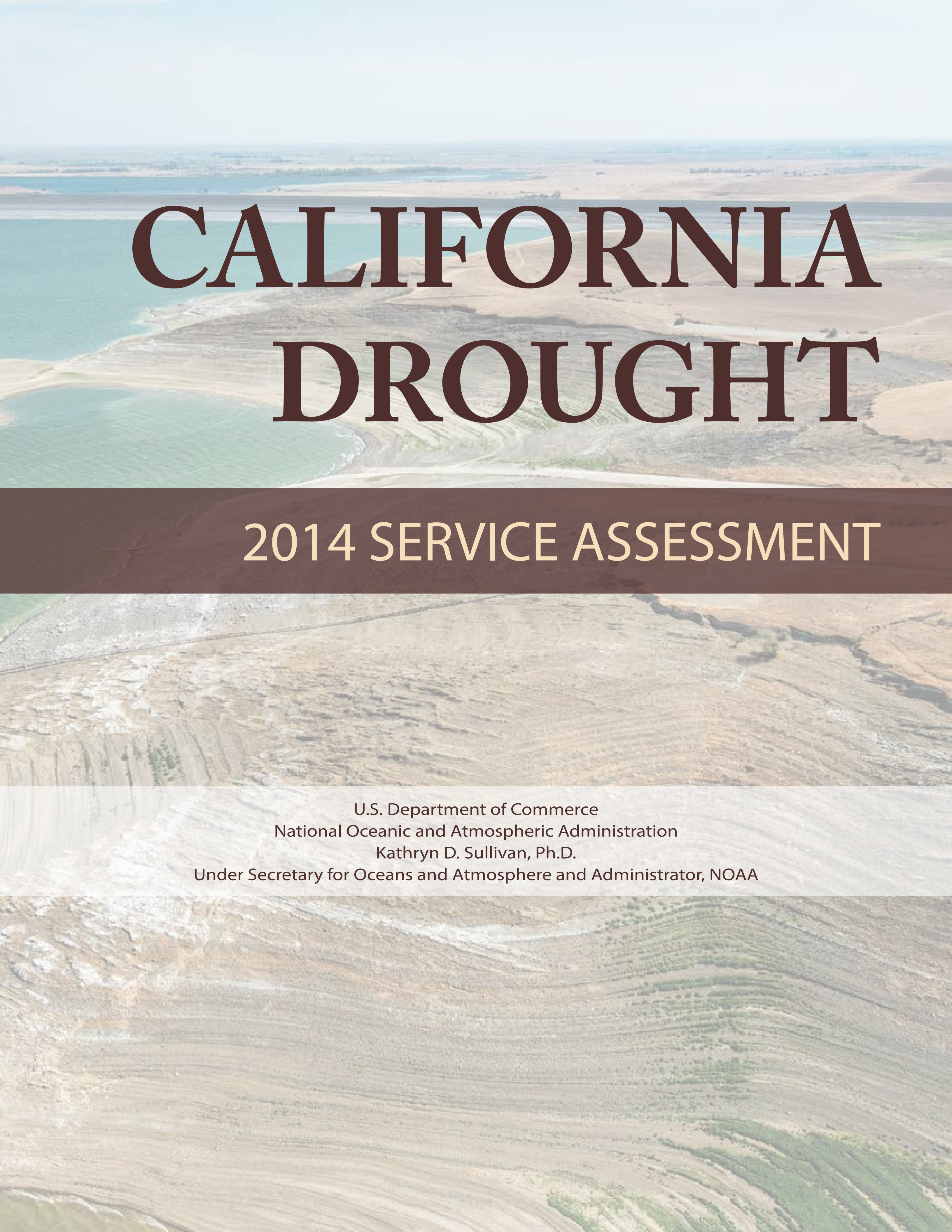
CALIFORNIA DROUGHT

2014 SERVICE ASSESSMENT

Cover and inside cover photo: Water levels remain low at San Luis Reservoir in Gustine, California, during the severe drought, August 19, 2014. Courtesy of California Department of Water Resources; Florence Low



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2014 SERVICE ASSESSMENT

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
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Under Secretary for Oceans and Atmosphere and Administrator, NOAA

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Editor's Note concerning usage of the "NCDC" acronym in this report:
In April 2015, NOAA's existing three National Data Centers—the National Climatic Data Center, the National Geophysical Data Center, and the National Oceanographic Data Center, which includes the National Coastal Data Development Center—merged into the National Centers for Environmental Information (NCEI). The demand for high-value environmental data and information has dramatically increased in recent years; therefore, the centers were merged to improve NOAA's ability to meet that demand. This report was written between 2014–2015, prior to the merger. For more information, visit: http://www.ncdc.noaa.gov/news/national-centers-environmental-information

Contents

Foreword

Vice Admiral Michael Devany

Greetings:

I am pleased to present the report "California Drought: 2014 Service Assessment," the first National Oceanic and Atmospheric Administration (NOAA) service assessment specific to drought. Since its onset in late 2011, the California drought and its associated wildfires and mudslides have taken a heavy toll on human life and the natural environment, with effects felt by economies in the state and across the Nation. The principal purpose of this report is for NOAA to identify resource management decisions that were affected by the current drought in California and to assess the use and effectiveness of our forecasts, indices, monitoring data, and services that are available to decision makers and stakeholders.

The report was developed with extensive consultations among a cross-NOAA team and personnel in State of California agencies, academic and research communities, private industry, and non-governmental organizations. The report identifies vulnerabilities of key sectors of California's economy to extended dry spells and drought and offers recommendations on effective use of water information, sustainability of agriculture and natural resources, and protection of key species and their habitat through improved scientific understanding of water-related issues, forecasts, environmental monitoring, technology transfer, and communication with stakeholders. The report is forward-looking in that it offers opportunities for improvement in NOAA capabilities to address drought-related issues critical to our mission.

The feedback we received from our partners and customers in California provides us with insight into improving NOAA services in the present and for the next major drought, wherever it may happen. This report has recommendations that touch every mission area of our agency, and its findings underscore NOAA's important role in providing communities with timely, reliable, and actionable information—environmental intelligence—to remain resilient to weather and climate extremes. Report recommendations advance each of NOAA's four goals: 1) to provide information and services that make communities more resilient; 2) to evolve NOAA's National Weather Service; 3) to invest in observational infrastructure; and 4) to achieve organizational excellence by providing our customers the best service possible. As such, I ask NOAA employees everywhere to review sections of this report relevant to their expertise, and challenge teams across the agency to assemble in discussion about how we may better serve drought-stricken communities that are counting on us.

I commend the team of authors (representing all parts of NOAA as well as the California State Climatologist) who invested a significant portion of their time over the past year in assembling this report. I also thank the National Integrated Drought Information System for providing support for the team's operation. Finally, thanks go to all NOAA employees and stakeholders who agreed to participate in interviews in order to improve the important work NOAA does every day in service to the State of California and the Nation.

Vice Admiral Devany, Deputy Under Secretary for Operations

Executive Summary

NOAA's science, service, and stewardship mission uniquely positions the agency to provide environmental intelligence and related decision support services to those who need it most, including weather and river forecast information for emergency responders, climate predictions and drought monitoring for agricultural and water users, and coastal science and habitat restoration planning for fisheries industries. We continually strive to improve our services—particularly as California's historic drought unfolds—through advancing science and enhancing our collaboration with public, private, and philanthropic stakeholders.

NOAA commissioned this assessment of its services for decision makers impacted by the historic California drought that began in late 2011 and was exacerbated in 2014. This assessment focuses on (1) documenting impacts highlighted by decision makers interviewed in three sectors: agriculture, water resources, and fisheries; and (2) assessing NOAA's environmental intelligence suite of services, including data, science, and forecasts provided to decision makers in those sectors. The assessment was conducted by a diverse team of experts across NOAA who spent time in the field meeting with and soliciting feedback from over one hundred individual stakeholders as well as California-based NOAA employees with whom they directly interface. Interviewees included technical experts, municipal government leaders, academics, industry representatives, non-government interests, and members of the media.

The team synthesized input from the interviews to develop the findings and recommendations contained in this report. Top findings include:

- **Improve seasonal prediction:** Numerous stakeholders commented on the need for a seasonal prediction capability focused on cool season mountain precipitation, both in California and in the Colorado River basin. Although relatively small in land area, the mountain areas in the southwestern United States provide the vast majority of water for California. Even a low confidence forecast for the total precipitation in those areas could go a long way in answering the most enduring question: "How much water will we get this year?"

Aqueduct near Tracy, California.
Photo Credit: Karin Gleason

- **Build Full Natural Flow (FNF) water resources modeling:** In a state where almost every drop of water is accounted for as it makes its way to the sea, a science-based modeling and forecast capability is needed to support and optimize the management of the water resources. A robust FNF modeling and forecast system would require collaboration among key agencies, including NOAA, the U.S. Geological Survey (USGS), U.S. Bureau of Reclamation, and the California Department of Water Resources (CA/DWR). NOAA should take on a leadership role in assembling this coalition.

- **Enhance NOAA internal coordination of drought services:** Most stakeholders accessed NOAA's drought-related services through local National Weather Service (NWS) field offices (e.g., Weather Forecast Office or River Forecast Center). NWS field offices often rely on products and services including data, seasonal prediction, and research capabilities that reside in national centers, labs, and extramural partners. They also rely on products and services funded in part by National Integrated Drought Information System (NIDIS), including the Western Regional Climate Center and the Regional Integrated Science Assessment's California-Nevada Applications Program. Continued and increased collaboration and communication between the NWS field offices and these entities are needed to fully realize the value of NOAA's drought services.

- **Promote and implement sub-regional or watershed-specific projects:** Current NOAA projects in the region are generally sector-specific, providing data and information at different spatial and temporal scales that also limits their application for management use. There is strong need for NOAA to develop projects on sub-regional or watershed scales that are designed to improve understanding of interrelated environmental changes at different scales and address multiple resource-use issues. The Russian River Habitat Blueprint is a good example of this.

This report contains several dozen findings and recommendations, many of which are targeted for our defined focus sectors. Readers with specific interests in one or more sector are encouraged to read its corresponding Chapters. All readers are encouraged to read Chapter 6, which details the overarching findings and recommendations.

Lake Oroville showing the Enterprise Bridge looking from the South Fork on September 5, 2014.
Photo Credit: Courtesy of California Department of Water Resources; Kelly M. Grow

Introduction

1

The economic and environmental impacts of California's drought (late 2011–2014) are historic, enormous in scale, and still ongoing. As water shortages become more commonplace and dangers of wildfires increase as dry conditions prevail, communities and businesses alike are turning to NOAA more than ever before for timely and actionable drought information, and are calling for these data in formats that are easy to access and understand.

As a result of the drought, government agencies at all levels as well as private sector companies are being forced to make unprecedented and sometimes controversial decisions concerning releases of water, distribution of disaster funding, and rules for household water usage. State and local officials, industry leaders, and federal and academic researchers are turning to NOAA's diverse teams of experts—meteorologists, climatologists, hydrologists, coastal habitat planners, fisheries managers, and others—to access the best environmental intelligence available so they can make informed decisions.

NOAA is working hand-in-hand with all our partners and the public to ensure the state is able to respond to drought and become more resilient to future drought. **The central purpose of this report is to identify opportunities to improve the timeliness, accessibility, relevance, and understandability of NOAA science, forecast, and data products to all those who must make decisions in the face of this historic drought.**

NOAA service assessments

NOAA has a lengthy history of assessing its forecast and warning services in the wake of a major weather event. This history dates to a tornado outbreak in Dallas, Texas, in 1957, where it was found that citizens "knew little or nothing of personal safety rules regarding an encounter with a tornado." Since then, service assessments have been conducted for major floods, hurricanes, winter storms, heat waves, wildfire outbreaks, and even a space weather event. However, this is the first time a service assessment on drought has been conducted.

Each NOAA service assessment is conducted by a team of diverse NOAA scientists and other professionals. Shortly after an event unfolds, teams travel to the impacted region to interview decision makers, principally in emergency management, and identify opportunities to sustain or improve the services provided by NOAA. Findings and recommendations from each assessment are tracked by the agency in an open and transparent manner in an effort to improve the services offered by NOAA.

Stanford turns off its water features.
Photo Credit: Chris Stachelski

Unlike most service assessments that focus on recommendations geared toward NOAA's National Weather Service, the unique nature of this drought spans the contributions from all of NOAA's line offices.

Goals of this report

The scope of this assessment included two goals: first, to describe impacts of the drought on the focus sectors (agriculture, fisheries, and water resources) and second, to assess the effectiveness of NOAA's environmental intelligence information in the form of forecasts, data, and science to support decision makers in those sectors. This report identifies improvements for specific NOAA products and processes to increase the effectiveness of NOAA's environmental intelligence. We also document a number of best practices and evaluate the effectiveness of our drought communications with the public and decision makers. Assessing the management and regulation of fisheries, which is conducted by NOAA's National Marine Fisheries Service (NMFS), was outside the scope of this assessment. In addition, educating stakeholders on NOAA's capabilities was outside the scope of this assessment.

This report also supports NOAA's science, service, and stewardship mission. In particular, NOAA's Resilient Communities priority focuses on providing environmental intelligence to enhance community resilience in a variety of ways, and in the near term will focus attention in three interrelated areas—coastal, water, and ocean resources—and deals with societal, economical,

Chapter Photo: A portion of the lawn surrounding the California State Capitol is left to burn as a reminder of the drought.
Photo Credit: Water Resources Subteam

and ecological components within these areas. California drought is one of the areas of focus within the water resilience strategy, and we continue to strive to deliver relevant and useful information and services to communities.

We solicited input from decision makers in three key sectors: agriculture, fisheries, and water resources. These sectors were identified as high priorities for NOAA. Nine NOAA staff members representing all parts of the agency, as well as the California State Climatologist, worked during summer 2014 to conduct interviews to inform this report. The team was divided into three subgroups corresponding to each of the three key sectors. Each team solicited feedback on the information and decision-support needs of local stakeholders as well as NOAA field-based employee perspectives on the effectiveness of intra-agency coordination and public communication.

Collectively, the team interviewed over 100 decision makers over the course of more than 35 meetings (Appendix I). Potential interviewees were chosen to represent a diversity of perspectives within the key sectors. The final set of interviewees reflected that preferred sampling and the practical constraints of availability within the assessment team's work period. The input received from these decision makers forms the basis for this report and the findings and recommendations herein. This report was also reviewed by approximately forty reviewers both inside and outside of NOAA who provided over four hundred comments that improved the report.

Report outline

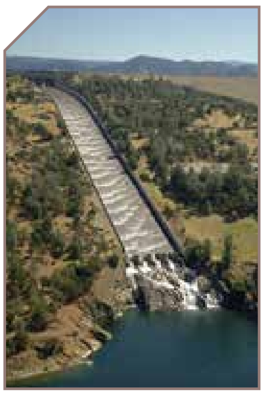
This report begins with a comprehensive overview of the drought (Chapter 2). Next we detail present-day challenges that decision makers in each key sector continue to face, highlight NOAA best practices for supporting those decision makers, and offer findings and recommendations to improve NOAA's effectiveness in the three sectors (Chapters 3–5). Following its charter, the team sought to identify recommendations that were implementable within six months of the finalization of the report but also considered longer-term recommendations especially where there was a clear consensus from stakeholders interviewed. Finally, we describe the possibilities of a future suite of drought decision services provided by NOAA (Chapter 6).

California Water Resources being studied and enjoyed in the recent past and in 2014







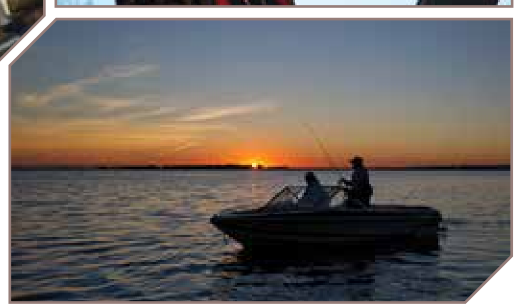










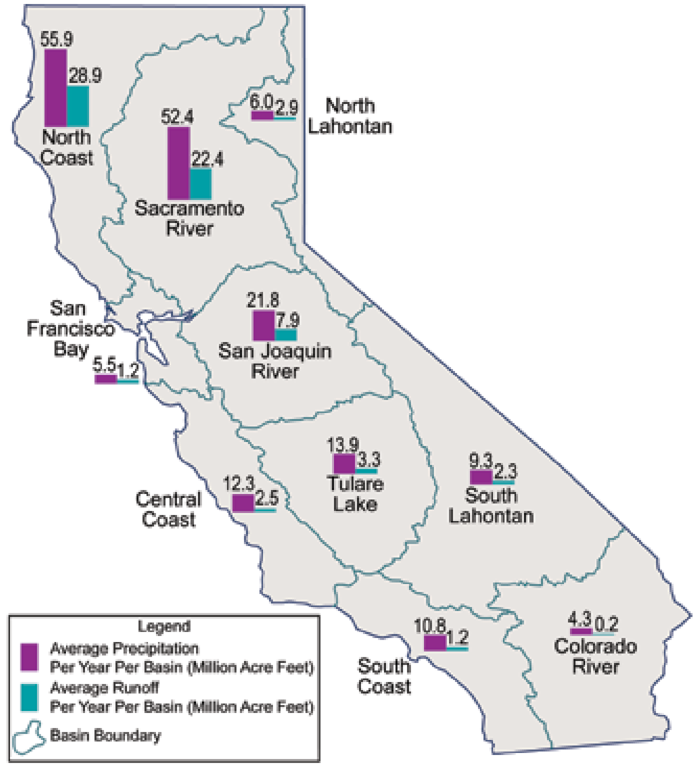


See Photo Credits page 59 for more information.

The California Drought:

2 Onset and Intensification

Droughts in California are not unusual and often extend many years. However, the current episode, which began in the late 2011 calendar year, may turn out to be the worst ever experienced by the state in terms of environmental and economic impacts. Three years of compounding dryness have enveloped most of the state in the extreme and exceptional categories of drought as depicted by the U.S. Drought Monitor (USDM) product. As a result, numerous industries in the state—including agriculture, water resources, and fisheries sectors—are experiencing major impacts and competing for water, while communities are experiencing cascading impacts on employment, tourism, health, and daily life.



Distribution of average annual precipitation and runoff by geographic region in California.
Source: California Department of Water Resources

Defining drought in California

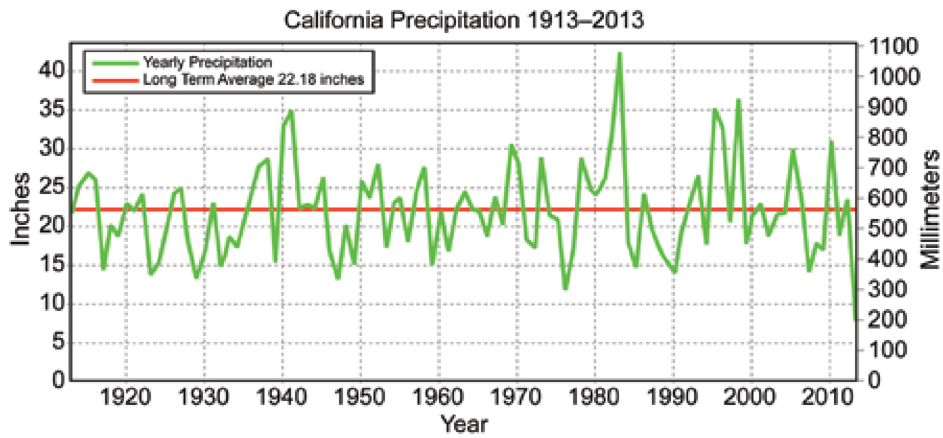
Drought in California is unique compared to most regions of the United States due to the distinct dry season most of the Golden State experiences. This natural dry season, a characteristic of a Mediterranean climate, exists across most of the state. It typically sets in between mid to late May and ends sometime between late September and early October. During this time period, very little, if any, precipitation falls across the state and whatever does is typically localized shower and thunderstorm activity in the deserts and interior mountains. Much of California has adapted to coping with its natural dry period by utilizing its reservoirs to store water for consumption, irrigation, wildlife management, and other uses. During periods of extended drought, groundwater has been used to substitute for the lack of surface water.

In addition to seasonal variations in precipitation, there are also regional differences in the average distribution of precipitation across the state. The mountains of northern and central California receive two to ten times more precipitation on average compared to the remainder of the state. Topography plays a large role in where and how much precipitation typically falls. The windward side of the Sierra Nevada, in northern and central California catches much of the precipitation from storm systems coming in off the Pacific Ocean.

As the winter months approach, the main storm track for many West Coast storms typically dips southward, kicking off the state's wet season. This season typically becomes more robust in November and December as storm systems become more numerous and often tap more moisture. Most of the total annual precipitation across California falls in the period between December and

Topographic map of California showing key cities. Major rivers are noted as blue lines on the map.
Source: California Department of Water Resources

Chapter Photo: CA/DWR's Frank Gehrke of California's Snow Surveys performs snow survey with California Legislative fellow Karen Morrison.
Photo Credit: Courtesy of California Department of Water Resources; Kelly M. Grow



Total average calendar year precipitation for California from 1913 through 2013 (green line) and long term average (red line).
Source: NOAA's National Climatic Data Center (NCDC)

March. Research by Michael Dettinger and others has shown that a significant percentage of wintertime precipitation falls in only a handful of larger events, which include atmospheric river events. Missing even just one or two of these storms can mean big deficits to the snowpack and annual precipitation.

By mid-February, the wet season is about halfway over and concerns often mount over water supplies and snowpack if the season has been lackluster for precipitation through this point. There have been seasons that have seen a marked turnaround with a wetter end of the season that often occurs in March due to a pattern change in the atmosphere, colloquially called a "March Miracle," that have managed to bolster seasonal precipitation totals to or above normal. However, if a "March Miracle" fails to occur, the ultimate fate of California's snowpack and thus water supply is determined by April since storm systems at that point become less frequent.

Evolution of the 2011–2014 drought: Onset and intensification

The last water year (defined as October 1 through September 30) in which California received above normal precipitation was 2010–2011. Although the 2011–2012 water year finished with below normal precipitation in California, the deficit was small enough for the state to only see minor impacts from the drought at that point. Even drier conditions prevailed with the 2012–2013 water year. Conditions grew even more dire following the exceptionally dry 2013–2014 water year, when the severity and geographic expanse of the drought gradually increased across the state.

For California, 2013 was the driest calendar year (January through December) in the 100 year record, and marked the only time the statewide average for calendar year total precipitation failed to exceed 10 inches, based on values computed by the National Climatic Data Center (NCDC).

California also experienced its warmest calendar year on record in 2014, based on data collected by NCDC, with an average temperature of 61.5 degrees Fahrenheit. The persistent heat throughout the year exacerbated drought conditions as evaporation removed much-needed water from the landscape and helped deplete already low reservoir levels. These reservoirs are largely fed by water in the mountains, especially the Sierra Nevada and southern Cascades. More than 60% of California's water supply originates in the Sierra Nevada and the Cascades. As of September 30, 2014, 154 reservoirs in California held 12.6 million acre feet (MAF) of water, which is 57% of average and 36% of capacity. The largest reservoir in California, Lake Shasta, was at around 1 MAF, which is 25% of capacity and 42% of average for that time of year.

Persistent atmospheric ridge played role in blocking storms

An area of high atmospheric pressure offshore of California persisted during the cooler seasons in 2012–2013 and 2013–2014. This ridge frequently blocked storm systems from the Pacific from moving into California, leading to all-time calendar year records for a lack of precipitation across the state at many locations. The dominance of this ridge was likely influenced by larger-scale atmospheric and oceanic patterns, including sea surface temperature trends. Downtown San Francisco, which has the longest set of continuous weather records in the state dating back to 1849, recorded its driest year ever in 2013 with 5.59 inches of precipitation, smashing the previous record low of 9.00 inches in 1917. During 2013, Fresno had below normal precipitation every month, resulting in its driest calendar year on record (dating back to 1878), with 3.01 inches.

The lack of precipitation during the 2013 calendar year laid a solid foundation for the drought to reach a historic level. For example, in Fresno, the total October–September water year precipitation for the last three water years (from 2011–2012 through 2013–2014) was 18.82 inches. This ranks as the driest three consecutive water years ever on record dating back to 1878, breaking the previous

Informational weather graphic from the National Weather Service office in Reno, Nevada explaining the main weather pattern behind the California drought during January 2014.

record low of 19.79 inches set during the 1931–1932 through 1933–1934 water years. After three consecutive below normal water years across the vast majority of the state, most weather stations showed total precipitation deficits equivalent to a year and a half of precipitation or more. This includes some of the wettest areas of the state in northern California, where the three-year total precipitation departure has exceeded 70 inches. Selected water year departures from normal, as well as the three-year total deficit, are shown in the table that follows.

Snowpack has also suffered as a result of the below normal precipitation. This is important as the vast majority of water resources in the state originate from spring snow melt in the mountains. According to data obtained from the California Department of Water Resources (CA/DWR), the average April 1, 2014, snowpack was 9.4 inch snow water equivalent or 31% of normal. Snowpack (up to highest terrain) in early May 2014 was 10% or less of average. Snowpack has not been this low since 1976–77, which was also the second driest water year on record in California. Comparing the eight-station northern Sierra index for 1976–77 and 2013–2014 suggests this past year was much wetter, but little precipitation went into snowpack. The lack of snowpack has impacted flows on rivers. Runoff volumes on major rivers in 2014 ranged from around 10% to 50% of average for the water year.

Comparison of the current drought to historical California droughts

California has seen exceptionally wet water years interspersed with exceptionally dry years as far back as the 1800s, when statehood began and reliable weather records were first kept. One of the earliest documented droughts in California took place from 1863 through 1865, following the legendary flooding that took place in the Central Valley in December 1861. This drought significantly altered the cattle industry by shrinking herds and forcing ranchers to relocate, especially in southern California, as grass did not grow due to the lack of sufficient water.

Since 1895, California has experienced at least ten significant droughts, most of which have lasted for several consecutive calendar years. The two longest-duration droughts both lasted at least five years, from 1928 through 1934 and from 1987 through 1992. A more severe, shorter-duration drought, considered the benchmark drought in the last 50 years by many, took place from 1975–1977. In just the last 15 years, California has experienced three significant droughts, from 2000 through 2003, from 2006 through 2009, and from late 2011 through the present. Wetter periods have been interspersed in between these dry periods, but the wetter periods have become shorter as have the transitional periods in between very wet and very dry years.

The longest, most severe statewide drought in California lasted from 1928 through 1934, with impacts in some areas extending to 1937 during the "Dust Bowl" era. Two of the more severe droughts that saw minimum annual precipitation records broken were the drought of 1917–1920, which had its greatest impacts in northern California, and the drought of 1947–1950, which had its biggest effects in central and southern California. The drought of 1922–1926 encompassed what NCDC computes as the driest water year on record statewide in California, which was 1923–1924.

Major Droughts in California Since 1895	Average Palmer Drought Severity Index for Period Based on Water Year
1897–1899	−1.22
1917–1920	−1.05
1922–1926	−0.74
1928–1934	−1.64
1947–1950	−1.04
1959–1962	−2.28
1975–1977	−3.23
1987–1992	−2.43
2000–2003	−1.49
2006–2009	−3.61
2011–?	−3.06

Table 2.1: Past major droughts and the average Palmer Drought Severity Index (PDSI) statewide during each severe drought since 1895 in California.

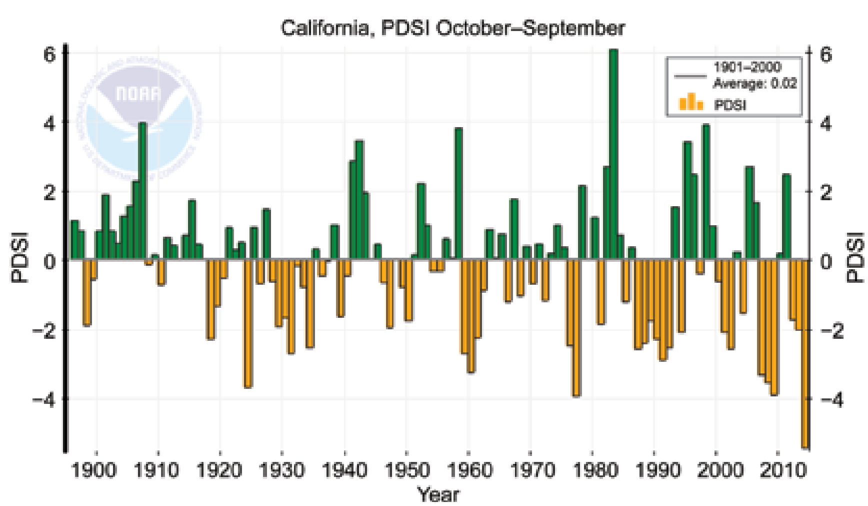
According to the Western Regional Climate Center (2008), the 1975–1977 drought resulted in 31 counties in California being declared disaster areas and caused $2.6 billion in economic losses. Many reservoirs and lakes dropped to record lows. Water shortages were exceptional, with impacts ranging from the temporary cessation of agricultural activities in some parts of the Central Valley, with a significant impact to livestock, to the construction of an emergency water pipeline across the Richmond-San Rafael Bridge in the Bay Area when local reservoirs ran extremely low.

As the Nation's most populated state today, directly comparing the current California drought to previous ones is challenging, as population growth and adjustments in water management and water use have occurred over the years. A comparison of historic droughts in California can be seen in the accompanying table along with the average Palmer Drought Severity Index (PDSI) for the state as a whole during each drought computed by NCDC. It should be noted that this is only one meteorological value used to compare drought, and that impacts, including monetary losses and water law changes, can be equally good, if not better, ways to rank a drought's historic importance.

Impacts of the current drought

The ongoing drought in California has presented the state with significant economic, environmental, and cultural impacts. The drought has impacted residents, visitors, and agencies in communities large and small. Landscapes, ecosystems, wildlife, and livestock have also been affected. Many of these impacts have yet to be comprehensively documented. Indeed, such an effort is needed for this and future droughts, particularly those that impact the Nation as this one does. Nonetheless, in 2014 alone, Howitt et al. (2014) estimates this drought has caused losses to more than 17,100 seasonal and part time jobs and $2.2 billion in direct economic losses, including crop losses, additional pumping costs, and livestock reductions. In addition, researchers estimate the state as a whole will see its surface water reduced by 6.6 MAF (average is around 18 MAF). These reductions and costs have compounding effects through the economy and the ecosystems with profound impacts on many in the state. Following the record to near-record dry year experienced across California in 2013, Governor Jerry Brown declared a State of Emergency on January 17, 2014 (CA/DWR 2014), due to the drought. This proclamation gave state water officials more flexibility to manage water supply under severe drought conditions and authority to enforce drought-related orders.

Agriculture is a significant sector of California's economy. Nine of the top ten agricultural sales counties in the country are located in the state according to the United States Department of Agriculture (USDA). Total agricultural sales in 2012 (USDA 2013) in California were $44.7 billion. Fresno County, the highest county in agriculture sales



Average statewide Palmer Drought Severity Index (PDSI) for California, for each October-September water year since 1895.
Graph courtesy of the National Climatic Data Center (NCDC)

nationally, was in the center of the drought. An additional six of the ten remaining top ten counties in agricultural sales nationally are located in California's Central Valley. This area has been one of the hardest hit by the drought from a meteorological, environmental, and economic standpoint. The drought has caused numerous fields to be left fallow and farms to close, leading to soaring unemployment in some communities.

Agriculture is the state's largest water supply user, consuming about 80% of the total water supply in the state. California produces over 350 different crops and leads the Nation in production of 75 commodities. California is the prime producer nationally of 12 different commodities, including almonds, artichokes, dates, figs, raisins, kiwifruit, olives, persimmons, pistachios, prunes, and walnuts. Most of this production would not be possible without irrigation. In an average year, California agriculture irrigates 9.6 million acres using roughly 34 MAF of water of the 43 MAF diverted from surface waters or pumped from groundwater.

The large use of water by agriculture versus the needs of water by communities and wildlife has created significant challenges in handling the state's water supply, especially with respect to groundwater. As the drought intensified in California, the use of water and the laws which allocate water came under increasing scrutiny. As water became more scarce, many water users faced cutbacks or cutoff to enable the state to manage its ***water resources.*** In 2014, California Governor Jerry Brown signed a law to strengthen local management and monitoring of groundwater basins. Up to that point, California remained the last western state in the United States to not manage groundwater, including the supply of it. Because of limited storage and the exceptionally meager snowpack in the winter of 2014, the Central Valley Project of the U.S. Bureau of Reclamation only granted 75% of their water allocation north of the Sacramento Delta and 65% south of the Delta to senior water rights holders (formally known as settlement contractors/water rights). Agricultural users received no water allocations for the first time in history. State Water Project contractors only got a 5% water allocation. For the first time, the U.S. Bureau of Reclamation released water from Millerton Lake behind Friant Dam near Fresno in May 2014. This was done to meet contractual obligations to deliver Central Valley Project water to the San Joaquin River Exchange Contractors.

The state's natural and manmade hydrological infrastructure has also been exceptionally tested and stressed by the drought. Several stream gauges have already recorded all-time record lows for any day of the year. Reservoirs have approached or exceeded all-time record lows, with some smaller ones at 5% or less of capacity. As a result, many water agencies and utility companies were faced with near-unprecedented challenges to supply water to their constituents, due to the severely reduced supply. The Santa Clara Valley Water District stated this drought has "caused them to take actions never done before." In addition to the concerns over the water supply, the drought has resulted in 'hidden' impacts to agencies. Energy costs for pumping were cited as essential in moving water supplies from one area of the state to another and were another expense they had to factor into plans. Even where water did exist, the continued dry weather also threatened the supply held in storage. Evapotranspiration alone was also a concern, as in some areas, such as those served by the Santa Clara Valley Water District, the amount of water loss through this method was expected to be greater than the loss from inflow.

According to the Association of California Water Agencies (2014), as of October 20, 2014, at least 236 local water agencies have implemented some form of mandatory water restrictions or conservation efforts, with the state of

Looking toward the Sierra Nevada from east of Big Pine, California in late June 2011 and slightly over a year later in early July 2012 shows a noticeable drop in snowpack. Photo Credits: Chris Stachelski

California reporting at least 58 local emergency proclamations from counties, cities, tribes, and special districts (Plumas County California 2014). Many of these water restrictions ban the draining and refilling of swimming pools, using hoses to wash sidewalks and other hard surfaces, limiting irrigation of landscaping, banning new landscaping, and requiring hose nozzle shut-offs. Violations of restrictions could result in fines.

Impacts of the drought have also extended to ***fisheries***, with the primary impact stemming from reduced river flows and reduced cold water pools upstream. Reduced river flows have also resulted in warmer rivers, which has affected the ability for certain species of fish to survive and resulted in a lack of water in some areas for fish to migrate. Decreased flows in the Sacramento River have also increased salinity values in the Sacramento Delta, which affects fish habitat. Extraordinary measures are being taken in California to protect salmon, including installing chillers at fish hatcheries, preserving eggs, and trucking fish directly from hatcheries to the Bay. Many endangered fish have been rescued from rivers. The drought will cause significant economic hardship to the commercial and recreational fishing industries if low survival of certain fish species results in a reduced or closed fishing season in a few years. The last closure of the salmon fishery in 2008–2009 in northern California resulted in the loss of $534 million and around 5,000 jobs.

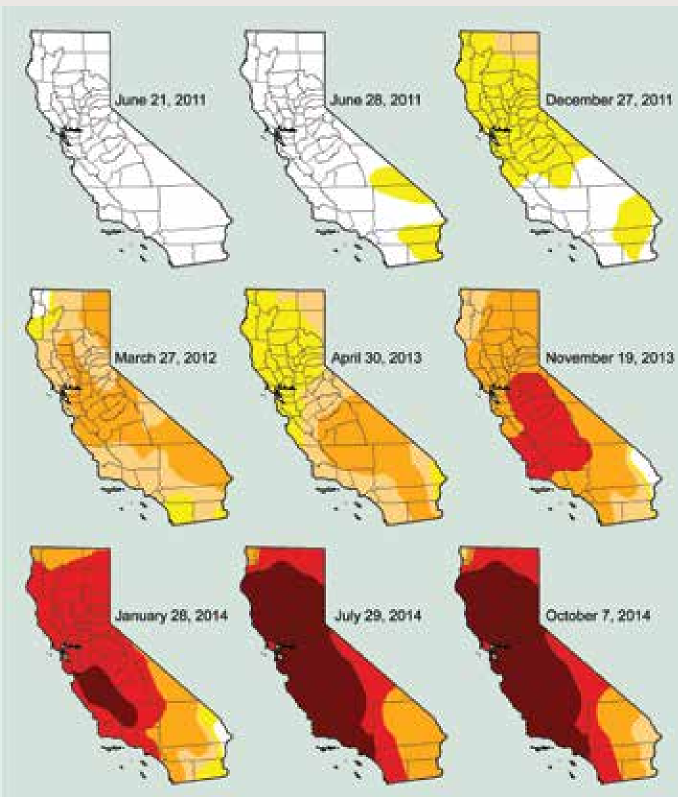
NOAA's Drought Task Force

Coincident with this assessment, NOAA's drought task force developed a rapid assessment paper on the causes of the 2014 California drought (Seager et al. 2014). That assessment identified the following weather conditions that were key to explaining the 2011–2014 drought:

- A high pressure ridge off the West Coast diverted the track of storms during all three winters, typical of historical droughts.
- West Coast high pressure was rendered more likely during 2011–14 by effects of sea surface temperature patterns over the world oceans.
- The drought's first year (2011/2012) was likely the most predictable, when La Niña effects largely explained high pressure off the West Coast, though simulations indicate that high pressure continued to be favored due to ocean effects in 2012–14.

Progression of the Drought from the U.S. Drought Monitor

The U.S. Drought Monitor (USDM) last showed no areas of drought conditions across California on June 21, 2011. The following week, on June 28, D0 conditions, or abnormally dry, were shown across eastern portions of the state extending from Inyo County into northeastern San Bernardino County and from eastern Riverside County to Imperial County. The USDM showed very little change in the area impacted by drought conditions until December 6, 2011, when D0 conditions began to encompass most of northeastern California, including the northern Sierra Nevada. By December 27, 2011, D0 conditions existed over all of northern and most of central California as well as the southeast deserts, with D1, or moderate drought conditions, noted across far northeast California. Between January and March of 2012, drought conditions expanded across the entire state, with D2, or severe drought conditions, existing across much of northern and central California. By July 24, 2012, the first area of D3, or extreme drought conditions, appeared on the USDM near Lake Tahoe and gradually expanded along the California and Nevada border over the remainder of the summer of 2012.



The 2012–2013 water season finally saw relief arrive in northern California between late November and mid-December of 2012 when enough precipitation fell to completely erase drought conditions from areas along the coast from the Bay Area northward and in the Sacramento Valley. However, this relief did not last long and by March 26th these areas fell back into D0 conditions on the USDM. Late-season precipitation dropped the far northern coastal areas out of drought conditions during most of April 2013. However, by April 30th the entire state once again was placed in some category on the USDM and has remained so since.

The drought moved into severe levels starting in the summer of 2013 when, on August 13th, D3 conditions were noted across south-central California across Kern, Kings, Monterey, San Luis Obispo, and Santa Barbara Counties for the first time. The D3 area expanded to include most of central California on November 19, 2013, and expanded into northern California on January 14, 2014. D4 conditions, or exceptional drought, were first noted on the U.S. Drought Monitor January 28, 2014, across the Salinas Valley and western San Joaquin Valley. The D4 area gradually expanded north and eventually south during the winter of 2014 and into the spring and summer months. On July 29, 2014, the USDM showed 58.41% of California in D4 conditions extending roughly from Los Angeles to Redding. This status held as of September 30, 2014.

Selected Records Set for Driest Calendar Year Ever in California During 2013				
Station	2013 Annual Precipitation (inches)	Normal Annual Precipitation (inches)	Previous Driest Year (inches)	Year Records Started
Burbank (Airport)	3.03	17.31	3.55/1947	1931
Camarillo (Airport)	2.97	15.22	3.44/2007	1948
Eureka	16.60	40.33	21.17/1929	1886
Los Angeles (Downtown)	3.60	14.93	4.08/1947&1953	1877
Fresno	3.01	11.50	3.55/1947	1878
Gilroy	2.56	20.54	11.16/1908	1906
Grant Grove	10.48	42.26	15.12/1947	1940
Hanford (City)	2.24	8.96	3.37/1947	1899
Honeydew	20.80	104.18	55.84/2007	1959
King City	1.80	12.06	3.14/1953	1902
Merced (City)	2.84	12.50	5.33/1917	1899
Monterey (City)	4.13	21.10	7.34/1917	1906
Oakland (Airport)	4.89	20.81	8.64/1976	1948
Napa	6.74	27.71	10.37/1939	1893
Paso Robles (Airport)	1.91	12.78	4.20/2007	1948
Red Bluff (Airport)	5.41	24.49	7.20/1976	1933
Sacramento (Downtown)	6.12	20.27	6.67/1976	1877
San Francisco (Airport)	3.38	20.65	9.20/1953	1927
San Francisco (Downtown)	5.59	23.65	9.00/1917	1849
San Jose	3.80	14.90	6.04/1929	1893
Santa Barbara (City)	3.95	19.43	3.99/1947	1893
Santa Cruz	5.07	31.35	11.85/1929	1893
Santa Maria (Airport)	2.99	13.95	3.30/1989	1906
Shasta Dam	16.71	65.82	27.99/1976	1943
Stockton (Airport)	4.59	14.06	5.60/1976	1948
Tahoe City	8.99	34.62	9.34/1976	1903
Visalia (City)	3.47	10.93	4.10/1910	1895

Table 2.2: Calendar year precipitation totals for for selected National Weather Service airport and cooperative observer weather stations for which 2013 was the driest calendar year on record. Table also shows the previous record and year. Source: Data is from the National Climatic Data Center (NCDC)

Selected 3 Year Station Water Year October–September Departures				
Station	2011–2012 Water Year Departure (inches)	2012–2013 Water Year Departure (inches)	2013–2014 Water Year Departure (inches)	3 Year Total Deficit (inches)
Burbank (Airport)	−8.54	−11.90	−11.94	−32.38
Camarillo (Airport)	−6.51	−10.36	−10.22	−27.09
Eureka	+0.68	−5.58	−19.31	−24.21
Los Angeles (Downtown)	−6.23	−9.00	−8.89	−24.12
Fresno	−3.35	−5.82	−6.51	−15.68
Gilroy	−8.84	−5.85	−11.38	−26.07
Grant Grove	−17.34	−17.09	−20.36	−54.79
Hanford (City)	−3.33	−4.54	−6.14	−14.01
Honeydew	−27.75	−34.06	−66.02	−127.83
King City	−3.80	−5.71	−6.59	−16.10
Merced (City)	−4.07	−5.59	−7.93	−17.59
Monterey (City)	−7.64	−7.98	−12.16	−27.78
Oakland (Airport)	−2.43	−6.42	−10.95	−19.80
Napa	−6.70	−8.63	−8.05	−23.38
Paso Robles (Airport)	−4.11	−8.13	−7.86	−20.10
Red Bluff (Airport)	−6.33	−8.31	−9.94	−24.58
Sacramento (Downtown)	−7.04	−3.28	−9.91	−20.23
San Francisco (Airport)	−7.33	−7.53	−11.66	−26.52
San Francisco (Downtown)	−7.99	−6.63	−10.90	−25.52
San Jose	−7.80	−4.82	−8.87	−21.49
Santa Barbara (City)	−8.35	−10.87	−11.74	−30.96
Santa Cruz	−10.61	−13.28	−16.95	−40.84
Santa Maria (Airport)	−4.31	−7.76	−9.45	−21.52
Shasta Dam	−21.37	−14.89	−31.34	−67.60
Stockton (Airport)	−5.99	−3.08	−6.24	−16.03
Tahoe City	−12.14	−9.43	−15.30	−36.87
Visalia (City)	−5.10	−6.51	−6.28	−17.89

Table 2.3: Precipitation departures from average for the water years 2012 to 2014 based on the October–September period for selected National Weather Service airport and cooperative observer weather stations.
Source: Data is from the National Climatic Data Center (NCDC)

Agriculture

3

From August 4–7, 2014, interviews were conducted with 23 federal, state, academic, and agricultural users concerning the value and effectiveness of NOAA products, services, and messages for the 2014 California drought. The findings and recommendations outlined below are a result of those interviews.

Throughout the current drought, members of the agricultural community have taken extreme measures to irrigate croplands, feed livestock, and maintain livelihoods. Indeed, Howitt et al. (2014) estimated that economic impacts from the 2014 drought will result in a 6.6 million acre-feet (MAF) reduction in surface water available to agriculture. This loss of surface water will be partially replaced by increasing groundwater pumping by 5 MAF. The resulting net water shortage of 1.6 MAF will cause losses of $810 million in crop revenue and $203 million in dairy and other livestock value, plus additional groundwater pumping costs of $454 million. These direct costs to agriculture total $1.5 billion. The total statewide economic cost of the 2014 drought is $2.2 billion, with a total loss of 17,100 seasonal and part-time jobs. While drought is common in the arid and semiarid parts of the West, agricultural producers still rely on consistent supplies of water for irrigation and sufficient forage for livestock. In the third year of this drought those resources have become severely strained.

Determining data needs of the agricultural community

Agricultural users desire increased collaboration with NOAA

While many members of the agricultural sector rely on NOAA services to provide short and long-range weather, climate, and streamflow forecasts, much of this interaction has been reduced or ceased entirely since a mandate by Congress in the mid-1990s to privatize NOAA's agricultural weather services. Not only did this action result in the closure of NOAA agricultural weather service forecast centers across the country and discontinuation of products such as fruit frost forecasts, it also led to a discontinuation of relationships and partnerships NOAA employees had built with the agricultural community in testing and developing new forecast products.

Several groups noted disappointment in the reduced interaction and the progress that NOAA could have made over this period of time. During the same 20-year period, NOAA built extensive relationships with other sectors such as the aviation, fire, and marine communities.

Chapter Photo: Rolling hills and mountains rise behind vineyards in southern San Joaquin Valley.
Photo Credit: Courtesy of California Department of Water Resources; John Chacon

Finding 3.1: While we recognize many Weather Forecast Offices (WFOs) in California have had an ongoing interaction with the agricultural sector, the interaction appears to be uneven across the WFOs, with the perception being that only limited interactions with the agricultural community are allowed. This policy, and the confusion surrounding what is allowed in terms of engagement and product delivery and support, has nevertheless curtailed interaction with an extremely important sector for California and the United States as a whole.

Recommendation 3.1a: While following current National Weather Service (NWS) policy for public-private partnerships, NWS, as well as other NOAA line offices, should develop a new dialogue with California agricultural producers regarding the delivery and accessibility of agricultural weather and climate products and services. While we note this is an issue for the United States as a whole, it is particularly important in California given the ongoing status of drought and the importance of California's agricultural products to the country.

Finding 3.2: WFOs in Northern California are conducting a pilot project, initiated in 2014, to help better evaluate workload needs during inactive weather forecast shifts, called "green days." This helps relieve forecasters who otherwise would be at a forecast desk and allow them to conduct professional development or outreach with the public and private sector. The Hanford WFO is currently using the workload assessment process to re-engage agricultural producers in their service area particularly in regards to drought and frost/freeze concerns.

Recommendation 3.2a: WFOs nationally should employ a similar workload assessment on "green days" to help expand partner engagement roles in the office to beyond just the Warning Coordination Meteorologist.

Mixed reactions, perceptions surrounding NOAA seasonal and El Niño forecasts:

Misperceptions of drought alleviation arose when NOAA's El Niño Watch was issued

In March 2014, NOAA issued an El Niño Watch predicting a 50% chance of El Niño developing in the summer or fall of 2014. This announcement led many in the agricultural community to speculate that drought conditions would likely improve in the coming winter, given that many Californians recall the intense 1997–98 El Niño event that resulted in heavy rains and flooding across parts of the state. The lingering memory of this event and the perception that El Niño will have similar impacts across California caused considerable confusion for understanding how the current drought would change.

Anecdotal evidence collected during the interview process described just how much confusion existed within the agriculture community. For example, some cattle producers in the northern part of the state, on hearing the potential for an El Niño, were even considering expanding their livestock operations despite rapidly deteriorating range and stock pond conditions and not having a strong historical El Niño signal in the region.

Finding 3.3: A high degree of misinformation exists regarding El Niño and what it could mean to California in terms of winter precipitation and temperatures. In the third year of this extreme drought in California, the NWS, WFOs and others devoted a significant amount of time explaining the impacts if an El Niño were to form and that it does not guarantee increased precipitation for all of California. There was also a perception by the WFOs that NOAA technical and communications staffs in national centers did not realize or understand the connotation El Niño brings to California given the lingering memory of the 1997–98 event. As a result, the WFOs and other regional partners spent an extensive amount of time working to correct misperceptions and encouraging citizens to be prepared for the drought to continue. El Niño in particular has become an emotive word with a connotation that varies by sector, region, and personal experience. In California, stakeholders interviewed frequently associate El Niño with wet extremes that are not reflected by the data, particularly for weak El Niño events. During strong El Niño Southern Oscillation (ENSO) events, and in regions that have teleconnections with ENSO, it may make sense to issue an official statement on ENSO. During weak or marginal events, however, it can cause confusion and misinterpretation of potential impacts. One prominent stakeholder in California reflected that he wished NOAA would not talk about El Niño at all as it created significant confusion for him. An alternative approach could be not to focus on whether an ENSO event will occur but instead on the associated impacts, such as the potential for emerging events or, in the case of California, the possibility of ameliorating or intensifying the ongoing drought. This will require an analysis that draws on the expertise and partnerships from all of NOAA's offices and programs.

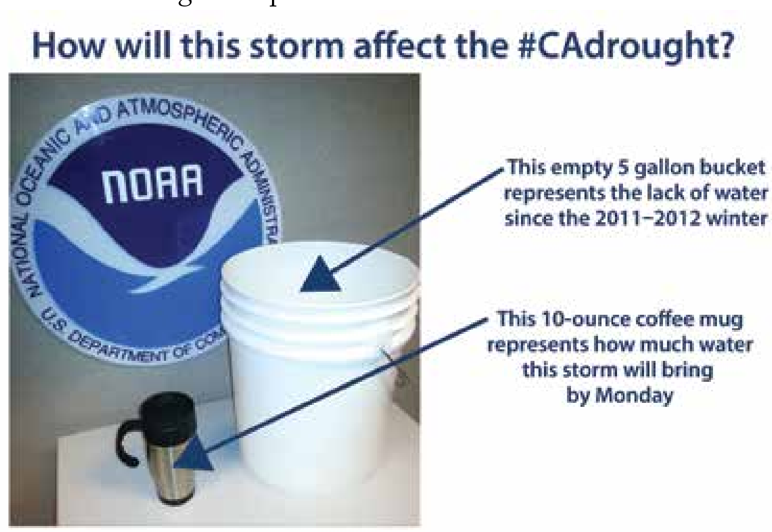
Recommendation 3.3a: NOAA, through NWS/Climate Prediction Center (CPC) and other offices providing climate services, should evaluate the purpose and effectiveness of issuing an El Niño or La Niña Watch.

Recommendation 3.3b: NOAA, through NWS regional offices, National Integrated Drought Information Service (NIDIS), and the Regional Climate Service Directors (RCSDs), should create an operational communications plan for drought events that would (1) improve technical coordination between the NOAA national centers and the WFOs, particularly for emerging events or areas where an existing event could intensify; (2) ensure consistent public messaging by including broadcast media and private sector partners; and (3) ensure mechanisms are in place for coordination with other federal and state agencies. For example, in California, following CPC's release of the El Niño Watch, supporting text and figures could have been provided to the WFOs to improve their partner emails and social media outreach. These figures and communications would have specifically addressed what El Niño means to California, what precipitation and runoff previous strong/weak events resulted in, and how they vary over space and time.

Agriculture users, for various reasons, do not rely on NOAA seasonal predictions

In addition to ENSO interpretation issues, agricultural producers in general had a difficult time understanding the Climate Prediction Center (CPC) seasonal outlooks products or finding value in using them. Many noted these products were interesting to view and were routinely examined, but did not make decisions based on the information. Uncertainty in the skill of seasonal forecasts was one factor, but so was difficulty in understanding what the forecast output meant. The WFOs noted this issue as well and described the seasonal information as most useful when it was put into some context, such as explaining the significance of an "equal chances" forecast. WFO perspectives on these seasonal predictions were found to be critical, as WFOs are often able to adapt CPC products to a local context. By combining the seasonal prediction with the WFO local knowledge and monitoring data, the WFOs provided a more complete picture to their customers that the drought was most likely not going to improve over the coming season despite not having a strong forecast. This is one example of WFO interpretation of a CPC product, but the team found many other examples where the WFOs were providing regional or local contextual information.

Another important point is how the WFOs delivered the CPC product to their audience. WFOs noted social media as rapidly becoming one of their key delivery mechanisms for this information and other important drought news to both general public and technical audiences. Platforms



Example of a weather graphic on the California drought used in social media by the National Weather Service in Sacramento, California.

like Twitter and Facebook were noted as being a much easier and more dynamic way to rapidly communicate breaking news than WFO websites. For example, the social media posts from WFO Hanford were particularly timely, innovative, and accessible to lay audiences. The messaging did not stop at these social media platforms, however, as the WFOs also utilized the full suite of communication tools at their disposal. These included: local listservs or partner emails, online posts (i.e. weather stories), and teleconferences and in-person briefings. Emergency managers, producers, state agencies, and universities all noted that the information they received from the WFOs was extremely useful and accurately characterized conditions as the drought evolved and intensified in 2014.

While the WFOs should be commended for their work during the drought, we did, however, find that there is no systematic or strategic direction for this type of communication. We also found that despite the importance of the information it seems the content and the frequency with which information gets communicated is inconsistent.

Finding 3.4: Given the slow-onset, incremental, and cumulative nature of drought, it is critical to continually contextualize weather and climate information so that stakeholders can anticipate opportunities if the drought improves, or risks if it intensifies. The WFOs are a trusted local source for many agricultural producers; and as such should be a key information provider. In the context of drought, however, the significance and importance of the WFOs consistently serving as an information broker between agricultural producers and climate products and services is not recognized within NOAA, nor is there an overall strategic approach and direction.

Recommendation 3.4a: NOAA should invest in products and processes that would help support or complement seasonal forecast information (e.g., maps, summary statements that include forecast confidence and note key uncertainties in the outlook). Additionally, teleconferences to answer frequently asked questions from a national perspective should include recognizing the WFOs, which are in many cases the local trusted source for providing the information.

Recommendation 3.4b: As part of the Weather Ready Nation process and in coordination with NIDIS, NWS should conduct an assessment to identify where WFOs, RFCs, and national centers have been successful at communicating climate information, and in particular slow-onset disasters like drought. Ideally, NWS would identify where climate information is currently successfully communicated (e.g., NWS Climate Service Program Managers) and where capacity is lacking to provide this information. In addition, NWS should consider the emerging role and capabilities of the National Water Center and the NIDIS Drought Portal in supporting drought and climate information.

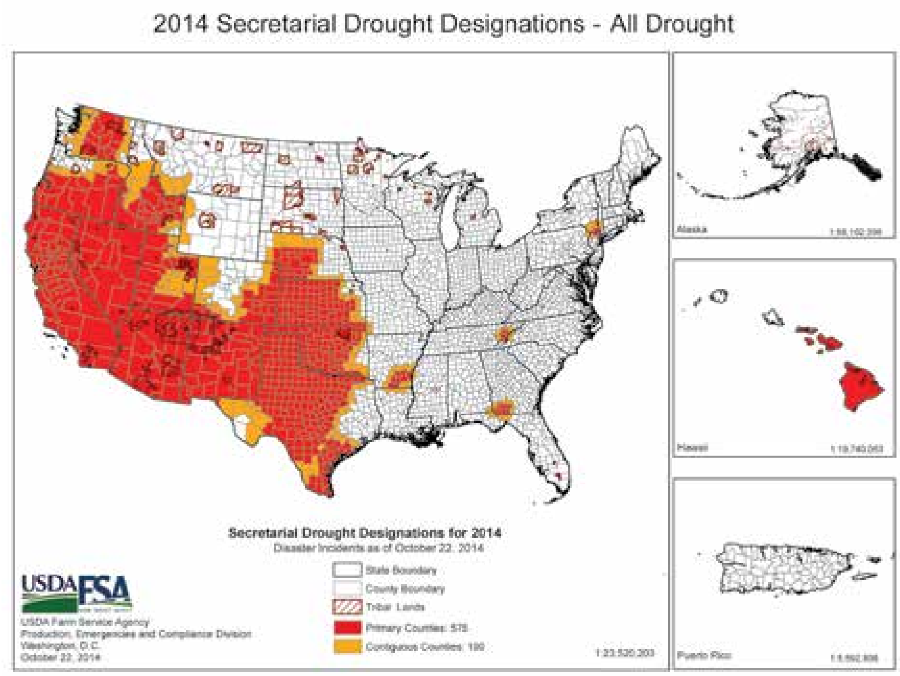
Recommendation 3.4c: On national and regional scales, excellent models already exist for providing interpretive information at seasonal timescales. Examples include the regional webinars coordinated by the National Climatic Data Center's (NCDC) Regional Climate Services Directors (e.g., Central and Southern regions) and the Monthly NCDC/CPC Climate Services Teleconferences for Media and Stakeholders. Working with the WFOs and other regional groups like the Western Regional Climate Center and the Western Governors Association, NOAA should develop a similar process for routinely interpreting climate and weather information in California and the western region as a whole. For example, an internal webinar already exists led by NCDC's Climate Monitoring Branch. The webinars were developed explicitly for NOAA personnel at the WFOs to provide them advance notice of and decision support for CPC's seasonal outlook products. It is not clear, however, if the existence of these webinars is widely known among the WFOs.

Improving drought monitoring in California

Agriculture users need to know how the U.S. Drought Monitor (USDM) works in order to provide impact information

In the United States, one of the primary composite indicators used to monitor drought is the U.S. Drought Monitor (drought.gov). The USDM integrates multiple data sources and derivative products from local to national scales and incorporates feedback and input into the process by maintaining and utilizing an expert user group of approximately 300 people from across the United States. These experts serve as a ground truth against the indicators. A convergence of evidence approach is used to combine the indices with impacts and feedback from experts through an iterative process each week. The USDM has been produced weekly since 1999 and involves collaboration between the National Drought Mitigation Center at the University of Nebraska, the U.S. Department of Agriculture (USDA), and NOAA.

For agricultural producers, the USDM is important because it is currently used as a trigger to initiate and/or terminate several programs in the USDA's Farm Service Agency (FSA). FSA uses the USDM in areas seeking approval of emergency haying and/or grazing through the Conservation Reserve Program as well as grazing losses due to drought under the Livestock Forage Disaster Program (LFP). The Internal Revenue Service (IRS) is also using the USDM for tax deferrals for livestock producers who involuntarily sold livestock due to drought conditions. Eligibility for these assistance programs is determined by county, therefore, it has become critical that the USDM reflect conditions on the ground and at a fairly fine spatial resolution.



County drought designations during 2014.
Map credit: United States Department of Agriculture (UDSA) Farm Service Agency (FSA)

The USDA has only relatively recently moved to this streamlined process where producers are automatically eligible for assistance when the USDM hits a specific drought category. Many producers are used to the old process and do not fully understand how the USDM weekly map is assembled. Many were under the impression that the USDM was simply a computer model driven by an unknown algorithm. The Farm Bill that passed in early 2014 compounded this issue in that it retroactively extended payments of the LFP back to 2012. Producers who already did not understand the USDM, and were using the new streamlined process going back to 2012, did not understand why their county did not qualify for LFP payments. This led to confusion on the part of the producers and on the part of the Farm Advisors who could not clearly explain the USDM process and why the USDM did not show certain counties in drought back in 2012 even though many producers were experiencing impacts at that time. There was a fundamental lack of understanding on the part of the producers and Farm Advisors and that had they known the process, the County Agricultural Commissioners, Farm Service Agency (FSA), or Natural Resources Conservation Service (NRCS) could have provided some of the impact information in 2012 that could have qualified those producers for the various IRS and FSA assistance programs. Also, there were several questions regarding what indicators go into producing the map, what these indicators actually describe, and how they are integrated with impacts that are reported. It was the impact reporting process that was also noted by University of California, Davis, Cooperative Extension. In particular, the process for reporting impacts was noted as problematic since little or no feedback was given on how the information was used to inform the USDM process. Several of those interviewed stated this feedback is critical for those collecting the data, like Cooperative Extension Farm Advisors and County Agricultural Commissioners, so they can improve how they collect and communicate the impact information. For example, it was unclear even what types of impact data were most useful to the USDM authors. The status of stock ponds was a specific example given of an important drought impact to producers, but it was unclear how or if this type of information could be incorporated into the USDM or whether there were other indicators the USDM already incorporates that could be used as a proxy for stock ponds. Another issue noted was that the impact information that is reported to the USDM process in the large east-west oriented counties of central and northern California (e.g., Madera or Fresno counties) overly represents impacts to irrigated agriculture. These counties extend from low-elevations where irrigated agriculture is dominant to the Sierra foothills, where livestock grazing is the primary production. The livestock producers are a smaller sector and therefore more effort should be made to include impacts to grazing land in the USDM process.

Finding 3.5: Agricultural users are not clear about how the USDM is produced, what the process is for reporting impacts, or how impacts reported inform the USDM process.

Recommendation 3.5a: The Sacramento WFO has a bi-weekly coordination call with all WFOs in California and Nevada, along with the RFC, state climatologists, and FSA. Impact information is shared along with suggestions for changes to the USDM, which is then communicated in a single summary to the USDM author. NOAA, working through the WFO/Western Region Headquarters, NIDIS, and the Regional Climate Services Director for the Western Region, should evaluate the bi-weekly calls, determine how effective they were at communicating drought conditions given California's unique circumstances, and whether all sectors (e.g., agricultural sector) are involved in the process.

Recommendation 3.5b: Working through state and local groups (such as the California Cattlemen's Association and the California Agricultural Commissioners and Sealers Association), NIDIS, the National Drought Mitigation Center (USDM), and USDA should produce a short summary describing the USDM, how it is assembled each week, and what the various drought levels mean. They should also explicitly state how agricultural and other users could supply information to the USDM (e.g., what types of impact information are needed). NIDIS/NOAA, NDMC, and USDA should also conduct a series of outreach and education webinars in California given the ongoing status of drought. The webinars and in-person meetings would also help to establish better relationships for impact information collection.

Various crops grown in Monterey County.
Photo courtey of: California Department of Water Resources, John Chacon

Important NOAA drought-related data products are not easy to find

In addition to improving understanding of the USDM, others noted products that were potentially useful for the agricultural community but were not broadly advertised or were "buried" on NWS webpages. One specific example that was noted as particularly useful for irrigated agriculture was the Forecast Reference Crop Evapotranspiration (FRET) product.

FRET was developed with the University of California, Davis, and the California Department of Water Resources (CA/DWR) and is an experimental forecast throughout NWS' Western region with a seven-day lead-time of the expected amount of daily reference evapotranspiration and a total reference of evapotranspiration for the seven-day period. The forecast is calculated by standardizing the short canopy vegetation (10 inch grasses or alfalfa) and is issued twice a day. Crop producers that are growing high-value products, especially tomatoes, are using FRET forecasts, as are producers that utilize micro sprinkler or drip irrigation. In addition to crop producers, another potential application of the FRET product was for water districts that have the ability to deliver water at a higher frequency.

Finding 3.6: FRET is an experimental product produced by NWS that has the potential to be useful for several sub-sectors of the agricultural community. Currently FRET is poorly advertised and it is unclear what if any evaluation is being done regarding who is using the product.

Recommendation 3.6a: The FRET product should be actively advertised to agricultural stakeholders, and an evaluation of who is using it and how it is being used should be conducted. Depending on the success of the product, NWS should consider expanding FRET nationally.

Recommendation 3.6b: NWS web standards should be updated to include evapotranspiration data in the point-and-click forecast pages, which users routinely bookmark as a single-source for weather information. Drought status information should also be included in these pages.

NOAA should reevaluate its Drought Information Statement product

The Drought Information Statement (DGT) product was also noted several times as being potentially useful, but it is also difficult to find. DGTs are text-based products issued by the WFOs for their respective county warning area and include a summary of current drought severity, impacts, forecasts, and products whenever the USDM has a drought intensity of a D2 or worse. The primary benefit of the DGT is that it consolidates drought impact information, which is extremely important for understanding how the drought is evolving. In addition to being difficult to find, however, other deficiencies were noted. In particular, the product does not take advantage of modern technologies such as including images and does not have the ability to notify users when the product is updated. Also, it is not clear how the product is used by the WFOs to provide impact information to the USDM process.

Finding 3.7: The DGT product has the potential to be a valuable tool for monitoring impacts related to drought. However, it does not use current technology and does not seem to be connected to the USDM process. Therefore, in its current form is not a useable or useful product. We also note the problem with the DGT is just one example of a more systematic issue with NWS legacy products using outdated technology.

Recommendation 3.7a: NWS should reevaluate the DGT product, how it could be modernized to take advantage of current technology (use of images and user notifications of updates), and how this product supports NWS drought communication, such as the USDM process, partner emails, or weather stories.

NOAA research can help the agricultural community better understand drought

Understanding why there are fewer fog days is important for growers

In addition to improving data, products, and services, stakeholders interviewed also encouraged NOAA to explore several research questions. An issue repeatedly raised was the reduced number of fog days in the Central Valley. This issue was also recently highlighted by Baldocchi and Waller (2014). Fog is a significant source of moisture for many crops. A reduction in the number of fog days has implications for increased irrigation demand and, in some cases, reduced protection against frost. But for fruit and nut trees reduced fog also means warmer air, which reduces the number of chill hours the trees require for rest and quiescence.

Finding 3.8: The number of fog days is an important component of agriculture in California's Central Valley; fog formation has high interannual variability, however, and it is not clear why over the last 30 years the number of fog days has declined.

Recommendation 3.8a: NOAA research programs should consider investigating fog trends along the West Coast and the processes contributing to the interannual variability of its occurrence in the winter.

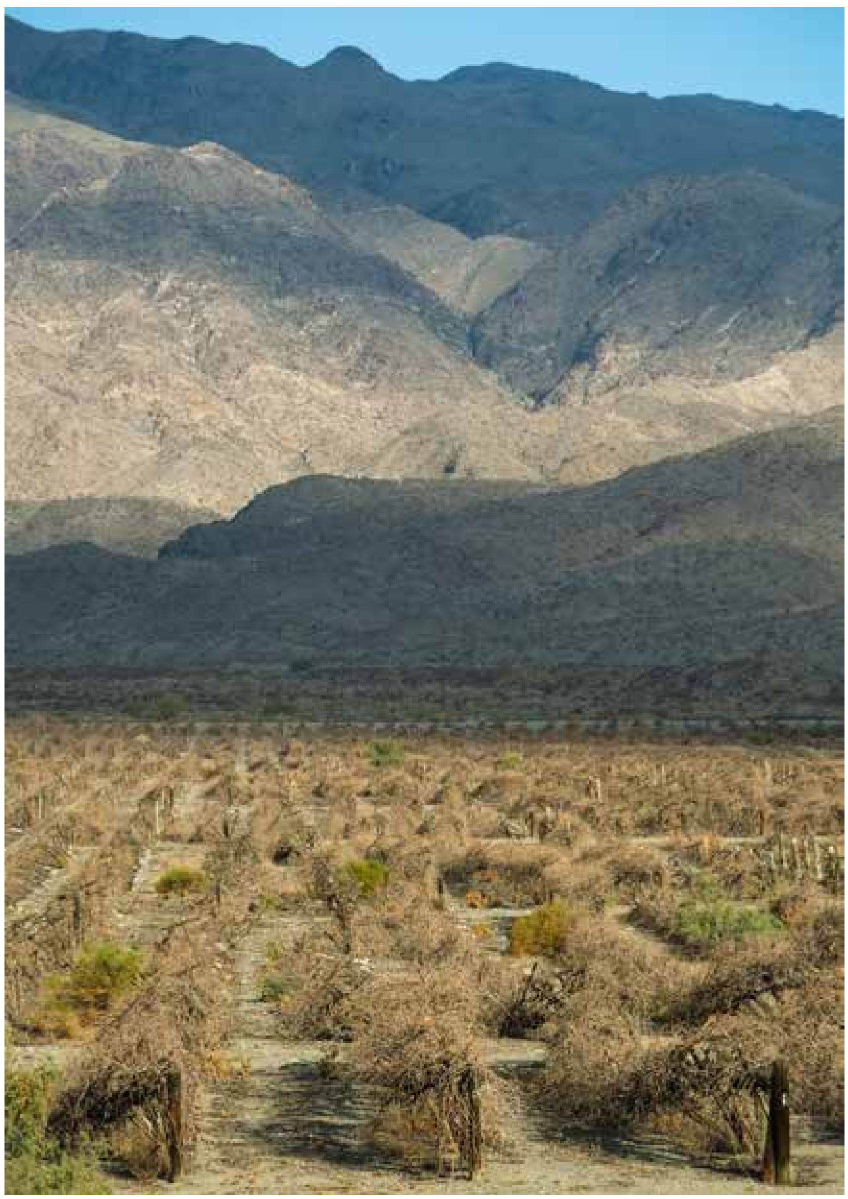
Drought is much more than a climate problem; it has important social and health impacts

In addition to the environmental impacts of drought, other issues discussed involved drought's impact on the economy, mental health, and the functioning of ecosystems. NOAA has two programs in particular that have a history of funding impacts research: the Sectorial Application Research Program (SARP) and its Coping with Drought initiative, and the Regionally Integrated Sciences and Assessment (RISA) program. SARP supports research on drought planning and addressing social, economic, and institutional challenges. RISA supports research teams that assess and address capacity to prepare for and adapt to climate variability and change. Both programs have developed research initiatives specifically to address drought impacts. However, they have not addressed these in the context of the complex interactions of these impacts following an intense and prolonged drought such as is being observed in California.

The marine layer moves in on the California coast and the Bixby Bridge.
Photo courtey of: California Department of Water Resources, John Chacon

Finding 3.9: Understanding cascading impacts of drought as they relate to the agriculture sector and society in general is extremely important for a state that provides a significant amount of agricultural production for the United States.

Recommendation 3.9a: NOAA research programs should consider ways to better understand the role weather and climate information plays in identifying risks and vulnerabilities that have economic dimensions, such as unemployment and food assistance programs, associated with cascading impacts specifically targeting the agriculture sector. In particular, NOAA's interdisciplinary research programs should explore opportunities to partner with USDA and state and Non-Governmental Organization (NGO) partners to enhance understanding of the role of weather and climate information in risk communication and risk management strategies important to agriculture, food security, and the links between food and water security.



Distressed vineyard in Coachella Valley on July 10, 2014.
Photo courtey of: California Department of Water Resources, Kelly M. Grow

4 Fisheries and Coastal Ecosystems

On August 26–29, interviews were conducted with more than 20 federal, state, academic, water, and fisheries stakeholders about the value and effectiveness of NOAA products, services, and messages for the 2014 California drought. The focus of these findings was on the products produced by NOAA within the confines of the existing regulations for enforcement. Some interviews were conducted in combination with the water resources subteam. The findings and recommendations outlined below are a result of those interviews.

NOAA routinely works with the State of California and other federal agencies on water, fisheries, ecosystems impacts, and wildlife strategies. As drought conditions worsened, notably in 2014, and with California facing its worst drought on record, a number of decisions were made to ensure California's threatened and endangered fish populations survive the drought. Also taken into consideration were impacts to the ecosystems and other wildlife in California that were impacted by the reduced precipitation and river flows.

Fisheries impacts of the current drought are widespread and include low river flows and limited storage in reservoirs and associated cold pools. The limited water supply poses challenges for water managers across multiple federal, state, and local agencies tasked with balancing the needs of agriculture, municipal users, and fisheries. NOAA Fisheries provides a wide range of research and supporting information to many different users in the fisheries management community. It also requires fish and wildlife managers, including NOAA, to revisit protections for vulnerable fish species and find new ways to collaborate to find successful paths forward with limited resources.

Chapter Photo: American river salmon. Photo Credit: Courtesy of California Department of Water Resources; Carl Costas

Challenges to decision makers

Better models and observations depicting surface, groundwater, and habitat conditions would serve the needs of many users

A major issue in assessing and forecasting the impact of drought on fisheries and ecosystems is insufficient information on the reduced amount and quality of water in the lakes, streams, and rivers, and on the distribution and abundance of key fish species in inland and coastal waters.

More data are needed to determine the current status of the hydrologic conditions to better support fisheries-related decisions and align those decisions with other water needs. NOAA's forecast information was heavily relied upon, but was not the only source of information

Map showing the water storage and distribution system in California. Source: Courtesy of California Department of Water Resources; CWP 2013 used by decision makers. The California Department of Water Resources (CA/DWR), Bureau of Reclamation (USBR), U.S. Geological Survey (USGS), and other state and federal agencies provided data or information that was crucial for making decisions related to fisheries or ecosystems. Collaboration and interaction between these agencies is critical to fisheries decisions and actions.

Low flow conditions in tributary streams and rivers are harder to predict due to lack of surface and subsurface data. Collecting this data and subsequent hydrologic modeling efforts to provide forecasts of low flow will be an expensive venture. In addition, the research and development of low flow hydrologic models is very limited. Budget initiatives would be needed to support this work as it is well beyond the funding levels provided today. However, drought conditions pose difficult choices on maintaining key fish habitats (often due to no water or excessively warm water), where to target habitat restoration, managing costly rescues of threatened and endangered species, and curtailing or changing hatchery operations. These choices are made even more difficult through the exacerbated impacts of unauthorized water diversions.

Finding 4.1: The current drought in California has caused historic absolute reduction in water availability for agriculture, fish habitats, and other uses statewide. The reduction in surface water flows is being partially compensated by increased pumping of groundwater that is believed not to be sustainable. There is a need for information on Full Natural Flow (FNF) in the region, for which reliable estimates are currently lacking. FNF is generally meant to characterize the natural water production of the river basin, unaltered by diversions, storage, or export or import of water to or from other watersheds at scales that are necessary for water management, including allocation of water on sub-basin scales. The lack of data to generate estimates of full natural flows to guide management decisions is a major challenge to water management in California, especially for the fisheries sector.

Recommendation 4.1a: NOAA should strengthen existing partnerships among federal agencies and other stakeholders for estimating and forecasting FNF in rivers and streams important to fisheries management. This effort can be built upon existing programs and collaboration among NOAA, the federal water agencies, and the state.

In addition to drought stressors, degraded water quality in the Bay Delta continues to impact salmon and other endangered fish resources

Water quality and salinity control in the Sacramento-San Joaquin River Delta is a multi-faceted element of the "Bay-Delta Water Quality Control Plan" of the State Water Resources Control Board, which includes causes and impacts of salt loading and other pollutants in an attempt to maintain integrity of estuarine ecosystems. It is implemented to support municipal and industrial uses, fish and wildlife habitat protection (and integrity of estuarine ecosystems), and agriculture in the Delta. For the Delta, the monthly mean position of the 2 parts per thousand (ppt) near-bottom salinity (the so-called X2 position) is monitored and maintained by releasing water from upstream reservoirs. This salinity indicator has ecological significance.

Drought exacerbates water quality issues in the region in several ways, including through: (1) lesser dilution of effluent from wastewater treatment plants, resulting in higher levels of ammonia (un-ionized) that exceed toxicity thresholds; (2) proliferation of protozoan infestation in fish (for example, the disease ich) that is promoted by higher water temperature; (3) more favorable conditions for onset of cyanobacteria blooms (harmful algal bloom releasing toxins); (4) the sheer increase of water temperature that creates metabolic costs in fish and other organisms; and (5) wider distribution and ecological impact from nonindigenous species.

Monitoring of water quality impacts, such as changes in water temperature, salinity, and acidity, are recorded at several monitoring sites operated by federal and state agencies. However, in most instances these data have limited spatial coverage and there is a general lack of data on toxic chemicals, including pesticides. Very little is known about the combined effects of environmental stressors, which has been identified as a priority information need by agencies and other organizations and stakeholders.

Finding 4.2: Degraded water quality has continued to impact the Delta and Bay resources, but the issue remains unresolved. There is well-documented scientific evidence that the health and productivity of the Sacramento-San Joaquin Delta ecosystem have deteriorated, as reflected in the decline of native fish species. Considerable scientific information exists on the effects of toxic chemicals on a variety of test species and at the sub-organism levels (i.e. cellular, biochemical, and physiological). However, information on the combined effect of environmental stressors is largely unknown, and can only be speculated. From NOAA's perspective, this capability would be critical for forecasting ecosystem-scale changes in water availability in response to human demand and to climate (wet and dry periods) and land-use changes at annual to decadal scales. NOAA has already taken foundational steps, with existing resources, in developing the West Coast Operational Forecast System, a three-dimensional hydrodynamic model for computing predicted water levels, currents, temperature, and salinity, both in open coastal waters and selected estuaries.

Recommendation 4.2a: NOAA should work with state and local officials and seek technical advice to determine the feasibility and application, building off of existing research efforts, of an operational estuarine circulation and hydrodynamic model that can describe the distribution of temperature and salinity in San Francisco Bay, including the location of the 2 ppt salinity contour (the X2 position).

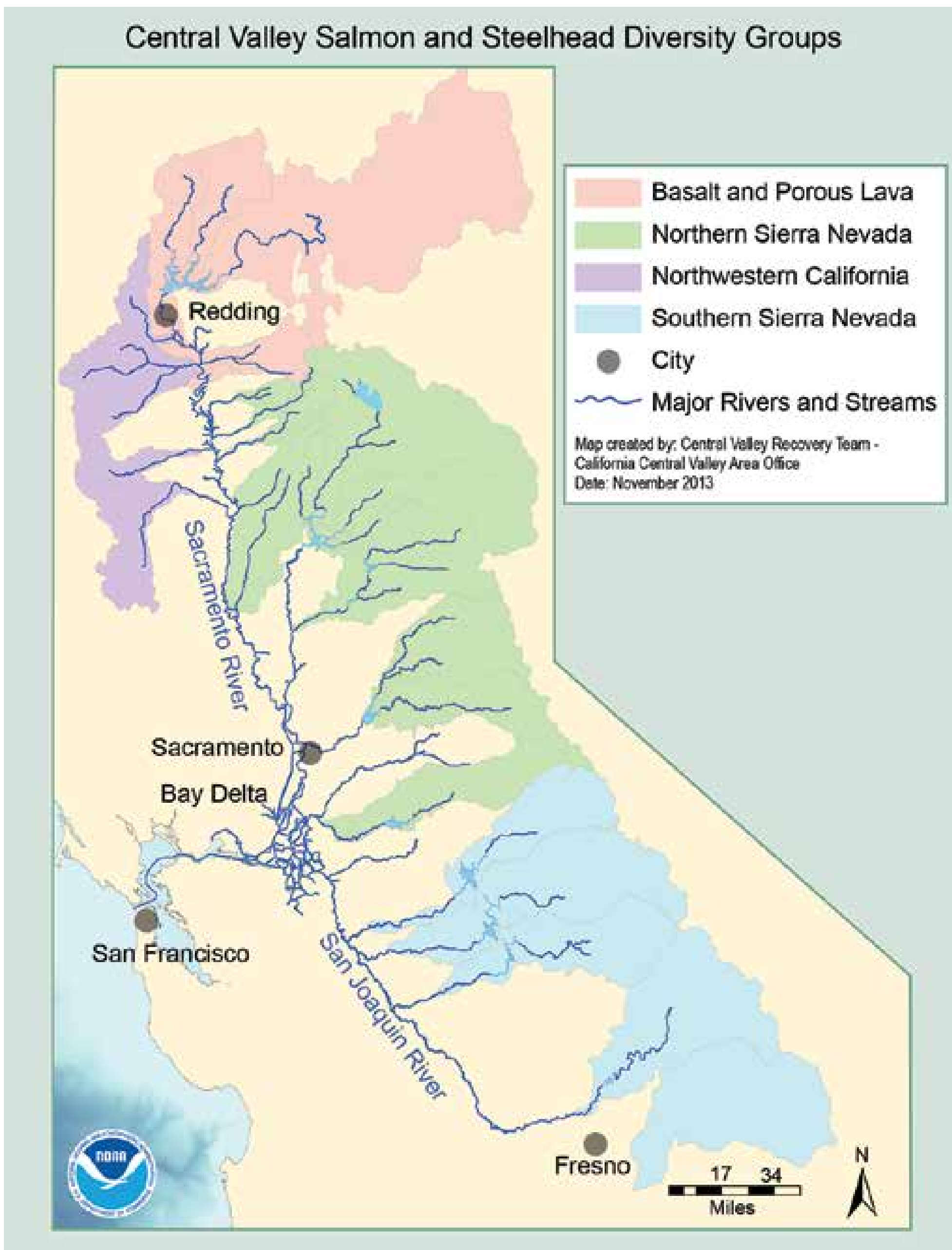
Recommendation 4.2b: NOAA should directly engage with state and federal agencies responsible for water quality management in the region, and focus on developing a coordinated and integrative plan to address combined effects of environmental stressors on the Delta ecosystem. The plan, which could be linked with CA/DWR's Interagency Ecology Program (IEP), would build upon their current scientific expertise and facilities, with an emphasis on developing new concepts and technologies that would better inform risk assessment and other management decisions. Assessing combined effects of environmental stressors, including those resulting from water availability and quality, may also offer better scientific understanding on significant decline in pelagic fish populations in the bay—termed Pelagic Organism Decline (POD)—which is a major priority for fisheries managers in the region.

Assessing combined effects of environmental stressors is already identified as a priority in the NOAA 5-Year Research and Development Plan and also noted in the Administration's nationwide initiatives. There are opportunities to leverage NOAA resources with state level investments, and such opportunities should be sought out. In essence, such a plan would require obtaining and blending the physical, biological, and social data and developing multi-hazard models and decision support systems.

More weather, water, biological, and economic data are needed to support more informed decision making

During the drought, decision makers, with limited data and forecast information, have relied upon the best science available and, where possible, utilized lessons learned from past experiences to make the best possible decisions in very challenging circumstances. Frequently, these decisions also relied upon input from other sources, such as the academic and research communities; state, local, and federal government agencies; and other stakeholders.

Stakeholders from the scientific community that were interviewed raised additional data needs. Some likened the ecosystem to a set of dials—i.e. turning one dial to impact the survival of one species may impact other species or other users of the water system. Therefore, they encouraged NOAA to try and capture this dynamic, where possible, in its products and services. University of California, Davis, researchers and others stated the need in California for realistic estimates of FNF at scales that



Location of key salmon watersheds in the Central Valley of California.
Source: California Central Valley Recovery Team, California Central Valley Area Office, November, 2013

are necessary for water management, including allocation of water on sub-basin scales. This is information that could be addressed by the NWC summit-to-sea treetop-to-bedrock modeling efforts and geointelligence program planned for the NOAA/NWS National Water Center (NWC).

NOAA's Sea Grant programs are another possible vehicle for helping to obtain state-of-the-art research on water-related issues and their impacts to local ecosystems. Sea Grants are NOAA-funded programs that support research and outreach, both through extramural grant programs as well as in-house extension agents that have relevant expertise.

Many individuals interviewed in this assessment emphasized that more data is needed for fisheries management, and that "the time is now" to engage in drought-related research and monitoring designed to benefit California and/or the entire Nation. It was acknowledged that better fisheries population and economic impact data is needed and would be useful in dealing with future droughts. There was also a desire to utilize satellite imagery and other remotely sensed data for documenting temporal changes in the Central Valley configuration, channel shapes, vegetation cover, etc. NOAA's Satellite systems aren't currently designed to observe this type of data; however other data sources, such as LANDSAT imagery, are available.

Currently, much of the Central Valley fish monitoring information is distributed "in-season" in preliminary form via email distribution lists, and the raw data are not available online. End-of-year, quality-checked datasets and annual reports, even if prepared, may not be widely available. A centralized source of monitoring data for species of management concern, including information on both juveniles and adults, would greatly improve the ability of all interested parties to (a) review data in-season (if the centralized source is updated frequently), and (b) conduct data analyses using a common source of quality-checked data (possible even if the centralized source is updated only annually). The centralized source could take several forms, ranging from a data "hub" which provides links to databases hosted by the responsible agency to a single centralized database including data from all sources.

USFWS employees release salmon hatchery fingerlings.
Photo Credit: Courtesy of USFWS Steve Martarano

Finding 4.3: There is a clear need for improved forecasting of weather, water temperature, flow in streams, and ocean conditions. In addition, better data and information in key areas related to decision making would greatly improve a fisheries manager's ability to deal with droughts. These include satellite data, fish abundance and distribution data, and economic impact data. In addition, a centralized source for the Central Valley fish monitoring data that is collected would greatly assist real-time water operations and fisheries management.

Recommendation 4.3a: NOAA should determine ways to model river temperature changes (critical for Chinook salmon), couple river models with reservoir models, and look for opportunities to expand monitoring to support fisheries management.

Recommendation 4.3b: NOAA, working with other government agencies, should coordinate and expand use of satellite imagery and other remotely-sensed data to better understand the decadal and drought-related changes in delta configuration, channel shapes, vegetation cover, agricultural practices, and other metrics for improving fisheries management and understanding ecosystem changes.

Recommendation 4.3c: NOAA should engage in or commission research studies and collect more fisheries and economic data related to the impacts of weather events such as drought.

Recommendation 4.3d: NOAA should engage in and/or support increased real-time fish monitoring and predictive modeling tools for fish distribution and density, especially in the Delta.

Finding 4.4: In San Francisco Bay and the Delta, potentially harmful occurrences and blooms of cyanobacteria, notably Microcystis, have been documented for over 15 years. Their toxins are present throughout the lower food web in the region, and as such, they pose a threat to human health, valued species, and ecosystem services. Microcystis blooms are promoted by increased light, water temperature, salinity, and water stratification, all of which are typically associated with drought. In addition, there is documentation of unusual algal blooms (Spring 2014) in the upper Sacramento River and Suisun Bay that may be related to drought (Glibert et al. 2014).

Recommendation 4.4a: NOAA should engage with the U.S. Environmental Protection Agency and other agencies, technical experts, and resource managers on developing a plan to address unusual and harmful algal blooms in the region under provisions of the Harmful Algal Blooms and Hypoxia Research and Control Amendments Act of 2013, with the ultimate purpose of developing an operational forecasting capability, technology transfer, and risk assessment.

NOAA tools that were used

Fisheries managers and stakeholders need localized information

Most of the information used by decision makers that came from NOAA was filtered or combined through products from other organizations, such as CA/DWR and USBRs 90% and 50% exceedance streamflow forecasts. Climate 15 day, 30 day, and 90 day outlook products generated out to one year from the Climate Prediction Center (CPC) and long range forecasts, such as the Extended Stream Flow Prediction (ESP) products from the California Nevada River Forecast Center (CNRFC), were synthesized with additional experimental forecast information available from CA/DWR and shared with multiple users. Specialized river forecast products on low flows were generated on a request basis by the CNRFC in cooperation with CA/DWR. All routine products issued by the CNRFC on river flow, from daily to extended streamflow predictions, were used by multiple users. NOAA's NWS and Oceanic and Atmospheric Research (OAR) Office rainfall data were used on a routine basis. NOAA's National Ocean Service data from the Physical Oceanographic Real-Time System (PORTS) on water level and currents was used. Data from other NOAA sources on salinity, acidity, water temperature, and toxic chemical contamination were also used.

NOAA Fisheries personnel, in order to develop management decisions, rely on weather, water, and climate products developed by NOAA, USGS, CA/DWR, and other federal and state agencies. While NOAA daily weather data is always of value in NOAA fisheries planning and response operations, some of NOAA's climate and river forecast products lack long-term forecast confidence, are not localized enough for project sites, or are not designed to collect the types of data fisheries managers need. For example, NOAA's river forecast models are not specifically engineered and calibrated to provide high quality low flow forecasts. Instead, they are typically calibrated to perform well in flooding situations. In areas identified as important for water resources assessment, they are also calibrated to deliver reliable long-range water supply projections. In addition, gauging streams accurately at low flows is a difficult challenge in many locations, but the data are necessary in managing water for fisheries purposes (e.g., water releases).

Deploying Aleutian wing trawl off NOAA Ship.
Photo Credit: Courtesy of Officers and Crew of NOAA Ship PISCES; Collection of Commander Jeremy Adams, NOAA Corps

Finding 4.5: NOAA weather/climate products are useful, but some climate products are not localized enough for fisheries managers and stakeholders.

Recommendation 4.5a: In an effort to improve the effectiveness of the use of NOAA data and forecast products, NOAA should examine ways to connect localized fisheries management needs with existing NOAA products. A fisheries liaison at the local NWS field offices would be one option to investigate. NOAA Fisheries offices should increase contacts and communication with WFOs for delivering forecasts and assessments that are compatible with scales of drought impact on fisheries and coastal ecosystems for its long and short range weather forecast products.

In preparing for future droughts, NOAA should consider preparedness exercises and pursue research opportunities

With California facing its worst drought on record, water access and availability is becoming an issue that intersects all sectors of California and the Nation's economy, including fisheries. To ensure the state's threatened and endangered fish populations survive the drought, NOAA staff are working closely with California state agencies and other federal agencies on water, fisheries, and wildlife strategies.

The severity of the current drought has demanded more of the collaborative and coordinated efforts among these agencies than any time in the past. As a means of maintaining and improving upon the collaborative and coordination efforts made between the agencies, a preparedness exercise could be developed and run to facilitate response to future droughts. Such exercises are employed for other extreme events and can help NOAA round out its Weather Ready Nation initiative.

Finding 4.6: NOAA should reshape its approach to providing information as a routine process and should adapt its products to better fit the impacts of the weather phenomena—extreme drought or floods.

Recommendation 4.6a: The current Delta Stewardship Council's Interim Science Action Agenda outlines a series of environmental issues, including scientific questions, ecosystem modeling, monitoring, and data management; some of the issues focus on water availability. NOAA may wish to contribute to implementing this plan, in particular, the drought-focused actions in the plan.

A few NOAA projects, especially the Habitat Blueprint, are key in rallying NOAA's diverse expertise into solving problems

In the context of the new NOAA Habitat Blueprint project in the Russian River watershed and the NOAA Hydrometeorology Testbed, relationships between NOAA's "wet" and "dry" experts have been forged or strengthened. The project is focusing on multiple issues related to water management, including water use, habitat resilience to floods and drought, and estuary/coastal area protection, with all line offices participating. The application of the Hydrometeorology Testbed is advancing research and forecast capabilities to improve water reservoir operations in light of increasing, multiple demands for water and impacts of weather. Sustaining this long-term, multi-agency project would require continued collaboration and contribution of resources from NOAA and its partners.

Salmon swim in Callifornia River.
Photo Credit: California Department of Water Resources, Carl Costas

Finding 4.7: NOAA's Habitat Blueprint approach, including the Hydrometeorology Testbed, was described by many NOAA interviewees as a "success" by offering a platform for cross line office and inter-disciplinary coordination, which has included placement of new weather data collection systems and water gauges and assessment of different water-release scenarios. Prior to the Habitat Blueprint, NOAA Restoration Center did not have a working arrangement with NWS for developing mutually beneficial and specifically tailored products for addressing key resource management questions. A much closer collaboration is now underway.

Recommendation 4.7a: Continue to develop and implement Habitat Blueprint projects that address regional or watershed-specific issues, are interdisciplinary in nature, and involve multiple federal, state, and local entities.

Recommendation 4.7b: Expand the Hydrometeorology Testbed and fully engage other federal agencies through the Integrated Water Resources Science and Service consortium to explore alternate water management practices such as a "Forecast-Informed Reservoir Operations" approach.

The Russian River watershed has been selected as the first Habitat Focus Area under NOAA's Habitat Blueprint. This is an important step to increase the effectiveness of NOAA's habitat conservation science and management efforts by identifying places where NOAA offices work to meet multiple habitat conservation objectives on a watershed scale.
Photo Credit: NOAA, Jenner

Water Resources

5

From August 25–29, interviews were conducted with more than 15 federal, state, academic, water, and water resources stakeholders about the value and effectiveness of NOAA products, services, and messages for the 2014 California drought. Some interviews were conducted in combination with the fisheries subteam. The findings and recommendations outlined below are a result of those interviews.

The conveyance of the water supply in California consists of an elaborate and geographically expansive network of reservoirs, lakes, aqueducts, canals, and rivers that store and move water from one area in the state to another. Weather conditions hundreds of miles away will often determine the local availability of water. At the same time, in areas that depend on groundwater for water supply, the local weather and runoff pattern play a leading role in water availability.

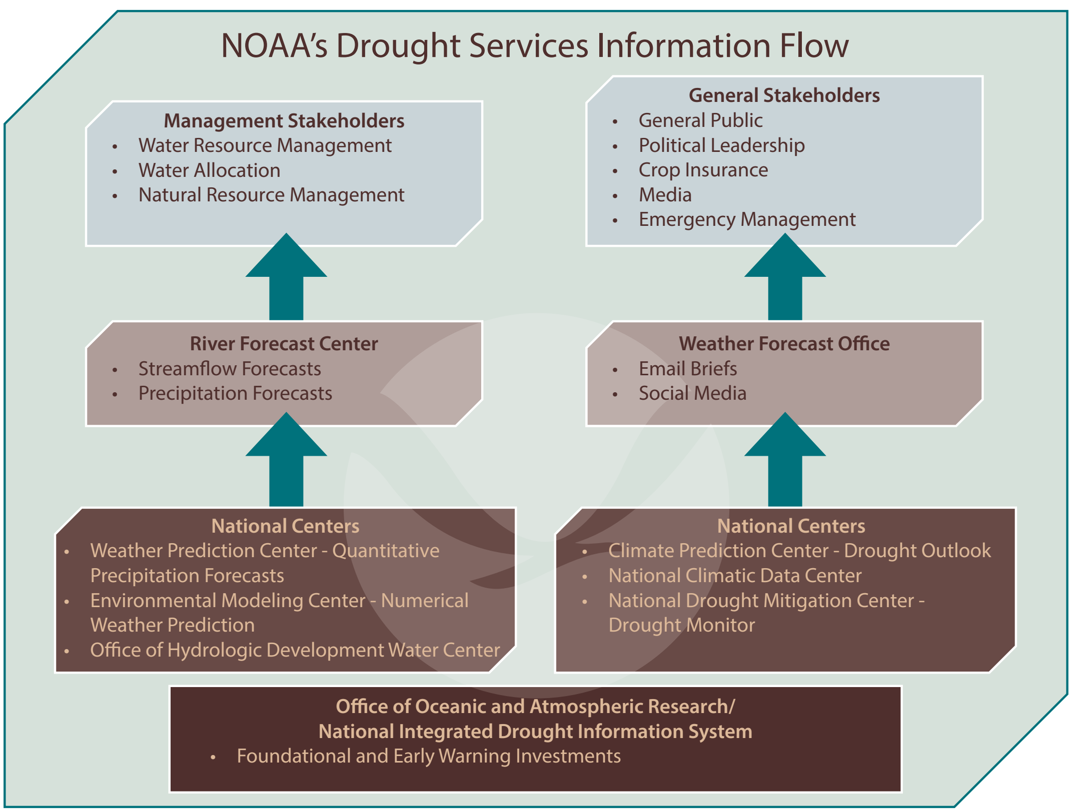
Due to the complex nature of California's water supply system, decisions made regarding water resources, including water management, in California are difficult in their execution and complexity. As a result, data and forecasts relating to water resources have to meet the methodology by which water is collected for consumption as well as meet the diverse array of users.

NOAA data and services that support decision making

NOAA streamflow forecasts are underutilized by water managers

The needs for NOAA drought information vary greatly depending on the user and their target audience. Stakeholders making quantitative decisions mitigating the impact of the drought have a need for scientifically sound and detailed information to inform those decisions. Stakeholders such as the media or a public relations official for an agency who seek to inform the public on drought conditions typically need more general information. This section focuses mostly on the former group of stakeholders. This group of stakeholders typically access NOAA services through the California-Nevada River Forecast Center (CNRFC). California's Department of Water Resources (CA/DWR) maintains excellent working relations with both the CNRFC and National Weather Service's Sacramento Weather Forecast Office (WFO) through their co-located offices. CA/DWR largely relies on the data and products issued by CNRFC and to a lesser extent forecasts and outlooks issued by the Climate Prediction Center (CPC).

Importantly, the water management stakeholders interviewed by the assessment largely did not utilize "drought" products such as the CPC drought outlook or the U.S. Drought Monitor (USDM) in their drought- and reservoir-management activities. These products do not contain a sufficient level of detail nor are they produced in an objective manner that supports their application to water resources management in California. Instead, water management agencies largely rely on the CNRFC forecasts and monitoring data that support it.



This diagram describes the flow of information through NOAA offices to decision makers affected by drought.

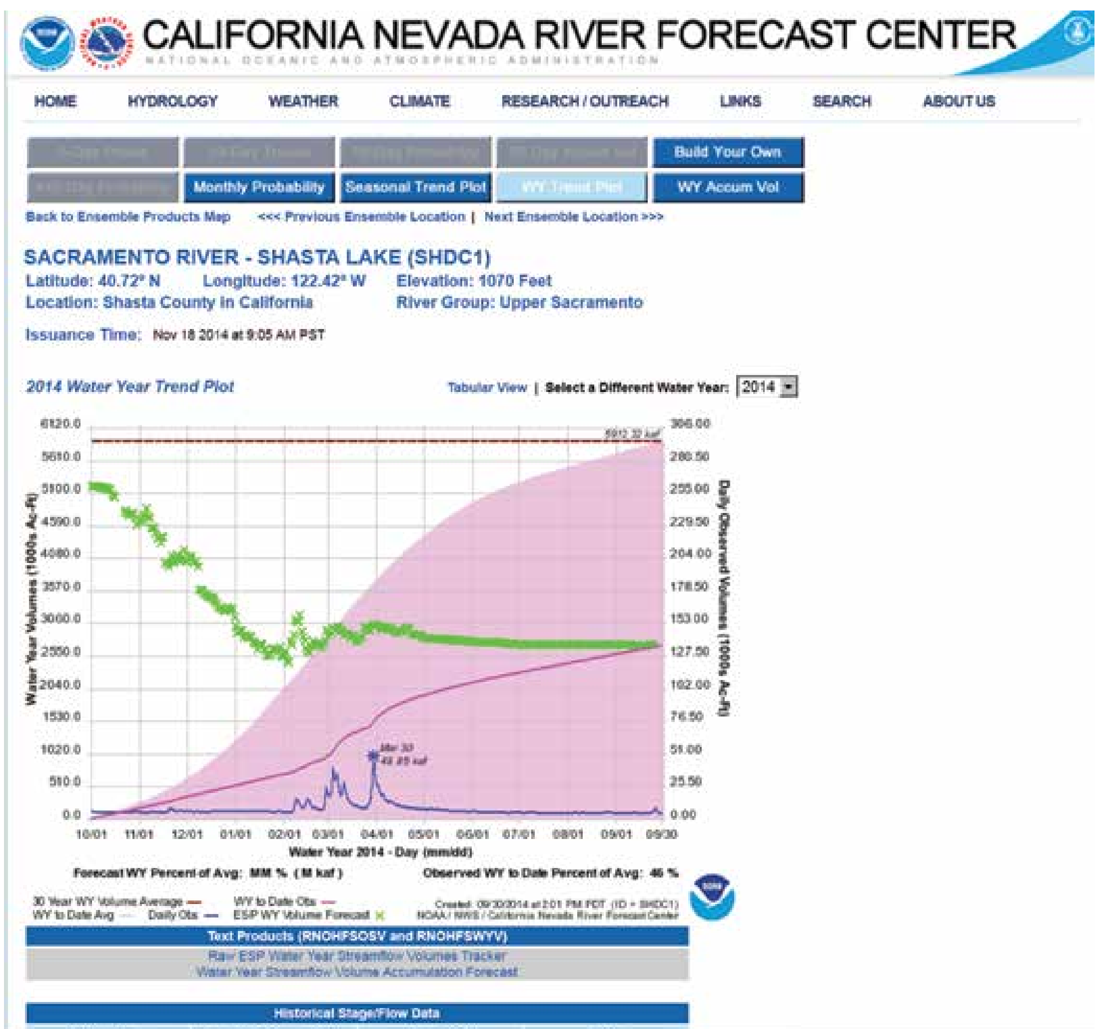
Chapter Photo: A serpentine stretch of the California Aqueduct in Palmdale, along mile post 327.50 on February 7, 2014.
Photo Credit: Courtesy of California Department of Water Resources; Florence Low

Every day, the CNRFC generates streamflow forecasts that include uncertainty extending from one day to one year into the future. These forecasts utilize weather forecast information from NOAA's calibrated Global Ensemble Forecast System (GEFS) reforecast and forecast data as well as historical climate data from the California Data Exchange Center (CDEC). The CNRFC also stated several challenges in creating long term forecasts which play a significant role in water resource management for lengthier periods. Longer-range forecasts beyond 15 days produced by the CNRFC are largely based on climatology. Although capabilities exist to calibrate streamflow forecasts beyond day 15 with the Climate Forecast System (CFS v2), according to CNRFC and others these climate forecasts have not yet demonstrated sufficient skill to be utilized in streamflow prediction.

On the weather prediction timescale, a reforecast strategy for the GEFS that includes regular updates to the reforecast runs is needed to calibrate the GEFS output for reliable streamflow prediction. These are used to create customizable water supply briefing pages that contain weather and climate information as well as the current state of water resources to customers. The CNRFC states that without available reliability and verification statistics on these graphs, calibrating forecasts for water management models is problematic. The development of these statistics has been hindered by having limited staff to devote to a finite number of products and services. These forecasts and webpages were well received and used by stakeholders because of their effectiveness in conveying the complex information needed to manage the state's water resources. For example, the Sacramento Municipal Utility District (SMUD) uses all 50 Ensemble Streamflow Prediction (ESP) traces to derive bulk statistics to optimize power generation.

Finding 5.1: CNRFC probabilistic streamflow forecasts (ensemble forecasts that describe a range of possible outcomes) contain valuable information that some stakeholder agencies have successfully applied to minimize risk functions for water management. However, these traces are still infrequently used by most water management operators due, in part, to institutional barriers within management agencies.

Recommendation 5.1a: NOAA's River Forecast Centers (RFCs) , National Water Center (NWC), and National Climatic Data Center (NCDC) should work to better educate users on ensemble forecasts, recognize and address institutional barriers that limit forecast application, and, moreover, to better market forecasts to users. Additionally, users of these products should work with NOAA on better ways to develop prototype decision support tools that leverage ensembles and to archive these ensemble forecasts and their associated hindcasts.



Inflows for Shasta Lake reservoir. Daily inflows are plotted in blue, accumulated inflows in pink, and daily median CNRFC inflow forecast in green.
Source: www.cnrfc.noaa.gov

Recommendation 5.1b: NOAA's National Water Center and National Climatic Data Center should invest in development of web-based tools for water resource forecast verification.

Recommendation 5.1c: NOAA's National Water Center and Climate Program Office should explore products that would facilitate the use of forecasts in reservoir operations.

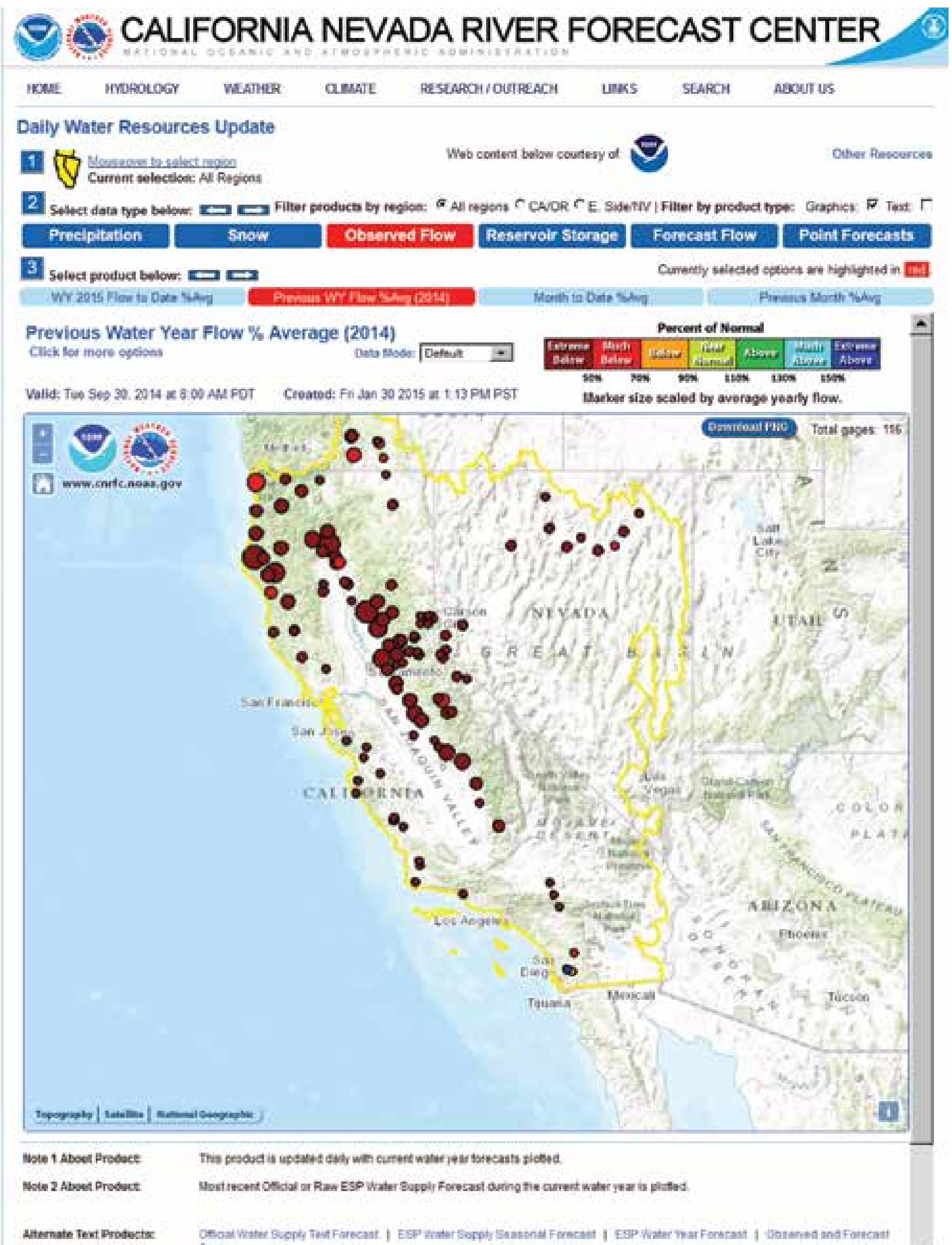
Finding 5.2: The major medium-range weather prediction model run by NOAA, the GEFS, is frequently updated and does not include an update to its reforecast data when updated, thereby making it impossible to calibrate streamflow forecasts to the operational GEFS.

Recommendation 5.2a: NOAA's National Centers for Environmental Prediction (NCEP) should adopt a reforecast update strategy closely tied to the GEFS model update cycle that includes a 1–2 year update to the reforecast model runs in order to support reliable probabilistic streamflow forecasts at RFCs. Better efforts to coordinate refreshes at regular intervals (such as every one, two, or five years) would allow for a better rebuild reanalysis and reforecasts of the model.

Focused seasonal prediction capacity on cool-season mountain precipitation is essential

Snowpack is especially critical to the state's water supply, as the vast majority of the state's water resources originate from snow accumulated in the high-elevation mountains during the cool season. A critical need identified by all water resources operators interviewed for this report is skillful seasonal forecasts focused on accumulated (or remaining as the season progresses) cool season precipitation in the watersheds important to the water resources of the state. These watersheds are primarily the watersheds in the Cascades, Sierra Nevada, and Southern California Mountains. Also important are areas important for groundwater recharge and stormwater management.

Most agencies that look into snowpack rely heavily on the snow surveys conducted by CA/DWR each year and make critical decisions on this factor between January and March. However, the CA/DWR snow surveys only deal with observed snow on the ground and do not address any large-scale predictions for snow in terms of short-term forecasts or longer-term seasonal outlooks. Snowpack forecasts are largely determined based on short lead time (generally less than one week into the future) forecasts issued by the WFOs with long-term assumptions based largely on long range outlooks and patterns discussed in products issued by CPC that give an idea of temperature and precipitation trends, but do not predict snow. Even in



Water Year 2014 streamflow volumes from the CNRFC water resources web-pages. Streamflow volumes colored by percent of average with circle sizes representing the relative average volumes at each point.
Source: www.cnrfc.noaa.gov

Lake Sabrina boat ramp dry dock April 15, 2014.
Photo credit: Courtesy of Lake Sabrina Boat Landing

above-normal precipitation water years, if snow levels (the altitude above which precipitation falls as snow and below which it falls as rain) tend to be high, a large number of precipitation events may result in very little precipitation falling as snow. This is especially typical in years when winter storms dominate with a subtropical fetch to them. As the United States Bureau of Reclamation (USBR) put it, "100% snowpack does not equal 100% runoff." Improving the forecasts available at the time of these allocations would greatly reduce risk of over- or under-allocating water from these projects and would permit decisions for greater allocations to be made earlier in the season. The USBR found that a great amount of uncertainty exists about extreme values of water supplies based on the lack of experience with forecasts at extreme levels and limited understanding of the potential impacts.

Since northern California, especially the northern Sierra Nevada into the southern Cascades, is heavily tapped for water because of its larger supply, users such as Pacific Gas & Electric (PG&E) pointed out the need for research to focus more on this area to improve forecasts and monitor climate change. One promising line of research into cool-season mountain prediction was identified by the Sonoma County Water Agency and others. They noted atmospheric river events are responsible for major fractions of the precipitation in the region. However, forecasting these remains difficult, as small shifts in a plume of moisture can make a difference between key watersheds being impacted. As the Monterey County Water Resources Agency stated "the message on drought in California varies greatly due to the various microclimates." Much of the information they obtain on atmospheric rivers comes from the Office of Oceanic and Atmospheric Research (OAR), the local NWS office in Monterey, CNRFC, and the Scripps Institute. They cited an excellent working relationship with some key partners as their reasoning for working with them.

Finding 5.3: Accumulated precipitation—typically snow—in the key watersheds of the Cascade, Sierra Nevada, southern California mountains, and groundwater recharge areas are the primary source for water resources in California and the western states, yet no focused seasonal forecast capacity exists for this all-important resource in order for agencies to make effective planning decisions and water allocations.

Recommendation 5.3a: NOAA (including CPC, RFCs, NWC, NCDC, and CPO) should invest in developing and operationalizing seasonal forecast techniques targeted at accumulated cool-season precipitation, specifically snowpack accumulation and snowmelt runoff, in the watersheds important for water resources.

NOAA can improve its water resources services by providing new tools

The CNRFC noted that despite the routine use in meteorology of normals developed with established methodology and expertise by NCDC, such as the normal daily high and low temperature or monthly precipitation for a given location, comparable normals have not been developed for data most important to water resources. These include products such as the Northern Sierra 8-Station Precipitation Index and the snow survey data critical to water resources prediction. Any averages computed have been done internally by the CNRFC or CA/DWR. Additionally, data archives need to be coordinated; however one limiting factor has long been the expense of such a dataset. A large amount of valuable historical observational information used by the CNRFC is archived by the CA/DWR, who has their own observation networks, but this is not part of larger regional or national climate archives.

Finding 5.4: The data most critical for water resources forecasting, including snowpack data, are not typically archived or analyzed at NCDC. Instead, the CNRFC and CA/DWR rely on the California Data Exchange (CDEC) and their own analytical tools for applying this data for water resources forecasting. This includes developing long-term averages or normals.

Recommendation 5.4a: NOAA/NCDC as well as the Western Region Climate Center (WRCC) in collaboration with the National Water Center should explore archiving data necessary for CNRFC forecast production and archiving (e.g., normals development, high snow elevation snowpack, snow climatology).

Lack of observations in snow cover and remote areas were also cited as forecasting challenges. In some cases, such as river gauges, the network of observations has declined slowly due to budget cuts in partner agencies over the years. It is this data from stream gauges, rain gauges, and snowfall observations that are used to calibrate hydrologic models and produce forecasts. While CNRFC is able to work on scientific advances to help make up for some of this data loss, current staffing levels do not allow the CNRFC to fully engage in modeling development work or engage in more complex snowpack research to leverage the use of some remotely-sensed snow products.

California hydropower interests use other CPC products, like Atlantic hurricane predictions, to create national energy projections

Of all the government agencies interviewed by the water resources sub-team, the State Water Project (SWP) of the CA/DWR had the greatest use of CPC products, as it deals extensively with energy trading. Despite their location in California, CA/DWR relies on the seasonal hurricane outlook for the Atlantic since it impacts natural gas consumption on the East Coast, which in turn drives up energy prices that triggers a higher cost to CA/DWR to move water around California. Additional outlooks in the one- to three-month time frame are also used, especially for energy purchases. Although the skill in these long-lead forecast products is generally quite low, the ability to access the same information as other traders provides an effective baseline for traders.

Finding 5.5: CA/DWR utilizes the Atlantic seasonal hurricane outlook and 1–3 month temperature and precipitation outlooks for energy trading for its pumping and power generation operations. Interestingly, they reported that the confidence level (even if zero skill) in these forecasts does not matter to their energy trading activities.

NOAA air and water temperature data critical in water planning

Water resource planning for many agencies is most critical in the January through April time period, as they adjust their operations and water exchanges based on cold season forecasts for precipitation. Federal and state agencies both commented on the importance of river temperature and salinity targets in their operations since it plays a critical role in the ability to transfer water through the Bay Delta (a critical nexus for moving water in both projects). Both agencies utilize NWS air temperature forecasts for their own modeling and prediction of water temperature and quality.

Finding 5.6: Air temperature forecasts are used in USBR water temperature modeling and targets for USBR water quality are important to water supply and fisheries management.

State officials need NOAA data now more than ever to facilitate water law and rights

The State Water Board has faced unprecedented challenges in administering the state's water law during this drought. In many instances, they lack basic information about water availability at the temporal and spatial scales needed to administer the water rights they oversee.

As such, they have turned to researchers at the University of California, Davis, to develop capacity to better monitor and predict water available to allocate. They noted that the drought's impact on streamflow is not understood at the level of detail needed by the Water Control Board. They proposed a significant NOAA role in expanding the surface water modeling currently done at CNRFC to model and forecast the full natural flow (FNF) at the scales needed by the Water Board (generally at the Hydrologic Unit Code (HUC) 12 level, or about 40 square kilometers). This would include linking surface water modeling (and the observations that drive it) to groundwater models as well as a rigorous accounting of all surface water depletions and accretions. This would be a major research and development effort involving at least three agencies (NOAA, USGS, and CA/DWR). If successful, it would provide an invaluable source of authoritative science-based information to the state. This could be an area that NOAA and the NWS look into as it develops the National Water Center or leverages OAR research and development assets. The CNRFC currently works with the University of California, Davis, on actual flows but the CNRFC only provides them with FNF access on special cases. Near real-time and forecast FNF values are difficult to produce given limited observational data.

Finding 5.7: There is a major need in the administration of water law and rights for scientifically defensible FNF estimates and forecasts on a daily basis to effectively administer water law during extreme drought where rights curtailments are required. (see recommendation HLF2a for corresponding recommendation)

Local water districts stated that they rely heavily on inflow forecasts for reservoir levels from CNRFC. Two water agencies the water resources sub-team interviewed also employed private sector meteorologists to augment the NOAA inflow forecasts with private sector meteorology information and forecasts. They noted that the private sector meteorologists tailored their information to a smaller scale. As noted previously, a major need exists for seasonal prediction of precipitation for water resources. While many water agencies are familiar with the current CPC precipitation outlooks and sometimes consult them for stakeholder communication, none of the agencies interviewed used the current CPC outlooks

A water fountain on the campus of Stanford University is drained of water as a conservation effort.
Photo Credit: Water Resources subteam

in any quantitative way for supporting decisions since they often lack details into their reasoning and fail to capture California's microclimates due to their larger-scale resolution.

Assessing water supply information is also a challenge in areas that depend heavily or entirely on groundwater. Many stakeholders had little idea on where to get groundwater values, sometimes due to the privately held nature of this data or communication issues between agencies on knowing how to access to it. However, at the county levels, many water management officials interviewed believed they had a good knowledge of their local groundwater supplies. Still, some officials interviewed had little to no information on groundwater supplies or had access only to data that were compiled 20 or more years ago. Thus decisions were being made on assumptions or even blindly, which could easily be underestimating the water supply in areas where groundwater is the only or primary source.

Stakeholders communication and infrastructure

Water districts note the news media's successful role in influencing water conservation

The media plays an important role in communicating drought impacts to the public. Coverage of the drought in print, broadcast, and electronic media has been extensive with many journalists covering stories on impacts to specific sectors of the economy, communities, and user groups. Broadcast meteorologists from two San Francisco market television stations both stated that the drought has gone on so long that changes to the U.S. Drought Monitor status go unnoticed unless there is a big change, such as the drought's rapid expansion in early 2014.

The Santa Clara Valley Water District and East Bay Municipal Utility District (MUD) both stated they felt media messaging of the drought was strong enough to convey to the public the importance of water conservation. East Bay MUD stated they did not even have to pay for advertising about water conservation with this drought as they have done in the past, saving the company money. Their customers have saved about 11% of water through mid-July 2014, which exceeds the goal of 10% set by the agency in February 2014. Since the drought of 2007–2009, East Bay MUD customers have cut back on water use, and water demand has dropped by 22% since 2005. Some of this is also likely due to the recession.

NOAA Water Resources Decision Support in California

NOAA's California-Nevada River Forecast Center (CNRFC) in Sacramento is co-located with the California Department of Water Resources (CA/DWR). Together, these two agencies collaborate to produce river condition forecasts and create customizable water supply briefings that play a significant role in decision support in managing state water. The co-location of these centers is a key component of the success of CNRFC and NOAA to serve the environmental intelligence needs of the state.

NOAA's 10 National Weather Service Weather Forecast Offices (WFOs) scattered in and around the state serve on the front lines for public, private, and philanthropic sector inquiries on meteorological and climatic information related to the drought. These offices issue forecasts, watches, and warnings; engage in maintaining an observing network; train weather observers; and conduct outreach and research. All of this information plays a key role in users of their products being able to make more effective water resources decisions. The WFOs collaborate closely with CA/DWR and CNRFC, which further strengthens the partnership between NOAA and the State.

Finding 5.8: Media messaging of this drought was noted by stakeholders to be effective in influencing the public to participate in water conservation.

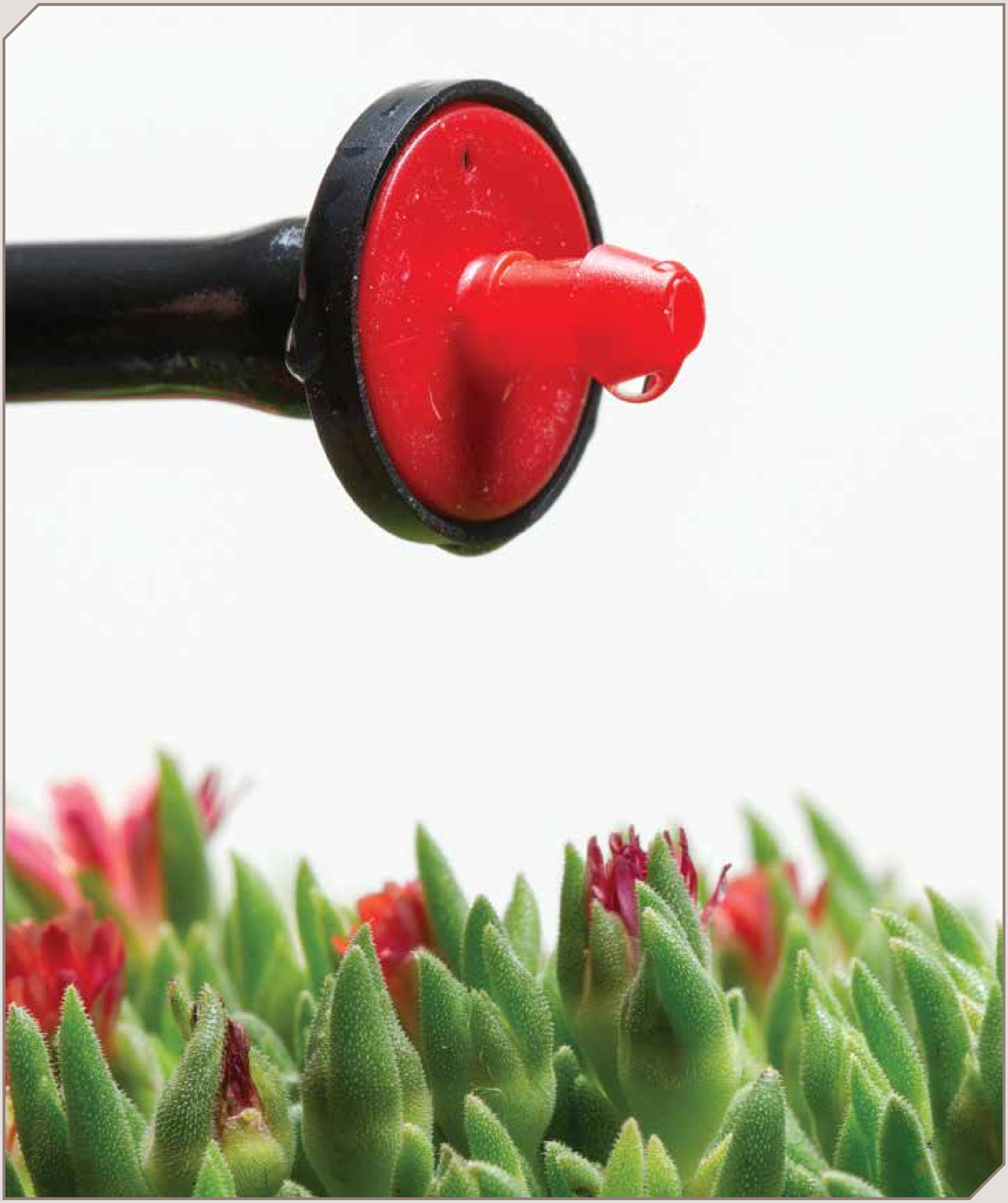
NOAA data was useful to sophisticated users, especially for research

More sophisticated users felt NOAA data met their needs for research purposes on the drought. Both staff at PG&E and researchers at Stanford University's Water in the West stated they heavily utilized NCDC's ranking maps for states and climate divisions for temperature and precipitation and found them valuable. Research users also found NCDC had a tremendous amount of data available for use on their website. NOAA's Earth System Resource Laboratory (ESRL) provides a wealth of information through the reanalysis data they provide, which helps in utilizing past drought patterns. However, at the more general public level, including the media, an understanding of this data and how to find it on NOAA webpages was lacking.

Finding 5.9: ESRL maps for National Centers for Atmospheric Research and National Centers for Environmental Prediction (NCAR/NCEP) reanalysis, NCDC ranking maps, and the NCDC webpage are useful for technical academics and research.

The Way Forward for NOAA

6



The California drought is a stark reminder that the United States is becoming increasingly vulnerable to weather, water, and climate extremes. The numerous stakeholders interviewed for this assessment underscore the important role NOAA data and information play in business, community, and household decisions. They are calling for more tailored products, consultation, and timely research.

The previous three Chapters highlight specific actions NOAA can take to help our partners safeguard California's economically important agriculture, water resources, fisheries, and coastal environments from the drought. This section outlines the larger-scale findings voiced by our stakeholders, which intersect NOAA's many mission elements and affect our larger user base. The recommendations listed were developed with input from NOAA employees in the state who work directly with many of these stakeholders and are familiar with their concerns.

Bottom line: Investments and improvements made now in NOAA science and services in California will enhance our partners' ability to make effective decisions in mitigating this drought and future droughts. Additionally, new research products, improved data tools, or best practices developed in California may be applicable elsewhere in the United States.

Matching NOAA investments in science, data, and forecasts to stakeholder needs

Improve skill, confidence, external communication, and internal education in seasonal climate and hydrologic prediction

A majority of the stakeholders interviewed for this assessment noted one of the best services NOAA could provide is improved seasonal predictions with increased confidence and better interpretation. These seasonal prediction products, produced by NOAA's Climate Prediction Center (CPC), are national in scale and are not designed to provide regional forecast information—information which is most relevant to decision makers interviewed by this team. For instance, federal and state officials managing California's water supply have a major unmet need for skillful predictions targeted at cool-season snowpack for the Sierra Nevada Mountains. Targeted forecasts for this important variable are not currently provided by NOAA's CPC because they only focus on a national outlook treating all areas equally even though water resources are disproportionally generated from relatively small areas in the mountains of the West. Having this type of information would be extremely valuable, as the number one question California water interests ask relates to how much precipitation these mountains will get this winter. More broadly, the Water Council recently adopted a position statement calling on federal agencies to support and maintain such a forecast capability (Western States Water Council 2014).

Interviews with NOAA's California-based Weather Forecast Offices (WFOs) and River Forecast Center (RFC) made it clear that product interpretation challenges exist within NOAA's National Weather Service (NWS) national centers (particularly the CPC), headquarters, regions, and even between WFOs themselves. These challenges include: consistent messaging on the near-term predictions and the role of a potential El Niño event; coordination of media and stakeholder engagements; and internal communication on the education of forecasts and prediction products. Numerous stakeholders, particularly those in the agriculture and water resources sectors, noted that the current generation of seasonal climate forecast products are not focused on the most critical regions or timeframes and contain too low confidence to be useful in their decision making. In particular, stakeholders expressed a strong and consistent need for forecasts focused on cool-season precipitation in the mountains. Furthermore, fisheries sector stakeholders find these products to not be particularly useful in local watershed planning projects because these products are nationally scaled.

High Level Finding (HLF) 1: Great interest exists for seasonal prediction products and El Niño Southern Oscillation (ENSO) discussions (monthly), especially for cool-season precipitation. These forecasts, however, typically have very low skill and confidence, rendering them near-useless for most decision makers interviewed. Further, the CPC forecast products were often prone to misinterpretation by both NOAA field offices and external stakeholder agencies.

Recommendation HLF 1a: NOAA should acknowledge the major importance of cool-season precipitation in providing water not only for California but for the western United States. As such, the Office of Oceanic and Atmospheric Research (OAR) should synthesize the state of research on predictability of accumulated cool-season precipitation in the mountains and scope an operational forecasting capability that is closely linked to supporting the water resource management community.

Recommendation HLF 1b: The CPC should work more closely with front line offices, especially the RFCs and WFOs in the NWS, to understanding local uses of and needs for seasonal prediction and how to more effectively communicate them to the public. Additionally, the effectiveness of internal education on seasonal prediction products should be assessed. To address this recommendation, NWS should develop a plan for improving two-way communications between CPC and field offices, documenting stakeholder

Chapter Photo: Drip emitters along with drought-tolerant plants are a good way to conserve water.
Photo Credit: Courtesy of California Department of Water Resources; John Chacon

use cases and requirements for seasonal prediction, and assess the effectiveness of internal education on seasonal prediction.

Improving NOAA collaboration with partner agencies and organizations

Broaden river forecasting tools to be more inclusive of the whole hydrologic system

In interviewing local decision makers, a consistent message was that NOAA's National Weather Service river forecasting services are too narrowly focused on certain elements of the hydrologic cycle. These river forecasting services are generally designed to monitor and predict flooding events and, in turn, produce flood watches and warnings to affected communities to reduce the loss of life and property. Low flow conditions do not pose flood dangers, thus, they are not traditionally the focus of NOAA's River Forecast Centers.

Engineer reviews river restoration design.
Photo Credit: Courtesy of California Department of Water Resources; John Chacon

Stakeholders, including NOAA's fisheries service, the state water board, agricultural water users, and many others, expressed high interest in forecast and monitoring efforts for the full range of hydrologic conditions including both high and low flows in order to show the interconnectedness between groundwater, salinity, local winds, fish populations, and more. In addition, the long-standing water supply forecast program in the western United States was extensively used by stakeholders in the region despite its low profile in the standard suite of climate and drought products offered by NOAA.

High Level Finding HLF 2: Many water decision makers—water boards, fisheries managers, coastal ecosystem planners, and recreational water users in particular—require a "whole" view of water system environments (physical and biological elements). NOAA river forecast models are typically designed for the purpose of forecasting flooding but are also increasingly used for low flow and water supply. For drought, a "full natural flows" model of surface water, including fluxes with ground water and its anomalies, is needed for fisheries managers, water boards, maritime industries, and others to support their actions mitigating the impact of drought at the sub-watershed scale.

Recommendation HLF 2a: NOAA should initiate (or expand through existing Integrated Water Resources Services and Science Memorandums of Understanding (MOUs)) a partnership among other federal and state agencies (particularly U.S. Geological Survey (USGS) and California Department of Water Resources (CA/DWR)) and other stakeholders for scoping modeling and monitoring activities needed to estimate and forecast full natural flows (FNFs) in streams and rivers in California. This will significantly enhance capacity and expertise in streamflow forecasting. Continuous low flow forecasting is essential for estimating impacts of drought and managing water resource, for which knowledge of groundwater and long-term snowmelt contribution to streamflow is critical. An added benefit of this approach will be significant scientific advances in ecohydrology and explicit inclusion of hydrologic variables in ecosystem-based studies.

Continue NOAA Habitat Blueprint and Hydrometeorological Testbed programs, as they are successful models for agency-wide and partner collaboration in drought planning

NOAA's Habitat Blueprint approach and Hydrometeorological Testbed were declared by many NOAA interviewees as a "success" by offering a platform for cross-line office and cross-disciplinary coordination, including placement of new gauges, and in water-release scenarios.

Recognizing the need for more concerted efforts to conserve (protect and restore) habitat, NOAA in 2011 developed a "Habitat Blueprint" agency-wide project concept. Focused on a specific site (e.g., California's Russian River), NOAA experts from across the agency (weather, satellites, climate, fisheries, oceans, and coasts) came together alongside local partners to determine ways of improving habitat conditions for fisheries and coastal and marine life.

Prior to the Habitat Blueprint for the Russian River, NOAA Restoration Center employees hadn't had a connection with NWS offices. As a result of the Habitat Blueprint process, NWS has offered tailored forecasts and data that helped in project planning.

High Level Finding HLF 3: NOAA's Habitat Blueprint and Hydrometeorological Testbed are examples of successful NOAA models for intra-agency and interagency collaboration, and for engaging with the research community.

NOAA has an opportunity to utilize these successful interagency frameworks to increase resilience to drought and other natural variability. In particular, through partnering with water resources management agencies to apply NOAA's environmental intelligence, NOAA could act as a change agent for increased resilience.

Recommendation HLF 3a: NOAA should expand the scope of the Hydrometeorological Testbed (HMT) in partnership with water resources agencies and other science organizations to promote "forecast-based reservoir operations," scope and develop the needed forecast methods, and develop relevant decision support models in order to enhance California's ability to mitigate potential drought impacts.

Strengthening NOAA internal coordination and communication

NOAA needs to invest in modern mapping and graphics technologies at a national level

NOAA line offices in California dealing with water resources frequently conduct outreach efforts with stakeholders through in-person meetings, conference calls, webinars, and social media. These stakeholders had varying needs, from requiring data and forecasts to make decisions on handling water supplies to communicating drought, weather patterns, and climate information to users. This group of stakeholders largely worked with the WFOs.

WFOs Sacramento and Monterey focused on making NWS and NOAA products more known to users. However, a lot of effort is also placed on clarifying products to make them more user-friendly. For example, the Monterey Warning Coordination Meteorologist (WCM) makes a visit at least once every six months to each of their county's Office of Emergency Service (OES) and gives an update on the products and services the WFO provides. This is in addition to meeting with the media as well as water management and municipal utility districts. Many of these partners expressed high praise for visits by the Monterey WCM as they made the flow of information better and made national-scale and highly technical products more personal and localized.

Tools for drought outreach are often created in-house at the WFOs or through partner agencies that the WFOs interact with. Both WFOs sought effective mapping interfaces, visuals, and resources from partner agencies to which they could refer people who were seeking information on the drought. Stakeholders interviewed stated that default national-level products, such as the U.S. Drought Monitor (USDM), drought outlook, and other CPC outlooks, lacked the level of detail and clarity they sought, and that the WFOs had more expertise in local effects and interpreting national products to a local scale. The resolution of national-scale graphics was coarse enough that one user at the Department of Water Resources stated it often appeared as though "CPC just put a big blob over California" with respect to their temperature and precipitation outlooks.

Given this, staffs at the WFOs spend time creating their own graphics to modernize the look of the mapping interfaces from DIFAX-era looking maps or to show more local detail from national or regional scale maps. However, the capabilities for this vary by office. The Enhanced Data Display (EDD) was developed by the NWS in Charleston, West Virginia, as part of the Weather-Ready Nation Pilot Project and is one tool WFOs have promoted as a way to obtain data visually. However, WFOs have received mixed feedback on this display tool. While partners and the public have found the look of the maps more desirable compared to traditional maps issued by the NWS, feedback was given that some customers have found that it takes too long for the maps to load on the internet and that they have to wait several minutes to generate a map, especially if bandwidth is limited. Additionally, tools are limited with most offices using Microsoft PowerPoint to design graphics. Graphics and mapping interfaces were designed by only a handful of staff members at WFOs who had self-taught knowledge of graphic design or completed Geographic Information System (GIS) courses on their own. Despite the limited amount of staff with these increasingly important skill sets, these graphics are becoming more popular. Graphics are now a key component of WFO content on social media and are heavily used in email briefings to partners as WFOs transition toward a more visual communications interface.

High Level Finding HLF 4: Graphic material generated by NOAA for stakeholders impacted by drought is typically created ad hoc by WFO staff trained in meteorology or by national centers with greater graphics and analytical capabilities in house. WFOs need better graphics and analysis capabilities to meet the growing visual medium being used as a communication tool in the NWS.

Recommendation HLF 4a: WFOs and NWS national centers alike should be equipped with modern graphics and analysis support software and equipment. Staffs should also receive regular trainings to ensure their data visualization skills are up to date.

Recommendation HLF 4b: The NWS Western Region has some graphic software and online training in its Decision Support Services toolkit. NWS should consider promoting these elements to other regions.

NOAA is not structured to efficiently support the provision of environmental intelligence for drought

This report has documented the importance of local NWS field offices, WFOs, and RFCs, for providing critical environmental intelligence to stakeholders. While this structure is a strength for the agency given the geographic distribution of these field offices, it is also hindered by its organization.

Neil Rambo (CA/DWR senior environmental scientist specialist) secures a land weather station on a peninsula at Folsom Lake near Granite Bay, California, on January 8, 2015. CA/DWR (California Department of Water Resources) collaborated earlier in the day with DRI (Desert Research Institute) and Mid- Pacific Region Bureau of Reclamation to install a buoy containing CIMIS (California Irrigation Management Information System) weather station sensors with additional energy flux sensors to monitor evaporation at Folsom Lake. Photo Credit: Courtesy of California Department of Water Resources; Florence Low

WFO's are hampered by outdated and limiting position staffing structures. Position descriptions have changed little in the 20 years since they were created during the modernization and restructuring (MAR) of the NWS, when they were driven by the core functions of forecasting, warning, and collecting observations. Now WFOs are increasingly called on to provide decision support services, such as in-person or virtual briefings and transmitting information in graphical format, exemplified by the highly successful original analyses and social media posts from WFO's Hanford, Sacramento, and Monterey. However, this has been difficult to replicate widely, as the communications, graphic arts, and social media skills widely vary among staff within all NOAA WFO field offices. This significantly impacted the WFOs' ability to increase their level of decision support for drought and to balance that with ongoing mission duties. The National Academy of Public Administration report ***Forecast for the Future: Assuring the Capacity of the National Weather Service*** (2013) on the NWS modernization echoed many of these concerns.

One of the main challenges WFOs expressed was the ability to interact with customers. While WFOs found no shortage of customers to interact with, the lack of resources to do so was the biggest challenge, in addition to finding ways to meet with partners they are not usually in contact with. WFO personnel assigned to work on the drought essentially performed work related to it—along with other climate services—in tandem with other duties and not as a full-time position. Ongoing staffing shortages in the NWS field offices have resulted in fewer bodies available for in-person outreach, since forecasters, hydrologists, and field office management have had to cover an increasing number of vacant operational shifts during this drought. WFO staff felt they had no choice but to curtail some outreach altogether even though requests were there. WFOs also reported the federal government shutdown in October 2013 resulted in cancelled meetings with partners that hurt relationships. For WFO Monterey in particular, the size of the area it serves and its physical location relative to the population centers is a challenge. WFO staff must often spend two to three hours each way driving to a meeting, which easily consumes an entire day. Some parts of the WFO Monterey County Forecast and Warning Area (CFWA) can take up to five hours to travel to. This includes the Russian River area, where a major research project is taking place.

Among the stakeholders interviewed, several recognized challenges with their ability to interact with the WFOs. PG&E worked extensively with the CNRFC. They also participate in the annual Extreme Precipitation Conference at the University of California, Davis. PG&E felt that a lot of research efforts in meteorology as a whole were piecemeal and that there was a need for NOAA to work more with universities, other government agencies, and private sectors to hold a local meeting at least once a year, either in person or virtually, to discuss research and needs of those with weather-related interests. The Monterey County Water Agency felt that the nature of turnover in NWS field office staff hurt local expertise with the forecast. They felt there was a difference between the expertise of someone with 20 years of experience and newer staff in their understanding of local weather patterns and concerns.

Many of the same budget constraints are also affecting national and regional centers and labs that provide critical environmental intelligence for drought. The ability of these national centers to meet with stakeholders—both external and internal to NOAA—has been dramatically curtailed over recent years. There is no question that these impacts have reduced NOAA's ability to coordinate internally and to meet the needs of external stakeholders. Nonetheless, NOAA needs to develop more effective ways to meet these challenges going forward in what will likely continue to be a budget-constrained environment. More effectively connecting capabilities and resources internally and serving stakeholders through local field offices is a philosophical approach we believe has merit. Regional capabilities such as the NWS Western Region Headquarters and its Regional Operations Center and Climate Services Program Manager, as well as NESDIS's Regional Climate Services Directors (RCSDs), are assets that should be utilized for these coordination functions.

High Level Finding HLF 5: Reduced staffing levels and staffing skills, especially in decision support, at WFOs and at national and regional centers, as well as the physical location of certain WFOs (particularly Monterey), have hurt the ability to effectively apply the depth of NOAA's forecasting, data, and science assets to stakeholder decision making impacted by the California drought.

Recommendation HLF 5a: NOAA should identify opportunities to utilize the field structure of the NWS to more effectively provide drought-related environmental intelligence. Over the long term, as opportunities and funding arise, WFOs in particular should be better optimized to provide the full suite of environmental intelligence offered by NOAA. This may include changes to staffing structure, office locations, and the supporting regional structure.

Unite NOAA national and local offices in external communications, and share best practices with one another

A positive result of the California drought has been that WFOs have taken steps in improving communications with external audiences. A WFO's primary communications vehicle is to conduct a weather briefing for state and local partners, and post forecast data online for public access. However, offices within California have taken new steps to better reach their audiences through more proactive tools, such as email listservs, social media posts (Facebook, Twitter), and regular teleconferences with each other and other federal agencies. CA/DWR noted that the WFOs sometimes do not accurately reflect the water supply status of the state and that potential exists to improve communications describing water supply through coordination with CA/DWR and CNRFC.

One such call—that helps guide federal aid and assistance from USDA—is the standing biweekly discussion with those who provide input into the U.S. Drought Monitor described in Chapter 3. Key players on these calls include NOAA, the USDA Farm Service Agency, the Western Regional Climate Center, and State Climatologists. The authors of the U.S. Drought Monitor are on those calls and use input that informs the weekly drought monitor map. However, these calls inadvertently focus on NWS staff while omitting key partners, such as USGS, local water managers, or federal/state snow surveyors, and thus rosters should be examined.

High Level Finding HLF 6: NOAA communications and analyses describing the drought status, historical context, and forecasts for drought were well received by stakeholders and helpful in supporting their decision making. A more cohesive approach among major NOAA entities (especially RFCs) to keep our local WFOs in the loop on national products and drought conditions (e.g., water supply) would enhance their ability to communicate drought relevant data, forecasts, and science to their constituents. Many WFOs have established email lists to notify external stakeholders—particularly other government agencies with capacity to mitigate drought impact—about important weather and climate information related to the drought, including longer-term seasonal predictions such as El Niño. Social media posts from the WFOs on regular drought data products—as well as non-weather items (e.g., impacts of dry conditions on livestock)—keep external partners updated on important data and keep their public followers interested on the drought's importance.

Recommendation HLF 6a: NOAA should more effectively utilize WFOs and their direct connection to state and local stakeholders to communicate environmental intelligence. NOAA should also use this process to learn from stakeholders about their drought-impacted decisions and communicate back to national NOAA drought service providers such as NCDC, CPC, and NIDIS. Further, these service providers should be encouraged to better work with and through local NWS offices, and NWS should be encouraged to be a more effective provider of the full range of environmental intelligence offered by NOAA. In particular, for water resources, NOAA and CA/DWR should enhance coordination between the water resources expertise at CNRFC and CA/DWR and the WFO communication activities.

NOAA needs to define its role in decision-support for drought risk communication and management

NOAA's line offices each have their own strengths and identity; however, with drought crossing multiple scientific disciplines, an agency-wide vision is needed to define the agency's decision support for drought. Using the work of the National Integrated Drought Information System (NIDIS) and the NIDIS Act of 2006 (P.L. 109–430) and the NIDIS Reauthorization Act of 2014 (P.L.113–86) as a guide, NOAA must create an approach that ensures smooth coordination and generates collaboration among the line offices.

To be clear, NOAA's response to the California drought was not well coordinated or even well communicated between line offices and the agency's centers and programs within them. The team encountered many examples of NOAA entities working independent of each other and sometimes at cross-purposes to each other.

In just one example, the team found that NIDIS was conducting drought workshops and discussions with CA/DWR while National Weather Service/Western Regional Headquarters (NWS/WRH) was providing California's OES with regular updates and discussions without any knowledge of the others' activities. In another example, local WFO staff coordinated media messaging internally and with each other, while CPC and NCDC staff interacted with media and were unconnected to that coordination. While recognizing NOAA is a large and complex agency and that internal coordination will never be perfect, there is major opportunity to improve NOAA's effectiveness in providing environmental intelligence for drought through a more cohesive team-oriented approach.

One way to spearhead interagency coordination could be through drought "gaming" or scenario exercises. Scenario exercises have been utilized successfully in other regions for drought (e.g., Canada and Colorado) as well as for other hazards (e.g., dam break tabletop exercises). Development of these drills would serve as a way for NOAA line offices to test ways to coordinate better and strengthen internal collaboration. These trainings could be scheduled when drought is not present or is expected to develop or worsen.

NOAA needs a comprehensive and inclusive plan for providing the suite of environmental intelligence it brings to drought-impacted decision makers. This plan should encompass the existing successful decision support tools being deployed, such as the Drought-Ready Communities guide developed by the National Drought Mitigation Center and NIDIS, regional climate webinars, brochures, and social media posts. Additionally, such a plan should include line office outreach and research that draw on findings conducted by preparedness and exercise events. Such an effort would lead to new methods and ideas of what decision support means to each line office and ultimately NOAA as a whole.

High Level Finding HLF 7: Despite existing interagency and intra-agency efforts like NIDIS, NOAA is not currently well integrated and, in the case of California drought, did not effectively draw on its many assets to communicate about a slow-onset, cross-sectorial disaster like drought.

Recommendation HLF 7a: NOAA should develop a plan for more effectively communicating the environmental intelligence required by stakeholders to plan for and mitigate the impacts of droughts. This plan should utilize the strengths across the agency, especially those at the NWS WFOs and RFCs, the NWS CPC, the NWS NWC, the NESDIS NCDC (including RCC), OAR NIDIS, OAR CPO (including Regional Integrated Sciences and Assessment (RISA)), and OAR Earth System Research Laboratory (ESRL). This plan should identify and empower cross-line office teams, such as the regional collaboration teams, and individuals, such as the regional climate service directors, to coordinate and leverage NOAA's environmental intelligence assets.

Recommendation HLF 7b: To test its plan and to promote the line office coordination needed to deliver drought environmental intelligence, NOAA should consider "drought gaming exercises" or drills that are coordinated across NOAA line offices with drought decision support responsibilities every three to five years. These exercises should be led by NIDIS and developed through all NOAA line offices to understand interagency issues on drought, including environmental impacts.

Recommendation HLF 7c: In addition to NIDIS, the Warning Coordination Meteorologists and Service Coordination Hydrologists at the National Weather Service and the Regional Climate Service Directors should take a lead role in these exercises, assessing ways to integrate into existing state and local preparedness and planning efforts and to improve NOAA cohesiveness for drought decision support.

In closing, drought is much more than a climate problem, it is a communication challenge

A primary goal of this report is to serve as a catalyst for further discussions within NOAA's offices about enhancing our drought products, services, and messages. A cohesive and coordinated NOAA working to support drought planning, preparedness, and mitigation, would be both more effective and a much better partner across federal, state, Tribal, and non-governmental partners than the current situation. While this report outlines a number of findings and recommendations, executing these ideas and others like it depends on the talents, resources, and expertise of NOAA employees. The authors of this report, which represent all of NOAA's line offices, have all expressed willingness in facilitating these discussions.

Spring 2015 will reveal clues about how the California drought will continue to evolve. The state needs a much above-average number of storm systems, particularly 'atmospheric river' storms that produce a healthy snowpack, to ensure an adequate water supply. But it's clear that California residents and businesses in the state and across the Nation must be prepared for any condition—wet or dry. Regardless of what happens, we hope recommendations from this report will be valuable for future years and for drought situations in other parts of the country.

The Folsom Dam auxiliary spillway construction site on February 26, 2014.
Photo Credit: Courtesy of California Department of Water Resources, Florence Low

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California Cattlemen's Association
California Department of Natural Resources
California Department of Water Resources
California Governor's Office
California Governor's Office of Emergency Services
California Rural Water Association
California State University, Fresno, Center for Irrigation Technology
Central Valley Project/USBR, Sacramento, CA
CSU Monterey Bay/NASA Ames Research Center Ecological Forecast Lab
Delta Stewardship Council
East Bay Municipal Utility District
Fresno County Office of Emergency Services
Golden Gate Salmon Association
KGO-TV, San Francisco, CA
KNTV, San Jose, CA
Metropolitan Water District, Sacramento, CA
Monterey County Water Resources Agency
Natural Resources Defense Council
NOAA/NWS California Nevada River Forecast Center, Sacramento, CA
NOAA/NWS Weather Forecast Office, Hanford, CA
NOAA/NWS Weather Forecast Office, Monterey, CA
NOAA/NWS Weather Forecast Office, Sacramento, CA
NOAA Restoration Center
NOAA Southwest Fisheries Science Center
NOAA West Coast Fisheries
Pacific Gas and Electric Company
Sacramento Bee
Sacramento Municipal Utility District
San Joaquin County Office of Emergency Services
Santa Clara Valley Water District
Sonoma County Water Agency
Sonoma County Winegrowers Association
Stanford University's Water in the West
State Water Contractors, Sacramento, CA
State Water Project, Sacramento, CA
State Water Resources Control Board, Sacramento, CA
University of California Cooperative Extension
University of California Davis
USDA Farm Service Agency California Programs

THANK YOU!

Appendix I : Acronyms

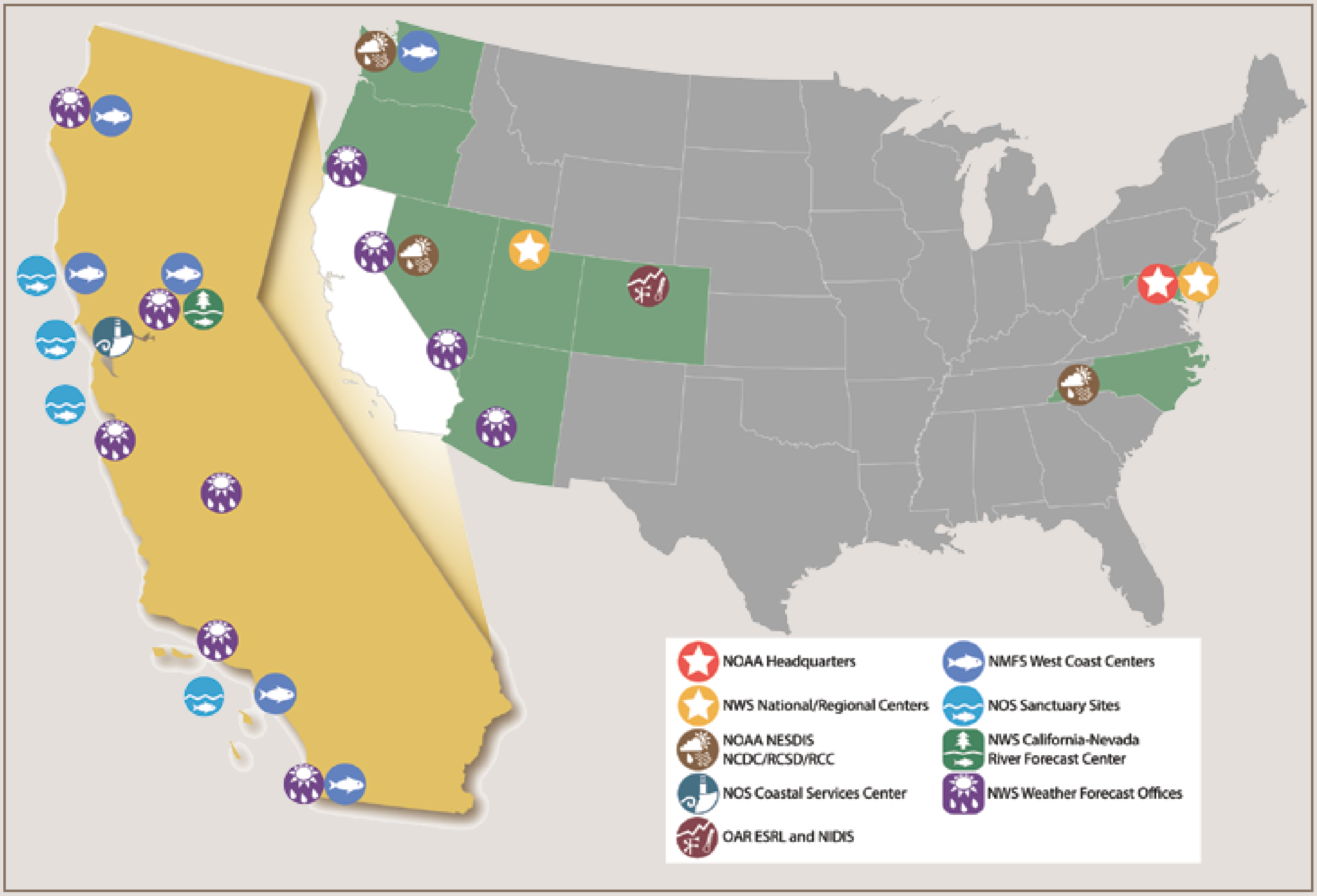
CA/DWR	Department of Water Resources (California)
CDEC	California Data Exchange Center
CFWA	County Forecast and Warning Area
CNRFC	California-Nevada River Forecast Center (NOAA)
CPC	Climate Prediction Center (NOAA)
CPO	Climate Program Office (NOAA)
DGT	Drought Information Statement
DIFAX	Digital Facsimile
EDD	Enhanced Data Display
ENSO	El Niño Southern Oscillation
ESP	Ensemble Streamflow Prediction
ESRL	Earth System Research Laboratory
FNF	Full Natural Flow
FRET	Forecast Reference Evapotranspiration
FSA	Farm Service Agency (USDA)
GEFS	Global Ensemble Forecast System
HMT	Hydrometeorological Testbed (NOAA)
IWRSS	Integrated Water Resources Science and Service
LANDSAT	Land Satellite (USGS)
LFP	Livestock Forage Disaster Program
MAF	Million Acre Feet
MUD	Municipal Utility District
NCAR	National Centers for Atmospheric Research
NCDC	National Climatic Data Center (NOAA)
NCEP	National Centers for Environmental Prediction
NDMC	National Drought Mitigation Center (University of Nebraska-Lincoln)
NESDIS	National Environmental Satellite, Data and Information Service (NOAA)
NIDIS	National Integrated Drought Information System
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service (NOAA)
NRCS	Natural Resources Conservation Service
NWC	National Water Center (NOAA)
NWS	National Weather Service (NOAA)
OAR	Office of Oceanic and Atmospheric Research (NOAA)
OCM	Office for Coastal Management (NOAA)
OES	Office of Emergency Services
PG&E	Pacific Gas & Electric Company
PORTS	Physical Oceanographic Real Time System
RCSD	Regional Climate Services Directors
RFC	River Forecast Center (NOAA)
RISA	Regional Integrated Sciences and Assessment (Program)
SARP	Sectorial Application Research Program
SMUD	Sacramento Municipal Utility District
USBR	United States Bureau of Reclamation
USDA	U.S. Department of Agriculture
USDM	U.S. Drought Monitor
USGS	U.S. Geological Survey
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office (NOAA)
WRCC	Western Regional Climate Center

Appendix II : NOAA in California

California is well-served by NOAA centers, programs, and offices with responsibilities for providing environmental intelligence to drought-impacted decision makers. These offices are distributed both within California and around the country (see figure). In particular:

- NWS Weather Forecast Offices with responsibilities for producing local forecast and for conducting local decision support activities.
- NWS California Nevada River Forecast Center with responsibility for generating streamflow forecasts and supporting water management agencies.
- NWS Climate Prediction Center with responsibility for generating seasonal forecasts and outlooks.
- NWS Regional and National Headquarters with administrative oversight and regional and national decision support capabilities
- NESDIS National Climatic Data Center with responsibilities for archiving, serving, and analyzing current and historical drought-related data
- OAR Climate Program Office and NIDIS program office with responsibilities for planning and executing activities related to NIDIS
- OAR labs, particularly ESRL/PSD, with responsibilities for conducting research related to drought
- NOAA's National Marine Sanctuaries
- NOS Office for Coastal Management (formerly Coastal Services Center) with responsibilities for working with coastal communities
- NMFS Regional Offices with responsibilities for managing and regulating fisheries

As noted in Chapter 6, NOAA's portfolio is complex.



Chapter 3: Agriculture

Finding 3.1: While we recognize many Weather Forecast Offices (WFOs) in California have had an ongoing interaction with the agricultural sector, the interaction appears to be uneven across the WFOs, with the perception being that only limited interactions with the agricultural community are allowed. Congress' mandate in the 1990s to privatize weather services, and the confusion surrounding what is allowed in terms of engagement and product delivery and support, has nevertheless curtailed interaction with an extremely important sector for California and the United States as a whole.

Recommendation 3.1a: While following current NWS policy for public-private partnerships, National Weather Service (NWS), as well as other NOAA line offices, should develop a new dialogue with California agricultural producers regarding the delivery and accessibility of agricultural weather and climate products and services. While we note this is an issue for the United States as a whole, it is particularly important in California given the ongoing status of drought and the importance of California's agricultural products to the country.

Finding 3.2: WFOs in Northern California are conducting a pilot project, initiated in 2014, to help better evaluate workload needs during inactive weather forecast shifts, called "green days." This helps relieve forecasters who otherwise would be required to work a forecast desk and allow them to conduct professional development or outreach away from the office. The Hanford WFO is currently using the workload assessment process to re-engage agricultural producers in their service area particularly in regards to drought and frost/freeze concerns.

Recommendation 3.2a: WFOs nationally should employ a similar workload assessment on "green days" to help expand partner engagement roles in the office to beyond just the Warning Coordination Meteorologist.

Finding 3.3: A high degree of misinformation exists regarding El Niño and what it could mean to California in terms of winter precipitation and temperatures. In the third year of this extreme drought in California, the NWS, WFOs and others devoted a significant amount of time explaining the impacts if an El Niño were to form and that it does not guarantee increased precipitation for all of California. There was also a perception by the WFOs that NOAA technical and communications staffs in national centers did not realize or understand the connotation El Niño brings to California given the lingering memory of the 1997–98 event. As a result, the WFOs and other regional partners spent much time working to correct misperceptions and encouraging citizens to be prepared for the drought to continue. El Niño in particular has become an emotive word with a connotation that varies by sector, region, and personal experience. In California, stakeholders interviewed frequently associate El Niño with wet extremes that are not reflected by the data, particularly for weak El Niño events. During strong El Niño Southern Oscillation (ENSO) events, and in regions that have teleconnections with ENSO, it may make sense to issue an official statement on ENSO. During weak or marginal events, however, it can cause confusion and misinterpretation of potential impacts. One prominent stakeholder in California reflected that he wished NOAA would not talk about El Niño at all as it created significant confusion for him. An alternative approach could be not to focus on whether an ENSO event will occur but instead on the associated impacts, such as the potential for emerging events or, in the case of California, the possibility of ameliorating or intensifying the ongoing drought. This will require an analysis that draws on the expertise and partnerships from all of NOAA's offices and programs.

Recommendation 3.3a: NOAA, through National Weather Service/Climate Prediction Center (NWS/CPC) and other offices providing climate services, should evaluate the purpose and effectiveness of issuing an El Niño or La Niña Watch.

Recommendation 3.3b: NOAA, through NWS regional offices, National Integrated Drought Information System (NIDIS), and the Regional Climate Services Directors (RCSDs), should create an operational communications plan for drought events that would (1) improve technical coordination between the NOAA national centers and the WFOs, particularly for emerging events or areas where an existing event could intensify; (2) ensure consistent public messaging by including broadcast media and private sector partners; and (3) ensure mechanisms are in place for coordination with other federal and state agencies. For example, in California, following CPC's release of the El Niño Watch, supporting text and figures could have been provided to the WFOs to improve their partner emails and social media outreach. These figures and communications would have specifically addressed what El Niño means to California, what precipitation and runoff previous strong/weak events resulted in, and how they vary over space and time.

Finding 3.4: Given the slow-onset, incremental, and cumulative nature of drought, it is critical to continually contextualize weather and climate information so that stakeholders can anticipate opportunities if the drought improves, or risks if it intensifies. The WFOs are a trusted local source for many agricultural producers; therefore, they should be a key messenger for this type of information. In the context of drought, however, the significance and importance of the WFOs consistently serving as an information broker between agricultural producers and climate products and services is not recognized within NOAA nor is there an overall strategic approach and direction.

Recommendation 3.4a: NOAA should invest in products and processes that would help support or complement seasonal forecast information (e.g., maps, summary statements that include forecast confidence and note key uncertainties in the outlook). Additionally, teleconferences to answer frequently asked questions from a national perspective should include recognizing the WFOs, which are in many cases the local trusted source for providing the information.

Recommendation 3.4b: As part of the Weather Ready Nation process and in coordination with NIDIS, NWS should conduct an assessment to identify where WFOs, River Forecast Centers (RFCs), and national centers have been successful at communicating climate information, and in particular slow-onset disasters like drought. Ideally, NWS would identify where climate information is currently successfully communicated (e.g., NWS Climate Service Program Managers) and where capacity is lacking to provide this information. In addition, NWS should consider the emerging role and capabilities of the National Water Center (NWC) and the NIDIS Drought Portal in supporting drought and climate information.

Recommendation 3.4c: On national and regional scales, excellent models already exist for providing interpretive information at seasonal timescales. Examples include the regional webinars coordinated by the National Climatic Data Center's (NCDC) Regional Climate Services Directors (e.g., Central and Southern regions) and the Monthly NCDC/CPC Climate Services Teleconferences for Media and Stakeholders. Working with the WFOs and other regional groups like the Western Regional Climate Center (WRCC) and the Western Governors Association, NOAA should develop a similar process for routinely interpreting climate and weather information in California and the western region as a whole. For example, an internal webinar already exists led by NCDC's Climate Monitoring Branch. The webinars were developed explicitly for NOAA personnel at the WFOs to provide them advance notice of and decision support for CPC's seasonal outlook products. It is not clear, however, if the existence of these webinars is widely known among the WFOs.

Finding 3.5: Agricultural users are not clear about how the USDM is produced, what the process is for reporting impacts, or how impacts reported inform the U.S. Drought Monitor (USDM) process.

Recommendation 3.5a: The Sacramento WFO has a bi-weekly coordination call with all WFOs in California and Nevada, along with the RFC, state climatologists, and Farm Service Agency (FSA). Impact information is shared along with suggestions for changes to the USDM, which is then communicated in a single summary to the USDM author. NOAA, working through the WFO/Western Region Headquarters, NIDIS, and the Regional Climate Services Director (RCSD) for the Western Region, should evaluate the bi-weekly calls, determine how effective they were at communicating drought conditions given California's unique circumstances, and whether all sectors (e.g., agricultural sector) are involved in the process.

Recommendation 3.5b: Working through state and local groups (such as the California Cattlemen's Association and the California Agricultural Commissioners and Sealers Association), NIDIS, the National Drought Mitigation Center (NDMC), and U.S. Department of Agriculture (USDA) should produce a short summary describing the USDM, how it is assembled each week, and what the various drought levels mean. They should also explicitly state how agricultural and other users could supply information to the USDM (e.g., what types of impact information are needed). NIDIS/NOAA, NDMC, and USDA should also conduct a series of outreach and education webinars in California given the ongoing status of drought. The webinars and in-person meetings would also help to establish better relationships for impact information collection.

Finding 3.6: Forecast Reference Evapotranspiration (FRET) is an experimental product produced by NWS that has the potential to be useful for several sub-sectors of the agricultural community. Currently FRET is poorly advertised and it is unclear what if any evaluation is being done regarding who is using the product.

Recommendation 3.6a: The FRET product should be actively advertised to agricultural stakeholders, and an evaluation of who is using it and how it is being used should be conducted. Depending on the success of the product, NWS should consider expanding FRET nationally.

Recommendation 3.6b: NWS web standards should be updated to include evapotranspiration data in the point-and-click forecast pages, which users routinely bookmark as a single-source for weather information. Drought status information should also be included in these pages.

Finding 3.7: The DGT product has the potential to be a valuable tool for monitoring impacts related to drought. However, it does not use current technology and does not seem to be connected to the USDM process. Therefore, in its current form is not a useable or useful product. We also note the problem with the DGT is just one example of a more systematic issue with NWS legacy products using outdated technology.

Recommendation 3.7a: NWS should reevaluate the Drought Information Statement (DGT) product, how it could be modernized to take advantage of current technology (use of images and user notifications of updates), and how this product supports NWS drought communication, such as the USDM process, partner emails, or weather stories.

Finding 3.8: The number of fog days is an important component of agriculture in California's Central Valley; fog formation has high interannual variability, however, and it is not clear why over the last 30 years the number of fog days has declined.

Recommendation 3.8a: NOAA research programs should consider investigating fog trends along the West Coast and the processes contributing to the interannual variability of its occurrence in the winter.

Finding 3.9: Understanding cascading impacts of drought as they relate to the agriculture sector and society in general is extremely important for a state that provides a significant amount of agricultural production for the United States.

Recommendation 3.9a: NOAA research programs should consider ways to better understand the role weather and climate information plays in identifying risks and vulnerabilities that have economic dimensions, such as unemployment and food assistance programs, associated with cascading impacts specifically targeting the agriculture sector. In particular, NOAA's interdisciplinary research programs should explore opportunities to partner with USDA and state and Non-governmental Organizations (NGO) partners to enhance understanding of the role of weather and climate information in risk communication and risk management strategies important to agriculture, food security, and the links between food and water security.

Chapter 4: Fisheries and Coastal Ecosystems

Finding 4.1: The current drought in California has caused historic absolute reduction in water availability for agriculture, fish habitats, and other uses statewide. The reduction in surface water flows is being partially compensated by increased pumping of groundwater that is believed not to be sustainable. There is a need for information on Full Natural Flow (FNF) in the region, for which reliable estimates are currently lacking. FNF is generally meant to characterize the natural water production of the river basin, unaltered by diversions, storage, or export or import of water to or from other watersheds at scales that are necessary for water management, including allocation of water on sub-basin scales. The lack of data to generate estimates of full natural flows to guide management decisions is a major challenge to water management in California, especially for the fisheries sector.

Recommendation 4.1a: NOAA should strengthen existing partnerships among federal agencies and other stakeholders for estimating and forecasting FNF in rivers and streams important to fisheries management. This effort can be built upon existing programs and collaboration among NOAA, the federal water agencies, and the state.

Finding 4.2: Degraded water quality has continued to impact the Delta and Bay resources, but the issue remains unresolved. There is well-documented scientific evidence that the health and productivity of the Sacramento-San Joaquin Delta ecosystem have deteriorated, as reflected in the decline of native fish species. Considerable scientific information exists on the effects of toxic chemicals on a variety of test species and at the sub-organism levels (i.e. cellular, biochemical, and physiological) levels. However, information on the combined effect of environmental stressors is largely unknown, and can only be speculated. From NOAA's perspective, this capability would be critical for forecasting ecosystem-scale changes in water availability in response to human demand and to climate (wet and dry periods) and land-use changes at annual to decadal scales. NOAA has already taken foundational steps, with existing resources, in developing the West Coast Operational Forecast System, a three-dimensional hydrodynamic model for computing predicted water levels, currents, temperature, and salinity, both in open coastal waters and selected estuaries.

Recommendation 4.2a: NOAA should work with state and local officials and seek technical advice to determine the feasibility and application, building off of existing research efforts, of an operational estuarine circulation and hydrodynamic model that can describe the distribution of temperature and salinity in San Francisco Bay, including the location of the 2 ppt salinity contour (the X2 position).

Recommendation 4.2b: NOAA should directly engage with state and federal agencies responsible for water quality management in the region, and focus on developing a coordinated and integrative plan to address combined effects of environmental stressors on the Delta ecosystem. The plan, which could be linked with CA/DWR's Interagency Ecology Program (IEP), would build upon their current scientific expertise and facilities, with an emphasis on developing new concepts and technologies that would better inform risk assessment and other management decisions. Assessing combined effects of environmental stressors, including those resulting from water availability and quality, may also offer better scientific understanding on significant decline in pelagic fish populations in the bay—termed Pelagic Organism Decline (POD)—which is a major priority for fisheries managers in the region.

Assessing combined effects of environmental stressors is already identified as a priority in the NOAA 5-Year Research and Development Plan and also noted in the Administration's nationwide initiatives. There are opportunities to leverage NOAA resources with state level investments, and such opportunities should be sought out. In essence, such a plan would require obtaining and blending the physical, biological, and social data and developing multi-hazard models and decision support systems.

Finding 4.3: There is a clear need for improved forecasting of weather, water temperature, flow in streams, and ocean conditions. In addition, better data and information in key areas related to decision making would greatly improve a fisheries manager's ability to deal with droughts. These include satellite data, fish abundance and distribution data, and economic impact data. In addition, a centralized source for the Central Valley fish monitoring data that is collected would greatly assist real-time water operations and fisheries management.

Recommendation 4.3a: NOAA should determine ways to model river temperature changes (critical for Chinook salmon), couple river models with reservoir models, and look for opportunities to expand monitoring to support fisheries management.

Recommendation 4.3b: NOAA, working with other government agencies, should coordinate and expand use of satellite imagery and other remotely-sensed data to better understand the decadal and drought-related changes in delta configuration, channel shapes, vegetation cover, agricultural practices, and other metrics for improving fisheries management and understanding ecosystem changes.

Recommendation 4.3c: NOAA should engage in or commission research studies and collect more fisheries and economic data related to the impacts of weather events such as drought.

Recommendation 4.3d: NOAA should engage in and/or support increased real-time fish monitoring and predictive modeling tools for fish distribution and density, especially in the Delta.

Finding 4.4: In San Francisco Bay and the Delta, potentially harmful occurrences and blooms of cyanobacteria, notably Microcystis, have been documented for over 15 years. Their toxins are present throughout the lower food web in the region, and as such, they pose a threat to human health, valued species, and ecosystem services. Microcystis blooms are promoted by increased light, water temperature, salinity, and water stratification, all of which are typically associated with drought. In addition, there is documentation of unusual algal blooms (Spring 2014) in the upper Sacramento River and Suisun Bay that may be related to drought (Glibert et al. 2014).

Recommendation 4.4a: NOAA should engage with the U.S. Environmental Protection Agency (EPA) and other agencies, technical experts, and resource managers on developing a plan to address unusual and harmful algal blooms in the region under provisions of the Harmful Algal Blooms and Hypoxia Research and Control Amendments Act of 2013, with the ultimate purpose of developing an operational forecasting capability, technology transfer, and risk assessment.

Finding 4.5: NOAA weather/climate products are useful, but some climate products are not localized enough for fisheries managers and stakeholders.

Recommendation 4.5a: In an effort to improve the effectiveness of the use of NOAA data and forecast products, NOAA should examine ways to connect localized fisheries management needs with existing NOAA products. A fisheries liaison at the local NWS field offices would be one option to investigate. NOAA Fisheries offices should increase contacts and communication with WFOs for delivering forecasts and assessments that are compatible with scales of drought impact on fisheries and coastal ecosystems for its long and short range weather forecast products.

Finding 4.6: NOAA should reshape its approach to providing information as a routine process and should adapt its products to better fit the impacts of the weather phenomena—extreme drought or floods.

Recommendation 4.6a: The current Delta Stewardship Council's Interim Science Action Agenda outlines a series of environmental issues, including scientific questions, ecosystem modeling, monitoring, and data management; some of the issues focus on water availability. NOAA may wish to contribute to implementing this plan, in particular, the drought-focused actions in the plan.

Finding 4.7: NOAA's Habitat Blueprint approach, including the Hydrometeorology Testbed, was described by many NOAA interviewees as a "success" by offering a platform for cross line office and inter-disciplinary coordination, which has included placement of new weather data collection systems and water gauges and assessment of different water-release scenarios. Prior to the Habitat Blueprint, NOAA Restoration Center did not have a working arrangement with NWS for developing mutually beneficial and specifically tailored products for addressing key resource management questions. A much closer collaboration is now underway.

Recommendation 4.7a: Continue to develop and implement Habitat Blueprint projects that address regional or watershed-specific issues, are interdisciplinary in nature, and involve multiple federal, state, and local entities.

Recommendation 4.7b: Expand the Hydrometeorology Testbed and fully engage other federal agencies through the Integrated Water Resources Science and Service consortium to explore alternate water management practices such as a "Forecast-Informed Reservoir Operations" approach.

Chapter 5: Water Resources

Finding 5.1: California-Nevada River Forecast Center (CNRFC) probabilistic streamflow forecasts (ensemble forecasts that describe a range of possible outcomes) contain valuable information that some stakeholder agencies have successfully applied to minimize risk functions for water management. However, these traces are still infrequently used by most water management operators due, in part, to institutional barriers within management agencies.

Recommendation 5.1a: NOAA's River Forecast Centers, National Water Center, and National Climatic Data Center should work to better educate users on ensemble forecasts, recognize and address institutional barriers that limit forecast application, and, moreover, to better market forecasts to users. Additionally, users of these products should work with NOAA on better ways to develop prototype decision support tools that leverage ensembles and to archive these ensemble forecasts and their associated hindcasts.

Recommendation 5.1b: NOAA's National Water Center and National Climatic Data Center should invest in development of web-based tools for water resource forecast verification.

Recommendation 5.1c: NOAA's National Water Center and Climate Program Office should explore products that would facilitate the use of forecasts in reservoir operations.

Finding 5.2: The major medium-range weather prediction model run by NOAA, the Global Ensemble Forecast system (GEFS), is frequently updated and does not include an update to its reforecast data when updated, thereby making it impossible to calibrate streamflow forecasts to the operational GEFS.

Recommendation 5.2a: NOAA's NCEP should adopt a reforecast update strategy closely tied to the GEFS model update cycle that includes a 1–2 year update to the reforecast model runs in order to support reliable probabilistic streamflow forecasts at RFCs. Better efforts to coordinate refreshes at regular intervals (such as every one, two, or five years) would allow for a better rebuild reanalysis and reforecasts of the model.

Finding 5.3: Accumulated precipitation—typically snow—in the key watersheds of the Cascade, Sierra Nevada, southern California mountains, and groundwater recharge areas are the primary source for water resources in California and the western states, yet no focused seasonal forecast capacity exists for this all-important resource in order for agencies to make effective planning decisions and water allocations.

Recommendation 5.3a: NOAA (including CPC, RFCs, NWC, NCDC, and CPO) should invest in developing and operationalizing seasonal forecast techniques targeted at accumulated cool-season precipitation, specifically snowpack accumulation and snowmelt runoff, in the watersheds important for water resources.

Finding 5.4: The data most critical for water resources forecasting, including snowpack data, are not typically archived or analyzed at NCDC. Instead, the CNRFC and CA/DWR rely on the California Data Exchange (CDEC) and their own analytical tools for applying this data for water resources forecasting. This includes developing long-term averages or normals.

Recommendation 5.4a: NOAA/NCDC as well as the Western Region Climate Center (WRCC) in collaboration with the National Water Center should explore archiving data necessary for CNRFC forecast production and archiving (e.g., normals development, high snow elevation snowpack, snow climatology).

Finding 5.5: CA/DWR utilizes the Atlantic seasonal hurricane outlook and 1–3 month temperature and precipitation outlooks for energy trading for its pumping and power generation operations. Interestingly, they reported that the confidence level (even if zero skill) in these forecasts does not matter to their energy trading activities.

Finding 5.6: Air temperature forecasts are used in U.S. Bureau of Reclamation (USBR) water temperature modeling and targets for USBR water quality are important to water supply and fisheries management.

Finding 5.7: There is a major need in the administration of water law and rights for scientifically defensible FNF estimates and forecasts on a daily basis to effectively administer water law during extreme drought where rights curtailments are required (see recommendation HLF2a for corresponding recommendation).

Finding 5.8: Media messaging of this drought was noted by stakeholders to be effective in influencing the public to participate in water conservation.

Finding 5.9: Earth System Research Laboratory (ESRL) maps for National Center for Atmospheric Research/National Center for Environmental Prediction (NCAR/NCEP) reanalysis, NCDC ranking maps, and the NCDC webpage are useful for technical academics and research.

Chapter 6: The Way Forward for NOAA

High Level Finding (HLF) 1: Great interest exists for seasonal prediction products and ENSO discussions (monthly), especially for cool-season precipitation. These forecasts, however, typically have very low skill and confidence, rendering them near-useless for most decision makers interviewed. Further, the CPC forecast products were often prone to misinterpretation by both NOAA field offices and external stakeholder agencies.

Recommendation HLF 1a: NOAA should acknowledge the major importance of cool-season precipitation in providing water not only for California but for the western United States. As such, Office of Oceanic and Atmospheric Research (OAR) should synthesize the state of research on predictability of accumulated cool-season precipitation in the mountains and scope an operational forecasting capability that is closely linked to supporting the water resource management community.

Recommendation HLF 1b: The Climate Prediction Center (CPC) should work more closely with front line offices, especially the RFCs and WFOs in the National Weather Service, to understanding local uses of and needs for seasonal prediction and how to more effectively communicate them to the public. Additionally, the effectiveness of internal education on seasonal prediction products should be assessed. To address this recommendation, NWS should develop a plan for improving two-way communications between CPC and field offices, documenting stakeholder use cases and requirements for seasonal prediction, and assess the effectiveness of internal education on seasonal prediction.

High Level Finding HLF 2: Many water decision makers—water boards, fisheries managers, coastal ecosystem planners, and recreational water users in particular—require a "whole" view of water system environments (physical and biological elements). NOAA river forecast models are typically designed for the purpose of forecasting flooding but are also increasingly used for low flow and water supply. For drought, a "full natural flows" model of surface water, including fluxes with ground water and its anomalies, is needed for fisheries managers, water boards, maritime industries, and others to support their actions mitigating the impact of drought at the sub-watershed scale.

Recommendation HLF 2a: NOAA should initiate (or expand through existing Integrated Water Resources Services and Science MOUs) a partnership among other federal and state agencies (particularly U.S. Geological Survey (USGS) and CA/DWR) and other stakeholders for scoping modeling and monitoring activities needed to estimate and forecast full natural flows (FNFs) in streams and rivers in California. This will significantly enhance capacity and expertise in streamflow forecasting. Continuous low flow forecasting is essential for estimating impacts of drought and managing water resource, for which knowledge of groundwater and long-term snowmelt contribution to streamflow is critical. An added benefit of this approach will be significant scientific advances in ecohydrology and explicit inclusion of hydrologic variables in ecosystem-based studies.

High Level Finding HLF 3: NOAA's Habitat Blueprint and Hydrometeorological Testbed are examples of successful NOAA models for intra-agency and interagency collaboration, and for engaging with the research community.

NOAA has an opportunity to utilize these successful interagency frameworks to increase resilience to drought and other natural variability. In particular, through partnering with water resources management agencies to apply NOAA's environmental intelligence, NOAA could act as a change agent for increased resilience.

Recommendation HLF 3a: NOAA should expand the scope of the Hydrometeorological Testbed (HMT) in partnership with water resources agencies and other science organizations to promote "forecast-based reservoir operations," scope and develop the needed forecast methods, and develop relevant decision support models in order to enhance California's ability to mitigate potential drought impacts.

High Level Finding HLF 4: Graphic material generated by NOAA for stakeholders impacted by drought is typically created ad hoc by WFO staff trained in meteorology or by national centers with greater graphics and analytical capabilities in house. WFOs need better graphics and analysis capabilities to meet the growing visual medium being used as a communication tool in the NWS.

Recommendation HLF 4a: WFOs and NWS national centers alike should be equipped with modern graphics and analysis support software and equipment. Staffs should also receive regular trainings to ensure their data visualization skills are up to date.

Recommendation HLF 4b: The NWS Western Region has some graphic software and online training in its Decision Support Services toolkit. NWS should consider promoting these elements to other regions.

High Level Finding HLF 5: Reduced staffing levels and staffing skills, especially in decision support, at WFOs and at national and regional centers, as well as the physical location of certain WFOs (particularly Monterey), have hurt the ability to effectively apply the depth of NOAA's forecasting, data, and science assets to stakeholder decision making impacted by the California drought.

Recommendation HLF 5a: NOAA should identify opportunities to utilize the field structure of the NWS to more effectively provide drought-related environmental intelligence. Over the long term, as opportunities and funding arise, WFOs in particular should be better optimized to provide the full suite of environmental intelligence offered by NOAA. This may include changes to staffing structure, office locations, and the supporting regional structure.

High Level Finding HLF 6: NOAA communications and analyses describing the drought status, historical context, and forecasts for drought were well received by stakeholders and helpful in supporting their decision making. A more cohesive approach among major NOAA entities (especially RFCs) to keep our local WFOs in the loop on national products and drought conditions (e.g., water supply) would enhance their ability to communicate drought relevant data, forecasts, and science to their constituents. Many WFOs have established email lists to notify external stakeholders—particularly other government agencies with capacity to mitigate drought impact—about important weather and climate information related to the drought, including longer-term seasonal predictions such as El Niño. Social media posts from the WFOs on regular drought data products—as well as non-weather items (e.g., impacts of dry conditions on livestock)—keep external partners updated on important data and keep their public followers interested on the drought's importance.

Recommendation HLF 6a: NOAA should more effectively utilize WFOs and their direct connection to state and local stakeholders to communicate environmental intelligence. NOAA should also use this process to learn from stakeholders about their drought-impacted decisions and communicate back to national NOAA drought service providers such as NCDC, CPC, and NIDIS. Further, these service providers should be encouraged to better work with and through local NWS offices, and NWS should be encouraged to be a more effective provider of the full range of environmental intelligence offered by NOAA. In particular, for water resources, NOAA and CA/DWR should enhance coordination between the water resources expertise at CNRFC and CA/DWR and the WFO communication activities.

High Level Finding HLF 7: Despite existing interagency and intra-agency efforts like NIDIS, NOAA is not currently well integrated and, in the case of California drought, did not effectively draw on its many assets to communicate about a slow-onset, cross-sectorial disaster like drought.

Recommendation HLF 7a: NOAA should develop a plan for more effectively communicating the environmental intelligence required by stakeholders to plan for and mitigate the impacts of droughts. This plan should utilize the strengths across the agency, especially those at the NWS WFOs and RFCs, the NWS CPC, the NWS NWC, the NESDIS NCDC (including RCC), OAR NIDIS, OAR Climate Program Office (CPO) including Regional Integrated Sciences and Assessment Program (RISA), and OAR ESRL. This plan should identify and empower cross-line office teams, such as the regional collaboration teams, and individuals, such as the regional climate service directors, to coordinate and leverage NOAA's environmental intelligence assets.

Recommendation HLF 7b: To test its plan and to promote the line office coordination needed to deliver drought environmental intelligence, NOAA should consider "drought gaming exercises" or drills that are coordinated across NOAA line offices with drought decision support responsibilities every three to five years. These exercises should be led by NIDIS and developed through all NOAA line offices to understand interagency issues on drought, including environmental impacts.

Recommendation HLF 7c: In addition to NIDIS, the Warning Coordination Meteorologists and Service Coordination Hydrologists at the National Weather Service and the Regional Climate Service Directors should take a lead role in these exercises, assessing ways to integrate into existing state and local preparedness and planning efforts and to improve NOAA cohesiveness for drought decision support.

Photo Credits for collage page 13:

All photos courtesy of California Department of Water Resources, http://pixel.water.ca.gov/. (Note: not all these pictures are from 2014). Left to right, top to bottom.
Row 1:♦Various crops grown in Monterey County. (John Chacon)♦Snow survey at Phillips Station/Sierra-at-Tahoe. Shot - 3/3/10. (Dale Kolke)♦Kangaroo Paw (drought-tolerant plants) make a beautiful addition to any setting. (John Chacon)
Row 2: ♦From the Oroville Feather River Fish Hatchery, 50,000 fingerlings were hauled in a trailer to the Yolo Bypass. They were weighed, tagged, and released into a rice field. Shot - 3/13/13. (John Chacon) ♦The installation of six 10′×12′× 6′ concrete box culverts for the Fish Passage Improvement Project across Mormon Slough at an old road barrier in San Joaquin County on September 11, 2013. (Florence Low) ♦Work on the intertie progresses on the Central Valley Project, with Delta Field Division, Doug Thompson and Jim Odom, Mendota Canal; State Water Project (SWP, USBR)
Row 3: ♦Aerial view showing water running down the Oroville spillway at Lake Oroville, California. (Paul Hames)♦A salmon swims past a viewing window at the Feather River Fish Hatchery and fish barrier dam in Oroville, California, on September 24, 2014. (Florence Low) ♦The water wise garden of Riverside with residents Lucy and Frank Heyming on June 4, 2013. (Florence Low)

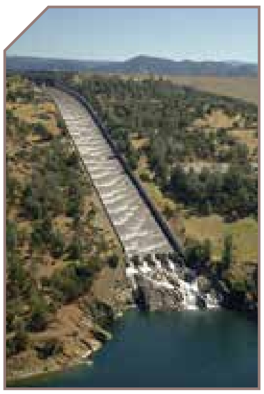
Row 4: ♦Instead of the traditional desalination approach normally used to treat seawater, Water FX cleans water through use of a Concentrated Solar Still. It uses existing technology adapting 400 kilowatt parabolic solar troughs originally designed for power generation. (John Chacon) ♦Performing predator sampling at Clifton Court Forebay. 12/29/14 (John Chacon) ♦Desert Research Institute staff Brad Lyles (left, DRI associate research hydrogeologist) and Wyatt Fereday (right, DRI staff hydrogeologist) set up equipment on a weather station buoy at Folsom Lake near Granite Bay, California, on January 8, 2015. CA/DWR (California Department of Water Resources) collaborates with DRI (Desert Research Institute) and Mid- Pacific Region Bureau of Reclamation to install a buoy containing CIMIS (California Irrigation Management Information System) weather station sensors with additional energy flux sensors to monitor evaporation at Folsom Lake. A land weather station was also installed on a peninsula at Folsom Lake. Visit http://owen.dri.edu for information about the Open Water Evaporation Network (OWEN) and current weather conditions for Folsom Lake. (Florence Low) ♦Geologist Tad Bedegrew and Senior Engineering Geologist Chris Bonds measure and record a pumping water level in a production well. (John Chacon)
Row 5: ♦A canoe, a gently flowing river, and nice weather make for a great day of recreation. (John Chacon) ♦ Topics at the the Whole Water Conference held in Monterey, California, included drought funding options, water shortage contingency plans, and conservation priorities. (John Chacon), ♦Lake Oroville showing The Enterprise Bridge looking from the South Fork on September 5th, 2014. (Kelly M. Grow)
Row 6: ♦The Antioch/Oakley Regional Shoreline park displays a sign announcing their water conservation efforts at the park on September 18, 2014. (Florence Low) ♦Sunrise on the O'Neill Forebay. C.A.S.T. Event 2012. (Unknown)

California Water Resources being studied and enjoyed in the recent past and in 2014







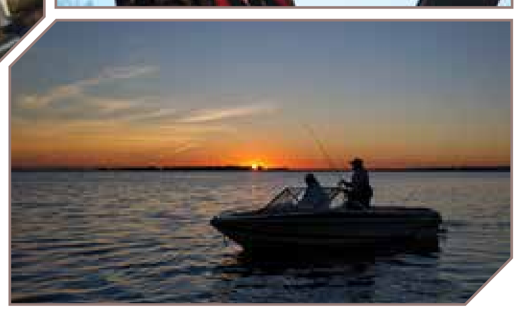












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This report summarizes the California Drought of 2014 and the impacts on Agriculture, Fisheries, and Water Resources.