California Department of Water Resources

"Window of Vulnerability," Dr. Qinqin Liu, DWR Climate Change Program, 2017

Climate Action Plan, Phase 3:

Climate Change Vulnerability Assessment

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Executive Summary

Climate change impacts have been widely documented globally, across the nation, and within the state. Loss of snowpack; longer, more frequent heat waves; and longer, more intense wildfire seasons are already being experienced in California. While uncertainties remain about the exact timing and extent of projected impacts, numerous climate-driven hazards represent a clear threat to Department of Water Resources (DWR) facilities, managed lands, operations, and staff activities. By conducting this department-wide vulnerability assessment, DWR seeks to better prepare its decision-making for an uncertain future.

This climate change vulnerability assessment (VA) provides the first evaluation of its kind for facilities owned and operated by DWR and the activities that DWR performs. This analysis draws from the extensive body of knowledge about climate change and attempts to evaluate, describe, and quantify — where possible — DWR's vulnerabilities to expected increases in wildfire, extreme heat, and sea-level rise, as well as to changes in hydrology and ecosystems that will impact DWR's facilities, operations, and other activities. Table ES-1 presents examples of vulnerabilities identified in this assessment and summarizes quantitative indicators of climate change risk.

Using a mid-century time horizon, climate-change-driven hazards assessed in this VA are presented under six categories: wildfire, extreme heat, sea-level rise, long-term persistent hydrologic changes, short-term extreme hydrologic events, and habitat and ecosystem services degradation. This assessment applies a common framework to examine vulnerability through three components of how DWR's assets and operations could be *exposed* to future climate hazards, how these assets and operations are *sensitive* (or susceptible) to impacts of this exposure, and the *capacity* of these assets and operations to cope with or adapt to changing conditions or events. Findings from each hazard are summarized below.

Wildfire

Wildfire has always been a component of California's landscape, and DWR owns and operates infrastructure, throughout the state, that has historically had some level of exposure to wildfire. Studies have shown that wildfires already have become larger, more common, and more severe. This trend is expected to continue and intensify as the climate warms, particularly affecting the western United States.

Results — Based on current research and future climate projections, DWR's facilities are likely not vulnerable to increased wildfire through mid-century. In all locations at moderate or high risk, existing management and maintenance practices protect infrastructure from current as well as future wildfire exposure levels. Wildfire vulnerability for DWR facilities will continue to be low, even in areas expected to burn more frequently under projected wildfire conditions. Vulnerability of staff and staff activities to wildfire will be increased, although this will be location dependent. By mid-century though, models indicate an increased exposure to wildfire throughout the Upper Feather River Watershed (UFRW) — the headwaters for the State Water Project (SWP). Wildfire vulnerability will continue to increase throughout the 21st century and should be an area of focus for adaptation planning.

Extreme Heat

Increasing temperatures because of climate change pose operational challenges associated with hydrological changes (type of precipitation and runoff timing) as well as potential health impacts to DWR staff, especially those working in the field.

Results — Although some areas in California are projected to experience moderate increases in extreme heat levels, utilizing the existing DWR safety plans and programs (e.g., DWR's Heat Illness Prevention Plan) could keep the vulnerability of staff at essentially the same level that exists now, through mid-century.

Sea-Level Rise

Many studies have examined the projected effects of sea-level rise on the California coast, San Francisco Bay (Bay), and the Sacramento-San Joaquin Delta (Delta). These studies clearly indicate that sea-level rise creates a key potential impact to DWR operations, and therefore should be incorporated into planning and decision-making where DWR owns or manages facilities or conducts operations of the SWP. DWR facilities potentially impacted by sea-level rise are classified into the following areas: Coastal, San Francisco Bay (including the Suisun Marsh), and the Sacramento-San Joaquin Delta.

Results — In terms of the exposure to coastal sea-level rise, DWR has one facility along the California coastline: the Eureka Flood Center. The Flood Center is located approximately 6.1 meters (20 feet) above mean sea level and therefore is considered to have very low risk of sea-level rise hazard. Moreover, DWR currently uses this facility only on a part-time basis for one employee.

DWR has several facilities in the Sacramento-San Joaquin Delta, a region that is also projected to experience effects of sea-level rise. Suisun Marsh, located in the San Francisco Estuary, is already experiencing increased pressure resulting from human activities, and sea-level rise presents an additional stress that could increase inundation of mud flats and low-lying areas, levee failures, and greater variation in environmental conditions. Ecological sensitivity to these changes is high, and adaptive capacity is complicated by a variety of factors such as multiple ownership and joint management entities; consequently, Suisun Marsh is considered to have high risk of potential impacts. Facilities in the Delta and Suisun Marsh that that are highly exposed to the current mean sea level are built to withstand and operate in brackish water, and so are expected to be able to operate under the projected higher sea levels.

Few DWR facilities are sensitive to rising sea levels, and so overall vulnerability is considered low. Suisun Marsh ecosystems are still vulnerable, nonetheless. Moreover, a failure of Delta levees (a consideration outside the scope of this assessment) could change the vulnerability determinations. Because of other ongoing efforts exploring the projected changes in flooding patterns under a changing climate, such as the Central Valley Flood Protection Plan (CVFPP) and California WaterFix, vulnerability of operations was not analyzed in this assessment.

Long-term Persistent Hydrologic Changes

Long-term persistent hydrologic change is the phenomenon of the hydrologic system in California shifting into different patterns than experienced in the past. This includes increases in the frequency, duration, and severity of dry periods and earlier Sierra Nevada snowmelt-based runoff. Such changes are some of the most concerning for water resources management because the hydrologic regime essentially shifts away from historical averages, and historical averages are what drives many water management decisions.

Long-term hydrologic changes caused by climate change pose serious challenges to DWR, particularly regarding operation of the SWP. Higher temperatures act to increase evapotranspiration, sublimation, and snowmelt rates while decreasing soil moisture and snow accumulation. These effects combine to reduce snowpack and water storage while also changing runoff patterns. Changes in precipitation may affect average annual precipitation rates and/or the frequency, magnitude, and duration of extreme events. These changes can affect water quantity and quality, and in turn, the ecosystems supported by Sierra Nevada watersheds. Implications of ecosystem impacts could include threatening populations of native species and affecting the historic function of ecosystem services. Both pose direct and indirect challenges for DWR's operations, managed lands, and facilities. To assess the likelihood and magnitude of impacts from long-term persistent hydrologic changes, a decision-scaling approach was used for this vulnerability assessment. This approach represents a new way of looking at impacts to California hydrology that DWR has not used before.

Results — The analysis indicates that there is a high likelihood that SWP performance will diminish significantly as the climate warms. SWP deliveries show a significant loss in performance, with the most acute loss of performance coming at the drier end of the range. The 25th percentile deliveries fall by 460,000 acre-feet between current conditions and 2050 conditions — a 17 percent reduction. Median performance falls by over 312,000 acre-feet (10 percent) and 75th percentile performance falls by almost 300,000 acre-feet (9 percent). Thus, SWP delivery performance is at risk to climate change.

Both end-of-April (end of wet season) and September 30th (end of dry season) Oroville storage will be diminished because of climate change. Analysis of end-of-April storage indicates a major shift in performance during dry-to-median years. The 25th percentile end-of-April storage performance falls by nearly 100,000 acre-feet while the 50th percentile performance falls by 130,000 acre-feet. For September 30th storage, impacts are felt more strongly toward the wetter end of the spectrum. The 25th, 50th, and 75th percentile September 30th storage at 2050 is reduced by 310,00, 350,000, and 450,000 acre-feet, respectively, compared to current conditions performance. Thus, SWP storage performance is at risk from climate change.

Seasonal Net Delta Outflow (NDO) and system shortages were also evaluated as part of this vulnerability analysis, both of which provide measures of the SWP's ability to meet regulatory requirements. Minor seasonal NDO performance shifts suggest that the SWP would be able to continue to meet today's regulatory requirements at mid-century. System shortages are rare under current conditions and are found to continue to be so under mid-century conditions. A small increase in magnitude and frequency of system shortages is likely to occur by mid-century, but shortages of greater than 1 million acre-feet (maf) would still be expected to occur in less than one percent of years. Based on the likelihood of minor shifts in NDO and system shortage performance, SWP's ability to continue meet today's regulatory requirements is at low risk due to climate change.

Short-term Extreme Hydrologic Events (Floods)

Flooding effects from short-term extreme hydrologic events have been well studied in California, including by DWR. These impacts are among the most important for DWR to understand and plan for as they have in the past, and have the potential in the future, to cause loss of life, property damage, and various operational disruptions across the state.

Nevertheless, evaluation of climate change impacts on short-term extreme hydrologic events is highly complex. While general circulation models (GCMs) are designed to simulate large scale, long-term processes over large areas around the globe, short-term extreme hydrologic events require analysis of highly localized climatic processes on very fine time scales — usually down to kilometers and hours. Furthermore, in California, flood protection infrastructure is a system of watersheds, reservoirs, river channels, levees, and floodplains. Beyond these physical connections between river systems, California's flood protection infrastructure is a complex combination of federal; State; and locally-owned, operated, and maintained facilities.

Results — Analysis of published studies at a statewide level found an increase in flood occurrences and magnitude under a warming climate. Peak flows are projected to occur significantly earlier in the year, likely because of the reduction in precipitation falling as snow and a greater portion of the watershed contributing to direct runoff. Maximum annual one-day and three-day flows are projected to increase, and storm durations are projected to decrease.

As part of DWR's flood management operation and maintenance activities focused on facilities associated with the State Plan of Flood Control (SPFC), changes in flow frequencies and flood hydrographs are evaluated throughout the Central Valley system. While flood operations are thus considered to have high risks from these impacts of climate change throughout the Central Valley, the risks are even higher, particularly for large events, in the San Joaquin Valley compared to Sacramento Valley watersheds.

Habitat and Ecosystem Services Degradation

Climate change is already affecting and will continue to affect ecosystems and ecosystem services in California. There are thousands of acres of land throughout California that DWR manages for habitat and protected species. Habitat types on those parcels include wetland, riparian, grassland, marsh, oak woodland, saltbush scrub, and others. Habitat quality varies widely, but much of the acreage is either occupied or potential habitat for sensitive species, migratory birds, and pollinators, and provides important ecosystem services such as carbon sequestration, flood attenuation, water purification, recreational opportunities, and aesthetic benefits.

Results — Impacts to lands owned or managed by DWR were examined for the Sacramento Valley, San Joaquin Valley, and Southwestern ecoregions — all of which have habitats that are already negatively impacted by non-climate related factors. Climate change will exacerbate stresses on listed species and habitat types, and as a result DWR may need to take additional action beyond what was originally intended to manage or restore lands for mitigation or other purposes. In other cases, degradation of species and habitat types may result in additional regulations under which DWR will be required to operate. Therefore, DWR-managed lands and related operations are vulnerable to additional degradation of habitat and ecosystem services resulting from climate change.

Table ES-1 Examples of Potential Vulnerabilities from Climate-Change-Driven Hazards by Mid-Century

<table>
<tr><th>Hazard</th><th>Examples of Potential Vulnerabilities</th></tr>
<tr><td rowspan="2">Wildfire</td><td>Wildfire occurrence and intensity are likely to adversely affect the Upper Feather River watershed, resulting in potential changes in runoff timing and water quality for the State Water Project (SWP).</td></tr>
<tr><td>
<table>
<tr><th>Upper Feather River Watershed Exposure</th><th>Early Century (2010–2039)</th><th>Mid-Century (2040–2069)</th></tr>
<tr><td>Very Low or Low</td><td>53%</td><td>10%</td></tr>
<tr><td>Moderate</td><td>48%</td><td>80%</td></tr>
<tr><td>High or Very High</td><td>0%</td><td>10%</td></tr>
</table>
</td></tr>
<tr><td>Extreme Heat</td><td>
Increased number of extreme heat days may prevent employees from completing field surveys (that are constrained by temperature parameters) for sensitive species or conducting regular maintenance activities, as well as affect emergency response.
The San Luis and San Joaquin Field Divisions and South Central and Southern Region Offices are likely to experience more extreme heat days.
Maintenance and construction activities, including emergency repairs, could take longer or be more expensive to complete because of work stoppage during extreme heat events.
<table>
<tr><th>Location Name</th><th colspan="2">Number of days exceeding 80 °F</th><th colspan="2">Number of days exceeding 95 °F</th><th colspan="2">Number of days exceeding 105 °F</th></tr>
<tr><th></th><th>1990–1999</th><th>2040–2049</th><th>1990–1999</th><th>2040–2049</th><th>1990–1999</th><th>2040–2049</th></tr>
<tr><td>Oroville Field Division</td><td>128–163</td><td>150–174</td><td>33–63</td><td>58–84</td><td>0–8</td><td>2–13</td></tr>
<tr><td>Delta Field Division</td><td>119–168</td><td>151–175</td><td>21–47</td><td>37–64</td><td>0–5</td><td>0–11</td></tr>
<tr><td>San Luis Field Division</td><td>121–165</td><td>146–171</td><td>15–35</td><td>28–61</td><td>0–1</td><td>0–7</td></tr>
<tr><td>San Joaquin Field Division</td><td>156–188</td><td>174–199</td><td>53–93</td><td>87–117</td><td>3–16</td><td>7–32</td></tr>
<tr><td>Southern Field Division</td><td>139–180</td><td>160–194</td><td>48–81</td><td>84–105</td><td>0–6</td><td>3–20</td></tr>
</table>
</td></tr>
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<tr>
<td rowspan="2">Sea-Level Rise</td>
<td>
<p>The Suisun Marsh will likely be impacted by increasing inundation of mud flats and low-lying areas and greater variation in environmental conditions.</p>
<p>Rising sea level coupled with storm surge and storm-driven stream flow into the Delta could result in substantial increases in stage elevation in the Delta.</p>
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<td>
<table>
<tr><th colspan="3">Projected Sea-Level Change</th></tr>
<tr><th>Location</th><th>2030</th><th>2050</th></tr>
<tr><td>North of Cape Mendocino</td><td>-4 to 23 cm</td><td>-3 to 48 cm</td></tr>
<tr><td>South of Cape Mendocino</td><td>4 to 30 cm</td><td>12 to 61 cm</td></tr>
</table>
</td>
</tr>
<tr>
<td rowspan="2">Long-term Persistent Hydrologic Changes</td>
<td>
<p>SWP performance is likely to diminish as the climate warms.</p>
<p>Rising sea level coupled with decreased streamflow resulting from a declining Sierra Nevada snowpack is highly likely to force difficult tradeoffs between Delta conditions, carryover reservoir storage, and project deliveries.</p>
</td>
</tr>
<tr>
<td>
<table>
<tr><th>Performance Metric</th><th>Probability that Mid-Century (2050) Performance will be Less than Current Performance</th></tr>
<tr><td>Oroville April Storage</td><td>76%</td></tr>
<tr><td>Oroville Carryover Storage</td><td>95%</td></tr>
<tr><td>Winter Net Delta Outflow</td><td>63%</td></tr>
<tr><td>Spring Net Delta Outflow</td><td>65%</td></tr>
<tr><td>Summer Net Delta Outflow</td><td>21%</td></tr>
<tr><td>Fall Net Delta Outflow</td><td>40%</td></tr>
<tr><td>SWP Deliveries</td><td>87%</td></tr>
<tr><td>System Shortages</td><td>76%</td></tr>
</table>
</td>
</tr>
<tr>
<td>Short-Term Extreme Hydrologic Changes</td>
<td>
<p>Peak flows are projected to occur significantly earlier in the year, likely because of the reduction in precipitation falling as snow and a greater portion of the watershed contributing to direct runoff.</p>
<p>Maximum annual 1-day and 3-day flows are projected to increase for all watersheds evaluated. This finding suggests that the increases in flood flows may be robust for durations up to 5–7 days.</p>
<p>Storm durations are projected to decrease in all major watersheds. The signal of shorter duration, but more intense floods is strongest in the San Joaquin Basin, but is also observed for most Sacramento watersheds.</p>
</td>
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</table>

Short-Term Extreme Hydrologic Changes (continued)

Projected changes in simulated flood hydrograph characteristics (2041–2070)

Location	Change in Date of Peak Flow (days)	Change in Annual 1-day average max flow (%)	Change in Annual 3-days average max flow (%)	Change in Flood Duration (days)
Sacramento River at Shasta Dam	7	22	23	-17
Feather River at Oroville	-3	33	36	-23
Yuba River at Smartville	-9	26	28	-12
American River at Folsom Dam	-4	30	31	-14
Mokelumne River at Pardee	-18	-29	26	-18
Calaveras River at New Hogan	6	14	14	-2
Stanislaus River at New Melones Dam	-24	23	20	-15
Tuolumne River at New Don Pedro	-19	13	9	-9
Merced River at Lake McClure	-22	19	14	-15
San Joaquin River at Millerton Lake	-27	9	4	-10
Kings River at Pine Flat Dam	-26	11	4	-9

Habitat and Ecosystem Services Degradation

Key ecosystem services such as habitat provision for sensitive species and floodwater attenuation could be disrupted by climate-influenced conditions that change too quickly for ecological adaptation to occur.

Cold water fisheries, such as those on the Feather River, may be impacted by warmer water in streams, leading to more species listed as endangered and more operational constraints.

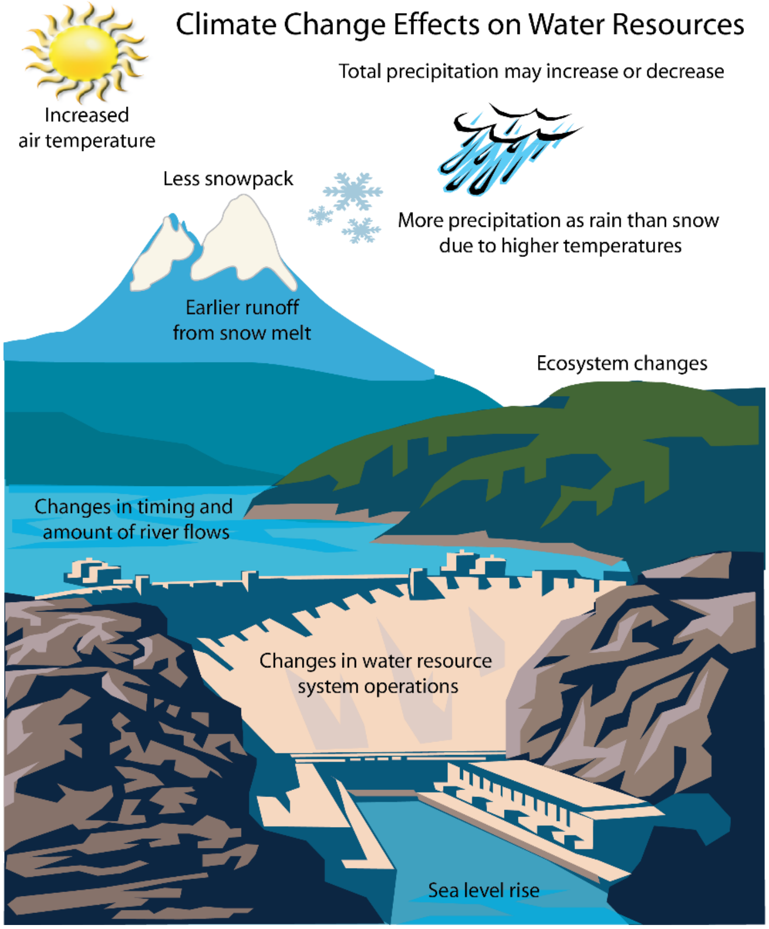
Warming temperatures could cause some species to migrate (i.e., northward in latitude and upward in elevation) in response to changing ecological conditions, making mitigation parcels purchased to protect them unsuitable in the future.

Chapter 1 — Introduction

In recent decades, science has detailed the changes in climate that have already occurred across the globe (Intergovernmental Panel on Climate Change, 2013), the nation (U.S. Global Change Research Program, 2014), and in California (California Energy Commission, 2012) (California Environmental Protection Agency, 2013) (National Climate Assessment, 2014). Many studies have described projected changes in climate and how they pose serious risks to water resources (National Climate Assessment, 2014) and the water management systems of California (Chung, et al., 2009) (Dettinger, Udall, & Georgakakos, 2015). Loss of snowpack, longer and more frequent heat waves, and longer, more intense wildfire seasons compared to historic conditions are already being experienced across California (California Environmental Protection Agency, 2013). These shifts, all of which affect water resources, are projected to continue changing and at faster rates through this century. Water resources are projected to be impacted by climate change in many ways (Figure 1-1). Achieving the California Department of Water Resources' (DWR's) mission into the future requires understanding where its responsibilities may be impacted by climate change, and to thus plan for these potential changes and the future uncertainties.

Much of California's water resource management infrastructure was designed and built with the expectation that historical observations of precipitation and streamflow were reasonable predictors of future precipitation and streamflow — so-called "stationarity" (Milly, 2008). Future conditions are likely to differ from anything observed in the past in important ways. Understanding how our existing infrastructure, operations, and activities will perform under projected future conditions is the first step toward preparing for climate change.

Figure 1-1 **Climate Change Affects Various Aspects of California's Water Resources.**



Purpose and Intent

Climate change vulnerability assessments (VA) conducted by water utilities have shown that the process of conducting the assessment raises awareness within the organizations about the risk of potential impacts of climate change, informs decision-making, and increases support for implementing adaptation measures that have been developed based on the analyses (U.S. Environmental Protection Agency, 2011) (U.S. Environmental Protection Agency, 2016[1]). Such assessments can also be used to help set management priorities and enable efficient allocation of scarce resources.

Planning for resilience makes sense at all levels — local, regional, State, and beyond — to maximize the potential to address the challenge of climate change. As one example, DWR has been facilitating assessment of the risks posed by climate change to the California water sector by assisting Integrated Regional Water Management (IRWM) groups with their infrastructure planning efforts, mainly through administration of publicly-funded grant programs which require that IRWM plans include considerations

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[1] Climate Ready Water Utilities (CRWU) website with tools and technical assistance: https://www.epa.gov/crwu.

of climate change. By conducting this department-wide VA, DWR will be able to make better business decisions in an uncertain future and continue to achieve its mission.

This climate change vulnerability assessment has been conducted in furtherance of the climate adaptation goals set forth in Governor Brown's Executive Order B-30-15 and recently enacted California legislation. Executive Order B-30-15, issued by Governor Brown in April 2015, requires State agencies to factor climate change into their planning and investment decisions. Assembly Bill 1482 (AB 1482), signed into law in October 2015, requires State agencies to address climate change vulnerabilities by, among other things: (1) educating the public about the consequences of climate change, including sea-level rise, extreme weather events, habitat loss, wildfire, and drought; (2) ensuring there is a continued repository of scientific data on climate change and climate adaptation in order to facilitate educated decision-making and to help identify primary risks from climate change to California residents, property, communities, and natural systems; and (3) considering potential climate change impacts in State investments and planning decisions. Assembly Bill 2800 (AB 2800), signed into law in September 2016, further requires State agencies to consider the current and future impacts of climate change when planning, designing, building, operating, and investing in State infrastructure. This assessment also supports many principles of the Safeguarding California Plan (2018 Update), specifically Principle 7: Increase investment in climate change vulnerability assessments of critical built infrastructure systems (California Natural Resources Agency, 2018).

This assessment is the first comprehensive examination of DWR's vulnerabilities to climate change. Initiating such an endeavor required evaluating and summarizing the many peer-reviewed studies relevant to water resources in California, which in itself is a major step forward contributing to water resources management in California. Additionally, in identifying clear gaps in how State Water Project operations could be affected by climate change, part of this vulnerability assessment includes a primary study conducted by DWR scientists and engineers in partnership with several university scientists. It is understood that this is a first examination of vulnerability, which will advance and likely be re-examined and updated periodically as more studies are conducted to understand the risks, as more adaptation is implemented, and as the needs change. The analysis draws from the extensive published scientific literature about climate change and attempts to evaluate, describe, and quantify — where possible — DWR's vulnerabilities to expected increases in extreme heat, wildfire, and sea-level rise, as well as changes in hydrology and ecosystems that will impact DWR's facilities, operations, and other activities.

This VA identifies the activities performed and specific assets owned and/or operated by DWR that have vulnerabilities related to climate change. It focuses on the mid-century (roughly 2030-2070) impacts from climate change, because this time horizon is within current project planning, and climate projections are more certain for this time period than for later in the century. To be clear, though, climate change impacts will continue—if not accelerate—through the end of this century and beyond. Facilities, operations, and activities that are identified as being moderately or highly vulnerable to climate change are suggested here to be prioritized for future adaptation planning. The vulnerabilities identified in this document will also form the basis for a DWR-specific climate change adaptation plan, which will outline strategies to reduce risks identified in this analysis.

Vulnerability Assessment Scope

With two significant exceptions, this VA only considers facilities and activities over which DWR holds operational control and sole or joint decision-making authority. Therefore, this is not a vulnerability assessment of the California water sector generally. This VA covers facilities that DWR owns and/or operates and the maintenance activities associated with those facilities. In addition, monitoring activities conducted by DWR employees are also included. The scope of this analysis has been intentionally limited in this way to make the findings most relevant to DWR managers and decision makers and to focus attention on vulnerabilities that DWR holds the greatest capacity to address.

This limited scope necessarily leaves several important potential vulnerabilities unevaluated because they are beyond DWR's decision making authority (e.g., properties where there are complicated joint management arrangements or where others have sole management responsibility, such as Sacramento-San Joaquin Delta [Delta] levees). Notably, the Delta Stewardship Council has initiated a comprehensive vulnerability assessment of the Delta. Chapter 8 discusses the most important of these potential vulnerabilities at a broad level and provides recommendations on potential steps to address them.

An exception to the scope limitations was made for the Suisun Marsh, which is a complex region with multiple entities working together to manage and restore the habitat. Because DWR is a primary management entity and thus may be able to implement adaptation strategies to offset climate change hazards, Suisun Marsh has been included in this assessment. Another exception was made for the Upper Feather River Watershed (UFRW). Although DWR owns a small fraction of land in the UFRW and does not have significant management authority, operations of the State Water Project (SWP) may be adversely affected by climate-induced changes in the watershed and thus its vulnerability is highly relevant to DWR.

Facilities, Activities, Staff, and Natural Lands That May be Impacted by Climate Change

For the purposes of this analysis, whenever impacts to specific sites are described, facilities, activities, and natural lands will be discussed in the context of the following categories: State Water Project (SWP) (including the field divisions and the California Aqueduct), Flood Facilities, Office Facilities, Suisun Marsh Facilities, and Managed Lands. Activities that may be impacted include: SWP operations and maintenance, State Plan of Flood Control maintenance, construction activities (especially long-term projects), biological surveys and monitoring, and restoration and management of mitigation and other lands.

The following is a brief, general description of each category to which all DWR-owned or -managed facilities and activities have been assigned for this analysis; a more detailed discussion of the specific facilities found within each category can be found in Appendix A.

State Water Project (including field divisions and the California Aqueduct)

The SWP is the nation's largest state-built water and power development and conveyance system. Its facilities include a complex water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. Its main purpose is to store water and distribute it to the San Francisco Bay Area, the San Joaquin Valley, the Central Coast, and Southern California. The project provides supplemental water to

27 million Californians and 750,000 acres of irrigated farmland[2]. The SWP also generates 2,000–5,000 GWh of hydroelectricity annually.

There are five field divisions in the DWR Division of Operations & Maintenance plus associated field offices which oversee day-to-day operation of the SWP. DWR also owns and maintains the California Aqueduct, which runs along the west side of the San Joaquin Valley and conveys water collected from the Sierra Nevada Mountains in Northern California to water users in the Central Coast, Bay Area, Central Valley, and Southern California. A right-of-way easement of varying width is generally located to the east and west of the Aqueduct. Five field division offices are distributed along the length of the SWP. DWR conducts maintenance and other activities for operation of the SWP, including biological and structural monitoring, repairs, and flow regulation.

Flood Facilities

DWR flood facilities include those associated with the State Plan of Flood Control, including the Sacramento River Flood Control Project and flood control projects in the Sacramento River and San Joaquin River watersheds[3]. The Sacramento River Flood Control Project was designed to manage storm flows that would otherwise flood farmland and cities in the Sacramento Valley. There are 10 overflow structures in the project: six weirs, three flood relief structures, and an emergency overflow roadway that serves as a “pressure relief valve” in the system during high-flow events that would normally overtop the banks. Activities include maintenance and repair of structures and biological monitoring. There are two flood maintenance yards, one in West Sacramento and the other near the town of Sutter.

Office Facilities

DWR office facilities include four regional offices located throughout the state in Red Bluff, West Sacramento, Fresno, and Glendale. Staff members are also located in several office buildings throughout Sacramento, including the Bryte Laboratory. Relevant activities of staff located in regional offices include fieldwork such as biological monitoring, engineering surveys, and equipment maintenance.

Suisun Marsh Facilities

The Suisun Marsh is the largest contiguous brackish marsh remaining on the West Coast of North America. Several facilities have been constructed by DWR and the U.S. Bureau of Reclamation (Reclamation) and operate in the Suisun Marsh. These facilities are identified in the Plan of Protection for the Suisun Marsh and the 1987 Suisun Marsh Preservation Agreement (SMPA)[4]. The purpose of these facilities is to provide low salinity water to managed wetlands. DWR staff’s activities in the Suisun Marsh include monitoring, restoration, and enhancement of thousands of acres of wetland habitat.

Managed Lands

DWR is charged with management of thousands of acres of land throughout the state. DWR land holdings include mitigation habitat, right-of-way easements, and restoration projects. There are mixed uses, but

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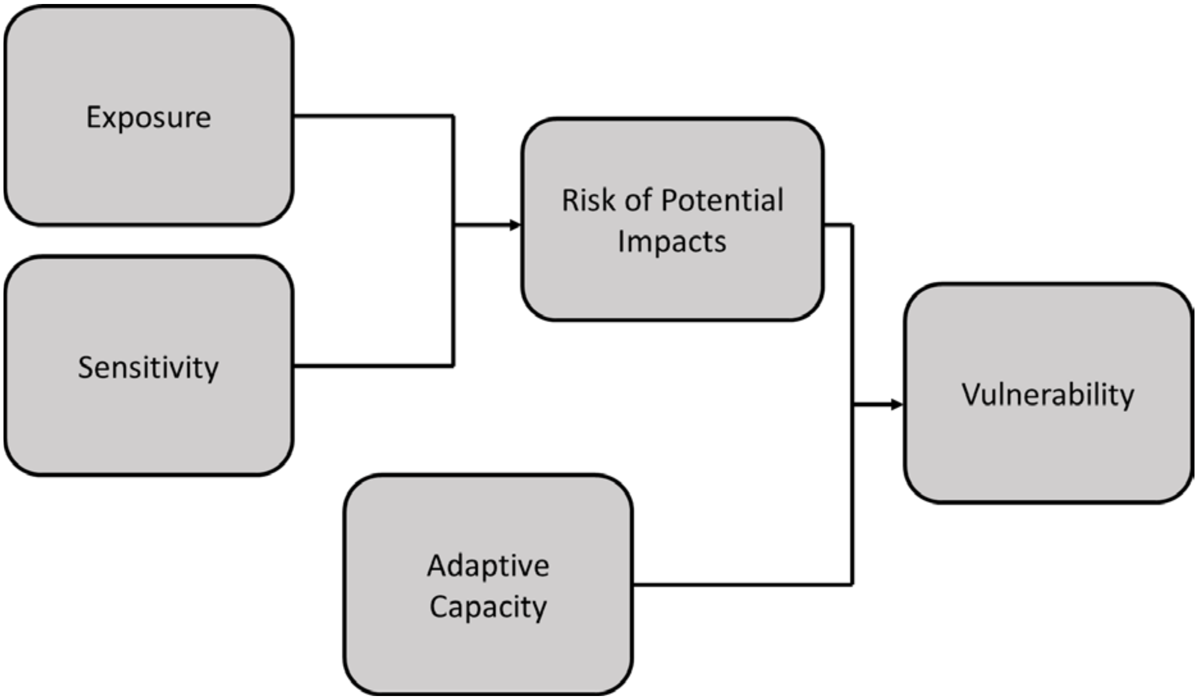
[2] http://www.water.ca.gov/swp/swptoday.cfm.
[3] California Water Code Section 9110 (f): http://www.oclaw.org/research/code/ca/WAT/9110./content.html#.VxEfFEdvmNo.
[4] http://www.water.ca.gov/suisun/.

most are managed for some type of habitat value, including: wetland, grassland, marsh, oak woodland, and saltbush scrub. Habitat quality varies widely, but much of the acreage is either occupied or potential habitat for sensitive species, migratory birds, and pollinators, and provides important ecosystem services such as carbon sequestration, flood attenuation, water purification, and aesthetic benefits. DWR management activities vary on a parcel-by-parcel basis, but may include biological monitoring, mowing and/or grading.

Methodology for Assessing Vulnerability of DWR Facilities, Lands, Staff Activities, and Operations to Climate Change

DWR conducted the VA by identifying relevant hazards to facilities, lands, staff activities, and operations because of potential climate change impacts within the scope of this report. The exposure and sensitivity of these components to those hazards–which taken together, define risk—and the degree of adaptive capacity was then determined (Figure 1-2). The major types of hazards covered by this VA are defined below, followed by the approach used to assess DWR's vulnerability to each hazard.

Figure 1-2 **The Conceptual Framing of Vulnerability Utilized in This Assessment Has Been Widely Used in Other Climate Change Assessments.**



Hazards

The following climate-change-driven hazards have been identified as presenting risks of potential impacts to DWR's work, properties, staff, and facilities. DWR is vulnerable to impacts from each of these hazards in varying degrees.

Wildfire

The occurrence of wildfires is increasing in the western United States (US), and according to statewide projections, the wildfire season is projected to get longer and burn more acreage (Westerling, 2018). In the early 1970s, the average length of the wildfire season was five months, and today it is seven months or longer (Dennison, Brewer, Arnold, & Moritz, 2014), largely related to rising temperatures and shifts in land use. Some DWR-owned or -managed lands and facilities are in wildfire-prone areas, and may be exposed to increased vulnerability to damage, loss of property or resources, or interruptions in service or access.

Extreme Heat

Extreme heat events, including intensely hot days and heat waves, will increase in the western U.S. in future years as the global average temperature increases (National Climate Assessment, 2014). Extreme heat is most harmful to young children and the elderly, although even healthy individuals can suffer when temperatures exceed 100 degrees Fahrenheit (°F). DWR performs numerous activities that require staff to work outside for extended periods, such as repairing or maintaining facilities and equipment and conducting biological surveys and monitoring; extreme heat events can be disruptive to these activities.

Sea-Level Rise

Sea-level rise is caused primarily by two factors driven by global warming: the added water from melting land ice and the expansion of sea water as it warms. In the past 100 years, sea level has risen about seven inches along the California coast, and is expected to rise between 5 to 24 inches by 2050 (National Research Council, 2012). As sea level rises, saltwater penetrates further into the Delta and changes the hydrodynamics of the Delta, resulting in significant influences on water operations and aquatic conditions, and causes increased stress on levees.

Long-Term Persistent Hydrologic and Short-Term Extreme Hydrologic Changes

Increasing temperatures over the last 50 years have already impacted the hydrology of California — causing the snowpack to runoff earlier (Hall & Kapnick, 2009), reducing soil moisture (National Climate Assessment, 2014), and moving toward more rain and less snow overall (Cuthbertson, Lynn, Anderson, & Redmond, 2014) (Brady & Sanford, 2016). Projections of future climate change suggest that precipitation patterns may also shift in the future, resulting in higher average annual precipitation in some parts of the state and lower average annual precipitation in other parts (National Climate Assessment, 2014). Further, projections also indicate that precipitation patterns may shift toward more extreme variability, resulting in more frequent, longer, or more severe droughts punctuated by extreme high-precipitation events (Das, Dettinger, Cayan, & Hidalgo, 2011). These changes could have impacts on DWR’s ability to deliver water, contribute to river conditions that support aquatic species, and protect public safety from flooding.

Habitat and Ecosystem Services Degradation

Climate change is affecting and will increasingly affect many habitat types in California where DWR has infrastructure, operational activities, and natural lands. The relatively rapid changes will cause additional pressure on what are, in some cases, small remnants of the natural ecosystems that existed prior to the large-scale development of California (PRBO Conservation Science, 2011). Ecosystem services are tangible and intangible benefits derived from natural resources that play an important role in sustaining economic viability and human well-being (Nelson, et al., 2013). Ecosystem services include air and water purification, outdoor recreation, carbon sequestration, and habitat provisions for species. Impacts to certain key ecosystem services and habitats in California will directly affect DWR's operations and activities. For example, water export operations in the Delta are tied to habitat conditions for listed species such as juvenile salmon and delta smelt. Working to promote resilience of Delta aquatic habitat and ecosystem services to climate change impacts is an important way to ensure persistence of those species and thus more reliable operation of the SWP.

Overall Vulnerability Assessment Approach

The framework through which climate change vulnerability is examined has been well-described and widely used in literature and practice (Intergovernmental Panel on Climate Change, 2007) (National Wildlife Federation, 2011). The framing applied here examines *vulnerability* to various climate change hazards is a function of *exposure (E), sensitivity (S), and adaptive capacity (AC)*. The exposure component seeks to capture the spatial extent to which an increased degree of hazard overlaps with the resource under examination (e.g., DWR facilities, operations, staff, managed lands). Sensitivity represents the susceptibility to harm of a facility, operations, or group of people when exposed to a climate hazard. Adaptive capacity, a somewhat nebulous but important concept in understanding vulnerability, is the ability to cope or the flexibility to take adaptive measures to mitigate or avoid the impacts of exposure. Together, exposure and sensitivity provide a measure of potential impacts or risks posed to DWR assets; adaptive capacity can offset the risk, thus lowering overall vulnerability (Box 1-1).

For each climate change hazard, vulnerability was assessed as consistently as possible. Most chapters rely on published studies and data overlaid or evaluated against locations of DWR facilities. Chapter 5 is unique in that it presents primary research, conducted within DWR with collaborators, to examine vulnerability of SWP operations and therefore it provides more details regarding methods, data, and modeling than the other chapters. In fact, Chapter 5 was published as a technical report in the State's recent Fourth Climate Change Assessment and was featured at a workshop on the Fourth Assessment held at the National Academies in August 2018 (Schwarz, et al., 2018).

Specific methods for determining the exposure, sensitivity and adaptive capacity for each hazard are described within the respective chapters. In some cases, exposure and sensitivity analysis was not necessary for each area of concern (i.e., Facilities and Lands, Operations, Staff Activities) to DWR. Table 1-1 summarizes what was analyzed and discussed within each chapter.

Box 1-1 **Definitions**

Definitions

Vulnerability — The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Exposure — Refers to extrinsic factors that affect a system; focused on character, magnitude, and rate of change the system is likely to experience.

Sensitivity — Refers to the innate characteristics of a system; considers tolerance to changes in factors such as temperature, precipitation, fire regimes, or other key processes.

Risk — Combined effects of exposure and sensitivity (also commonly referred to as "potential impact").

Adaptive Capacity — The ability of a system, human or natural, to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

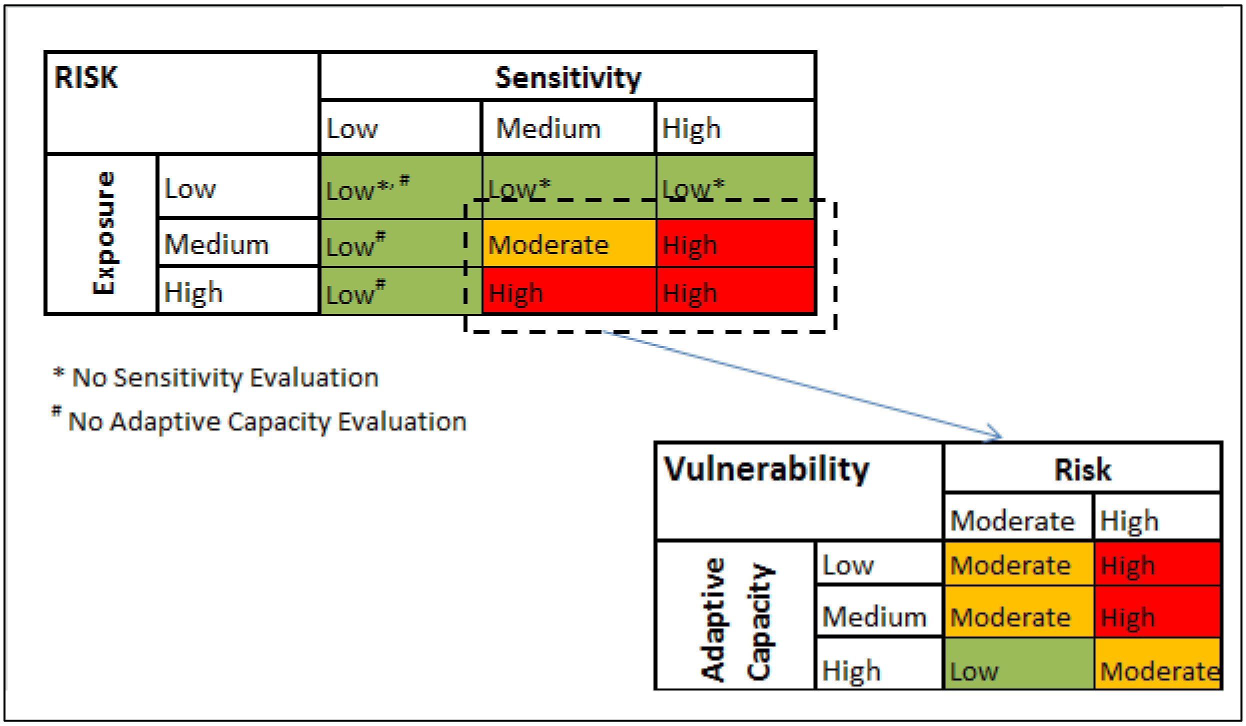
Table 1-1 Exposure and Sensitivity Analysis Was Conducted for Different Categories for Each Climate Change-Driven Hazard.

Climate-Change-Driven Hazard	Facilities and Lands	Operations	Staff Activities
Wildfire	X	X	
Extreme Heat			X
Sea-Level Rise	X	X*	
Long-Term Persistent Hydrologic Changes		X	
Short-Term Extreme Hydrologic Changes (Floods)	X	X	X
Habitat and Ecosystem Services Degradation	X	X	

*Discussed in Long-Term Persistent Hydrologic Changes chapter. Refer to each chapter for reasoning for evaluating certain assets for each hazard.

For each hazard, the exposure analysis was used as a screening tool; facilities, lands, operations, or activities that had little or no exposure to anticipated climate change impacts were not analyzed further for sensitivity or adaptive capacity. Likewise, if the analysis identified some exposure, but little or no sensitivity to climate change impacts, the category was determined to have low risk and was not analyzed further for adaptive capacity. Facilities, lands, operations, or activities with moderate or high-risk levels were assessed more thoroughly for their adaptive capacity. Figure 1-3 below illustrates how values for exposure, sensitivity, and adaptive capacity were used to define the overall level of vulnerability for each facility and activity under DWR's purview.

Figure 1-3 **Vulnerability Is a Function of Exposure, Sensitivity and Adaptive Capacity.**



RISK		**Sensitivity**		
		Low	Medium	High
Exposure	Low	Low*, #	Low*	Low*
	Medium	Low#	Moderate	High
	High	Low#	High	High

* No Sensitivity Evaluation

\# No Adaptive Capacity Evaluation

Vulnerability		**Risk**	
		Moderate	High
Adaptive Capacity	Low	Moderate	High
	Medium	Moderate	High
	High	Low	Moderate

Adaptive capacity as defined in this document includes "coping capacity," a measure of intrinsic adaptability, plus other aspects of DWR's ability to respond to vulnerabilities through social, economic, and technological means. Because of the various regulatory restrictions on DWR's operations and the permanent nature of its infrastructure, coping capacity may not be high in many instances because there are few opportunities to relocate vulnerable structures or substantially change operations. But as a State agency, DWR has significant capacity in terms of financial and technological means to address many of the vulnerabilities (if State resources are directed to such activities), thus overall adaptive capacity may be considered substantial (though not limitless) in that respect. But the capacity to cope or adapt has shown to not necessarily be used in practice, meaning that capacity only indicates the potential to cope or adapt, not necessarily what is implemented (O'Brien, Eriksen, Sygna, & Naess, 2006).

Synergistic Hazard Effects

In addition to examining each climate change hazard independently, this document, in Chapter 7, discusses potential additive or synergistic effects that may arise because of the interacting or compounding effects of different vulnerabilities. *Synergy* occurs when two or more hazards create a combined effect greater than the additive effect of each individually. For example, drought-stressed watersheds will be increasingly vulnerable to wildfires, which impact ecosystem services such as erosion control and water pollution remediation. As well, the already-stressed Delta ecosystem will be affected simultaneously by changing hydrology that further limits water supply for protected species at key times of year while rising sea level will push saline water further into the Delta. These synergistic effects should be considered to the extent possible to understand overall vulnerability, but information may not be readily available to fully understand the interactions amongst these compounding effects.

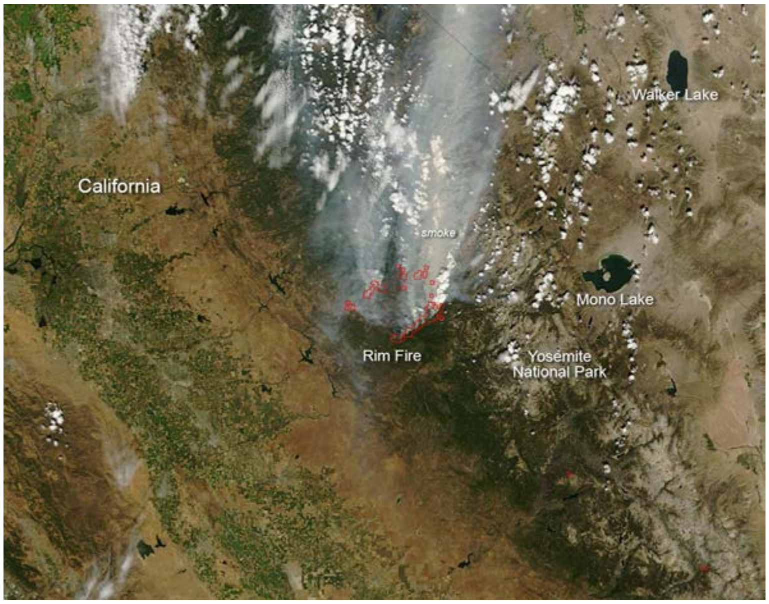
Climate Change Vulnerabilities Outside the Scope of This Assessment

Chapter 8 considers impacts from important climate-change-driven hazards to facilities, resources, or activities that have the potential to affect DWR but that are outside of the authority and control of DWR and are therefore outside the scope of this analysis. Two examples are risks to Delta levees and the regional electrical grid. These are areas where DWR does not have sole decision-making authority and thus cannot independently implement adaptation strategies to reduce vulnerability. In these cases, DWR will have to work with other agencies, land managers, or private owners to address vulnerabilities. In Chapter 8, the complexities of such vulnerabilities, the parties involved, and possible steps to assess and address these vulnerabilities in the future, are discussed.

Future Updates to the Vulnerability Assessment

This vulnerability assessment was conducted primarily by DWR’s Climate Change Program from 2013 to 2016. Each chapter was led by different team members, at different stages of the overall assessment process, with different levels of data and research available, and different levels of engagement from staff across the Department. At a minimum, this assessment should be updated every five years to consider new information about climate change-driven hazards and the vulnerability of DWR staff, facilities, and lands to them. It is anticipated that future updates will build upon the framework provided by this VA by incorporating new modeling projections and results of ongoing studies being conducted by DWR and others. Future updates should specifically incorporate findings from California’s Climate Change Assessments, as well as the National Climate Assessment. Updates should also include information about actions identified as “next steps” in this current analysis, and attempt to better integrate information throughout the assessment. Reduction in vulnerabilities rising from implementation of the upcoming DWR Climate Change Adaptation Plan will also be discussed in future updates.

Chapter 2 — Wildfire



Satellite Image of the Rim Fire, August 2013[5]

Wildfire has always been a component of California's landscape. Statewide, DWR owns and operates infrastructure that has historically had some level of exposure to wildfire. Some of this infrastructure (e.g., pipelines, canals, levees) has very low sensitivity to wildfire; a fire could burn over the facility and cause little or no damage and might not even interrupt operations of the facility. Other types of DWR infrastructure, such as pumping plants and associated electrical equipment, are more sensitive to wildfire, potentially leading to short-term service interruptions or even longer-term outages.

Wildfire can also have significant impacts on landscapes not owned or managed by DWR but that are vitally important to the function of DWR facilities and operations; paramount among these is the Upper Feather River Watershed (UFRW) that supplies snowmelt runoff to Oroville Reservoir. Wildfire in the UFRW could result in increased sediment loading into streams and reservoirs, thereby impacting water quality, decreasing water supply capacity, and potentially disrupting services. Studies of wildfires in the Sierra Nevada during the past century indicate that wildfires are increasing and that fires have extended to higher elevations (Schwartz, et al., 2015).

This chapter describes the projected exposure and sensitivity of DWR facilities and operations to increased wildfire, and where relevant, adaptive capacity. A majority of DWR facilities have some baseline/existing exposure to wildfire. The analysis approach used here takes into consideration both the

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[5] https://www.nasa.gov/content/rim-fire-california.

baseline wildfire exposure and the degree to which the wildfire exposure is expected to change by mid-century due to climate change.

Relevant Studies Conducted to Date or in Progress

Many studies have shown that wildfires have already become more common, larger, and more severe (Miller, Safford, Crimmins, & Thode, 2009) (California Environmental Protection Agency, 2013) (Dennison, Brewer, Arnold, & Moritz, 2014). This trend is expected to continue and intensify as the climate warms (Krawchuck & Moritz, 2012) (Bryant & Westerling, Scenarios to Evaluate Long-Term Wildfire Risk in California, 2012) (Hurteau, Westerling, Wiedinmyer, & Bryant, 2014), with the western US being particularly at risk (Dennison, Brewer, Arnold, & Moritz, 2014).

The National Research Council (NRC) has estimated that for each degree Celsius (1.8 ° F) of temperature increase, the size of the area burned in the western U.S. could quadruple (National Research Council, 2011). The fire season is also increasing in length (Climate Central, 2012), extending the period during which fire suppression and firefighting resources need to be expended. But land use changes (e.g., development in the wildland-urban interface), land management decisions, and vegetation types will also influence regional impacts (California Department of Forestry and Fire Protection, 2010) (Bryant & Westerling, Scenarios for future wildfire risk in California: links between changing demography, land use, climate and wildfire, 2014) (Westerling, et al., 2014) (Abatzoglou & Williams, Climate change has added to western US forest fire, 2016).

Wildfire Vulnerability Assessment Approach

This section describes the data sources and methodology for assessing the exposure and sensitivity of DWR facilities and operations to the increased incidence of wildfire influenced by climate change.

Exposure

Data for this wildfire exposure analysis were obtained from the study "*Fire and Climate Change in California*" (Krawchuck & Moritz, 2012), which was published as part of the California Energy Commission Public Interest Energy Research Program for California's Third Climate Change Assessment (California Energy Commission, 2012). The Krawchuk and Moritz dataset contains probabilities of one or more fires occurring within 30-year time periods from 1971–2000 (baseline period), 2010–2039, 2040–2069, and 2070–2099 (future projections).

For each of the three future time periods, the researchers ran their model with climate data extracted from two Global Climate Models (also known as General Circulation Models or GCMs); the Geophysical Fluid Dynamics Laboratory (GFDL) and the Parallel Climate Model (PCM). They also used two greenhouse gas (GHG) emissions scenarios, A2 and B1, which represent possible future conditions of demographic development, socio-economic development, and technologic change, and two land use projections (business-as-usual and smart-growth). The model outcomes yielded the probability that one or more fires will occur during a 30-year time period for each grid cell (approximately 1 kilometer [km] x 1 km) of the state under various future conditions.

To be conservative, at each grid cell the maximum modeled probability of wildfire was used from the suite of simulations available (i.e., maximum of PCM A2, PCM B1, GFDL A2, and GFDL B1).

Facilities and Lands

A DWR asset list was compiled for the purposes of this study and represents the best-known locations of DWR facilities and other major assets as of publication of this document (Appendix A). All DWR facilities were mapped to assign fire probability at each location for each time period. The projected change in probability for the future time period was plotted against baseline probabilities for each grid cell statewide.

Exposure curves were plotted as a function of baseline fire probability vs. projected change in fire probability from baseline, which serves to classify the exposure with respect to the relative magnitude of probability. The curves divide the space into very low, low, moderate, high, and very high exposure regions (Figure 2-1). Because this is a new approach by DWR to categorizing future exposure to changes in wildfire regime, these curves were defined based on the judgment of DWR staff in consultation with wildfire experts[6]. The curves in Figure 2-1 are polynomial equations with increasing y-intercepts and continuously increasing slopes. This reflects an expert judgment that the level of exposure to wildfire regime change increases at an increasing rate.

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[6] Personal communication with California Department of Forestry and Fire Protection (CAL FIRE) staff members Chris Keithley and David Sapsis. January 2014.

Figure 2-1 **Climate Change May Heighten Wildfire Exposure at an Increasing Rate.**

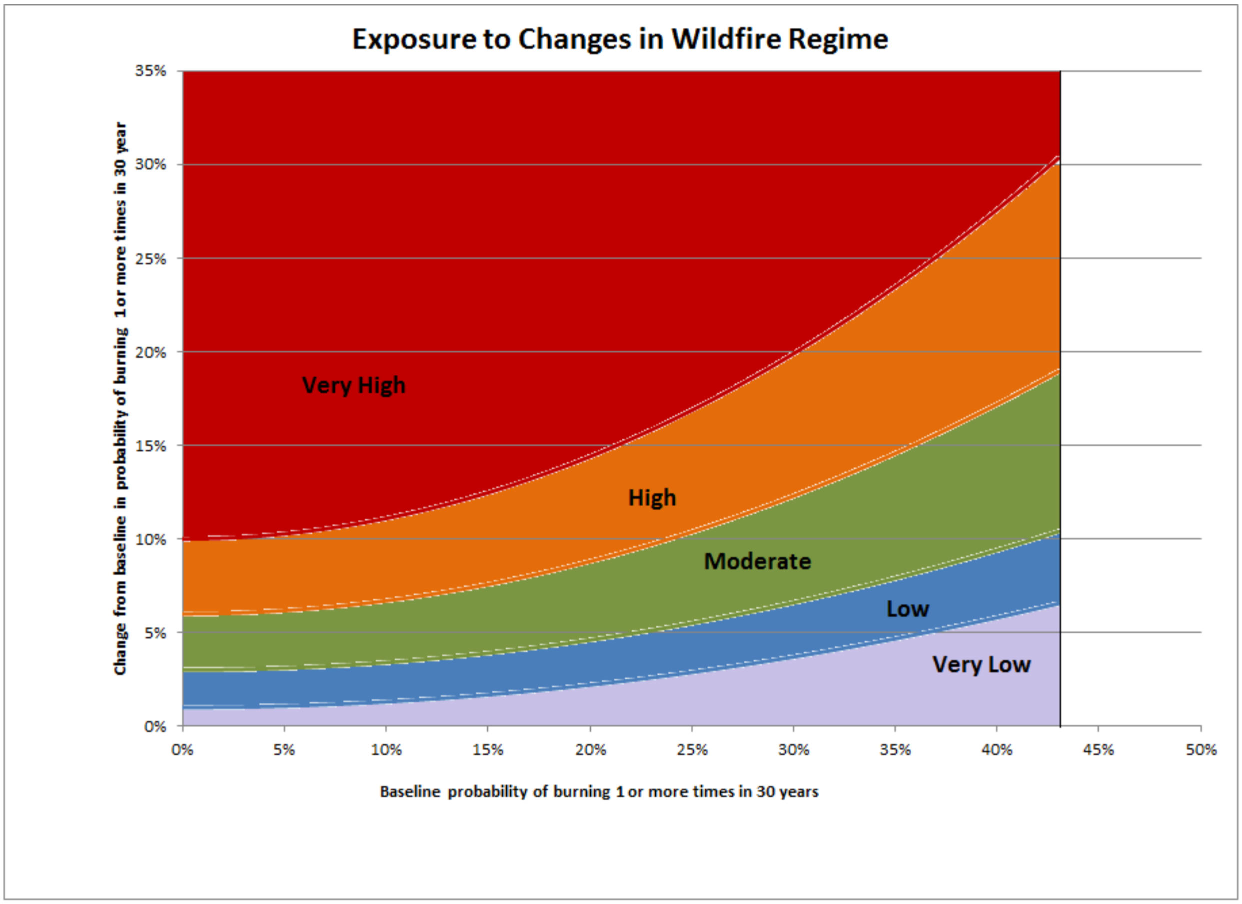
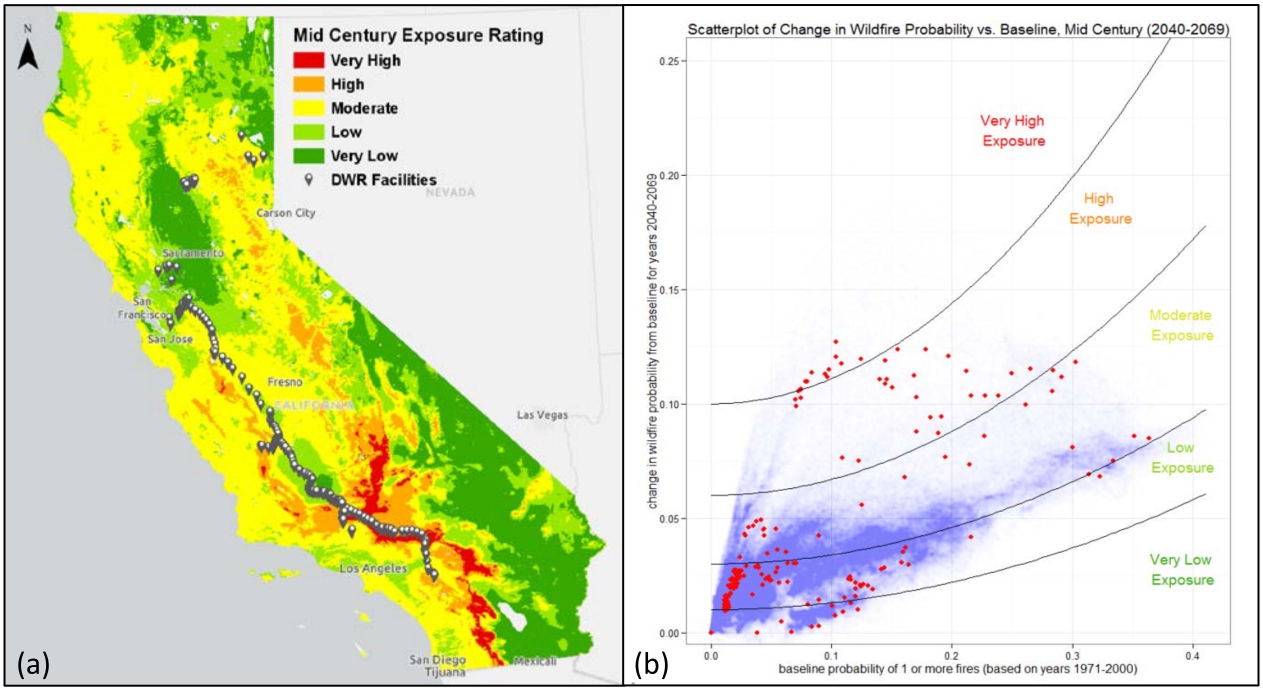


Figure 2-2 shows mid-century wildfire exposure to changes in wildfire regime. The black dots on the map represent DWR facilities. Each black dot on the left panel corresponds to a red dot on the right panel, purple dots (which appear as a cloud) on the right panel represent other grid cells throughout the state that do not contain DWR facilities. These facilities were further assessed for their sensitivity in the following sections.

Figure 2-2 a-b Climate Change May Increase the Wildfire Exposure of Facilities at Mid-Century (2040–2069).



Note: Figure 2-2(a) represents mid-century (2040–2069) exposure ratings as a function of the change in wildfire probability from baseline years 1971–2000; Figure 2-2(b) depicts each grid cell displayed in figure (a) as the baseline probability of occurrence of one or more fires and change in said probability by mid-century (the cloud of violet dots),. The red dots on figure (b) are plotted accordingly for DWR facility locations identified in figure (a).

Operations

SWP operations could be affected by indirect impacts from wildfire, such as denuded landscapes with increased erosion potential. For example, some portions of the California Aqueduct may be at risk from mudslides related to the loss of stabilizing vegetation following a wildfire. Upper Feather River Watershed impacts also have the potential to affect operations and are discussed below.

Upper Feather River Watershed

As the primary source of water for the SWP, wildfire in the UFRW is of concern to DWR operations because of the possibility of changing runoff patterns, water quality issues, increased overland flow rates, and sediment yields.

Three SWP reservoirs in the upper watershed, Frenchman, Davis, and Antelope, are operated by DWR for recreation and water supply. Lake Oroville is operated by DWR for water supply, flood control, hydropower, and recreation. Also, Pacific Gas and Electric Co. (PG&E) operates Lake Almanor and a series of reservoirs on the North Fork of the Feather River for hydropower, and which are also part of the headwaters of the SWP.

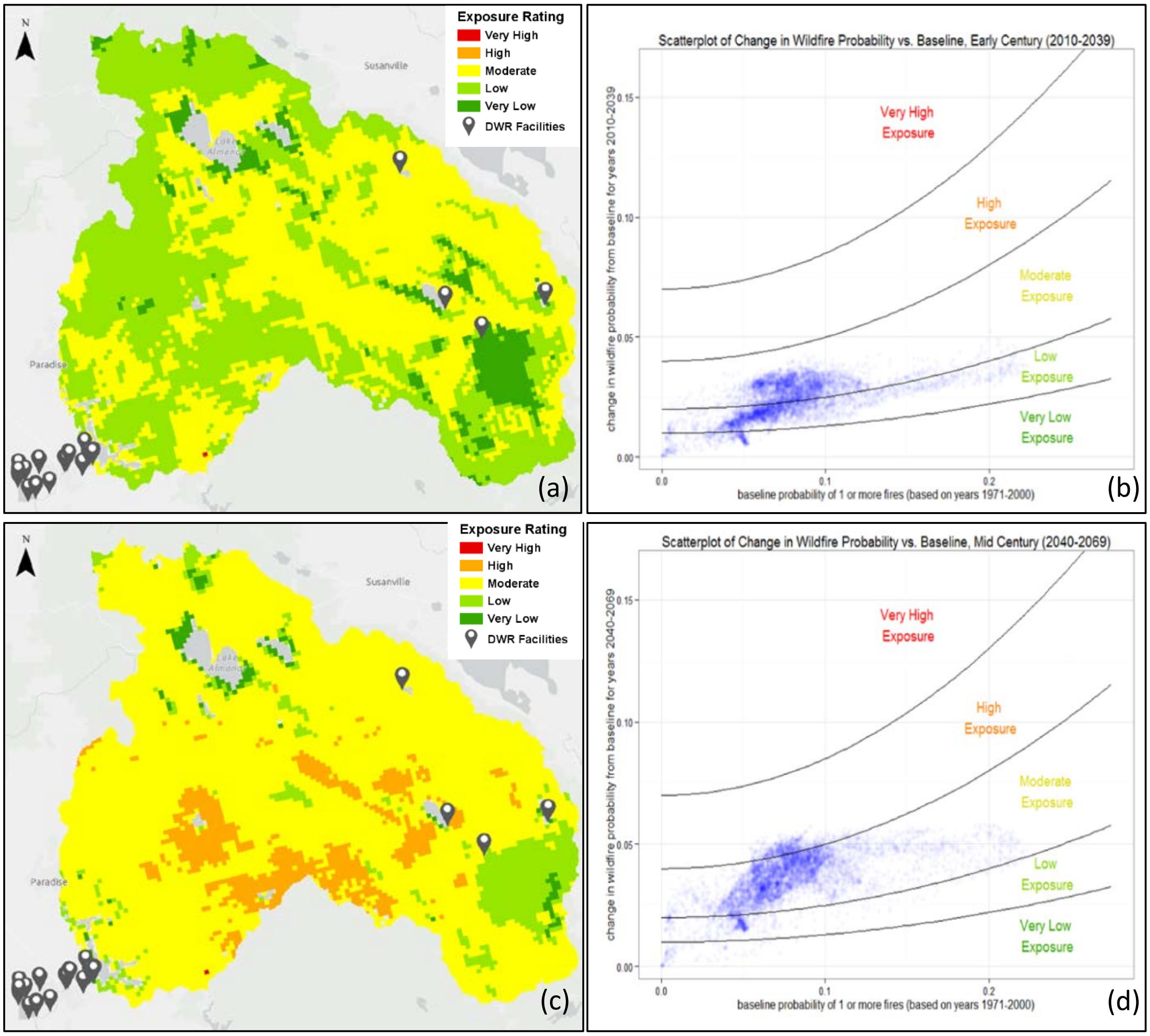
The UFRW is comprised of approximately 70 percent mixed conifer forest (pine, fir, and cedar species), which is at increasing risk of large, high-severity fires (Stoddard, Sanchez Meador, Fule, & Korb, 2015). Miller et al. (2009) found that mean and maximum fire size and total burned area in the Sierra Nevada have increased between the early 1980s and 2007. They also showed that forest fire severity (a measure of the effect of fire on vegetation) rose during the period 1984 to 2007, with the pattern concentrated in middle-elevation conifer forests. Stand-replacing fires ("high severity") at the beginning of the record burned at an average of about 17 percent, while the average for the last 10-year period was 30 percent. Miller et al. (2009) concluded that both climate change and increasing forest fuels explained the patterns they analyzed.

As was done to assess the statewide DWR facilities, the Krawchuk and Moritz dataset was used to evaluate the impacts of projected change in wildfire regime for the UFRW. The analysis demonstrates that the entire watershed experiences an increase in exposure level. In early century conditions, the watershed has mostly very low to moderate exposure to changes in wildfire regime, but by mid-century nearly all the watershed is projected to face a higher level of exposure (classified as "moderate"), notably that only small areas rank as high exposure and low exposure (Figure 2-3 and Table 2-1).

Table 2-1 Climate Change May Increase Wildfire Exposure Levels of the Upper Feather River Watershed (Early and Mid-Century).

Wildfire Exposure	Early Century (2010–39)	Mid-Century (2040–69)
Very Low	6.5%	2%
Low	46%	8%
Moderate	48%	80%
High	0%	10%
Very High	0%	0%

Figure 2-3 a-d Feather River Watershed Wildfire Exposure May Increase Due to Climate Change (Early and Mid-Century).



Figures 2-3 (a) and (c) represent early-century (2010–2039) (a) and mid-century (2040–2069) (c) exposure ratings as a function of the change in wildfire probability from baseline years 1971–2000 for the Feather River USGS Hydrologic Unit Code (HUC)-8 watershed; figures 2-3 (b) and (d) depict each grid cell displayed in figures (a) and (c) as blue dots plotted per the baseline probability of one or more fires and change in probability by mid-century.

Sensitivity

Analysis of the sensitivity of DWR facilities, lands, and operations to the increased incidence of wildfire caused by climate change is discussed in the section below.

Facilities and Lands

With input from California Department of Forestry and Fire Protection (CAL FIRE) experts, an "Integrated Fire Analysis/Structure Risk Assessment" form was developed to assess various aspects of sensitivity of DWR facilities to current and future wildfire risk. Net wildfire risk was determined based on the integration of risk levels for three factors: roof type, hazard class, and property defense/ignition zone. A numerical scoring system was used to minimize subjective assessments (Appendix C). Site visits were conducted by DWR Climate Change Program staff and onsite facility managers to complete the Integrated Fire Analysis/Structure Risk Assessment form and evaluate the sensitivity of each of these facilities.

Operations

The sensitivity of SWP operations to changes in wildfire regime in the watershed is difficult to assess. Wildfires can change several properties of a watershed and can have short-term and long-term effects on the hydrology of the watershed depending on their severity and intensity (Gould, et al., 2016). In general, the conditions of the watershed existing after the occurrence of a wildfire tend to result in increased inflows and contaminant loadings to receiving water bodies (Ice, Neary, & Adams, 2004). Because of the many ways that increased wildfire in the UFRW could affect SWP operations, it was beyond the scope of this assessment to produce a comprehensive sensitivity analysis of wildfire on SWP operations. Instead, a qualitative assessment of the ways in which a changing wildfire regime could influence SWP operations is provided.

Wildfires can increase surface runoff by destroying both the vegetation canopy and the organic litter on the soil surface, reducing the amount of precipitation that is intercepted by the canopy of leaves and the forest floor. Wildfires can also burn the surface of the soil and create a water-repellant soil layer that obstructs infiltration of water into the subsurface, increasing direct runoff and extending the recovery time for the watershed by reducing plant growth (Gould, et al., 2016).

The loss of vegetation exposes the surface to the impacts of erosional processes. With reduced vegetative cover, runoff can create channel incisions that form a streamlined pathway for runoff and sediments to reach SWP reservoirs. Wildfires can also destroy root systems of vegetation along channel banks, leading to instability and greater potential for erosion (Gould, et al., 2016). Further, Goode et al. (2012) suggested that under climate change, sediment yields in western semi-arid basins could be as much as 10 times greater than was observed in the 20th century. Although some coarse sediment is important for properly functioning geomorphic processes, a dramatic increase could affect aquatic ecosystem function, impair water quality, increase maintenance costs, and reduce reservoir capacity and life expectancy.

Surface runoff in watersheds affected by wildfires often transports contaminants that can result in long-term degradation of aquatic environments and negative impacts to recreational activities. Sediments often carry phosphorus and nitrogen from plant tissues, which can overstimulate growth of aquatic vegetation leading to depletion of oxygen levels. The deposition of ash can affect fish by limiting visibility, clogging gills, and/or affecting production and species composition of aquatic insects/food base. Fire retardants, which often contain ammonia, nitrogen, and phosphorus, can be an additional source of nutrient pollution into aquatic systems (University of Wyoming, 2013).

Watersheds often require a decade or more to recover from a large or intense wildfire (Agee, 1996). In the UFRW, areas dominated by mixed conifer forests may be most affected because of their spatial extent, longer recovery period, and watershed characteristics that are more susceptible to impacts from wildfires. At lower elevations, irrigated agriculture may also be impacted. Carrying roughly 60 percent of the inflow to Oroville Reservoir, the North Fork of the Feather River may contribute to increased sediment loading and thereby reduce water quality[7].

Wildfire Vulnerability Assessment Results

The VA determined the level of vulnerability to changes in wildfire occurrence through development of a risk assessment, followed by an evaluation of the capacity of DWR assets and operations to adapt to those changes. Facilities and lands were scored quantitatively based on a combination of exposure and sensitivity, using a scoring methodology presented further in Appendix B. Operations was qualitatively examined. Risk to staff was not assessed here.

Facilities and Lands

Risk

Much of the land surrounding SWP facilities is agricultural or grassland, although desert scrub and chaparral predominate in the Southern Region and forested lands surround the Oroville facility in the Northern Region. Urban and agricultural lands, particularly irrigated acreage, and low-fuel habitat types such as annual grassland and desert scrub are less sensitive to wildfire than other habitat types (CAL FIRE, personal communication).

Site visits confirmed that the overall risk for most facilities and structures was low, once all factors (roof type, hazard class, and property defense/ignition zone) were considered. But out of all DWR facilities examined, four sites near Oroville, two sites in the Upper Feather River, and three structures in the Southern Region scored risk values of “Moderate” to “High” (Table 2-2). The risk to these facilities is from the combined effects of the habitat in the “Property Defense” zone adjacent to the structures and the “Vegetation Clearance” zone out to 200 feet from the structure. In the case of facilities in the Northern Region, vegetative classification in these zones with moderate risk was “pine,” and for facilities in the Southern Region it was “chaparral.” Both of those vegetation types are more likely to contain fuels that will carry a large wildfire (CAL FIRE, personal communication).

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[7] Sacramento River Watershed Program. Upper Feather River Watershed. http://www.sacriver.org/aboutwatershed/roadmap/watersheds/feather/upper-feather-river-watershed. Accessed 9/1/2016.

Table 2-2 **Several DWR Facilities Have Moderate or High Risk to Wildfire.**

Region	Facility	Structure Name	Risk Score*
NRO	Feather River Fish Hatchery	Office & Maintenance Shop	8
NRO	Edward Hyatt Power Plant	Warehouse Building (Butler)	11
NRO	Edward Hyatt Power Plant	Office Trailer	10
NRO	Edward Hyatt Power Plant	Security Trailer	10
NRO	Antelope Valley Dam & Reservoir	Instrumentation Building	11
NRO	Antelope Valley Dam & Reservoir	Outlet Control Building	11
SRO	William Warne Power Plant	Power Plant	9
SRO	William Warne Power Plant	Oil Storage Building	8
SRO	William Warne Power Plant	Weld Shop	8

*Combined scores of 7 or less = Low Risk; 8-11 = Moderate Risk; 12 or more = High Risk. See Appendix B. DWR Integrated Wildfire Analysis.

Adaptive Capacity

The infrastructure for which DWR is responsible is largely immobile and therefore does not have a high inherent capacity to adjust to increased wildfire; however, the landscapes that surround most of the facilities are primarily agricultural, urban, or fire-adapted low-fuel habitat types that have low wildfire risk.

In all locations that were evaluated, existing management and maintenance practices protect infrastructure from the current wildfire exposure level. Current practices include the clearing of vegetation and implementation of fire contingency plans. For these nine sites that scored as moderate-high risk, DWR possesses the financial means to increase the level of intervention to reduce the sensitivity of these facilities to increases in wildfire exposure expected in the future.

Vulnerability

Overall, DWR’s facilities are prepared for increased wildfire exposure through mid-century. Wildfire vulnerability for facilities will continue to be low, even under conditions of substantially increased wildfire potential.

Operations

DWR’s operations consist of operation and maintenance of SWP facilities and an assortment of water supply and flood management infrastructure, including the SWP facilities. Wildfire could stop ongoing operations of any infrastructure, if it is not built to withstand such an event.

Risk

Much of the UFRW that provides the water supply for the SWP is exposed to changing wildfire regimes and there are myriad ways in which the operations of the SWP could be sensitive to this increase in wildfire frequency and severity. For example, increased sediment inflow from the erosion of burned soils could possibly interrupt fieldwork and maintenance activities. Future extent of exposure and sensitivity of the UFRW will be determined by forest management practices that are outside of DWR’s control. For these reasons, SWP operations are assumed to be at risk from changing wildfire regimes.

Adaptive Capacity

Existing management plans and emergency response plans are important indicators of adaptive capacity in a watershed. They encourage social and economic support, and describe the current best practices to implement those strategies (Sham, Tuccillo, & Rooke, 2013) (U.S. Forest Service, 2013). While DWR operates several facilities in the Feather River Watershed, the majority (65 percent) of the watershed is publicly owned and managed by the U.S. Forest Service as part of the Plumas National Forest. The two primary management planning documents for this region that provide management actions for wildfire, including managing upland vegetation to reduce the risk of catastrophic wildfire, are the *Feather River Watershed Management Strategy, May 2004*[8] and the *Upper Feather River Integrated Regional Water Management Plan, November 2016*[9].

The Feather River Watershed Management Strategy was prepared to help implement the Monterey Settlement Agreement of 2003. The document outlines priorities for watershed management and restoration activities. The recommended actions related to vegetation management (e.g., forest thinning) would likely reduce wildfire risk, though these benefits are not the target of the strategy (Sapsis, et al., 2016). The Upper Feather River Integrated Regional Water Management Plan likewise details management actions and coordination opportunities that will result in decreased risk of high intensity wildfires.

In the lower portion of the Feather River watershed and area surrounding Lake Oroville, DWR has had a more active role in developing management plans related to wildfire. As a requirement of the FERC Project No. 2100 Settlement Agreement, DWR developed a *Fuel Load Management Plan, 2012*[10] within the FERC project boundary. The plan identifies fuel load reduction strategies to provide land and resource managers a strategic approach to reduce the potential for wildfire within the FERC project boundary. The plan will be updated to account for changing conditions at least every 10 years.

Vulnerability

Overall, DWR’s operation of the SWP is vulnerable to increased wildfire risk throughout the UFRW though mid-century and should be a priority area of focus for adaptation planning. Adaptation planning for the UFRW will be complex because the watershed includes many different land owners and interests and DWR is not the dominant land owner or interest in the area. Any adaptation strategy employed in the watershed would require intense multi-stakeholder cooperation and coordination.

Staff

Because of the sporadic nature of wildfire and projected increases of wildfire frequency throughout California, DWR staff could potentially be at higher risk and more vulnerable to wildfire. Staff exposure to wildfire will be highly dependent on location; for example, in 2017, DWR staff were unable to report to work because of the Devil’s Canyon area fires in Southern California, because their homes or their

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[8] Feather River Watershed Management Strategy: http://www.water.ca.gov/environmentalservices/docs/mntry_plus/FeatherRiverStrategy.pdf.

[9] Upper Feather River Watershed IRWM Plan: http://featherriver.org/.

[10] http://www.water.ca.gov/orovillerelicensing/docs/settlement_agreement/SA%20RMP.pdf.

route to work was affected by the fire. Existing protocols for fieldwork and maintenance activities may need to be modified to create adaptive capacity to wildfire vulnerability to staff.

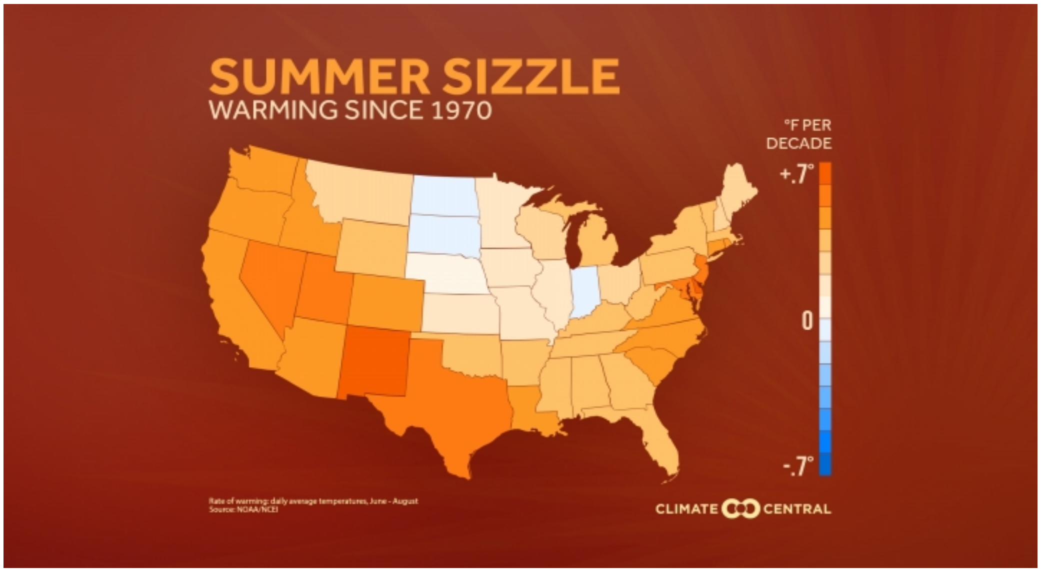
Other Considerations

Two topics were identified as potential vulnerabilities for DWR that are out of scope for this VA: electrical transmission interruption and sediment influx into reservoirs. These hazards are discussed in Chapter 8.

Next Steps

Increasing wildfire frequency and intensity will continue to be a topic of research in California, given increased incidents in recent years during the drought and with higher temperatures. With additional information on sensitivities posed to operations, adaptation strategies could be developed to reduce risks of increasing wildfire, such as meadow restoration, controlled burns, and forest thinning.

Chapter 3 — Extreme Heat



U.S. Faces Rise in Extreme Heat[11]

Increasing temperatures pose operational challenges associated with potential health impacts to DWR staff, especially those working in the field, as well as hydrological changes (type of precipitation and runoff timing). Potential impacts to operations from hydrological changes are addressed in Chapters 5 and 6. This section will focus on the potential impacts of increasing temperatures and extreme heat events on outdoor work activities.

Relevant Studies and Other Efforts Conducted to Date or in Progress

According to the Western Region Climate Center, the mean temperature statewide in California has increased 1.1 to 2 °F in the past century (Abatzoglou, Redmond, & Edward, 2009) (California Department of Water Resources, 2014). Both minimum and maximum annual temperatures have increased, but the minimum temperatures have increased more (1.6 to 2.5 °F) than the maximums (0.4 to 1.4 °F) (California Department of Water Resources, 2014). A recent study by Scripps Institution of Oceanography projected future temperatures across California. The results indicate that by 2060–2069, mean temperatures may be 3.4 to 4.9 °F higher across the state compared to the 1985–1994 period (Pierce, et al., 2012) (California Department of Water Resources, 2014). Seasonal trends indicate a greater increase in the summer months (4.1 to 6.5 °F) than in the winter months (2.7 to 3.6 °F) by 2060–2069. While these changes in mean temperatures may contribute to a number of water management

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[11] http://assets.climatecentral.org/images/made/2016SummerTrendsMap_CONUS_en_title_lg_720_405_s_c1_c_c.jpg

changes, it is the projected increase in maximum summertime temperatures and extreme heat events that poses the highest risk to the health and safety of DWR staff working outdoors.[12]

Both changes in mean temperatures and more extreme weather events may create increases in public health risks associated with heat-related illness and mortality, respiratory impacts, and infectious diseases (California Natural Resources Agency, 2014). Higher ambient temperatures in California are already associated with increased mortality related to cardiovascular disease (Basu & Ostro, 2008). In general, extreme heat brings greater risk of death from dehydration, heat stroke, heart attack, and other heat-related illnesses (California Natural Resources Agency, 2014).

Other relevant reports that pertain to potential impacts from extreme heat are described below.

- **Preparing California for Extreme Heat: Guidance and Recommendations** (California Department of Public Health, 2013). This report was developed by the Heat Adaptation Workshop, a subcommittee of the Public Health Workgroup, Governor's Climate Action Team (CAT). It provides guidance for incorporating extreme heat projections, based on current climate change models, into planning and decision making in California.
- **Risky Business: The Economic Risks of Climate Change in the United States** (Risky Business Project, 2014). This report uses a standard risk-assessment approach to determine the range of potential consequences for each region of the U.S. and selected sectors of the economy. The report found that extreme heat, especially in the Southwest, threatens labor productivity, human health, and energy systems (Table 3-1).
- **DWR Heat Illness Prevention Plan** (DWR 2015) — Heat illness is a serious medical condition resulting from the body's inability to cope with heat and to cool itself. The effects of heat illness can range from heat exhaustion to heat stroke. The DWR Heat Illness Prevention Plan (HIPP) outlines procedures staff need to implement when working outdoors to protect themselves against heat illness and the proper responses for a possible heat illness event, all in compliance with the requirements of the California Department of Industrial Relations, Division of Occupational Safety and Health (Cal/OSHA). In May 2015, the HIPP was updated to incorporate new Cal/OSHA requirements, which now include procedures for two outdoor temperature thresholds: 80 °F and 95 °F.

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[12] For regional observational and projected temperature trends, see California Water Plan Update 2013, Volume 2, *Regional Reports* (California Department of Water Resources, 2014).

Table 3-1 California's Increasing Heat Will Impact Productivity, Energy Demand, and Community Health.

	2020–2039	2040–2059
Average summer temperature	76–79	78–80
Number of days over 95 °F	36–43	41–55
Change in labor productivity (%)	-0.2 to 0.1	-0.5 to -0.2
Change in electricity demand (%)	-0.1 to 1.5	1.1 to 3.2
Change in energy expenditure (%)	-0.7 to 2.8	1.9 to 6.1
Change in mortality (per 100,000)	-3 to 3	-2 to 6

Extreme Heat Vulnerability Assessment Approach

The primary focus for this extreme heat analysis is DWR staff because their outdoor activities are likely to be affected by increased heat waves and extreme heat days. Data sources and methodology for assessing exposure and sensitivity are described below.

Exposure

To assess exposure to extreme heat events, the DWR Climate Change Program staff interviewed regional office staff and managers to obtain initial data and refine a screening survey on heat exposure. An "Extreme Heat Screening Questionnaire" was then sent to DWR branch chiefs in January 2014 to identify which branches have staff in the field between May and October. A more detailed survey was then conducted to gather information on the type of activities occurring between May and October and how summer temperatures currently affect staff activities. The survey targeted supervisors, and in a few cases staff, who were identified in the initial questionnaire. The purpose of the survey was to help assess staff's current exposure to extreme heat and identify where DWR has flexibility, along with potential constraints, to reduce that exposure. The questionnaire and relevant portions of the survey results are available in Appendix C. Most DWR outdoor work occurs in the Central Valley and the southern interior and Mojave Desert regions (Figures 3-1 and 3-2).

Figure 3-1 **The Western Regional Climate Center Has Divided California into 11 Climate Regions.**

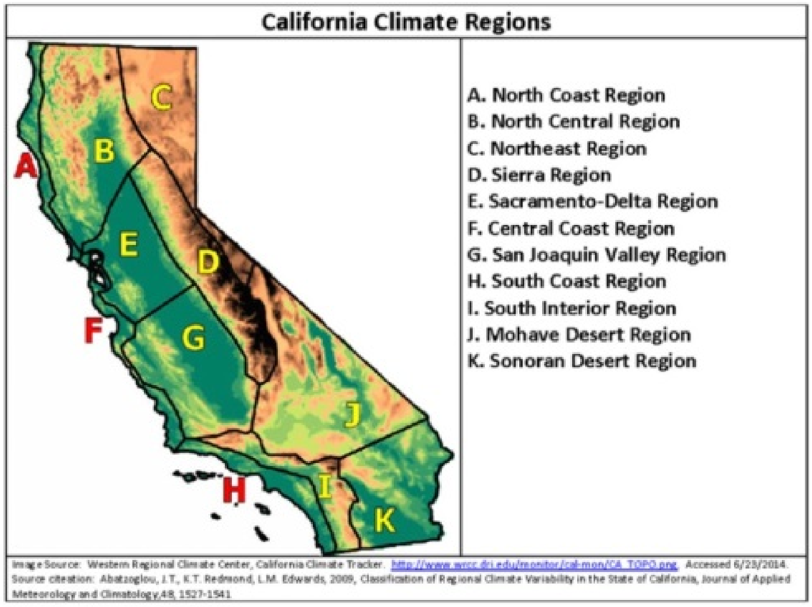
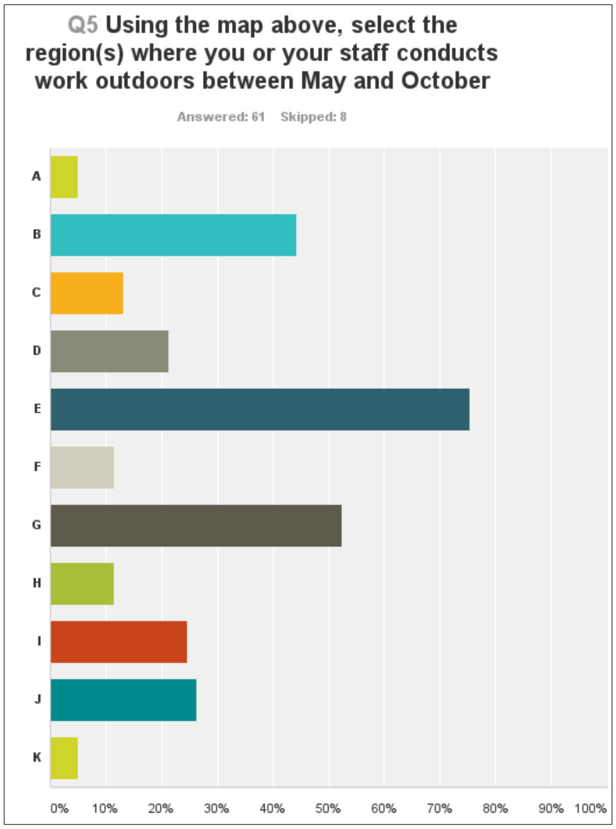


Image Source: Western Regional Climate Center, California Climate Tracker. http://www.wrcc.dri.edu/monitor/cal-mon/CA_TOPO.png. Accessed 6/23/2014.
Source citation: Abatzoglou, J.T., K.T. Redmond, L.M. Edwards, 2009, Classification of Regional Climate Variability in the State of California, Journal of Applied Meteorology and Climatology,48, 1527-1541

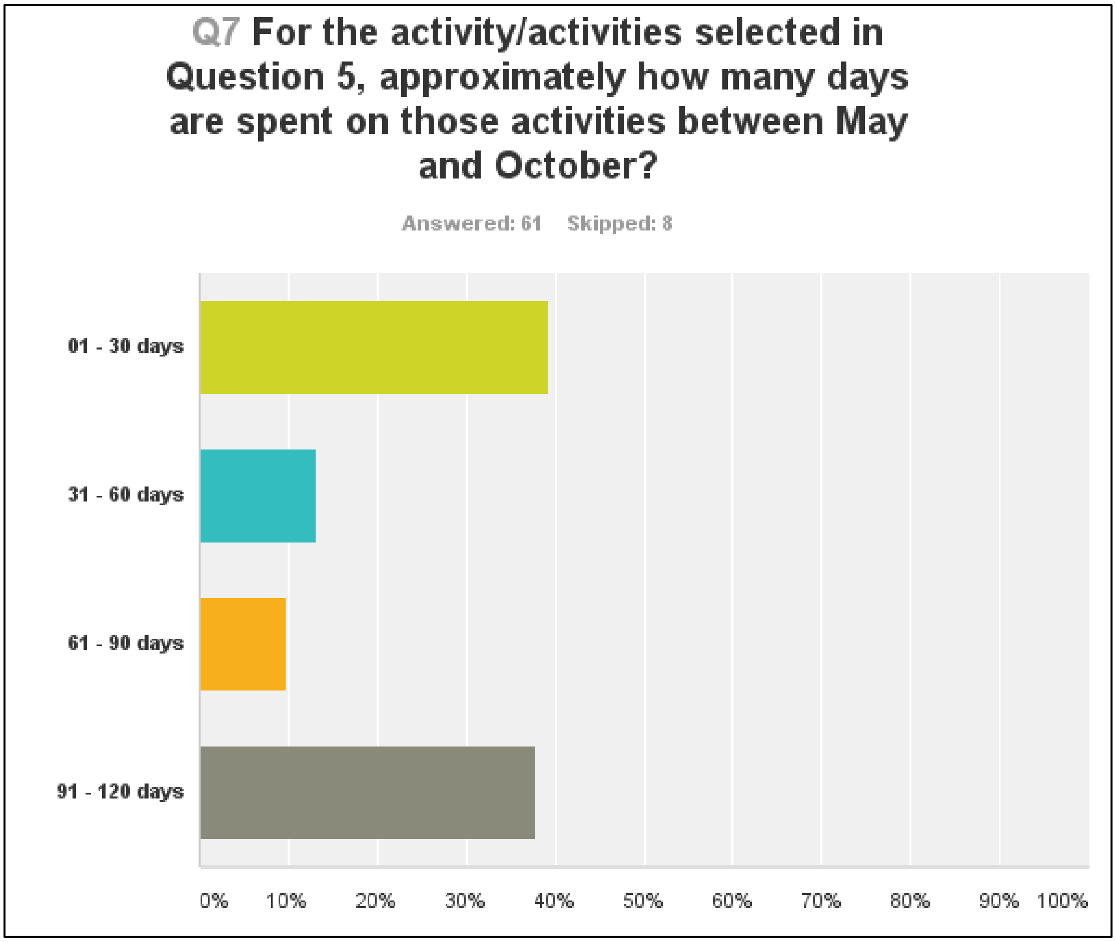
Figure 3-2 **A Survey of DWR Branch Chiefs Shows the Climate Regions Where Staff Works Outdoors.**



Note: This data is from a survey of branch chiefs collected January 2014. Letters correspond to Western Regional Climate Center California Climate Regions (see Figure 3-1).

The number of days spent outdoors during May to October varied greatly, with nearly 40 percent of respondents reporting having staff in the field for either less than a month or greater than three months (Figure 3-3). About 75 percent of the time, these activities are conducted with two or more staff, and about 80 percent of these activities require consecutive days outside. Slightly over half of the respondents replied that they were generally able to make scheduling modifications when temperatures exceed 85 °F; however, there are some limitations. Over 80 percent of the respondents identified certain activities that must be completed within a specific timeframe during the May to October time period. In addition, nearly 40 percent of respondents replied that they have had to adjust staff scheduling and work activities during past heat waves.

Figure 3-3 A Survey of Branch Chiefs Shows the Number of Days Staff Spend in the Field Between May and October.



Note: This data is from a survey of branch chiefs collected January 2014.

DWR Climate Program Staff analyzed climate model projection results available from Cal-Adapt[13] to assess the potential impacts of warming temperatures on outdoor staff activities. Cal-Adapt data utilized for this assessment are based on the Geophysical Fluid Dynamics Laboratory (GFDL) global circulation

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[13] Cal Adapt: http://cal-adapt.org/.

model and the A2 emissions scenario. This projection represents the higher end of the range of warming projected by the entire suite of climate model projections. This assessment evaluated three temperature points (80, 95, and 105 °F) to quantify the number of days projected to be above these thresholds. The 80 and 95 °F thresholds are used in DWR's HIPP and the 105 °F is used by the National Weather Service as a trigger for warning the public.

The National Weather Service (NWS) issues heat alerts using a Heat Index value. The *Heat Index*, also known as the "apparent temperature," is a measure of how hot it feels when relative humidity is factored in with the actual air temperature. When the Heat Index is expected to exceed 105 to 110 °F for two consecutive days, the NWS will initiate alert procedures. At these apparent temperatures sunstroke, muscle cramps, and/or heat exhaustion are more likely to occur, and heat stroke is possible with prolonged exposures and/or physical activity. Since daily maximum temperatures can reach or exceed 105 °F during the summer months in portions of California, this threshold was included to assess the potential increase in these more extreme heat days, given the potential health implications.

The increase in the number of days above each threshold was modeled for the period 2040–2049 and was compared to the 1990–1999 base period (Table 3-2). Based on the results of the screening survey, this analysis was conducted for each of the regional offices, field divisions, and the Sutter and Sacramento maintenance yard locations, as well as one additional, representative location in the Delta (Rio Vista). The ranges represent the minimum to maximum number of days that exceeded the 80, 95, or 105°F temperature thresholds annually over the 10-year period. From Table 3-2, it is notable that exposure of 105 °F days *at least doubles* on the high end of the projected ranges for the majority of DWR Region Offices and Field Divisions.

Table 3-2 Outdoor Workers May Be Exposed to More Days Exceeding Certain Temperatures.

Location Name	80 ºF		95 ºF		105 ºF	
	1990–1999	2040–2049	1990–1999	2040–2049	1990–1999	2040–2049
Northern Region Office	142–173	150–180	48–89	75–95	6–16	9–32
Oroville Field Division	128–163	150–174	33–63	58–84	0–8	2–13
Sutter Yard	140–177	157–178	38–70	67–93	0–10	2–16
North Central Region Office	133–170	152–176	20–50	38–67	0–4	1–7
Delta (Rio Vista)	115–160	148–170	12–28	19–50	0–3	0–4
Delta Field Division	119–168	151–175	21–47	37–64	0–5	0–11
San Luis Field Division	121–165	146–171	15–35	28–61	0–1	0–7
South Central Region Office	151–183	166–192	48–86	85–116	3–15	6–29
Southern Region Office	132–162	146–183	3–18	12–45	0–0	0–3
San Joaquin Field Division	156–188	174–199	53–93	87–117	3–16	7–32
Southern Field Division	139–180	160–194	48–81	84–105	0–6	3–20

Sensitivity

Sensitivity to warming temperatures will vary depending on the individual. Staff currently working in cooler areas may be less acclimated to extreme heat events and may not have access to air conditioning to cool off if overheated. Therefore, staff working outdoors in the Delta or near the Southern Region Office may be more sensitive to the projected increases in temperature. At the same time, even in areas accustomed to high summer temperatures may experience *entire summers with days above 95 °F with one third of those above 105 °F*. This could limit safe fieldwork conditions, as jobs with extensive fieldwork traditionally have scheduled long fieldwork for cooler days that may no longer be available in these hotter regions until later fall months.

Extreme Heat Vulnerability Assessment Results

Vulnerability of DWR Staff to extreme heat was determined from analysis of the risk and adaptive capacity across the state.

Risk

Across all DWR locations, there is a similar pattern for each of the three thresholds (80 °F, 95 °F, and 105 °F) when comparing the range of days exceeding the threshold for the historical period (1990–1999) with the mid-century (2040–2049). In all cases, the range of days exceeding the threshold for the mid-century period falls within the historical period on the lower end of the range but exceeds it on the upper end of the range (Table 3-2).

For the mid-century period, the percent change from the historical period increased more in the locations that were slightly cooler in the historical period (i.e., North Central Region Office, Rio Vista, Delta Field Division, and the Southern Region Office) for both the 80 °F and 95 °F thresholds. For the 105 °F threshold, the greatest increases occurred at all locations south of and including San Luis Field Division. The percent change ranged from 1 percent to 29 percent for the 80 °F threshold, with the largest increases occurring at the Rio Vista and Delta field division locations (Table 3-3). For the 95 °F threshold, the percent change increases to 7 percent to 300 percent, with the largest increases at the North Central Region Office and the Southern Region Office. Finally, for the 105 °F threshold, the percent change ranged from 33 percent to *600 percent*, with the greatest increase at San Luis and Southern field divisions and the Southern Region Office.

Table 3-3 **Compared to the Historical Period, the Percent Change in Number of Days Exceeding Temperature Thresholds Will Increase by Mid-Century (2040–2049).**

Location Name	80 ºF	95 ºF	105 ºF
Northern Region Office	4–6%	7–56%	50–100%
Oroville Field Division	7–17%	33–75%	0–63%
Sutter Yard	1–12%	33–76%	0–60%
North Central Region Office	4–14%	34–90%	0–75%
Delta (Rio Vista)	6–29%	58–79%	0–33%
Delta Field Division	4–27%	36–76%	0–120%
San Luis Field Division	4–21%	74–87%	0–600%
South Central Region Office	5–10%	35–77%	93–100%
San Joaquin Field Division	6–12%	26–64%	100–133%
Southern Field Division	8–15%	30–75%	0-233%
Southern Region Office	11–13%	150–300%	0–200%

While all staff working outdoors will be exposed to warming temperatures, projections for the mid-century indicate that the increases will either be within the range or slightly above the range to which they are currently exposed.

For both construction and operations and maintenance activities, there may be multiple implications, including delays in completing scheduled work activities; heat-related disruptions to the power grid that impact ability to operate (e.g., pumps go offline); short-term increases in workload as scheduled activities get moved into shorter work windows; increased costs associated with higher staffing levels to offset the need for more on-site rest periods; and increases in staff sick days for existing health conditions exacerbated by heat and heat illness. These constraints could be particularly challenging during emergency response operations, when staff may need to work around-the-clock to address the emergency to protect public safety or critical infrastructure.

Another set of activities that may be vulnerable are conducting sampling, monitoring, and various ecological surveys, which could be problematic for real-time compliance monitoring.

Adaptive Capacity

Fortunately, DWR already has a fair amount of adaptive capacity to address the risk to staff from warming temperatures and extreme heat events. Based on the statewide survey results, supervisors do have some ability to shift work schedules to the cooler portions of the day, and nearly half indicated that they can reschedule certain work activities. In addition, DWR has protective measures for staff in place via the implementation of the HIPP.

Vulnerability

The combination of a moderate increase in exposure and existing adaptive capacity will likely keep the vulnerability of staff at essentially the same level that exists now through mid-century.

Other Considerations

Extreme heat events can strain the electrical grid from both a loss in generation capacity and an increase in demand. Analysis of reduced electrical transmission resulting from extreme heat is out of scope for this assessment but may affect DWR’s operations and is therefore discussed in Chapter 8.

Next Steps

The analysis conducted for this assessment was an initial evaluation of the potential impacts of warming temperatures under a single future scenario. Future updates to the VA could include a more robust assessment with a subset of the newer global climate models (CMIP 5)[14] under multiple emissions scenarios. This initial analysis did indicate that regions have historically experienced and are projected to experience different levels of high temperatures, which creates different levels of vulnerability. This analysis did not attempt to quantify the potential budget impacts of heat-related project delays and increased staffing costs, but this could also be explored in the future, especially in areas where staff have

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[14] http://cmip-pcmdi.llnl.gov/cmip5/.

high numbers of fieldwork days in the summer. DWR’s HIPP may need to be updated to account for increasing extreme heat. Options could include evaluating additional protective procedures for staff working in high temperatures to reduce their vulnerability to heat exhaustion and heat stroke. Outdoor staff activities may need to be modified by implementing the buddy system more frequently, instituting more on-site cooldown periods, and using longer acclimation periods for new staff entering a high-temperature work area.

Chapter 4 — Sea-Level Rise

Sea-Level Rise on the California Coast[15]

After a long period of relative stability over the past few thousand years, global mean sea level rose seven inches in the 20th century (Koop, et al., 2016), which is consistent with the observational record at the Golden Gate. Projections indicate that sea level will rise at a much higher rate during the 21st century, primarily because of rising global average temperatures which cause ocean water to warm and expand and land-based ice (e.g., glaciers) to melt (National Research Council, 2012) (Intergovernmental Panel on Climate Change, 2013).

With a direct connection to the San Francisco Bay and the Pacific Ocean, the Sacramento-San Joaquin Delta will also be impacted by sea-level rise. Rising sea and tide levels could further stress the large network of levees, increase saltwater intrusion, and change hydrology of the rivers and sloughs that flow through the Delta. Such shifts would affect aquatic conditions and water operations (Cloern, et al., 2011).

This chapter focuses on assessing the vulnerability of DWR facilities and lands. Staff activities are unlikely to be affected by sea-level rise directly and are thus not assessed as part of this analysis. Operational impacts to the SWP from sea-level rise are outside the scope of this assessment, as will be discussed later in this chapter.

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[15] http://www.reimaginerpe.org/cj/research/sea_level_rise.

Relevant Studies Conducted to Date or in Progress

Many studies have examined the projected effects of sea-level rise on the California coast, San Francisco Bay, and the Sacramento-San Joaquin Delta (Delta) (Cloern, et al., 2011) (Hebeger, Cooley, & Herrera, 2011) (National Research Council, 2012) (Heberger, Cooley, Moore, & Herrera, 2012). These studies clearly indicate that sea-level rise poses hazards to economics, social, and environmental assets along the coast and inland. Therefore, sea-level rise is a key hazard to assess for DWR facilities and operations, especially those related to the SWP.

Sea-Level Rise Vulnerability Assessment Approach

Data sources and methodology for assessing exposure and sensitivity are described below.

Exposure

DWR facilities that have potential exposure to sea-level rise areas are classified into the following areas: Coastal, San Francisco Bay (Bay), and the Sacramento-San Joaquin Delta (Delta). Since available data differ in these three areas, the methodologies for calculating exposure to sea-level-rise hazards are likewise different for each area. In all cases, exposure is assessed as the probability of inundation or other damage from rising seas and storm surges. Note that sea-level rise is one contribution of many to the actual water surface level at any given location and time; other factors include tides, storm surge, and atmospheric pressure (California Climate Action Team, Coastal and Ocean Working Group, 2013). In addition, river outflows are more important in the Sacramento-San Joaquin Delta than in the inland portions of the San Francisco Bay, and are therefore included as part of the modelled projections for the San Francisco Bay and Delta regions.

This VA assessed the exposure of DWR facilities to sea-level rise impacts using facility location, elevation, and projected sea level as criteria. The approach taken in this exposure screening process is informed by recommendations of the Coastal and Ocean Working Group of the Governor's Climate Action Team (California Climate Action Team, Coastal and Ocean Working Group, 2013). Specifically, the approach took sea-level rise projections from the National Research Council (NRC) report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington* (National Research Council, 2012). Studies used in this analysis included storms and other extreme events, where available.

Coastal

Humboldt Bay was identified as the only coastal area of focus for this vulnerability assessment. The only coastal-located DWR facility is in this area (Table 4-2), therefore no other areas along the south coast were examined. Elevation and inundation data for coastal areas were obtained from the study *Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping, Final Report* (Northern Hydrology and Engineering, 2015). Inundation maps of the Humboldt Bay area were combined with modeled 100-year high water elevations for sea-level rise amounts of 0.5, 1.0, 1.5, and 2 meters based on methods from Knowles (2010).

Sea-level rise projections were obtained from the NRC report on sea-level rise on the West Coast of the United States (NRC 2012). The NRC report lists ranges of potential sea-level rise on top of year 2000 levels for three-time periods: 2030, 2050, and 2100. Table 4-1 shows the projected ranges of sea-level change. Best available science highlighted in OPC's 2018 updated SLR guidance shows updated projected levels, which the future updates to this vulnerability assessment will incorporate.

Table 4-1 **The National Research Council Projects Sea Level Along the West Coast.**

Location	2030	2050	2100
North of Cape Mendocino	-4 to 23 cm	-3 to 48 cm	10 to 143 cm
South of Cape Mendocino	4 to 30 cm	12 to 61 cm	42 to 167 cm

Table 4-2 **The Eureka Flood Center Has Low Exposure to Sea-Level Rise Through Mid-Century.**

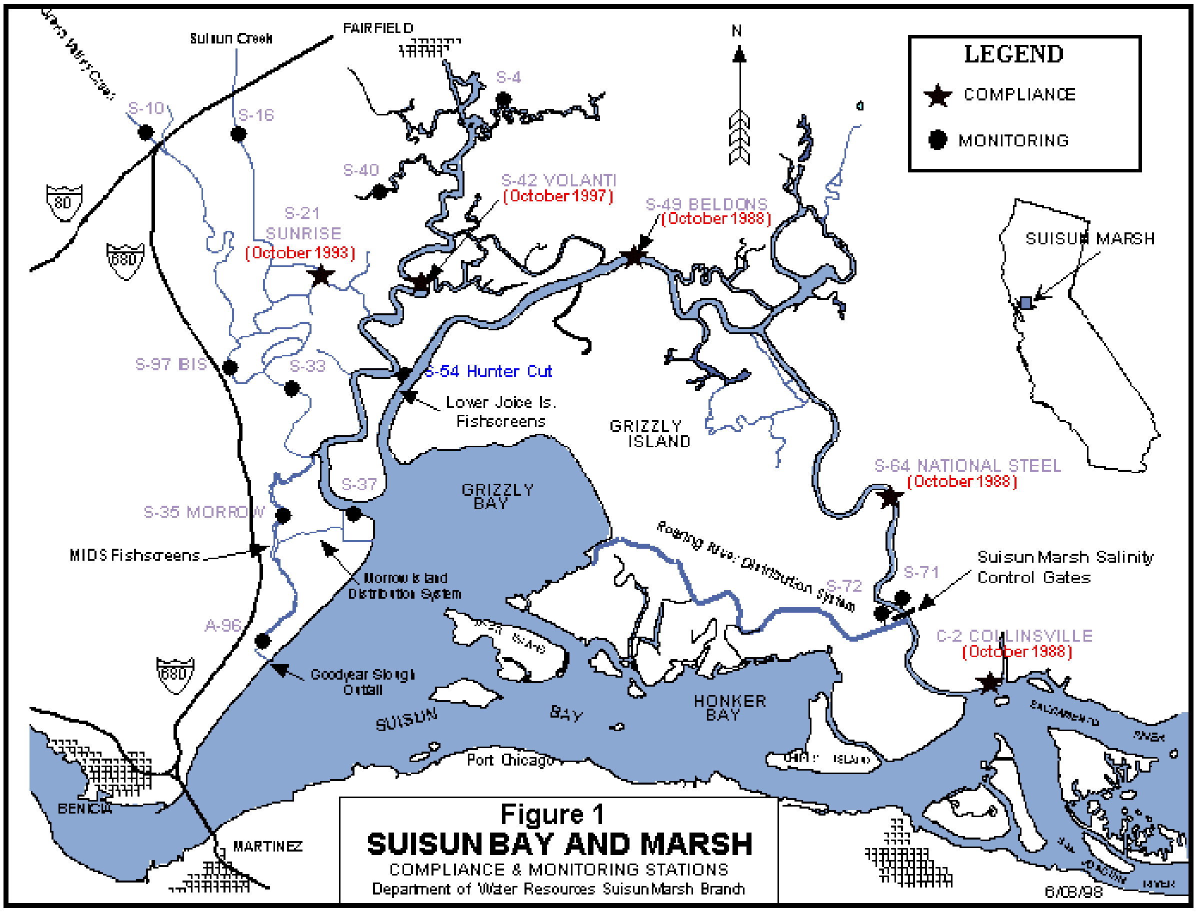
Facility/Program	Asset Name	Approx. Elevation (AMSL)*	Exposure Rating	
			2030	**2050**
Flood Control	Eureka Flood Center	6.1m (20 ft)	Low	Low

*AMSL = Above Mean Sea Level

San Francisco Bay

This region includes the San Francisco Bay inland to the confluence of the Sacramento and San Joaquin rivers (approximately Antioch). DWR has very little infrastructure within the San Francisco Bay itself. The facilities identified for inclusion in this study are all within the Suisun Marsh area (Figure 4-1 and Table 4-3).

Figure 4-1 Suisun Bay and Marsh Contain Numerous Compliance and Monitoring Stations.[16]



Two datasets were used to calculate relative exposure to SLR: land surface elevations from Wang and Atelievich (2012) and the SLR projections Knowles (2010) modeled for the Suisun Marsh, from which the elevations were derived from DWR-created LiDAR data. Knowles used 50 centimeters (cm), 100 cm, and 150 cm sea-level rise above year 2000 levels. The model incorporates 100-year flood elevations with sea-level rise.

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[16] http://www.water.ca.gov/suisun/dataReports/suisun_iep_data.cfm.

Table 4-3 Suisun Marsh Facilities Have a Range of Sea-Level Rise Exposure Ratings.

Facility/Program	Asset Name	Approx. Elevation (AMSL, feet)	Exposure Rating	
			2030	**2050**
Suisun Marsh	Salinity Control Gates	--	High	High
	Salinity Control Building	8	Low	Low

*AMSL = Above Mean Sea Level

Sacramento-San Joaquin Delta

The Delta is especially sensitive to the combined effects of multiple aspects of climate change. Areas within the Delta have water surface elevations that are affected by a variety of factors, including mean sea level, tidal fluxes and freshwater inflows, barometric pressure, and temporary water fluxes from wind and storm surge. Because climate change can increase mean sea level, alter freshwater flows, and intensify storm surge, the facilities in the Delta may be particularly vulnerable to the synergistic effects of these multiple aspects of climate change.

A detailed modeling analysis of the combined effects of mean sea level, tidal fluxes, freshwater inflows, barometric pressure, and temporary water fluxes because of wind and storm surge was beyond the scope of this study. Further, much of this analysis was conducted as part of the Central Valley Flood Protection Plan (CVFPP) 2017 Update[17]. The CVFPP 2017 includes technical analyses of reservoir, riverine and estuary simulations, hydrologic and economic analysis, and ecological assessments. One technical component of the plan is to evaluate the impact of hydrologic changes driven by climate change and sea-level rise during large flood events on the State Plan of Flood Control levees. Note that most of the State Plan of Flood Control levees are outside of the Delta; however, flood protection facilities throughout the Central Valley have important implications for the amount and timing of flood flows entering the Delta.

The analysis below presents a summary of the modeling and analysis conducted as part of the CVFPP 2017, highlighting the DWR facilities in the Delta that may be exposed to rising sea levels.

Figures 4-2, 4-3, and 4-4 below represent the locations of the three major facilities in the Delta owned by DWR:

- North Central Region Office;
- North Bay Aqueduct; and
- Clifton Court Forebay.

For each location, the effect of increased stream flows resulting from climate change, increased mean sea level, and storm surge were calculated at the closest available analysis point. The data shown in Figures

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[17] https://water.ca.gov/Programs/Flood-Management/Flood-Planning-and-Studies/Central-Valley-Flood-Protection-Plan

4-2 through 4-4 below illustrate the change in water surface elevation from approximately 40 cm of mean sea-level rise plus flows from a 100-year flood event (a flood event that has a 1 percent probability of occurring in any given year) and the residual storm surge[18].

Near the North Central Region Office, the CVFPP projects that an increase of approximately 0.6 feet is expected from the Yolo Bypass and 1.1 feet in the Sacramento River (Figure 4-2). Figure 4-3 shows that the North Bay Aqueduct intake is expected to experience an increase in water surface elevation of 1 foot during a 100-year flood, mostly caused by the backwater effect of the Yolo Bypass. Figure 4-4 shows that in the southern Delta, a much larger increase of 2.6 to 3.6 feet is projected near the Clifton Court Forebay. This increase is the result of two reinforcing effects.

1. The San Joaquin River watershed is generally higher in elevation compared to the rest of the Sierras and has historically received more snow and less rain at higher elevations. Temperature increases will result in increased direct runoff as more of the watershed receives rain and less snow falls at mid-century.
2. In this location of the Delta, the Sacramento River creates a backwater effect on Middle River, Old River, and Grantline Canal. As flows from the San Joaquin River reach the Delta, the backwater effects on Middle River, Old River, and Grantline Canal create a hydraulic dam which results in the San Joaquin flows backing up and raising water surface elevations even higher.

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[18] Residual storm surge in this analysis is the amount of storm surge existing when the flood waters from a storm arrive in the Delta, several hours after the storm would have made landfall at the Delta causing the greatest storm surge.

Figure 4-2 Locations near the DWR West Sacramento Office May Experience Higher Water Surface Elevation Changes (in feet), Between Current and Future Climate During a 100-Year Flood.

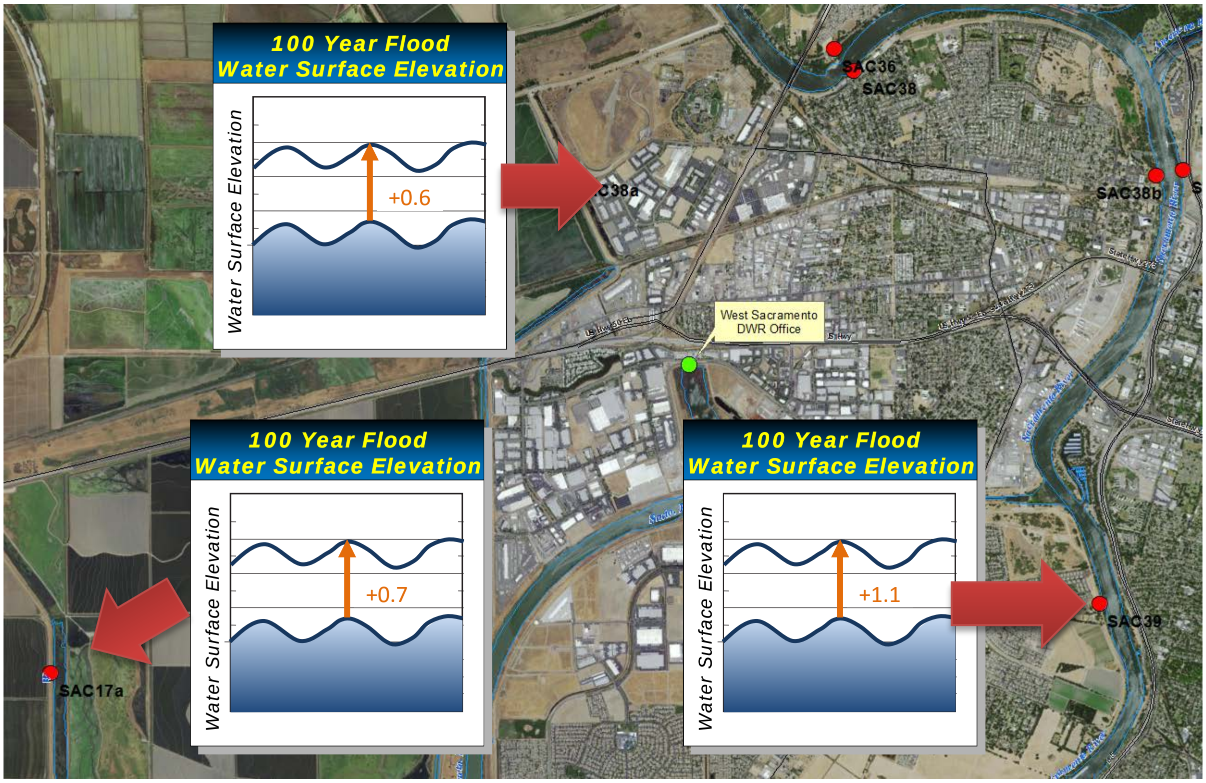


Figure 4-3 The North Bay Aqueduct May Experience Higher Water Surface Elevation (in feet), Between Current and Future Climate During a 100-Year Flood.

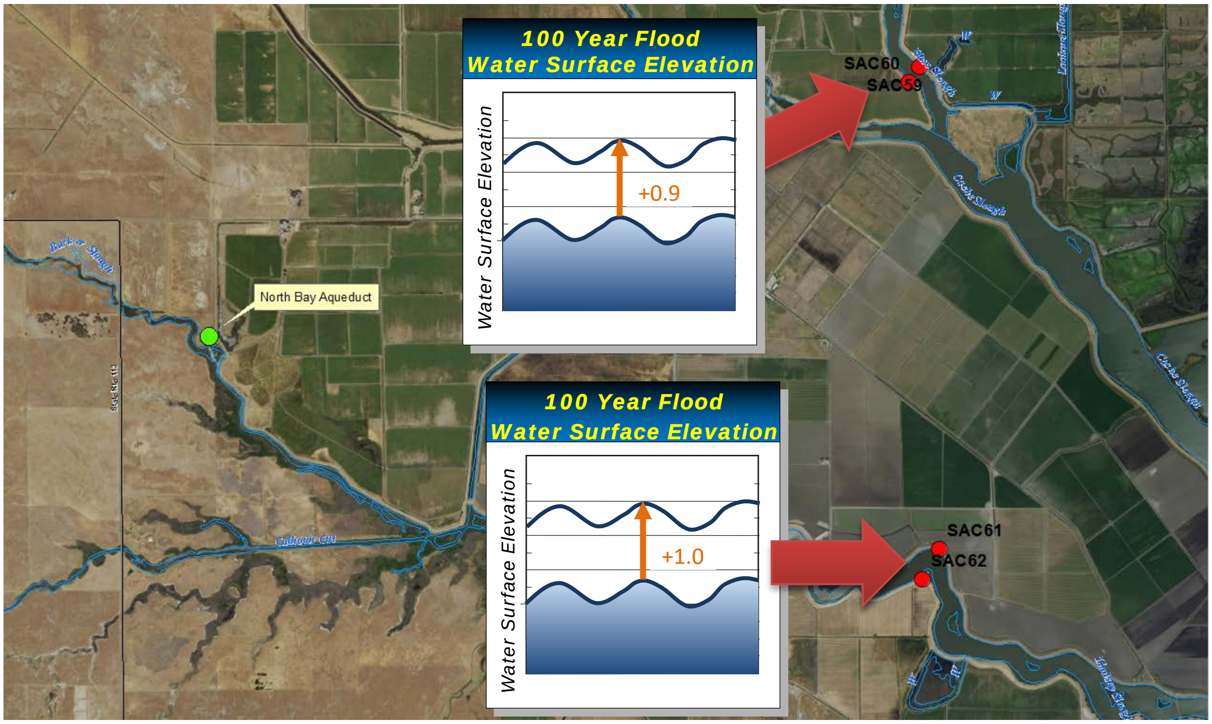
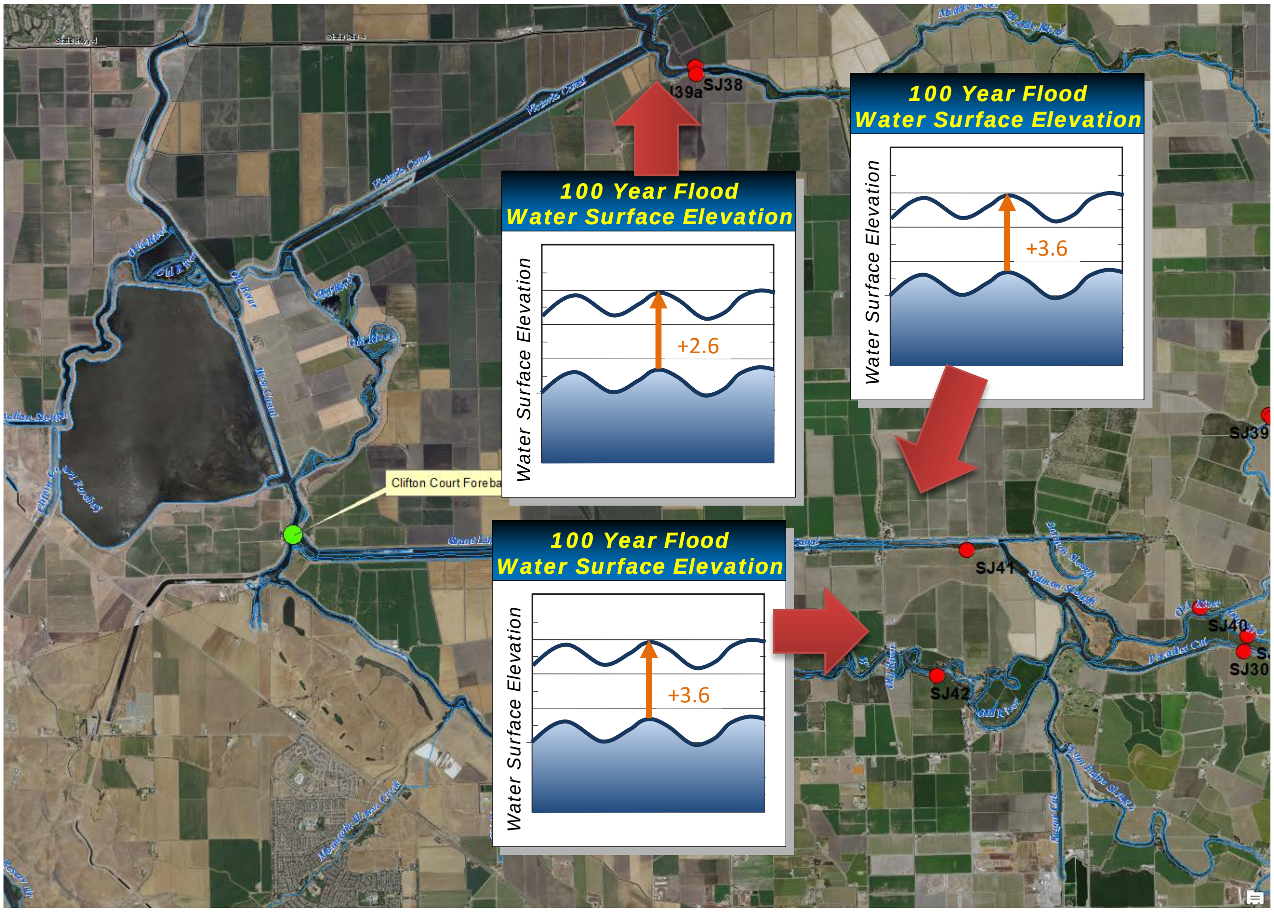


Figure 4-4 **Clifton Court Forebay May Experience Higher Water Surface Elevation (in feet), Between Current and Future Climate During a 100-year Flood.**



Facility exposures (low or high) to sea-level rise were evaluated based on the analysis above and based on their proximity to Delta waters and their elevation above mean sea level. Assets on Delta islands and assets in direct contact with Delta waters (e.g., control gates, pumping plants) were assumed to have high exposure during all time periods. For these facilities, elevation is at or below current sea level, and exposure is automatically listed as high for all time periods. All other DWR facilities within the Delta were analyzed based on their elevation and location (Table 4-4).

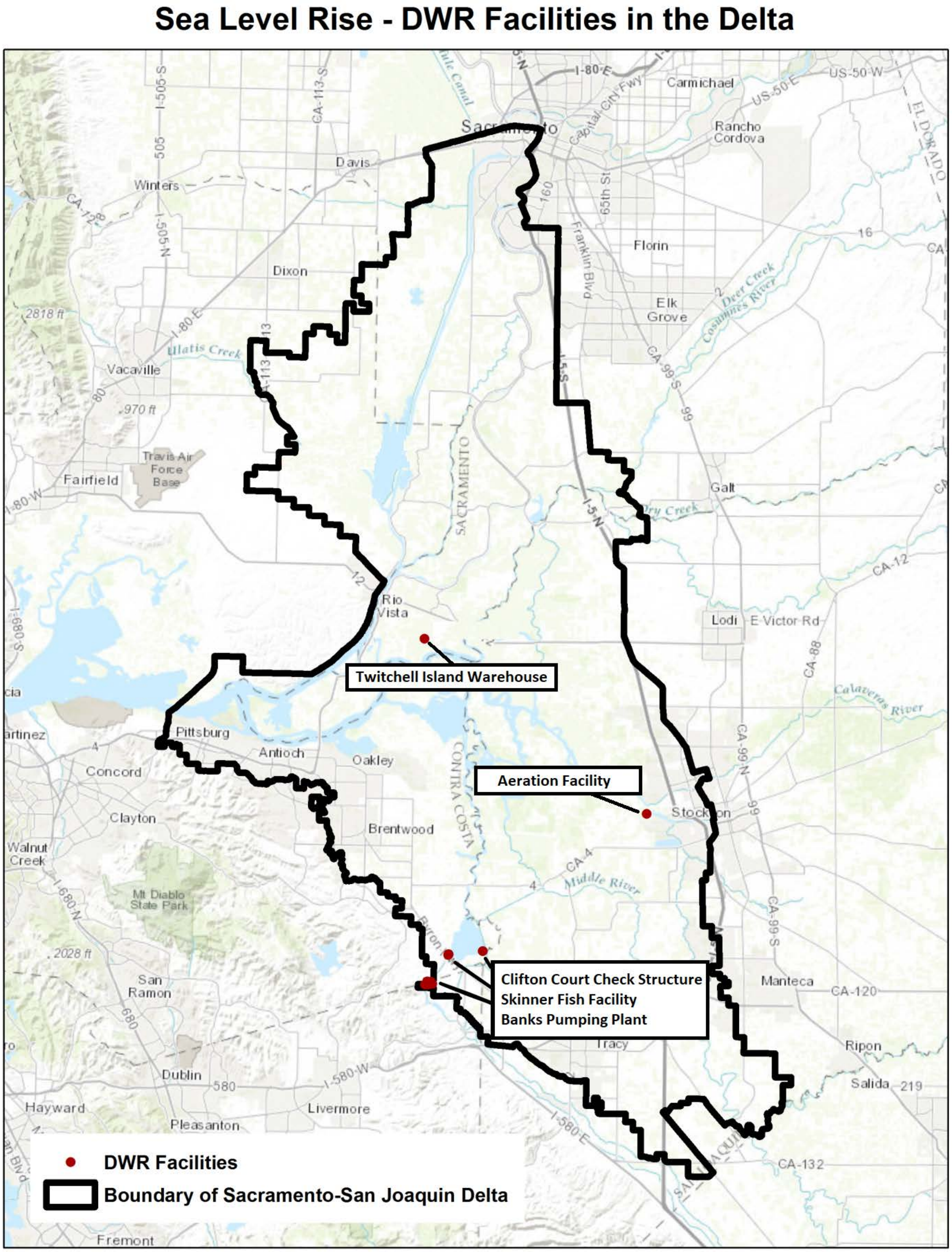
Table 4-4 **DWR Facilities in the Delta Mostly Have Low Exposure to Sea-Level Rise.**

Facility/Program	Asset Name	Approx. Elevation (AMSL, feet)	Exposure Rating	
			2030	**2050**
SWP — Barker Slough Pumping Plant	Control Building	23	Low	Low
	Compressor Building	23	Low	Low
SWP — Clifton Court	Clifton Court Check Structure	--	High	High
	Clifton Court Accessory Buildings	16	Low	Low
SWP — Banks Pumping Plant	Pumping Plant	--	High	High
	Switchyard Control Building	144	Low	Low
	Area Control Center (Visitor's Center)	16	Low	Low
Delta O&M Center	Administration Center	143	Low	Low
	Plant Maintenance Shop	138	Low	Low
	Civil Maintenance HQ	137	Low	Low
	Vehicle Storage Building	136	Low	Low
	Mobile Equipment Repair	136	Low	Low
	Civil Maintenance Warehouse	136	Low	Low
	Heavy Equipment Storage	136	Low	Low
	Plant Maintenance Vehicle Storage	136	Low	Low
	Water Treatment Plant	144	Low	Low
	Guard Station Building	124	Low	Low
	Warehouse and Welding Shop	137	Low	Low

Table 4-4 Exposure of DWR Facilities in the Delta to Sea-Level Rise (continued)

Facility/Program	Asset Name	Approx. Elevation (AMSL, Feet)	Exposure Rating	
			2030	2050
SWP — John Skinner Fish Protection Facility	Fish Holding Tank 1	11	Low	Low
	Fish Holding Tank 2	10	Low	Low
	Control Building	11	Low	Low
	Vehicle Storage Building	10	Low	Low
	Skinner Fish Facility Screens	--	High	High
Bay-Delta Office — Other	Aeration Facility (South Delta Branch)	--	High	High
Flood Control Materials Depots	Brennan Island Warehouse	21	Low	Low
	Twitchell Island Warehouse	-5	High	High
	Rio Vista	13	Low	Low
	Stockton Warehouse	13	Low	Low
NCRO IRWM/DOE/DES	Office @ 3500 Industrial Blvd. West Sacramento	19	Low	Low

Figure 4-5 **Some DWR Facilities in the Delta Have High Exposure to Sea-Level Rise.**



Sensitivity

Coastal

The Eureka Flood Center was determined to have low exposure to sea-level rise, and therefore sensitivity analysis was not conducted.

San Francisco Bay

In the Suisun Marsh, the salinity control gates have high exposure to sea-level rise, but because they are already in frequent contact with saltwater and were designed to maintain their ability to function under inundation, sensitivity was determined to be low. But natural lands, such as upland marsh habitat, may be affected depending on elevation.

Delta

Facilities within the Delta that were determined to have high exposure were the Banks Pumping Plant, Skinner Fish Facility, and the South Delta Aeration Facility (Table 4-4), as well as numerous temporary barriers (Old River at Tracy, Head of Old River, Middle River, Grant Line Canal). As with structures in the Suisun Marsh, these facilities have been designed and are operated with the presumption of frequent contact with brackish water and therefore were determined to have low sensitivity to sea-level rise.

Sea-Level Rise Vulnerability Assessment Results

Facilities and Lands

Risk

Coastal

DWR historically has had only one facility along the California coastline — the Eureka Flood Center, currently staffed with one part-time DWR employee. This facility is located on Woodley Island in Humboldt Bay, north of the Mendocino triple junction, and falls in the sea-level rise projection regime for areas on the coast North of Cape Mendocino. The Flood Center is located on land at 6.1 meters (m) above mean sea level (North American Vertical Datum of 1988 [NVD88]), and therefore can be considered to have low risk to sea-level rise through mid-century.

San Francisco Bay

DWR owns and maintains several facilities within San Francisco Bay, specifically in the Suisun Marsh, that will be exposed to sea-level rise; however, these facilities have low sensitivity (because of existing frequent contact with water) and thus overall risk from increasing sea level is low.

Nonetheless, the Suisun Marsh itself is already being impacted by changes resulting from human activities, and will be impacted in the future by increasing inundation of mud flats and low-lying areas, levee and dike failures, and greater variation in environmental conditions (Moyle, Manfree, & Fiedler, 2014). Sensitivity to these changes is high, and adaptive capacity is complicated by a variety of factors such as multiple ownership and joint management entities. Therefore, while the DWR facilities score relatively low risk to SLR, the marsh itself may be considered at high risk to impacts of climate change, which warrants further examination.

Delta
The Delta facilities that have high exposure to current sea level were determined to have low sensitivity to sea-level rise, because of their design and current frequent contact with brackish water.

Adaptive Capacity

Although Delta facilities themselves were determined to have low risk from sea-level rise directly, failure of levees within the Delta might jeopardize those structures. Many efforts are underway that could increase the resilience of the Delta (and the Suisun Marsh) to future climate change impacts, either by planning for increased stresses on levees or by increasing habitat and natural infrastructure to sustain species and provide other critical ecosystem services. Key efforts are the Delta Levees Investment Strategy (DLIS) and projects being undertaken by DWR through its Delta Levees Programs and California WaterFix and EcoRestore efforts.

Following passage of the Delta Reform Act of 2009, the Delta Stewardship Council launched the DLIS to update priorities for State investments in the Delta levee system, with the purpose of reducing the likelihood and consequences of levee failures and to protect people, property, and State interests.

California EcoRestore[19] is another initiative that will help increase Delta resilience and increase the adaptive capacity of the Delta area. California EcoRestore will help coordinate and advance at least 30,000 acres of critical habitat restoration in the Delta and Suisun Marsh. A broad range of habitat restoration projects will be pursued, including projects to address aquatic, sub-tidal, tidal, riparian, floodplain, and upland ecosystem needs.

Vulnerability

Overall vulnerability of DWR’s facilities to direct sea-level rise is low and will continue to be low through mid-century, with the exception of Suisun Marsh. However, a failure of Delta levees (a consideration outside the scope of this assessment) could change the vulnerability determinations.

Operations

Vulnerability of SWP operations to sea-level rise is analyzed in Chapter 5 in conjunction with Long-Term Persistent Hydrologic Changes.

Other Considerations

Subsidence and seismic events

Subsidence — the sinking of land in relation to the surrounding area — within Delta islands results in increased pressure on levees, and will compound the effects of sea-level rise. Seismic events can cause immediate land movements which can dramatically and immediately affect local relative sea levels (National Research Council, 2012). These events are outside the scope of this study but are discussed in Chapter 8.

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[19] http://resources.ca.gov/ecorestore/.

Next Steps

Future updates to this VA should consider analysis of sea-level rise and flood impacts in the CVFPP and other ongoing flood planning efforts, and other studies on the Suisun Marsh's sensitivity to SLR.

Chapter 5 — Long-term Persistent Hydrologic Changes

Lake Oroville — 2011 and 2016[20]

Hydrologic changes caused by climate change pose serious risks to DWR assets, particularly operation of the SWP. Higher temperatures act to increase evapotranspiration, sublimation, and snowmelt rates, and decrease soil moisture and snow accumulation. These effects combine to reduce snowpack and water storage, and change runoff patterns. Changes in precipitation may affect average annual precipitation rates and the frequency, magnitude, and duration of extreme events. These changes can affect water quantity and quality, and in turn, the ecosystems supported by the watershed and water systems dependent on the watersheds.

Higher temperatures and reduced precipitation result in less snowpack. In California, snowmelt provides an annual average of 15 million acre-feet (maf) of water, slowly released from high-elevation watersheds from about April to July. Much of the State's water infrastructure, including the SWP, was designed to capture and store winter and spring runoff to prevent downstream flooding and deliver the stored water during drier summer and fall months when it is needed for water supply. These infrastructure assets were designed to operate within historical ranges of precipitation, seasonality, and temperature regimes, all of which are shifting under a changing climate.

Projections now indicate that by the end of this century the Sierra snowpack may diminish by 48–65 percent from 1961–1990 levels (Pierce & Cayan, 2013). Warmer temperatures increase the proportion of precipitation falling as rain instead of snow and cause earlier and more rapid melt of the snowpack, which results in larger volumes of runoff entering reservoirs during the winter and early spring and less runoff arriving in late spring and early summer. This trend in runoff patterns, observed in streamflow patterns beginning in the mid-20th century (Dettinger & Cayan, 1995), challenge the flood storage capacity of

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[20] http://ktla.com/2016/03/17/dramatic-images-show-improved-drought-conditions-in-california-due-to-el-nino/

reservoirs during winter, leading to higher downstream flow during flood events and reduced late summer storage levels.

Climate change also affects water demand for both agricultural and urban use. Warmer temperatures extend growing seasons, increase evapotranspiration, and reduce soil moisture — all of which increase the amount of water needed for irrigation, urban landscaping, and environmental needs (U.S. Global Change Research Program, 2014).

Changes in California's hydrology are among the most difficult impacts to predict because of the large degree of uncertainty in climate change projections of precipitation. At mid-century, downscaled global climate models project precipitation changes of *minus* 18 percent to *plus* 28 percent. The uncertainty is caused by several factors, a major one of which is future rates of global GHG emissions and the climate's response to higher GHG concentrations in the atmosphere. Nevertheless, changes in climate coupled with the extreme inter-annual variability of precipitation in California yields potential impacts varying from beneficial to disastrous.

While the assessment of risk has typically been conducted through a top-down approach, there is growing interest in alternative methods to assess risks. This has led to the development and use of tools such as Decision Scaling (Brown, Ghile, Laverty, & Li, 2012), Robust Decision-Making (Groves & Lempert, 2007), scenario analysis, and others. These alternatives do not rely on precise predictions of future values, as are presented in previous sections for SLR and wildfire. Instead they offer a method to evaluate management threshold points at which the system can no longer function effectively and then develop probabilities whether the system could surpass such a threshold in the future.

DWR's vulnerability assessment of hydrologic impacts adopted an approach to climate change analysis known as "Decision Scaling" (Brown, Ghile, Laverty, & Li, 2012). Decision scaling integrates vulnerability-based analysis with traditional risk-based assessment methods. The approach allows for the assessment of sensitivity to a wide range of potential future climate conditions, the estimation of the probability of specific outcomes, and the ability to plan for changes informed by the best available science, yet it is not reliant on a precise prediction of future values.

This chapter focuses on the effects of long-term persistent hydrologic changes on the operation of the SWP. Because these changes will occur incrementally over time, they are unlikely to impact staff activities or facilities and so the vulnerability of staff activities and facilities are not assessed in this chapter. Significant impacts on flooding and flood protection infrastructure are discussed in the Short-term Extreme Event Hydrologic Impacts section in Chapter 6. Long and short-term hydrologic impacts are discussed separately because of the ways in which the hydrological changes manifest themselves and the different modeling tools and methods currently used to simulate impacts on water resource management systems. Efforts are underway to integrate modeling of water supply and flood management systems, but such integrated analysis tools were not available for this assessment.

Finally, while this analysis of long-term persistent hydrologic changes provides consideration of severe annual conditions by taking into consideration all of the drought sequences that have occurred in the last 1,100-years as evidenced by the paleo dendrochronological record (Meko et al., 2014), uncertainty remains about how climate change could lead to fundamental changes in atmospheric dynamics leading to droughts even more extreme than those evaluated here.

Relevant Studies Conducted to Date or In Progress

Impacts of climate change on snowpack and hydrology have been well studied and a substantial amount of information exists about expected future impacts. Recent global (Intergovernmental Panel on Climate Change, 2013), national (U.S. Global Change Research Program, 2014), regional, and statewide (California Natural Resources Agency, 2018) climate assessments have all highlighted climate-change-driven impacts to water supply, water demand, increased flooding and drought, and changes to hydrologic processes. An array of academic research has also focused on specific aspects of climate change impacts on California's hydro-climate (Dettinger, 2013) (Cayan, et al., 2010) (Das, Maurer, Pierce, Dettinger, & Cayan, 2013).

The SWP and the major watersheds of the Sierra Nevada that supply water to the SWP have also been the focus of many studies and analyses conducted by DWR and others; a selection of those studies is listed below.

- **"Estimating Historical California Precipitation Phase Trends Using Gridded Precipitation, Precipitation Phase, and Elevation Data," DWR Memorandum Report** (Cuthbertson, Lynn, Anderson, & Redmond, 2014)
  This exploratory study develops and describes a methodology that uses readily available research data sets to produce gridded estimates of historical rainfall as a fraction of total precipitation for areas comprising the major water-supply watersheds of California.

- **Paleoclimate (Tree-Ring) Study** (Meko, Woodhouse, & Touchan, 2014)
  New hydroclimate reconstructions, using updated tree-ring chronologies for the Klamath, San Joaquin, and Sacramento river basins, allow assessment of hydrologic variability over centuries, and gives historic context for assessing recent droughts.

- **Hydrological Response to climate warming: The Upper Feather River Watershed** (Huang, Kadir, & Chung, 2012)
  The hydrological response and sensitivity to climate warming of the Upper Feather River Basin, a snow-dominated watershed in Northern California and headwaters of the SWP, were evaluated and quantified using observed changes, detrending, and specified temperature-based sensitivity simulations.

- **Isolated and integrated effects of sea level rise, seasonal runoff shifts, and annual runoff volume on California's largest water supply** (Wang, Yin, & Chung, 2011)
  This study contains a detailed analysis of climate change impacts on seasonal pattern shift of inflow to reservoirs, annual inflow volume change, and sea-level rise on water supply in the Central Valley of California.

- **Using Future Climate Projections to Support Water Resources Decision Making in California** (Chung, et al., 2009)
  The report, prepared for the State's Second Climate Change Assessment, evaluates how climate change could affect the reliability of California's water supply and how information from global

climate models can be used to inform water resources planning and decision making in California.

- **Progress on Incorporating Climate Change into Management of California's Water Resources** (California Department of Water Resources, 2006)
  An article in the March 2008 special issue of ***Climatic Change*** *— California at a Crossroads: Climate Change Science Informing Policy*, is a condensed version of the original 2006 report of the same name, which DWR produced as part of the State's First Climate Change Assessment.

- **Sacramento-San Joaquin Basin Climate Impact Assessment** (U.S. Bureau of Reclamation, 2016)
  This Basin Study includes an overview of the current climate and hydrology of California's Central Valley, including observed historical trends in temperature and precipitation. Future hydrologic projections are used to evaluate how climate change could impact water availability and management and water demands.

Hydrologic Impacts Vulnerability Assessment Approach

DWR's vulnerability assessment for long-term persistent hydrologic changes from climate change focuses on impacts to operation of the SWP. DWR owns and operates the SWP for water supply, flood control, maintenance of environmental and water quality conditions, hydropower, and recreation. Consequently, analysis of SWP performance under climate changed conditions yields an array of "impact metrics" across these areas of concern.

Decision Scaling Impact Metrics

As noted above, a decision scaling approach was used for this vulnerability assessment. This approach allows DWR to assess climate vulnerability across a wide range of potential future climate conditions. Decision scaling is composed of three primary parts. The first, *exposure*, is determined by the conditional probability density of future climate conditions. Next, *sensitivity*, is evaluated by analyzing the performance of the water system under the full range of climate conditions. Finally, exposure and sensitivity are combined to estimate the probability distribution of future water system performance, which is the *vulnerability* of the system to potential future climate change (Brown, Ghile, Laverty, & Li, 2012). Decision-relevant metrics are identified that can be used to characterize the adequacy of system performance. Table 5-1 lists the decision-relevant metrics used for this vulnerability assessment. [21]

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[21] These metrics are only a small subset of the information available. Additional data and metrics can be explored in the future to evaluate additional vulnerabilities as needed.

Table 5-1 Five State Water Project Performance Metrics Are Used in this Vulnerability Assessment.

1.	Oroville End-of-April Storage levels
2.	Oroville Carryover Storage levels
3.	Seasonal Delta Outflow
4.	Average Annual SWP Deliveries
5.	Average Annual System Shortages

Each of the five metrics describes an important element of the SWP system.

- **End-of-April Oroville Storage** represents the amount of water the SWP has in storage at the end of the main runoff season and the beginning of the irrigation and high-water demand season. This metric provides important information about water supply and summer regulatory conditions.
- **Oroville Carryover Storage** represents the amount of water the SWP has in storage at the end of the irrigation and high-water demand season but before winter rains begin (September 30th). This metric describes how much water DWR is carrying over from one year to the next and provides important information about the drought resilience of the system. Oroville carryover storage is also important for downstream river water temperature control for salmonid rearing and survival conditions.
- **Seasonal Net Delta Outflow (NDO)** is related to Delta conditions and how regulatory constraints affect system operations. Delta conditions dictate water project operations in certain months of the year. Maintaining ecosystem conditions and water quality for Delta agricultural diverters is a critical aspect of the SWP operations. While there are several different regulatory standards that must be met (and these change from month to month), NDO provides a reasonable aggregate metric for Delta conditions.
- **Average Annual SWP Deliveries** informs water supply reliability for the SWP's 29 water contractors.
- **Average Annual System Shortages** provide information about the frequency and severity of conditions within the system under which not all regulatory and water demand conditions can be met. While rare, these conditions have occurred in recent years (e.g., 2014 and 2015), and occur when available storage and inflow to the system are insufficient to meet all needs within the system.

Water Resources System Model

To complete this type of assessment, a modeling process was needed that could rapidly simulate SWP and Central Valley Project (CVP) operations. DWR uses a model called CalSim-II and its simplified faster-run version, CalLite 3.0, to simulate SWP and CVP operations[22]. CalLite 3.0 was chosen as the modeling platform to use for the analysis because of its faster runtime and relative ease of use. DWR estimates that the trade-off for CalLite 3.0's faster speed is an approximate error of 1 percent when compared with a

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[22] While the Vulnerability Assessment focuses on DWR vulnerabilities and thus the SWP, the SWP is operated in a cooperative manner with the CVP (owned by the U.S. Bureau of Reclamation), thus water system models like CalSim-II and CalLite 3.0 must simulate both systems to accurately simulate the SWP.

corresponding run of CalSim-II (Islam, et al., 2014). Key CalSim-II and CalLite 3.0 input variables include:

- Streamflows from Central Valley rivers;
- Regulatory requirements (such as Delta water quality and minimum instream flows); and
- Operational rules (such as priorities and water delivery demands).

As CalLite 3.0 runs, input variables calculate the monthly system conditions such as:

- Reservoir storage levels;
- Flow in rivers downstream of reservoirs;
- Deliveries to SWP and CVP contractors; and
- Delta water quality parameters.

Climate Stress Test

A climate stress test was conducted using CalLite 3.0 to systematically explore system performance and vulnerabilities over a wide range of internal (natural) climate variability and climate change (e.g., changes in mean precipitation and mean temperature). The representations of internal variability and climate change are not driven by GCM projections; rather, hydrologic internal variability is explored by running an 1,100-year hydrological sequence of temperature and precipitation based on historically observed and paleo-reconstructed climate and streamflow data (described in Box 5.1) and subsequently perturbed under a wide range of climate changes. Because the stress test explores such a wide range of potential climate and natural variability impacts, it significantly reduces the possibility of under-exploring important vulnerabilities from biases and error propagated into an analysis that would have used downscaled GCM projections.

Climate changes are explored by increasing the mean temperature of the 1,100-year climatological sequence (Box 5.1) in 0.5 degree Celsius (°C) increments up to +4.0 °C temperature and increasing and decreasing average annual precipitation in 10 percent increments from -20 percent to +30 percent. The nine temperature and six precipitation states produce a total of 54 combinations of temperature and precipitation changes applied to the 1,100-year climatological sequence. The explored range of temperature and precipitation extends far enough to cover the full range of mid-century changes projected by GCMs included in the Coupled Model Intercomparison Project Phase 5 (CMIP5).

Since precipitation and temperature changes can vary both spatially and temporally, the relationships of temperature and precipitation, both observed and projected, with several geographical and time scale factors, including elevation, latitude, and season were investigated. Extensive analysis revealed a significant trend in differential seasonal warming that indicated spring and summer have been warming faster than fall and winter. Based on this differential warming trend in the observed record, increments of 0.5 °C warming were applied differentially across the seasons (Table 5-2).

Box 5.1 Development of climatological sequences

To represent current climate conditions, this study uses the historical reconstructed streamflow record of the Sacramento 4-river flow (900–2013) (Meko et al. 2014) coupled with historical daily temperature and precipitation 1950–2013 (Livneh et al. 2013). The reconstructed streamflow record of the Sacramento 4-river flow provides information about long-term inter-annual variability by providing an 1,100-year record of the wet and dry cycles that the basin has endured. The Sacramento 4-river flow includes annual water-year (October 1st–September 30th) streamflow on the Sacramento River at Bend Bridge, the American River inflow to Folsom Reservoir, Yuba River at Smartsville, and Feather River inflow to Oroville Reservoir, and thereby covers the major inflow points to the SWP. Additional flows into the SWP not covered by the Sacramento 4-river flow are highly correlated to the Sacramento 4-river flow (Meko et. al. 2014).

While the paleo-dendrochronology reconstructed streamflow record of the Sacramento 4-river flow provides important long-term inter-annual variability information, the annual streamflow values from this record do not provide sufficient information about the spatiotemporal distribution of temperature and precipitation that would have produced such runoff.

To reconstruct plausible spatiotemporal distributions of temperature and precipitation, the historical daily temperature and precipitation data provide detailed information about the spatial distribution across California and temporal distribution across each year of temperature and precipitation at 1/16 degree (approximately 8-kilometer by 8-kilometer grid spacing).

There were a series of steps taken to create a timeseries of gridded temperature and precipitation over the watersheds that flow into the SWP. The gridded dataset reflects the long-term inter-annual variability of the reconstructed streamflow record of the Sacramento 4-river index. At the same time this process maintains the spatial and temporal distributions of the observed climate data. The following steps were taken:

1. Prior to using the historical observed temperature data, it was necessary to remove the warming trend in the data. Temperature detrending was achieved by applying a linear trend to the data so that the detrended temperature time series had a trend line of slope zero and average value equal to the average temperature from 1981 through 2010. This procedure was applied grid cell by grid cell across the SWP inflow watershed area. The detrended historical temperature allows reference to current/recent historical conditions when developing the stress test matrix (as opposed to more abstract reference to mid-20th-century temperatures at the mean of the historical timeseries). The observed historical precipitation data showed no similar trend. As a result, it required no detrending.
2. The Sacramento Soil Moisture Accounting Model (SAC-SMA-DS) was used to simulate streamflows in the Sacramento, Feather, Yuba, and American rivers of the Sacramento basin using the historical (1950–2003) detrended temperature and precipitation data. These four river flows make up the Sacramento 4-river index flows.
3. For each reconstructed Sacramento 4-river annual streamflow from 900 through 1949, the closest historical observed (1950–2003) analogue flow was associated to it.
4. The gridded (detrended) temperature and precipitation data for the analogue historical observed water year was then used for those historical reconstructed years.
5. For years 1950 through 2000, the gridded detrended temperature and precipitation data were incorporated chronologically to create an 1,100-year record of temperature and precipitation.

This method of reconstructing full years of temperature and precipitation ensures that spatial and temporal correlations are maintained. It also allows for exploration of a much wider range of hydrologic inter-annual variability than is present in just the observed record.

Table 5-2 The Observed Warming Trend Is Applied Differentially Across the Seasons in This Analysis.

Season	Percent of warming
Winter (DJF)	18.8
Spring (MAM)	43.0
Summer (JJA)	31.1
Fall (SON)	7.1

Each of the 54 combinations of temperature and precipitation across the Central Valley watershed was then run through the enhanced, distributed Sacramento Soil Moisture Accounting Model (SAC-SMA-DS) for Sacramento River, San Joaquin, and Tulare Lake watersheds to generate 54 corresponding 1,100-year hydrological sequences. Each of these hydrologic sequences was preprocessed to generate a complete set of inputs for CalLite 3.0, which was then run for each hydrologic sequence.

Sea-Level Rise

For operational purposes, it was important to estimate sea-level rise as a function of temperature, and to associate the appropriate amount of sea-level rise with the temperature perturbation to which each CalLite run was subjected. Sea-level rise increases saline intrusion into the Delta. During the spring and fall, when regulations dictate maximum salinity conditions in the Delta and minimum outflow requirements from the Delta, DWR and Reclamation must release additional water from reservoirs or reduce exports from the Delta to offset this intrusion and maintain required regulatory conditions.

At the time of this study, three sea-level-rise scenarios were parameterized in CalLite: 0 centimeters (cm) [0 inches], 15 cm [6 inches], and 45 cm [18 inches]. The National Research Council (2012) approximated the anticipated future rate of sea-level rise along the California coast, south of Cape Mendocino, for the years 2030, 2050, and 2100. These projections, in conjunction with values for projected global temperature increase by year from IPCC (2013), were used to estimate the amount of sea-level rise that should be expected along the California coast, south of Cape Mendocino, for each temperature band shown in Table 5-3. This coarse discretization of sea-level rise is a limitation of the model and may cause underestimation of impacts at higher temperatures (e.g., more than 2.5 °C [4.5 °F], when sea-level rise would likely exceed 45 cm [18 in.]).

Table 5-3 Three Sea-Level Rise Scenarios Are Available within CalLite 3.0, Assigned by Level of Temperature Change.

Temperature Change relative to Recent Historical Average Temperature	Sea-Level Rise Relative to Recent Historical Average Sea Level
0 °C (0 °F)	0 cm (0 in.)
0.5 °C - 1.0 °C (0.9 °F - 1.8 °F)	15 cm (6 in.)
≥ 1.5 °C (2.7 °F)	45 cm (18 in.)

Hydrologic Impacts Vulnerability Assessment Results

Exposure

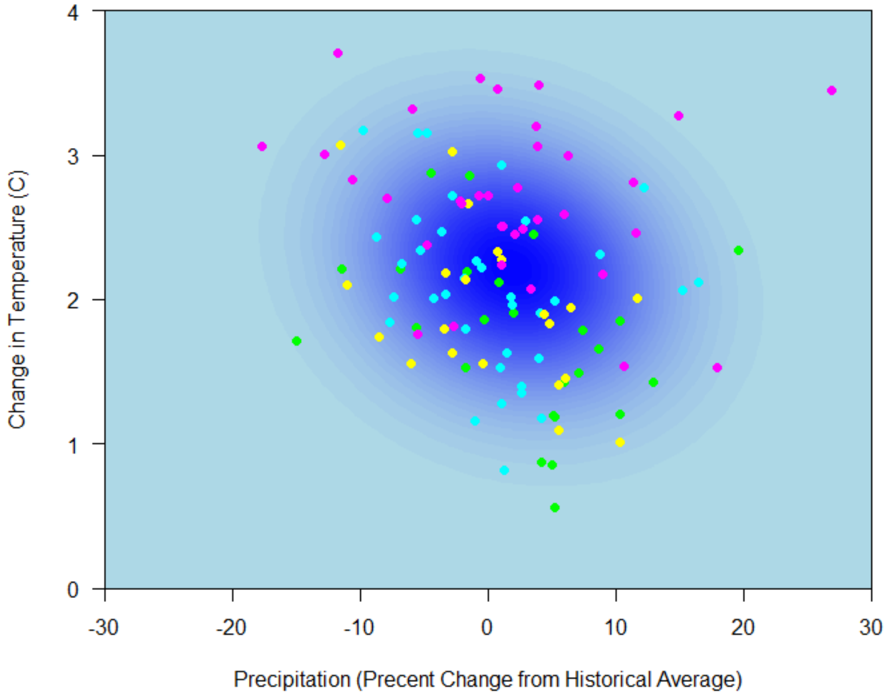
Operation of the SWP is exposed to changing climate conditions throughout the state. In the watersheds from which SWP water supplies originate, higher temperatures and changes in precipitation are expected to change inflows to SWP reservoirs — increasing winter runoff and decreasing spring and summer runoff. In the Sacramento-San Joaquin Delta, water supplies interact with the Delta's complex hydrology and are influenced by diversions, return flows, sea level, tides, and flows from several rivers. Throughout the SWP's service areas, demand for SWP water supplies will be affected by higher temperatures and changing precipitation.

Exposure to climate change for these areas has been estimated using data from an ensemble of 36 projections from the CMIP5 to develop probabilistic climate information. The ensemble of models indicates a range of future outcomes in temperature and precipitation (Figure 5-1).

Using the CMIP5 ensemble, the relative likelihood (probability density) of each climate state was calculated. This was done by:

1. Calculating the vector of future mean annual precipitation and temperature changes for all climate projections (shown in Figure 5-1).
2. Mean changes from the full ensemble of GCMs were then reduced to 14 data points to account for the potential sampling biases because of the structural similarities in GCMs (Knutti, Masson, & Gettelman, 2013). In so doing, all model runs were weighted equally and combined by arithmetic averaging within each model group.
3. The computed 14 data points were used to define a probability density function (pdf) (Whateley, Steinschneider, & Brown, 2014).
4. The Gaussian pdf was used to obtain the contingent normalized probability weights of the 54-plausible mean temperature and precipitation changes, hereafter referred to as the GCM-informed pdf. Similar approaches have been taken by others ((Borgomeo, Farmer, & Hall, 2015) (Steinschneider, McCrary, Mearns, & Brown, 2015); (Tebaldi, 2005)).

Figure 5-1 CMIP5 GCM-Projected Range of Likely Climate Changes by 2050



Notes:
GCM = General Circulation Model
CMIP5 = Coupled Model Intercomparison Project Phase 5

Figure 5-1 shows the GCM-informed pdf for climate change (temperature and precipitation) at 2050 over the SWP watershed area. Deeper blue colors represent greater model agreement and therefore a higher probability of climate states in that region of the figure. Lighter blue colors represent future conditions projected by fewer models but are still considered possible. By expressing the range of climate changes in the future as probabilistic possibilities, one can get a deeper understanding of the range of potential exposures and the likelihood of experiencing those levels of exposure.

Sensitivity

The decision scaling approach described above was used to explore system performance for each of the metrics listed in Table 5-1. The system performance response surfaces describe how the system performs over the range of temperature and precipitation changes.[23]

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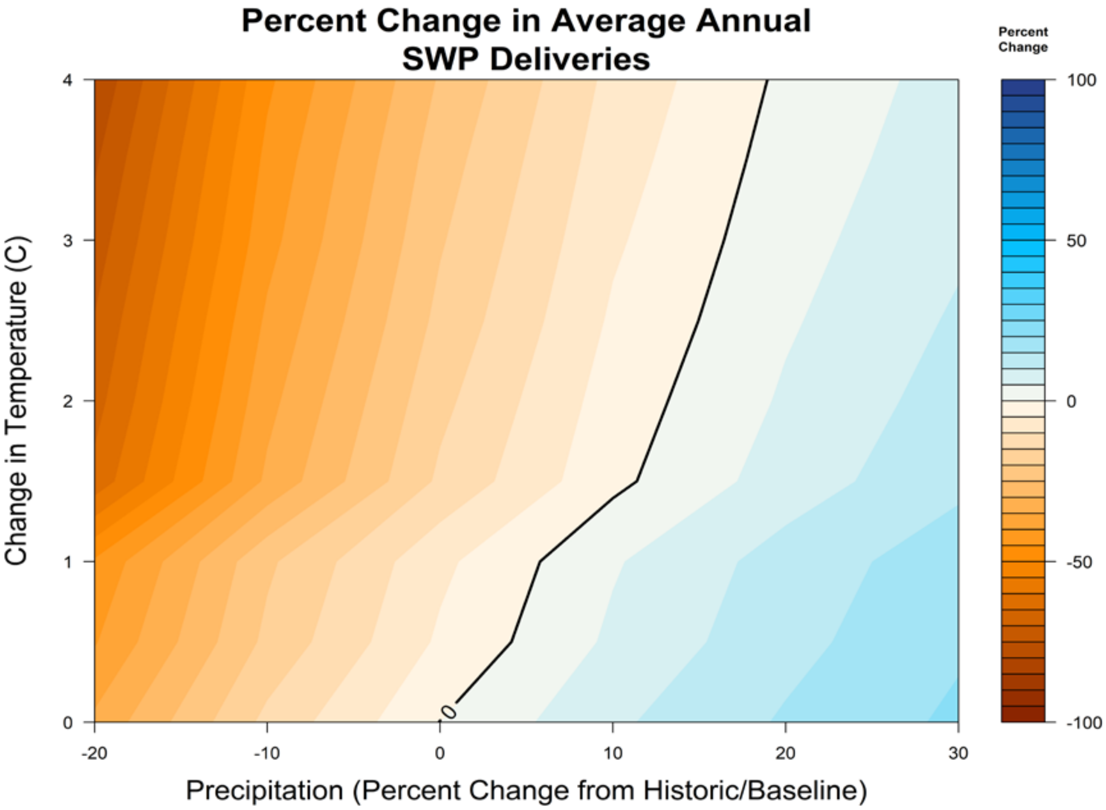
[23] See Box 5.2: "Understanding System Response Surfaces" for additional information on interpreting the information in these graphics.

Box 5.2 Understanding the Response Surfaces.

For each performance metric, the response surface shows the performance that would be expected for various combinations of change in precipitation, warming, and sea level associated with warming. In the example below, annual SWP deliveries are shown. The value at 0 degrees warming and 0 change in precipitation essentially represents current conditions (i.e., the long-term average of annual SWP deliveries that would be expected if climate conditions remained stable at today's levels). This level of performance is referred to as the "current conditions estimate" and represents the simulated long-term average system performance over the 1,100-year hydrological sequence with no climate warming beyond what has already occurred and no change in precipitation from historical levels, i.e., 0 percent change. A black line extends up and to the right from 0 degrees warming and 0 percent change in precipitation. This line represents system performance at the same level as the current conditions estimate. In other words, current performance levels can be maintained for the given metric at these combinations of warming and precipitation change. For example, current Average Annual SWP Deliveries could be maintained at 2 °C of warming coupled with about 13 percent higher precipitation rates or 4 °C warming and about 19 percent higher precipitation rates.



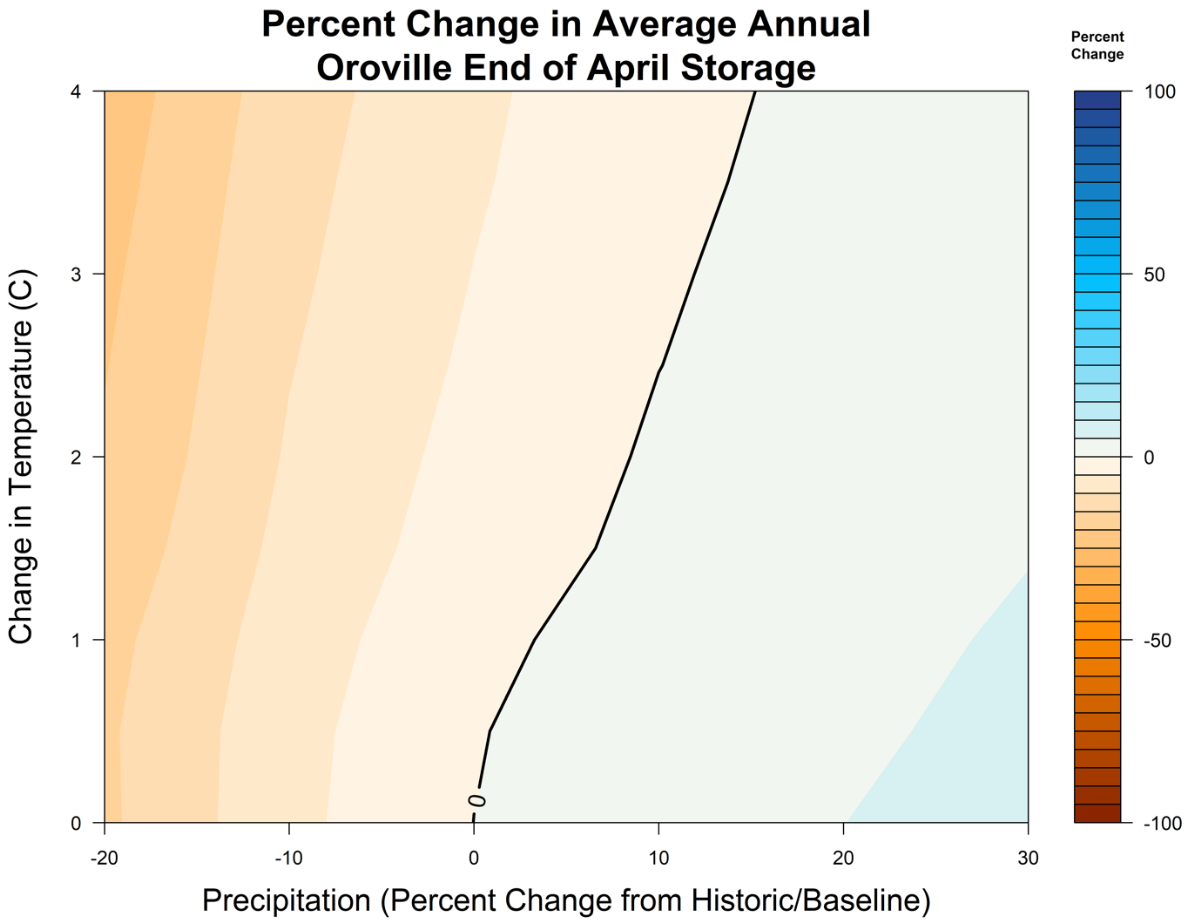
Each color band represents consistent system performance across a range of temperature and precipitation combinations. Bars that are more vertical indicate that the performance of the system is more sensitive to changes in average annual precipitation levels, while bars that are more horizontal indicate that the system performance is more sensitive to warming temperatures. Blue colors represent performance superior to current conditions and orange/red colors represent performance inferior to current conditions.

It is important to note that the response surface does not describe performance at any given time in the future. The response surface simply illustrates how the system performs, on average, over the 1,100-year hydrologic time sequence and across the range of precipitation and temperature. Also of importance is that the response surfaces presented in this report are for the current system infrastructure configuration, operations priorities, and regulations. The surfaces would change if any of these were to change in the future.

Performance Metric 1: Oroville End-of-April Storage

Historical-simulated Oroville end-of-April storage levels are approximately 3.1 million acre-feet (maf). The response surface for Oroville end-of-April Storage (Figure 5-2) shows that this metric is moderately sensitive to changes in temperature, precipitation, and sea level. For example, at a 2 °C increase in temperature, a 10 percent increase in precipitation would be required to offset the storage losses resulting from the temperature increase. This metric is less sensitive than end-of-September Oroville storage (Figure 5-3) to temperature increases because it essentially measures accumulated runoff into Oroville Reservoir during the winter rainy season. Higher temperatures are likely to result in less snowfall and faster melting rates of snow, resulting in more of the winter precipitation ending up in the reservoir and less stored at higher watershed elevations as snow. While storage levels rise from increased winter runoff, less water remains stored in the upper watershed to replenish the reservoir later in the season.

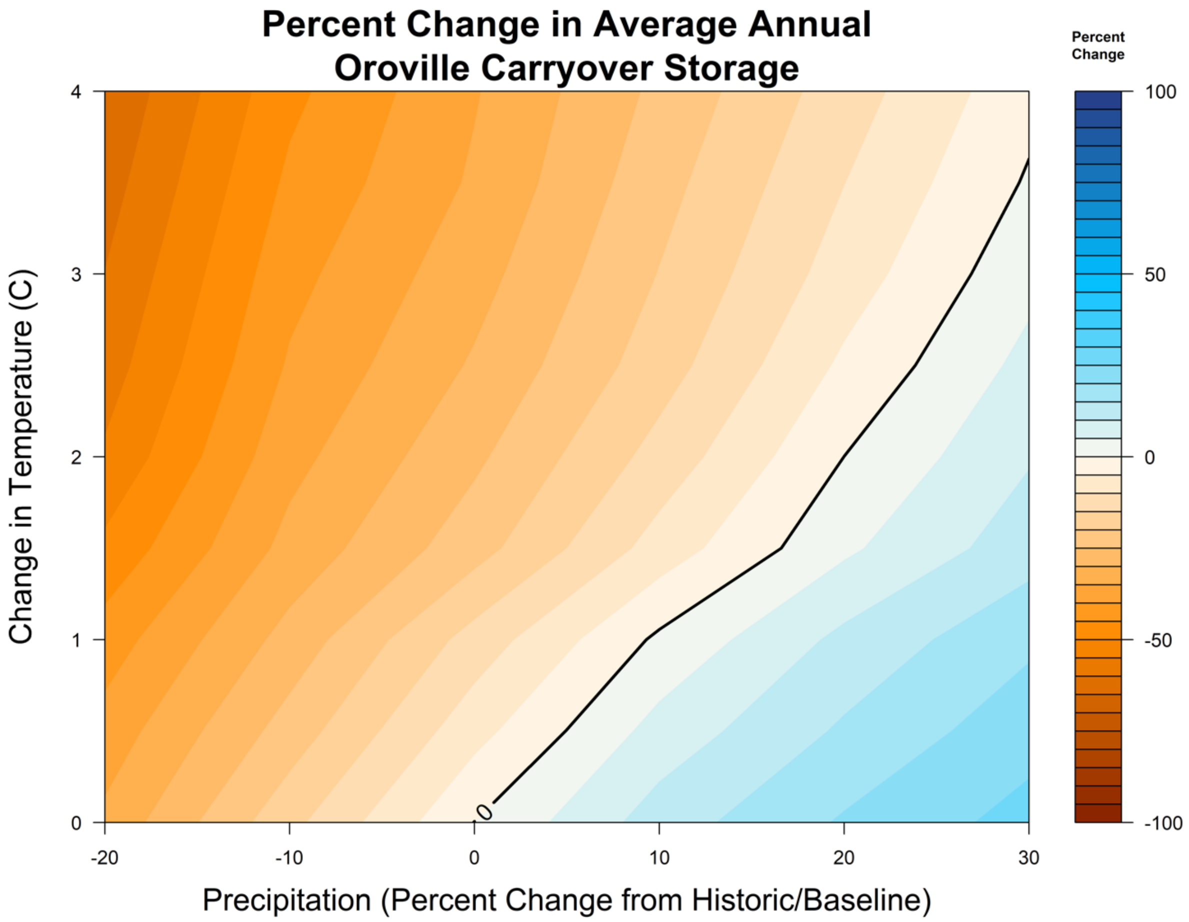
Figure 5-2 **Oroville April 1st Storage**



Performance Metric 2: Oroville Carryover Storage

Historical simulated end-of-September Oroville Carryover Storage levels are approximately 2 maf. The response surface for Oroville Carryover Storage (Figure 5-3) shows that this metric is highly sensitive to changes in temperature and precipitation. At temperature increases above 2 °C, average annual precipitation increases of 20 percent or more are needed to offset declines in storage. As described above for the end-of-April storage metric, higher temperatures result in more winter precipitation falling as rain instead of snow and earlier snowmelt runoff. Less snowpack remains in the upper watershed for late-season replenishment and culminates in much lower storage levels at the end-of-the summer. This system response is also related to the higher sea levels associated with greater warming. A sea-level rise of 45 cm is projected with a temperature increase of 1.5 °C or more, thus requiring greater storage releases during the summer months to repel sea water intrusion and meet Delta outflow and salinity requirements.

Figure 5-3 **Oroville September 30th Storage**



Performance Metric 3: Seasonal Net Delta Outflow

Delta conditions dictate water project operations in summer and fall when maintenance of ecosystem conditions and water quality in the Delta is a critical aspect of system operations. While there are a number of regulatory standards that must be met, and which change from month to month, NDO provides a reasonable aggregate metric for Delta conditions. The upstream conditions that influence NDO change throughout the year. Winter NDO is driven by rainfall events and the resulting high flows in rivers flowing into the Delta. Spring NDO is driven primarily by snowmelt, which is sensitive to temperature changes. Summer and fall NDO are largely driven by regulatory outflow requirements. Since regulatory requirements are given high priority in water operations decisions, CalLite 3.0 attempts to meet all regulatory requirements first, which can come at the expense of other important system functions such as carryover storage, cold-water storage for aquatic resources, and water deliveries.

Response surfaces for seasonal NDO conditions indicate that temperature changes have little effect on winter (Figure 5-4a) and fall NDO (Figure 5-5b) and a relatively weak influence on spring NDO (Figure 5-4b). Summer NDO exhibits unique behavior, indicating that NDO is likely to increase under future climate conditions. The summer NDO response surface (Figure 5-5a) and, to a lesser extent, the fall NDO response surface (Figure 5-5b), show discontinuities in the system performance at 0.5 °C, 1.0 °C, and 1.5 °C (0.9 °F, 1.8 °F, and 2.7 °F). These discontinuities are caused by the step changes in sea-level rise (Table 5-3) associated with different levels of warming. For example, the discontinuity between 1.0 °C and 1.5 °C is caused by the shift from 15 cm to 45 cm in sea-level rise. Higher sea levels increase hydrostatic pressure of sea water pushing into the Delta, requiring greater releases of fresh water (more NDO) to counteract the sea water intrusion and maintain regulated salinity conditions in the Delta. In the case of summer NDO (Figure 5-5a), sea-level increases results in NDO that will need to exceed historical simulated outflows.

Sea-level rise is not the only influence on summer and fall NDO. Minimum NDO requirements[24] and minimum average monthly Delta outflow at Chipps Island[25] scale as a function of various wetness indices in the watersheds that feed the Delta. Under wetter climate conditions, these indices become wetter, resulting in increases in required Delta outflows. Drier future conditions result in drier indices, which results in relaxation or reduction of Delta outflow conditions. This effect is evident in the slight right-leaning tilt of color bands on the response surface.

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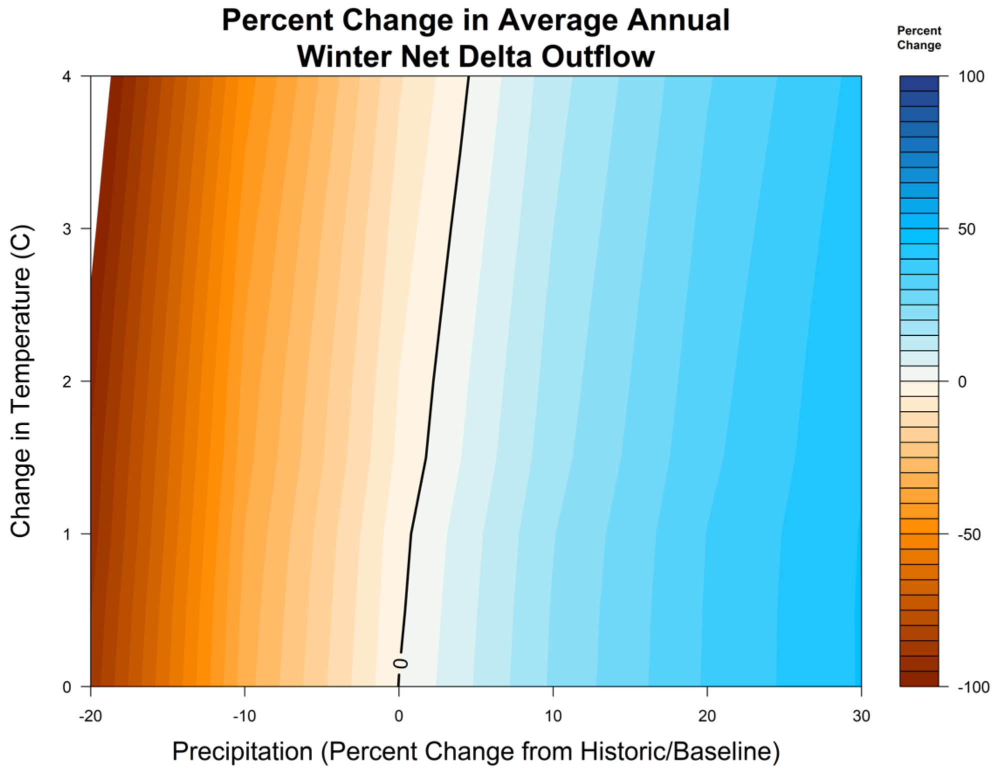
[24] State Water Resources Control Board Decision 1641

[25] State Water Resources Control Board Decision 1485

Figure 5-4 a-b **Winter and Spring Net Delta Outflow**



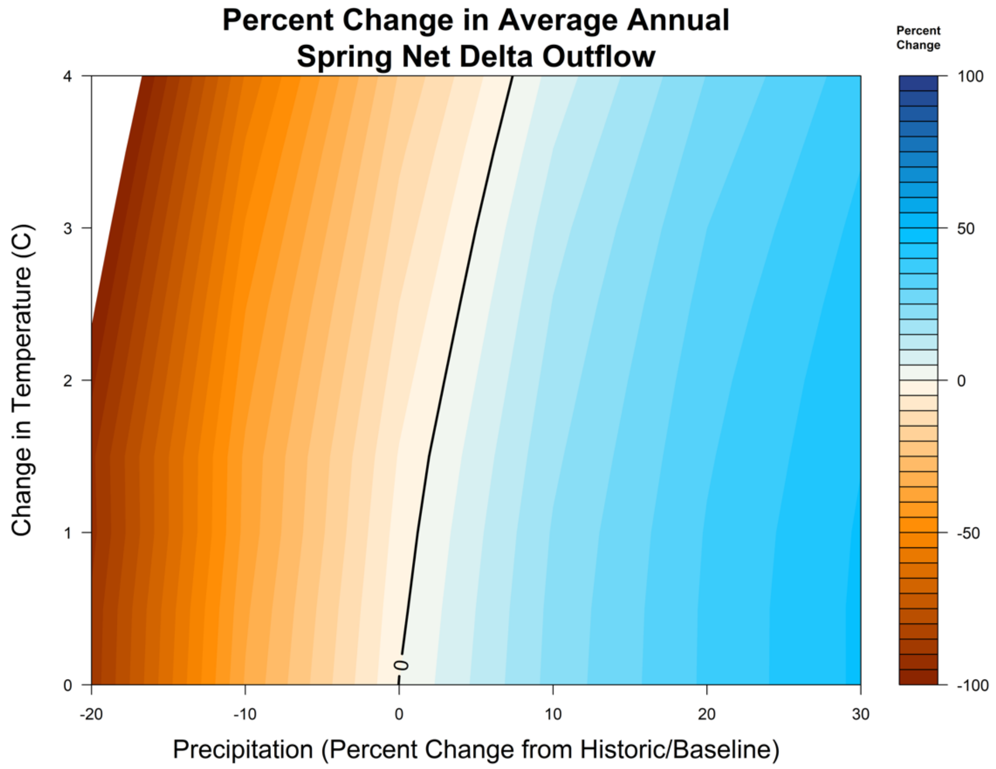
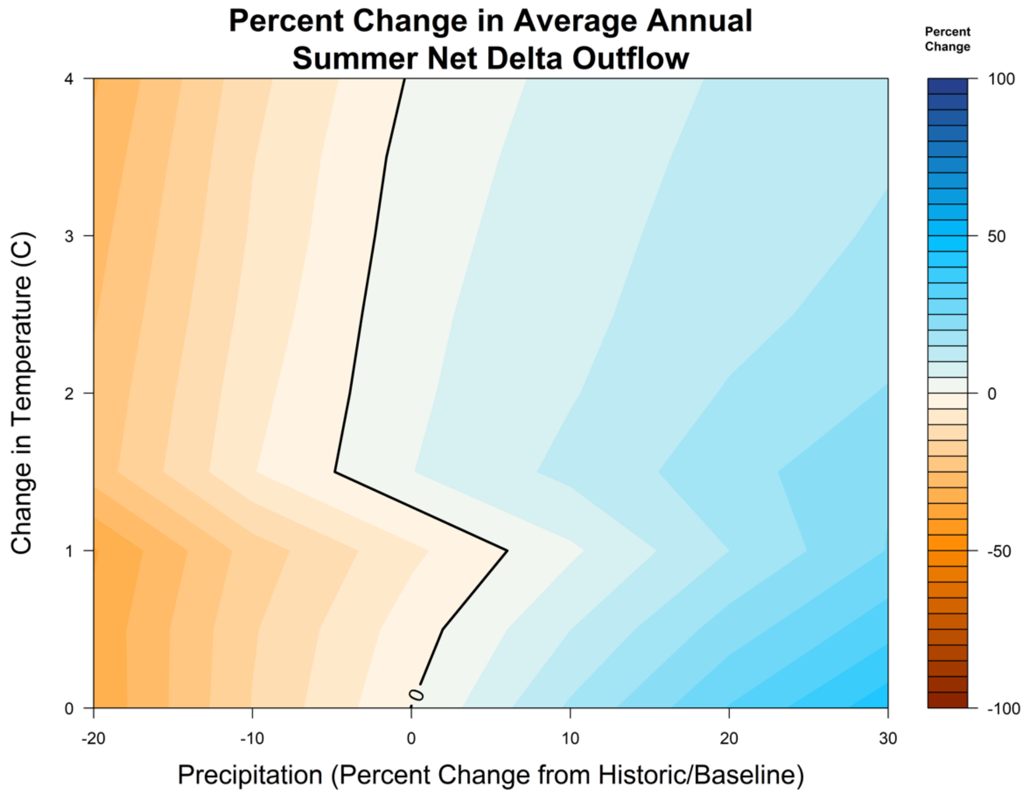
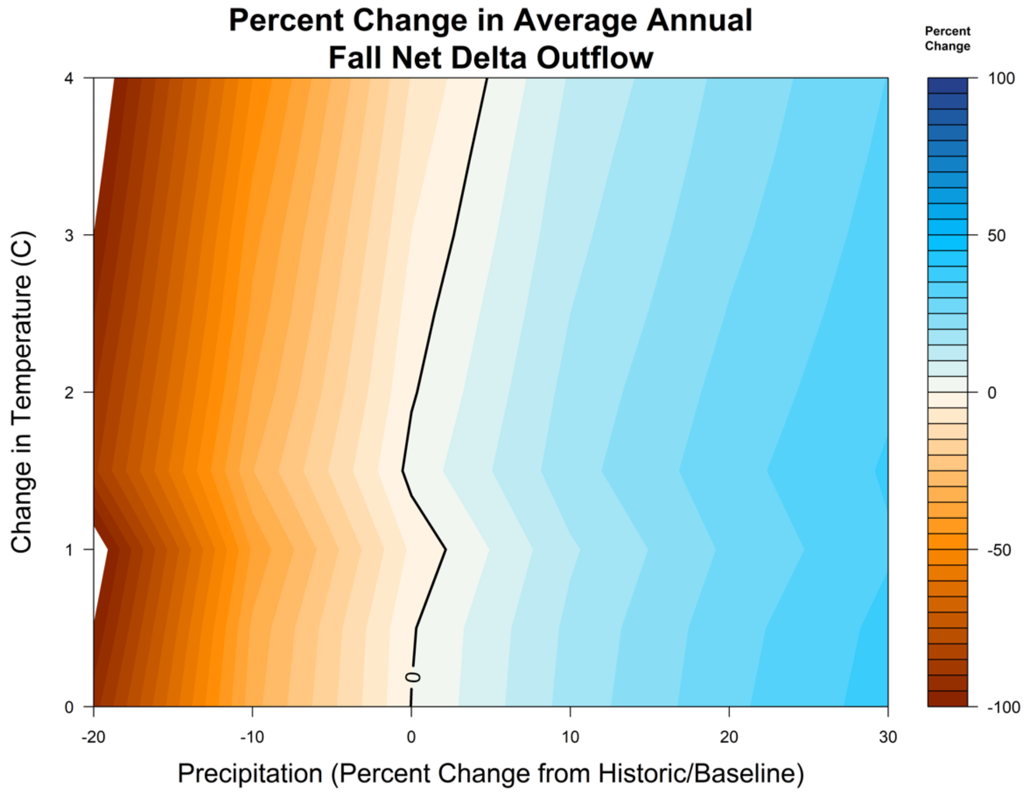


Figure 5-5 a-b **Summer and Fall Net Delta Outflow**

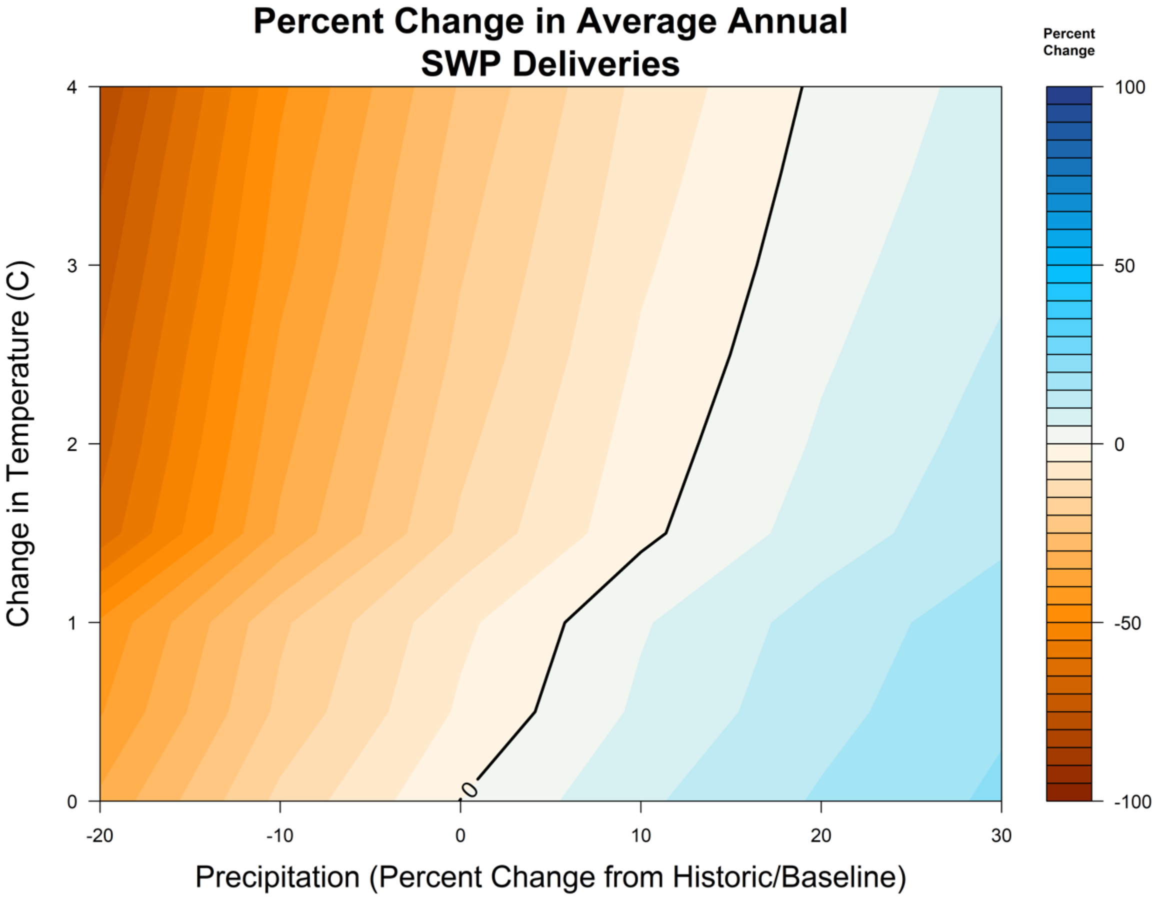




Performance Metric 4: Average Annual SWP Deliveries

The response surface for average annual SWP Deliveries shows sensitivity to changes in temperature, precipitation, and sea-level rise (Figure 5-6). Each color band in the SWP deliveries response surface represents a change in system performance of five percent. The performance bands become narrower to the left (less precipitation) and wider to the right (more precipitation), indicating that SWP deliveries are more sensitive to decreases in precipitation than increases in precipitation. As in summer and fall NDO, inflection points in the response surface at 0.5 °C, 1.0 °C, and 1.5 °C (0.9 °F, 1.8 °F, and 2.7 °F) are caused by the step changes in sea-level rise (Table 5-3) associated with different levels of warming.

Figure 5-6 Averge Annual SWP Deliveries

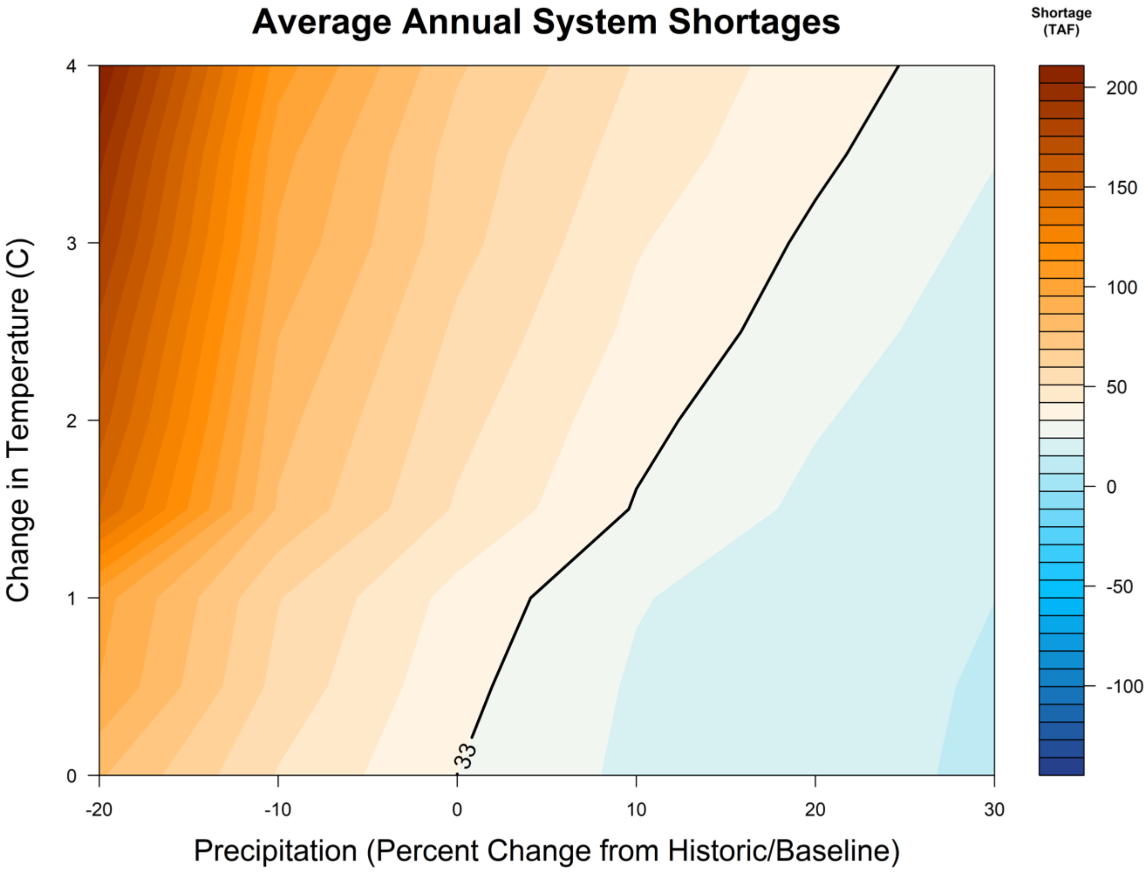


Performance Metric 5: Average Annual System Shortages

System shortages occur when there is not enough water in the system to meet all water demands and regulatory requirements. In CalLite 3.0 simulations, these shortages typically result in the relaxation of Delta water quality or outflow requirements. The shortage amount is the amount of water that would be needed to satisfy all requirements. Shortages have been rare but do occur periodically (e.g., 2014 and 2015). This metric indicates potential system vulnerabilities and potential need to adapt regulatory systems to ensure that operators have the flexibility and capability to identify and respond to certain conditions when they arise.

The response surface for average annual system shortages displays results in terms of absolute values of thousand acre-feet (taf) per year. Historically, average annual system shortages been very low, averaging around 33 taf per year, though some dry years have had much larger shortages. Years with normal or above normal precipitation have had no shortages at all. The response surface shows that system shortages increase by about 10 taf per year, per °C. Decreases in average annual precipitation drive significant increases in system shortages as can be seen by narrower color bands to the left of current performance levels.

Figure 5-7 **Average Annual System Shortages**

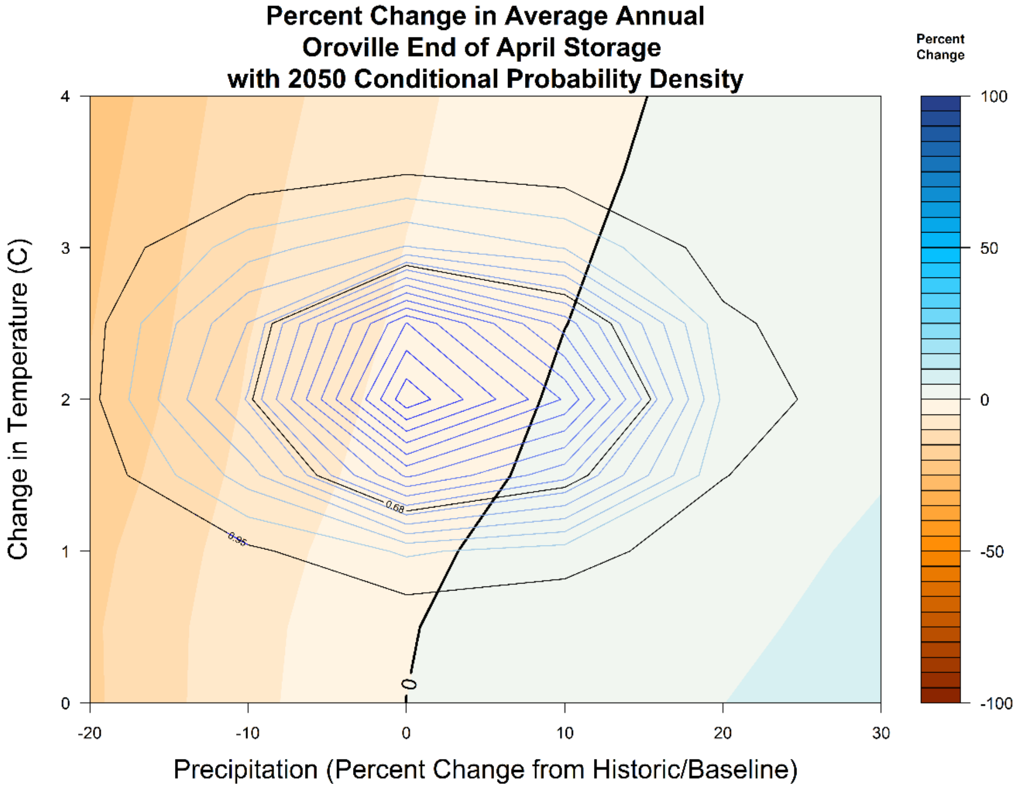


Risk

By combining the results of modeling SWP's sensitivity to changes in climate and the mid-century GCM-informed pdf of future Central Valley watershed climate conditions (see "Exposure" section of this chapter), probabilistic estimates of risk are developed for each of the decision-relevant performance metrics.

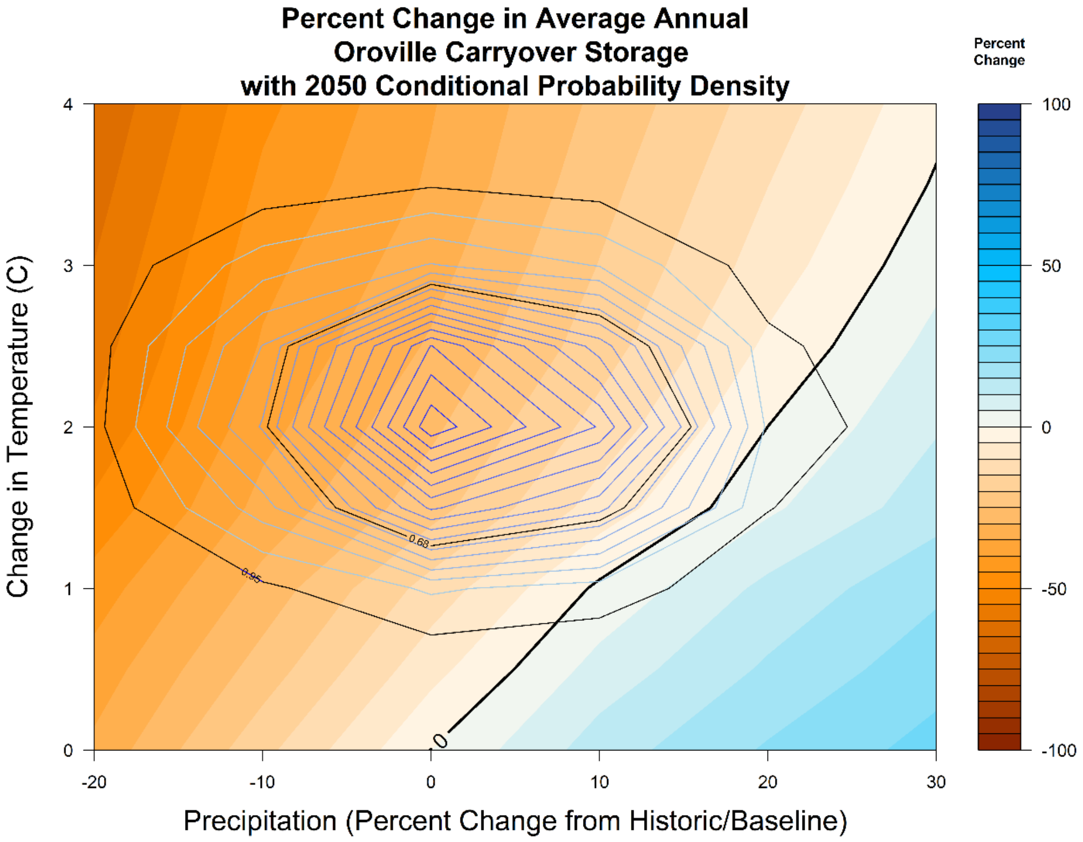
Figures 5-8 through 5-12 below show the mid-century GCM-informed pdf superimposed on each of the performance metrics at 2050 conditions in order to graphically illustrate the probabilistic range of future system performance. As the circles of the GCM-informed pdf get lighter in color, the conditional probability density of that outcome decreases. The mid-century climate probability density is roughly centered at no change in precipitation and about 2 °C change in temperature, with significant uncertainties in precipitation extending from about -20 percent to +26 percent change and in temperature from +0.5 °C to +3.5 °C. Despite this range of uncertainty, it is shown that for all metrics except seasonal NDO, the majority of the GCM-informed pdf at 2050 overlays decreased SWP performance and only a small portion overlays areas of increasing system performance. This situation is especially acute for average Oroville September storage. For the seasonal NDO, Figures 5-10 a-d, the GCM-informed pdf at 2050 is generally evenly distributed across higher and lower levels of NDO.

Figure 5-8 **Average Annual Oroville End-of-April Storage with GCM-informed pdf at 2050**



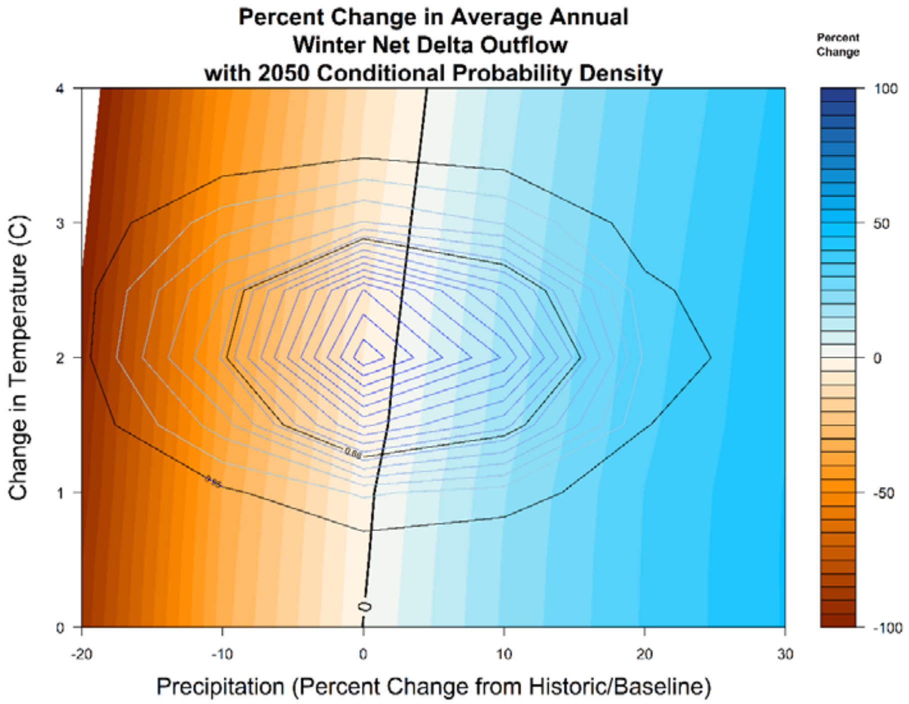
Notes:
GCM = General Circulation Model
pdf = probability density function

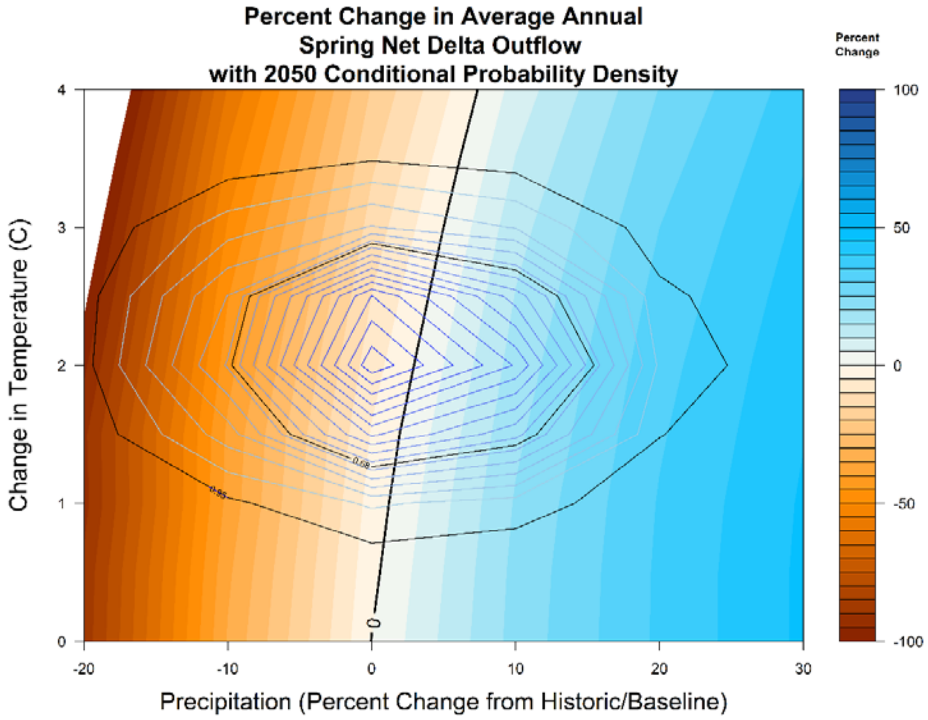
Figure 5-9 Average Annual Oroville Carryover Storage with GCM-informed pdf at 2050



Notes:
GCM = General Circulation Model
pdf = probability density function

Figure 5-10 a-b **Average Annual Winter and Spring Net Delta Outflow with GCM-informed pdf at 2050**



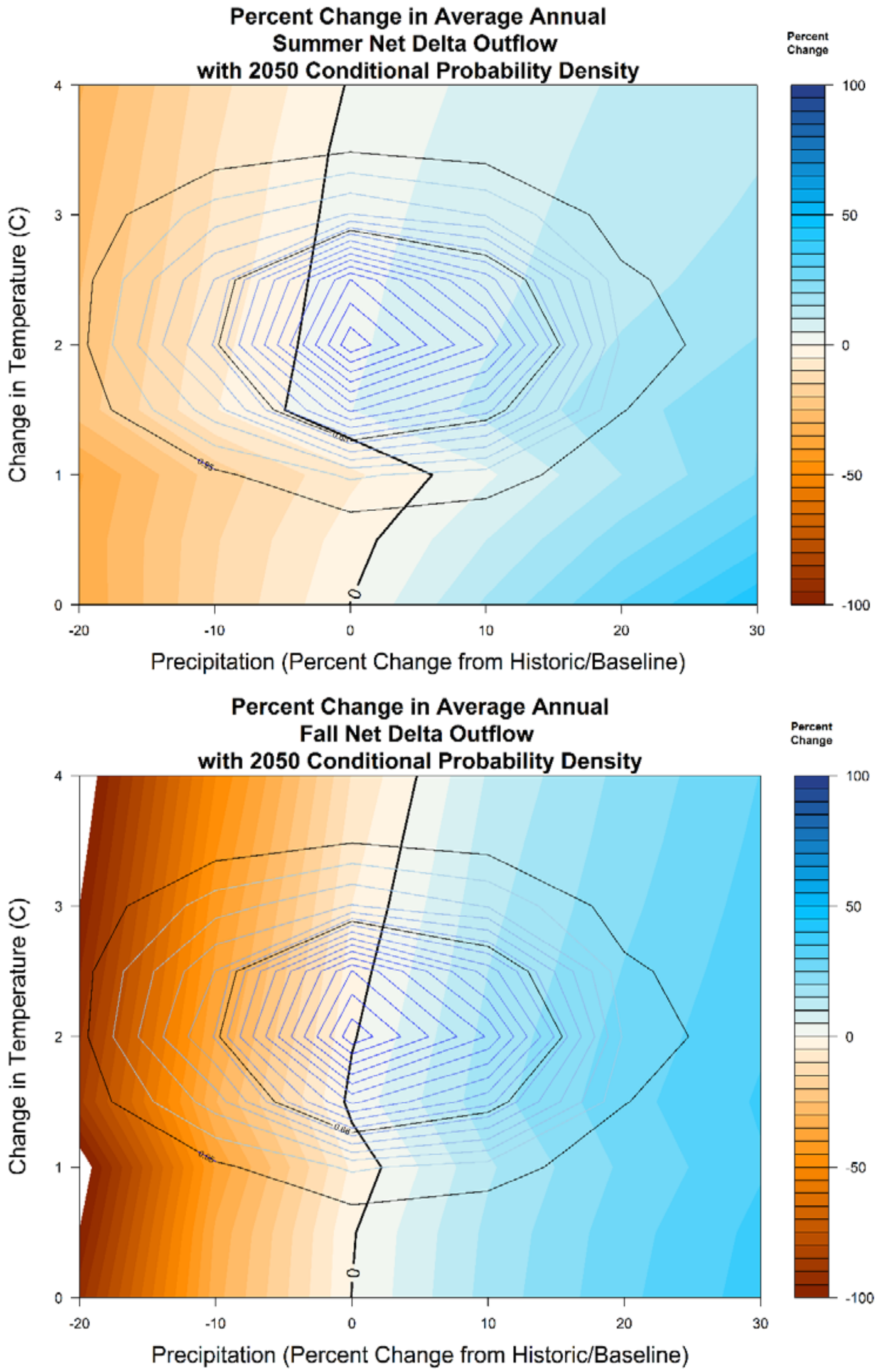


Notes:

GCM = General Circulation Model

pdf = probability density function

Figure 5-10 c-d **Average Annual Summer and Fall Net Delta Outflow with GCM-informed pdf at 2050**



Notes:
GCM = General Circulation Model
pdf = probability density function

Figure 5-11 Average Annual SWP Deliveries with GCM-informed pdf at 2050

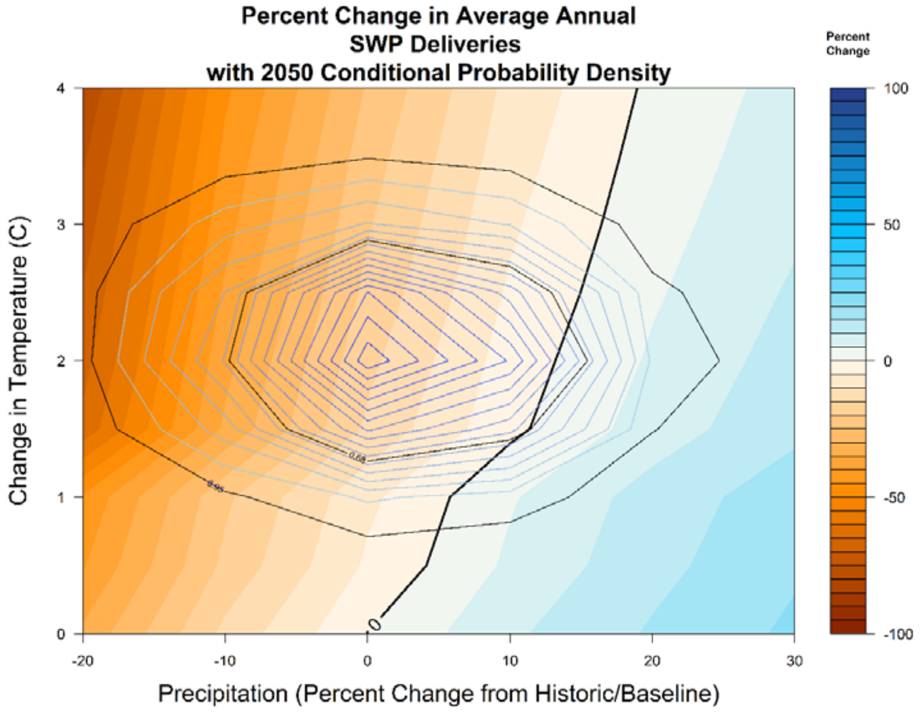
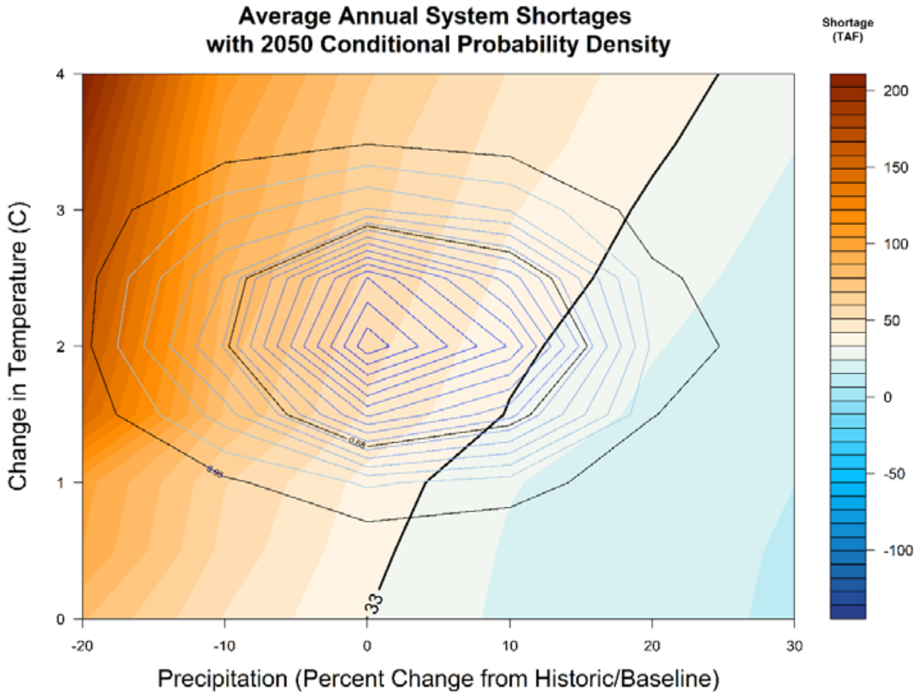


Figure 5-12 Average Annual System Shortage with GCM-informed pdf at 2050



Notes:
GCM = General Circulation Model
SWP = State Water Project
pdf = probability density function

Vulnerability

Figures 5-8 through 5-12 summarized long-term average system performance. While this is one important measure of changing risk, regulators, water managers, and SWP contractors are often more focused on risks associated with changing annual conditions, particularly those in the driest years. The analysis below provides information about the changing distribution of annual performance (i.e., how does system performance change across the entire distribution of hydrologic conditions from the wettest years to the driest years).

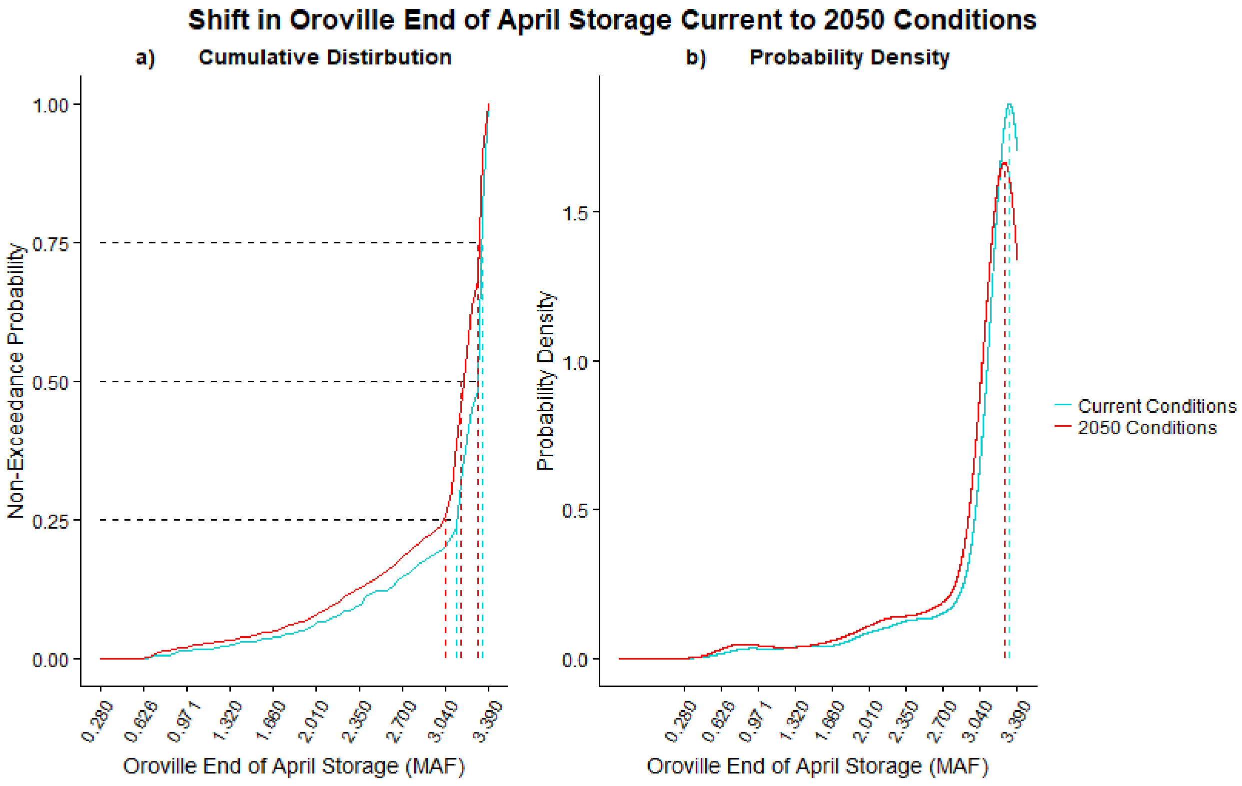
For each performance metric, the cumulative distribution function (cdf) and pdf is calculated. The cdf provides the probability that the system will be at or below a given level of performance. The pdf provides a measure of the relative likelihood of one level of performance over another or the probability that the system will fall within a given range of performance. The cdf and pdf consider the annual system performance across all 54 combinations of temperature and precipitation and weights each combination by its associated conditional GCM-informed probability density. The cdf and pdf for each performance metric can be calculated at current conditions and at any future time-period. Comparing cdf and pdfs for current conditions against mid-century conditions illustrates the shift in the distribution of annual performance.

For each performance metric shown in Figures 5-13 through 5-18, the 25th, 50th, and 75th percentile values of performance are calculated from the cdf and provided for both current conditions and 2050 conditions (notated as P25, P50, and P75 in the light blue table below the pdf curves). The most likely level of system performance, or mode, is calculated from the pdf for both current conditions and 2050 conditions (the light blue table below pdf curves). The 25th, 50th and 75th percentile values help illustrate how system performance will change in dry years, median years, and wet years, respectively, while the mode provides a measure of the expected value of performance across the entire range of year types and future climate uncertainty.

Vulnerability to Annual Shifts in Oroville April Storage Conditions

For Oroville end-of-April storage (Figure 5-13a-b), a major shift in performance is apparent in the cdf during dry to above normal wet years. The 25th percentile performance falls by nearly 100,000 acre-feet while 50th percentile performance falls by 130,000 acre-feet. During very wet years (75th percentile and above), Oroville end-of-April storage is nearly identical at current and 2050 conditions. This is because Oroville is full in wet years and additional inflow from earlier runoff of snowmelt does not result in additional storage. There is high certainty that future conditions will be warmer, resulting in increasing amounts of winter precipitation entering the reservoir by April. Yet it appears that climate change will still result in significant reductions to Oroville end-of-April storage in dry to above normal wet years, likely the result of reductions in end-of-September Oroville carryover storage (see Figure 5-14 a-b) (i.e., starting out the winter with lower storage levels will result in lower end-of-winter storage conditions in all but the wettest years). Additionally, higher evapotranspiration rates, sublimation rates, and reduced soil moisture all contribute to reduced runoff and inflow to the reservoir. The pdf shows that the most frequent annual Oroville end-of-April storage under future conditions (2050) is reduced by 50,000 acre-feet, which is 1.5 percent less than current conditions.

Figure 5-13a-b **Cumulative Distribution and Probability Density for Oroville End-of-April Storage**



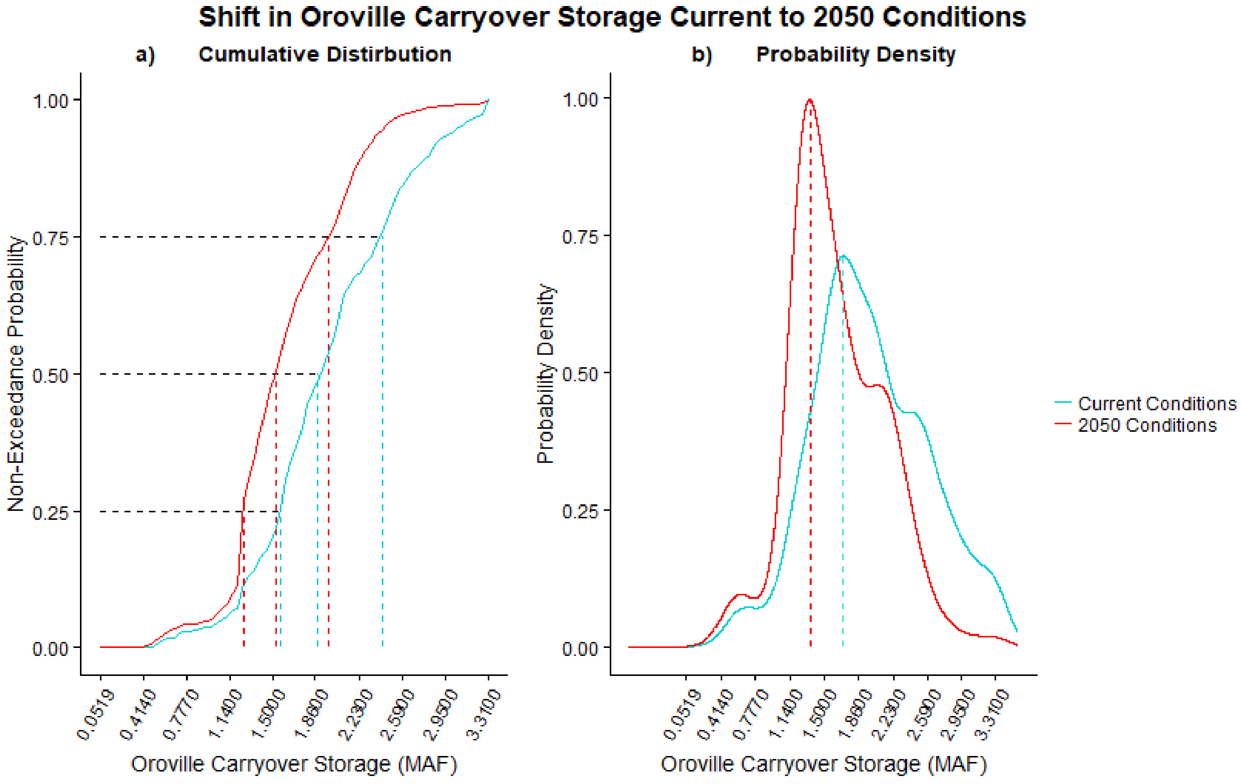
	P25	P50	P75
Current Conditions	3.13	3.3	3.34
2050 Conditions	3.05	3.17	3.3

	Mode
Current Conditions	3.32
2050 Conditions	3.27

Vulnerability to Annual Shifts in Oroville Carryover Storage Conditions

Climate change impacts on Oroville carryover storage (Figure 5-14a-b) are seen more strongly toward the wet end-of-the spectrum, directly opposite of impacts seen on Oroville end-of-April storage. At the dry end-of-the spectrum (below 25th percentile) declining performance becomes smaller and smaller, which is attributed to a management target that Oroville storage remain above 1 maf. When Oroville storage nears this level, water allocations for other purposes are reduced to the extent possible to maintain this minimum target. Toward the median (50th percentile) and wet (75th percentile) ends of the spectrum, large reductions in storage are seen at 350,000 and 450,000 acre-feet, respectively. Even during the very wettest years (above 75th percentile), Oroville carryover storage is significantly reduced. The pdf shows the most likely future condition of Oroville carryover storage is reduced by 350,000 acre-feet. The pdf shows that Oroville ends September with much lower levels of storage more frequently and with less year-to-year variability than under current conditions.

Figure 5-14 a-b **Cumulative Distribution and Probability Density for Oroville Carryover Storage**



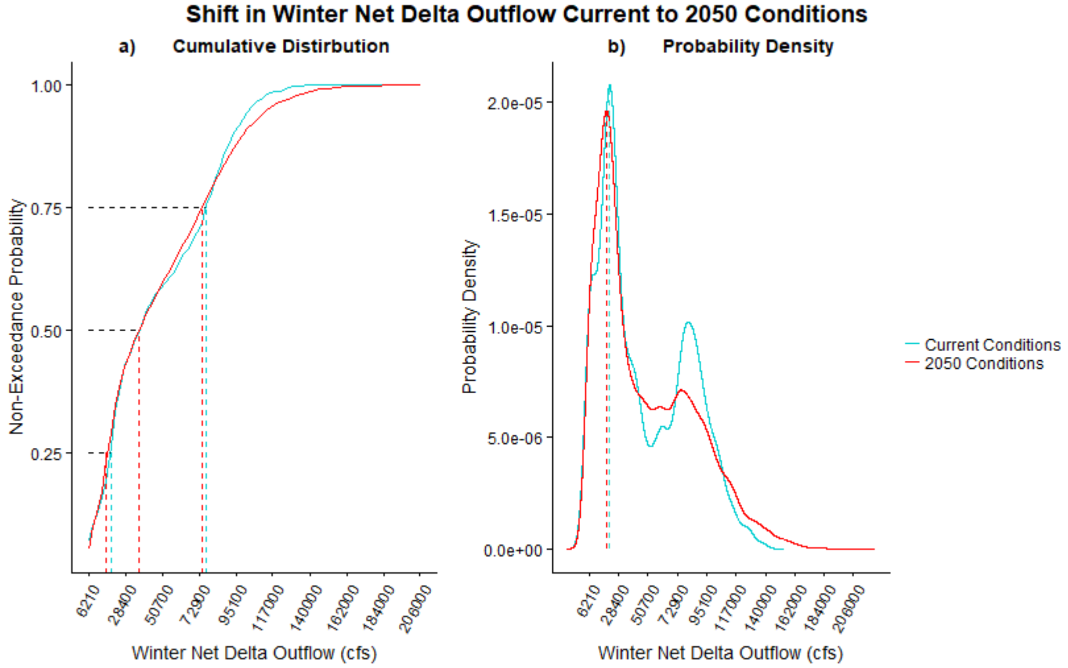
	P25	P50	P75
Current Conditions	1.57	1.88	2.42
2050 Conditions	1.26	1.53	1.97

	Mode
Current Conditions	1.7
2050 Conditions	1.35

Vulnerability to Annual Shifts in Seasonal Net Delta Outflow

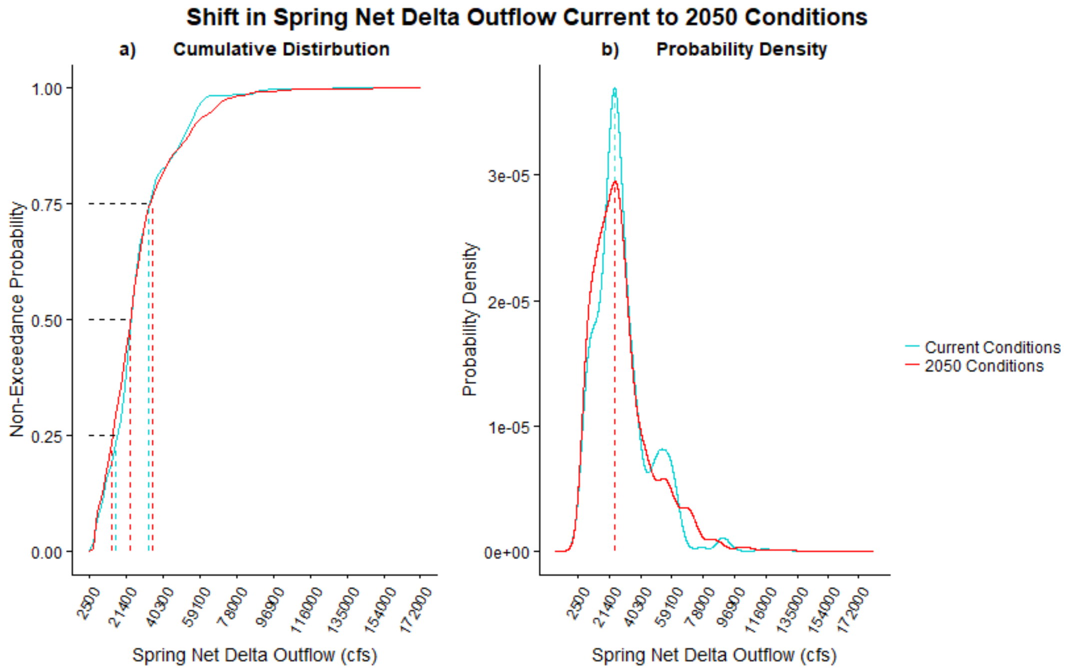
The annual cdf and pdf of seasonal net Delta outflow (Figures 5-15 and 5-16) give a more nuanced picture than the response surfaces (5-10a-d) of how Delta outflows are likely to change under 2050 conditions. The cdf and pdf show that changes in NDO are likely to be relatively small on an annual basis. Slight shifts are seen in all seasons, with winter, spring, and fall NDO increasing slightly above the 75th percentile and summer NDO increasing slightly at all levels below the 80th percentile and decreasing above the 80th percentile. Increasing summer NDO, as noted above, is attributed to increased outflow necessary to counteract salinity intrusion into the Delta caused by higher sea levels. The relatively small shifts in summer NDO indicate that DWR and USBR will continue to be able to meet Delta regulatory requirements but there will be fewer years in which summer NDO exceeds required conditions.

Figure 5-15 **Winter and Spring Net Delta Outflow**



	P25	P50	P75
Current Conditions	19900	36400	77500
2050 Conditions	17200	36400	74700

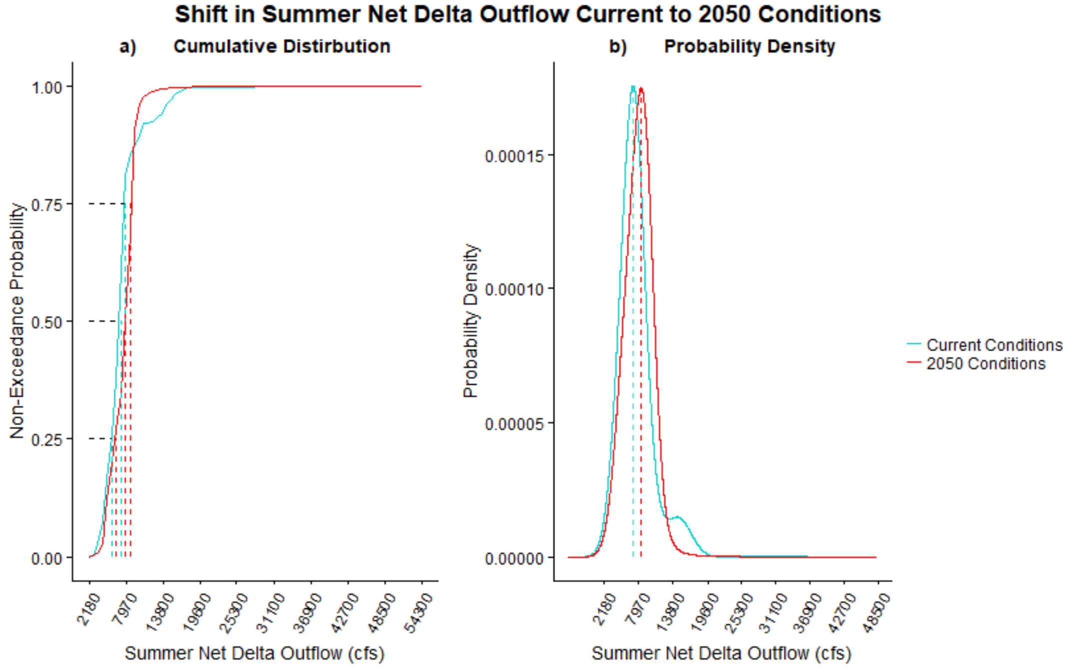
	Mode
Current Conditions	22000
2050 Conditions	19600



	P25	P50	P75
Current Conditions	16500	23400	32800
2050 Conditions	14100	23400	35100

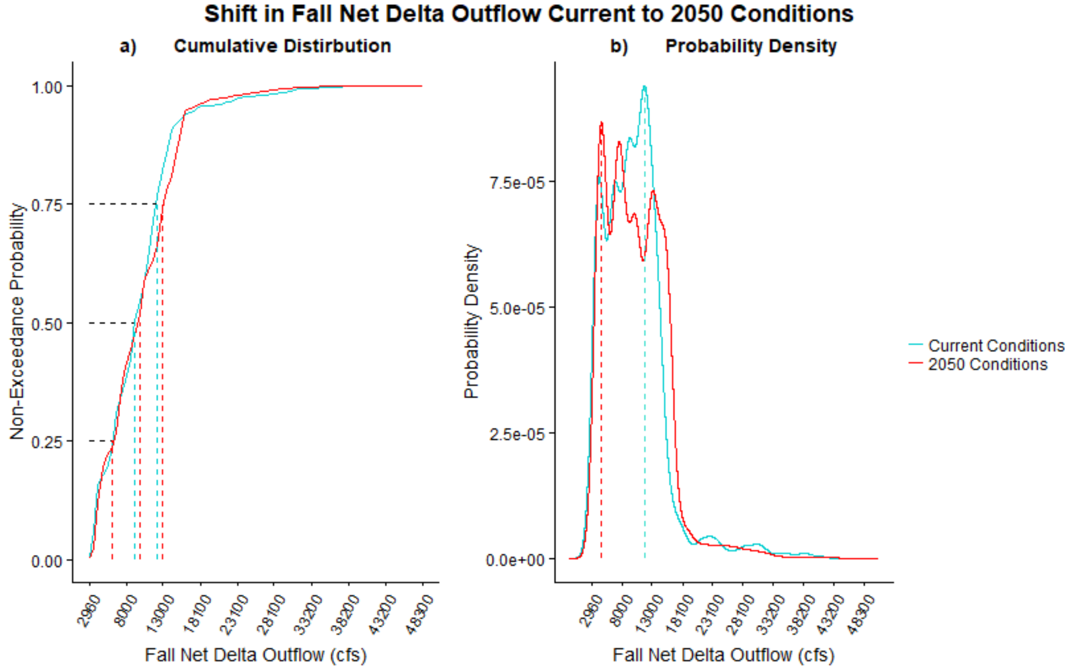
	Mode
Current Conditions	24400
2050 Conditions	24600

Figure 5-16 **Summer and Fall Net Delta Outflow**



	P25	P50	P75
Current Conditions	5750	7170	7890
2050 Conditions	6460	7890	8600

	Mode
Current Conditions	7020
2050 Conditions	8380



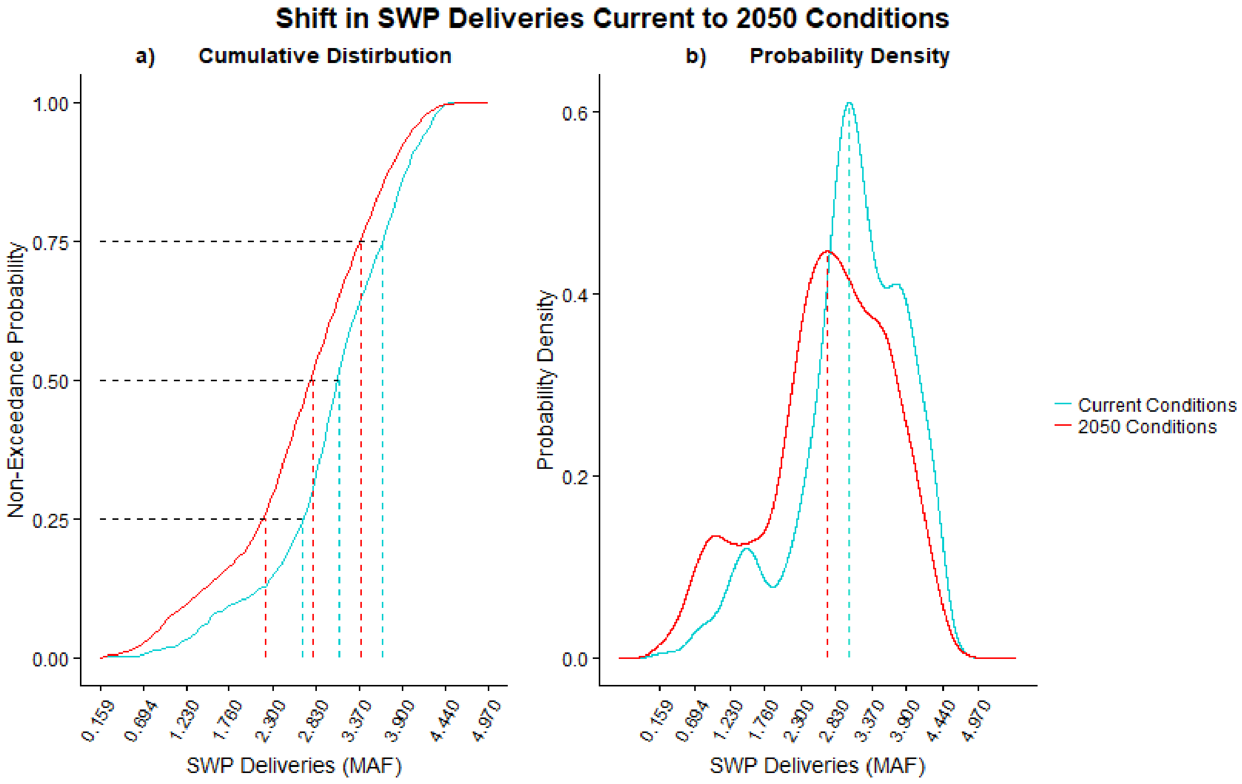
	P25	P50	P75
Current Conditions	6070	9170	12300
2050 Conditions	6070	9790	12900

	Mode
Current Conditions	11700
2050 Conditions	4580

Vulnerability to Annual Shifts in SWP Deliveries

SWP deliveries (Figure 5-17a-b) show a significant loss in performance across the entire range of non-exceedance probabilities with the most acute loss of performance coming at the drier end of the range. The 25th percentile deliveries fall by over 450,000 acre-feet (17 percent) between current conditions and 2050 conditions. Median performance falls by over 300,000 acre-feet (10 percent) and 75th percentile performance falls by 260,000 acre-feet (7 percent). This is an important result, indicating that not only will SWP deliveries be less reliable in the future, but the largest reductions will occur in the driest years placing additional stress on SWP water contractors. The pdf shows the most likely level of SWP delivery performance at 2050 is about 300,000 acre-feet less than current conditions, with deliveries less than current levels being more likely and deliveries higher than current levels being less likely.

Figure 5-17 a-b Cumulative Distribution and Probability Density for Annual SWP Deliveries



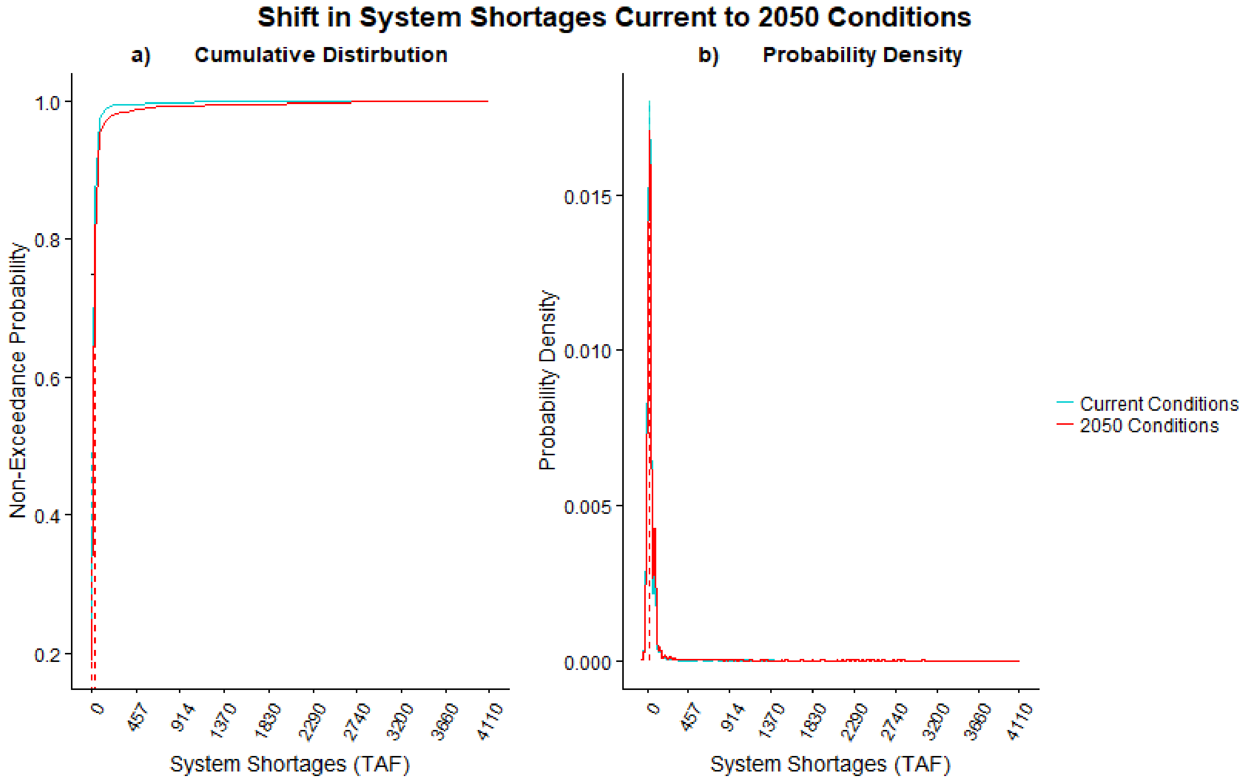
	P25	P50	P75
Current Conditions	2.66	3.12	3.65
2050 Conditions	2.2	2.8	3.39

	Mode
Current Conditions	3.03
2050 Conditions	2.71

Vulnerability to System Shortages

The cdf and pdf of system shortages (Figure 5-18a-b) provides a different view of the likelihood of system shortages in the future than did the response surface of system shortages (5-12). The cdf and pdf illustrate that system shortages are rare under current conditions and will continue to be so under 2050 conditions. A small increase in magnitude and frequency of system shortages is likely to occur by 2050 but shortages of greater than a 1 maf would still be expected to occur in less than 1 percent of years.

Figure 5-18 a-b Cumulative Distribution and Probability Density for Annual System Shortages



	P25	P50	P75
Current Conditions	0	0	28
2050 Conditions	0	28	28

	Mode
Current Conditions	25.9
2050 Conditions	26.1

Vulnerability Assessment Summary

The analysis above indicates a high likelihood of significantly diminished SWP storage and deliveries in the future as the climate warms. Reductions in Oroville carryover storage, which means entering the dry season with a smaller cushion when winter rains do not materialize, imperils California to future droughts. Lower storage levels also reduce the amount of hydroelectric generation from the Hyatt-Thermalito complex and will hamper recreational opportunities on Lake Oroville.

The results of the vulnerability assessment suggest that climate change will not impede DWR's ability to meet today's regulatory standards when exposed to mid-century conditions, as evidenced by the performance results for summer and fall NDO and system shortage. Indeed, for the metrics analyzed in this vulnerability assessment, the SWP appears to be relatively capable to continue meeting today's regulatory requirements at mid-century, albeit at the cost of water delivery reductions, which show considerable vulnerability to changing climate. Without significant adaptation, SWP delivery reliability is likely to diminish as the climate warms. Table 5-4 summarizes the probability of long-term average reductions of all performance metrics evaluated in this assessment.

Table 5-4 Probability that Performance at Mid-Century will be Inferior to Current Performance (Based on Long-Term Average Metrics)

Performance Metric	Probability of Inferior Mid-Century (2050) Performance relative to Current Performance
Oroville April Storage	76%
Oroville Carryover Storage	95%
Winter Net Delta Outflow	65%
Spring Net Delta Outflow	65%
Summer Net Delta Outflow	21%
Fall Net Delta Outflow	56%
SWP Deliveries	93%
System Shortages	87%

Adaptive Capacity

SWP facilities and operations can be adapted to ameliorate losses in performance. Several structural improvements, such as conveyance infrastructure in the Delta, non-structural improvements, such as upper meadow restoration and forest management in the Upper Feather River Watershed, and operational improvements, such as forecast-based operations of reservoirs could be analyzed. Adaptation strategies, such as those evaluated in the California Water Plan Update 2013 and USBR Sacramento-San Joaquin Basin Study, range in cost from a few million dollars to billions of dollars and range in social acceptability from highly acceptable to highly contentious. Adaptation strategies will be evaluated in DWR's forthcoming Climate Change Adaptation Plan.

Next Steps

As described above, vulnerabilities to the SWP from persistent long-term changes in climate are significant and highly probable (see Table 5-4). In fact, Oroville carryover storage and SWP deliveries are very likely[26] to perform less than current performance based on the model scenarios considered in this assessment. The performance of the SWP will diminish over the coming decades if nothing is done to adapt to climate change. The approach taken here provides opportunities to improve planning for climate change. Decision scaling allows quantification of the risks and costs associated with both the status quo and those of adaptation strategies. Planners can use this information to make informed selections of adaptation strategies based on which strategies are most likely to improve conditions for decision-relevant performance metrics.

Uncertainty associated with projecting future climate conditions is dependent on the limitations of climate modelling, and that uncertainty is unlikely to be reduced soon. Therefore, DWR planning objectives must acknowledge and accommodate this uncertainty. It is not feasible to plan for every possible climate outcome; however, with these quantitative assessments of future risk, we can establish quantitative adaptation objectives that address this uncertainty. For example, a quantitative climate adaptation objective could be:

> *For mid-century conditions, decision scaling analysis indicates that there is a 22 percent probability that long-term average annual SWP deliveries will fall below 2 maf; implement adaptation strategies that reduce the probability of this condition to no more than 5 percent.*

Objectives like this acknowledge that we cannot plan for all tail-end probabilities (i.e., a 1 percent likelihood); there will always be residual risk. The example objective also acknowledges that climate adaptation is a moving target. Climate change will not stop at mid-century. Impacts are expected to become increasingly more severe toward the end of the century. Thus, adaptation objectives and the strategies we implement to achieve those objectives will need to be continually revised.

The analysis conducted here is a first step in DWR’s use of decision scaling to evaluate the vulnerability of the SWP to climate change. Characterization of the changing likelihood of acute drought conditions could be useful in evaluating adaptation strategies such as precipitation enhancement, increased skill in sub-seasonal forecasting, and upper watershed management in DWR’s forthcoming Climate Change Adaptation Plan.

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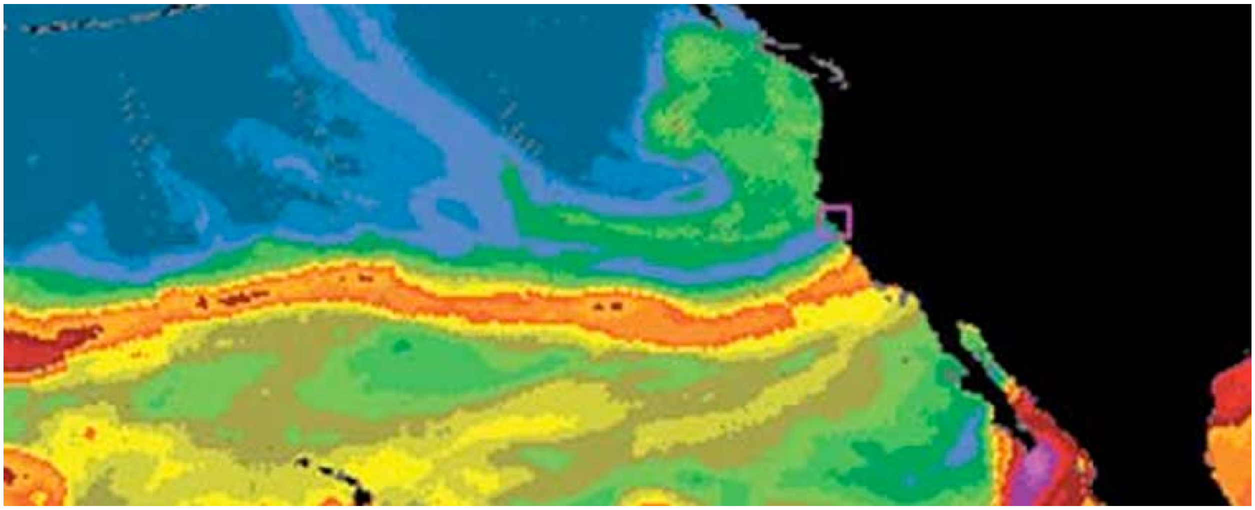
[26] Terminology used to describe likelihood is based on the IPCC Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties, available online at: https://www.ipcc.ch/report/ar4/wg1/uncertainty-guidance-note-for-the-fourth-assessment-report/.

Chapter 6 — Short-term Extreme Hydrologic Events



Depiction of Atmospheric River Making Landfall over California[27]

Flooding impacts from short-term extreme hydrologic events have been well studied in California, especially by DWR. In recent years, significant effort has been expended looking at how climate change will affect these short-term extreme hydrologic events.[28] These impacts are among the most important for DWR to understand and plan for. These impacts have, in the past, and have the potential in the future, to cause loss of life, loss of property, other large-scale damage, and various operational disruptions across the state. But the evaluation of climate change impacts on short-term extreme hydrologic events is extremely complex.

GCMs are designed to simulate large scale, long-term processes over large areas around the globe. Evaluation of the impacts of climate change on short-term extreme hydrologic events requires analysis of highly localized climatic processes on very fine time scales — usually down to kilometers and hours. Furthermore, in California, flood protection infrastructure is generally a system of watersheds, reservoirs, river channels, levees, and floodplains. Releases from upstream reservoirs can obviously affect channel flows downstream. In some cases, improvement of flood protection in one location may increase flood risks downstream, and conversely, modifying reservoir operations on one river may allow reservoir operators on another river to provide additional flood benefits.

Beyond the physical connections between river systems, California’s flood protection infrastructure is a complex combination of federal, State, and locally owned, operated, and maintained facilities. Because of these characteristics, analysis and adaptation of California’s complex flood protection facilities must be

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[27] https://scripps.ucsd.edu/news/3066.

[28] A summary of the past and current work in this area is provided below in the “Relevant Studies Conducted to Date or In Progress” section.

approached comprehensively. This is particularly important in the Central Valley, where most of DWR's flood protection assets and activities are located.

Central Valley Flood Protection Planning and the 2017 CVFPP

The Central Valley Flood Protection Board (CVFPB) and DWR, through the CVFPP, have been evaluating and planning for short-term extreme hydrological events and potential intensification of those events resulting from climate change in the Central Valley. Additional extreme event planning is also being conducted on a regional and statewide basis. Rather than conducting another potentially duplicative analysis, these very thorough, cross-jurisdictional research and planning efforts are relied upon in this VA to assess DWR's potential increased risk of flooding.

Relevant Studies Conducted to Date or In Progress

- **2017 Central Valley Flood Protection Plan** (Central Valley Flood Protection Board, 2017) The 2017 CVFPP Update serves as a long-range plan that guides the State's participation in managing flood risk in the Central Valley. It will guide investments in multi-benefit flood projects over the next 30 years. Specific recommended actions to increase resilience include expanding flood conveyance capacities, restoring floodplains, and coordinating reservoir operations.

  The 2017 CVFPP also includes several accompanying analyses through its Technical Series documents. Of relevance to this VA is the Climate Change Analysis Technical Memorandum (Central Valley Flood Protection Board, 2017) which is summarized in detail below.

- **State Plan of Flood Control — Attachment F: Flood Hazard Exposure Analysis** (California Department of Water Resources, 2013)
  This analysis used GIS data to identify the population, property, structures, facilities, and crops located within 100-year (and 500-year, when available) floodplains, as well as CVFPP floodplains. It qualitatively describes effects that flood events could have on the function of multiple types of inundated structures including residential, commercial, industrial, and public. Changes in land use and population are also discussed.

- **California's Flood Future — Recommendations for Managing the State's Flood Risk** (California Department of Water Resources, 2013)
  This report summarizes the risk to critical infrastructure, vital community services, agricultural areas, and water supplies and quality from impacts of a major flood. It highlights numerous short and long-term solutions that will require improved planning and permitting, and stable funding mechanisms to implement them.

- **Potential increase in floods in California's Sierra Nevada under future climate projections** (Das, Dettinger, Cayan, & Hidalgo, 2011)
  This study found that by mid-century, some climate projections yield increased frequency of storms and floods in the Northern Sierra Nevada and Southern Sierra Nevada.

- **Increase in flood magnitudes in California under warming climates** (Das, Maurer, Pierce, Dettinger, & Cayan, 2013)

This study found that larger floods will occur in both the Northern and Southern Sierra Nevada watersheds regardless of the direction of change in mean precipitation. The increases in simulated 50-year flood flows are larger (at 95 percent confidence level) than would be expected because of natural variability before mid-century, as early as 2035.

- **USBR Basin-wide Feasibility Studies**[29]
  Basin Studies, funded with federal WaterSMART grants, evaluate the impacts of climate change and identify the strategies to address imbalances in water supply and demand. Studies for the Sacramento and San Joaquin river Basins, Southeast California Regional Basin, and Truckee Basin have been completed, and a new basin study for the American River has been launched. Each study includes future projections of supply and demand, an analysis of how the basins' existing water and power operations and infrastructure will perform in the face of changing water realities, mitigation and adaptation strategies, and a trade-off analysis of those strategies.

Short-term Extreme Hydrologic Events Vulnerability Assessment Approach

Exposure

Analyzing and quantifying the specific impacts that climate change will have on short-term extreme hydrologic events in California is extremely difficult as noted above. But numerous studies using varied methodologies, datasets, and metrics of change have concluded that California's hydrology, particularly winter hydrology when California faces the risks of flooding, will become more extreme in the future. Based on the results of these and other studies, DWR faces high exposure to increased short-term extreme hydrologic events resulting from climate change.

Sensitivity

Staff Activities

During extreme events, DWR staff may be reassigned from their normal duties to work on emergency flood control or other activities to respond to the extreme event on the public and/or DWR infrastructure. Depending on the extent and duration of the event, physical safety, mental distress, and overtime pay and other costs may be considerable. Sensitivity is thus high for short-term extreme events.

Facilities and Lands

As noted above, evaluation of flood risk, and changing flood risk because of climate change, requires a comprehensive analysis of the entire Central Valley flood protection system. An original analysis would be required to identify DWR facilities and lands that will be vulnerable to future flooding risks, but such an analysis was beyond the scope of this assessment. But to provide a screening level analysis of climate change vulnerability of DWR facilities and lands to future flooding, an analysis was conducted using the Federal Emergency Management Agency (FEMA) Special Flood Hazard Area 500-year floodplain data.

The 500-year floodplain maps indicate areas that would be flooded under existing conditions during a flooding event with a 0.2 percent chance of occurrence in any year, but they do not indicate how this

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[29] http://www.usbr.gov/watersmart/bsp/.

flood risk would change as a consequence of climate change. Nonetheless, assessment of DWR facilities and lands that are located within the 500-year floodplain provide a good indication of the facilities and lands that would be likely to be exposed to flooding risks more frequently under a changing climate.

DWR owns and operates two flood maintenance yards, Sutter and Sacramento, which are located on the Sacramento River levee near Sutter and in West Sacramento, respectively. While these facilities are not technically located within the FEMA 500-year floodplain, additional evaluation of these facilities was undertaken because of their criticality during a flood event. Site visits were conducted at each maintenance yard to observe site access, sensitivity and adaptive capacity to flooding, as well as overall site conditions.

Operations

The analysis of sensitivity of DWR operations to changes in short-term extreme hydrologic events draws from the 2017 CVFPP Climate Change Analysis Technical Memorandum (Central Valley Flood Protection Board, 2017). This report provides the basis for the vulnerability assessment from climate change focusing on changes in (1) the magnitude of flooding events, (2) flood hydrograph characteristics (including peak flood volume, timing of the peak, and flood duration) in flood-prone Central Valley areas and Oroville Reservoir, and (3) flood frequencies (and associated magnitudes).

California’s current flood infrastructure is typically designed to protect against floods with a certain occurrence frequency, representing socially acceptable risk, such as the 100-year flood maps used for insurance purposes. Current real-time flood management practices are informed by forecasted flood hydrographs. Therefore, analysis of flood frequencies, magnitudes, volumes, and hydrographs under climate change conditions yields insights to guide flood management planning, investment, and operations.

For assessing changes in flood hydrographs and for assessing peak flows and flood volumes entering Oroville Reservoir during very large storm events, the approach used 20 downscaled climate projections based on the localized constructed analog (LOCA) method (Pierce, 2014). These 20 projections were selected by the DWR Climate Change Technical Advisory Group (CCTAG) as being the most appropriate for use in California water resource evaluations and analyses (California Department of Water Resources, Climate Change Technical Advisory Group, 2015). The 20 climate change scenarios were run through a calibrated and validated hydrologic model (Variable Infiltration Capacity [VIC] model [Liang et al., 1994]) to produce daily streamflow projections. Historical temperature and precipitation data were also run through the VIC model to generate historical streamflow simulations. These historical simulations served as the baseline condition. Peak reservoir inflow, total reservoir inflow volume statistics, and down stream flow characteristics were calculated from streamflow projections and compared with their historical baseline counterparts.

For assessing changes in flood frequencies, an ensemble-informed approach was applied. This approach has been applied in many water resource planning studies in California, including the California WaterFix resource impact assessment. The approach used bias-corrected and spatially downscaled climate projections from over 100 CMIP5 climate model simulations. To characterize changes over time, three different periods were considered: near term (2011–2040), mid-century (2041–2070), and late century (2071–2099). Accordingly, three climate change scenarios were developed. In each scenario, the median (of all climate model simulation) estimates of projected temperature and precipitation change were used with quantile mapping to adjust the historical temperature and precipitation data according to the monthly climate shifts indicated during each future climate period.

Daily hydrologic modeling for the period from 1915 to 2010 were analyzed, which used both historical meteorology and adjusted meteorology reflecting future climate projections. Flows were routed to various river locations, and changes between the climate scenario and historical reference period flows were computed as a percentage change. For each year of the historical reference period and the future climate scenario, the maximum 1-, 3-, 7-, and 15-day unregulated flows were calculated for routed flows at specific locations. Log Pearson Type 3 fitting was then performed based on the Bulletin 17B method used in the USGS's PeakFQ software from maximum 1-, 3-, 7-, and 15-day durations for each year, both with and without climate change (United States Geological Survey, Interagency Advisory Committee on Water Data, 1982). Next, the percentage change in flow was calculated for the specific frequency, such as the 200-, 100-, 50-, 25-, 10-, and 2-year flows by comparing the two frequency curves.

Short-term Extreme Events Vulnerability Assessment Results

Risk

Staff Activities

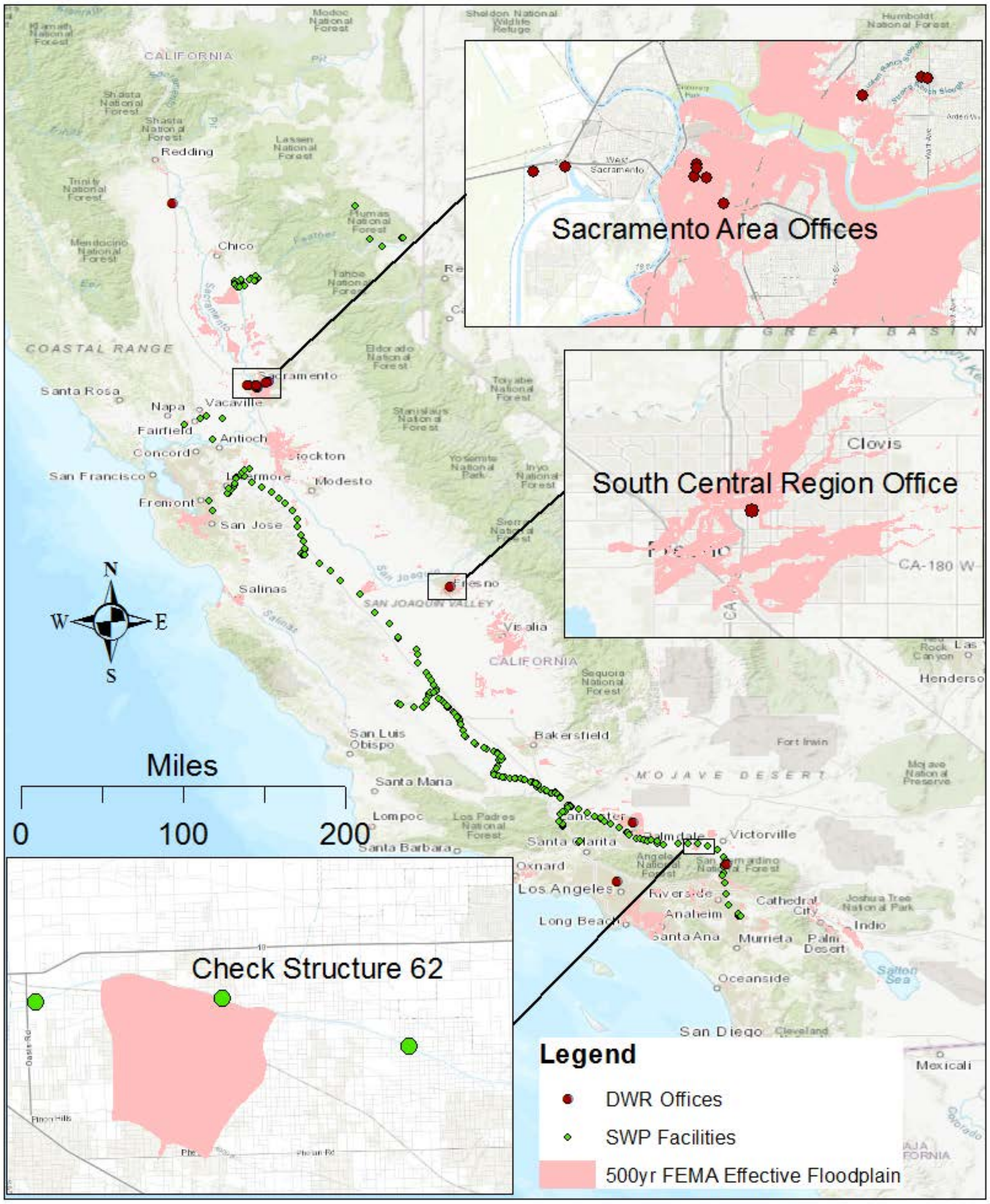
Because of DWR's role in emergency response, DWR staff activities will have both high exposure and high sensitivity to increases in short-term extreme flood events. One likely direct impact to DWR from increasing extreme event risk will be increased staffing requirements for the State-Federal Flood Operation Center (FOC) and related field operations. The FOC, located in Sacramento, is a component of DWR's Flood Operations Branch. Year-round, the FOC is the focal point for the collection, analysis, and dissemination of flood and water-related information to stakeholders. During emergency situations, the FOC provides a facility from which DWR can centrally coordinate flood emergency response statewide. Climate change is likely to increase the frequency and duration of extreme hydrologic events that cause emergency situations and require additional staffing and operation of the FOC.

Staff from regional offices are often assigned to assist with levee patrol and emergency repair work during flood events. All DWR staff are required to be ready to assist during flood emergencies, which could potentially lead to temporary reassignment of large numbers of staff during an extreme event.

Facilities and Lands

Figure 6-1 shows the FEMA 500-year floodplain areas overlaid with the locations of DWR's facilities and lands. Only seven DWR facilities are located within the 500-year floodplain area (Table 6-1). Five of the seven locations are office buildings in the downtown Sacramento area: Bonderson, Resources, the Operations and Maintenance Testing and Analysis Office, the Central Warehouse and Training Center, and the Division of Safety of Dams. The South Central Region Office in Fresno is also located just inside the 500-year floodplain, as well as a check structure (Number 62) on the California Aqueduct near Victorville.

Figure 6-1 **Some DWR Facilities Are Located Within the FEMA 500-Year Floodplain.**



Each of the six building locations within the 500-year floodplain could be vulnerable to significant damage and disruption of government services during a flood event. The South Central Region Office, Bonderson, Resources, and Division of Safety of Dams buildings all house state employees conducting mission critical activities. These employees would not be able to access their office buildings during a flooding event. Damage to office buildings, and the documents and equipment (including communication systems) inside of them, could take months to repair and likely lead to large scale and costly disruptions in State services.

Importantly, under conditions that would cause damage and disruption of DWR buildings in downtown Sacramento, most of downtown Sacramento would likely be flooded. This will cause loss of life, massive damage, and displacement of thousands of people and businesses, further exacerbating the disruption of State services and the mitigation and reconstruction activities to return services. Because of these likely impacts, the risk to these facilities is considered high.

The DWR Warehouse and Training Center and Division of O&M Testing and Analysis Office house facilities and staff that are not conducting mission critical activities. Damage to these facilities would be less disruptive to DWRs activities, therefore the sensitivity of these faculties is considered low.

Check structure Number 62 along the California Aqueduct near Victorville, is a concrete and steel structure that aqueduct operators use to control water flow through the aqueduct. Flooding of this structure would likely cause temporary disruption in the ability of DWR to move water through the SWP south of the check structure; however, the disruption would be temporary and would abate as soon as flood waters receded. Further, a short-term disruption in SWP water deliveries south of Check Structure Number 62 during such a flooding event would be unlikely to be problematic, therefore the risk to this facility is considered low.

Table 6-1 Exposure, Sensitivity, and Risk Are Assessed Each DWR Facility Located Within the 500-year Floodplain.

Region	Facility	Exposure	Sensitivity	Risk
SCR	South Central Regional Office	Moderate	High	High
HQ	Bonderson Building	Moderate	High	High
HQ	Resources Building	Moderate	High	High
HQ	DWR Warehouse and Training Center	Moderate	Low	Low
HQ	Division of Safety of Dams HQ	Moderate	High	High
HQ	O&M Testing and Analysis Office	Moderate	Low	Low
SCR	Check structure #62	Moderate	Low	Low

Operations

DWR’s flood management operation and maintenance activities are focused on facilities associated with the State Plan of Flood Control (SPFC). Figure 6-2 shows the locations of SPFC projects throughout the state. These projects include levees, weirs, dams and reservoirs, flood bypasses, pumping plants, bank protection, and flow control structures. Because this vulnerability assessment focuses on climate change vulnerabilities that DWR has the authority to address, particular attention is given to the expected climate change effects on inflows to and resulting outflows from Oroville Reservoir, though analysis of changes in flow frequencies and flood hydrographs throughout the Central Valley system are provided.

It is important to note that the SPFC is only a portion of the larger system that provides flood protection for the Central Valley. The SPFC relies on many other features that do not meet the definition of the SPFC. For example, non-SPFC reservoirs provide substantial regulation of flows to levels that SPFC facilities can mostly handle. Private levees, locally operated drainage systems, and other facilities work in conjunction with SPFC facilities. Management practices such as emergency response, floodplain management, land use regulation/zoning, insurance, and other practices are part of the overall flood protection system. All parts of the system, including the SPFC, depend on the other parts of the system to operate.

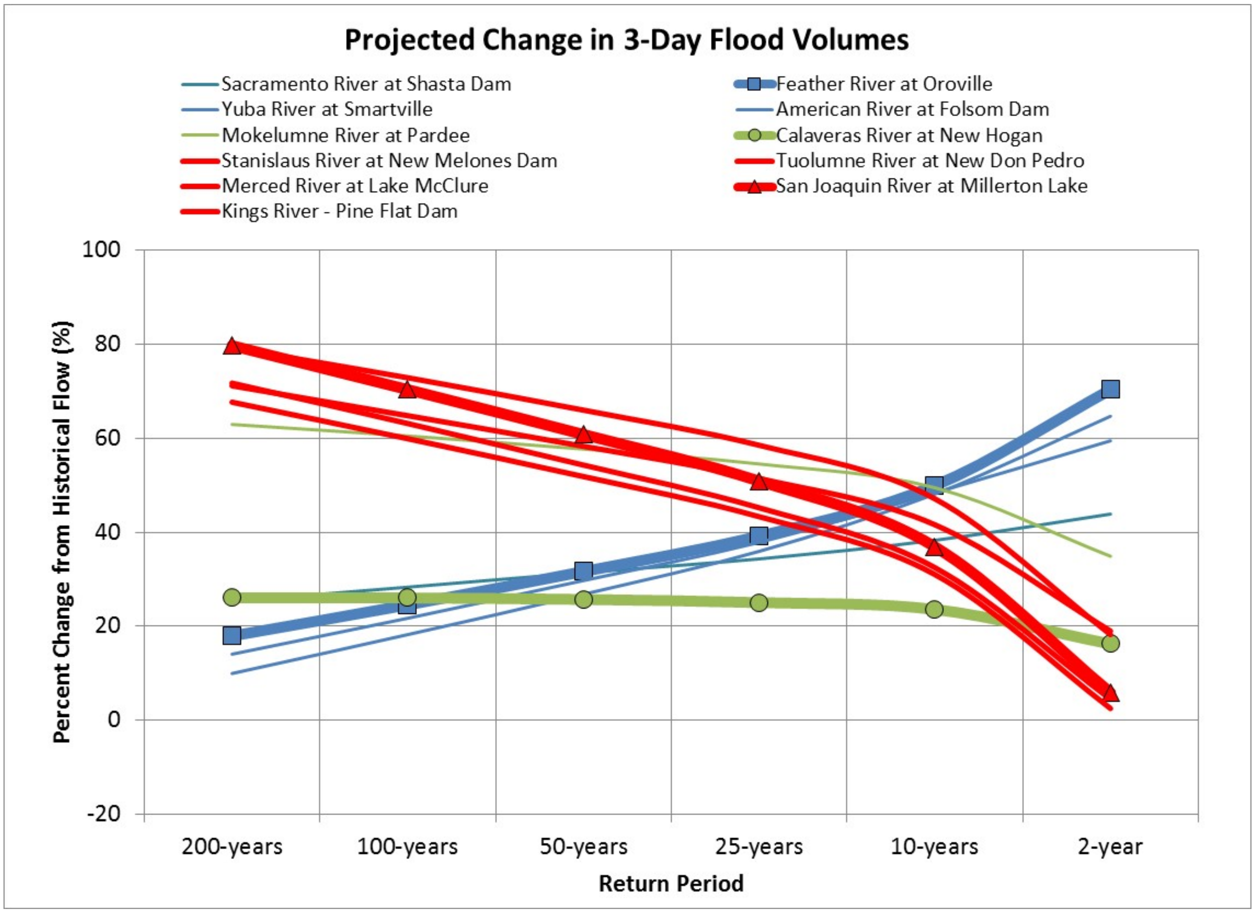
Figure 6-2 Federal/State Flood Damage Reduction Projects Are Located Throughout the Sacramento and San Joaquin River Basins that Comprise the State Plan of Flood Control.

Source: CVFPB, 2010

Central Valley Rivers Flood Frequency and Hydrograph Changes

Figure 6-3 shows potential hydrologic responses of key watersheds in the mid-century for floods with different return periods (frequencies). In the Sacramento River Basin, the largest percentage change in flood magnitudes occurs with the 2-year return interval and the smallest percentage change occurs with the 200-year return interval. It is the opposite for San Joaquin Valley watersheds where climate change poses a significantly greater threat to increased flood magnitudes. That is, the percentage change in hydrologic response from climate change is greater for the 100-year return period than the 10-year. This contrast is attributed to both watershed characteristics and historical storm behavior. In Sacramento Valley watersheds, historical (baseline) large storms have rained to the top of the watersheds. Consequently, additional warming would not result in additional direct runoff resulting from conversion of snow to rain compared to historical events; however, storms occurring under warmer climate conditions could hold more moisture than their historical analogues, resulting in increased runoff and peak flow volumes. In high-elevation San Joaquin watersheds, though, historical storms have produced snow at the top of the watersheds. Warming is expected to raise the rain-snow elevation, reducing snowfall and increasing rainfall, leading to bigger floods, particularly for large events with low recurrence frequency.

Figure 6-3 Flood Magnitudes with Different Return Periods May Change Under a 2041–2070 Climate Change Scenario.



Source: CVFPP 2017

Table 6-2 shows the changes in date of peak flow, magnitudes of 1-day and 3-day annual maximum flows, and duration of flood in the mid-century for those key watersheds. In general, peak flows in the San Joaquin Valley watersheds are expected to occur almost a month earlier. In comparison, there is no consensus for Sacramento Valley basins. Flows may peak later in several basins, but in a much smaller order (from a few days up to 7 days). Maximum annual 1-day and 3-day flows are projected to increase for all basins. Such peak flow increases are higher in the Sacramento Valley compared to those in the San Joaquin Valley. Meanwhile, storm durations are projected to decrease across all basins.

Table 6-2 Simulated Flood Hydrograph Characteristics May Change at Mid-Century (2041–2070).

Location	Change in Date of Peak Flow (days)	Change in Annual 1-day average max flow (%)	Change in Annual 3-days average max flow (%)	Change in Flood Duration (days)
Sacramento River at Shasta Dam	7	22	23	-17
Feather River at Oroville	-3	33	36	-23
Yuba River at Smartville	-9	26	28	-12
American River at Folsom Dam	-4	30	31	-14
Mokelumne River at Pardee	-18	-29	26	-18
Calaveras River at New Hogan	6	14	14	-2
Stanislaus River at New Melones Dam	-24	23	20	-15
Tuolumne River at New Don Pedro	-19	13	9	-9
Merced River at Lake McClure	-22	19	14	-15
San Joaquin River at Millerton Lake	-27	9	4	-10
Kings River at Pine Flat Dam	-26	11	4	-9

Notes: Changes are computed with respect to 1981–2010 climatological average.

Source: Adapted from CVFPP 2017

The signal of shorter duration but more intense floods (in magnitude) poses challenges to SPFC facilities. Flood operations are thus considered to have high risks from climate change. Compared to Sacramento Valley watersheds, the risks are even higher in San Joaquin Valley watersheds, particularly for large events.

Adaptive Capacity

Staff Activities

DWR prepares staff for situations, such as floods, that can disrupt their normal work schedule and activities. Flood fighting, emergency management training (e.g., SEMS/NEMS, CPR), and other relevant training opportunities are offered to staff, and in many cases, are required to be retaken on a regular basis. Large-scale drills (e.g., Golden Guardian) help staff prepare for an actual extreme event so it can be handled as safely and efficiently as possible. This preparation increases the adaptive capacity of DWR's staff.

Facilities and Lands

DWR office buildings located within the 500-year floodplain have little adaptive capacity. Locating State office buildings in downtown Sacramento facilitates public access to their government agencies and facilitates cooperation and communication within and between State agencies, the Legislature, and the Governor's Office. While some modifications to the buildings could be undertaken to minimize damage during a flood, such as minimizing critical facilities on lower levels of buildings, access to the buildings would likely be cut off during a severe flooding event, rendering the buildings unusable for staff. Of note, the State recently broke ground for a new Resources Building adjacent to the existing one in downtown Sacramento.

The Sacramento Yard is located adjacent to the Sacramento River on a levee in West Sacramento, well above the floodplain. All equipment and buildings are stored on the top of the levee, so overall risk to the facility is low; however, a levee breach near this facility would lead to widespread flooding of the residential streets surrounding the facility. This could prohibit DWR staff from being able to access the site and respond to the flood emergency. Alternatively, the DWR facility is located adjacent to an Army Corps of Engineers facility, which increases the potential for staffing and funding assistance to respond to emergencies related to this facility.

The Sutter Yard is located on Highway 20, approximately one mile south of the town of Sutter. All equipment and buildings are located behind a levee that contains Wadsworth Canal, which is connected to the Sutter Bypass approximately 2.5 miles to the southwest. A levee breach either on the Wadsworth Canal or the Sutter Bypass flood control levees near this facility could potentially lead to widespread flooding surrounding the facility. This could prohibit DWR staff from being able to access the site and respond to flood emergencies. But many Sutter Yard staff are centrally located, some with residences in and around the town of Sutter, and may be able to respond during a flood emergency.

Operations

DWR has invested significantly in flood improvements since 2007 when bond funding became available to evaluate the adequacy of SPFC facilities and improve these facilities. In 2012, the Central Valley Flood Protection Board in cooperation with DWR developed the CVFPP 2012, which proposed a State Systemwide Investment Approach (SSIA). Since then, improvements have been made to about 200 miles of urban SPFC levees and about 100 miles of non-urban SPFC levees. A range of relevant projects and programs have been launched, including the Feather River West Levee Project; West Sacramento Levee Repair and Improvement Projects; modernized control systems for San Joaquin River facilities; forecast-coordinated operations (F-CO) on the Yuba and Feather Rivers and in the San Joaquin River Basin; forecast-informed operations (F-IO) for reservoirs in the Yuba, Feather, and American rivers; flood emergency preparedness and response improvements.

The Central Valley Flood Protection Board recently adopted the CVFPP 2017. This update refined the SSIA approach defined in the 2012 update and proposed new flood management strategies. The update also made recommendations for flood management policy issues, land use and floodplain management, residual risk management, and operations and maintenance of the flood system. Implementation of those recommended improvements would help improve the adaptive capacity of the current flood management system in a changing climate.

Vulnerability

Staff Activities

Overall, staff activities are highly vulnerable to being affected by extreme events, such as flooding. Dangerous conditions, emergency reassignments, overtime pay, and inability to access facilities or equipment that might be isolated by floodwaters will all affect DWR’s staff.

Facilities and Lands

Overall vulnerability of the Sacramento Maintenance Yard to flooding is low, although staff’s ability to reach the facility could be compromised by widespread flooding in West Sacramento. Vulnerability of the

Sutter Yard is also low, but the levees that protect the area from the Sutter Bypass and Wadsworth Canal are essential for continued operations.

Operations

DWR's flood management and operations are vulnerable to increased flood risk throughout the Central Valley. The flood risk is expected to continue increasing throughout the 21st century. San Joaquin Valley watersheds are at higher risk from climate-change-driven extreme hydrologic events and are deemed more vulnerable when compared with Sacramento Valley watersheds.

Other Considerations

Wildfire can significantly alter the hydrologic response of a watershed to the extent that even modest rainstorms can produce dangerous flash floods and debris flows. Fast-moving, highly destructive debris flows triggered by intense rainfall are one of the most dangerous post-fire hazards. The risk of floods and debris flows after fires increases because of vegetation loss and soil exposure. Cases of sudden and deadly debris flow are well documented in the western United States, particularly in Southern California. These flows are a risk to life and property because they can occur with little warning, can exert great impulsive loads on objects in their path, and may strip vegetation, block drainage ways, and damage infrastructure.

Next Steps

Climate uncertainty

One option to address climate change uncertainty is to utilize the decision scaling approach (as applied in water supply analysis in Chapter 5) in assessing flood vulnerabilities. In fact, DWR has recently engaged with the U.S. Army Corps of Engineers-Hydrologic Engineering Center to initiate a pilot flood vulnerability study in the Tuolumne River watershed. The study, while still being fully developed, will employ state-of-the-science tools and data to model atmospheric river processes across a wide range of climate change uncertainty using a decision-scaling approach. In addition, it is becoming more clear that the weather phenomenon known as atmospheric rivers (AR) are associated with to the most severe flooding events in California history (Dettinger, 2013), and that AR events are likely to become more severe in the future (Warner, Clifford, & Salathe, 2015). ARs are narrow, concentrated moisture bands in the atmosphere that transport water vapor to the Western United States. Evaluating the changing characteristics of atmospheric rivers from climate change should be a key focus of future studies and assessment of flood risks.

New studies

Future climate evaluations on flood risk should incorporate any new findings that arise from ongoing research on ARs. DWR has invested in a state-of-the-science network of sensors that can track ARs and identify conditions leading to flooding. DWR has also initiated a collaborative effort with the Scripps Institution of Oceanography and the Jet Propulsion Laboratory (National Aeronautics and Space Administration) in developing forecasting tools that provide better forecasts on ARs with longer lead times (on the sub-seasonal to seasonal scale). Continued research is required on areas including (1) inland evolution of ARs that impact freezing elevation, moisture flux, duration and direction of flow, and (2) climatic physics driving ARs and their seasonal organization. Insights gained in these areas can advance our understanding of how and where the moisture flow transitions to rainfall or snowfall, when and where the most extreme precipitation falls, and how these processes may evolve with climate change, leading to better predictions on flood timing and volume.

Chapter 7 — Habitat and Ecosystem Services Degradation

Sierra Nevada Tree Die-Off, 2016[30]

Healthy, functioning ecosystems provide multiple benefits related to water management, including sustaining aquatic fisheries, reducing flood risk, and protecting water quality (Box 7-1). This chapter explores the climate change-driven impacts to natural resources that provide the ecosystem-based services which are intricately connected to the water cycle and DWR's operations.

Climate change is already affecting and will continue to affect habitat and ecosystem services in California (PRBO Conservation Science, 2011). Wildlife and plant species distributions are shifting in response to changing environmental conditions, impacts to important life-cycle events have been observed (e.g., changes in reproduction and migration patterns), and some species populations are declining (California Environmental Protection Agency, 2013). Negative impacts to species may result in adoption of additional regulations with which DWR will be required to comply. In addition to these direct impacts, climate change is indirectly affecting ecosystems by exacerbating existing stressors, such as urbanization, habitat fragmentation, and invasive species.

Many natural areas in California have been highly modified for urban and agricultural purposes, which has resulted in a large and prosperous economy, yet has left only remnants of certain habitat types in the state — riparian corridors and wetlands in particular (California Department of Fish and Wildlife, 2015). These land use changes have created stress on many ecosystems and species and contributed to increases in the number of listed and sensitive species and at-risk habitat types. These changes directly affect

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[30] https://www.sfgate.com/news/article/bark-beetles-California-dead-trees-fire-risk-7390544.php.

DWR’s ability to operate the SWP. Climate change will likely exacerbate stresses on certain species and habitat types and therefore may require additional action by DWR to help mitigate potential impacts on species and habitats and, if appropriate, restore the affected habitats.

The benefits provided by ecosystem services are embodied within the broader concept of environmental stewardship, which is one of the three foundational actions in the California Water Plan Update 2013 (California Department of Water Resources, 2014) and is a key component within the California Water Action Plan[31], the Central Valley Flood System Conservation Strategy[32], and the Safeguarding California Plan[33]. Environmental stewardship, as defined in DWR’s Environmental Stewardship Policy[34], is a concept and commitment to manage and protect the natural resources (water, air, land, plants, and animals) and ecosystems in a sustainable manner to ensure they are available for future generations as DWR carries out its planning activities and facilitates meeting future water supply, flood risk reduction, and environmental protection needs of Californians.

Box 7-1 Ecosystems and Ecosystem Services

An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit and may contain multiple habitat types within it (Millennium Ecosystem Assessment, 2005). Ecosystem services are the benefits people obtain from these ecosystems including provisions (e.g.., food and water); regulation (including climate and disease); cultural services (e.g., spiritual and recreational); and support services, such as nutrient cycling and crop pollination, that maintain the necessary conditions for life on Earth (Nelson, et al., 2013).

There are thousands of acres of land throughout California for which DWR is charged with management. Habitat types on those parcels include wetland, riparian, grassland, marsh, oak woodland, and saltbush scrub. Habitat quality varies widely, but much of the acreage is either occupied by or potential habitat for sensitive species, migratory birds, and pollinators, and provides important ecosystem services such as carbon sequestration, flood attenuation, water purification, and aesthetic benefits. In addition to providing existing key ecosystem services, there may be opportunities for DWR-owned or managed land to be a part of a landscape-level approach to resource conservation and climate change adaptation in California, by serving as wildlife refugia and/or movement corridors.

Types of land holdings owned and/or managed by DWR include mitigation property, restoration projects, and right-of-way easements. Mitigation land is managed to offset project impacts, and typically has strict criteria that must be met for it to provide mitigation of impacts for a long term, often in perpetuity. Therefore, DWR’s management is often required to maintain the desired ecological balance (e.g., minimize invasive species or habitat degradation), and climate change effects could impact the conditions on these sites such that they no longer meet the mitigation criteria. Restoration projects represent a

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[31] CA Water Action Plan: http://resources.ca.gov/california_water_action_plan/.

[32] CVFPP Conservation Strategy: http://www.water.ca.gov/conservationstrategy/cs_new.cfm.

[33] Safeguarding California: http://www.water.ca.gov/conservationstrategy/cs_new.cfm.

[34] DWR Environmental Stewardship Policy: http://www.water.ca.gov/cvfmp/docs/WhitePaperEnvironmentalStewardship03250%20Finalv2.pdf.

substantial financial investment for DWR, and likewise need to be protected from factors that could degrade the area. DWR right-of-way lands, such as those surrounding certain lakes, flood control basins, and along the California Aqueduct and other infrastructure facilities, also contain important habitat that must be managed appropriately to control invasive species and protect against damage from encroachment of neighboring activities, such as farming.

Relevant Studies Conducted to Date or in Progress

Research on the effects of climate change on ecosystem services indicates that changes in precipitation and temperatures will affect habitat and ecosystem services in different ways and with varying severity (Shaw, et al., 2009) (PRBO Conservation Science, 2011) (Cornwell, et al., 2012) (Nelson, et al., 2013). It will be important to consider the changes in these services in decision-making as we make difficult choices in the future about allocation and use of resources (Holzman, 2012). CDFW recently assessed the impacts of various future climate projections on California vegetation. The report, *A Climate Change Vulnerability Assessment of California's Terrestrial Vegetation* (Thorne, Boynton, Holguin, Steward, & Bjorkman, 2016), included a climate change vulnerability analysis at the macro-habitat scale for 42 different terrestrial vegetation types (macrogroups). The report evaluated exposure, sensitivity, and adaptive capacity for all macrogroups under several different future climate scenarios (three GCMs and two emissions scenarios). These models are a subset of the models selected for the State's Fourth Climate Change Assessment. The study found that many of the vegetation community types in California are highly or nearly highly vulnerable under future projected climate scenarios. Additionally, extreme events, such as multi-year droughts, large wildfires, and other secondary impacts of climate change, will exacerbate the impacts of increased temperature and changing hydrology.

Habitat and Ecosystem Services Vulnerability Assessment Approach

Increasing dry periods, extreme heat, and wildfires are all examples of climate change impacts that could affect the natural lands owned and managed by DWR. These are assets, both from the financial and ecosystem services perspectives, which will need to be managed in an adaptive fashion. Ideally, management plans will be updated (or if necessary, created) to ensure that adequate monitoring and best management practices (BMPs) are applied to all lands for which DWR has responsibility. This chapter focuses on impacts at a broad level but can serve as a foundation for those more detailed, regionally-specific plans.

Exposure and sensitivity analysis for DWR's habitat and ecosystem services was conducted in a qualitative fashion (i.e., general discussion of vulnerability by ecoregion), partly because of a lack of compiled, site-specific information for DWR-owned and -managed lands. While exact acreages are not currently available, the vast majority of DWR-owned and -managed land falls within the Sacramento Valley Ecoregion, the San Joaquin Valley Ecoregion and the Southwestern Ecoregion [ecoregions derived from (PRBO Conservation Science, 2011)] (Figure 7-1). Specific properties within each ecoregion with moderate or high risk to climate change are discussed. Habitat types within each ecoregion follow the classifications described in *A Manual of California Vegetation* (Sawyer, Keeler-Wolf, & Evans, 2009). Because of the lack of a complete inventory of all properties, it is possible that there are additional vulnerable properties owned or managed by DWR that are not mentioned in this report.

Figure 7-1 The State Water Project Traverses Many of California's Ecoregions.[35]

Habitat and Ecosystem Services Impacts by Ecoregion

The Sacramento-San Joaquin Delta and Suisun Marsh fall within the boundaries of both the Sacramento Valley Ecoregion and the San Joaquin Valley Ecoregion. Given the uniqueness of the Sacramento-San

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[35] Figure from "Projected Effects of Climate Change in California: Ecoregional Summaries Emphasizing Consequences for Wildlife": http://data.prbo.org/apps/bssc/uploads/Ecoregional021011.pdf.

Joaquin Delta and Suisun Marsh regions, the potential impacts to those regions will be discussed separately from the Sacramento Valley and San Joaquin Valley Ecoregions.

Sacramento Valley Ecoregion

Warmer winter and nighttime temperatures are expected in the Sacramento Valley ecoregion, with climate models indicating changes in runoff timing and volume. Habitat types within this ecoregion are vernal pools and other seasonal wetlands, such as riparian, oak woodland, and grassland. Much of this ecoregion is actively cultivated or is managed habitat, therefore changes in land management and land use will be more important than shifts in natural vegetation. But, grasslands within this ecoregion are projected to decrease by as much as 20 percent by 2070 (PRBO Conservation Science, 2011).

The greatest effects of climate change on wildlife populations will likely result from changes in water availability; species sensitive to the timing, amount, and reliability of water supplies could be severely impacted (California Environmental Protection Agency, 2013). Several fish species, for example, are particularly sensitive to the timing of spring runoff and average flow. Chinook salmon are also sensitive to increases in water temperatures, especially in the spawning and rearing areas below the major rim dams. Cold-water pool management for salmon in Shasta, Oroville, and Folsom reservoirs may become more challenging as changes in hydrology and longer, more severe droughts impact flood and water supply management.

Sacramento-San Joaquin Delta and Suisun Marsh

Historically, the Sacramento-San Joaquin Delta (Delta) had three primary landscapes: flood basins in the North Delta; tidal islands in the Central Delta; and distributary rivers in the South Delta with a diverse mix of habitat types (San Francisco Estuary Institute, 2012). Today, land use is mostly dominated by agriculture with only remnant wetland and riparian habitats remaining (San Francisco Estuary Institute, 2014). The Delta is now a network of deep, engineered channels within a matrix of leveed agriculture, supporting declining native wildlife and increasing invasive species populations (San Francisco Estuary Institute, 2014). Habitat types within this ecoregion are brackish tidal wetlands (Suisun and western Delta), freshwater wetlands, managed and other seasonal wetlands, riparian, and grassland.

Historically, the Suisun Marsh was dominated by tidal wetlands with grasslands in the surrounding upland areas. Between the 1850s and the 1930s, approximately 44,000 acres were reclaimed for agricultural purposes (Miller, Miller, Cohen, & Schultz, 1975). The reclaimed tidal wetlands proved unsuitable for agriculture and were primarily converted to private duck clubs. Today, Suisun Marsh has approximately 51,500 acres of managed wetland, 27,000 acres of upland habitat, and 7,700 acres of tidal wetland.

Tidal wetlands are highly susceptible to sea-level rise and associated changes in salinity and other impacts from climate change. For this region, those impacts may include a decline in the biodiversity with subsequent effects on ecosystem functioning and services (Parker, et al., 2011). Based on model projections for the region, increases in water temperature will affect the physiological rates of fishes and invertebrates and result in higher mortality rates and shifts in spawning timing to earlier in the year (Wagner, Stacey, Brown, & Dettinger, 2011).

Another potentially significant impact on habitat and biodiversity could result from the failure of levees and subsequent flooding of subsided islands resulting from increased pressure from sea-level rise and/or damage or overtopping from larger storm events. If those flooded islands are not drained and reclaimed, it would result in more open, deep-water habitat than has existed in either the historical or modern Delta.

San Joaquin Valley Ecoregion

In the San Joaquin Valley, mean annual temperature is projected to increase by 2.5 °C by 2070 (PRBO Conservation Science, 2011). Climate change will mean warmer winter temperatures, earlier warming in the spring, and increased summer temperatures. Like the Sacramento Valley Ecoregion, much of the San Joaquin Valley lands have been converted to farms, cities, or other managed lands. Native habitat types within this region include vernal pools and other seasonal wetlands, riparian, oak woodland, grassland, and saltbush scrub.

For the period 1910–2003, minimum temperatures in the San Joaquin Valley have warmed at a highly significant rate in all seasons, particularly in summer and fall (~3 °C) (Christy & Norris, 2006). These authors suggested that the warming trends in the San Joaquin Valley, and smaller cooling trends (for minimum temperatures in summer) in the adjacent southern Sierra Nevada, are related to the altered surface environment from the growth of irrigated agriculture, essentially changing a high-albedo desert into a darker, moister, vegetated plain. The darker surface allows for more absorption of solar energy while the additional water mass in plant material and wet ground increases the heat capacity, providing a daytime repository of energy that is then lost at night (PRBO Conservation Science, 2011).

In the San Joaquin Valley, the predominant effects of climate change on wildlife populations will likely result from changes in water availability. In turn, water availability will be directly affected by climate change, and indirectly affected by management decisions designed to capture and store water for human consumption. Some wildlife species have come to rely on certain types of agriculture, so if water management causes severe changes in the amount of grain crops, some row crops, and pasturelands, some wildlife taxa may be impacted. Species sensitive to the timing, amount, and reliability of water supplies could be severely impacted (PRBO Conservation Science, 2011).

Southwestern Ecoregion

No DWR managed lands were identified in the Southwestern Ecoregion, and therefore this region is not discussed in this chapter.

Habitat and Ecosystem Services Vulnerability Assessment Results

Facilities

Risk and Adaptive Capacity

In this chapter, property-specific adaptive capacity discussions are included with the risk assessment rather than being addressed separately. The majority of DWR-owned and -managed habitat and ecosystem properties are found within the Sacramento-San Joaquin Delta Ecoregion; however, habitat and ecosystem services connected with Oroville and other reservoirs and right-of-way holdings along the California Aqueduct are also at risk because of changes in temperature and precipitation.

Sacramento Valley Ecoregion

The flood management system along the Sacramento River and tributaries manages flood flows from an area of approximately 27,000 square miles and includes the Feather River, American River, and the Sutter and Yolo bypasses, and contains a variety of habitats managed by DWR. These habitats include riparian, grassland, freshwater wetland, and seasonal wetlands. More detailed information regarding the location and estimated acreage of these habitat types was not readily available for this assessment. But as discussed above, these habitat types are at risk under projected changes in climate, which are expected to make management of these lands more challenging for DWR.

Sacramento-San Joaquin Delta Ecoregion

There are numerous properties owned or managed by DWR in the Sacramento-San Joaquin Delta ecoregion that provide important habitat and ecosystem services benefits. Properties within the Northern Delta, Western Delta, and the Suisun Marsh are described below.

Northern Delta

Yolo Bypass

The Yolo Bypass provides multiple benefits, including flood risk reduction, agricultural production, and habitat for numerous species. Many projects that will assist in flood management and contribute to mitigation or restoration of listed and non-listed species are being implemented [36]. Changes in hydrology and the frequency, intensity, and duration of both storm events and droughts associated with climate change could potentially impact the ability of the bypass to continue providing those benefits. It could also make managing and balancing the needs of these benefits more difficult. Historically, this region had a flood basin landscape where seasonal, long-term duration flooding occurred, and this provided habitat for several floodplain-specific fish species, including the Sacramento splittail and juvenile Chinook salmon (San Francisco Estuary Institute, 2014). Today, the Yolo Bypass floodplain is dominated by agricultural uses, but there are also seasonal wetlands, riparian, and upland habitat. Inundation of the bypass for flood risk reduction in the winter and spring continues to provide seasonal flooding, but less frequently and usually for a shorter duration than occurred historically.

As air temperatures increase and more precipitation falls as rain rather than snow, there is more potential for inundation of the bypass in the winter months. Droughts are anticipated to become more intense, and last longer. Combined, these changes may result in changed inundation patterns of the bypass. For native floodplain fish species, such as Sacramento splittail and juvenile Chinook, changes in inundation patterns could have serious implications for maintaining and enhancing their populations.

Inundation of the Yolo Bypass in the winter and spring also increases food web productivity both within the bypass and the central Delta which benefits fish species, wintering waterfowl, shorebirds, and wildlife species. The change in hydrology puts the habitat at moderate risk to impacts from climate change, however, there is some adaptive capacity to reduce this risk by allowing for more frequent and longer duration inundation in lower flow years by modifying operation of the weirs and the toe drain.

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[36] http://www.water.ca.gov/environmentalservices/yolobypass/yolo_bypass_salmonid.cfm.

Prospect Island

Under the Fish Restoration Program Agreement (FRPA), DWR is currently planning a tidal restoration project on Prospect Island to support the recovery of delta smelt, Chinook salmon, and other Delta-dependent fish and wildlife. Both the existing habitat and the proposed tidal habitat on Prospect Island have high exposure but low sensitivity to flooding, and moderate exposure to sea-level rise and drought. They also have moderate sensitivity to increases in air and water temperatures and changes in hydrology. Once restored, the tidal wetlands will have high sensitivity to the increase in the depth and duration of inundation associated with sea-level rise. These impacts may result in changes in vegetation, species composition, and even the conversion of habitat type (e.g., upland to tidal and tidal to subtidal) putting the habitat at high risk. Ultimately, these impacts may affect DWR's long-term obligation to support the recovery of delta smelt and Chinook salmon (U.S. Fish and Wildlife Service, 2008).

Western Delta

Twitchell/Sherman

The protection of Twitchell and Sherman islands is an important factor of maintaining water quality in the western Delta. Nevertheless, both islands are deeply subsided and at risk for levee failure. More extreme storm events and sea-level rise will likely put additional pressure on those levees and increase the risk for levee failure. Inundation of one or both islands would result in salinity intrusion in the Delta and create an expanse of deep, open water. The change in the salinity gradient would also impact aquatic species and wetland plant composition in the region and could create additional challenges for operation of the SWP. In addition, the conversion to deep, open water has lower habitat value to native aquatic species and may benefit some non-native aquatic species.

DWR currently has wetland carbon sequestration and subsidence reversal demonstration projects on both islands that would be lost in the event of levee failure. To help increase levee stability, the Sherman Island Reclamation District (RD 341) constructed approximately 6,000 linear feet of setback levee. The project also included adding approximately seven acres of intertidal channel-margin habitat and about two acres of riparian scrub shrub along Mayberry Slough. While the channel margin and riparian habitat may be susceptible to inundation from sea-level rise, this habitat increases the regional resiliency by protecting the levee from increasing storm surges and increasing important habitat types.

Dutch Slough and Ironhouse

DWR, in partnership with other entities, began the Dutch Slough Tidal Marsh Restoration Project in 2015. The topography of the Dutch Slough and Ironhouse sites is unusually diverse relative to other lands in the Delta, with site elevations ranging from 10 feet below to 15 feet above sea level. This topography provides an opportunity to create a large area of tidal marsh and complex intertidal channels, shaded channels, native grasslands, and riparian forests. The primary goal of the project is to provide ecosystem benefits, including habitat for sensitive aquatic species.

Like Prospect Island, the Dutch Slough Tidal Marsh Restoration Project is at moderate risk to the increases in air and water temperatures, more extreme wet and dry periods, and projected changes in hydrology, and is also at high risk from sea-level rise. These impacts may result in changes in vegetation, species composition, and even the conversion of habitat type (i.e., upland to tidal and tidal to subtidal). But this project is being designed to adapt to the anticipated impacts from climate change, including sea-level rise. As part of the project, new levees are being constructed to protect the adjacent urban area.

These levees are designed to meet 300-year level of flood protection and to account for sea-level rise using projections for 2050. The base of the levees is being built wider than needed now so they can be raised in the future, if needed.

Suisun Marsh

Blacklock

In 2003, DWR purchased Blacklock for tidal restoration under the Suisun Marsh Habitat Management, Preservation, and Restoration Plan. Restoration began in 2008 and its goals include restoring the area to a fully functioning, self-sustaining marsh ecosystem, increasing emergent wetlands to provide habitat for tidal marsh species, and assisting in the recovery of at-risk species. Elevations on the property range from approximately 1.9 feet below sea level to 9.2 feet above sea level, putting it at high risk to impacts from sea-level rise. The existing habitat is also at moderate risk associated with changes in vegetation and species composition because of increases in air and water temperatures and salinity intrusion.

Overlook Club (Property 322)

DWR acquired the Overlook Club, one of three parcels on Bradmoor Island, in 2013, with plans to restore the property to meet tidal marsh restoration requirements under the Biological Opinions and the Incidental Take Permit for the Fish Restoration Program Agreement and the Suisun Marsh Habitat Management, Preservation, and Restoration Plan. The property is currently maintained as a managed wetland, primarily for waterfowl habitat and recreational hunting, and consists of approximately 36 acres of upland grassland, 33 acres of tidal berm, and 156 acres of managed wetland. The property, like the other properties in Suisun Marsh, is at high risk of inundation from sea-level rise and changes in vegetation and species composition from increases in air and water temperatures and salinity intrusion. But Bradmoor Island is a unique feature within the Suisun Marsh because of the presence of a hill in the central portion of the island and its proximity to Little Honker Bay, which may provide a local sediment source to the property once it is restored. This local sediment source has the potential to help the Overlook Club keep pace with sea-level rise and maintain the tidal marsh habitat being restored.

San Joaquin Valley Ecoregion

The San Joaquin River Basin and California Aqueduct are both found within the San Joaquin Valley ecoregion, and both contain riparian habitat as well as upland habitat including grassland and saltbush scrub.

California Aqueduct

The DWR right-of-way along the California Aqueduct varies in width as it traverses the west side of the San Joaquin Valley, but cumulatively amounts to substantial acreage that currently provides habitat for wildlife, including sensitive species. In some areas though, the boundaries have been encroached upon because of lack of fencing, signage, and enforcement, and thus an unknown amount of habitat has been lost to adjacent farming operations.

Operations

Risk

The status of species and the ecosystems on which they rely already influence SWP operations, flood management activities, and maintenance activities. As discussed above, climate change is likely to impact those species and their habitats in significant, and in some cases, unpredictable ways. This, in turn, could further constrain DWR's management options. In some cases, the impacts may be short-term or seasonal in nature. For example, under projected changes in water temperatures and hydrology, conditions in the Delta will favor growth of invasive aquatic species, such as water hyacinth, that can clog water intakes at the North Bay Aqueduct and Banks Pumping Plant. Other impacts, especially to native species, have the potential to fundamentally alter how we manage the system because of regulations, policies, and permit conditions.

For regular maintenance activities and new projects, more protective regulations could alter work windows, require additional permits and additional mitigation, and increase costs. For SWP operations, existing regulations could impact the timing and amount of water exported south of the Delta, resulting in less reliable water deliveries. Other potential factors that may impact DWR's operations include additional challenges in balancing upstream and downstream environmental objectives, changes to the fish and wildlife objectives in the State Water Quality Control Board's Bay-Delta Water Quality Control Plan[37], and potential listing of additional species under the federal Endangered Species Act and/or California Endangered Species Act.

Adaptive Capacity

DWR has many programs, projects, policies, and procedures in place that can help increase the resiliency of our managed lands in the face of a changing climate. The CVFPP seeks to provide a comprehensive, long-term approach to improving riverine habitat and floodplains as part of an integrated flood management plan. The North Delta Flood Control and Ecosystem Restoration Project[38] is another example of a project that is designed to support flood control improvements while also providing benefits to aquatic and terrestrial habitats, species, and ecological processes.

Ongoing and proposed habitat restoration projects in the Delta to meet DWR's obligations under the Fish Restoration Program Agreement[39], the Delta Levees Programs, the Operations Criteria and Plan (OCAP)[40], the Suisun Marsh Habitat Management, Preservation, and Restoration Plan[41], and other habitat restoration projects in the Delta — such as Dutch Slough and Prospect Island — also improve the resiliency of DWR's managed lands while contributing to the adaptive capacity of the Delta region as a whole.

Vulnerability

Climate change is expected to exacerbate stresses on certain species and habitat types, and these may require additional action by DWR to help mitigate potential impacts to those species and habitats and, if appropriate, restore those habitats. In other cases, degradation of species and habitat types may result in additional regulations with which DWR must comply. Consequently, DWR-managed lands and operations are vulnerable to additional degradation of habitat and ecosystem services resulting from climate change.

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[37] http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/.
[38] http://www.water.ca.gov/floodsafe/fessro/levees/north_delta/docs/.
[39] http://www.water.ca.gov/environmentalservices/frpa.cfm.
[40] http://www.water.ca.gov/OCAPstudies/.
[41] https://www.wildlife.ca.gov/Regions/3/Suisun-Marsh.

Other Considerations

Upper Feather River Watershed

As with the discussion of wildfire impacts on the UFRW in Chapter 2, climate change impacts on the ecosystem services in the watershed may directly or indirectly affect water supplies in Lake Oroville and the potential of habitat restoration to offset water supply impacts.

The Delta

Needless to say, impacts to Delta ecosystem services associated with large scale levee failures, seismic events, and long-term habitat restoration goals (e.g., California WaterFix and EcoRestore), would be substantial.

Recreation

Ecosystem services that are used by Californians for recreation — particularly water-dependent activities such as fishing, swimming, and boating — will be directly impacted by climate change as stream and reservoirs warm and sea-level rises (California Department of Water Resources, 2014). Changing rainfall patterns and increased temperatures will also impact recreational opportunities (California Department of Water Resources, 2014), which is one of the important roles of the State Water Project. As more people seek out water-related activities in hot summer months, there will be an increase in crowded conditions and more stress on water quality. Analysis of the specific impacts of climate change on recreation activities on DWR-owned or -managed lands is outside of the scope of this VA.

Next Steps

California Aqueduct Right-of-Way Habitat Restoration

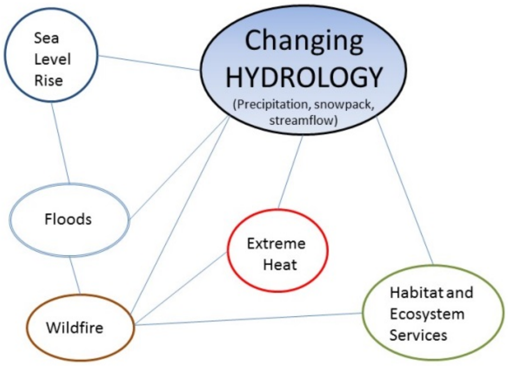
It is unclear exactly how many acres of habitat exist along the California Aqueduct right-of-way; however, these lands are currently providing important ecosystem services (or could be with restoration). A next step would be identification of lands that could provide additional ecosystem services consistent with other SWP purposes. Part of this step could include education for DWR staff, decision-makers, and the public about the benefits of native habitat along the right-of-way and identification of sources of funding to carry out potential work.

Data Gaps

Managed Lands Inventory

Evaluation of the specific impacts to DWR-owned and -managed lands for this analysis was very challenging because of the lack of readily available digitized maps. Currently, information must be obtained on a parcel-by-parcel basis, so significant work would need to be done to create a compiled map of all parcels. A complete inventory of all land holdings, with accompanying information about habitat types and sensitive species on the site, is needed to understand the exposure, sensitivity, and overall vulnerability of DWR properties to climate change, including mitigation habitat intended for management in perpetuity for specific species or habitat types. Digitizing all parcels with relevant data would provide valuable information that could help establish priorities for habitat and ecosystem projects.

Chapter 8 — Compounded Effects of Climate Vulnerabilities



Synergistic Effects of Climate Change Impacts

Climate warming alone would be enough to exacerbate existing hydrological, ecological, and other challenges faced by DWR and other resource managers in California. But numerous other variables, many of them also climate-driven, will also influence these challenges. While many of the climate change vulnerabilities discussed in this document pose threats to DWR's facilities and operations in and of themselves, the combined effects of the risks may be even greater than has been identified by examining each vulnerability in isolation. It is important to understand how multiple effects of climate change can interact because there could be implications for identifying and prioritizing adaptation measures.

Changing Hydrology and Sea-Level Rise Impacts in the Delta

The compounding of sea-level rise, Delta subsidence, increased peak river flows, and other extreme events as discussed above would likely exert even greater pressure on levees and thereby heighten the risk of levee failure. As a result, much of the Delta levee system will be below design thresholds within 50–100 years from continued subsidence combined with sea-level rise (Brooks, et al., 2012).

Climate change and associated impacts on hydrological conditions might result in secondary changes to regulatory programs, water rights, or aquatic species conditions. Changes in land use within the Delta and Suisun Marsh driven by sea-level rise might also lead to regulatory changes and impacts to native species resulting in modifications to system operations. There could also be additional municipal demands being placed on DWR's system, and a need for new infrastructure as current water intakes become impacted by deteriorating water quality from salinity intrusion.

The impacts will likely result in the adoption of additional regulations relating to water quality, streamflow, upstream river temperatures, Delta salinity, and Delta outflows to protect aquatic species. Additional regulations may further constrain operations of the SWP resulting in reductions to delivery reliability and reservoir storage levels.

Changing Hydrology and Increased Extreme Heat Days

The number of extremely hot days will continue to increase in the southwestern United States (National Climate Assessment, 2014). Increased heat waves will dominate summer months and will affect hydropower generation and electricity demand (Jaglom, et al., 2014), as well as humans' and other species' ability to tolerate regional conditions. Humans rely on air conditioning during heat waves, which increases water demand and electricity consumption, and California will have the potential for energy deficits as high as 17 percent during peak demand periods (Miller, Hayhoe, Jin, & Auffhammer, 2008). Wildlife will be stressed by both changing streamflow conditions and streamflow temperatures. California's native inland fish species are already in decline, and climate change will further reduce the distribution and abundance of these species, whereas non-native species are expected to expand their range (Moyle, Quinones, & Kiernan, 2012) .

Hydropower Impacts

Increased evaporation rates from higher temperatures and changes in snowpack amount and runoff timing may affect the volume of water available for hydropower (U.S. Bureau of Reclamation, 2016), which is in addition to the projected more frequent and longer lasting droughts. This may lead to increased use of more carbon-intensive energy sources, which can also be costlier than hydropower. A recently published report exploring the impacts of the recent drought on hydroelectricity generation found that the shift from hydropower to natural gas and other sources of electricity led to a 10 percent increase in carbon emissions in the state between 2012 and 2015, at the cost of $2 billion for ratepayers (Gleick, 2016).

Changing Hydrology and Increased Wildfire

Extended Drought, Wildfire, and Stream Sediment Loads

As wildfire extent and intensity increases in a hotter future with climate change, soils in the Sierra Nevada and chaparral-dominated watersheds will be more vulnerable to interacting effects of post-wildfire soil erosion and sediment transport. Suspended sediment export from burned watersheds can be as much as 10 times greater than unburned watersheds (Coombs & Melack, 2012). This results in more turbidity in streams and reservoirs (Donohue & Molinos, 2008), which can negatively affect aquatic life, and requires a greater need for water treatment downstream for human uses because of the higher amount of organic material in runoff.

Chapter 9 — Key Climate Change Vulnerabilities Outside the Scope of this Assessment

Roaring River Levees at Grizzly Island, January 2017[42]

This assessment does not cover all aspects of ways in which climate change affects California water resources. While climate-change-driven hazards are assessed against DWR's facilities, lands, operations, and staff activities, there are threats outside the scope of this analysis for which DWR does not have sole authority, ability to address, or could not be assessed because of data gaps. Some of these vulnerabilities are described below. DWR is an active partner in cooperative efforts to assess and respond to these vulnerabilities.

Sacramento-San Joaquin Delta Levees

Relevant Studies Conducted to Date or In Progress

The Delta already has high exposure to sea-level rise, as most of it is already at or below current sea level. Much of this land is protected by levees, and sea-level rise is expected to increase the risk of levee failure and therefore the risk of island inundation (California Department of Water Resources, 2009). Sacramento-San Joaquin Delta levees are intricately connected to California's water supply and DWR's operations, yet 65 percent of Delta levees were constructed and are maintained by island landowners or local reclamation districts[43]. The foundations of these levees are often composed of peat soil formed by decomposed marsh vegetation. Oxidation of those soils, combined with compaction and natural settling,

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[42] Source: DWR Pixel FL_Flood_Aerials-9039.jpg

[43] http://www.watereducation.org/aquapedia/sacramento-san-joaquin-delta-levees

creates subsidence — a critical problem that puts additional stress on levees that were not designed to withstand sea-level rise and the changing hydrology that climate change will bring (Bates & Lund, 2013).

While a Delta levee failure could have significant impacts on SWP operations and other Delta conditions for which DWR has an interest, this VA does not address climate change vulnerabilities related to Delta levee failures because of the complex ownership and management of individual Delta levees. Several previous studies have looked at existing risks of Delta levee failures. Two of the most notable studies conducted to date are listed below.

- **Delta Risk Management Strategy (DRMS) — Phase 2** (California Department of Water Resources, 2011)
  The purpose of the DRMS was to assess the performance of Delta and Suisun Marsh levees under various stressors to evaluate the consequences of levee failures to the Delta, and California as a whole (Phase 1), and to develop and evaluate risk reduction strategies (Phase 2). The risk reductions are quantified under alternative management strategies, defined as either "building blocks" or "trial scenarios." *Building blocks* include improved levees, a through-Delta conveyance, and raised highways. *Trial scenarios* are ensembles of building blocks that achieve multiple risk reduction objectives or benefits for State assets and resources in the Delta and Suisun Marsh.

- **CASCaDE — Computational Assessments of Scenarios of Change for the Delta Ecosystem** (U.S. Geological Survey, 2015)
  CASCaDE II builds upon a set of linked models used to assess Delta ecosystem response to climate change (CASCaDE I) to develop a holistic view of the Bay-Delta-River-Watershed system. The tools developed under CASCaDE II will be used to anticipate and diagnose Delta ecosystem responses changes.

Seismic Events

Seismic events can affect DWR facilities, lands, operations, and staff activities in many ways. For example, seismic events can cause sudden land movements which can dramatically and immediately affect local relative sea levels (National Research Council, 2012). Climate change has the potential to exacerbate the consequences of impacts resulting from a seismic event (e.g., by increasing sea levels that put additional pressure on Delta levees), but there is no evidence to suggest that seismic events will become more or less common as the climate changes. For this reason, this document does not discuss vulnerabilities of DWR facilities and activities to seismic events.

Subsidence

Subsidence — the sinking of land in relation to the land around it — within Delta islands results in increased pressure on levees and will compound the effects of sea-level rise. The influence of sea-level rise on DWR facilities, lands, operations, and staff activities are also affected by short-term extreme events which can temporarily increase sea levels. Furthermore, a combination of sea-level rise, ongoing Delta subsidence, and large flood events — potentially coupled with a seismic event — could result in devastating consequences for the Delta with rippling effects throughout California because of the connectedness of California's water supply. But these compounding, extreme events are outside the scope of this study.

Feather River Watershed Management

Chapter 2 described the increasing vulnerability of the Feather River Watershed, with large percentages of the watershed at risk. The vulnerability of the watershed to changes in hydrology and increased wildfire risk pose potential threats to DWR facilities, activities, and operations, necessitating that DWR monitor and reduce those risks over time.

Updates to this VA could attempt to quantify how changes in habitat extent and composition in the UFRW might constrain or enhance flood and water supply operations. Healthy, widespread riparian habitat could reduce the volume of cold water releases needed, whereas loss of riparian habitat could require dedication of more water to meet temperature requirements. The UFRW may also provide adaptation opportunities for impacts of climate change on SWP operations.

Sediment Influx into Oroville

One concern related to the increase in wildfire occurrence is the potential for the incidence of high intensity wildfires leaving large swaths of a watershed denuded of vegetation, thus causing soils to be destabilized. Subsequent storms would likely mobilize large volumes of destabilized soils and deliver large sediment pulses to water bodies. Goode et al. (2012) suggests that climate change in western semi-arid basins could increase sediment yields by up to 10 times greater than those observed in the 20th century. Although some sediment transport of various particle sizes is important for properly functioning geomorphic processes, a dramatic increase in certain size classes beyond historic levels could affect aquatic ecosystem function, impair water quality, increase maintenance costs, and reduce reservoir capacity and life expectancy.

Electrical Grid Interruptions

Disruptions to the electrical grid caused by wildfires, extreme heat, or supply shortages would likely have significant implications for the DWR's ability to operate the SWP. The risk to California's energy infrastructure was assessed in 2012 as part of California's Third Climate Change Assessment (Sathaye, Dale, Larsen, & Fitts, 2012). In part, the study found that key transmission corridors are vulnerable to increased fire frequency. Additional energy generation infrastructure, such as coastal power plants and substations, was found to be vulnerable to sea-level encroachment.

These impacts undoubtedly carry risks for operation of DWR facilities, particularly for the SWP, one of the largest generators and users of electricity in the State. But coordination, regulation, and management of electricity generation and transmission are outside DWR's sole purview and authority and therefore have not been addressed in this document. DWR will continue to work with partners at the California Energy Commission, California Independent System Operator, Western Area Power Administration, U.S. Department of Energy, and the Western Electricity Coordinating Council to encourage and support additional assessment and planning for these impacts.

Chapter 10 — Conclusions

Hazards resulting from changes in climate, projected by mid-century and evaluated in this assessment, pose risks to DWR operations, facilities, managed lands, and staff activities. Vulnerabilities identified for each hazard are summarized below.

Wildfire

DWR facilities themselves are generally at low risk from increased wildfires resulting from climate change, largely because of existing maintenance activities that manage vegetation on the perimeters of infrastructure such as canals, pumping plants, and other SWP structures. Wildfire vulnerability will continue to be low even as exposure increases through mid-century; however, the UFRW, which represents the headwaters of the SWP, could see a dramatic increase in wildfire vulnerability — moving from “low” in most of the watershed to “moderate” or “high” exposure. This increase has implications for SWP operations because wildfire can affect runoff patterns and rates, water quality, and sediment yields.

Extreme Heat

While all DWR staff working outdoors will be exposed to warming temperatures, projections for mid-century indicate that the increases will likely be similar to the range they are exposed to now. Moreover, existing measures to protect staff, such as the HIPP, could be modified to lower overall vulnerability.

Sea-Level Rise

DWR owns and operates a single facility on the coast, the Eureka Flood Center, which will continue to have low exposure through mid-century. Facilities within the San Francisco Bay and the Delta will be exposed to increasing sea levels, but have low sensitivity because of existing contact with sea or brackish water, and therefore have low vulnerability. Increasing inundation of mud-flats and low-lying areas in the Suisun Marsh make sensitivity of this area high, compounded by limited adaptive capacity.

Long-term Persistent Hydrologic Impacts

It is very likely that SWP storage and deliveries will diminish significantly in the future as the climate warms. Reductions in September Oroville storage mean that the SWP will be less capable of coping with successive winters with low precipitation. Lower storage levels in the future may also likely reduce the amount of hydroelectric generation from the Hyatt-Thermalito Complex and will reduce recreational opportunities on Lake Oroville.

Because SWP deliveries are made only after regulatory standards are met, SWP deliveries show considerable vulnerability to changing climate. Without significant adaptation, SWP delivery reliability is likely to diminish as the climate warms. Nevertheless, this analysis suggests that climate change will not impede DWR’s ability to meet today’s regulatory standards at mid-century.

Short-term Extreme Events (Floods)

Analysis of published studies at a statewide level found an increase in flood occurrences and magnitude under a warming climate. Peak flows are projected to occur significantly earlier in the year, likely from the reduction in precipitation falling as snow and a greater portion of the watershed contributing to direct runoff. Maximum, annual 1-day and 3-day flows are projected to increase, and storm durations are projected to decrease. Thus, it is assumed that DWR faces high-exposure to increased short-term hydrologic events to which its flood management and operations are vulnerable.

Habitat and Ecosystem Services Degradation

Virtually all habitats within California are at risk from climate change and are likely to be affected by increasing temperatures, changing precipitation patterns, and the loss of snowpack, which will likely result in less water available for environmental, urban, and agricultural purposes. Degradation of species and habitat types may result in additional regulations within which DWR will be required to operate.

Future Needs

This assessment identified several areas for future work that could benefit future updates of this vulnerability assessment. First, a better understanding of how climate change could intensify atmospheric rivers is needed, which would inform flood management. Second, a comprehensive inventory of DWR-managed lands and assessment of their vulnerability to climate impacts would be especially important for considering the risks to mitigation habitat areas, which were intended for management in perpetuity. Third, interacting and cumulative effects of climate change can increase the risks of climate change substantially and warrants additional analysis (Adger, Brown, & Surminski, 2018). Fourth, additional assessment could examine DWR infrastructure, operations, and activities with respect to lands managed by other (non-DWR) entities to identify specific vulnerabilities not yet captured. This could be conducted through coordination and partnerships across jurisdictions and land owners to examine vulnerability and adapt across sectors.

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Appendix A: DWR Facilities and Managed Lands

	Name/ Facility	**Location/ Address**
Southern FD	Cedar Springs Dam (Office)	Silverwood Lake
Southern FD	Cedar Springs Dam (Lab)	Silverwood Lake
Southern FD	Perris Dam Reservoir (Visitor Center)	Lake Perris
Southern FD	Perris Dam Reservoir	Lake Perris
Southern FD	Pearblossom O&M	Pearblossom
Southern FD	Pearblossom Pumping Plant	Pearblossom
Southern FD	Mojave Siphon Pumping Plant	MP 403.44
Southern FD	Devil Canyon Pumping Plant	MP 412.73
Southern FD	Southern O&M center	Castaic
Southern FD	Alamo Pumping Plant	MP 305.73
Southern FD	Oso Pumping Plant	MP 1.49 WB
Southern FD	William Warne Pumping Plant	MP 14.07 WB
Southern FD	Vista Del Lago	Pyramid Lake
Southern FD	Vista Del Lago (Visitor Center)	Pyramid Lake
Southern FD	Green Spot Pumping Plant	Highland
Southern FD	Crafton Hills Pumping Plant	Yucaipa
Southern FD	Cherry Valley Pumping Plant	Cherry Valley
Southern FD	Devil Canyon Water Quality	
Southern FD	Castaic Dam/ Recreation	Castaic Lake
Southern FD	Castaic O&M	Castaic Lake
Southern FD	Check Structure #43	MP 309.7

	Name/ Facility	**Location/ Address**
San Joaquin FD	Lost Hills O&M Subcenter	Lost Hills
San Joaquin FD	Buena Vista Pumping Plant	MP 250.99
San Joaquin FD	Teerink Pumping Plant	MP 278.13
San Joaquin FD	San Joaquin O&M	~MP 280.1
San Joaquin FD	Edmonston Pumping Plant	MP 293.45
San Joaquin FD	Chrisman Pumping Plant	Mettler
San Joaquin FD	Las Perillas Pumping Plant	MP 1.16
San Joaquin FD	Badger Hill Pumping Plant	MP 4.27
San Joaquin FD	Devil's Den Pumping Plant	MP 14.86 Coastal
San Joaquin FD	Bluestone Pumping Plant	MP 19.04 Coastal
San Joaquin FD	Polonio Pass Pumping Plant	MP 26.53 Coastal

Appendix A: DWR Facilities and Managed Lands (continued)

	Name/ Facility	**Location/ Address**
San Luis FD	Gianelli Pumping and Generating Plant	San Luis Reservoir/O'Neill Forebay
San Luis FD	San Luis O&M and Visitor Center	San Luis Reservoir/O'Neill Forebay
San Luis FD	Romero Visitor Center	State Hwy 152/Gustine
San Luis FD	Dos Amigos Pumping Plant	MP 86.73
San Luis FD	Coalinga O&M	Coalinga
Delta FD	Delta FD O&M Center	Byron
Delta FD	Skinner Fish Facility	Byron
Delta FD	South Bay Pump Plant	Byron
Delta FD	Patterson Maint. Yard	Livermore
Delta FD	Del Valle Pump Plant	Livermore
Delta FD	Barker Slough Pumping Plant	Dixon
Delta FD	Montezuma Slough Salinity Control Structure	Suisun Bay
Delta FD	Cordelia Pump Plant	Cordelia
Delta FD	Harvey Banks Pumping Plant	Tracy
Delta FD	North Bay Maint. Yard	Fairfield
Oroville FD	Oroville O&M	460 Glen Drive Oroville, CA 95966
Oroville FD	Thermalito Pumping and Generating	Grand Ave, Thermalito, CA
Oroville FD	Hyatt Pumping and Generating/ Control Center	Oroville
Oroville FD	Thermalito Diversion Dam Pumping Plant	Oroville
Oroville FD	Feather River Fish Hatchery	Oroville
Oroville FD	Beckwourth Sub Center	Beckwourth
Oroville FD	Kelly Ridge	Oroville
Oroville FD	Thermalito Boat launch (Monument Hill)	Oroville
Oroville FD	Restroom at Dam (Left Abutment)	Oroville
Oroville FD	Antelope kiosk and restrooms	Antelope Dam, Plumas County
Oroville FD	Fish rearing raceways	HWY 99

Appendix A: DWR Facilities and Managed Lands (continued)

	Name/ Facility	**Location/ Address**
Leased Facilities	6325 Bridgehead Rd. Antioch	Antioch
Leased Facilities	121 W. Carriage Lane. Suite 101, Lancaster	Lancaster
Leased Facilities	Southern Region. 770 Fairmont Suite #102	Glendale
Leased Facilities	4300 West Capitol Ave, Sacramento	West Sacramento
Leased Facilities	Resources Building	Sacramento
Leased Facilities	Bonderson Building	Sacramento
Leased Facilities	1721 13th/ 1730 14th street (Training Center)	Sacramento
Leased Facilities	909 S street, Sacramento	Sacramento
Leased Facilities	220 X street, Suite 200, Sacramento	Sacramento
Leased Facilities	3310 El Camino, Sacramento	Sacramento
Leased Facilities	809 North Market Blvd, Sacramento	Sacramento
Leased Facilities	3500 Industrial Blvd.	West Sacramento
Leased Facilities	3374 E. Shields Ave	Fresno
Leased Facilities	2440 Main Street	Red Bluff
DFM	Eureka Flood Center	Eureka
DFM	Sutter Yard	Sutter
DFM/ DOE/ DES	West Sac Flood Yard/Bryte Lab	West Sacramento

Managed Lands	
Sacramento-SJ Delta	Yolo Bypass
Sacramento-SJ Delta	Prospect Island
Sacramento-SJ Delta	Twitchell & Sherman Islands
Sacramento-SJ Delta	Dutch Slough
Sacramento-SJ Delta	Meins Landing
Sacramento-SJ Delta	Blacklock
Sacramento-SJ Delta	Overlook/Property 322
Suisun Marsh Facilities	Suisun Marsh Salinity Control Gates
Suisun Marsh Facilities	Roaring River Distribution System
Suisun Marsh Facilities	Morrow Island Distribution System
Suisun Marsh Facilities	Goodyear Slough Outfall

Appendix B. DWR Integrated Wildfire Analysis

Integrated Fire Analysis for DWR Facility/Structure Risk Assessment

Net risk for wildfire will be determined based on the integration of risk levels for three factors:

1. Roof type.
2. Hazard class.
3. Property defense/Ignition zone.

Roof type – the following values will be assigned based on roof type; higher numbers indicate higher fire risk

- Metal/Steel/Concrete = 1.
- Asphalt = 3.
- Wood = 5.

Hazard class (per NFPA)

- Class A (involves ordinary combustible materials like paper, wood, fabrics and rubber; this type of fire is effectively quenched by water or insulating by other suitable chemical agent) = 1.
- Class B (mostly involves flammable liquids [gasoline, oils, greases, tars, paints, etc.] and flammable gases. Dry chemicals and carbon dioxide are typically used to extinguish these fires) = 3.
- Class C (involves live electrical equipment like motors, generators, and other appliances. For safety reasons, nonconducting extinguishing agents such as dry chemicals or carbon dioxide are usually used to put out these fires) =5.
- Class D (involves combustible materials such as magnesium, sodium, lithium potassium, etc. Sodium carbonate, graphite, bicarbonate, sodium chloride, and salt-based chemicals extinguish these fires) = 7.
- Class K (fires in cooking appliances that involve combustible cooking media [vegetable, animal oils or fats]) = 1.

Property defense/Ignition zone

A. Surrounding landscape? (out to 1 mile?).
    - Urban = 1.
    - Agricultural = 1.
    - Wetland = 1.
    - Grassland = 3.
    - Forest = 5.
    - Shrub/Chaparral = 5.

B. Vegetation within 200 feet of the structure?
  - Bare = 0.
  - Urban/Landscaping = 1.
  - Agricultural = 1.
  - Grassland = 3.
  - Shrubland = 5.
  - Forest = 5.

C. Proximity of Emergency Services
  - Within 5 miles = 0.
  - 20 miles or more = 3.
  - 50 miles or more = 5.

A combined score of 6 or less = Low risk

A combined score of 7-10 = Moderate risk

A combined score of 10 or more = High risk

Facilities with moderate or high risk will be examined in more detail for potential adaptive capacity (e.g., change vegetation management, proximity to high-value facilities which would likely be part of an emergency plan).

DWR Wildfire Sensitivity Analysis Checklist (page 1)

Facility/Structure Information

Facility/Structure name: ____

Footprint (sq. ft.; acres; etc.): _______________________________

Location: ____

Site evaluation conducted by:_______________________

Date of site evaluation:___________________

Evaluation Questions

What is the land-use status of property surrounding this structure? (check all that apply)

________ urban ___________ agricultural ___________ forest ___________ grassland

________ wetland ________ shrubland/chaparral ______________ (other) please specify

Who provides the nearest emergency fire services and how far are they from the facility?____

Are there high-value structures nearby that would be protected from wildfire impacts by another entity? (e.g., BOR, USACE, Southern California Edison)? ____________ If yes, provide details about the other structure(s), including who manages it: ____

____

____

Rough sketch of facility/structure with surrounding land use identified.

DWR Wildfire Sensitivity Analysis Checklist (page 2)

What would happen if the facility/structure burns?

a) How would this affect facility/structure function?

____

____

____

____

b) What would approximate loss value be? (describe how loss value determined)

____

____

c) Has the area surrounding the structure (within 10 miles) burned in the last 20 years?

____

d) If yes to ‘c’, please describe the circumstances and outcome

____

____

DWR Wildfire Sensitivity Analysis Checklist (page 3)

e) Is there an existing action plan or agreement/MOU (formal or informal) that would be implemented if this facility was at risk from an approaching wildfire?
If so, please describe:
____
____
____

Other Notes/Comments:

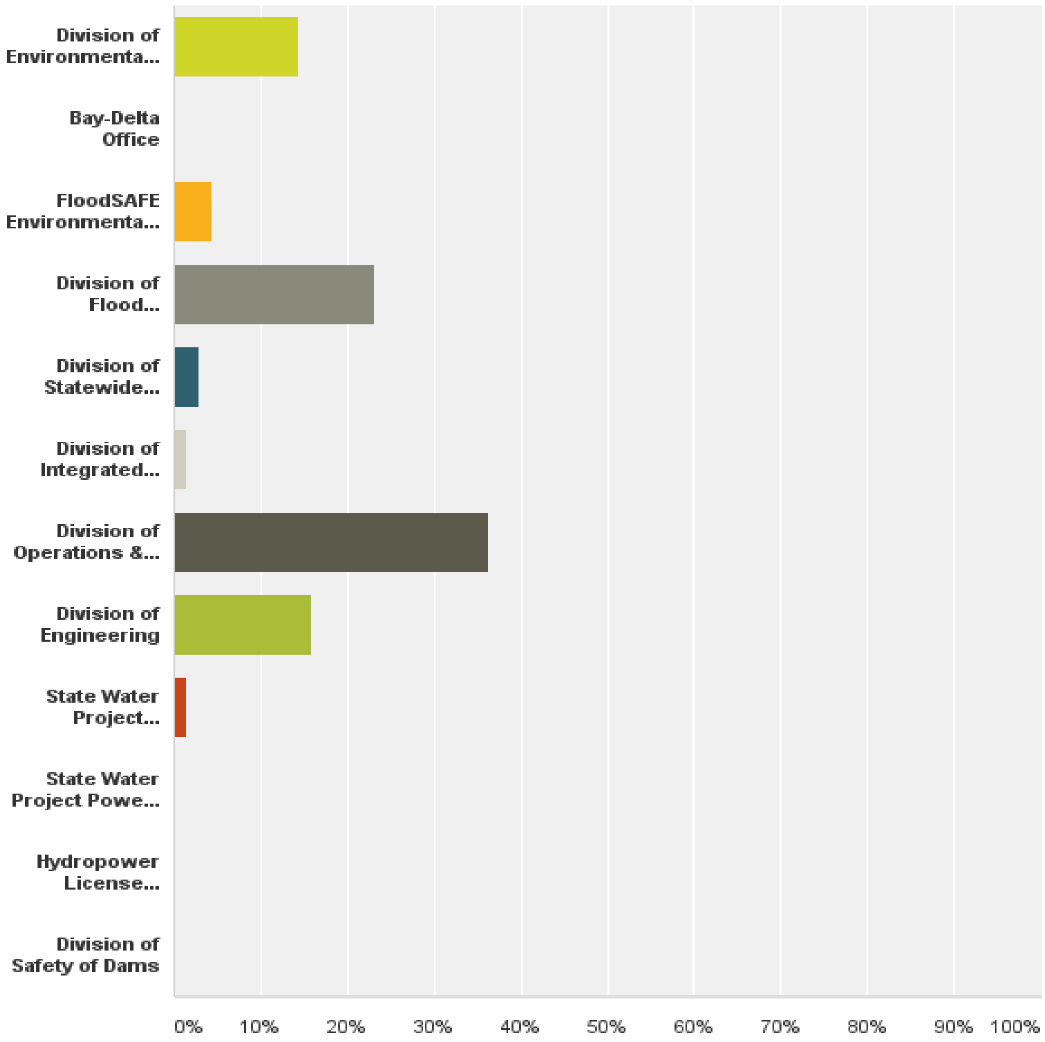
____
____
____
____
____
____
____

Based on this evaluation, the climate change SENSITIVITY level for this facility/structure is:

______HIGH   ______ MEDIUM   _______ LOW

Appendix C. Extreme Heat Surveys and DWR Heat Illness Prevention Plan

The following survey questions were sent to DWR staff:

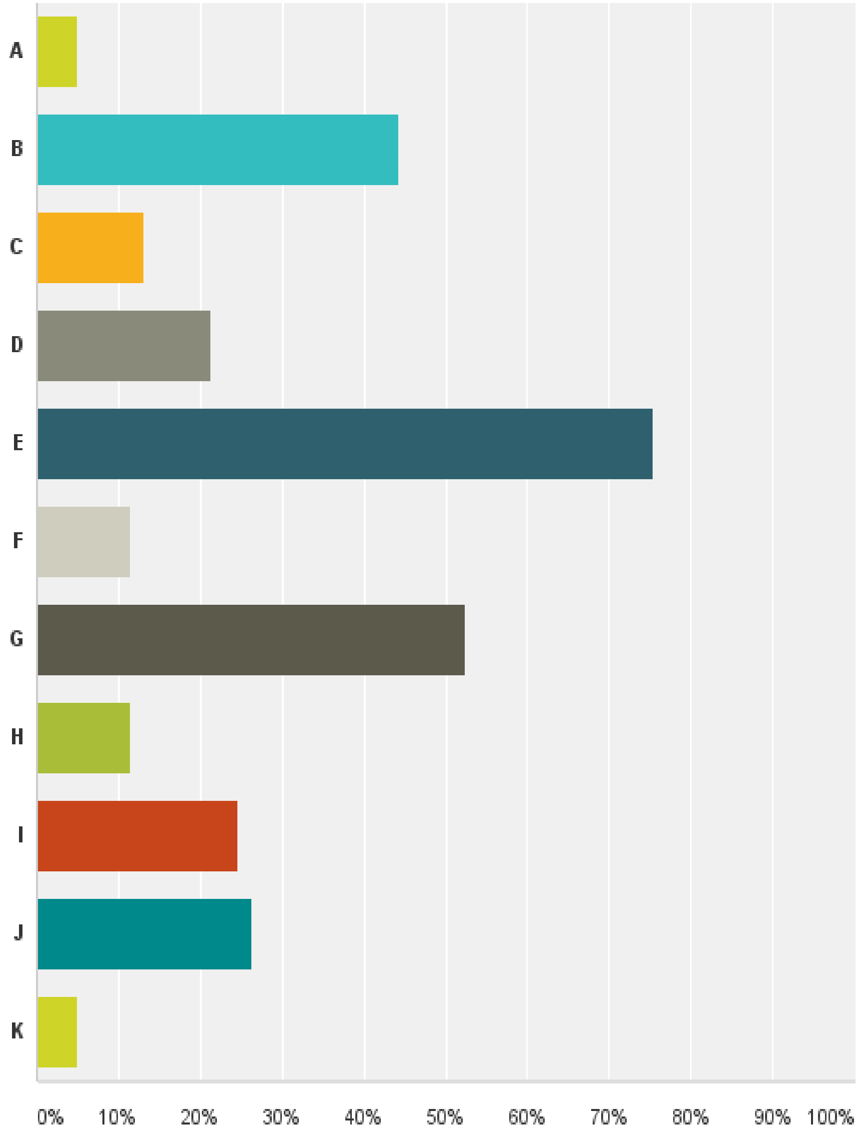


Q3 What Division/Office do you work for?

Answered: 69 Skipped: 0

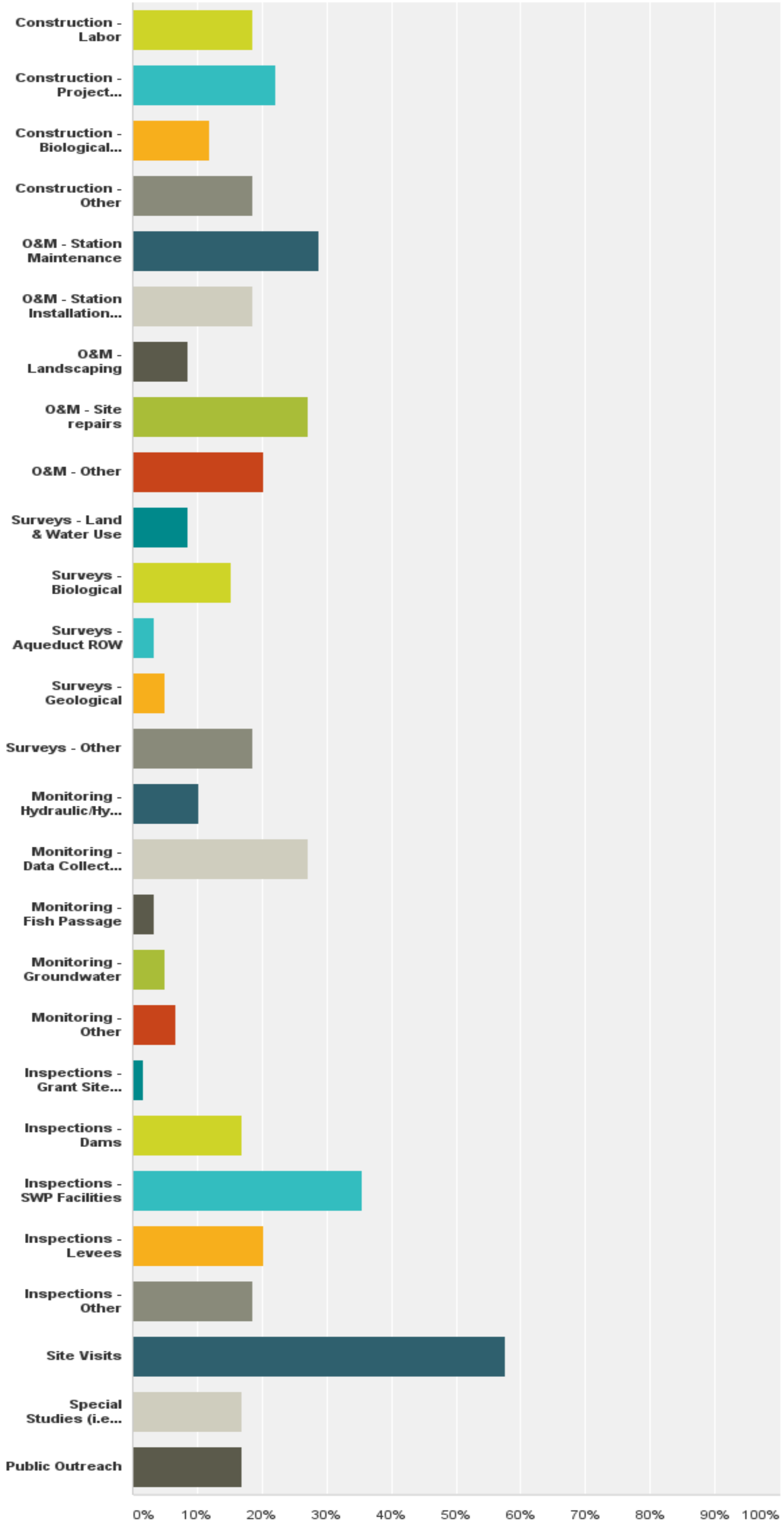
Q5 Using the map above, select the region(s) where you or your staff conducts work outdoors between May and October

Answered: 61 Skipped: 8



Q6 What type of outdoor activity (activities) do you or your staff conduct between May and October (select all that apply)

Answered: 59 Skipped: 10



DWR Heat Illness Prevention Plan – Summary of Requirements

- For temperatures that equal or exceed 80 °F, the worksite supervisor or designated lead person shall:
  - Prior to each workday, review forecasted temperature and humidity and compare it against the National Weather Service Heat Index to evaluate risk level.
  - Ensure employees have an adequate supply of readily accessible drinking water.
  - Encourage frequent consumption of small quantities of water.
  - Ensure employees have adequate access to shade.
  - Allow and encourage preventative cool-down rest periods, as needed or requested, throughout the work shift.
  - Ensure that any employee who takes a preventative cool-down rest is monitored and asked if he or she is experiencing symptoms of heat illness. If they are, they shall be monitored and encouraged to remain on rest until any symptoms have abated.
- For temperatures that equal or exceed 95 °F, the worksite supervisor or designated lead person shall implement the above procedures plus:
  - Initiate tailgate meeting to review weather forecast and DWR’s heat illness prevention and emergency response procedures and provide reminders to drink water frequently and inform employees of their right to take cool-down rests when necessary.
  - Ensure that effective communication by voice, observation, or electronic means is maintained.
  - Observe all employees closely for signs and symptoms of heat illness by one or more of the following procedures:
    - Supervisor or project lead observation of 20 or fewer employees.
    - Employees will be assigned a “buddy” to watch for signs and symptoms of heat illness and initiate emergency procedures, if necessary.
    - Solo work should be minimized, reviewed, and preapproved. If a “buddy” cannot be assigned, the worksite supervisor or designated lead person shall implement communication procedures at frequent intervals throughout the shift.
  - Shall designate one or more employees on each worksite as authorized to call emergency medical services.
  - Shall remind employees throughout the work shift to drink plenty of water.

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