <https://calmatters.org/environment/water/2025/04/delta-levees-risk-of-floods-repairs-cost-3-billion/>
- Bouma-Gregson, K., Bosworth, D. H., Flynn, T. M., Maguire, A., Rinde, J., & Hartman, R. (2024). Delta blue(green)s: The effect of drought and drought-management actions on *Microcystis* in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 22(1), Article 2. <https://doi.org/10.15447/sfews.2024v22iss1art2>
- Brandenberg, S. J., Stewart, J. P., Liu, Z., Wang, P., Zimmaro, P., Bachand, S., Deverel, S. J., Diaz, J., Andrews, S., Uhlemann, S., Nico, P., & Ulrich, C. (2022). Next generation multi-hazard levee risk assessment (final report to the Delta Stewardship Council). University of California, Los Angeles.
- Brandon, C., Kratzer, B., Aggarwal, A., Heubaum, H., & Novenario, C. (2025). The compelling investment case for climate adaptation. World Resources Institute. <https://www.wri.org/insights/climate-adaptation-investment-case>
- California Natural Resources Agency (CNRA). (2024). California's nature-based solutions climate targets. <https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Expanding-Nature-Based-Solutions/Californias-NBS-Climate-Targets-2024.pdf>
- California Office of Emergency Health Hazard Assessment (OEHHA). (2023). Winter chill. <https://oehha.ca.gov/climate-change/epic-2022/changes-climate/winter-chill>
- California-Nevada Climate Applications Program. (2022). Evaporative demand. https://cnap.ucsd.edu/wp-content/uploads/sites/430/2022/02/CNAPEvaporativeDemand_final.pdf
- Colombano, D. D., Rudnick, J., Rowlands, N. A., Christman, M. A., Dahm, C. N., Thompson, J.K., & Windham-Myers, L. (2025). Five perspectives to advance science-informed decision-making in the era of climate change and extreme events. *San Francisco Estuary and Watershed Science*, 23(3), Article 1. <https://doi.org/10.15447/sfews.2025v23iss3art1>
- Dahm, C. N., Colombano, D. D., & Dahlgren, R. A. (2025). Recent findings and



prospects for water quality effects from catastrophic wildfires in California, USA. *San Francisco Estuary and Watershed Science*, 23(3), Article 2. <https://doi.org/10.15447/sfews.2025v23iss3art2>

Delta Independent Science Board (ISB). (2016). Workshop report—Earthquakes and high water as levee hazards in the Sacramento-San Joaquin Delta. <https://deltacouncil.ca.gov/pdf/isb/products/2016-09-30-isb-final-levee-workshop-report.pdf>

Delta Independent Science Board (ISB). (2017). Review of research on the Sacramento-San Joaquin Delta as an evolving place. <https://deltacouncil.ca.gov/pdf/isb/products/2017-05-18-isb-delta-as-a-place.pdf>

Delta Independent Science Board (ISB). (2022). Review of water supply reliability estimation related to the Sacramento-San Joaquin Delta. <https://deltacouncil.ca.gov/pdf/isb/products/2022-06-16-isb-water-supply-reliability-review.pdf>

Delta Independent Science Board (ISB). (2025a). Emerging climate science symposium recordings. YouTube. <https://www.youtube.com/playlist?list=PLqTHClIW1Hhp5SLOlOI56o4BkQVqOEwul>

Delta Independent Science Board (ISB). (2025b). Draft review: Science to inform management of subsided lands in the Sacramento-San Joaquin Delta. <https://deltacouncil.ca.gov/pdf/isb/meeting-materials/2024-07-02-draft-isb-review-subsidence.pdf>

Delta Protection Commission (DPC). (2012). Economic sustainability plan for the Sacramento-San Joaquin Delta. <https://delta.ca.gov/wp-content/uploads/2021/05/Delta-Economic-Sustainability-Plan-2012-508.pdf>

Delta Protection Commission (DPC). (2020). The state of Delta agriculture: Economic impact, conservation, and trends. <https://delta.ca.gov/wp-content/uploads/2020/07/Ag-ESP-update-agricultural-trends-FINAL-508.pdf>

Delta Protection Commission (DPC). (2025). Sacramento-San Joaquin Delta National Heritage Area. <https://delta.ca.gov/NHA/>

Delta Stewardship Council (DSC). (2021a). Delta adapts: Creating a climate resilient future: Vulnerability assessment. <https://deltacouncil.ca.gov/pdf/delta-plan/2021-06-25-delta-adapts-vulnerability-assessment.pdf>

Delta Stewardship Council (DSC). (2021b). Delta adapts: Creating a climate resilient future: Equity technical memorandum. <https://deltacouncil.ca.gov/pdf/delta-plan/2021-06-16-equity-technical-memorandum.pdf>

Delta Stewardship Council (DSC). (2021c). Delta adapts: Creating a climate resilient future: Water supply technical memorandum. <https://www.deltacouncil.ca.gov/pdf/delta-plan/2021-06-16-water-supply-technical-memorandum.pdf>

Delta Stewardship Council (DSC). (2021d). Delta adapts: Creating a climate resilient



- future: Crop yield and agricultural production technical memorandum. <https://deltacouncil.ca.gov/pdf/delta-plan/2021-06-07-crop-yield-and-agricultural-production-technical-memorandum.pdf>
- Delta Stewardship Council (DSC). (2022). The Delta Plan, chapter 4: Protect, restore, and enhance the Delta ecosystem. <https://deltacouncil.ca.gov/pdf/delta-plan/2022-06-29-chapter-4-protect-restore-and-enhance-the-delta-ecosystem.pdf>
- Delta Stewardship Council (DSC). (2024a). Delta Plan Executive Summary. <https://deltacouncil.ca.gov/pdf/delta-plan/2024-01-31-amended-executive-summary.pdf>
- Delta Stewardship Council (DSC). (2024b). Delta levees, output performance measure 7.3. <https://viewperformance.deltacouncil.ca.gov/index.php/pm/delta-levees>
- Delta Stewardship Council (DSC). (2024c). The Delta Plan, chapter 7: Reduce risk to people, property, and State interests in the Delta (as amended in 2024). <https://deltacouncil.ca.gov/pdf/delta-plan/2024-01-30-chapter-7.pdf>
- Delta Stewardship Council (DSC). (2025a). Tribal and environmental justice in the Sacramento-San Joaquin Delta: History, current perspectives, and recommendations for a way forward. <https://deltacouncil.ca.gov/pdf/2025-04-24-tribal-and-environmental-justice-in-the-sacramento-san-joaquin-delta-issue-paper.pdf>
- Delta Stewardship Council (DSC). (2025b). Delta adapts: Creating a climate resilient future: Adaptation plan. <https://www.deltacouncil.ca.gov/pdf/delta-plan/2025-06-26-delta-adapts-adaptation-plan.pdf>
- Department of Water Resources (DWR). (2009). Executive summary, phase 1: Delta risk management strategy. https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/SJRECWA/sjrecwa_3.pdf
- Deverel, S. J., Dore, S., & Schmutte, C. (2020). Solutions for subsidence in the California Delta, USA, an extreme example of organic-soil drainage gone awry. *Proceedings of the International Association of Hydrological Sciences*, 382, 837–842. <https://doi.org/10.5194/piahs-382-837-2020>
- Deverel, S. J., Ingram, T., Lucero, C., & Drexler, J. Z. (2014). Impounded marshes on subsided islands: Simulated vertical accretion, processes, and effects, Sacramento-San Joaquin Delta, CA, USA. *San Francisco Estuary and Watershed Science*, 12(2), Article 5. <https://doi.org/10.15447/sfews.2014v12iss2art5>
- Diez, J. M., D'Antonio, C. M., Dukes, J. S., Grosholz, E. D., Olden, J. D., Sorte, C. J., Blumenthal, D. M., Bradley, B. A., Early, R., Ibáñez, I., Jones, S. J., Lawler, J. J., & Miller, L. P. (2012). Will extreme climatic events facilitate biological invasions? *Frontiers in Ecology and the Environment*, 10(5), 249–257. <https://doi.org/10.1890/110137>
- Diffenbaugh, N. S., Swain, D. L., & Touma, D. (2015). Anthropogenic warming has



- increased drought risk in California. *Proceedings of the National Academy of Sciences*, 112(13), 3931–3936. <https://doi.org/10.1073/pnas.1422385112>
- DWR. (2009). Using future climate projections to support water resources decision making in California. https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/PCFFA_71_Chung.pdf
- DWR. (2014). Delta levees special flood control projects: 2014 guidelines for providing funding to local public agencies. <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Work-With-Us/Grants-And-Loans/Delta-Levees-Special-Flood-Control-Projects/Files/2014-Guidelines.pdf>
- DWR. (2016). Delta levees maintenance subventions program: 2016 guidelines. <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Work-With-Us/Grants-And-Loans/Delta-Levees-Maintenance-Subventions/Files/08-26-16-Subventions-Guidelines.pdf>
- DWR. (2017). Flood system long-term operations, maintenance, repair, replacement, and rehabilitation cost evaluation. 2017 Central Valley flood protection plan update.
- DWR. (2024). The State Water Project delivery capability report 2023. https://data.cnra.ca.gov/dataset/a3bb1ddd-624b-4c3d-95e7-2aa6b3bf2b5b/resource/92356681-957a-48ee-97c4-529d25b9dbb2/download/final_dcr2023_v2.pdf
- DWR. (2025a). Compilation of 2018 Delta levee five-year plan data. <https://water.ca.gov/-/media/DWR-Website/Web-Pages/Work-With-Us/Grants-And-Loans/Delta-Levees-Special-Flood-Control-Projects/Files/Compilation-of-2018-Delta-Levees-Five-Year-Plan-Data.pdf>
- DWR. (2025b). San Joaquin basin Flood-MAR watershed studies. <https://cadwr.app.box.com/s/1mmbblsok46ljheicf0kmfx7q3hhhng2>
- DWR. (2025c). The State Water Project draft delivery capability report 2025. Sacramento, CA. Retrieved on February 10, 2026 from <https://data.cnra.ca.gov/dataset/state-water-project-delivery-capability-report-dcr-2025/resource/5d238ff5-899b-4357-8835-5b043f61f5da>
- DWR. (N.d. a). *State Water Project*. California Department of Water Resources. Retrieved on August 1, 2025, from <https://water.ca.gov/programs/state-water-project>
- DWR. (N.d. b). *Delta levees special flood control projects*. California Department of Water Resources. Retrieved on August 5, 2025, from <https://water.ca.gov/Work-With-Us/Grants-And-Loans/Delta-Levees-Special-Flood-Control-Projects>
- Eller, F., Lambertini, C., Nguyen, L. X., & Brix, H. (2014). Increased invasive potential of non-native *Phragmites australis*: Elevated CO₂ and temperature alleviate salinity



- effects on photosynthesis and growth. *Global Change Biology*, 20(2), 531–543. <https://doi.org/10.1111/gcb.12346>
- Feinstein, L., Phurisamban, R., Ford, A., Tyler, C., & Crawford, A. (2017). Drought and equity in California. Pacific Institute. https://pacinst.org/wp-content/uploads/2017/01/PI_DroughtAndEquityInCA_Jan_2017.pdf
- Gaertner, M., Biggs, R., Te Beest, M., Hui, C., Molofsky, J., & Richardson, D. M. (2014). Invasive plants as drivers of regime shifts: Identifying high-priority invaders that alter feedback relationships. *Diversity and Distributions*, 20(7), 733–744. <https://doi.org/10.1111/ddi.12182>
- Gershunov, A., Hatchett, B., Weyant, A., Dettinger, M., Su, L., Rhoades, A., Williams, P., Anderson, M., Rittelmeyer, P., Lettenmayer, D., Cayan, D., Niño, R. L., Guirguis, K., Corringham, T., Maendly, R., & Ralph, F. M. (2025). Atmospheric rivers and floods in California's changing hydroclimate. *San Francisco Estuary and Watershed Science*, 23(3), Article 3. <https://doi.org/10.15447/sfews.2025v23iss3art3>
- Governor's Office of Land Use and Climate Innovation (LCI). (2025). Climate equity and vulnerable communities. Governor's Office of Land Use and Climate Innovation. Retrieved on February 2, 2026, from <https://lci.ca.gov/climate/icarp/vulnerable-communities.html>
- Governor's Office of Land Use and Climate Innovation (LCI). (2026). Statewide Summary. California's Fifth Climate Change Assessment.
- Greene, C. (2018). Broadening understandings of drought – The climate vulnerability of farmworkers and rural communities in California (USA). *Environmental Science & Policy*, 89 (283–291). <https://doi.org/10.1016/j.envsci.2018.08.002>
- Hankins, D. L. (2024). Climate resilience through ecocultural stewardship. *Proceedings of the National Academy of Sciences*. 121(32), Article e2310072121. <https://doi.org/10.1073/pnas.2310072121>
- Harke, M. J., Steffen, M. M., Gobler, C. J., Otten, T. J., Wilhelm, S. W., Wood, S. A., & Paerl, H. W. (2016). A review of the global ecology, genomics, and biogeography of the toxic cyanobacterium, *Microcystis* spp. *Harmful Algae*, 54, 4–20. <https://doi.org/10.1016/j.hal.2015.12.007>
- Hatch, R., Falcon, R., & Lopez, N. (2026). Building an inclusive future: a participatory approach to transformative climate change resilience. California's Fifth Climate Change Assessment, California Natural Resources Agency.
- Hatchett, B. J., Daudert, B., Garner, C. B., Oakley, N. S., Putnam, A. E., & White, A. B. (2017). Winter snow level rise in the Northern Sierra Nevada from 2008 to 2017. *Water*, 9(11), Article 899. <https://doi.org/10.3390/w9110899>
- Heyser, H. (2025). Rice: The other climate- and wildlife-friendly solution for the Delta. <https://delta.ca.gov/delta-rice/>



- Hopf, F. (2011). Levee failure modes and influences on flood risk in the Sacramento-San Joaquin Delta. <https://cawaterlibrary.net/wp-content/uploads/2023/10/HOPF-DISSERTATION.pdf>
- Intergovernmental Panel on Climate Change (IPCC). [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. (2019). Summary for policymakers. In: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems https://www.ipcc.ch/site/assets/uploads/2019/11/02_Summary-for-Policymakers_SPM.pdf
- IPCC (2023). Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001
- IPCC. [Reisinger, A., D. Cammarano, A. Fischlin, J.S. Fuglestedt, G. Hansen, Y. Jung, C. Ludden, V. Masson-Delmotte, R. Matthews, J.B.K. Mintenbeck, D.J. Orendain, A. Pirani, E. Poloczanskaa, & J. Romero (eds.)]. (2023). Annex I: Glossary in: Climate change 2023: synthesis report. IPCC, Geneva, Switzerland, pp. 119-130, doi: [10.59327/IPCC/AR6-9789291691647.002](https://doi.org/10.59327/IPCC/AR6-9789291691647.002).
- Jones, S. F., Schutte, C. A., Roberts, B. J., & Thorne, K. M. (2022). Seasonal impoundment management reduces nitrogen cycling but not resilience to surface fire in a tidal wetland. *Journal of Environmental Management*, 303, Article 114153. <https://doi.org/10.1016/j.jenvman.2021.114153>
- Knowles, N., Cronkite-Ratcliff, C., Pierce, D. W., & Cayan, D. R. (2018). Responses of unimpaired flows, storage, and managed flows to scenarios of climate change in the San Francisco Bay-Delta watershed. *Water Resources Research*, 54(10), 7631-7650. <https://doi.org/10.1029/2018WR022852>
- Kroeger, K. D., Crooks, S., Moseman-Valtierra, S., & Tang, J. (2017). Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. *Scientific Reports*, 7(1), Article 11914. <https://doi.org/10.1038/s41598-017-12138-4>
- Kudela, R. M., Howard, M. D., Monismith, S., & Paerl, H. W. (2023). Status, trends, and drivers of harmful algal blooms along the freshwater-to-marine gradient in the San Francisco Bay-Delta system. *San Francisco Estuary and Watershed Science*, 20(4), Article 6. <https://doi.org/10.15447/sfews.2023v20iss4art6>
- Lehman, P. W., Kurobe, T., & Teh, S. J. (2022). Impact of extreme wet and dry years on the persistence of *Microcystis* harmful algal blooms in San Francisco



- Estuary. *Quaternary International*, 621, 16–25. <https://doi.org/10.1016/j.quaint.2019.12.003>
- Lehman, P. W., Kurobe, T., Lesmeister, S., Baxa, D., Tung, A., & Teh, S. J. (2017). Impacts of the 2014 severe drought on the *Microcystis* bloom in San Francisco Estuary. *Harmful Algae*, 63, 94–108. <https://doi.org/10.1016/j.hal.2017.01.011>
- Liu, Z. (2024). Seismic risk assessment of spatially distributed levee system in the Sacramento-San Joaquin Delta. *UCLA*. <https://escholarship.org/uc/item/25r3275x>
- Lobell, D. B., & Field, C. B. (2011). California perennial crops in a changing climate. *Climatic Change*, 109(S1), 317–333. <https://doi.org/10.1007/s10584-011-0303-6>
- Mahardja, B., Bashevkin, S. M., Pien, C., Khanna, S., Pearson, D., Davis, B., & Basu, R. (2025). Heatwaves and rising temperatures in the upper San Francisco Estuary: Trends and effects on ecosystems and humans. *San Francisco Estuary and Watershed Science*, 23(1), Article 4. <https://doi.org/10.15447/sfews.2025v23iss1art4>
- Maven's Notebook. (2024a, August 14). *Central Valley Project*. Maven's Notebook. <https://mavensnotebook.com/explainers/where-does-californias-water-come-from/central-valley-project/>
- Maven's Notebook. (2024b, November 20). *Delta Stewardship Council: The economic and environmental imperatives of Delta levees*. Maven's Notebook. <https://mavensnotebook.com/2024/11/20/delta-stewardship-council-the-economic-and-environmental-imperatives-of-delta-levees/>
- McLellan, N. L., & Manderville, R. A. (2017). Toxic mechanisms of microcystins in mammals. *Toxicology Research*, 6(4), 391–405. <https://doi.org/10.1039/c7tx00043j>
- Meadows, R. (2025a, June 19). *Partnering with tribes to restore a Delta wetland: Benefits go both ways*. Maven's Notebook. <https://mavensnotebook.com/2025/06/19/notebook-feature-partnering-with-tribes-to-restore-a-delta-wetland-benefits-go-both-ways/>
- Meadows, R. (2025b, December 9). *The biggest threat to the Delta you've (probably) never heard of*. Maven's Notebook. <https://mavensnotebook.com/2025/12/09/sediment-the-biggest-threat-to-the-delta-youve-probably-never-heard-of/>
- Metropolitan Water District of Southern California (Metropolitan). Multi-benefit landscape restoration on Webb Tract. <https://d1q0afiq12ywwq.cloudfront.net/media/1d5nktxz/webb-tract-multi-benefit-landscape-fact-sheet-final-web-1262026.pdf>
- Michael, J., Howitt, R., Medellín-Azuara, J., & MacEwan, D. (2010). A retrospective estimate of the economic impacts of reduced water supplies to the San Joaquin Valley in 2009. *University of the Pacific*. <https://www.pacificcbpr.org/wp-content/uploads/2022/07/September-2010-A-Retrospective-Estimate-of-the-Economic->



[Impacts-of-Reduced-Water-Supplies-to-the-San-Joaquin-Valley-in-2009-SJV_Rev_Jobs_2009_092810-1.pdf](#)

- Mount, J., & Twiss, R. (2005). Subsidence, sea level rise, and seismicity in the Sacramento-San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 3(1), Article 7. <https://escholarship.org/uc/item/4k44725p>
- Mount, J., Hanak, E., & Gartell, G. (2022, May). The Sacramento-San Joaquin Delta. Retrieved on November 5, 2025, from <https://www.ppic.org/publication/the-sacramento-san-joaquin-delta/>
- Moyle, P. B., Kiernan, J. D., Crain, P. K., & Quiñones, R. M. (2013). Climate change vulnerability of native and alien freshwater fishes of California: A systematic assessment approach. *PLoS ONE*, 8 (5), Article e63883. <https://doi.org/10.1371/journal.pone.0063883>
- Najibi, N. & Steinschneider, S. (2023). A process-based approach to bottom-up climate risk assessments: Developing a statewide, weather-regime based stochastic weather generator for California. *Biological and Environmental Engineering Cornell University*. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Resources-for-Water-Managers/Files/WGENCalifornia_Final_Report_final_20230808.pdf
- Najibi, N., Perez, A. J., Arnold, W., Schwarz, A., Maendly, R. & Steinschneider, S. (2024). A statewide, weather-regime based stochastic weather generator for process-based bottom-up climate risk assessments in California – Part I: Model evaluation. *Climate Services*, 34. <https://doi.org/10.1016/j.cliser.2024.100489>
- National Academies of Sciences, Engineering, and Medicine (NAS). (2025). Review of the long-term operations of the Central Valley Project and the State Water Project. Washington, DC: *The National Academies Press*. <https://doi.org/10.17226/29130>
- Norris, J. (2025). California Fifth Climate Change Assessment Regional Synthesis Reports Climate Analysis Coordination Workgroup. UC Los Angeles.
- Ocean Protection Council (OPC). (2024). State of California sea level rise guidance: 2024 science and policy update. <https://opc.ca.gov/wp-content/uploads/2024/05/California-Sea-Level-Rise-Guidance-2024-508.pdf>
- Oregon Climate Change Research Institute (OCCRI). (2025). Tribal climate adaptation guidebook. <https://tribalclimateadaptationguidebook.org/>
- Paerl, H. W. (2018). Mitigating toxic planktonic cyanobacterial blooms in aquatic ecosystems facing increasing anthropogenic and climatic pressures. *Toxins*, 10(2), Article 76. <https://doi.org/10.3390/toxins10020076>
- Pathak, T. B., Maskey, M. L., Dahlberg, J. A., Kearns, F., Bali, K. M., & Zaccaria, D. (2018). Climate change trends and impacts on California agriculture: A detailed review. *Agronomy*, 8(3), Article 25. <https://doi.org/10.3390/agronomy8030025>



- Pierce, D. (2025). *LOCA statistical downscaling (localized constructed analogs)*. Scripps Institution of Oceanography. <https://loca.ucsd.edu/>
- Pozzi, T., Lubell, M., & Correa, L. (2025). The governance of climate adaptation in the California Delta. *Center for Environmental Policy and Behavior, UC Davis*. https://tarapozzi.shinyapps.io/delta_adaptation/
- Preece, E. P., Paerl, H. W., Plaas, H. E., & Cooke, J. (2025). From drought to deluge: hydrologic extremes alter nutrient-driven harmful cyanobacterial blooms. *Environmental Pollution*, 382, Article 126731. <https://doi.org/10.1016/j.envpol.2025.126731>
- Preece, E., Berg, M., Lee, T., Odkins, K., & Rinde, J. (2024). Cyanobacterial harmful algal bloom monitoring strategy for the Sacramento-San Joaquin Delta. <https://deltacouncil.ca.gov/pdf/science-program/2024-10-21-final-delta-chabs-monitoring-strategy.pdf>
- Pyšek, P., Hulme, P. E., Simberloff, D., Bacher, S., Blackburn, T. M., Carlton, J. T., Dawson, W., Essl, F., Foxcroft, L. C., Genovesi, P., Jeschke, J. M., Kühn, I., Liebhold, A. M., Mandrak, N. E., Meyerson, L. A., Pauchard, A., Pergl, J., Roy, H. E., Seebens, H., ... Richardson, D. M. (2020). Scientists' warning on invasive alien species. *Biological Reviews*, 95(6), 1511–1534. <https://doi.org/10.1111/brv.12627>
- Rhoades, A., Bercos-Hickey, E., Szinai, J., Wehner, M., Yates, D., and Zhou, Y. [Lawrence Berkeley National Laboratory]. (2026). The impacts of climate change on atmospheric river storms and California's water resource infrastructure. *California's Fifth Climate Change Assessment*.
- Rudnick, J., Tomari, K., Dobbin, K., Lubell, M., & Biedenweg, K. (2023). California Delta residents survey. Ann Arbor, MI: *Inter-university Consortium for Political and Social Research* [distributor], 2024-07-01. <https://doi.org/10.3886/E195447V2>
- Schwartz, M., Hall, A., Sun, F., Walton, D., & Berg, N. (2017). Significant and inevitable end-of-twenty-first-century advances in surface runoff timing in California's Sierra Nevada. *Journal of Hydrometeorology*, 18(12), 3181–3197. <https://doi.org/10.1175/JHM-D-16-0257.1>
- Schwarz, A., Ray, P., Wi, S., Brown, C., He, M., & Correa, M. [California Department of Water Resources] (2018). Climate change risks faced by the California Central Valley water resource system. (Nos. CCCA4-EXT-2018-001). *California's Fourth Climate Change Assessment*. https://www.energy.ca.gov/sites/default/files/2019-12/Water_CCCA4-EXT-2018-001_ada.pdf
- Sheposh, R. (2024). *Phenotypic plasticity*. EBSCO. Retrieved February 9, 2026 from <https://www.ebsco.com/research-starters/science/phenotypic-plasticity>
- Sorte, C. J. B., Ibáñez, I., Blumenthal, D. M., Molinari, N. A., Miller, L. P., Grosholz, E. D., Diez, J. M., D'Antonio, C. M., Olden, J. D., Jones, S. J., & Dukes, J. S. (2013). Poised to prosper? A cross-system comparison of climate change effects on native and



- non-native species performance. *Ecology Letters*, 16(2), 261–270. <https://doi.org/10.1111/ele.12017>
- State Water Resources Control Board (SWRCB). (2025). SAFER dashboard. State Water Resources Control Board. Retrieved on December 2, 2025 from https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/saferdashboard.html
- Stein, L. Y., & Lidstrom, M. E. (2024). Greenhouse gas mitigation requires caution. *Science*, 384(6700), 1068–1069. <https://doi.org/10.1126/science.adi0503>
- Stevenson, S. (2025). California Fifth Climate Change Assessment Regional Synthesis Reports Climate Analysis Coordination Workgroup. UC Santa Barbara.
- Stone, S. L., Sacks, J., Lahm, P., Clune, A., Radinovich, L., D'Alessandro, M., Wayland, M., & Mirabelli, M. (2019). Wildfire smoke: A guide for public health officials. A report for the U.S. Environmental Protection Agency. (No. EPA-452/R-19-901). <https://document.airnow.gov/wildfire-smoke-guide.pdf>
- U.S. Army Corps of Engineers (USACE). (2025). USACE CAP section 205 – small flood risk management projects fact sheet https://planning.erdc.dren.mil/toolbox/library/FactSheets/CAP_Sec205_FactSheet_15Apr2025.pdf
- U.S. Census Bureau. (2022, April 11). *Glossary*. U.S. Census Bureau. <https://www.census.gov/programs-surveys/geography/about/glossary.html#>
- U.S. Chamber of Commerce, Allstate, and the U.S. Chamber of Commerce Foundation. (2024). The preparedness payoff: The economic benefits of investing in climate resilience. https://www.uschamber.com/assets/documents/USCC_2024_Allstate_Climate_Resiliency_Report.pdf
- U.S. Environmental Protection Agency (U.S. EPA). (2021). Climate change and social vulnerability in the United States: A focus on six impacts. https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf
- U.S. Geological Survey (USGS). (2019, June 8). Watersheds and drainage basins. U.S. Geological Survey. <https://www.usgs.gov/water-science-school/science/watersheds-and-drainage-basins>
- Ulrich, P. (2025). California Fifth Climate Change Assessment Regional Synthesis Reports Climate Analysis Coordination Workgroup. UC Davis.
- Vaughn, L. J., Deverel, S. J., Panlasigui, S., Drexler, J. Z., Olds, M. A., Díaz, J. T., Harris, K. F., Morris, J., Grenier, L., Robinson, A. H., & Ball, D. A. (2024). Managed wetlands for climate action: Potential greenhouse gas and subsidence mitigation in the Sacramento–San Joaquin Delta. *San Francisco Estuary and Watershed Science*, 22(2), Article 3. <https://doi.org/10.15447/sfews.2024v22iss2art3>
- Vicarelli, M., Sudmeier-Rieux, K., Alsadadi, A., Shrestha, A., Schütze, S., Kang, M. M., Leue, M., Wasielewski, D., & Mysiak, J. (2024). On the cost-effectiveness of nature-based solutions for reducing disaster risk. *Science of The Total Environment*, 947,



Article 174524. <https://doi.org/10.1016/j.scitotenv.2024.174524>

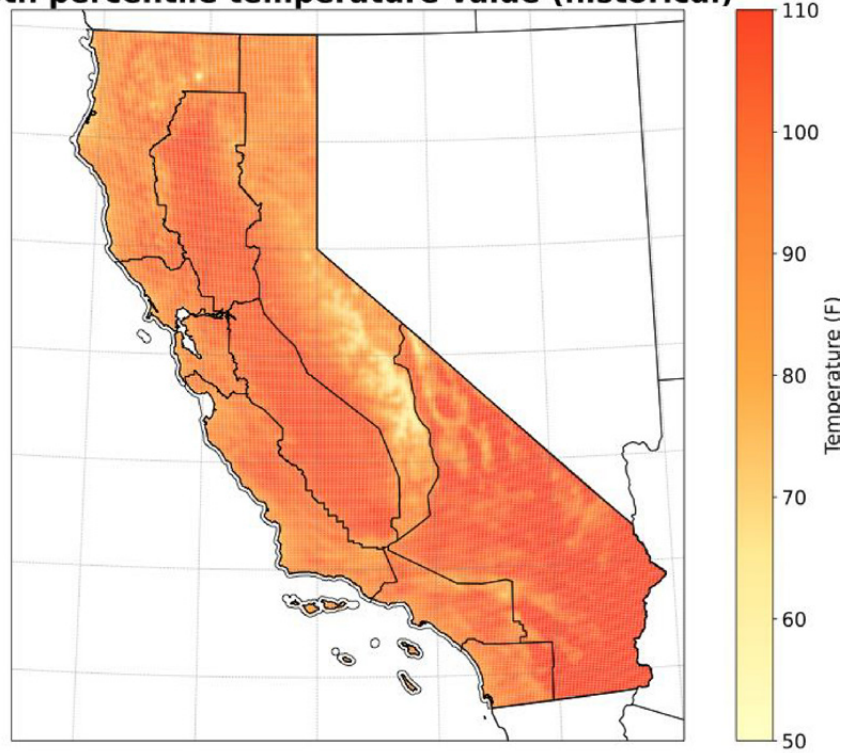
- Visser, P. M., Verspagen, J. M. H., Sandrini, G., Stal, L. J., Matthijs, H. C. P., Davis, T. W., Paerl, H. W., & Huisman, J. (2016). How rising CO₂ and global warming may stimulate harmful cyanobacterial blooms. *Harmful Algae*, 54, 145–159. <https://doi.org/10.1016/j.hal.2015.12.006>
- Wang, J., Hongbing, Y., Reyes, E., Smith, T., & Chung, F. [California Department of Water Resources.] (2018). Mean and extreme climate change impacts on the State Water Project. (Nos. CCCA4-EXT-2018-004). *California's Fourth Climate Change Assessment*. https://www.energy.ca.gov/sites/default/files/2019-12/Water_CCCA4-EXT-2018-004_ada.pdf
- Water Education Foundation (WEF). (N.d.). *Sacramento-San Joaquin Delta levees*. Water Education Foundation. Retrieved on August 6, 2025, from <https://www.watereducation.org/aquapedia/sacramento-san-joaquin-delta-levees>
- Windham-Myers, L., Oikawa, P., Deverel, S., Chapple, D., Drexler, J. Z., & Stern, D. (2023). Carbon sequestration and subsidence reversal in the Sacramento-San Joaquin Delta and Suisun Bay: Management opportunities for climate mitigation and adaptation. *San Francisco Estuary and Watershed Science*, 20(4), Article 7. <https://doi.org/10.15447/sfews.2023v20iss4art7>
- Ye, R., & Horwath, W. R. (2016). Nitrous oxide uptake in rewetted wetlands with contrasting soil organic carbon contents. *Soil Biology & Biochemistry*, 100, 110–117. https://www.researchgate.net/publication/304104928_Nitrous_oxide_uptake_in_rewetted_wetlands_with_contrasting_soil_organic_carbon_contents
- Ye, R., Espe, M. B., Linquist, B., Parikh, S. J., Doane, T. A., & Horwath, W. R. (2016). A soil carbon proxy to predict CH₄ and N₂O emissions from rewetted agricultural peatlands. *Agriculture, Ecosystems & Environment*, 220, 64–75. <https://linquist.ucdavis.edu/sites/g/files/dgvnsk6581/files/inline-files/2016-Ye-et-al-AEE.pdf>

Appendix

Supplemental Figures

Figure 32. Thresholds Used to Define Extreme Heat Events Statewide.

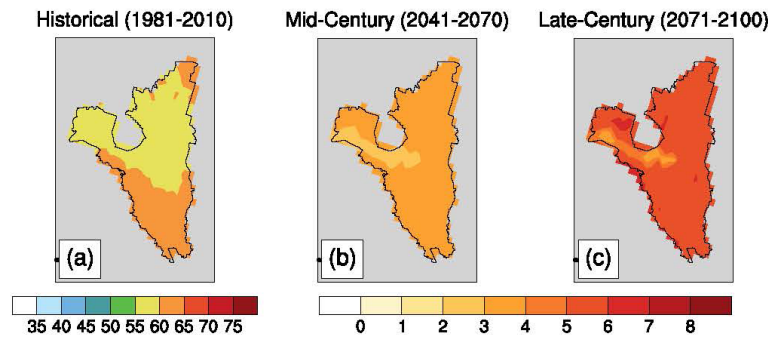
98th percentile temperature value (historical)



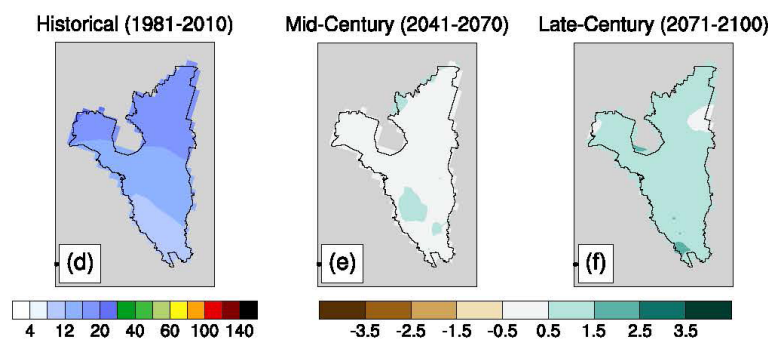
Map of the temperature threshold used to define an extreme heat event, which is the 98th percentile temperature value for the historical period (1981-2010) (Stevenson, 2025).

Figure 33. Spatial Patterns of Changes in Temperature and Precipitation.

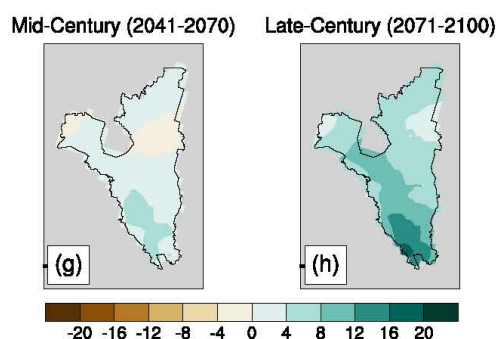
Mean Daily Temperature Change from Historical (°F)



Annual Precipitation Change from Historical (in/yr)



Change from Historical (%)



Change in average annual (a) temperature (°F), (b) precipitation (inches per year), and (c) precipitation (percentage of 1981-2010 inches per year). Projections are shown for GCMs downscaled for California using LOCA2 and the SSP370 scenario (Ulrich, 2025).